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Yellowstone River
Channel Migration Zone Mapping
Park County Update

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PARK
COUNTY
MONTANA

Executive Summary

This report contains the results of a Channel Migration Zone Mapping effort for approximately 86 miles of the Yellowstone River between Gardiner and Springdale, in Park County, Montana. This study was funded through a Montana Department of Natural Resources and Conservation (DNRC) Reclamation and Development Planning Grant (Grant Agreement No. RITP-23-0194), that was awarded to Park County in June 2023. ***The goal of this Planning Grant was to update the Yellowstone CMZ map so that it can be used as a tool to evaluate flood-related impacts in Park County, assist in emergency flood response preparation, and identify projects that will help mitigate future flood risks while also supporting healthy river functions such as floodplain connectivity, flood attenuation, natural channel movement and erosion / sedimentation processes, water quality, and in-stream fisheries habitat.***

From the City of Gardiner, Montana and to the Park County line near Springdale, Montana, the Yellowstone River corridor has multiple transportation lines adjacent to the river and bridge crossings that are critical for accessing emergency services, towns, businesses, and private residences property. Rapid development along the corridor has increased property values and placed additional infrastructure within the corridor that is at risk of both flooding and bankline migration. This section of river was strongly impacted by the June 10 to 16, 2022 Federal Emergency Management Agency (FEMA) declared national disaster flood event, with markedly rapid lateral migration rates in areas that had not previously seen erosion. This is an update to the 2009 Channel Migration Zone Mapping effort and reflects impacts to the corridor from the 2022 flood utilizing availability of higher resolution data, and assesses a new understanding of risks associated with development along the Yellowstone River in Park County, Montana.

The objective with the mapping and interpretations provided in this document is to assist river corridor landowners and other stakeholders in understanding the nature of Yellowstone 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 health, resiliency, and ecological vibrancy. The Yellowstone River is critical for the economic health and character of Park County. Adoption of a CMZ approach to management of the river corridor represents an opportunity for the long-term vibrancy of Park County at a reduced cost to landowners.

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Glossary and Abbreviations

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

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

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

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

Bankfull Discharge – The discharge corresponding to the stage at which flow is contained within the limits of the river channel and does not spill out onto the floodplain. Bankfull discharge is typically between the 1.5- and 2-year flood event, and in the Northern Rockies it tends to occur during spring runoff.

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 (based on average annual migration rates).

DNRC – Department of Natural Resources and Conservation.

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

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

Flood 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.

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

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

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

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

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

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

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

Morphology – Of, or pertaining to, shape.

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

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

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

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

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

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

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

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

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

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

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

1 Introduction

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

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

This is an update to the 2009 CMZ Mapping effort and reflects changes in channel locations since then, including impacts of the 2022 flood. High resolution post-2022 flood data were used to better capture the changes associated with that event, and to capture how those changes may pose risks to development projects located within or adjacent to the active stream corridor.

Note: All river mile references in this report are based on the 2009 Yellowstone Cumulative Effects Study stationing.

This report contains the results of a CMZ Mapping effort for approximately 86 miles of the Yellowstone River in Park County, Montana. From the City of Gardiner, Montana and to the Park County Line near Springdale, MT, the river corridor has multiple transportation lines adjacent to the river and bridge crossings that are critical for accessing emergency services, towns, businesses, and private residences property. Recent development along the corridor has increased property values and put additional infrastructure at risk of both flooding and/or channel migration. This section of river was strongly impacted by the June 10 to 16, 2022 FEMA declared national disaster flood event, with markedly rapid lateral migration rates in areas that had not previously seen measurable erosion.

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

This project is based upon work supported by the DNRC under Agreement No. RITP-23-0194 and was administered by Park County, Montana.

1.1 Background and History

The Yellowstone River watershed encompasses approximately 71,000 square miles of area in Montana, Wyoming and North Dakota (Figure 1). It originates in Yellowstone National Park and is considered the longest free-flowing river in the lower 48 of the United States, as the mainstem has no major dams or reservoirs.

The 86 miles of river in Park County (Figure 2) drains an area of 4,716 square miles with the only major tributary being the Shields River, which enters the Yellowstone River below the City of Livingston. There are several major irrigation diversions, including the Park Branch Canal and Livingston Ditch. With no dams on the river or major tributaries and only a few significant diversions, it behaves as a snow melt system with a natural hydrograph that tends to peak during late spring and early summer months.

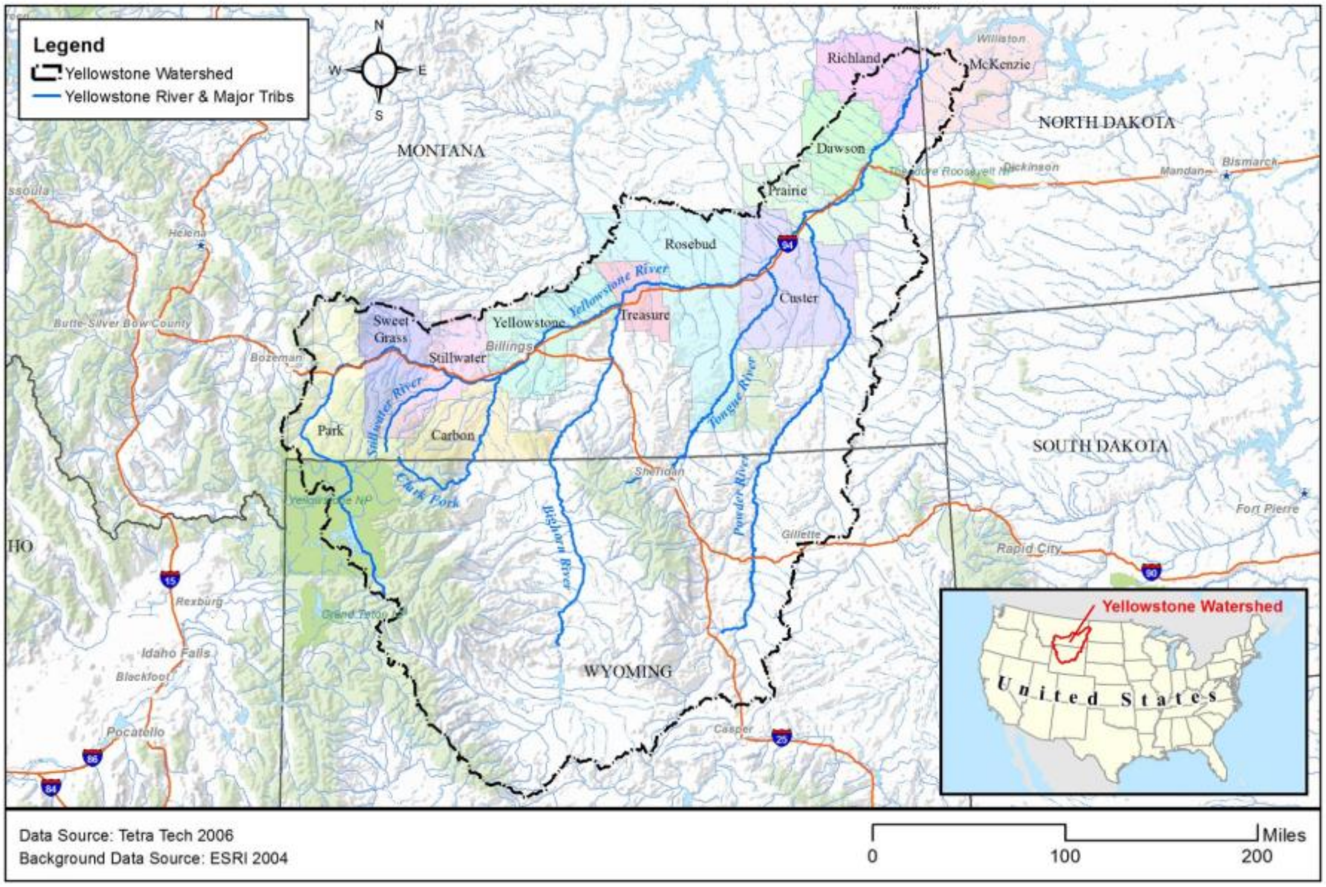

Figure 1. The Yellowstone River watershed.

In 1996 and 1997, the Yellowstone River was subjected to back-to-back "near" 100-year flood events. In response to extensive bank erosion, numerous erosion control projects (primarily rock riprap) were permitted, and installed, to protect both public and private infrastructure along the river. Subsequently, the US Army Corps of Engineers (USACE) was sued for failing to assess the cumulative impacts of the installation of the bank armor. The result of this lawsuit was an approximate 15-year effort to study and assess the river from the town of Gardiner where the river exits Yellowstone National Park to its confluence with the Missouri River in North Dakota, a total river distance of 565 miles.

The resulting Cumulative Effects Analysis (CEA)(USACE, 2015) for the Yellowstone River Corridor Study was led jointly by the Yellowstone River Conservation District Council and the USACE, with participation from multiple federal, state and local agencies as well as several non-profit organizations and private businesses. The study was undertaken as a result of public attention and concerns about the combined effects of damaging flood events and increased development pressures along the Yellowstone River Corridor.

The CEA Study focuses on numerous physical, biological and social components of the Yellowstone River. Extensive mapping of historic banklines were digitized from georeferenced imagery starting in 1948 and continuing up to 2001. Understanding the rates and characteristics of the river's movements through time led to including a CMZ Mapping effort for the entire Yellowstone River study area which was released in 2009 (Boyd and Thatcher, 2009).

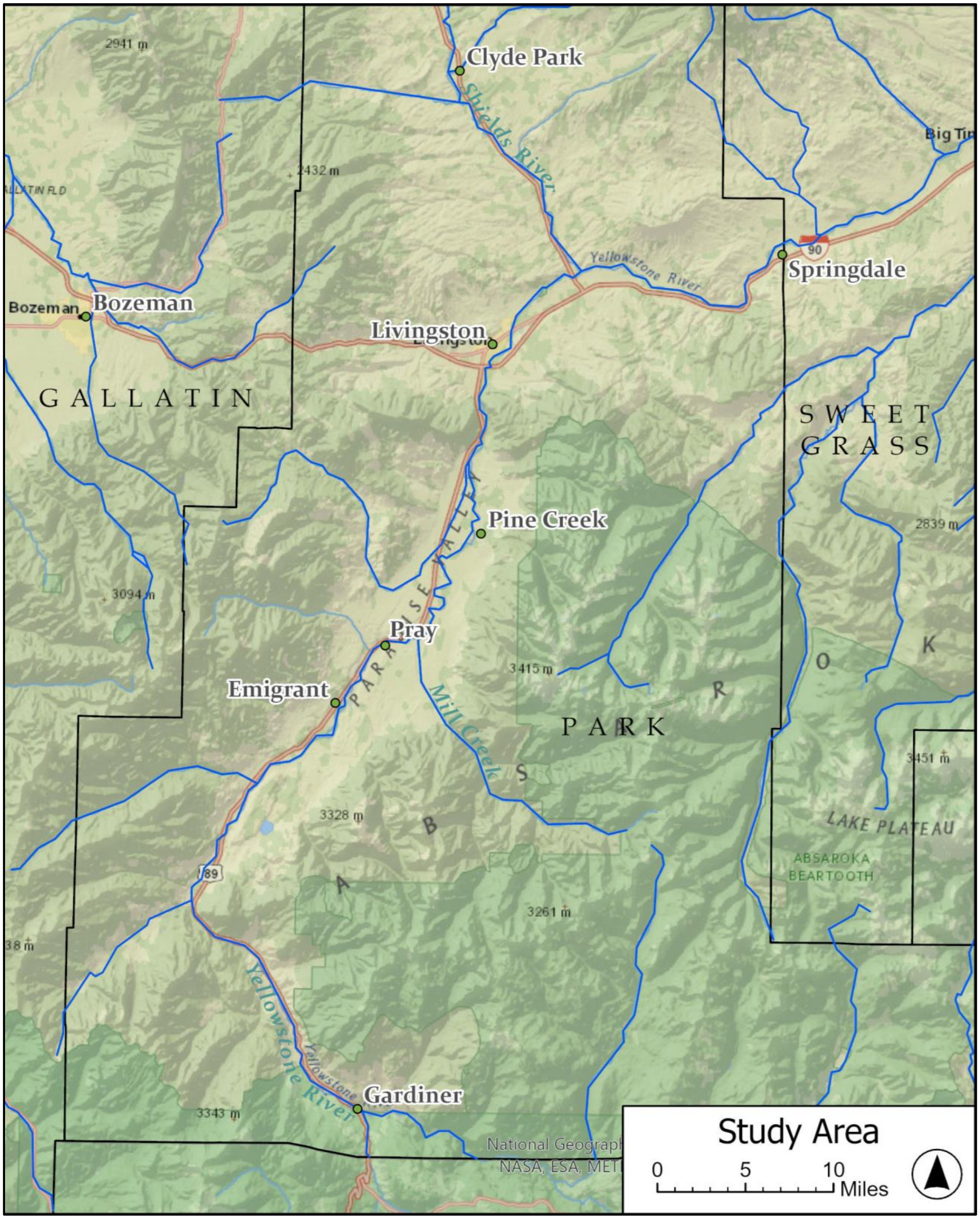

Figure 2. CMZ Mapping extent on the Yellowstone River.

1.2 Other Relevant Studies

In addition to the Cumulative Effects Analysis, the 1996-1997 Yellowstone floods, Montana's Governor convened a group of diverse stakeholders into the Upper Yellowstone Governor's Task Force to discuss the issues, competing values, and uses that impact the Yellowstone River. The recommendations generated by this group are captured in the 2003 Governor's Upper Yellowstone River Task Force Final Recommendations Report. In this report, the task force identified the need for Channel Migration Zone Mapping and provided recommendations to address ongoing issues like bank stabilization, bridges, public infrastructure, fisheries, and future river assessment needs.

This work also established the Upper Yellowstone Special Resource Management Zone and Upper Yellowstone Special Resource Management Plan. In 2011, the USACE designated the portion of the Upper Yellowstone between Emigrant and Springdale (approximately) as a Special Resource Management Zone - due to the cumulative impacts in this reach - and developed a Special Resource Management Plan (SAMP) to help address further degradation. The SAMP notes that a major issue for this stretch of the river is 'forced morphology', or the transformation of the river from one channel type (i.e. meandering/multi-channel) to another type (i.e. straightened/single-channel) caused by channel modifications like rip-rap (bank armoring) and levees. The SAMP also notes that the projects that have the greatest potential to negatively impact channel morphology and all associated river functions are: stabilization of riverbanks; confinement of flood flows to channels by disallowing overbank flooding; and removal or addition of sediment from or to the channel network.

The 2023 Park County Hazard Mitigation Plan lists CMZ map updates, and flood mitigation project assessment and implementation as necessary actions to reduce flood hazard risks in Park County.

Other ongoing studies related to the 2022 flood event include a levee breach analysis for the City of Livingston to evaluate potential impacts and costs associated with levee breach scenarios, and FEMA floodplain map updates along the mainstem of the Yellowstone River in Park County.

1.3 The Project Team

This project work was performed by Tony Thatcher of DTM Consulting (DTM), Jeannette Blank of Montana Freshwater Partners (MFP) and Karin Boyd of Slough Creek Consulting (SCC). Over the past 18 years, the team has been collaborating to develop Channel Migration Zone maps for over 1,500 miles of channel on numerous rivers in Montana, to provide rational and scientifically-sound tools for river management. It is the overall goal to facilitate the understanding of rivers regarding the risks they pose to infrastructure, so that those risks can be managed and hopefully avoided. Furthermore, the project team believes the mapping supports the premise that managing rivers as dynamic, deformable systems contributes to ecological and geomorphic resilience while supporting sustainable, cost-effective development.

1.4 What is Channel Migration Zone Mapping?

The goal of CMZ mapping is to provide a cost-effective and scientifically based tool to assist land managers, property owners, agency personnel, and other stakeholders in making sound land use decisions along river corridors. Typically, projects constructed in stream environments such as bank stabilization, homes and outbuildings, access roads, pivots, and diversion structures are built without a full consideration of site conditions related to river process and associated risk. As a result, projects commonly require unanticipated and costly maintenance or modification to accommodate 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 3).

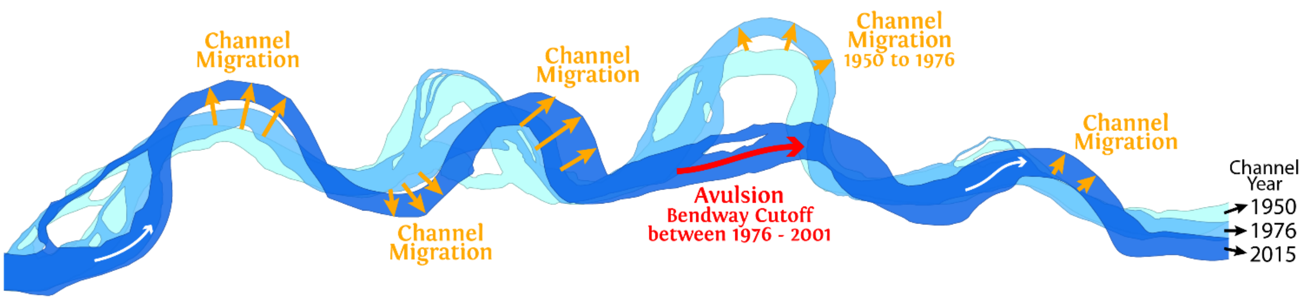

Figure 3. Typical patterns of channel migration and avulsion evaluated in CMZ development.

Note: The word "Zone" is used within the context of Channel Migration Zone Mapping and does not relate to regulatory zoning.

The fundamental approach to CMZ mapping is to identify the corridor area that a stream channel or series of stream channels can be expected to occupy over a given timeframe – typically 100 years based on average annual rates of movement. This is defined by first mapping historic channel locations to define the Historic Migration Zone, or HMZ (Figure 3). Using those mapped banklines, migration distances are measured between suites of air photos to generate a migration vector dataset that is exported from the GIS project for analysis. The measurements are evaluated statistically to determine mean migration rates for any given river segment (reach). The mean rates are then extended to the life of the CMZ, which in this case is 100 years. This 100-year mean migration distance defines the Erosion Buffer, which is added to the modern bankline to define the Erosion Hazard Area, or EHA.

Although the mean migration rate is the most commonly used to develop the EHA, there may be substantial data outliers, unique physical or hydrologic conditions, or intended uses that would warrant using a different statistic to capture a wider range of potential risk (e.g. 90^{th} percentile value). These more conservative values are provided in this report in the event a user would like to adopt a wider EHA buffer at any given site.

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. This is why the EHA buffers are developed at a reach scale, as it best addresses natural variability. To that end, the study area has been segmented into a series of reaches that are geomorphically similar and can be characterized by average migration rates. Reach breaks can be defined by changes in flow or sediment loads at tributary confluences, changes in geologic confinement, or changes in stream pattern. In Park County, reaches are on the order of two to twelve 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 3), historic side channels that may reactivate, and areas where the modern channel is perched above its floodplain. Avulsions can also occur due to channel blockages (ice, landslides, or debris), however those events are rare and impossible to predict.

Additionally, for this study, a generalized geotechnical setback area was developed for areas with over-steepened banks due to the 2022 flooding. A 2:1 slope was defined from the 2023 channel outer banklines to reflect the likelihood of the bank laying back and assuming a more natural angle of repose. This geotechnical setback is overlain on the final CMZ mapping to highlight at risk areas. Note that this geotechnical assessment is not intended to replace site-specific assessment of materials and stability, but rather is intended to highlight areas that may need additional attention due to bankline adjustments in response to channel migration.

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

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

The individual map units comprising the CMZ are as follows:

$$CMZ = HMZ + EHA + AHZ$$

The Rappe and Abbe (2003) guidance for CMZ mapping includes the removal of the RMA from the CMZ such that areas that are "no longer accessible" by the river are not identified on the maps. In our experience, identifying those areas that have become restricted due to human activities like levee building or bank armoring provides insight as to the extent of overall encroachment into the CMZ and highlights potential restoration sites where there may be opportunity for floodplain reconnection or CMZ restoration. It is also important to note that these restricted areas are not protected by fail-proof treatments. There are numerous examples of bank armor failure along the Yellowstone River in Park County that serve as a reminder that properties within the mapped CMZ will continue to have some level of risk despite efforts to control channel movement with bank stabilization treatments. For this reason, the areas of the natural CMZ that have become isolated are contained within the overall CMZ boundary and highlighted as "restricted" within the natural CMZ footprint.

Each map unit listed above is individually identified on the maps to show the basis for including any given area in the CMZ footprint (Figure 4).

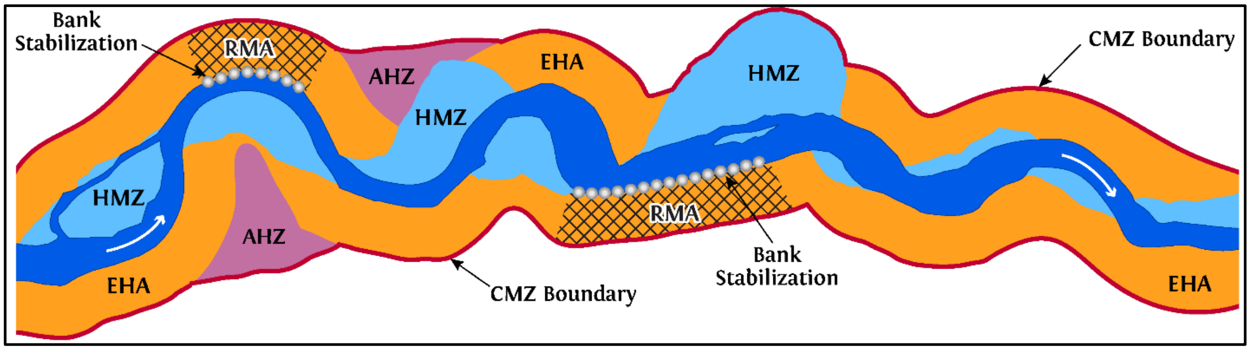

Figure 4. Channel Migration Zone mapping units.

Although the basic concept for CMZ mapping efforts is largely the same throughout the country, different approaches to defining and presenting CMZ boundaries are used depending on specific needs and situations. These differences in assessment techniques can be driven by the channel type, different project scales, the type and quality of supporting information, the intended use of the mapping, etc. For this study, the CMZ is defined as a composite area made up of the existing channel, the collective footprint of mapped historic channel locations shown in the 1948, 1999, 2011, 2015, 2021, and 2023 imagery (HMZ), and an EHA, that is based on reach-scale average migration rates. Areas beyond the Erosion Buffer that pose risks of channel avulsion are identified as Avulsion Hazard Areas or AHZ. This approach generally falls into the minimum standards of practice for Reach Scale, Moderate to High Level of Effort mapping studies as defined by the Washington Department of Ecology (www.ecy.wa.gov).

1.5 Relative Levels of Risk

The natural processes of streambank migration and channel avulsion both create 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 allow some relative comparison of the type and magnitude of their risk. In general, the EHA delineates areas that have a demonstrable risk of channel occupation due to channel migration over the next 100 years. Such bank erosion can occur across a wide range of flows, and the risk of erosion into this map unit is relatively high. In contrast, avulsions tend to be a flood-driven process; the AHZ delineates areas where conditions may support an avulsion, although the likelihood of such an event is highly variable between sites and typically depends on floods, debris jams, landslides, or ice jams. Large, long duration floods have the potential to drive extensive avulsions, even after decades of no such events. During the spring of 2011, for example, the Musselshell River flood drove 59 avulsions in three weeks, carving 9 miles of new channel while abandoning about 37 miles of old river channel (Boyd et al, 2012).

1.6 Uncertainty

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

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

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

Uncertainty also stems from the general paradigm that “the past is the key to the future.” As predicted future migration is based on an assessment of historic channel behavior, the drivers of channel migration over the past 72 years – the span of the historic imagery - are assumed to be relatively consistent over the next century. If conditions change significantly, uncertainty regarding the proposed boundaries will increase. These conditions include system hydrology, sediment delivery rates, climate, valley morphology, riparian vegetation densities and extents, and channel stability. Bank armor and floodplain modifications, such as bridges, dikes, levees, or structures could also affect map boundaries.

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

1.7 Potentiel Channel Migration Zone Applications

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 the understanding of the risks and benefits of channel movement.
- Facilitate productive discussion between regulatory, planning, and development interests active within the river corridor.
- Help communities and developers integrate dynamic river corridors into land use planning.
- Assist long-term residents in conveying their experiences of river process and associated risk to newcomers.
- Develop project priorities, timelines, and funding mechanisms.

Note:
The CMZ mapping developed in this study was developed without any explicit intent of either providing regulatory boundaries or overriding site-specific assessments. Any future use of the maps as a regulatory tool should include a careful review of the mapping criteria to ensure that the approach used is appropriate for that application.

1.8 Other River Hazards

The CMZ maps identify areas where river erosion can be expected to occur over the next century. It is important to note that river erosion is only one of a series of hazards associated with river corridors. Flooding, ice jams, and landslides are other significant hazards associated with rivers like the Yellowstone River.

1.8.1 Flooding

The CMZ maps do not delineate areas prone to flooding. The difference between mapped flood boundaries (i.e. FEMA floodplain maps) and CMZ boundaries can be substantial. In cases where the floodplain is broad and low, the CMZ tends to be narrower than the flood corridor (left schematic on Figure 5). 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 5). This is a common problem in Montana because of the extent of high glacial terraces that are above base flood elevations, but not erosion-resistant.

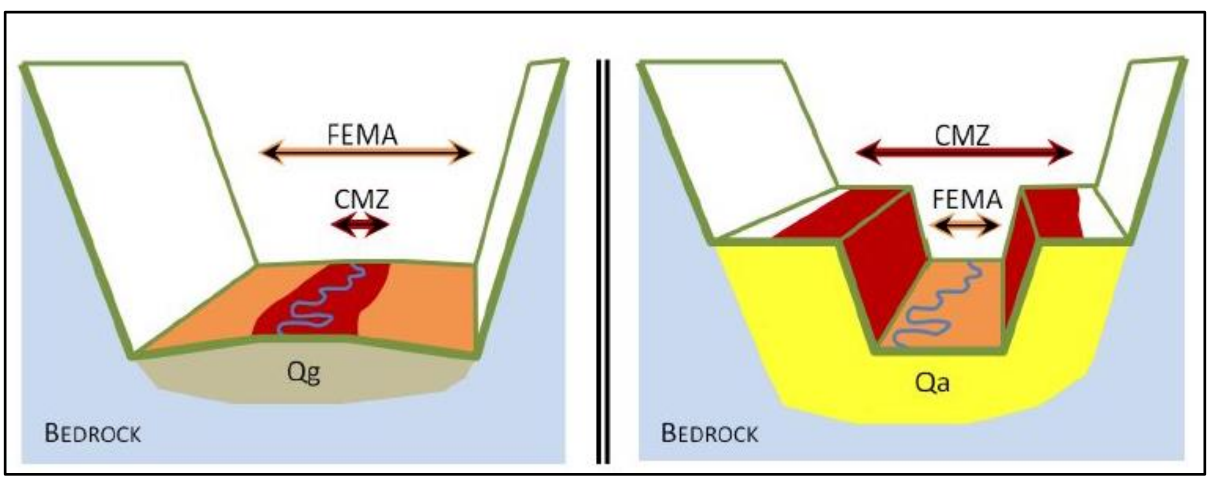

Figure 5. Schematic comparisons between CMZ and flood mapping boundaries (Washington Department of Ecology).

Figure 6 and Figure 7 show a National Park Service housing structure on the Yellowstone River in Gardiner, Montana that was undermined during the 2022 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 safe from all river hazards. In 2005, after experiencing massive flood damages in St. George, Utah (Figure 8), 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 6. A National Park Service housing structure in Livingston, MT shown moments before falling into the Yellowstone River on June 13, 2022 (Gina Riquier / NPS).

Figure 7. The same structure is shown floating downstream before eventually breaking up and depositing significant piles of debris on downstream properties (Gina Riquier / NPS).

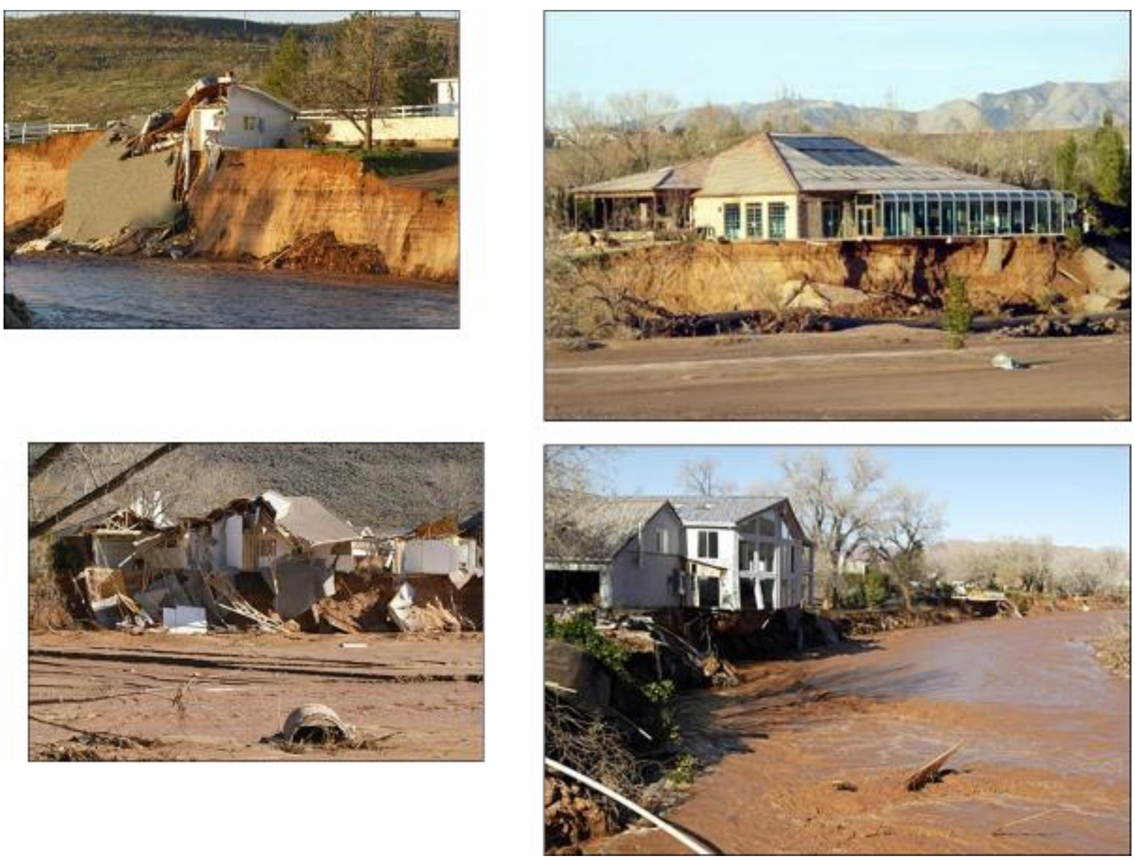

Figure 8. Photos from a 2005 flood event in Saint George Utah, where homes several feet above the mapped floodplain were destroyed by channel migration (originally sourced from Utahfloodrelief.com).

An example floodplain map for the City of Livingston is shown in Figure 9. The floodplain boundaries cover much of the valley bottom, and the regulatory floodway, which is crosshatched in red, identifies the area of river and adjacent land areas that “must be reserved in order to discharge the base flood without cumulatively increasing the water surface elevation more than a designated height” (www.fema.gov). Communities are responsible for prohibiting encroachments including fill and new construction in floodway areas unless hydrologic and hydraulic analyses show that it will not increase flood levels in the community. The combined risks of flooding and channel migration on the Yellowstone River should both be considered threats to human health and safety.

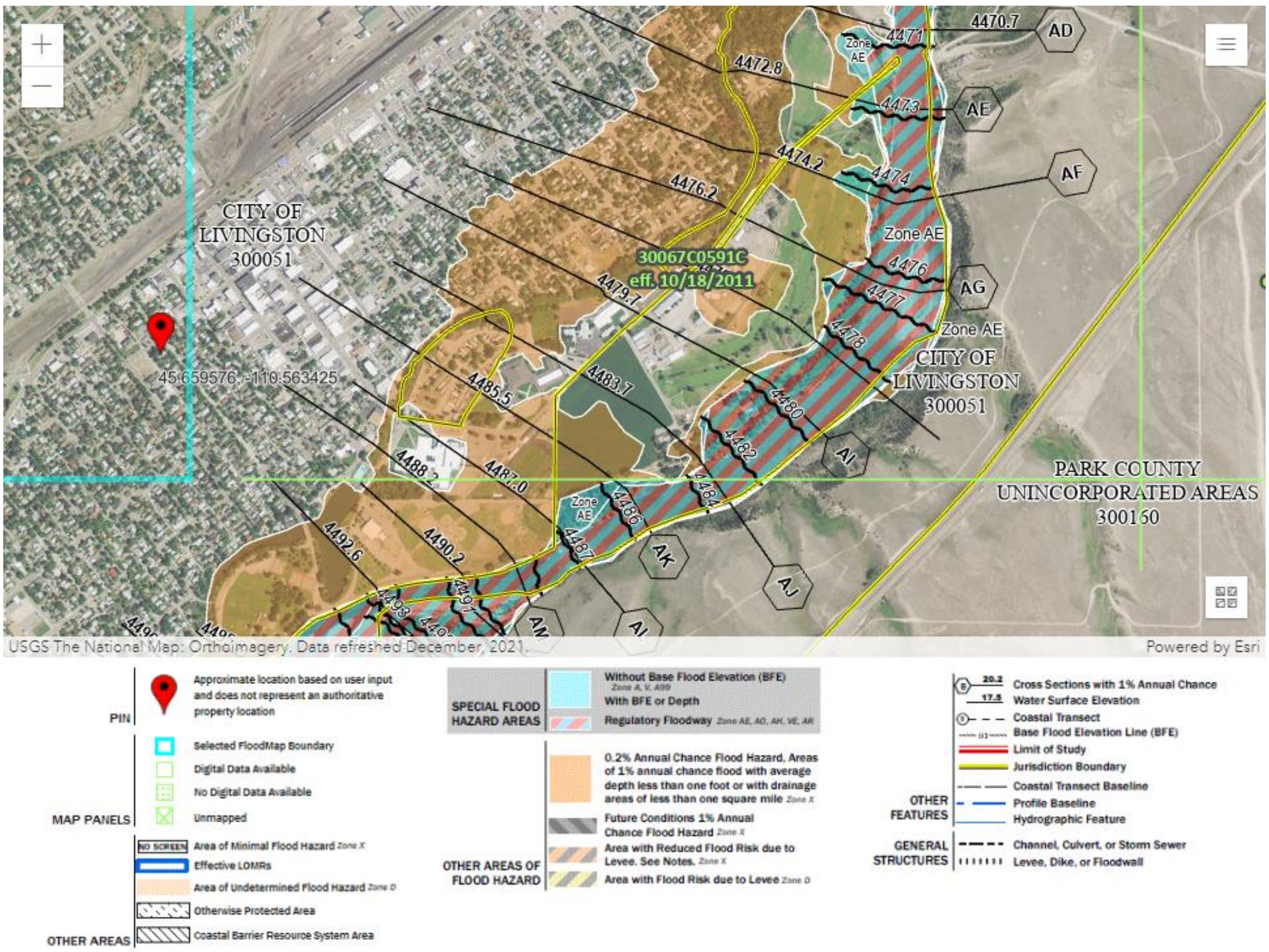

Figure 9. FEMA flood map in Livingston, MT (fema.gov).

1.8.2 Ice Jams

Another serious river hazard, especially in Montana, is ice jamming. Over 4,559 ice jams have been recorded in Montana since 1894, which is the most in the United States (CRREL Ice Jam Database), with 219 jams located on the Yellowstone River. Although ice jams are most common in Montana during February and March, ice jam flooding has happened on the Yellowstone River as early as November and as late as May. 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.

Figure 10. Yellowstone River ice jam near Mill Creek, January 2024 (Livingston Enterprise).

1.8.3 Landslides

The Yellowstone River in Park County is bounded in several areas by mapped historic landslides. Though no recent slide activity has impacted the river corridor, the potential for landslides is real if the conditions are appropriate. If any of these areas should fail, there is potential for either deflection of the river channel or damming of the river in the most severe case. The Yellowstone region is also known for earthquake risk. Earthquake activity, when combined with landslide potential can be catastrophic, as witnessed by the 1959 Hebgen Lake earthquake which triggered a massive landslide and formed Earthquake Lake, nearby, on the Madison River. That said, even relatively small hillslope failures can deflect stream courses and create hazards that may exceed the boundaries of the mapped CMZ.

1.9 Disclaimer and Limitations

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

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

1.10 Acknowledgements

We would like to extend our gratitude to Greg Coleman (Park County Office of Emergency Management Director), Kristen Galbraith (Park County Director of Grants & Special Projects), and their supporting staff of Park County for their assistance in data transfer, contract management, scheduling, and document review. Additional review and input from the City of Livingston, state agencies and members of the Upper Yellowstone River Assessment Committee were critical for reviewing the revised mapping and providing input on areas of concern. Finally, thanks to Headwaters Economics for providing funding for hi-resolution satellite imagery to assess post-flood impacts.

2 Physical Setting

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

2.1 Geography

The headwaters of the Yellowstone River are on the Yellowstone Plateau within Yellowstone National Park, about 85 miles south of Gardiner (Figure 11). The Yellowstone Plateau averages about 8,000 feet in elevation with some mountains reaching over 12,000 feet. The upper Yellowstone River above the Park/Sweet Grass County line near Springdale has a watershed area of approximately 4,716 square miles with one large contributing watershed of the Shields River that is 853 square miles in size.

As the Yellowstone River flows northward out of Yellowstone National Park and into the project area, it flows through a moderately confined valley from Gardiner to Yankee Jim Canyon (Figure 12). As the river exits the canyon, it enters the Paradise Valley, an approximately 30-mile-long north-south trending valley that is bound by high mountains of the Absaroka Range on the east and the Gallatin Range on the west (Figure 12). The highest peak near the valley is Mount Cowan which reaches 11,212 feet in elevation. The Paradise Valley ends abruptly near Carter's Bridge, where a bedrock constriction narrows the valley just upstream of Livingston. Below Livingston, the river swings to the east and past the Shields River confluence to Springdale which is near the Park/Sweet Grass County line. The complex watershed geography includes snowcapped peaks, steep mountain tributary streams, confined canyons and broad alluvial valleys.

2.2 Geology and Geomorphology

The character of the Yellowstone River and its host valley is strongly controlled by local geology. In the uppermost project area near Gardiner, glacial deposits form high terraces adjacent to the river that underlie much of the town of Gardiner (Figure 13 and Figure 14). About 14 miles downstream, Yankee Jim Canyon forms a tight constriction through Archean-age gneissic rocks that create a steep channel with rapids that are a popular recreational float (Figure 15).

As the river exits Yankee Jim Canyon, it enters a broad alluvial valley, the upstream half of which was overrun by the Northern Yellowstone Glacier; a Pinedale-age (20,000-15,000 years ago) feature that flowed from the Yellowstone Plateau ice sheet for about 40 miles into the Yellowstone River valley (Figure 16). The ice was over 2,000 feet thick and extended downstream to the Eightmile terminal moraines, which are near Mill Creek and Chico Hot Springs (Pierce, 1979). Several tributary glaciers joined the much larger ice flow.

The glacial imprint on the Yellowstone River valley imparts a strong influence on river behavior. From Yankee Jim Canyon to Mill Creek, the valley was under ice and thus did not receive high volumes of glacial outwash gravels. In this section, the width of the river corridor varies substantially over small stream segments, and relatively low floodplain surfaces are common (Figure 17). Below Mill Creek, conditions change dramatically as large braided stream outwash channels drained the glacier, creating high gravel terraces that border the stream channel in places like the Weeping Wall and Mallard's Rest, contributing large quantities of gravel to the river that contribute to point bar formation and channel migration (Figure 18).

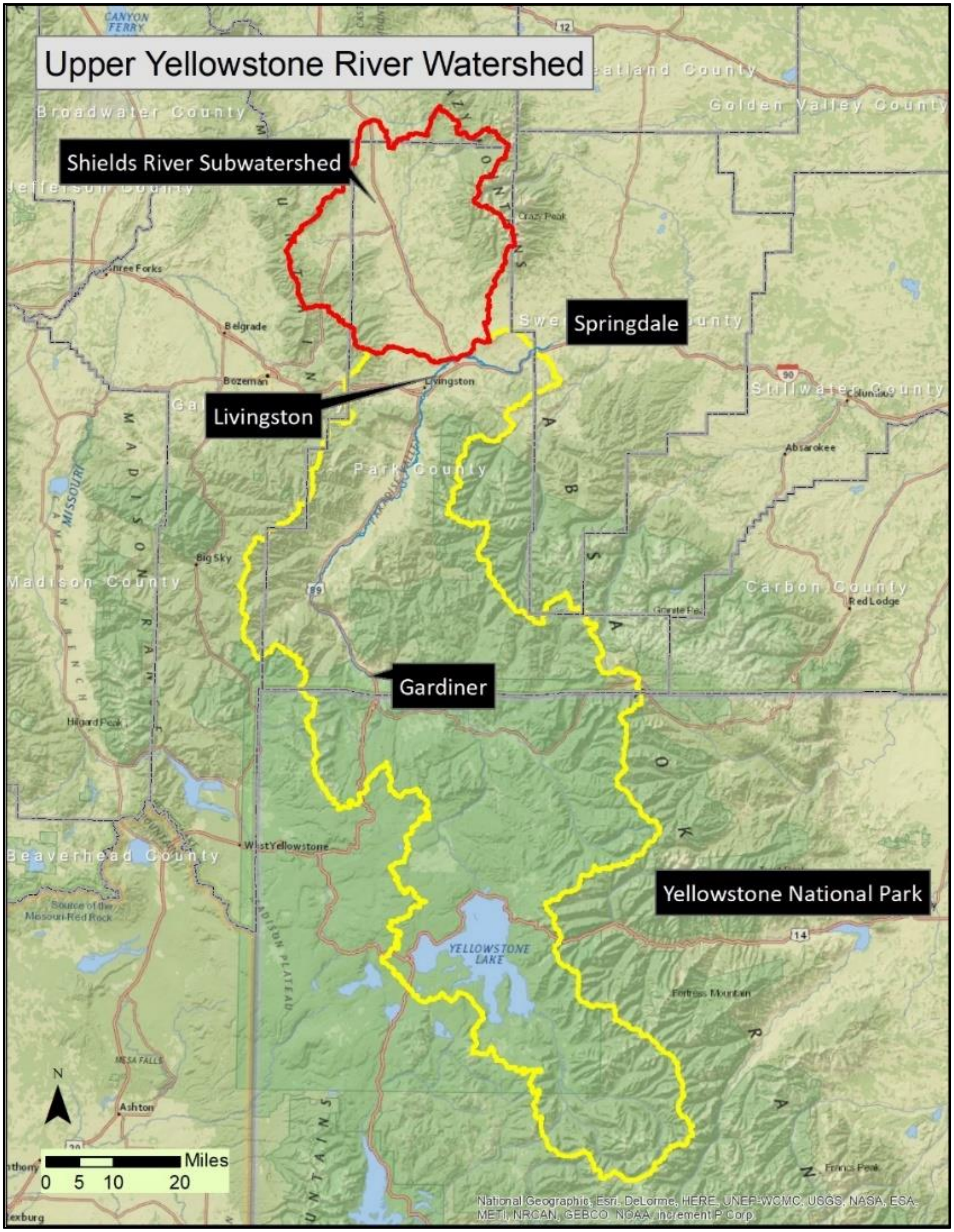

Figure 11. Watershed boundaries for Upper Yellowstone and Shields Rivers.

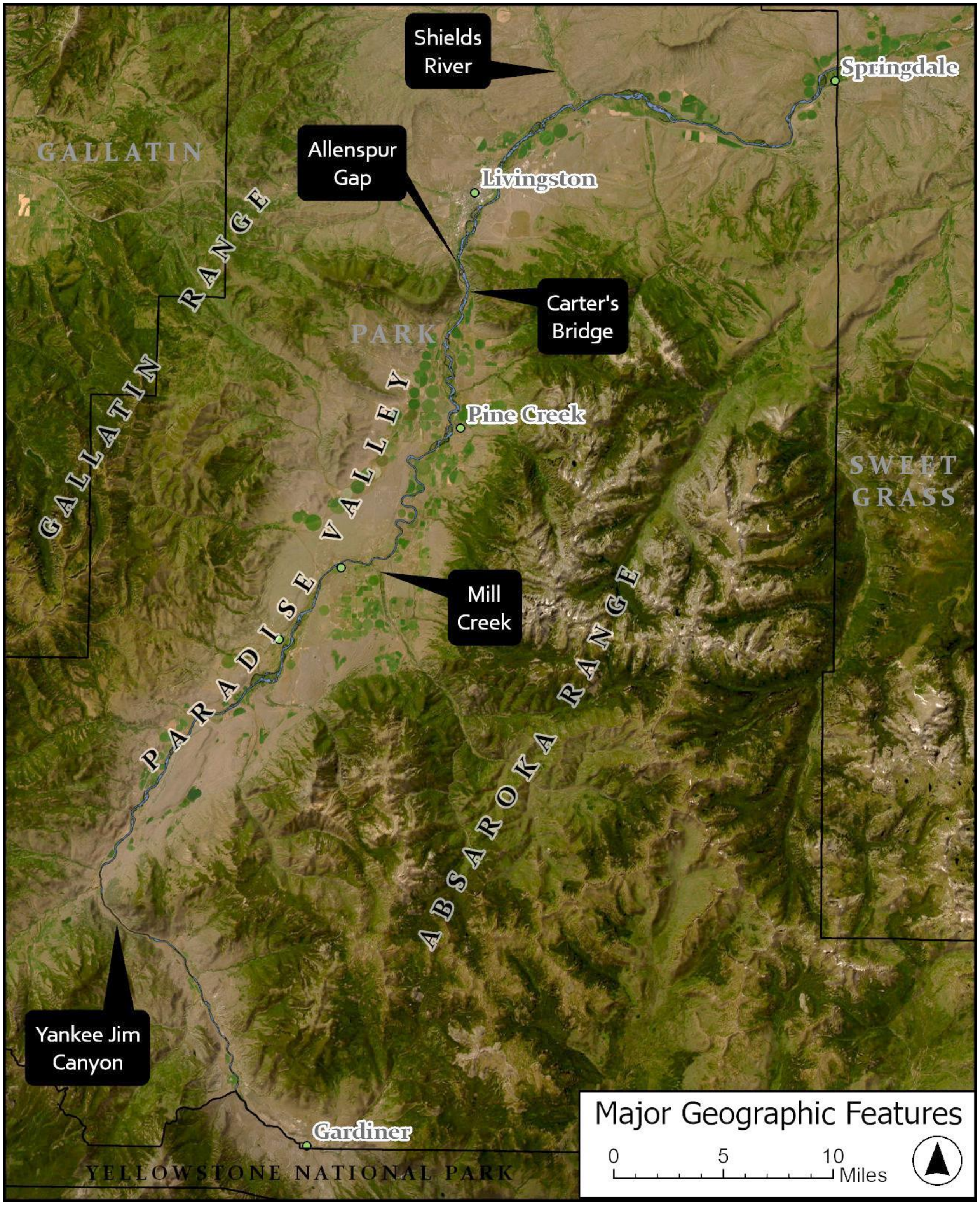

Figure 12. Major geographic features of project area.

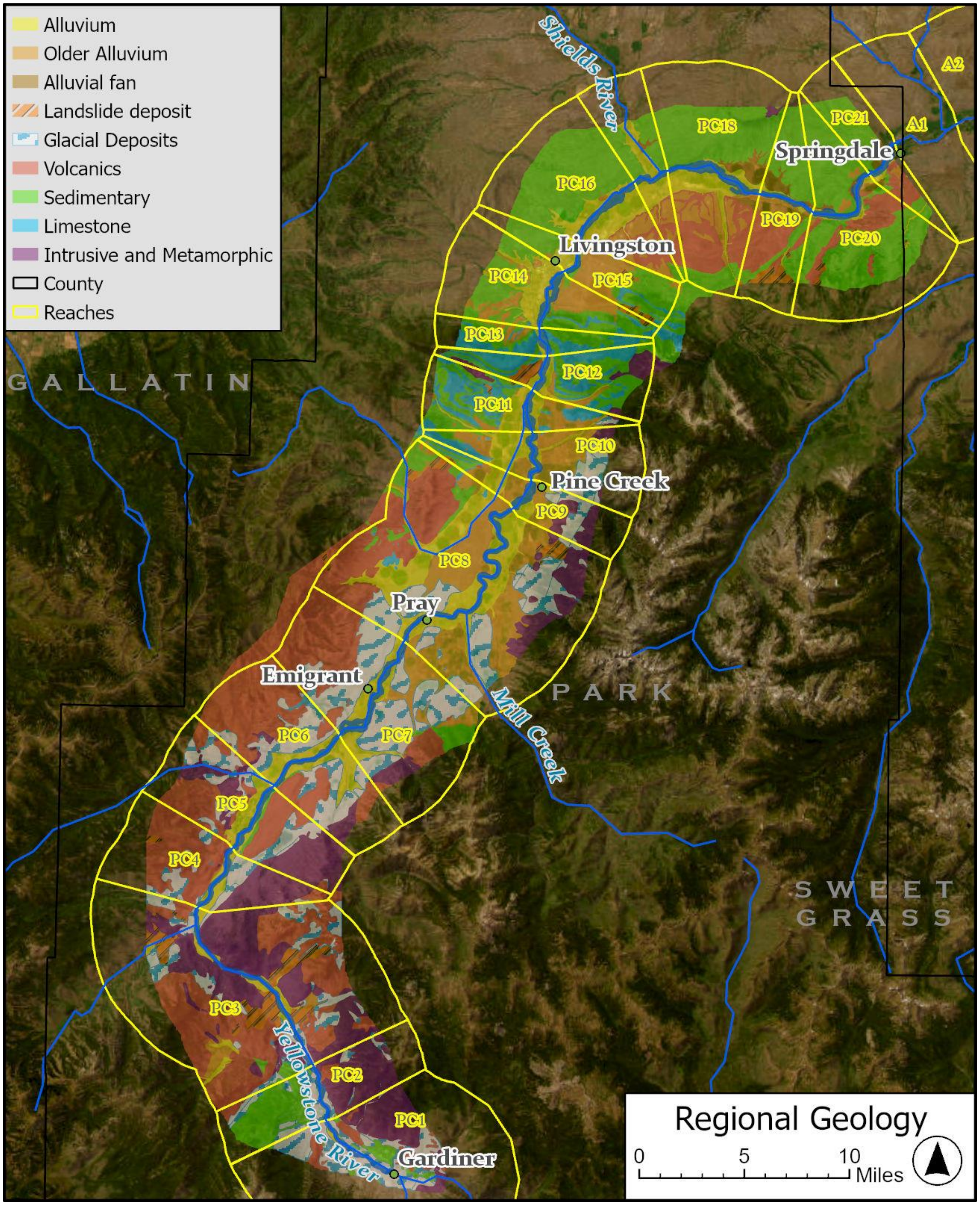

Figure 13. Simplified geologic map of the project area.

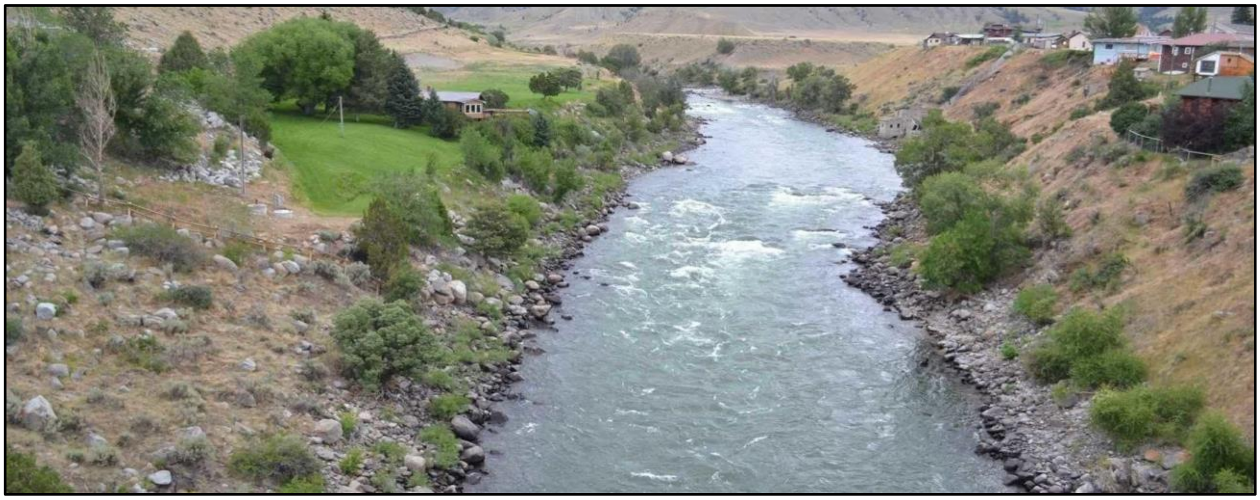

Figure 14. View upstream from Gardiner bridge showing flat glacial terrace on right.

Figure 15. View upstream of bedrock geology of Yankee Jim Canyon (Montana Angler).

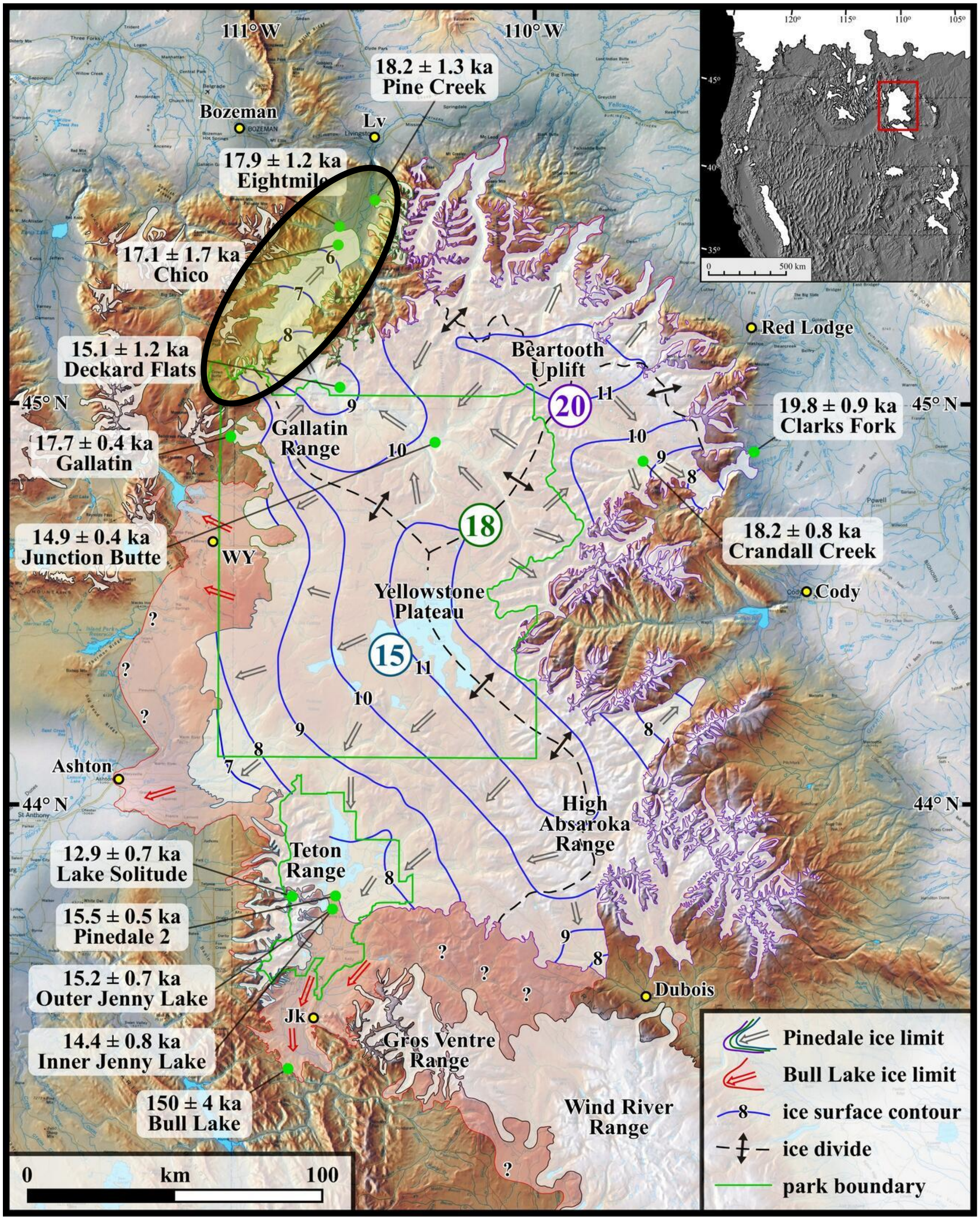

Figure 16. Map showing ice cover in the Yellowstone Region during the Pinedale and Bull Lake Glaciations. Blue lines are contours in thousands of feet showing the reconstructed ice surface. The Yellowstone River valley north of Gardiner is highlighted in the black circle (USGS).

Figure 17. View downstream from 2 miles upstream of Emigrant Bridge showing active narrow corridor in foreground widening out to an approximate 1/2 mile wide riparian corridor; note low adjacent floodplain surfaces; Sixmile Creek is on right of photo (Kestral Aerial Services).

Figure 18. High eroding outwash terrace against river at the Weeping Wall below Pine Creek (Kestral Aerial Services),

The Paradise Valley rapidly tapers near Carter’s Bridge where bedrock exposures of limestone and other sedimentary rocks form a valley bottom constriction (Figure 19). This is known as Allenspur Gap, which is a notch carved through a limestone and sandstone ridge that runs perpendicular to the river. Within this notch, the river bottom is 1,000 to 1,800 feet wide, so that the river is not entirely confined. In the early 1970’s, a dam was proposed for Allenspur Canyon but was ultimately defeated largely due to local resistance. Allenspur Dam was proposed as a 380-foot tall dam with a 250,000 watt power plant that would have inundated the Paradise Valley up to 30 miles upstream.

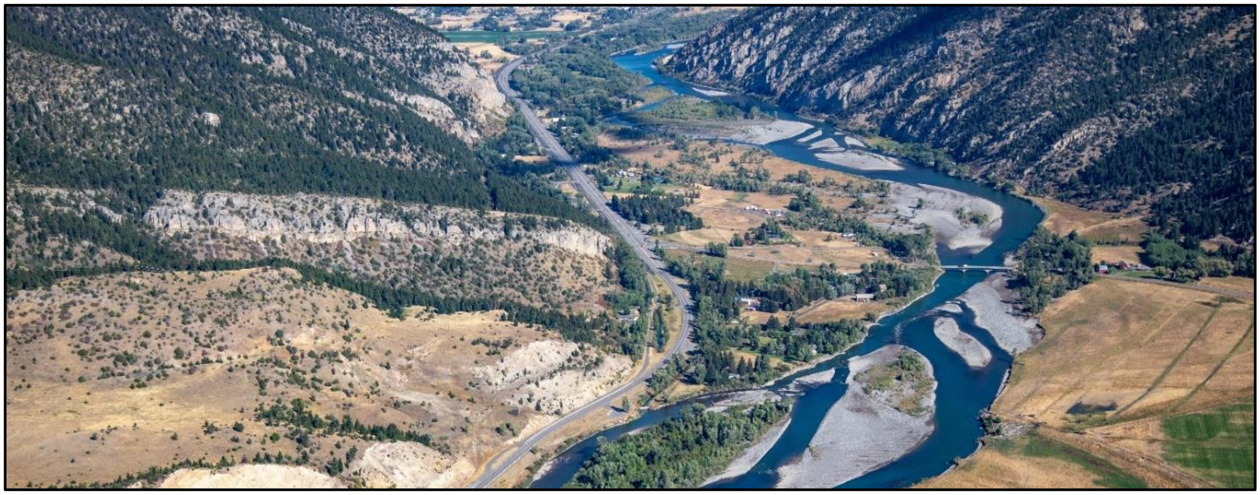

Figure 19. View downstream showing Allenspur Gap bedrock constriction near Carter’s Bridge - photo center (Kestral Aerial Services).

From Allenspur Gap to the mouth of the Shields River, the town of Livingston has expanded on both sides of the river resulting in a highly developed river segment. Bank armor is extensive. Below the Shields River the stream corridor widens with long multi-thread channel segments supporting broad riparian forests (Figure 20).

Figure 20. Wide active stream corridor below Shields River confluence (Kestral Aerial Services).

2.3 Flood History

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

Park County sits near the headwaters of the Yellowstone River and maintains a natural spring snowmelt hydrograph, typically peaking in mid-June. There have been seven 10-year or greater flood events on the river in the past 28 years. For many decades the peak flood of record was the event of 1918, when the river peaked at about 30,000 cfs in early June. No additional major floods occurred until 1971, when flows exceeded a 25-year event (Figure 21).

Major geomorphic work was done on the river in 1996 and 1997 when sequential years of heavy snowmelt runoff created two 25-year plus flood events in early June. These floods were followed by a rash of 310 permits to armor banklines through the project reach. The spring of 2011 saw an even larger event that was just over a 50-year flood at Corwin Springs. This was a system-wide event that caused a major oil pipeline rupture downstream near Laurel.

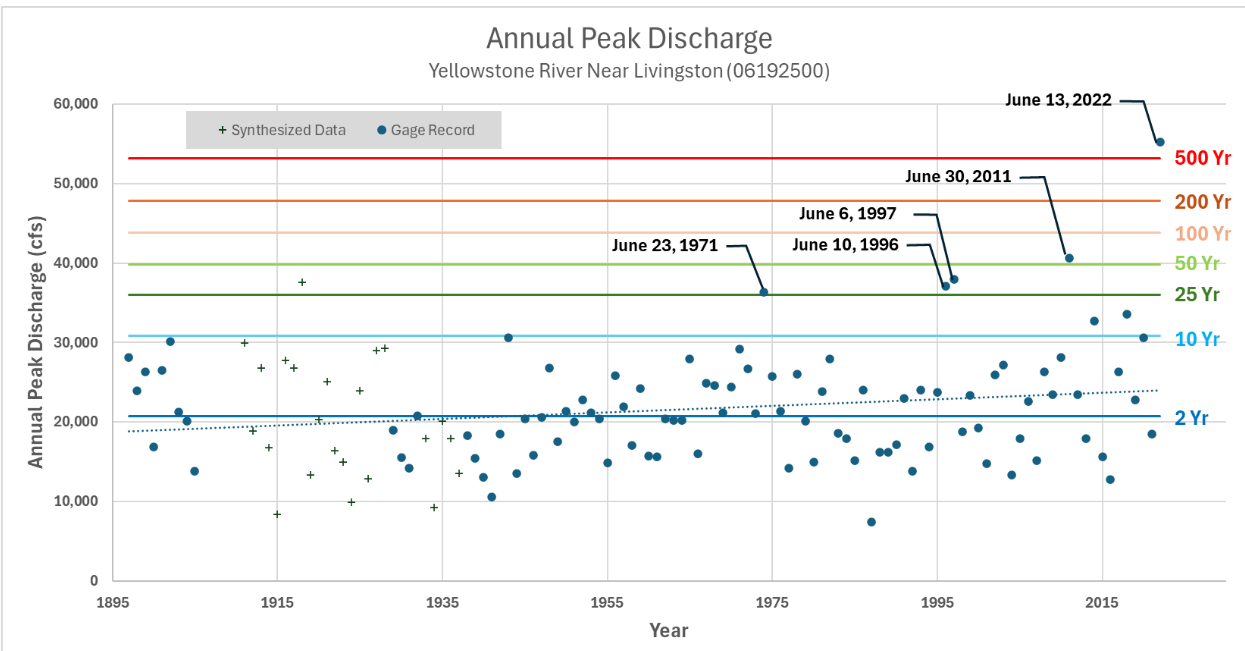

Figure 21. Annual peak floods for USGS 06192500 Yellowstone River near Livingston (Carter's Bridge).

In late May and early June of 2022, an atmospheric river that had soaked the Pacific northwest dropped several inches of rain in southern Montana and northern Wyoming. The rainfall event coincided with a warm spell that sped up snowmelt. The Absaroka and Beartooth Ranges received up to 5 inches of rain, which was combined with up to an additional 5 additional inches of snowmelt coming off saturated soils (nasa.gov). On Monday, June 13, 2022, the stage of the Yellowstone River at Corwin Springs rose rapidly, reaching a record elevation that was about 2.5 feet higher than the previous record which was set in 1918. The peak discharge at Corwin Springs was estimated by the USGS to be 54,700 cfs.

The flooding was extensive. Yellowstone National Park was closed on June 13 and over 10,000 visitors were evacuated due to safety concerns (Figure 22).

Figure 22. 2022 flood destruction of the Highway 89 North Entrance Road to Yellowstone National Park on the Gardner River, which joins the Yellowstone River at Gardiner.

Although the 2022 event was extreme, it was also short, with flows exceeding 30,000 cfs for about a day. Whereas the instantaneous peak on July 13 was 54,700 cfs, the mean daily flow value on that day was 47,200 cfs. Figure 23 shows mean daily flow hydrographs at Corwin Springs for all the major floods since 1971; the very sharp rise and fall of flows during 2022 was extremely unusual as can be seen by the shapes of the hydrographs.

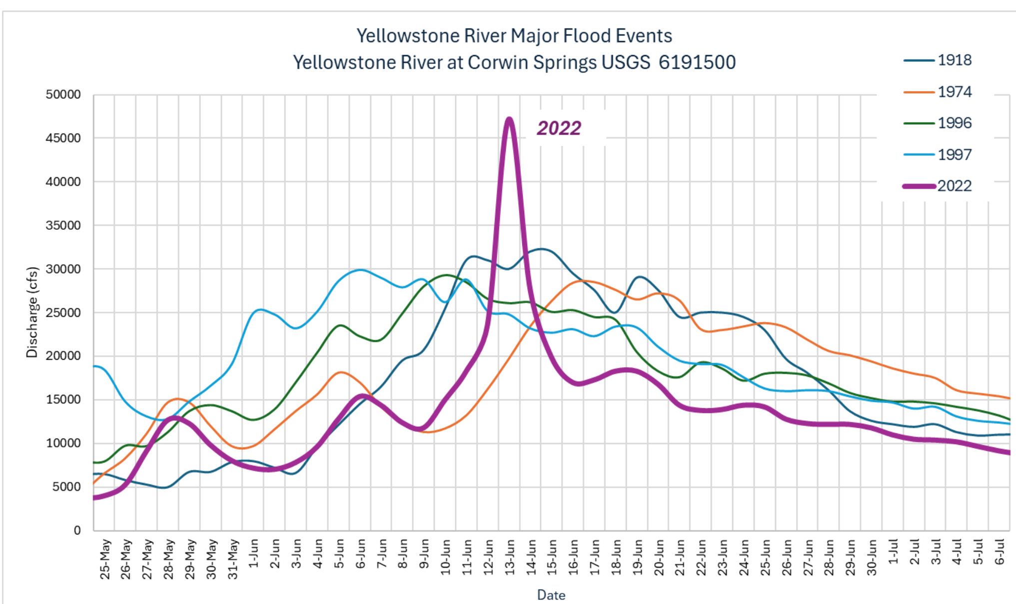

Figure 23. Spring snowmelt hydrographs for major floods on at Corwin Springs. Flows are mean daily values; note short duration of 2022 flood.

The short duration of the 2022 flood made it a different type of event than the previous floods shown in Figure 23. While the magnitude of the flood event is important for evaluating rates of channel change, it is also important to put the duration of the events into perspective (Figure 24). For example, a 25-year flood that lasts for weeks may result in more geomorphic changes than a more extreme but short duration event that may primarily cause flood damage. In 2011, a three-week runoff event on the Musselshell River resulted in 59 avulsions and 37 mile shortening of the river, completely changing its geomorphic form (width, slope, pattern). In 1997, the Yellowstone River stayed above 20,000 cfs on the Corwin Springs USGS gage for almost three weeks, causing extensive bank erosion and channel movement. The June 2022 event peaked quickly before dropping back down, only exceeding a mean daily flow of 20,000 cfs for 3 days. Bank erosion was common, but a longer duration flood would have created much more damage. That said, the rapidly rising flows created extensive floodplain damage due to high volumes of wood and sediment entering in the river (Figure 25 to Figure 27). That material will continue to be reworked in coming years, creating a potentially long adjustment period post-2022.

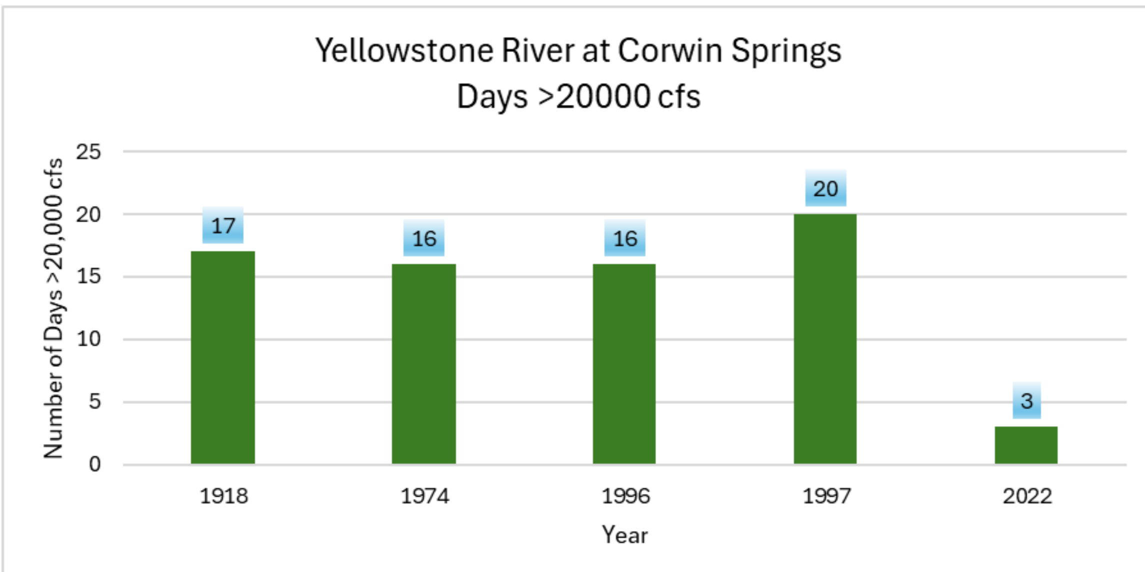

Figure 24. Number of days mean daily flows exceeded 20,000 cfs at Corwin Springs for major flood events.

Figure 25. Woody debris removal from Yellowstone River floodplain following 2022 flood (Kestrel Aerial Services).

Figure 26. High terrace erosion at Mallards Rest that threatened the access road behind the photographer and resulted in closure.

Figure 27. Miles of fencing were destroyed during the 2022 flood.

Although the short duration 2022 flood did not completely alter the form of the river system-wide, the very high peak caused different processes to occur, creating major changes in certain areas. One of the most striking changes was where the river is deeply entrenched in coarse outwash material upstream of Yankee Jim Canyon. In these sections, coarse boulders accumulated from the high banks had been naturally protecting the bank toes, forming a natural riprap that helped stabilize the channel during previous floods. Although the 2022 event was relatively short, its extreme magnitude caused that material to mobilize, destabilizing those banks which resulted in extensive erosion, channel widening, and downstream sediment delivery. Figure 26 shows one area near Gardiner where the river almost doubled in width from 120 to 220 feet.

Figure 28. Time series of channel segment near Gardiner showing relatively stable channel form from 1948-1922 followed by about 100 feet of widening during the 2022 flood; the house circled in the 2021 image was lost during the flood.

2.4 Dikes and Levees

There are approximately 18.5 miles of floodplain dikes and levees on the Yellowstone River in Park County, including those in the City of Livingston and along the private spring creeks at the northern end of Paradise Valley. These features are maintained to limit floodwater in adjacent land area and reduce channel migration, though none are certified floodplain levees.

2.5 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. No on-the-ground mapping of armor was performed, so the mapped features likely underestimates the amount of actual armor within the system on current and active channels. 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.

Based on the 2015 Cumulative Effects Assessment (USACE, 2015), there were approximately 23.1 miles of armor on the Yellowstone River in Park County in 2001. This armor inventory was updated for this study to include 2011 and 2023 conditions, noting both new and lost armor at each time period. By 2011, the amount of armor had increased to 28.9 miles and by 2023 there were 31.5 miles of armor. Another way to look at this is in terms of the percent of bankline that is armored, not including levees. From 2001 to 2023 the percentage of armored bankline has increased from 13% to 18%. Some reaches are upwards of 25% armored (USACE, 2015).

This is in addition to approximately 18.5 miles of levees along the Yellowstone River in Park County.

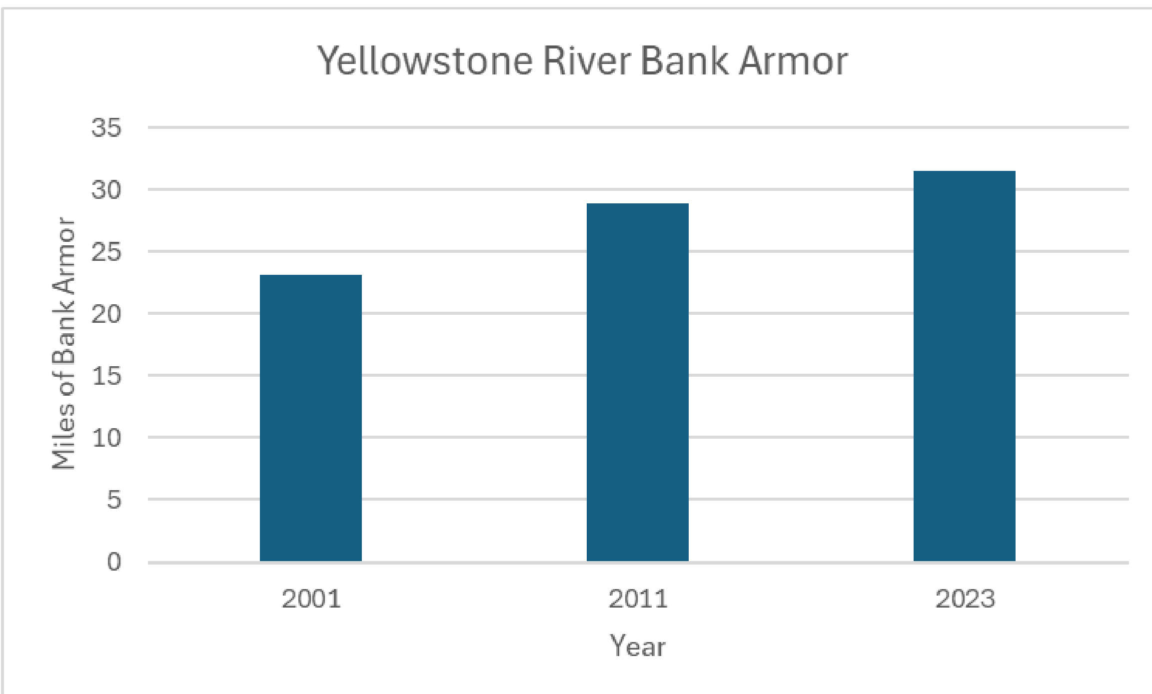

Figure 29. Growth in mapped bank armor in Park County, 2001-2023.

3 Methods

The development of the Park County Yellowstone 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 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 1 and Figure 30). These reaches were developed for the 2015 Cumulative Effects Study and were not revised for this mapping effort. There are 21 reaches defined for the 86 miles of Yellowstone River in the county. The reaches are numbered from upstream to downstream starting in Gardiner, MT and ending at the county line near Springdale, MT.

Table 1. Park County Mapping Project reaches from 2015 Cumulative Effects Assessment.

Reach	General Location	Upstream RM	Downstream RM	Length (mi)
PC01	Gardiner to Little Trail Creek	564.7	560.2	4.5
PC02	Devil's Slide area	560.2	557.1	3.1
PC03	Corwin Springs to Carbella; Yankee Jim Canyon	557.1	546.8	10.3
PC04	Carbella to Hwy 89 Bridge	546.8	543.2	3.6
PC05	Hwy 89 Br. to Big Creek	543.2	539.3	3.9
PC06	Big Creek to Six Mile Creek	539.3	535.1	4.2
PC07	Six Mile Cr to Grey Owl	535.1	528.1	7
PC08	Grey Owl to just below Mallard's Rest	528.1	516.3	11.8
PC09	To Pine Creek	516.3	514.4	1.9
PC10	To downstream of Deep Creek; Weeping wall, Jumping Rainbow; onset of spring creeks	514.4	510.9	3.5
PC11	To near Suce Creek, Wineglass Mountain to west	510.9	508.6	2.3
PC12	To Carters Bridge	508.6	506.6	2
PC13	Through Allenspur Canyon upstream of Livingston	506.6	505.0	1.6
PC14	To Livingston	505.0	501.6	3.4
PC15	To Mayor's Landing	501.6	499.8	1.8
PC16	To just upstream of Hwy 89 Bridge	499.8	495.5	4.3
PC17	Through Hwy 89 Bridge crossing to Shields River	495.5	493.5	2
PC18	To below Mission Creek	493.5	488.2	5.3
PC19	To near Locke Creek	488.2	485.5	2.7
PC20	To Irrigation Diversion on River Left	485.5	481.0	4.5
PC21	To County Line near Springdale	481.0	478.4	2.6

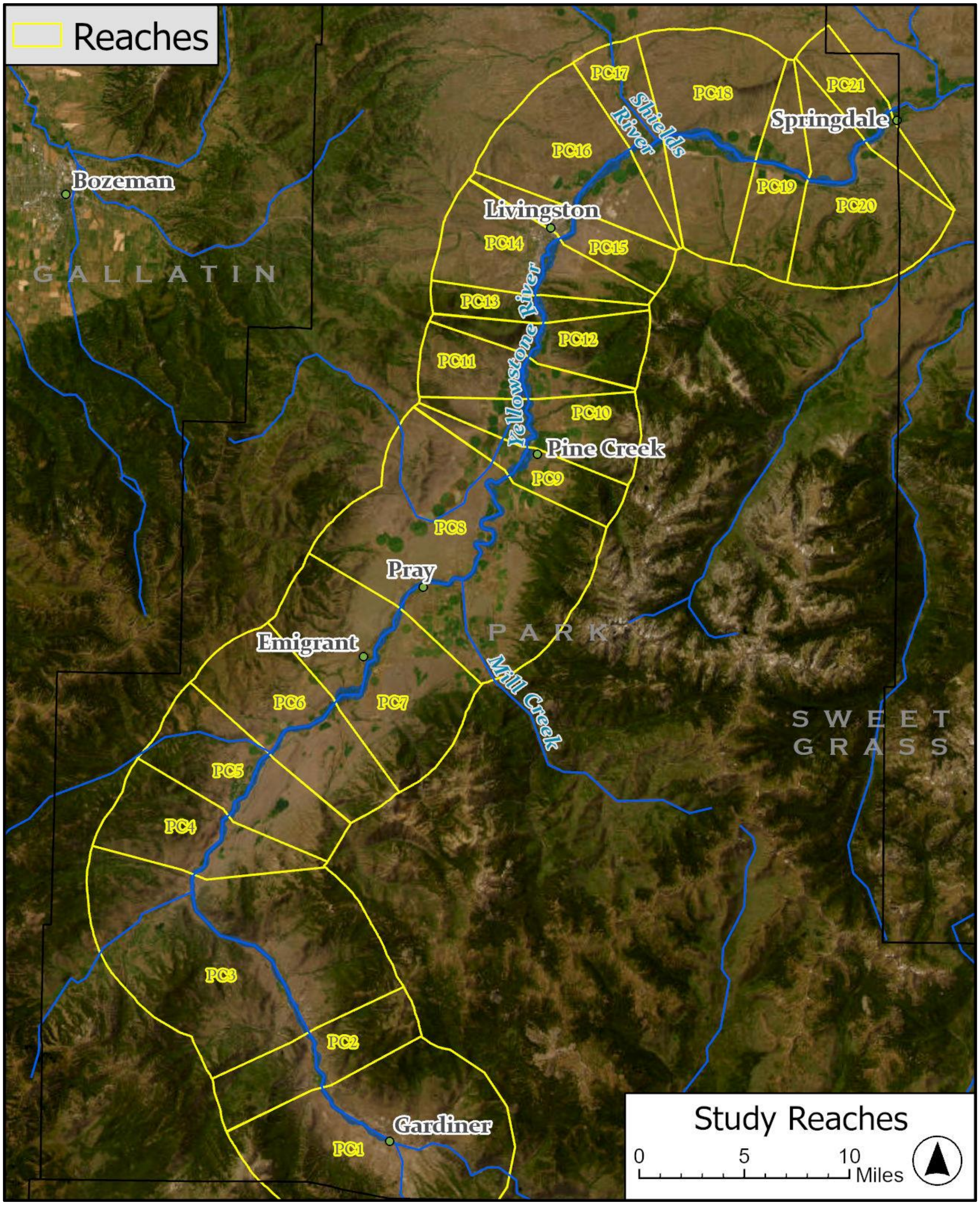

Figure 30. Yellowstone River CMZ Mapping project reaches.

3.2 GIS Project Development

All project data was compiled using ESRI's ArcGIS Pro Geographic Information System (GIS) utilizing a common coordinate system - Montana State Plane NAD83 Meters. The orthorectified air photos provide the basis for Channel Migration Zone mapping. Other existing datasets included roads, 2020 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. Stream stationing at tenth-of-a-mile increments and reaches developed for the Yellowstone River Cumulative Effects Study are used as the linear and spatial referencing for all discussions.

3.3 Aerial Photography

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

This project is an update and integration of the 2009 channel migration study which utilized river locations as defined by bankfull channel extents digitized from imagery between 1948 and 1999. This update includes river locations from four newer suites of imagery, including pre-flood (2021 NAIP) and post-flood (2023 50cm satellite) imagery. General information for each of the imagery suites are shown in Table 2 and discussed below. In general, the imagery spans from 1948 to 2023. Additionally, there are several partial imagery suites available for Park County which were used to refine the channel migration history, though no banklines were mapped for these imagery suites.

Table 2. Aerial photography used for the Yellowstone River Channel Migration Mapping Study.

Year	Source	Scale	Image Date(s)	Notes
1948	USDA	1:20,000	NA	Georeferenced
1999 DOQQ	USDA	~ 1 meter resolution	NA	
2011 NAIP	USDA	~ 1 meter resolution	NA	No Islands were mapped.
2015 NAIP	USDA	~ 1 meter resolution	NA	Digital Download, Compressed County Mosaics (color)
2021 NAIP	USDA	~ 1 meter resolution	NA	Digital Download, Compressed County Mosaics (color)
2023	WorldView2 / WorldView3	50-cm	July 12, Sept 19, and Sept 24, 2023	Processed by LandInfo Wordwide Mapping, LLC

The 1948 imagery consists of high-resolution scans from archival imagery from the USDA. The individual images were merged into a single georeferenced mosaic for each time period. Starting with the Digital Orthophoto Quad imagery from the 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 on odd numbered years. The 2023 NAIP imagery was not collected for Park County, likely due to cloud cover or wildfire smoke impairing the image quality. To capture the impacts of the 2022 flood the missing 2023 imagery was replaced with WorldView-2/3 archived satellite imagery acquired through Land Info Worldwide Mapping. The imagery was delivered 50-cm pan-sharpened mosaic tiles (Figure 31). The mosaic was visually assessed for spatial accuracy using 2021 NAIP imagery.

Figure 31. Example 50-cm WorldView 2/3, ~0.5 miles below Pine Creek Bridge.

Figure 32 to Figure 37 provide imagery examples at the same location along with the associated digitized bankfull channel boundaries.

Figure 32. Example 1948 imagery at Point of Rocks.

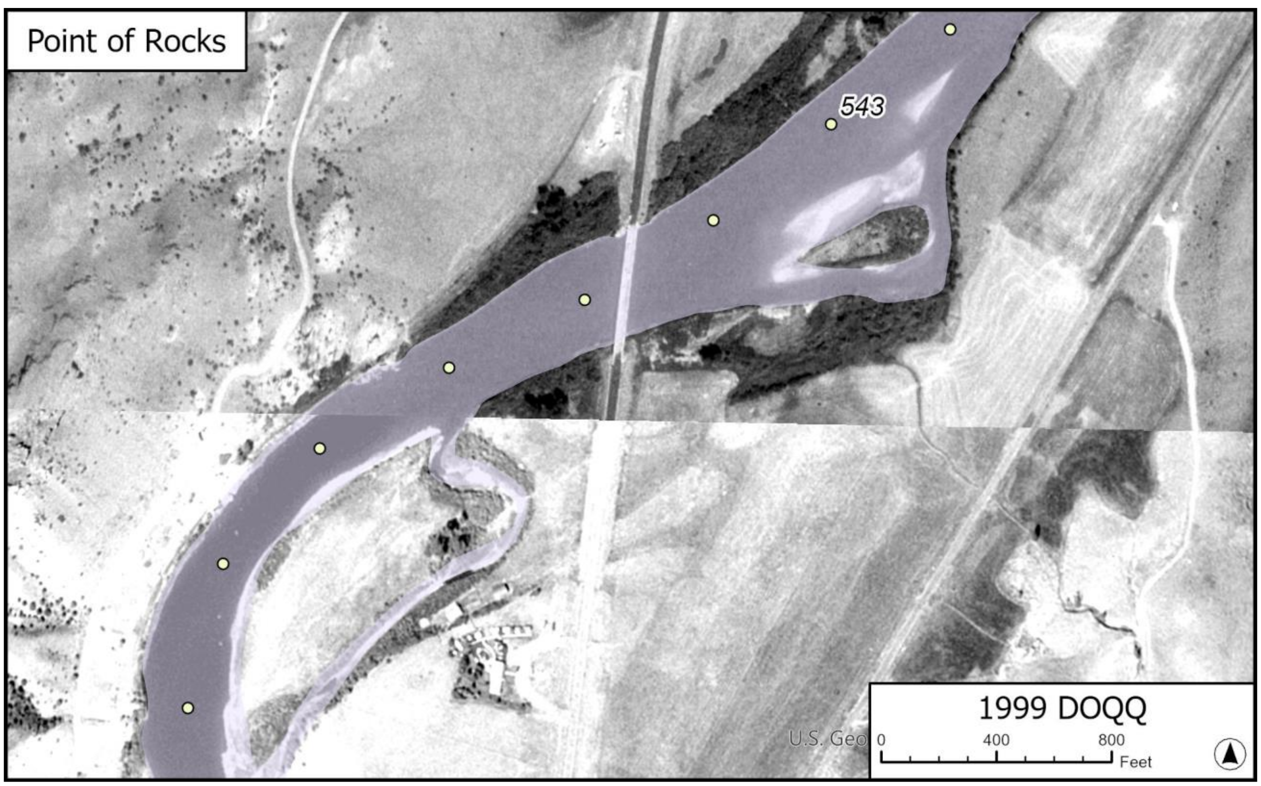

Figure 33. Example of 1999 DOQQ imagery at Point of Rocks.

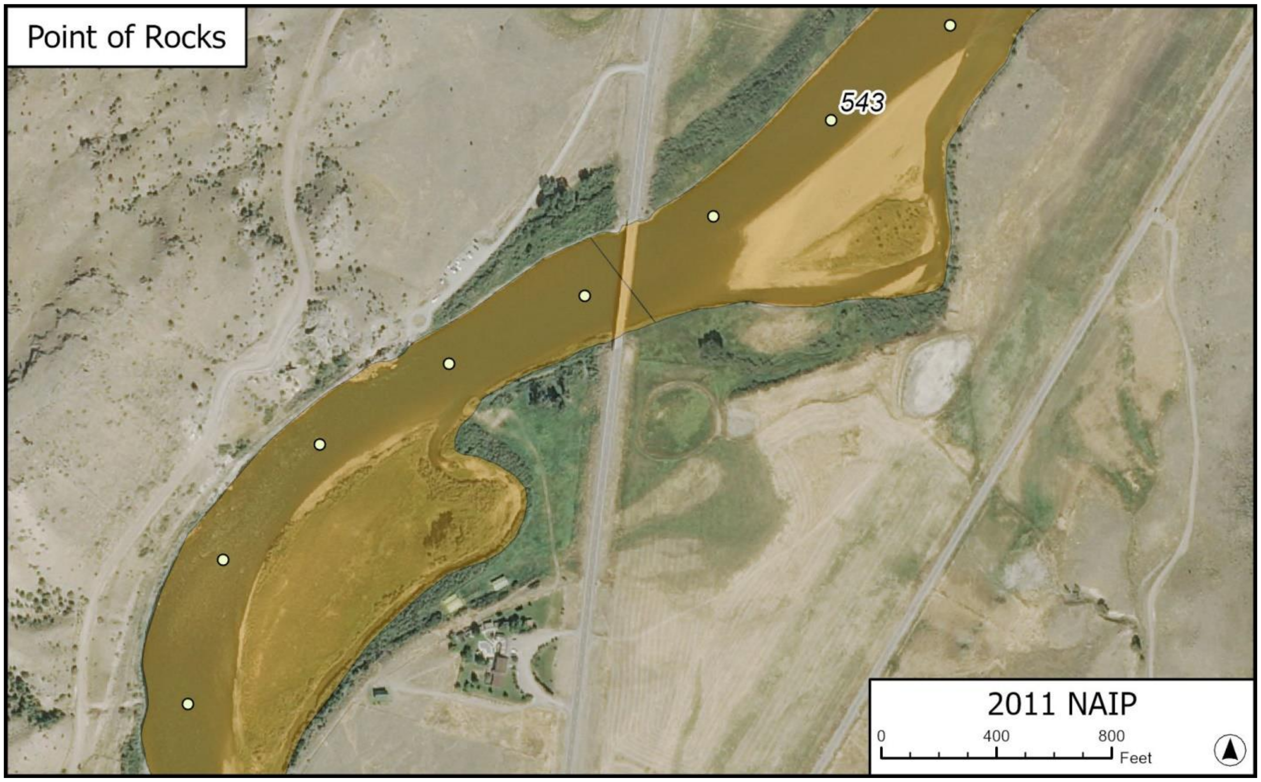

Figure 34. Example of 2011 NAIP imagery at Point of Rocks.

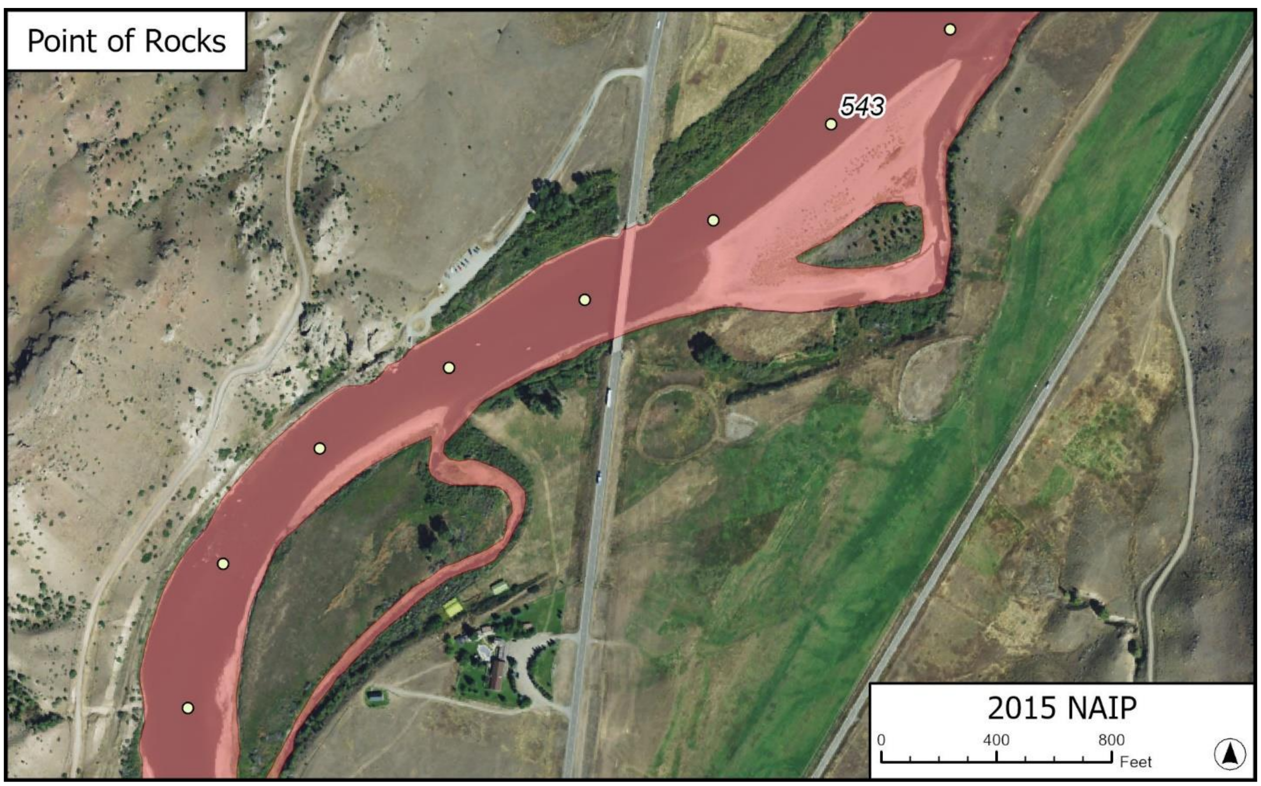

Figure 35. Example of 2015 NAIP imagery at Point of Rocks.

Figure 36. Example of 2021 NAIP imagery at Point of Rocks.

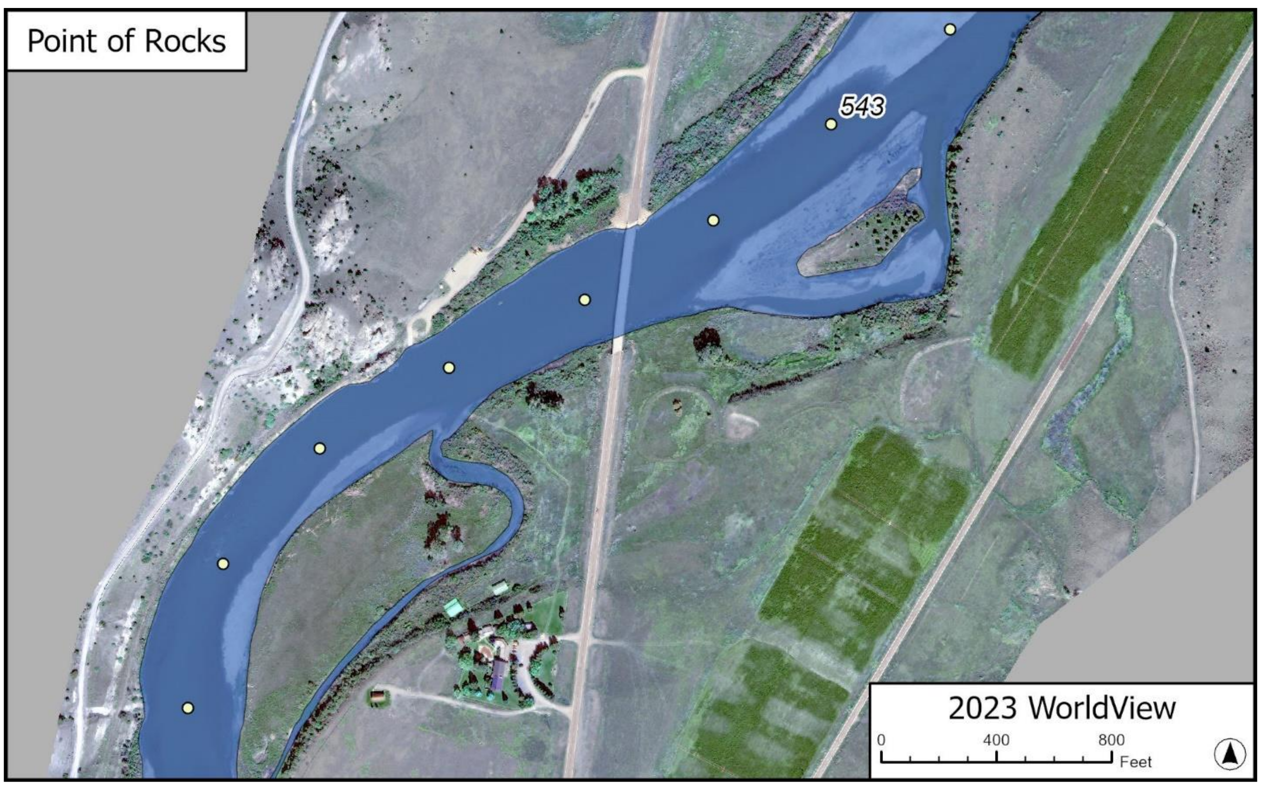

Figure 37. Example of 2023 50-cm WorldView imagery at Point of Rocks.

3.4 Bankline Mapping

Bankline mapping was developed for each suite of imagery to approximate bankfull conditions. Banklines prior to 2015 were developed for the Yellowstone River Cumulative Effects Assessment. 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.

Examples of the bankline mapping can be found in Section 3.3.

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

Once the banklines were digitized, they were evaluated in terms of discernable channel migration between 1948 and 2023. Where migration was clear, vectors (arrows with orientation and length) were drawn in the GIS to record that change. At each site of bankline migration, measurements were made in the GIS approximately every 500-700 feet (Figure 38). A total of 1,382 measurements were made along the length of the Yellowstone River in Park County. 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.

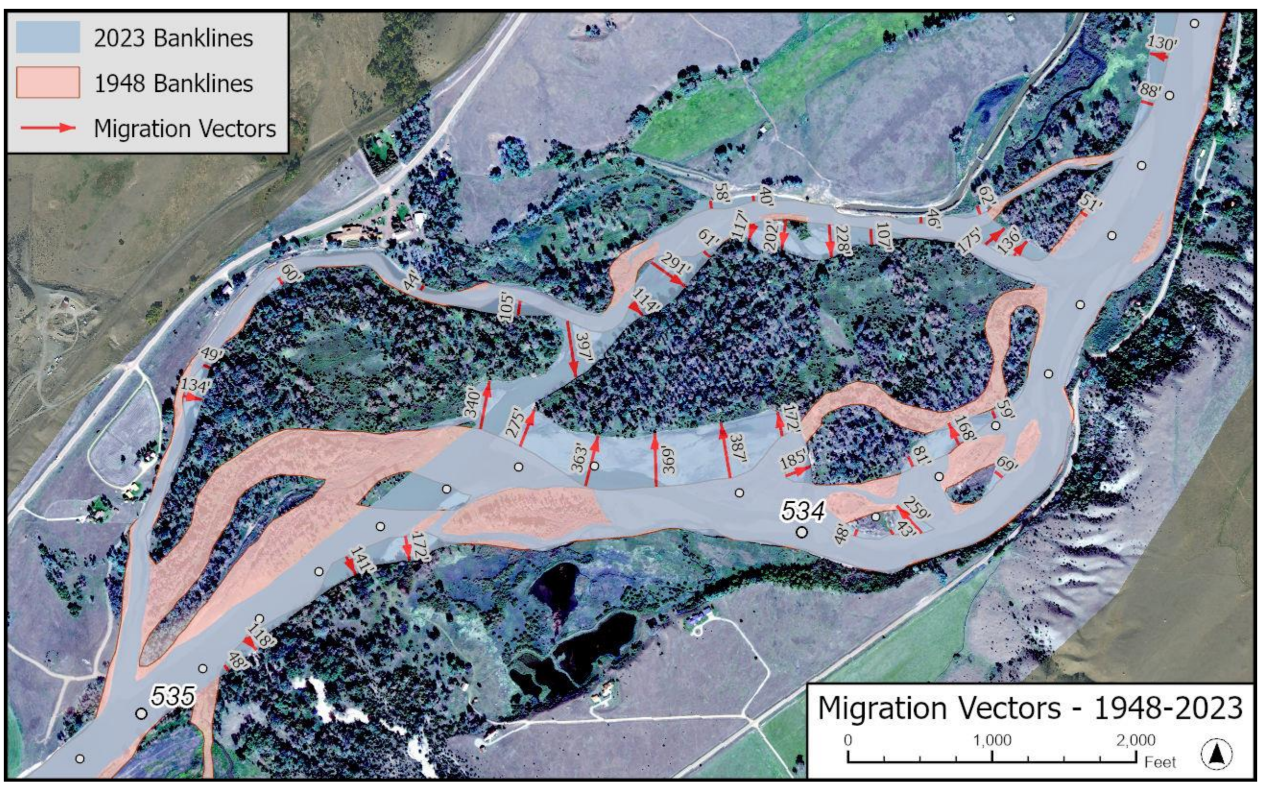

Figure 38. Example of migration measurements between 1948 and 2023 (migration distance in feet).

The Erosion Hazard Area (EHA) is based on measured migration rates, which are derived from measured migration distances. Migration distances between the 1948 and 2023 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 500-700 feet along eroding banklines to capture the entire range of migration distances at a given site. The minimum amount of movement captured is 40 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 1,382 measurements were made, with 651 measurements being greater than 40 feet. The migration measurements were also attributed with whether they are measuring migration through valley bottom alluvium (Qal) or through terrace materials. Note that terrace migration rates were not summarized by reach due to a similarity between rates on terraces for all reaches.

Error! Reference source not found. 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 dots above the boxes. The results show that 10 of the 21 reaches have individual areas of markedly high migration rates that show up as outliers on the plot.

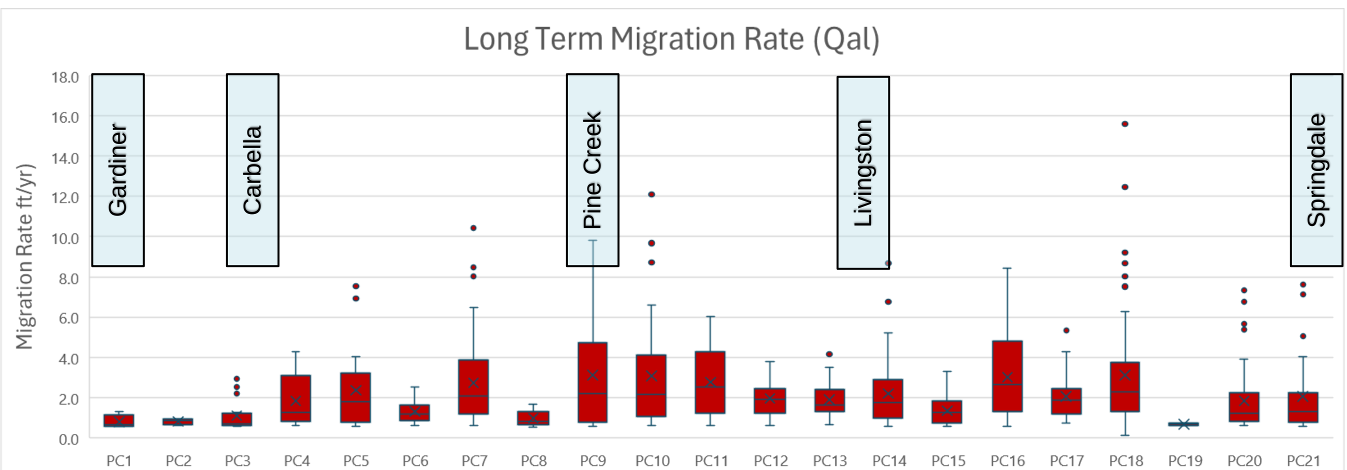

Figure 39. Annual migration rate box and whisker plots.

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

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 many systems where the migration rates cluster and show limited variability, the mean value is used to define the buffer. This was the case with the Yellowstone River. For terraces, a 100-year buffer of 80 feet was used for low and high terraces (Qt1 and Qt2), while 69 feet was used for the glacial outwash terraces (Qg) in the uppermost reaches.

Table 3 shows the resulting 100-year erosion buffer distance values for each reach. They range from about 80 feet in the more confined reaches, to over 300 feet in less confined reaches. These buffer widths were placed on the landward edge of the 2023 banklines and are shown as “Erosion Hazard Area” on the CMZ maps. If the buffer is partly or fully within the Historic Migration Zone (HMZ), it is trumped by the HMZ map unit and thus underlies it. As a result, the buffer is not always visible on the maps.

Table 3. Mean migration annual rate and 100-year EHA buffer by reach for alluvium.

Reach	Number of Measurements	Mean Annual Migration Rate (ft/yr)	90th Percentile Annual Migration Rate (ft/yr)	100- Year Buffer Width (ft)
PC1	4	0.80	1.12	80
PC2	4	0.80	0.91	80
PC3	20	1.10	2.35	110
PC4	17	1.83	4.01	183
PC5	26	2.36	5.47	236
PC6	14	1.30	2.10	130
PC7	87	2.71	5.61	271
PC8	12	0.96	1.45	96
PC9	26	3.11	6.54	311
PC10	32	3.07	6.43	307
PC11	20	2.76	4.84	276
PC12	31	1.95	3.43	195
PC13	23	1.89	3.40	189
PC14	50	2.19	4.09	219
PC15	23	1.35	2.07	135
PC16	64	3.01	6.09	301
PC17	24	2.06	3.22	206
PC18	81	3.11	7.51	311
PC19	2	0.66	0.71	66
PC20	59	1.83	3.58	183
PC21	32	2.06	4.93	206

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 40. 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.

Once the buffers are placed on the 2023 banklines, areas of bedrock geology are clipped out (Figure 41) to reflect the likely lack of lateral channel migration in those areas during the 100-year life of the CMZ.

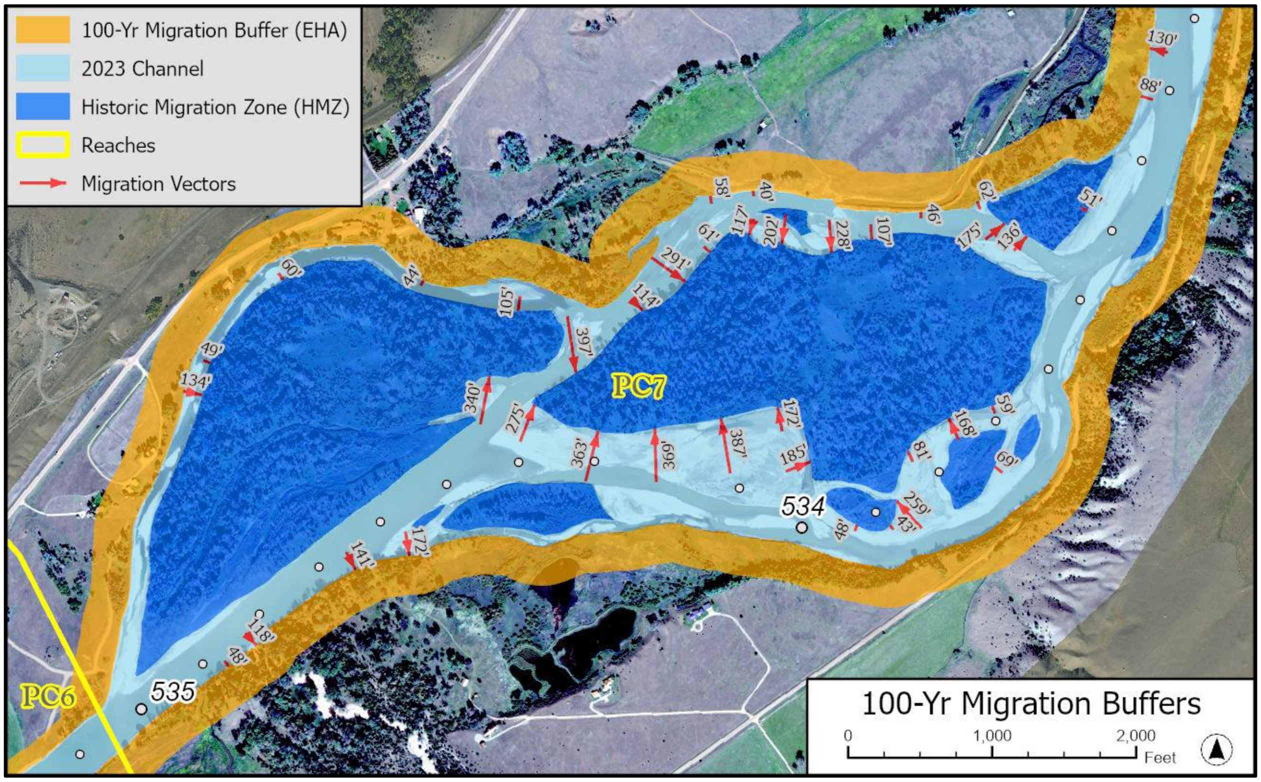

Figure 40. The Erosion Hazard Area (EHA) is a buffer placed on the 2023 banklines based on 100 years of channel migration for the reach.

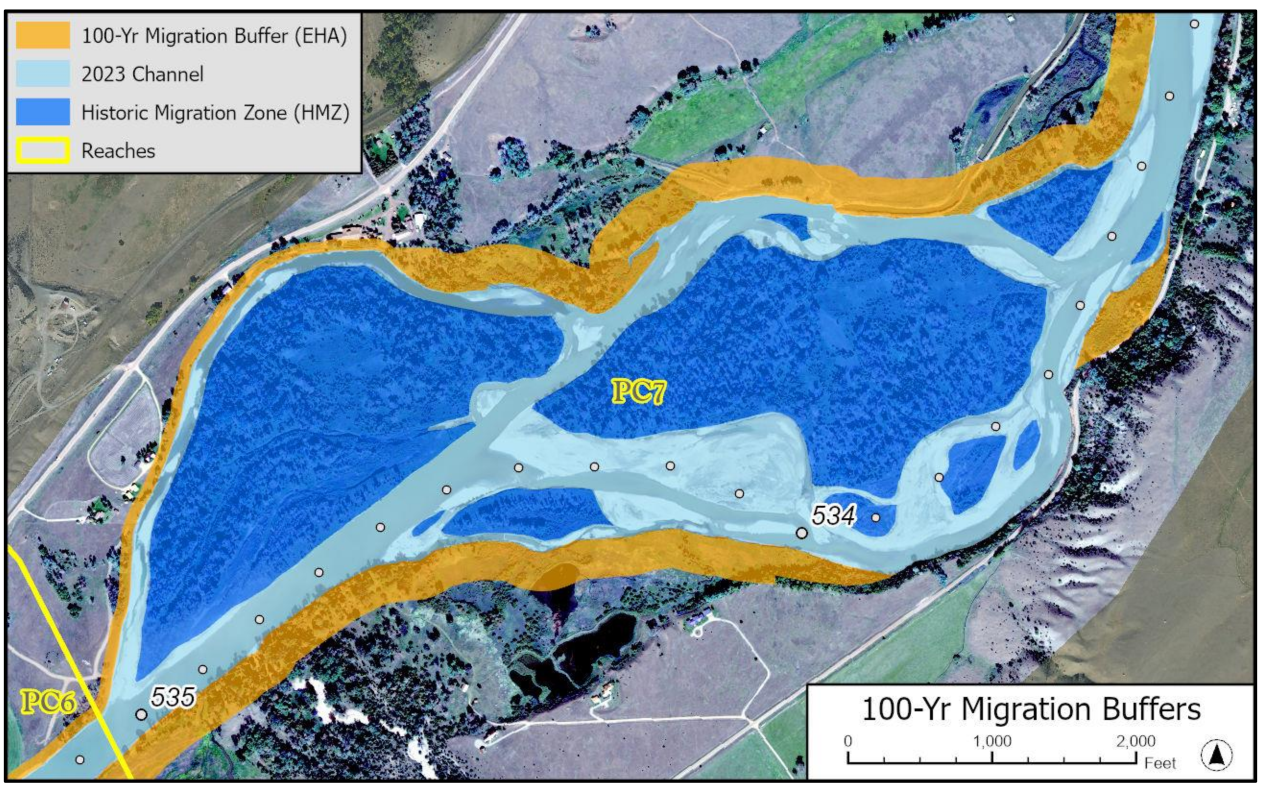

Figure 41. 100-year migration buffers clipped for geology and erosion resistant terraces.

3.6 Avulsion Hazard Mapping

The avulsion hazard mapping captures areas beyond the core CMZ (HMZ + EHA) that show some propensity for developing new active channels in floodplain areas, 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 four feet above the LiDAR water surface elevation.
- Swales carrying concentrated floodwaters during the 2022 flood.
- Well-defined continuous flow paths that intersect the core CMZ (HMZ and EHA) boundaries

The Yellowstone River floodplain generally has a well-defined boundary as defined by terrace margins that creates a complex riparian corridor. While there are areas with networks of floodplain swales, such the spring creeks immediately upstream of Carter's Bridge, the area around the Livingston HealthCare hospital in Livingston, and several areas around the Hwy 89 Bridge, many of these areas are captured by the HMZ and thus do not have a mapped avulsion hazard.

The Avulsion Hazard Zone (AHZ) includes the areas of the river landscape, such as relic channels and swales that are at risk of channel occupation outside of the Historic Migration Zone (HMZ). These areas are identified using a Relative Elevation Model derived from the 2020 hi-resolution LiDAR elevation collected between Sept 13 - Oct 9, 2020. REM models depict the elevations adjacent to the river channel and are critical for identifying potential avulsion pathways. Figure 42 shows an example of the REM downstream of the Hwy 86 Bridge. Historic river channels show up as dark blue pathways in the floodplain, with warmer colors (yellows and reds) indicating areas above the river channel. Potential flow paths are shown in dashed lines.

The AHZ is defined by the outer most flow pathway that has potential connectivity to the main channel either by overtopping the bank or by erosion through the bank to connect to the swale. A minimum difference in elevation of four feet between the river and the head of the swale was required to define a potential avulsion path. The AHZ is placed beyond any Erosion Hazard Area (EHA) buffer (Figure 43).

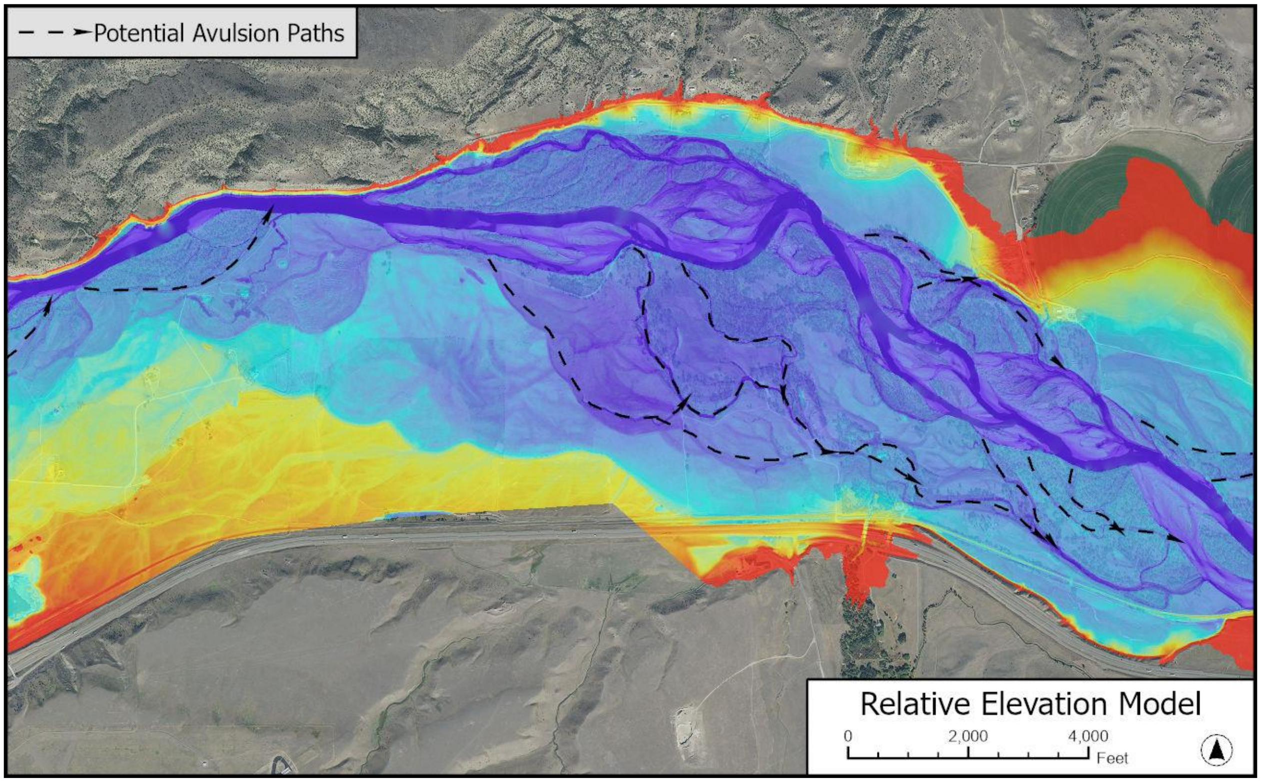

Figure 42. Example Relative Elevation Model and potential avulsion pathways downstream of Hwy 89 Bridge.

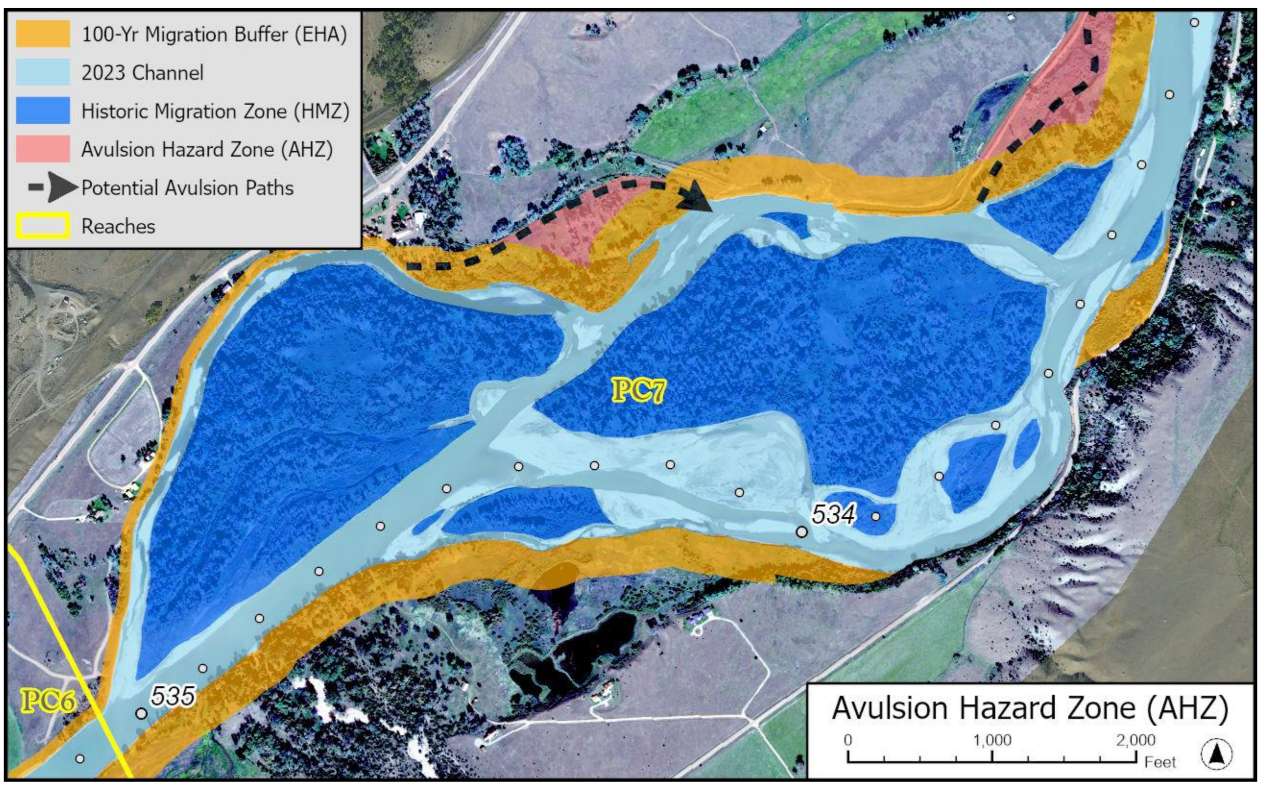

Figure 43. Example avulsion pathways.

3.7 Rapidly Eroding Bankline Assessment

The June 2022 Yellowstone River flood resulted in unique impacts to some of the banklines where they were over steepened due to rapid erosion. This was most evident in the confined upper reaches between Gardiner, MT and Yankee Jim Canyon where banklines that were naturally armored experienced erosion where the natural armor was mobilized. This resulted in banklines that were steeper than their natural angle of repose (Figure 44). These banklines will continue to "lay back" over time to reach a more natural slope angle, even if the toe of the bank experiences no more lateral movement.

To help identify this hazard, a 2:1 (2 horizontal to 1 vertical) surface was created from the mapped 2023 banklines. A 2:1 slope angle is consistent with FWP and CD assessment criteria for projects and permitting. Areas that were identified as exceeding the 2:1 surface were highlighted if they were greater than 10 feet high (Figure 45). This overlay on the CMZ maps indicates areas that will likely see continued adjustment to the top of bank, independent of any natural channel movement.

Figure 44. A bankline with a vertical scarp associated with 2022 bankline erosion.

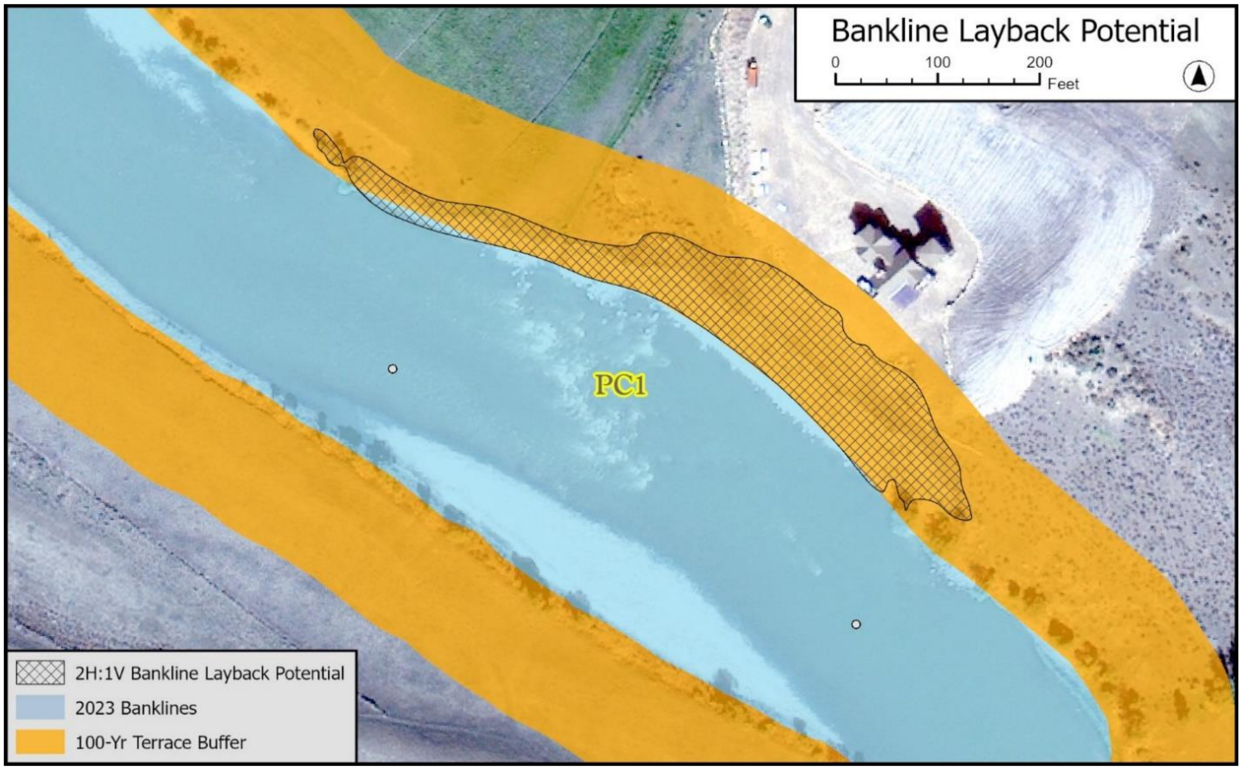

Figure 45. High, overly-steepened banklines resulting from the 2022 flooding were identified as at risk of continued layback as the bankline adjusts to the new channel location. Note that the home was moved back ~100' after the flood.

3.8 Composite Map

The composite map integrates all elements of the Channel Migration Zone map.

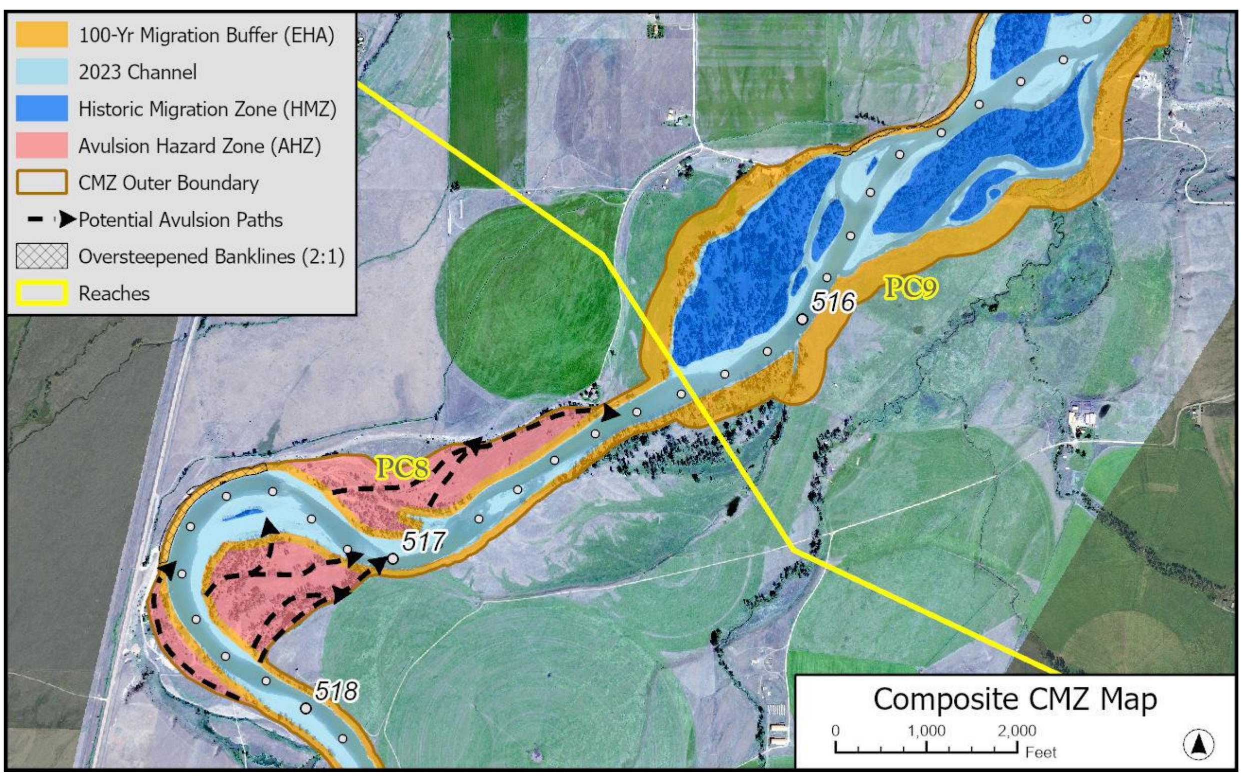

Figure 46. The composite CMZ map.

4 Channel Migration Concerns for the Yellowstone River in Park County

The following sections describe areas of concern on the Upper Yellowstone River resulting from channel migration and in some cases the 2022 flood. The descriptions are organized either by geography, as in the Gardiner area, or by topic. Several of the areas of concern identify specific locations identified by Park County personnel, internal review and public outreach, where channel migration or flooding are impacting existing infrastructure.

Note: All references to River Miles (RMs) reflect the river stationing used in the Yellowstone Cumulative Effects Assessment and differ from the Fish Wildlife and Parks river stationing. Wherever streambanks or floodplain areas are described as “right” or “left”, that refers to the side of the river as viewed in the downstream direction. For example, “RM 492.4R” refers to the right streambank located 492.4 miles upstream of the river’s mouth.

4.1 Gardiner and the Upper River

The area around Gardiner, MT deserves special attention due to the unique flood impacts in that area. In the 2009 CMZ mapping, the area through Gardiner displayed no evidence of lateral channel migration between 1948 and 1998. The high terraces on either side of the river were naturally armored with large glacial boulders and had been stable for the period of photographic record that included multiple 25-year plus flood events (Table 4). The 2022 flood mobilized this natural toe armor in several locations, resulting in channel migration towards roadways, structures, and completely undermining one structure. This erosion widened the channel and left vertical banks in several locations once the floodwaters receded.

The only roads in and out of Gardiner are either south through Yellowstone National Park to Mammoth or north on Hwy 89 through Yankee Jim Canyon. The flood destroyed access roads into Yellowstone National Park by washing out the North Entrance Road to Mammoth in several locations. Access from the south into Gardiner was not reestablished until October 29, 2024 after a 4-mile, $21 million dollar new access road was completed. To the north, flood waters eroded towards Hwy 89 and covered the highway roadbed through Yankee Jim Canyon and it was not known if the road had been lost until the floodwaters receded. Gardiner was largely inaccessible immediately following the flood.

Continued adjustments of the channel are visible in several locations (Figure 47), though currently they are not placing infrastructure at immediate risk.

Table 4. Locations of significant post-flood erosion between Gardiner and Yankee Jim Canyon.

Location (River Mile/Bank)	Impact	Threat/Description
RM564.0/Left	Up to 80 feet of erosion	None. Undeveloped.
RM563.9/Right (NPS Housing)	Up to 125 feet of erosion	NPS housing undermined and lost to the river. Continued erosion towards Hwy 89, homes and trailer court possible if the bankline continues to erode.
RM563.5/Left	Up to 75 feet of erosion	Undeveloped, though the old stage road could be impacted.
RM562.9/Right	Up to 50 feet of erosion	No immediate threat.
RM562.3/Left (below Treatment Plant)	Up to 65 feet of erosion into high terrace	None. Though the old stage road could be impacted.
RM56.9/Right	85 feet of erosion into high terrace	Home was moved back 100 feet to accommodate the new bank location.
RM560.0/Left	Up to 60 feet of erosion into low bench	River has widened significantly and post-flood erosion towards Yellowstone Riverside Lodge presents risk to the structures.
RM558.9/Left	Up to 55 feet of erosion into terrace	None. Though the old stage road could be impacted.
RM558/Left (Below La Duke Picnic Area)	Up to 50 feet of erosion into high terrace.	None
RM557.3/Right (Gravel Pit)	Up to 80 feet of post-flood erosion into gravel pit.	Unconsolidated banks in the gravel pit area (now occupied by cabins) present risk of continued erosion. Extensive new riprap is present.
RM556.4/Left (Below Yellowstone Hot Springs)	Over 100 feet of post flood erosion into low terrace	Erosion is approaching Old Yellowstone Trail
RM555.2/Left	Up to 75 feet of erosion into bench below Mulherin Creek	None.

Figure 47. Bankline below La Duke Picnic Area showing actively eroding banklines where the river moved up to 50 feet. Photo is at peak runoff on June 10, 2024.

4.2 Threats to Transportation Infrastructure

The transportation infrastructure along and passing over the Yellowstone River provides critical access to communities, emergency services, recreation, commercial transport, residential properties and businesses. While the roads, bridges and rails in Park County weathered several significant flood events, especially those in the mid-90s, the system was strained to the limit during the June 2022 flood. There were numerous instances of road and bridge damage and loss on public and private property away from the Yellowstone River due to the 2022 flood. The Montana Floods 2022 Park County Damage Assessment Reports (Park County, 2022) document notes that while some major roads experienced debris on the road and in guard rails, no major damage or closures to the roads due to the flood. Exceptions to this such as the Carbella and Point of Rocks bridges are discussed below.

The bridges appeared to take the greatest impact of the transportation network. Of the fifteen bridges over the Yellowstone in Park County, there were two full failures resulting from the flood - Carbella Bridge and the old railroad bridge paired just upstream of the Hwy 89 Bridge (Table 5).

Hwy 89, Interstate 90, East River Road and the railroad are the major transportation corridors in Park County, often running parallel to the river and acting as the bankline. Where this occurs, there is usually a significant amount of armoring to restrict channel migration into the road or railway, though there are several places where the river has moved laterally and is beginning to encroach into the transportation corridor.

A discussion of key issues with the transportation infrastructure follows, starting in Gardiner and moving downstream to Springdale.

Table 5. List of bridges and impacts.

Bridge	Roadway	RM	Impact
Gardiner Bridge	Hwy 89	564.7	No significant impacts
Corwin Springs	Cinnabar Basin Road	556.6	No significant impacts
Carbella Bridge	Tom Miner Basin Road	547.4	Complete failure during the flood. Replacement is under construction with a summer 2024 target completion.
Point of Rocks Bridge	Hwy 89	543.2	The river left end was flanked. The road approach was rebuilt after the flood.
Emigrant Bridge	Murphy Lane	531.5	No significant impacts
Mill Creek Bridge	Mill Creek Road	525.0	No significant impacts
Pine Creek Bridge	Pine Creek Road	514.4	No significant impacts
Carter's Bridge	East River Road	506.6	No significant impacts
Interstate Bridges	I-90	502.7	Some damage to pylons on 9th St Island Road
9th Street Bridge	9th Street Island Drive	502.2	No significant impacts
Veteran's Bridge	Hwy 89	499.8	No significant impacts
Railroad Bridge	BNSF Railroad	499.8	No significant impacts, but caused significant backwatering during flood event.
Old Railroad Bridge		494.5	Partial failure resulting in removal.
Hwy 89 Bridge	Hwy 89	494.5	Continued degradation of the alignment to flow with the loss of the upstream railroad bridge.
Springdale Bridge	Convict Grade Road	479.0	No significant impacts

There was no notable erosion where the Gardiner Bridge crosses the river. If this bridge were to fail, though, it would bisect the town and completely cutoff access to the north entrance of Yellowstone National Park with no viable options for alternative routes. There has been some discussion of improving the old stagecoach road on the west side of the river down through Yankee Jim Canyon to provide critical access should bridge or road failures isolate Gardiner. The 2022 flood did erode towards the old stagecoach road in several places, making it less of an option as an emergency corridor in the future.

At the downstream end of Gardiner (RM 563.8R), there was approximately 125 feet of erosion into the right bankline during and in the year after the flood. This is the site where the National Park Service housing structure famously fell into the river at the peak of the flood. The current bankline is now approximately 160 feet from the roadway, with the road grade approximately 75 feet above the river surface. Work to terrace and stabilize the bank was performed, though no new armoring of the toe was included.

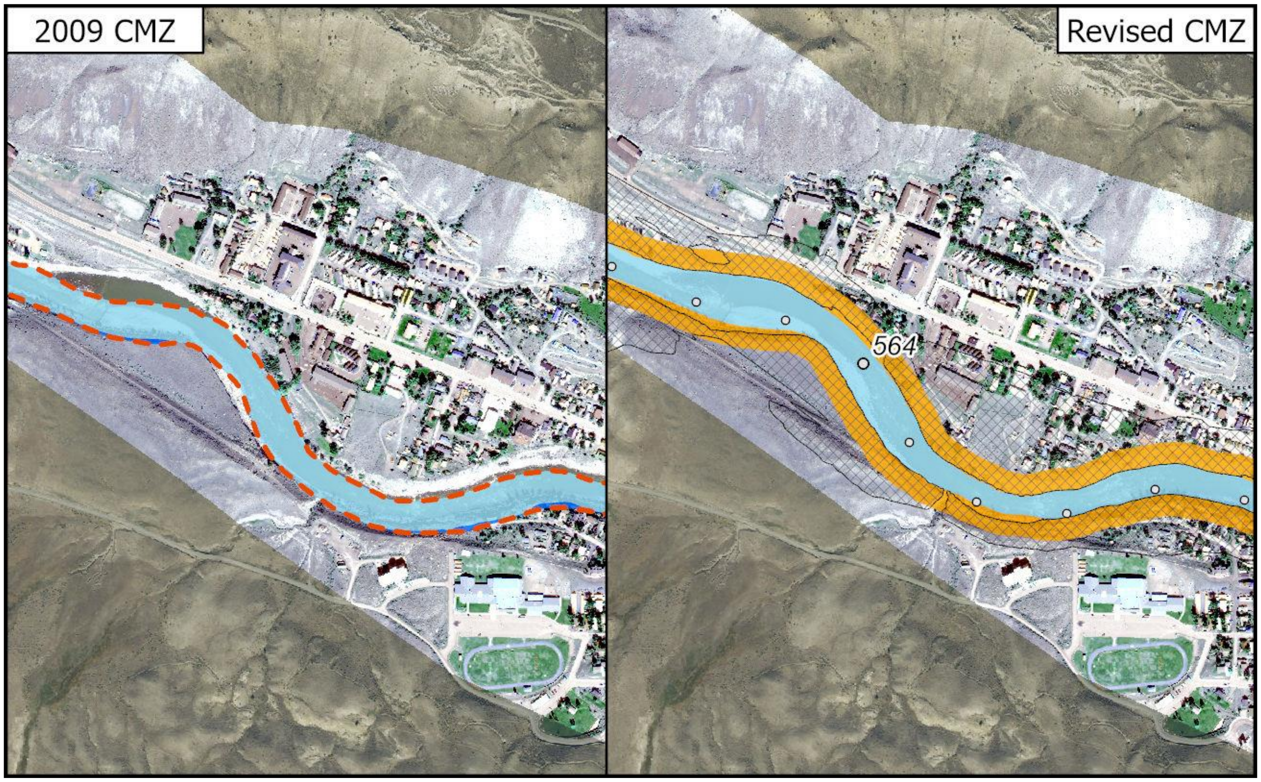

Figure 48. Terrace erosion at the northwest end of Gardiner, MT.

Between Gardiner and Yankee Jim Canyon there are several locations where Hwy 89 runs alongside the river and forms its right bank, though no significant damage to existing bank stabilization along the roadway was noted with our remote review (Note: there are locations of significant erosion in this reach, though it did not impact the roadway). During the peak of the flood, Hwy 89 was completely inundated with floodwater as it passed through Yankee Jim Canyon, temporarily cutting off all road access to Gardiner. There was concern that as the water receded there would be damage to the road or even complete loss, again isolating Gardiner. The old stagecoach road located across the river from Hwy 89 may have been the only emergency access, but this road was also unsafe for travel during the flood and had areas of significant erosion along portions of the bluffs that stabilize the roadbed. Alternate travel routes south through Yellowstone National Park were also not an option due to damage to the South Entrance Road to Mammoth.

The Carbella Bridge at RM 547.4 was completely destroyed as floodwaters overtopped the decking and washed the historic structure downstream. The crossing provides the primary access to homes, ranches and recreation in the Tom Miner Basin. The Old Yellowstone Trail Road has been providing access during the reconstruction of the bridge. Note that the bridge failure was not due to channel migration, but rather an undersized bridge restricting floodwater passage.

Figure 49. The Carbella Bridge seen as it collapsed into the river (source unknown).

Figure 50. Reconstruction of the Carbella Bridge following the flood (Stahly Engineering).

The Point of Rocks Bridge (RM 543.2) on Hwy 89 is located in a relatively stable section of river where the river follows a section of Hyalite Peaks volcanic bedrock on river left. No notable bankline erosion was mapped for nearly a mile upstream and a half a mile downstream of the bridge. The bridge is oriented slightly askew to the river channel, with the left (northern) end downstream of the right end. The bridge was flanked on the northern end, eroding out the northern approach. No damage to the bridge structure itself was noted. The approach was repaired quickly once the flood water receded.

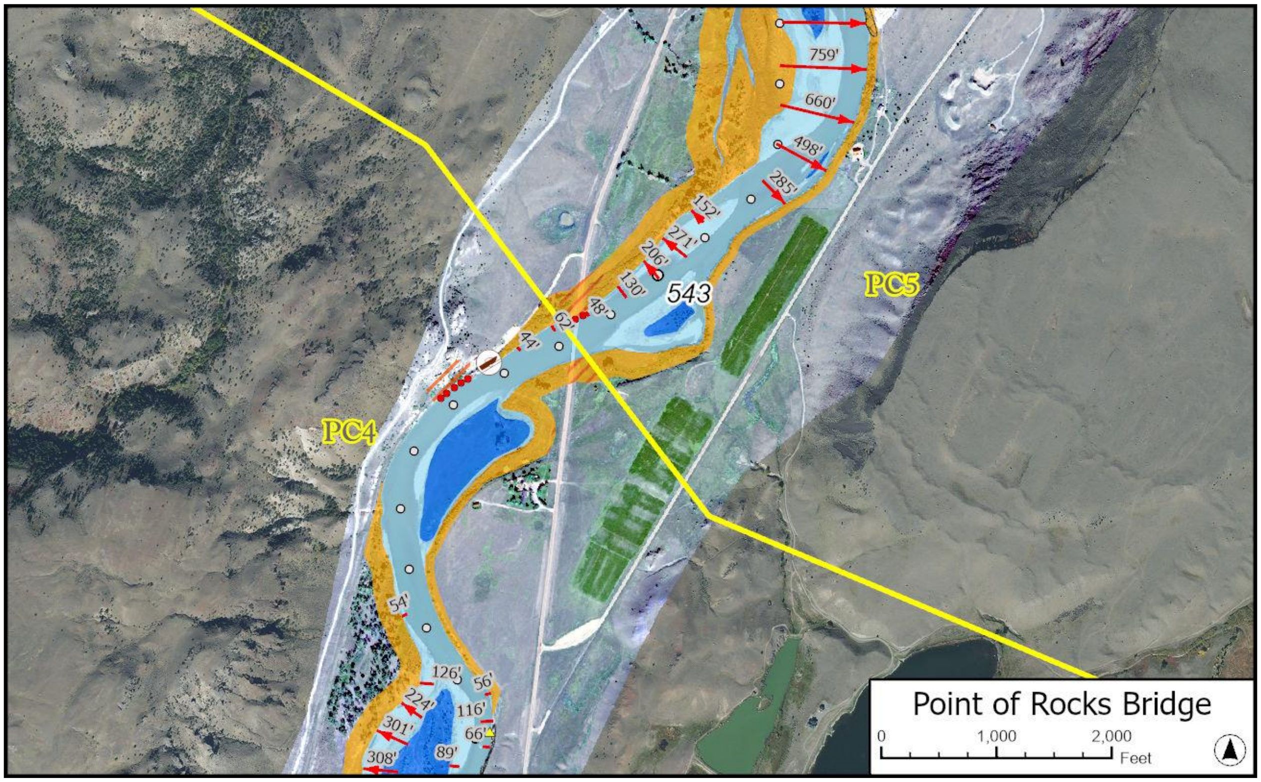

Figure 51. Point of Rocks Bridge showing significant erosion above and below the bridge, but a stable area at the bridge crossing.

Figure 52. Point of Rocks Bridge showing where the northern approach was flanked during the flood. (Samuel Wilson/Chronicle/Report for America).

Between the Point of Rocks and Emigrant Bridges there are two areas of concern where erosion is approaching roadways. Upstream of the rest area at RM 539.7 the river is bounded on the left side by Hwy 89 for approximately 0.25 miles (Figure 53). Though the river closest to the rest area has seen over 200 feet of erosion since 1948, this section of river is now heavily armored, and no notable erosion was measured from the 2022 flood. This section should be monitored to ensure a failure does not impact the highway.

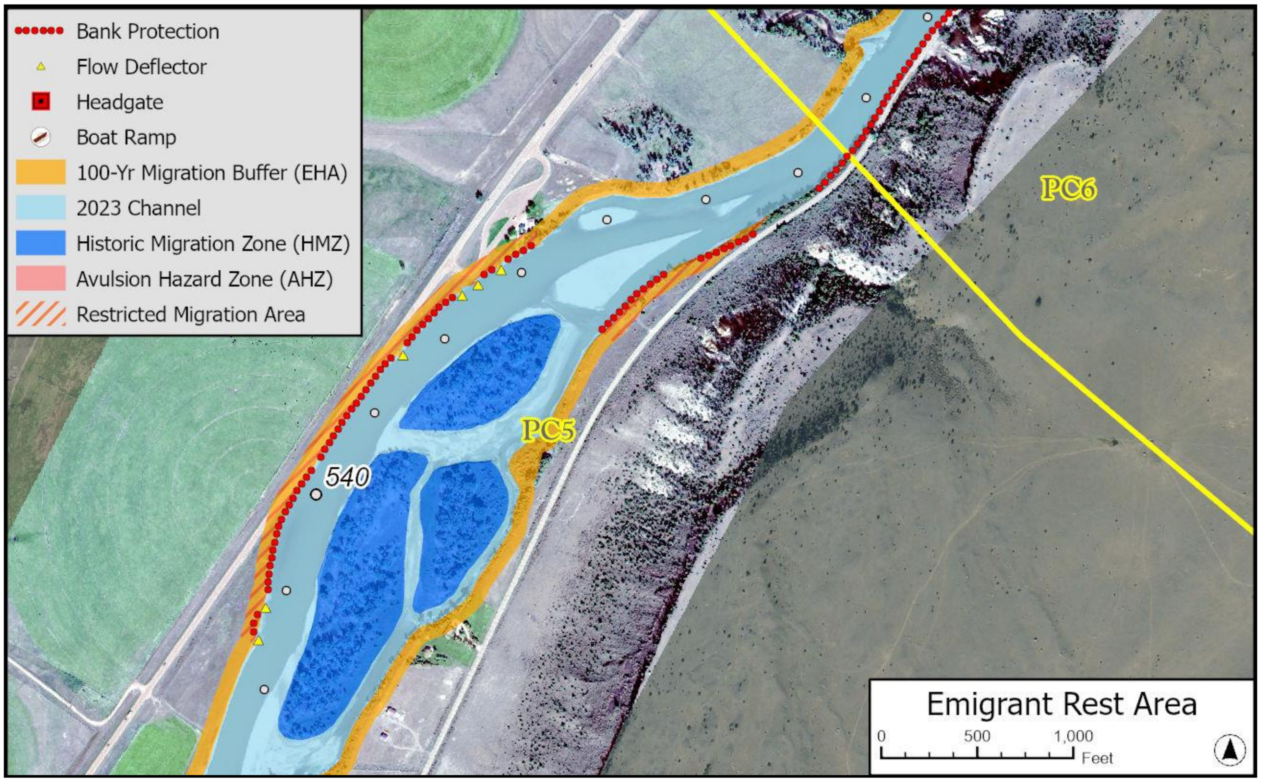

Figure 53. Hwy 89 near the Emigrant Rest Area.

A second area of concern is at the Six Mile fishing access site (RM 537.8, left) where there appears to be up to 15 feet of erosion post-flood below where the existing rock bank protection ends (Figure 54). This area did not show significant erosion in the period before the 2022 flood, but should be monitored to see if the erosion continues towards the roadway.

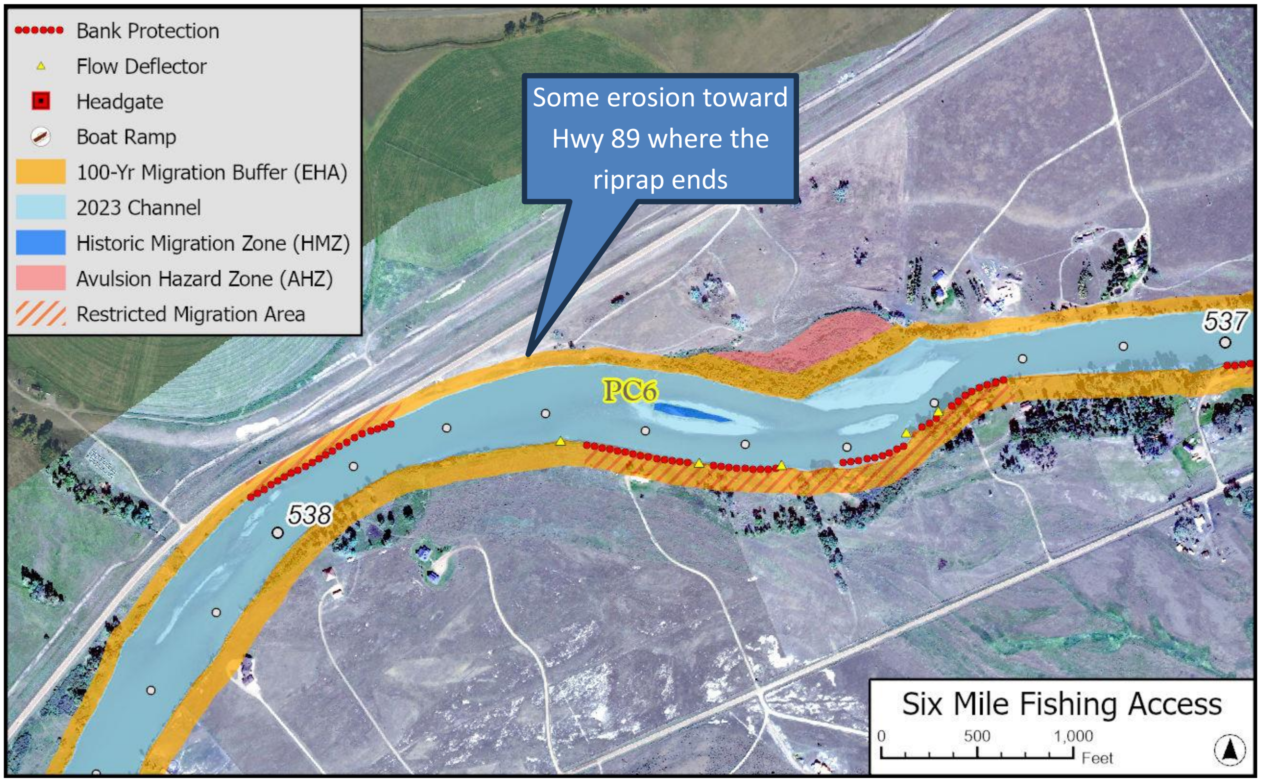

Figure 54. Six Mile fishing access site.

The East River Road closely parallels the river downstream of Point of Rocks and served as a critical route to Gardiner while the Point of Rocks bridge was being repaired. While these sections of road appear to be heavily armored and showed little impact from the 2022 flood, they should be monitored to ensure this important access route is available in emergencies.

The approach to the Emigrant bridge should be closely monitored (Figure 55). There has been over 300 feet of erosion on the left bank just upstream of the bridge, removing most of the mature cottonwood forest that protected the left bank. While the alignment is currently good as the river passes under the bridge, the left bank erosion has taken out mature vegetation that has helped stabilize the bank. Additionally, a large bar has formed upstream on river right, along with low-flow mid-channel bars, concentrating flows against the left bank. The approach may rapidly degrade with loss of mature bankline vegetation. This was a concern noted by the landowners at the Emigrant outreach meeting.

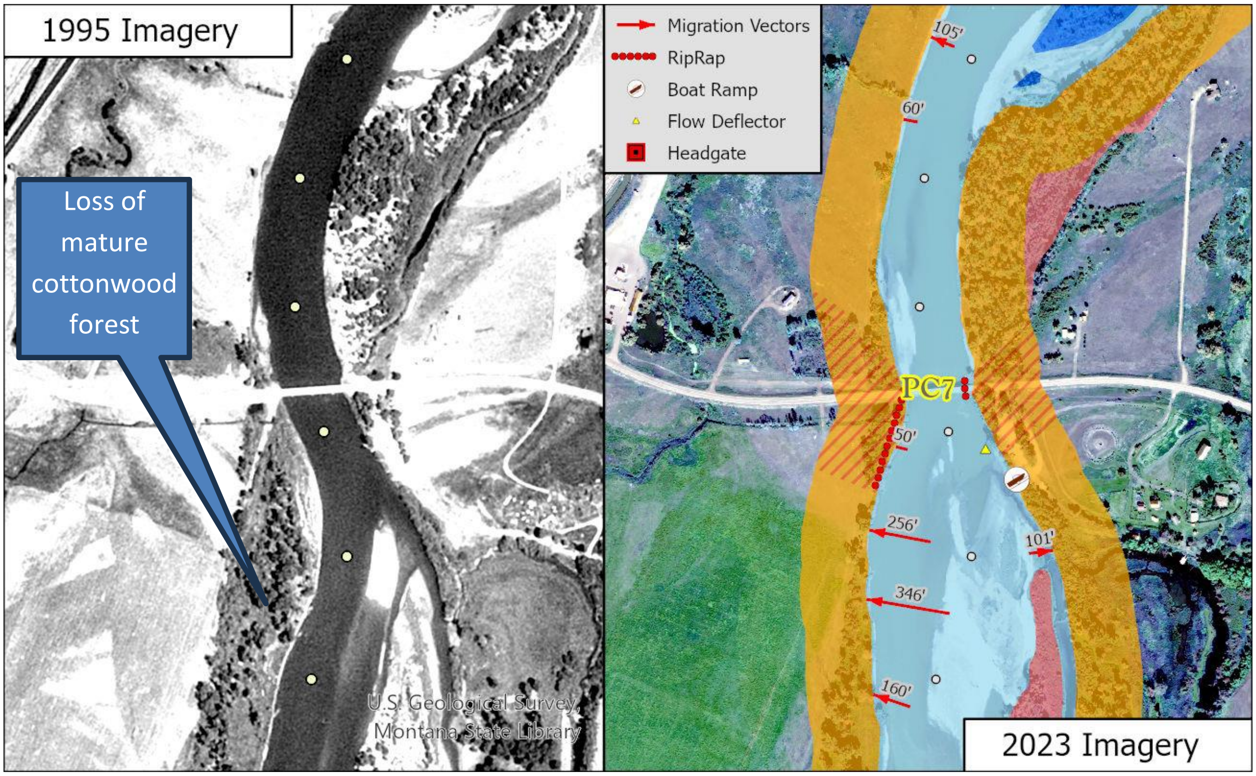

Figure 55. Extensive erosion on the left bank upstream of Emigrant Bridge, removing most of the cottonwood forest.

Downstream of Emigrant at RM 530.5L the river has seen between 350 to 750 feet of erosion to the west in the past 72 years. These are some of the highest erosion rates in the corridor. While in 1948 the river was approximately 650 feet from Hwy 89, it is now less than 60 feet. Over 100 feet of erosion has occurred post-2022 flood. This section of river has a large floodplain creating extensive avulsion hazard areas on either side of the river upstream and downstream. While this will relieve flood pressures on the roadway, the current trend is for continued migration toward Hwy 89.

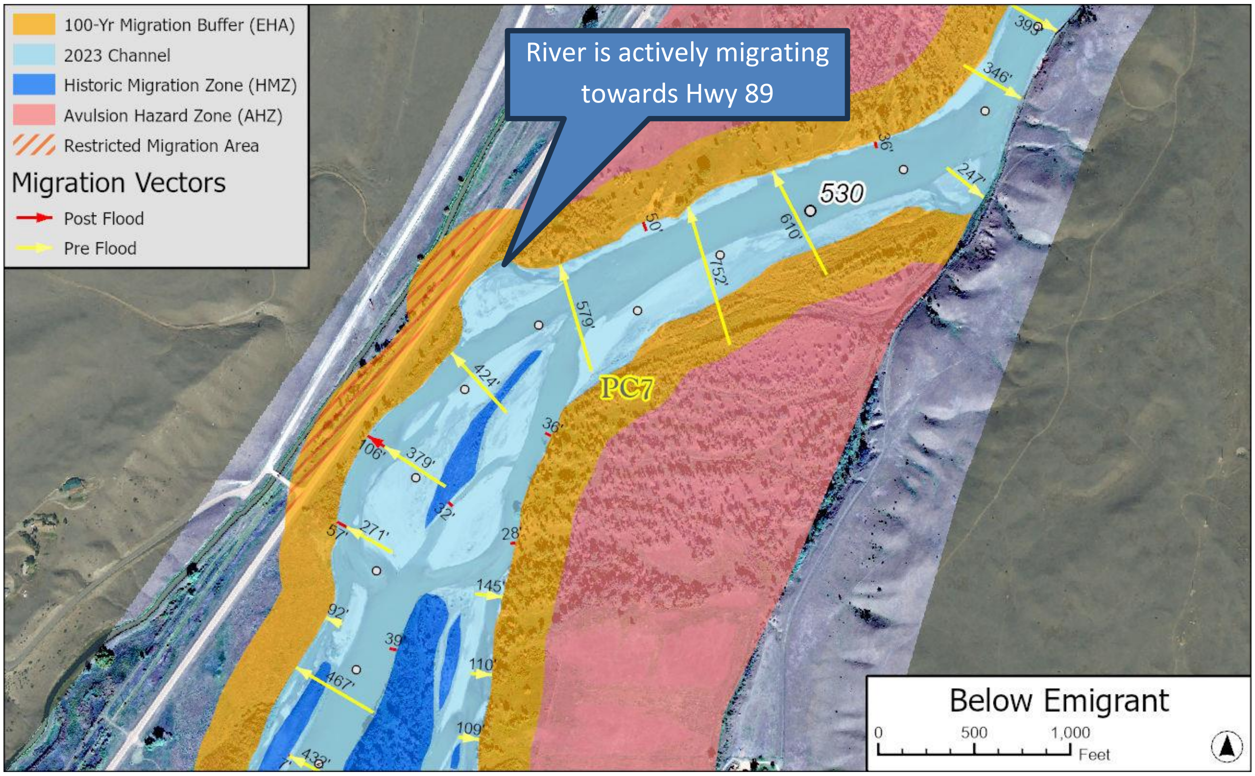

Figure 56. Over 600 feet of erosion towards Hwy 89.

From the Grey Owl Fishing Access Site to Carter's Bridge there are several sections of Hwy 89 that form the left bank of the river. These sections all appear to be heavily armored and no notable erosion was mapped. One area of concern may be the section of Hwy 89 just upstream of Carter's Bridge where the Livingston Ditch diversion is located (Figure 57). If this roadway were to be closed along with Carter's Bridge, there would be no access from Livingston into the Paradise Valley without passing over Trail Creek Road to the west.

At the south end of Livingston, the Yellowstone River passes below a pair of Interstate 90 bridges that form a a constriction between the 9th Street and Seibeck Islands (Figure 58). The right channel on the eastern side of the island currently serves as the primary channel and maintains a good alignment under the bridges. As recently as 2009, however, the western channel carried the primary flows, resulting in a severe more-than-ninety degree left turn in order for the river to pass under the interstate. This channel currently acts as a secondary or overflow channel during high flows. Since acquiring the primary flows, the eastern channel has seen increased lateral movement into both the island and the right bank immediately upstream of the bridges. Some damage to the bridge pylons on the 9th Street Island Road was noted post-flood.

The right bank just upstream of the interstate bridge has seen upwards of 135 feet of post-flood channel migration. If this area continues to erode, the alignment through the bridge will likely degrade, which can create complex hydraulics at bridge piers and abutments that were designed for a different approach angle. This spot is a small piece of floodplain and isolating it to maintain the river alignment through bank stabilization would likely have little impact on river health or process. Further downstream, the 9th Street Drive Bridge which accesses 9th Street Island was replaced in 2011 after it began sagging due to damage, likely by high water (Chronicle, March 15, 2011). The new bridge spans the western secondary channel with one support and provides the only access to the properties on the island.

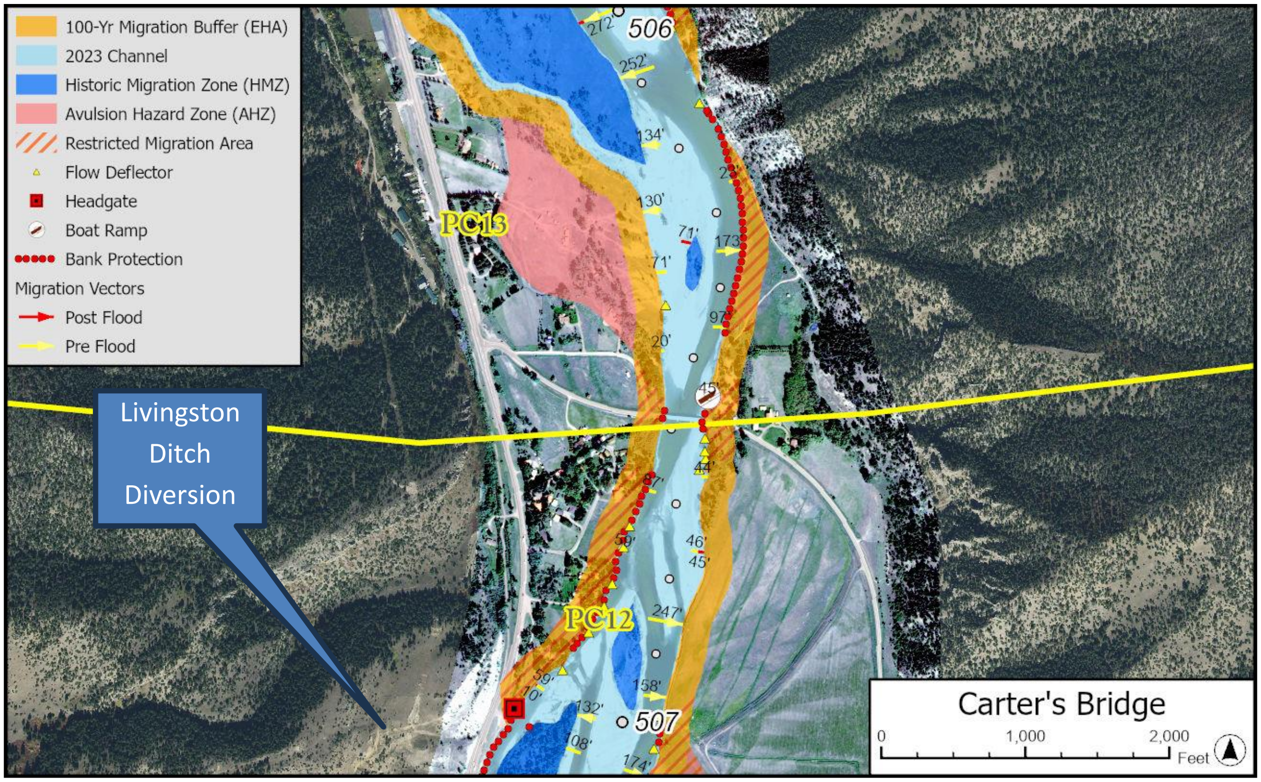

Figure 57. The area around Carter's Bridge has the highest density of infrastructure, bank protection, and levees.

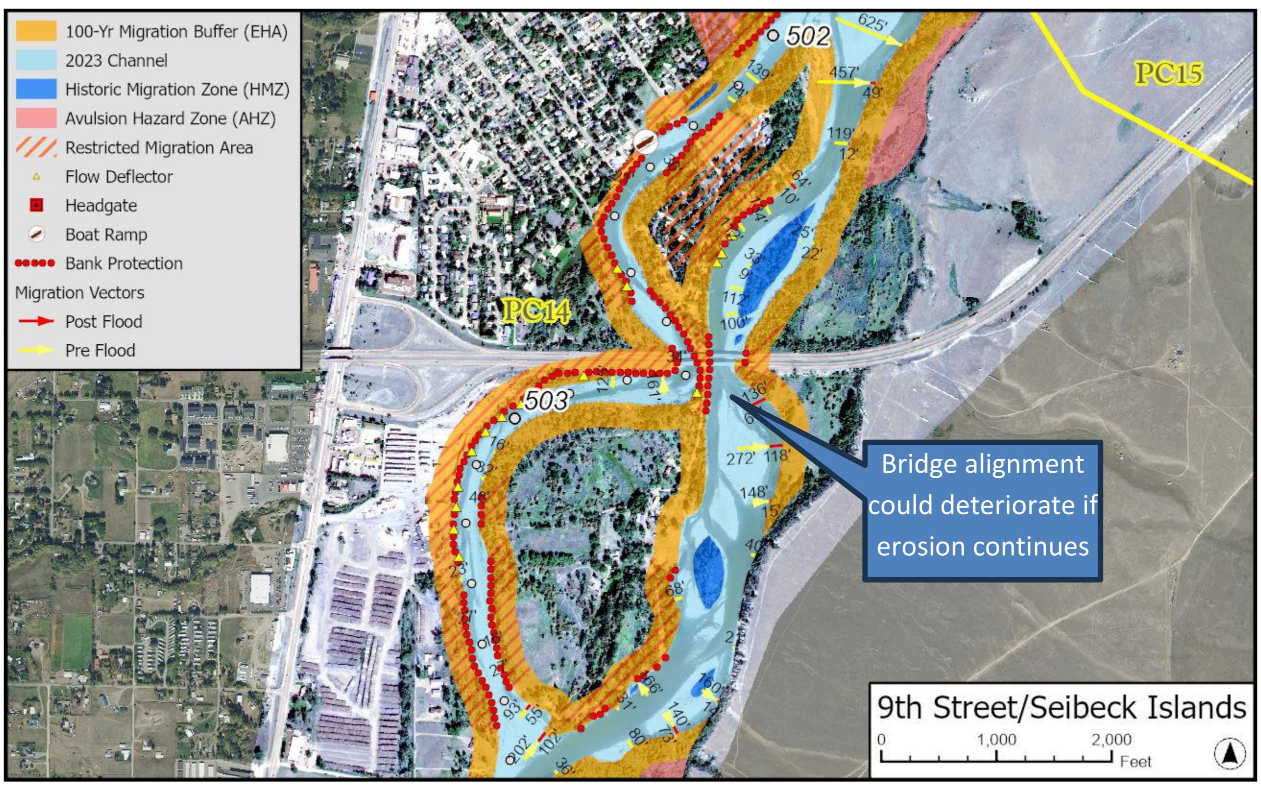

Figure 58. 9th Street and Seibeck Islands.

At the eastern edge of Livingston, the Veteran's Bridge (Hwy 89, formerly known as the KPRK Bridge) and Railroad Bridge span the Yellowstone, creating another constriction. The Veteran's was upgraded in 2013 providing proper conveyance under the bridge. Immediately downstream, the railroad bridge is considered to be undersized, resulting in backwatering of flood waters and contributing to flooding on both sides of the river upstream of the bridge. This site will be discussed in greater detail in Section 4.3.

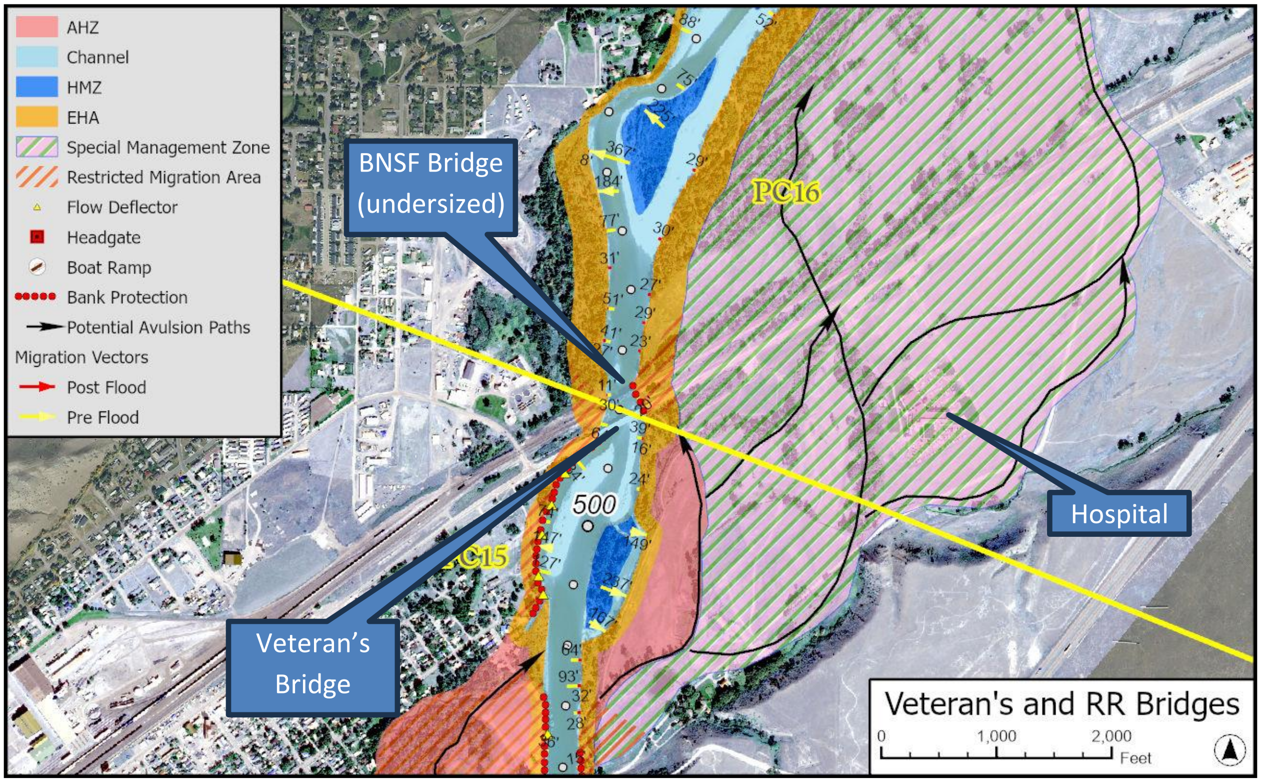

Figure 59. Veteran's and railroad bridges in Livingston, MT.

At RM 495 the Hwy 89 Bridge site presents one of the most challenging maintenance issues in the corridor. The non-active North Pacific Railway Bridge which was constructed in 1897 was located immediately upstream of the highway bridge (Figure 60). When the rail bridge was constructed, it was built perpendicular to the flow of the river. The Hwy 89 Bridge was co-located in the same location many years later. Over time, the river has shifted to the north and created a pair of 90 degree turns for the river to pass under. For many years northern approach to the railroad bridge acted as protection for the bridge just downstream. After the 2022 flood, the railroad bridge began to sag, resulting in a closure of the Hwy 89 Bridge until the rail bridge could be removed. On August 24, 2022 the railroad bridge was demolished with explosives (Figure 61), resulting in minor damage to the adjacent Hwy 89 Bridge. The damage has been repaired and the highway bridge is open. Given that the northern bridge approach on the left bank and the right bank immediately upstream continue to bear the full force of the river and is forced to make two dogleg turns, one can expect continued challenges in maintaining this bridge, especially during flood events when complex hydraulics through the turn can amplify scour potential. Of note is that the river used to be located to the south as seen in the 1873 and 1888 GLO maps (Figure 60). The former channel is still on the right floodplain and is mapped as an avulsion risk. Should this avulsion occur, proper alignment under the bridge would be restored.

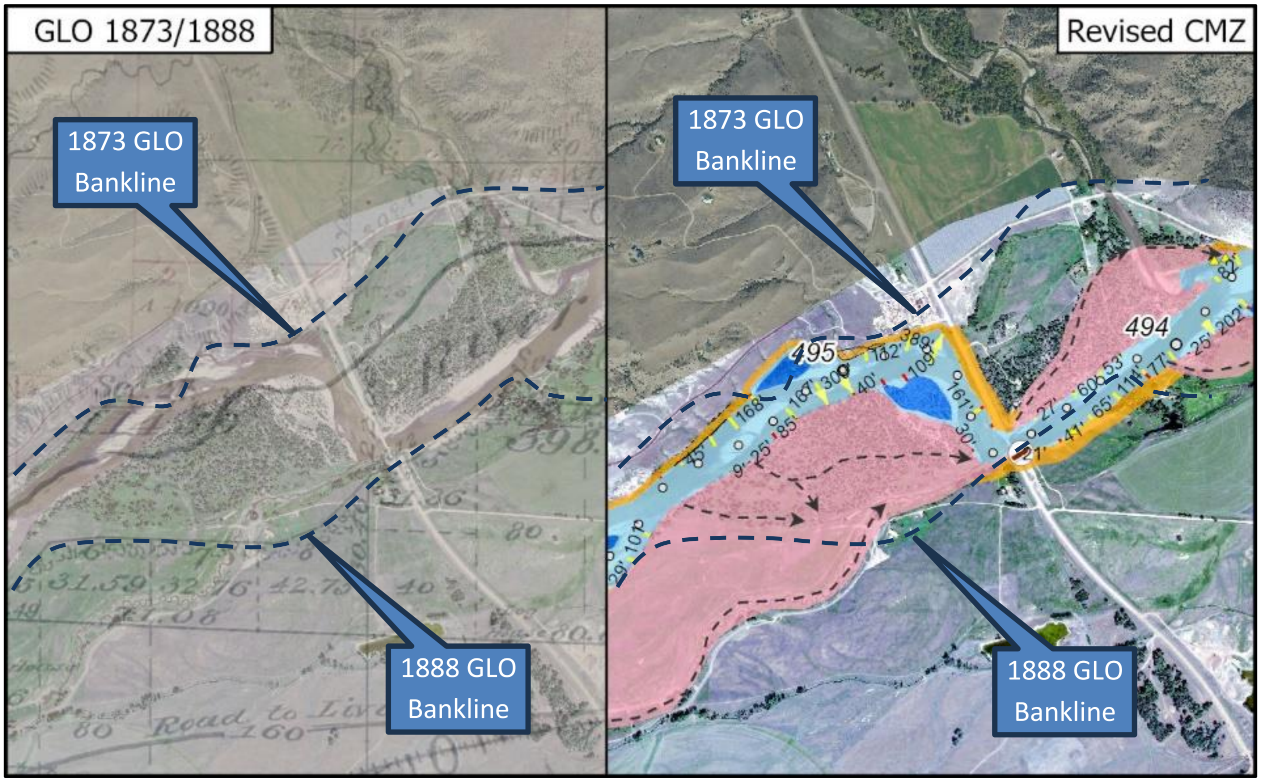

Figure 60. The Highway 89 Bridge site showing the late-1800s channel location.

Figure 61. Implosion of the Northern Pacific Railway Bridge on August 24, 2022 (Bozeman Chronicle).

The final bridge crossing in Park County is the Springdale Bridge where Convict Grade Road crosses the Yellowstone. According to Historic Bridges of Montana (US Department of Interior, 1982):

> *The Springdale Bridge was built in 1908 and 1916 by the Minneapolis Steel and Machinery Company. It consists of two pin-connected spans: a 234-foot Pennsylvania through truss (1908) and a 108-foot Pratt through truss (1916). The bridge originally connected the Northern Pacific station at Springsdale [sic] with Hunter's Hot Springs, a resort widely publicized by the Northern Pacific Railroad. Because they were built on a bend in the Yellowstone River, bridges at the site have had a history of damaged substructures.*
> *-http://npshistory.com/publications/habs-haer-hals/haer-mt-bridges.pdf*

The current Springdale Bridge was built in 1987 just downstream of the previous bridge site (Figure 62). The most recent inspections show no issues and no damage was noted post-flood. The former bridge abutments are still in place upstream on river right where a side channel joins the primary flow.

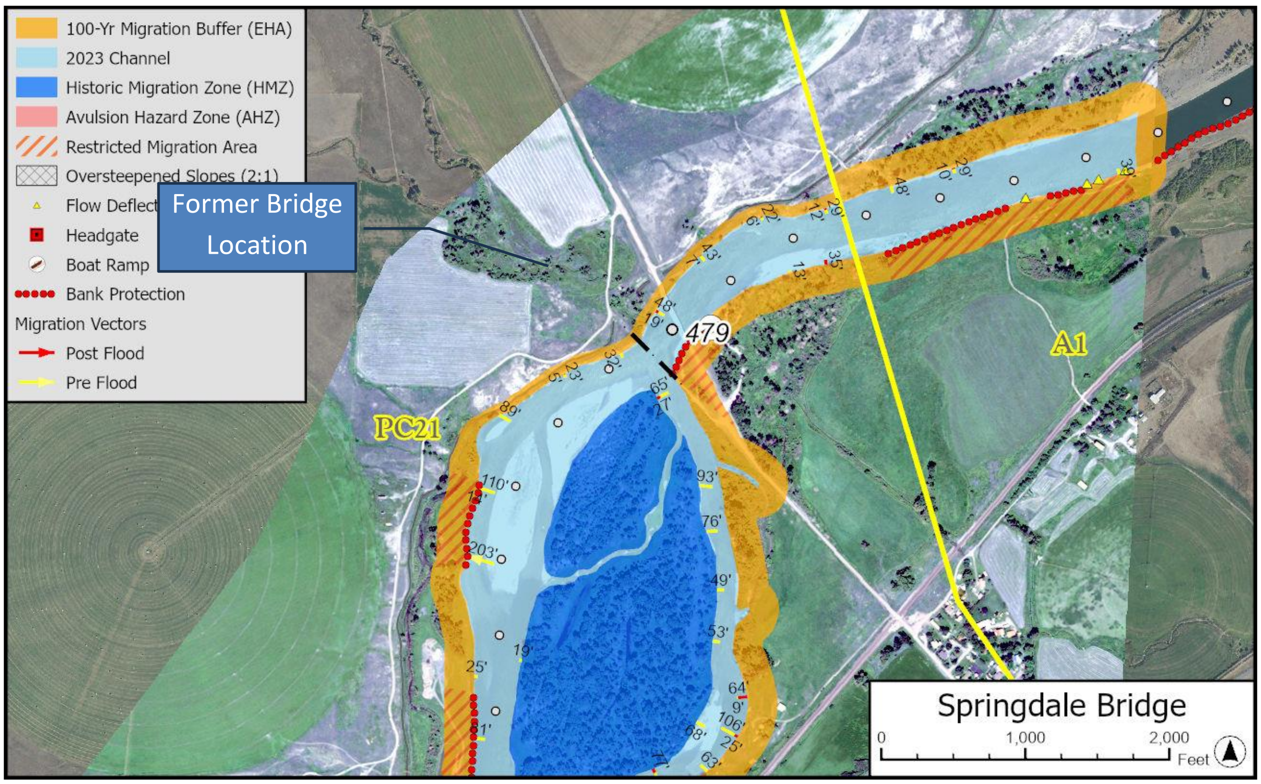

Figure 62. Springdale Bridge site showing former bridge location.

4.3 Hospital Area Discussion

The area around Livingston HealthCare received a lot of attention during meetings with the City and County. The hospital is a critical piece of public health and safety and accessing it in an emergency is of critical importance. During the 2022 flood, water overtopped the right bank above Veteran's Bridge due in part to backwatering of the railroad bridge downstream and the failure of the Sundling Ditch diversion. Water was conveyed by the Sundling Ditch and a network of historic river channel swales, eventually flooding Hwy 89 and surrounding the hospital with water, which cut off access to the hospital and forced an evacuation of the hospital patients. Up to two feet of water covered Swingley Road just east of the hospital and businesses located east of Swingley Road were flooded and sustained significant damage.

While this was not a channel migration issue and the risk of the river avulsing into the swales on the east bank and bypassing the bridges is minimal, a small area of the right bank floodplain upstream of the bridge does meet the criteria of avulsion risk. If the highway and rail grades did not act as a barrier to avulsion, the avulsion risk mapping would extend through the entire right floodplain as defined by the historic swales. As such, this area poses a greater flooding risk than that of avulsion. New FEMA flood hazard mapping is due for release that should help with understanding the unique risks associated with this area. For this CMZ mapping effort we have created a Special Risk Area to highlight the multiple concerns here.

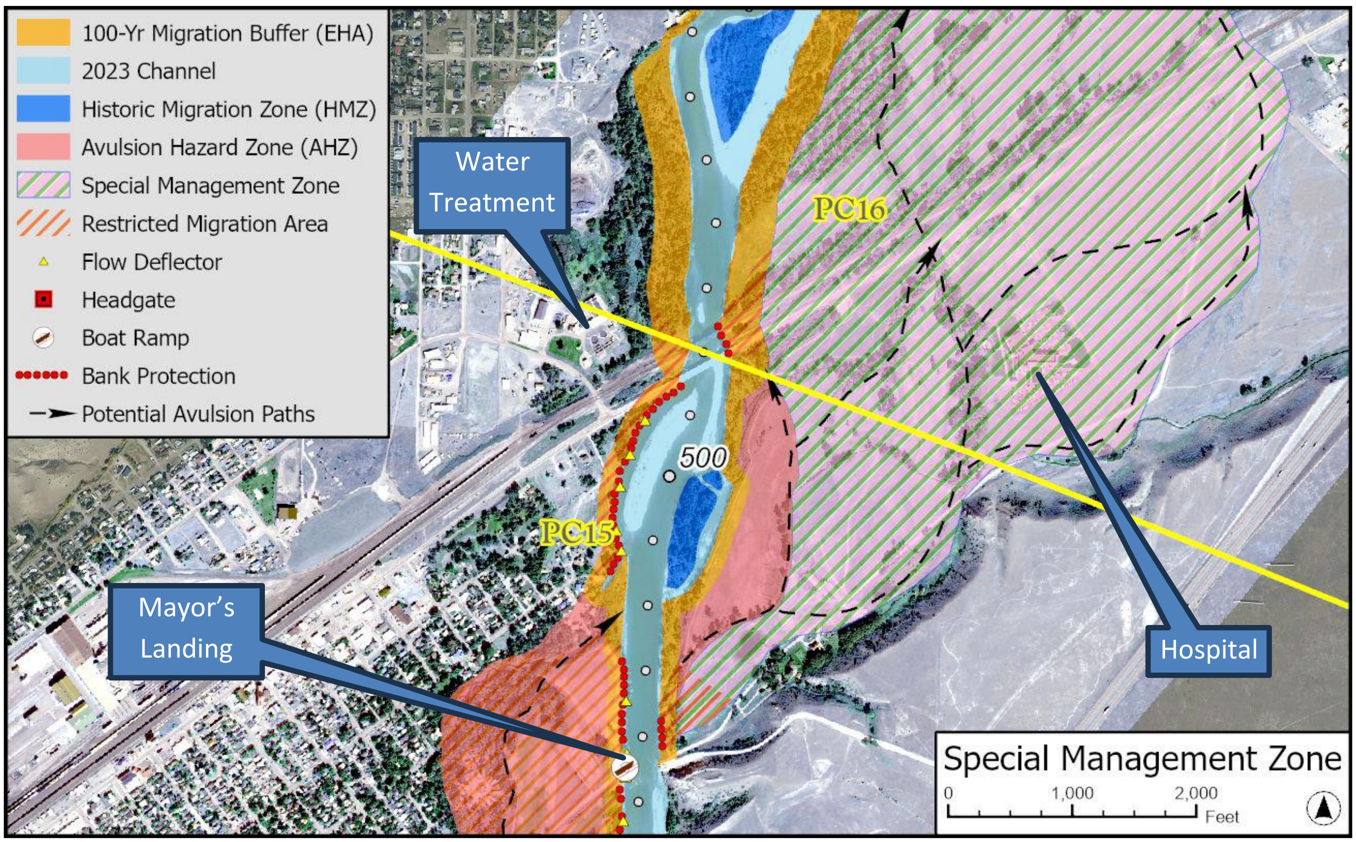

Figure 63. The Special Management area associated with the hospital in Livingston.

Additionally, as pressure for further development in the area is ongoing, there are discussions of additional flood risk studies to better understand the challenges associated with extreme events such as June 2022.

4.4 Impacts to Property

The Park County 2022 flood damage assessment indicates that the greatest impacts from the flood were to residential structures and commercial property (Table 6). While most of the impacts were minor and associated with flooding, numerous structures were impacted by channel migration.

Table 6. Park County 2022 flood damage assessment summary from the DNRC County Assist Team Operations (adapted from Park County Final Damage Assessment Report, June 2022).

Category	Total Assessed	Minor Damage	Partially Destroyed	Completely Destroyed	No Damage
Residential Structures	234	127	76	3	28
Commercial Structures	46	18	16	0	12
Bridges and Roads	40	10	11	15	7
Public Buildings	10	5	3	1	1
Other (debris removal, water control, protective measures, ag equip, utilities	105	38	21	9	37

As property values increase along river corridors, the desire to protect those investments also tends to increase. This trend is especially true when land is converted from large parcel agricultural use to small parcel private homes. Loss of grazing or hay land bears less financial risk than erosion into a home built on a short section of bankline. This problem is often compounded when bank protection efforts end at either a property boundary or are designed to be short enough to avoid more extensive permitting. Short sections of bank armoring (most commonly referred to as riprap) are problematic for several reasons: a) they provide a false sense of security for property owners who for example build homes much closer to the river than would be otherwise advisable because it is believed that the riprap will provide permanent protection from erosion; b) they often trigger excessive bank erosion immediately upstream and downstream of the armor which can damage neighboring properties and lead to erosion that can eventually undermine the armored section causing it to fail. Figure 64 illustrates two short sections of riprap protecting homes on small parcels and not designed based on river planform and dynamics. Accelerated erosion is evident upstream, downstream and in between segments of armor. Bank armor, whether it be rock riprap, root wads, flow deflectors, or other structures require continued maintenance, and yet still fail on large rivers such as the Yellowstone. Some failures can be on a large scale, as seen downstream of the study area where over 1,000 feet of armor was flanked, abandoning the armor mid-river and the outside bendway eroding hundreds of feet beyond the flanked riprap (Figure 65).

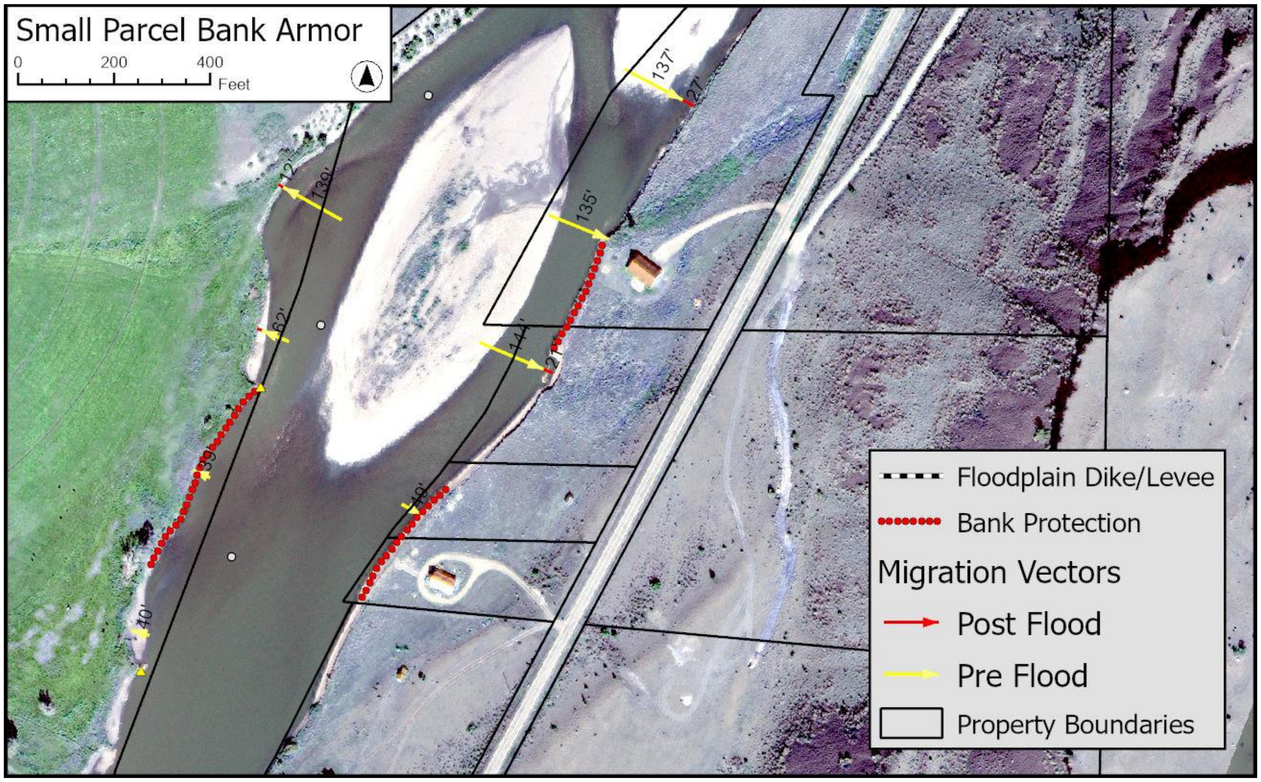

Figure 64. Bank armor is often correlated with land ownership and structure protection.

Figure 65. Failed bank armor (2011) in the middle of the Yellowstone River near Park City, MT where the bankline has rapidly eroded back towards the home in the background.

Below the Pine Creek Bridge fishing access site the river makes a sweeping right hand bend before swinging back left at the Weeping Wall. Prior to the 2022 flood, this left bankline had essentially no measurable lateral erosion. Since the flood, this bendway is now seeing active erosion with up to 127 feet of movement. This bank is up to 20 feet high and is mapped as oversteepened, meaning that it exceeds a 2 to 1 (horizontal to vertical) slope. It is expected that the bendway will continue to move laterally as it adjusts to the steep slopes, potentially encroaching on the newly developed private campground.

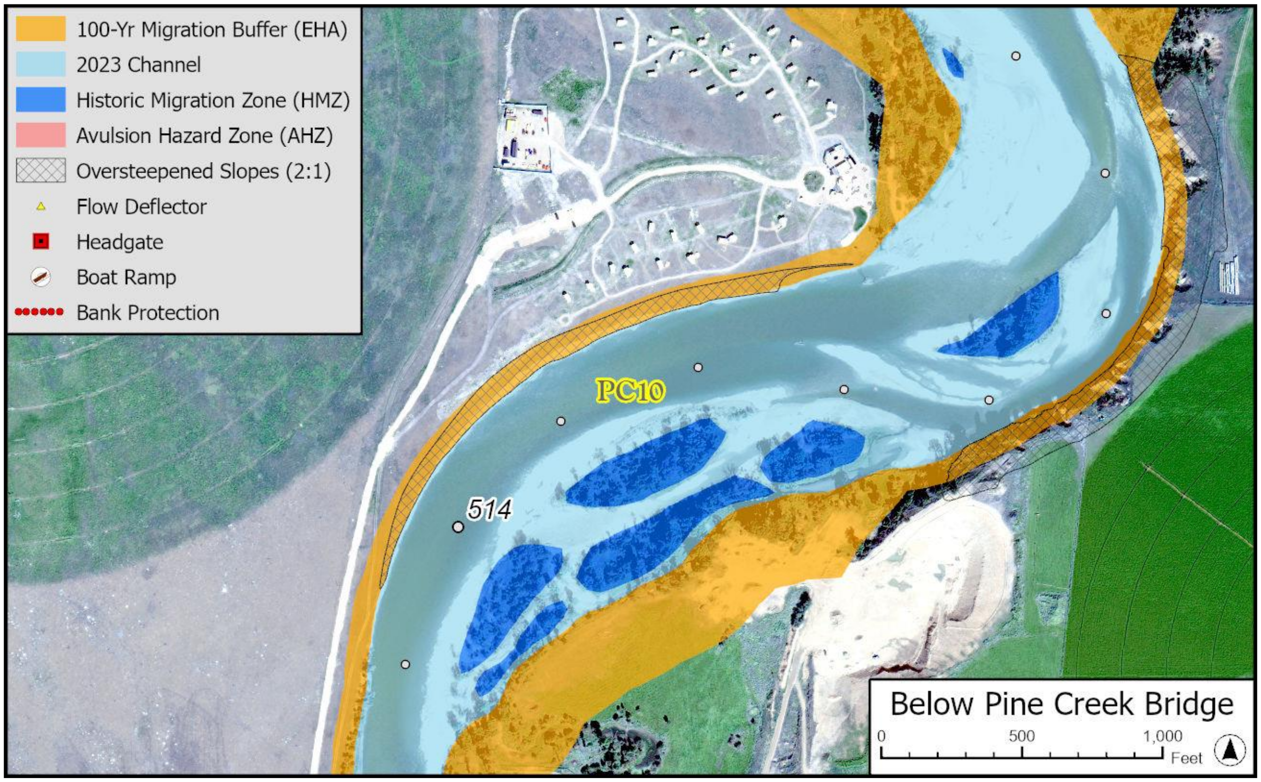

Figure 66. 100 plus feet of post-flood channel erosion below Pine Creek Bridge into new private campground.

4.5 Irrigation Infrastructure

There are six major diversions and associated canals from the Yellowstone River in Park County. For the most part, the irrigation infrastructure was not severely impacted by the flood, though the Montana Floods 2022 Park County Damage Assessment Reports (Park County, 2022) notes several instances where debris accumulated in canals and needed to be removed.

The upper most diversion is the Park Branch Canal on river left (RM 533.6) upstream of Emigrant (Figure 67). This is the primary irrigation canal on the west side of the Paradise Valley, providing water as far north as Allenspur. Until the early 1990s, this canal diversion was located on a small side channel. Local input notes that the upstream end of the side channel was managed with jersey barriers and dredging to maintain flow to the diversion point. Sometime between 1991 and 1995 the large island separating the side channel from the main channel was split, bringing flows more directly to the diversion. Currently this avulsion is the primary flow path, leaving the eastern channel as a secondary/high-flow channel. Recreational boaters have noted that the diversion dam poses a navigation risk as flows drop in the summer. If the new channel continues to expand and capture more of the primary flows, maintaining this diversion point will become more challenging.

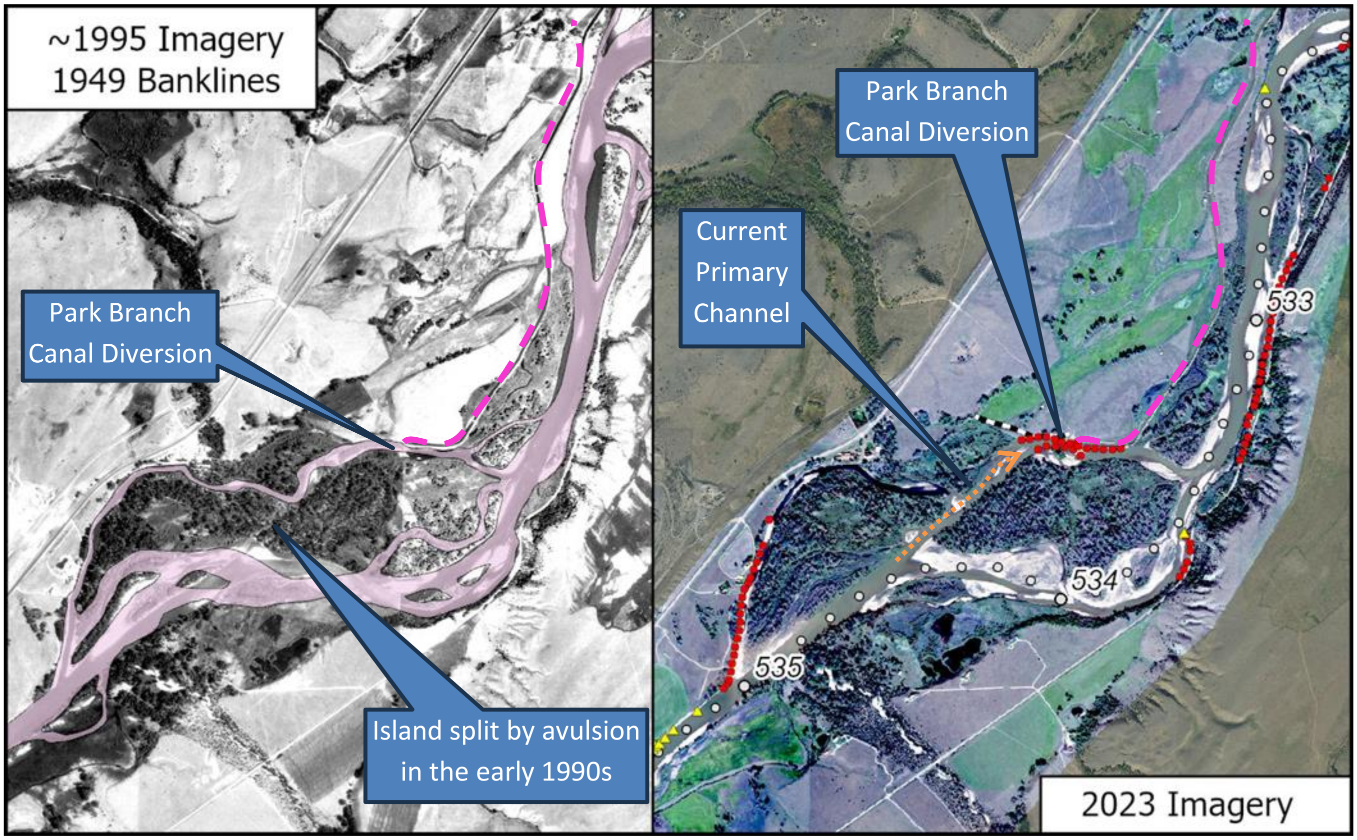

Figure 67. The Park Branch Canal diversion.

On the right bank at RM518.5 above Mallard's Rest, a cobble diversion structure is maintained that routes water to a pump site (Figure 68). This reach is relatively stable and this diversion does not appear to have any concerns in terms of channel migration.

The Livingston Ditch diversion is on river left at RM 507 where Hwy 89 pulls away from the river above Carters Bridge (Figure 69). This major canal wraps around the west and north sides of Livingston before terminating near the Hwy 89 Bridge. This reach has the highest density of armor and levees of any on the Yellowstone River. The diversion site is on a historic side channel separated from the main channel by a relatively stable island and contains a diversion dam that spans the side channel. There is rapid channel turnover above Carter's Bridge has trimmed the lower end of the island since 1948. If the island were to be lost, more flows would be concentrated at the diversion requiring additional maintenance or reconfiguration of the diversion.

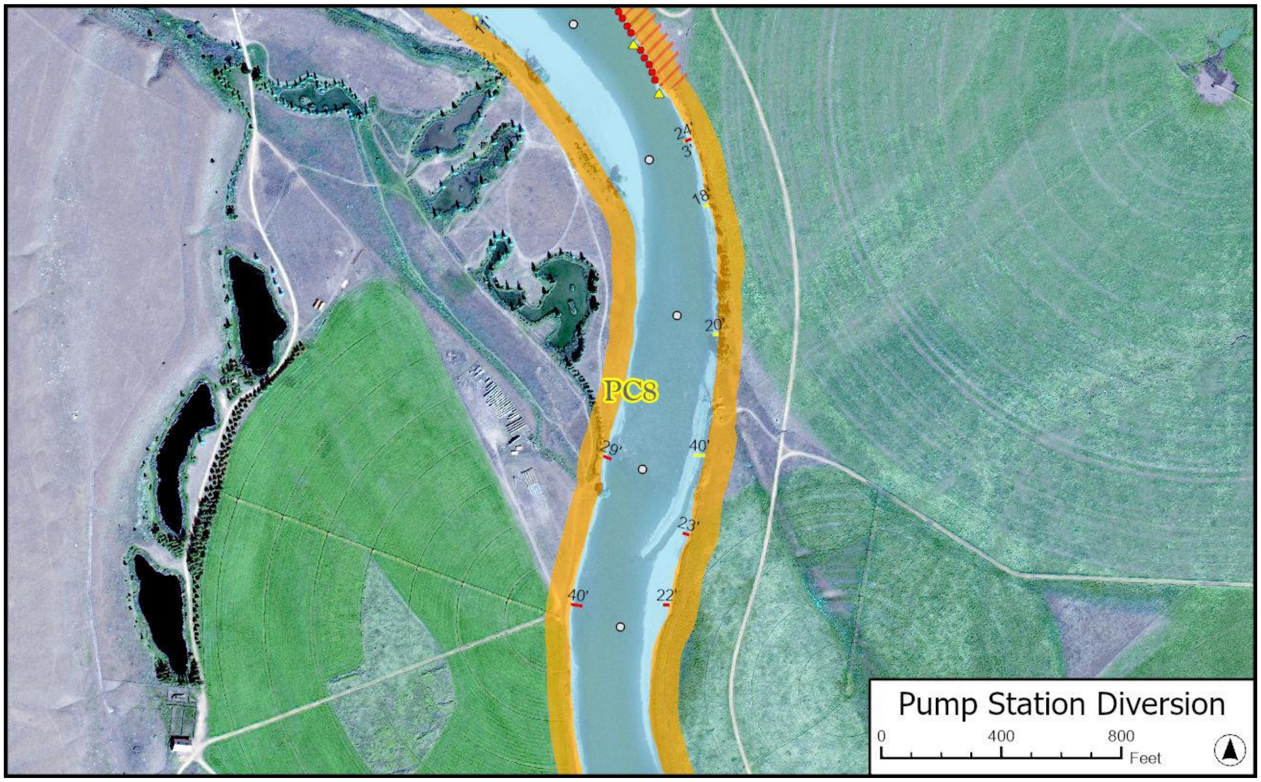

Figure 68. Cobble diversion for pump station above Mallard's Rest (RM 518.4).

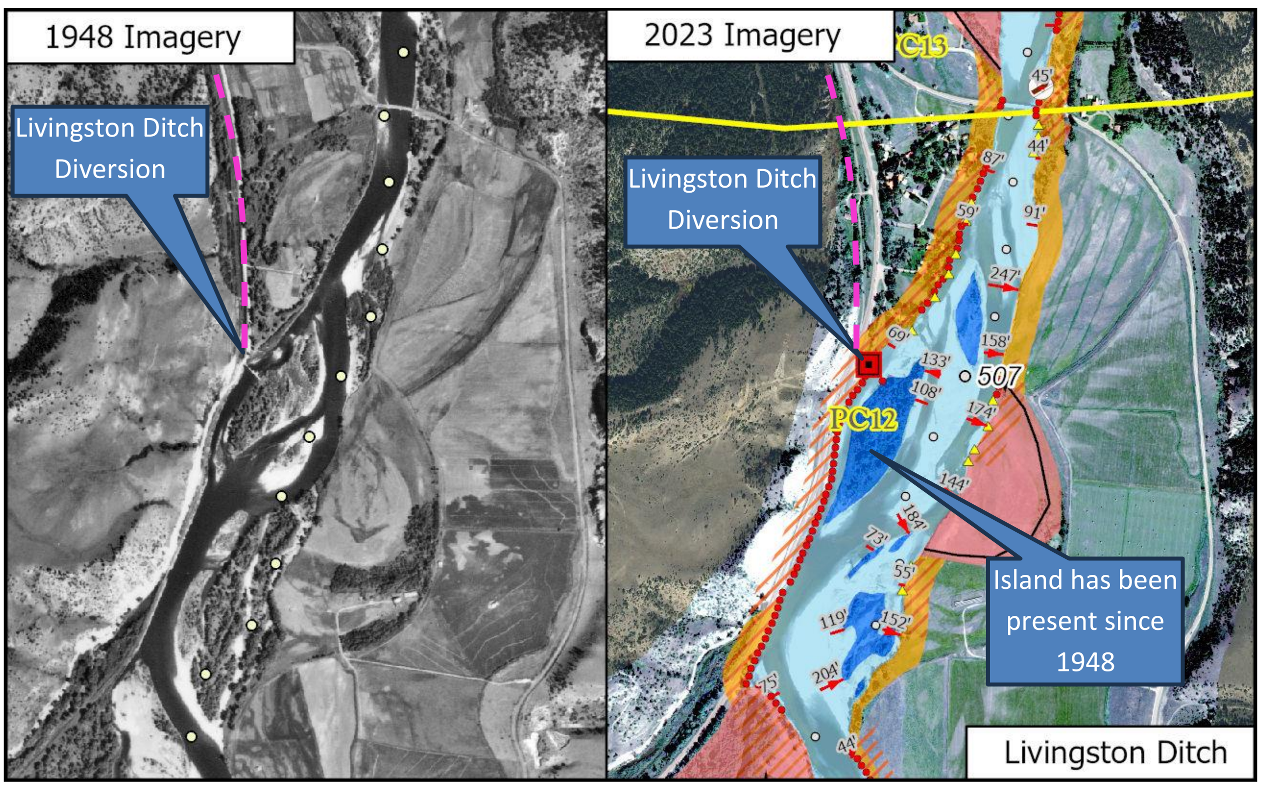

Figure 69. Livingston Ditch diversion above Carter's Bridge.

Just above Veteran's Bridge the Sundling Ditch exits on river right (RM500.4R). This is a relatively small diversion, though during the 2022 flood it served as the weak point in this bankline. The diversion failed near the peak of the flood, conveying water into a network of swales, including those surrounding the hospital. See Section 4.3 for a discussion of this area.

The Heart K Ranch diversion (RM496.7R) irrigates a bench on river right upstream of the Hwy 89 Bridge (Figure 70). This is an extremely active section of river with high channel turnover rates in the broad valley bottom and the right bankline is heavily armored for approximately 3,000 feet upstream and several hundred feet downstream of the diversion. The floodplain and avulsion hazard area below the diversion provides important flood relief above the Hwy 89 Bridge by allowing flood waters to spread out and take pressure off of the poorly aligned bridge approach.

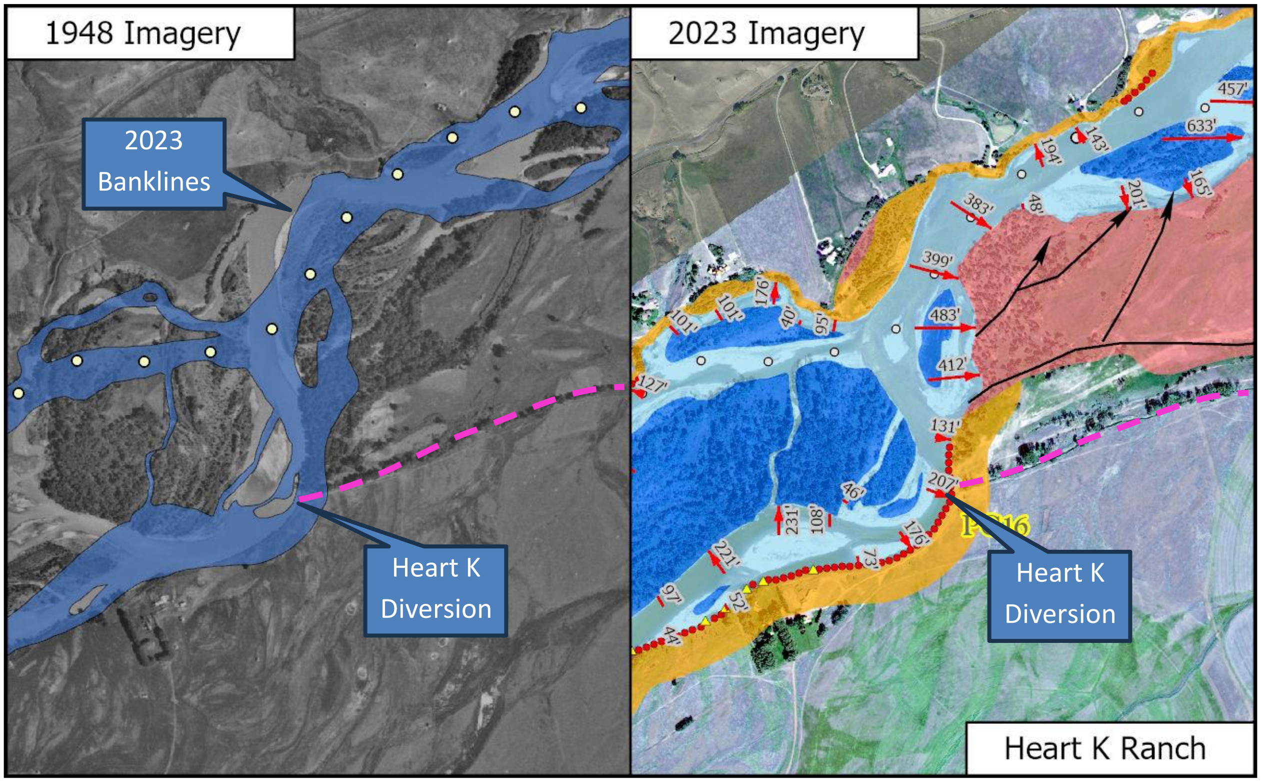

Figure 70. Heart K Rach irrigation diversion showing extensive bank armor in an active river corridor.

At RM 492.2L a large canal is diverted from a small side channel on river left (Figure 71). Historically this seems to be a stable section of the river and no notable issues are associated with it in terms of lateral channel migration. The diversion and canal are armored with rock riprap and some historic barbs, some of which have been lost due to erosion.

The last irrigation diversion in Park County is on river left at RM480.9L upstream of the Springdale Bridge (Figure 72). The site is located where the river makes a strong right turn while following a high terrace. The canal is heavily armored where it continues to follow the toe of the terrace for approximately 0.5 miles. While no notable erosion has occurred into the canal, the diversion site and initial 750 feet of canal likely receive high river energy during runoff events due to the channel narrowing between the terraces on the left and the railroad/Interstate grades that form the right bank.

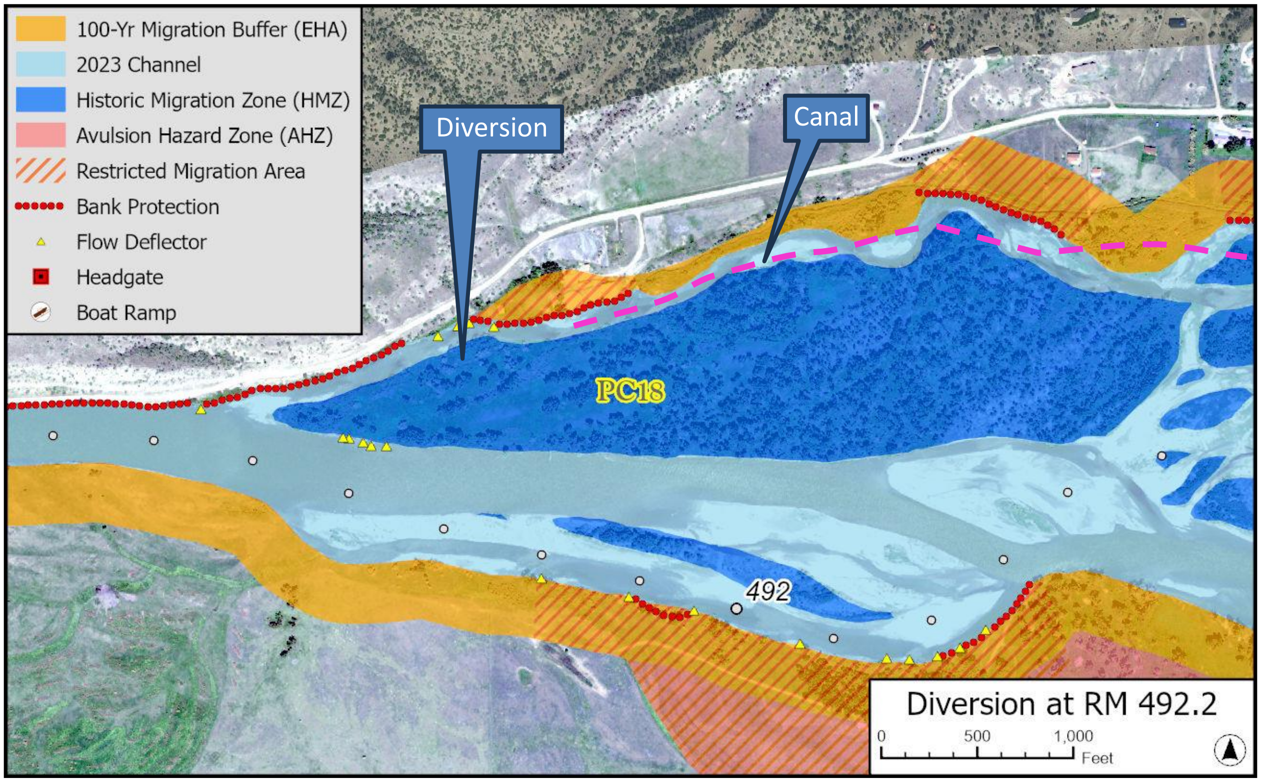

Figure 71. Diversion at RM 492.2L.

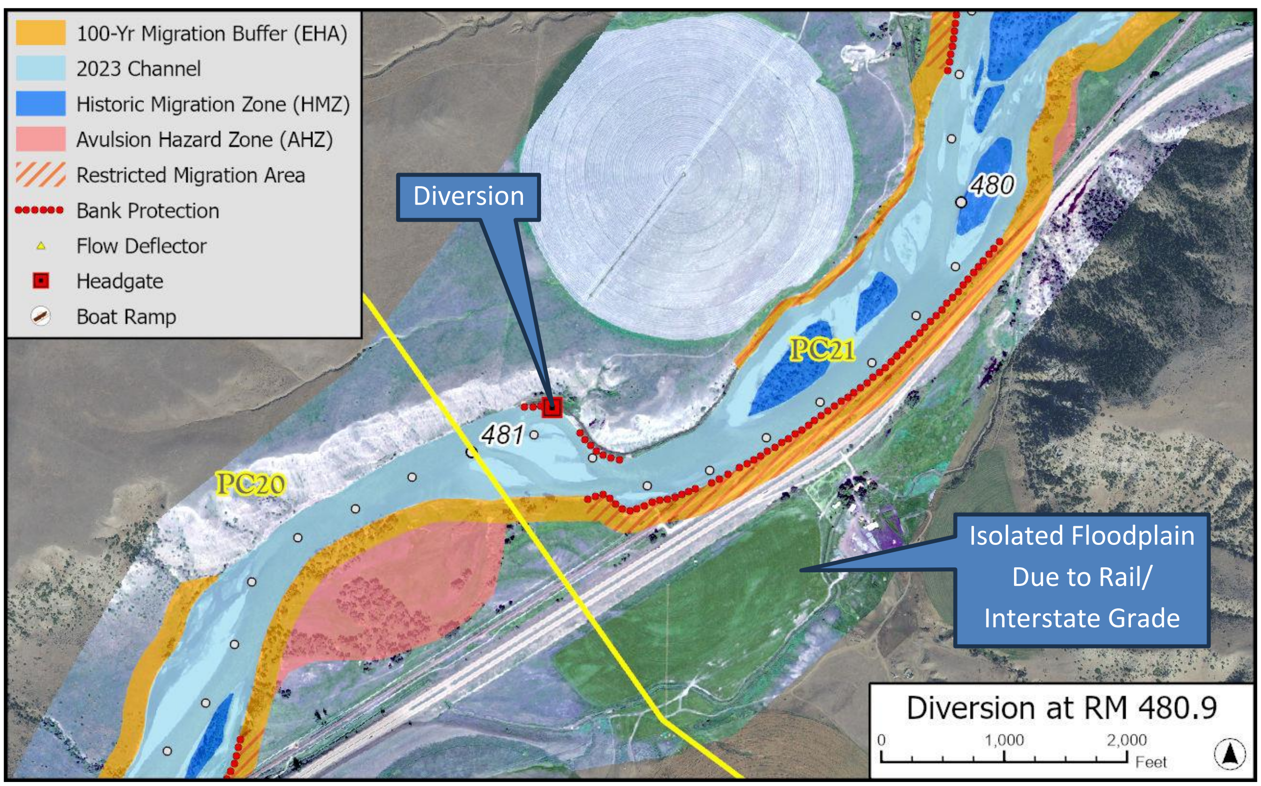

Figure 72. Diversion at RM 480.9L.

5 Public Outreach and Review

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

Public outreach activities included 3 focus-group meetings; 3 public meetings; a published article in the Livingston Enterprise newspaper; social media outreach; and meeting announcements via newsletters, emails, websites and newspaper publications.

Focus group meetings were held early in the draft CMZ map development process to present the material to local government office leads who would are most engaged in City and County leadership, planning, emergency response, public safety, public works, engineering and roads. The City focus-meeting was held on April 25,2024 at the City conference room and was attended by the City Planner/Floodplain Administrator, City Engineer, City Building Director, and Fire Chief. The County focus-meeting was held on April 26, 2024 at the County meeting room and was attended the County Public Works Engineer, the County's consulting engineer, County Finance Director, County Emergency Management Director, and two County Commissioners (note that this meeting was publicly noticed because elected officials were in attendance). These meetings were held in person and CMZ concepts, mapping methods, and draft map results were present in a slide presentation format. Hardcopy maps were provided and used to facilitate a discussion about City and County concerns for critical infrastructure and public safety within the mapped CMZ. These discussions provided input for the project database described in the next section.

The draft CMZ map was presented at a third focus-group meeting for the members of the Upper Yellowstone River Assessment Committee on May 13, 2024. This meeting was held at the USDA meeting room in Livingston and was attended by members of the committee, including individuals from the Conservation District, Fish Wildlife and Parks, County Planning/Floodplain Administration, US Army Corps of Engineers, local non-profit organizations, local landowners, and technical experts. This was an in-person meeting with several individuals participating remotely. The format of the meeting included a slide presentation of CMZ concepts, mapping methods and the draft map results, followed by a group discussion to answer questions and identify areas of concern and project needs to address risk.

The focus-group meetings provided very good technical input on the map itself and served as an opportunity to understand how the map could be improved for public consumption and use. Based on this feedback, the map and presentation materials were updated in preparation for three public meetings. Public meetings were held from 6-7:30pm in Livingston at the County meeting room on June 3, 2024; in Emigrant at the Community Hall on June 6, 2024; and in Gardiner at the Community Center on June 10, 2024. The meetings were announced in four Livingston Enterprise publications, County Newsletter, Upper Yellowstone Watershed Group newsletter, County social media, Montana Freshwater Partners social media, and via email. The meetings followed the same presentation and discussion format and was attended by local landowners and residents.

6 Projects Database

Table 7 presents a list of specific projects or project concepts identified during the CMZ update process. Where possible, it includes specific locations, features and problematic areas within the mapped CMZ that were raised during the focus-meetings and public meetings. The summary data serves as a potential project list that could be used in future funding requests that would specifically address hazards associated with the channel migration zone and associated flood-induced impacts. Each 'project' is categorized into the following flood risk mitigation strategies to provide additional clarification on the purpose and intent of the potential project as they relate to channel migration processes:

1. Hazard avoidance via preservation, open spaces, voluntary easements
2. Building energy dissipation and sediment storage into the system
3. Mitigating flooding in constrained areas
4. Infrastructure considerations and retrofits; and
5. Community Planning

Table 7. Project List.

Project Type	Issue, Location, Strategy, and Primary Benefits
Over Steepened High Terraces Gardiner to Tom Miner	**Hazard:** 2022 flood eroded and exposed previously stable banks and terrace walls to increased erosion risks. Terraces are too tall and steep for most traditional bank armoring treatments to be effective. **Locations:** The following locations show significant post-flood erosion and potential risk to infrastructure. • RM563.9/Right – North end of town and site of lost NPS housing structure. Up to 125 feet of erosion. Continued erosion towards Hwy 89, homes and trailer court possible if the bankline continues to erode. • RM563.5/Left - Up to 75 feet of erosion. No current threat to infrastructure, but the old stage road could be impacted. • RM562.3/Left (across and below Treatment Plant) - Up to 65 feet of erosion into high terrace. No current threat to infrastructure, though the old stage road could be impacted. • RM56.9/Right - 85 feet of erosion into high terrace. A home was moved back 100 feet to accommodate the new bank location. • RM560.0/Left - Up to 60 feet of erosion into low bench. The river has widened significantly and post-flood erosion towards Yellowstone Riverside Lodge presents risk to the structures. • RM558.9/Left - Up to 55 feet of erosion into terrace. No current risk to infrastructure, though the old stage road could be impacted. • RM557.3/Right (Gravel Pit) - Up to 80 feet of post-flood erosion into gravel pit bankline. Unconsolidated banks in the gravel pit area (now occupied by cabins) present risk of continued erosion. Extensive new riprap is present. • RM556.4/Left (Below Yellowstone Hot Springs) - Over 100 feet of post flood erosion into low terrace. Erosion is approaching Old Yellowstone Trail Road.

Project Type	Issue, Location, Strategy, and Primary Benefits
	Hazard Mitigation Strategies: • Community planning/hazard avoidance to discourage further development w/in CMZ & geotechnical setback • Move/retrofit public infrastructure, utilities to avoid hazard areas. **Primary Benefits:** • Public health and safety • Natural river processes supported by removing structures from risk and eliminating the need for engineered armoring of riverbanks, which in turn, allows for natural river processes associated with channel migration, floodplain access, and sediment transport to continue unimpeded.
Primary & Secondary Access Routes to Gardiner & Yellowstone NP North Entrance	**Hazard:** Hwy 89 and Old Yellowstone Trail Road access routes encroach into CMZ & geotechnical setback corridor, placing critical primary and secondary access routes to Gardiner/Yellowstone NP at significant risk of erosion/flooding. **Locations:** These locations include those listed in the Over Steepened High Terraces section, above, plus areas between Carbella and Gardiner where Hwy 89 parallels the river and forms the riverbank. **Hazard Mitigation Strategies:** • Infrastructure considerations and retrofits for road alignment to maintain roadway integrity (i.e. roadway armoring/structural engineered alternatives, re-alignment away from CMZ). • **3:1 slopes are recommended over steeper 2:1 slopes to increase stability and provide the potential for vegetation growth.** **Primary Benefits:** • Public health & safety and the ability to maintain emergency access to and from the community of Gardiner is critical. Engineered armoring to would be necessary for long-term protection of current roadbed and alignment but would likely impact natural river processes to some degree. • Alternatively, aligning portions of roadway away from CMZ/Geotech corridor would reduce risk significantly and maintain river functions.
Other Hwy 89 CMZ Encroachment	**Hazard:** Hwy 89 encroaches into the CMZ/Geotech setback corridor in multiple locations, primarily between Gardiner and Livingston. **Locations:** • RM539.9L - Emigrant Rest Area • RM537.9L – Six Mile Fishing Access • RM530.5L – One mile downstream of Emigrant • RM536.9L – Below Yellowstone's Edge RV Park • RM507.3L – Above Carter's Bridge

Project Type	Issue, Location, Strategy, and Primary Benefits
	Hazard Mitigation Strategies: • Infrastructure considerations and retrofits for alignment to maintain roadway integrity. **Primary Benefits:** • Public health & safety/emergency access routes • Transportation corridor integrity • Realignment away from CMZ would benefit natural river processes such as channel migration, floodplain access, and sediment transport to continue unimpeded
At-Risk Bridges	**Hazard:** Several bridges show deficiencies in terms of floodwater conveyance and/or channel alignment. **Locations:** • Emigrant Bridge – natural channel migration has shifted the upstream channel alignment such that the channel may not align properly with existing bridge span • Carters Bridge – bridge span is undersized causing excess backwater and erosion upstream during large flood events • BNSF Railroad Bridge – bridge is undersized causing excess backwater and erosion upstream during large flood events • Hwy 89 Bridge – natural channel migration has shifted the upstream channel alignment such that the channel does not align properly with existing bridge span **Hazard Mitigation Strategies:** • Infrastructure considerations and retrofits to increase bridge spans to accommodate large flood events and future channel alignments. • These would include gradually funneling the CMZ to the bridge opening which means identifying problems early and proactively flaring bank protection outward upstream of the bridge. Commonly means working out of the right-of-way. • Increase conveyance by placing culverts on either side of bridge to pass overbank flood water. **Primary Benefits:** • Public health & safety/emergency access routes • Transportation corridor integrity • Improvement alignment and increasing bridge spans allows flood water to pass through unimpeded, reducing backwater and erosive impacts upstream.
At-Risk Irrigation Diversion Structures	**Hazard:** Three irrigation diversions are of concern as the river adjusts channel position. **Locations:**

Project Type	Issue, Location, Strategy, and Primary Benefits
	• Park Branch Canal Intake – primary river channel has shift towards the intake structure increasing risk to structure's integrity and increasing risk of boating accidents at intake structure • Livingston Ditch Intake – Hwy 89 and upstream armoring has forced channel alignment toward intake, increasing risk to structure's integrity • Sundling Ditch – current ditch alignment causes ditch to behave like an active side channel during large flood events and enhances floodwater conveyance into 'Special Flood Hazard Zone' around Livingston HealthCare **Hazard Mitigation Strategies:** • Infrastructure considerations and retrofits to improve intake protection/integrity and/or redesign intake structure to reduce current risk exposure • A site-specific hydraulic evaluation is recommended to optimize long-term performance of the diversion. **Primary Benefits:** • Irrigation users/local agricultural economy • Public health & safety • Potential to benefit river functions if intake improves reduce armored bank treatments.
Problematic Bank Armor	**Hazard:** Multiple locations between Gardiner and Springdale where existing bank armor (i.e. riprap, barbs, levees, etc.) have failed or are at risk of failing or being flanked. Problematic bank armor has resulted in excessive erosion to natural banklines upstream and downstream of armored reach and instream hazards for boaters. **Locations:** A full assessment and listing of failing or at-risk bank armor is beyond the scope of this project. Though there are numerous locations where scalloping above or below existing bank armor indicates potential problems. **Hazard Mitigation Strategies:** • Hazard avoidance (i.e. site new structures outside of CMZ corridor, remove problematic bank armor) • Infrastructure considerations and retrofits (integrate vegetated bank treatments upstream/downstream of bank armor and/or replace bank armor with natural bank treatments that improve bank stability with fewer unintended consequences). • Consider planform dynamics in any bank armor design. **Primary Benefits:** • Public health & safety • Adjacent property owners • River functions associated with channel migration, floodplain accessibility, vegetated bankline integrity, and sediment transport.

Project Type	Issue, Location, Strategy, and Primary Benefits
9th Street Island	**Hazard:** The 9th Street Island is located within the historic and active CMZ and all of the existing structures on the island are exposed to significant avulsion, erosion and flood risks. These risks cannot be avoided or eliminated because of the location of the island relative to the active Yellowstone CMZ. **Locations:** Almost all locations on 9th Street and Seibeck Islands are at risk of continued channel migration and/or flooding. **Hazard Mitigation Strategies:** • Hazard avoidance/Mitigating flooding in constrained areas (i.e. prohibit future growth/development, seek funding for voluntary buyouts) • Infrastructure considerations and retrofits (ensure island ingress/egress routes are maintained as emergency evacuation routes) **Primary Benefits:** • Public health & safety • Prohibit future growth and limit future bank armoring will support natural river functions and reduce additional constraints for river movement and flood conveyance.
Livingston Levee	**Hazard:** The Livingston levee is a non-FEMA certified levee that protects substantial development within the historic Yellowstone CMZ. The levee's structural integrity was compromised in several locations during the 2022 flood. Channel migration, the potential for future development to further constrain the river along the levee, and flooding are the biggest hazards to the existing structure. **Locations:** Left riverbank from just below the Interstate bridges to Mayor's Landing. **Hazard Mitigation Strategies:** • Mitigating flooding in constrained areas (i.e. maintain open lots/properties, natural banklines within CMZ corridor) • Infrastructure considerations and retrofits for levee structure and setbacks • Build energy dissipation and sediment storage into the system (i.e. seek funding for voluntary buyout/easements for properties providing flood storage and CMZ functions, integrate secondary flood storage capacity into public open spaces in Livingston river corridor reach). **Primary Benefits:** • Public health & safety • Supports existing river functions associated with flood conveyance, channel movement, sediment transport etc.
Hospital Special Hazard Zone	**Hazard:** Side channel and Sundling Ditch avulsion risks, coupled with Hwy 89 and BNSF Railroad bridge and track constraints exacerbate backwatering and flooding

Project Type	Issue, Location, Strategy, and Primary Benefits
	across the Special Hazard Zone area and impedes the conveyance of floodwater away from this area resulting in significant flooding damage to the structures and flooding across Hwy 89. **Locations:** This area extends from RM500.4R to 498.2R and encompasses the entire right floodplain. **Hazard Mitigation Strategies:** • Mitigating flooding in constrained areas (i.e. maintain open lots/properties, natural banklines within CMZ corridor) • Infrastructure considerations and retrofits for levee structure (i.e. BNSF bridge improvements, increase flood conveyance under Hwy 89 and Swingly Rd) by placing additional culverts or increasing the size of existing culverts. • Build energy dissipation and sediment storage into the system (i.e. seek funding for voluntary buyout/easements for properties providing flood storage and CMZ functions, integrate secondary flood storage capacity into public open spaces within the Livingston river corridor reach) • Hazard avoidance/community planning (i.e. evaluate risk to existing and future development under large flood event scenarios, integrate open space into future developments to serve as flood storage and conveyance pathways, site new buildings in locations that will be less prone to flooding, redesign hospital access points to ensure safe access routes will be maintained under large flood events) **Primary Benefits:** • Public health & safety • Supports existing river functions associated with flood conveyance, channel movement, sediment transport etc.
Critical Locations to Maintain or Re-establish Floodplain Connectivity and Open Space	**Hazard:** Open space and floodplain connectivity within the CMZ corridor are critical for dissipating the erosive forces of the river during large flood events and are imperative for supporting a healthy functioning river corridor. The following locations are relatively undeveloped with limited bank armoring or may have restoration opportunities that could improve floodplain connectivity. These undeveloped and unarmored properties are especially important because they provide the necessary space for river movement and flooding that reduces flood impacts on nearby infrastructure. **Locations:** • RM560.0L - Yellowstone Riverside Lodge – floodplain access. • RM552.0L – Across from Joe Brown Fishing Access Site – floodplain access. • RM543.5R - Above Point of Rocks Bridge – floodplain access. • RM541.9L - Avulsion Hazard Area is currently diked along a former channel – floodplain connectivity. • RM540.0R – Across from Emigrant Rest Area – floodplain access. • RM534.4L/R –Park Branch Canal area – floodplain access.

Project Type	Issue, Location, Strategy, and Primary Benefits
	• RM531.8R - Upstream of Emigrant Bridge – floodplain access. • RM517.5R – Mallard's Rest inside bendway – floodplain access. • RM514.4 to 507.5 – Avulsion Hazard Zones between Pine Creek Bridge and Carters Bridge – floodplain connectivity. • RM506.6L to 504.0L – Avulsion Hazard Zones between Carter's Bridge and RY Timber should be maintained for flood mitigation – floodplain access. • RM502.7R to 499.8R - Maintain unrestricted CMZ areas between I-90 Bridge and Veteran's Bridge – floodplain access. • RM500.0L - KPRK property – floodplain access. • RM496.5R to 494.5R - Heart K property to Hwy 89 Bridge - Maintain Avulsion Hazard Zone – floodplain access. • RM494.4 to 479.0 - Maintain unrestricted CMZ corridor between Hwy 89 Bridge and Springdale Bridge – floodplain access. **Hazard Mitigation Strategies:** • Hazard avoidance via preservation, open spaces, voluntary easements. **Primary Benefits:** • Public health & safety for downstream/adjacent structures • Supports existing river functions associated with floodplain connectivity, channel movement, sediment transport, floodplain regeneration, instream habitat, etc.
Additional Public Outreach/Education Needs	In addition to the projects listed above, there is a significant need for additional public outreach and education about the updated Yellowstone Channel Migration Map and report. Outreach is needed to elevate the awareness of the risks associated with the Channel Migration Zone and educate private property owners, local municipalities and real estate professionals on how to reduce and avoid risks. This in turn, will reduce Park County's vulnerability to future disasters and costly impacts from flooding and other natural river events. The following outreach efforts are recommended: CMZ presentations to local watershed groups, CD board members, City/County staff, real estate groups and consultants/contractors working on the river. Develop and distribute CMZ property reports to individual property owners within mapped CMZ corridor. Develop a CMZ property report application that integrates with the interactive online CMZ map that would allow users to generate a CMZ report for a selected property or specified reaches.

7 CMZ Management Concepts

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

The management of the river as a "corridor" is an important first application of CMZ mapping. Minimizing economic losses due to land loss, infrastructure failure, or bank armor loss should consider the following:

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

Whereas CMZ mapping is commonly used to identify development risks, it is also important to recognize the role that channel migration plays in maintaining geomorphic stability and optimizing the ecological function of these rivers. The Yellowstone 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 Yellowstone River corridor is 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.

7.1 CMZ Management and Maintenance Considerations

The nature of human encroachment into the natural CMZ of a river can sometimes be directly correlated to infrastructure maintenance costs. For example, the Nooksack River in Washington State flows from the northern Cascades westward to Bellingham Bay near Bellingham, Washington. As the river leaves the mountains and crosses the coastal plain near Everson, Washington, it rapidly loses gradient and deposits high volumes of coarse sediment as a result. As this is a productive farming area, armored levees have been constructed along much of the length of this dynamic river, and they require frequent and costly maintenance. As part of a larger geomorphic study of the river completed for Whatcom County, AGI and others (2019) evaluated the maintenance requirements on the levees as a function of river corridor width. The evaluation was prompted by a perceived correlation between corridor width and cost of maintenance, in that corridor areas that were more confined by levees experienced more erosive damage. Figure 73 show the results of that analysis. First, several levees were segmented in terms how much they impinge into the river corridor. Some areas reflect corridor narrowing in long levee segments and others represent “hooks”, where the lowermost end of a levee turns directly into the stream corridor. The width values range from 590 to 2450 feet and the levees were sorted by width from narrowest (left on graphic) to widest (right on graphic). Second, those levee segments were evaluated for maintenance intensity, which is the length of maintenance that has been recorded per foot of levee segment. In plotting both the width value and maintenance intensity value for each levee segment, and sorting those by corridor width, an inverse relationship between the two can be seen, in that confining levee segments require substantially more maintenance than less confining structures. The primary drivers for this are twofold: first, where the corridor is narrower, the river spends more time flowing directly on the levee resulting in more damage, and second, the hydraulics at narrowing points and hooks can be especially damaging to the levees. These results are relevant to the Yellowstone River, especially in the spring creek area.

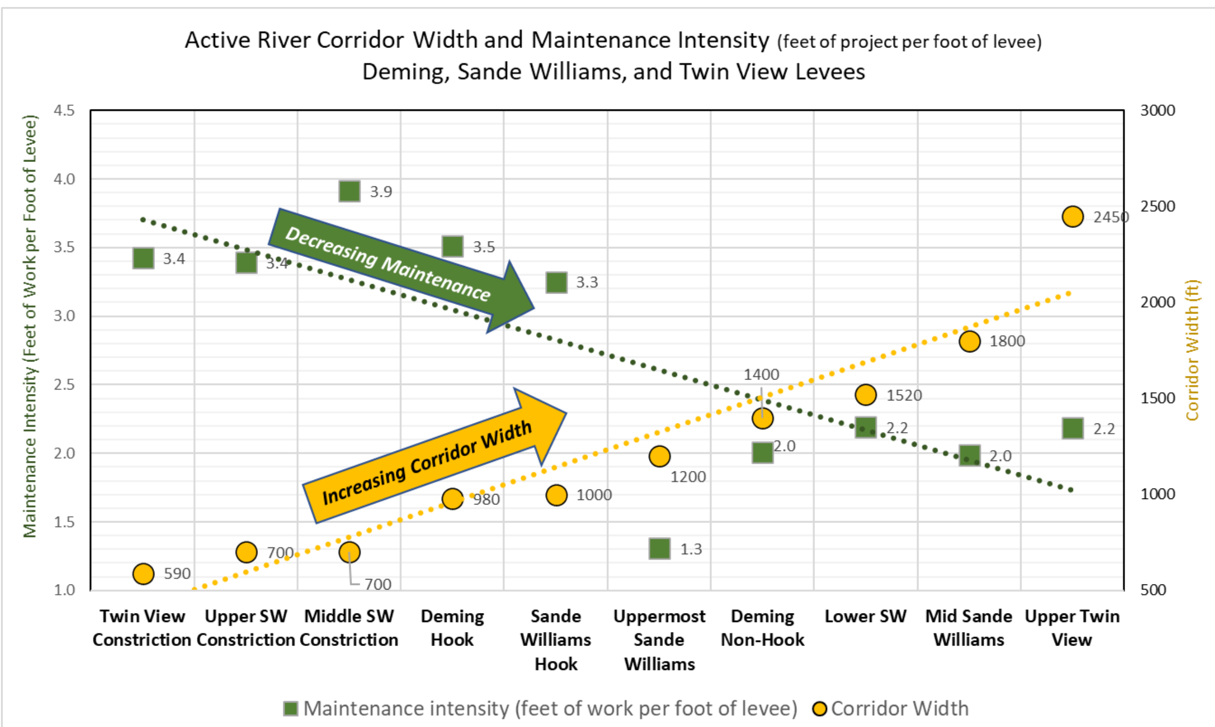

Figure 73. Nooksack River levee segments sorted by corridor width showing reduced maintenance intensity in wider sections.

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, appropriate bridge spans, and define anticipated future alignment issues so support cost-effective risk mitigation.

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

7.4 Long-Term Resiliency

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

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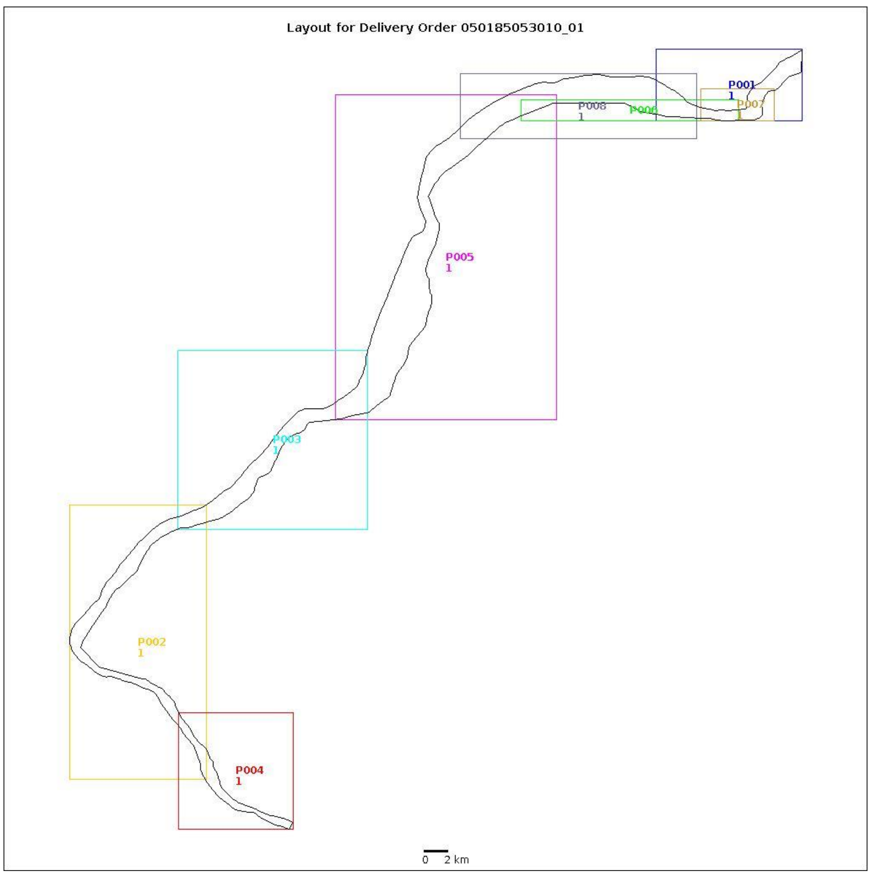
Appendix A – 2023 Imagery Information

A combined 50-cm mosaic was created from WorldView-2 (50-cm) and WorldView-3 (30-cm) satellite imagery by LandInfo Worldwide Mapping, LLC to represent post-flood conditions. The imagery were orthorectified and delivered as a single 50-cm mosaic image. The mosaic was visually assessed for spatial accuracy using 2021 NAIP imagery.

Source Imagery:

Tile	Date	Source	Resolution
P001	July 12, 2023	WorldView-2	50-cm
P002	Sept 24, 2023	WorldView-3	30-cm
P003	Sept 24, 2023	WorldView-3	30-cm
P004	Sept 24, 2023	WorldView-3	30-cm
P005	Sept 19, 2023	WorldView-3	30-cm
P006	Sept 19, 2023	WorldView-3	30-cm
P007	Sept 19, 2023	WorldView-3	30-cm
P008	July 12, 2023	WorldView-2	50-cm



Appendix B: 11x17 CMZ Maps (Separate Document)