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Channel Migration Mapping
Sun River (Phase 1)
Elk Creek (Phase 2)

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Executive Summary

This report contains the results of a Channel Migration Zone (CMZ) mapping effort for segments of the Sun River and Elk Creek which drain the northern Rocky Mountains west of Great Falls, Montana. The mapping extent on the Sun River consists of 51 miles of channel extending from just north of Augusta downstream to Vaughn. Just over 14 miles of Elk Creek were mapped, extending from the confluence between Elk Creek and Smith Creek down to the Sun River confluence.

Historic imagery beginning in the mid-1950s was used to measure migration rates on both streams. Hundreds of measurements were collected and statistically analyzed to determine mean rates of movement. On the Sun River, maximum migration distances measured for the 1957-2019 timeframe range from about 250 feet in upper reaches to over 900 feet near Vaughn. At least 10 avulsions have occurred in the project reach since 1957, with two currently developing. Elk Creek is a much smaller channel, and the maximum migration distance measured was 262 feet. Over the 14 miles of Elk Creek mapping, a total of 16 avulsions were identified as having occurred since 1955. Four of those occurred during the recent floods of 2018/2019.

Rapid channel migration on these streams is in part driven by their geologic setting on the Rocky Mountain Front, where Pleistocene-aged glaciers have affected the geomorphology of both streams. The toe of the Sun River glacier near Augusta fed braided streams that carried gravels downstream, forming high terraces that bound the Sun River valley. Approaching Great Falls, the river enters low gradient areas that were historically inundated by a large glacial lake (Glacial Lake Great Falls), causing coarse sediment deposition and driving rapid channel change, especially during floods. Tributary watersheds of Upper Elk Creek (Smith and Ford Creeks) were similarly covered by glacial ice and are prolific producers of coarse sediment.

A combined look at channel form and flood history shows that, between the late 1970s and 2011, these streams were relatively quiescent in terms of floods and channel change. Both Elk Creek and the Sun River narrowed during that time, as did numerous rivers around the state. As a result, many stakeholders have had little direct experience with rapidly shifting channel locations until recently.

Our objective with the mapping and interpretations provided in this document is to assist river corridor landowners and other stakeholders in understanding the dynamic nature of the Sun River and Elk Creek, focusing not only on the challenges that channel migration creates but also the critical contributions that these processes provide to stream heath, resilience, and ecological vibrancy.

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Glossary and Abbreviations

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

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

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

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

CD – Conservation District.

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

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

DNRC – Department of Natural Resources and Conservation.

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

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

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

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

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

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

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

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

Hydrologic Unit Code (HUC) – 2 to 12 digit codes used to identify hydrologic units based on the area of land upstream from a specific point on the stream that contributes surface water runoff directly to this outlet point (drainage area).

HUC-8 (Subbasin) -- HUC level described as a cataloging unit that can be as small as 700 square miles, but most are larger. Also called 4th level HUC.

HUC-10 (Watershed) – HUC level that typically ranges from 62 t0 390 square miles. Also called 5th level or Watershed 5th level HUC.

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

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

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

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

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

Morphology - Of or pertaining to shape.

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

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

RDGP - Reclamation and Development Grants Program, DNRC.

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

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

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

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

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

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

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

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

1 Introduction

The Sun River Channel Migration Zone (CMZ) mapping project extends 51 river miles from just upstream of the Highway 287 bridge down to the mouth of Muddy Creek at Vaughn (Figure 1). The Sun River Watershed encompasses 1875 square miles (HUC8) and the Elk Creek Watershed is 193 square miles in area (HUC10). River corridor communities located within or adjacent to the Sun River corridor include Simms, Fort Shaw, Sun River, and Vaughn. The Elk Creek Mapping extent consists of 14.1 miles up from the river mouth and includes the town of Augusta. The Sun River mapping work (Phase 1) was funded through a Montana Department of Natural Resources and Conservation (DNRC) HB233 grant with additional support from Cascade Conservation District and the Montana Department of Environmental Quality (DEQ). Phase 2, which consists of Elk Creek mapping and further discussion of specific issues on the Sun River, was funded by a DNRC HB223 grant awarded to Lewis and Clark Conservation District, with additional direct support from the Lewis and Clark CD.

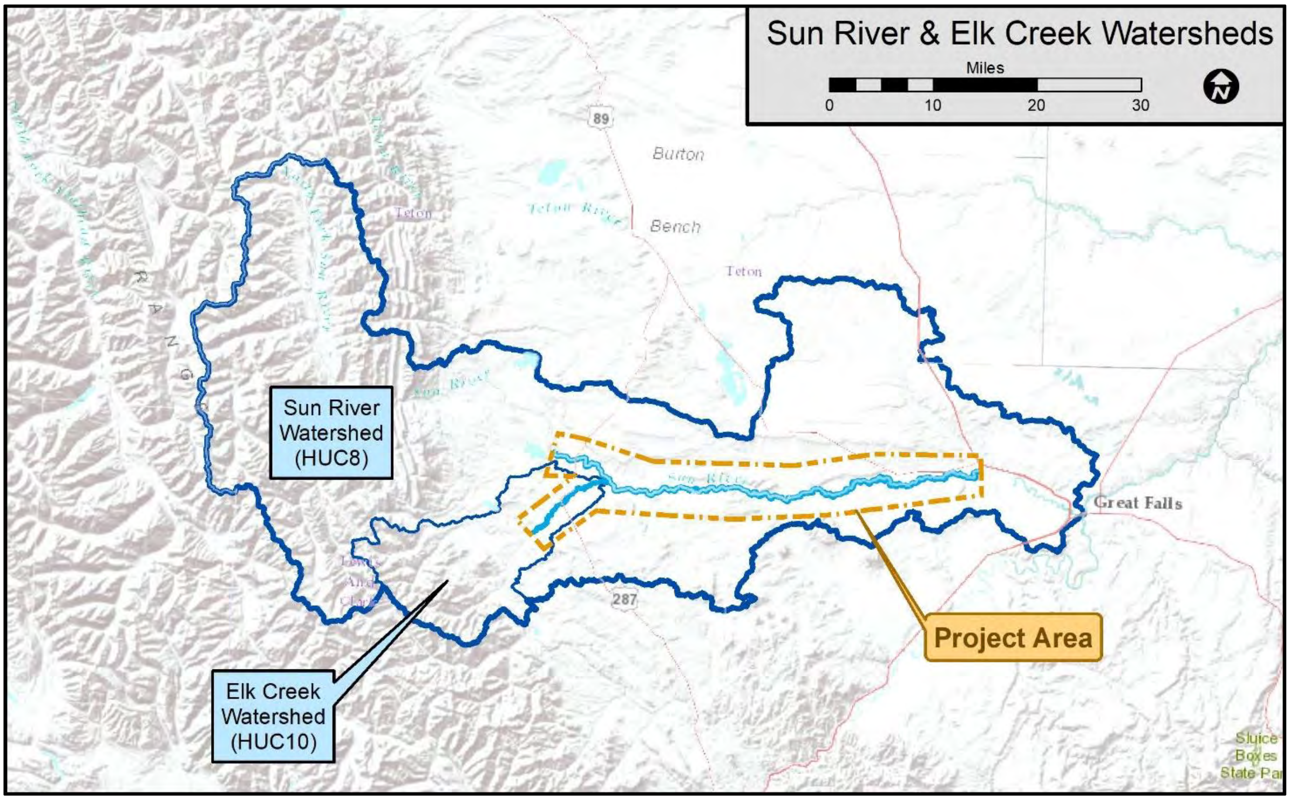


Figure 1. CMZ mapping extent on the Sun River from the Highway 287 Bridge to the mouth of Muddy Creek near Vaughn and Elk Creek from Smith Creek to the confluence with the Sun River.

1.1 The Project Team

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

1.2 What is Channel Migration Zone Mapping?

The goal of Channel Migration Zone (CMZ) mapping is to provide a cost-effective and scientifically based tool to assist land managers, property owners, agency personnel, and other stakeholders in making sound land use decisions along river corridors. Typically, projects constructed in stream environments such as bank stabilization, homes and outbuildings, access roads, pivots, and diversion structures are built without a full consideration of site conditions related to river process and associated risk. As a result, projects commonly require unanticipated and costly maintenance or modification to accommodate river dynamics. CMZ mapping is therefore intended to identify those areas of risk, to reduce the risk of project failure while minimizing the impacts of development on natural river process and associated ecological function. The mapping is also intended to provide an educational tool to show historic stream channel locations and rates of movement in any given area.

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

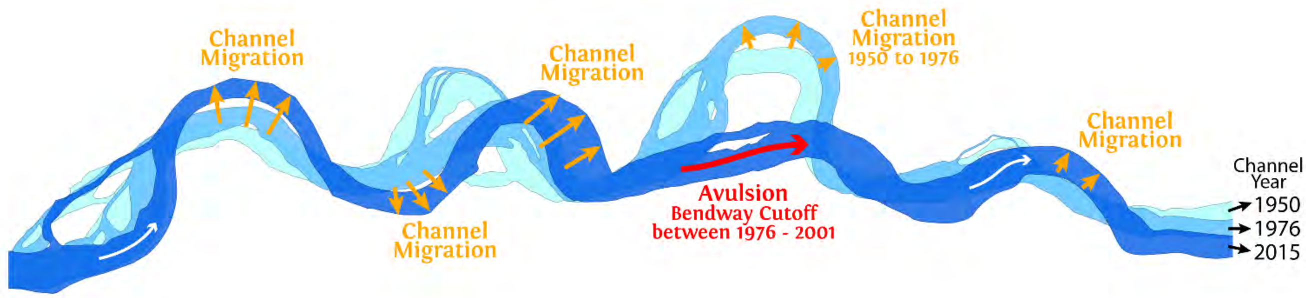


Figure 2. Typical patterns of channel migration and avulsion evaluated in CMZ development.

The fundamental approach to CMZ mapping is to identify the corridor area that a stream channel or series of stream channels can be expected to occupy over a given timeframe – typically 100 years. This is defined by first mapping historic channel locations to define the Historic Migration Zone, or HMZ (Figure 2). Using those mapped banklines, migration distances are measured between suites of air photos, which allows the calculation of migration rate (feet per year) at any site. Average annual migration rates are calculated on a reach scale and extended to the life of the CMZ, which in this case is 100 years. This 100-year mean migration distance defines the Erosion Buffer, which is added to the modern bankline to define the Erosion Hazard Area, or EHA.

Channel migration rates are affected by geomorphic influences such as geology, channel type, stream size, sediment volume, sediment size, flow patterns, slope, bank materials, and land use. For example, an unconfined meandering channel with high sediment loads would have higher migration rates than a geologically confined channel flowing through a bedrock canyon. To address this natural variability, the study area has been segmented into a series of reaches that are geomorphically similar and can be characterized by average migration rates. Reach breaks can be defined by changes in flow or sediment loads at tributary confluences, changes in geologic confinement, or changes in stream pattern. Reaches are typically on the order of five- to 10-miles-long. Within any given reach, dozens to hundreds of migration measurements may be collected.

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

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

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

The individual map units comprising the CMZ are as follows:

$$CMZ = HMZ + EHA + AHZ$$

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

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

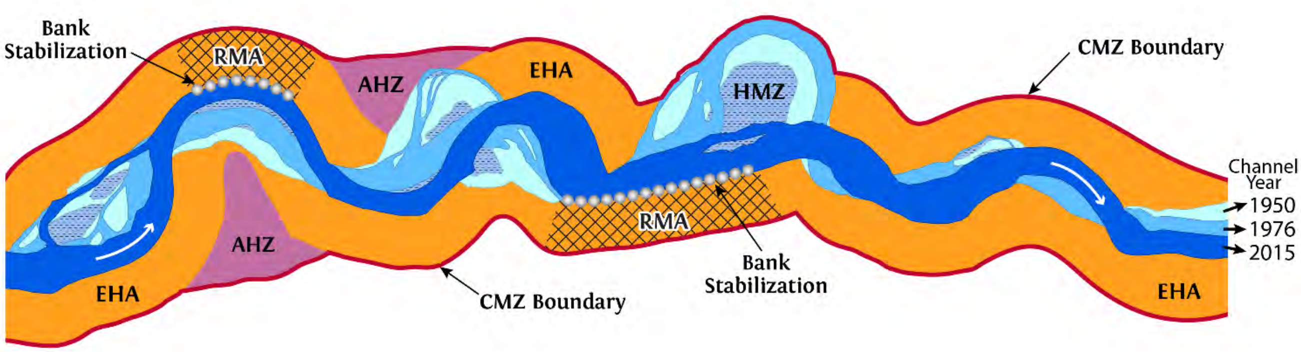


Figure 3. Channel Migration Zone mapping units.

Although the basic concept for Channel Migration Zone mapping efforts is largely the same throughout the country, different approaches to defining CMZ boundaries are used depending on specific needs and situations. These differences in assessment techniques can be driven by the channel type, different project scales, the type and quality of supporting information, the intended use of the mapping, etc. For this study, the CMZ is defined as a composite area made up of the existing channel, the collective footprint of mapped historic channel locations shown in the 1957, 1977/78, 1995, 2017, and 2019 imagery (Historic Migration Zone, or HMZ), and an Erosion Hazard Area (EHA), that is based on reach-scale average migration rates. Areas beyond the Erosion Buffer that pose risks of channel avulsion are identified as Avulsion Hazard Areas or AHZ. This approach generally falls into the minimum standards of practice for Reach Scale, Moderate to High Level of Effort mapping studies as defined by the Washington Department of Ecology (www.ecy.wa.gov). This approach does not, however include a geotechnical setback on hillslopes; these areas would require a more site-specific analysis than presented here.

1.3 Relative Levels of Risk

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

1.4 Uncertainty

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

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

The Sun River shows historic patterns of lateral migration and avulsion, locally within a broad floodplain surface that has dense networks of historic channels. With potential contributing factors, such as woody debris jamming, sediment slugs, landslides, or ice jams, dramatic change could potentially occur virtually anywhere in the stream corridor or adjacent floodplain. As the goal of this mapping effort is to highlight those areas most prone to either migration or avulsion based on specific criteria, there is clearly the potential for changes in the river corridor that do not meet those criteria and thus are not predicted as high risk.

Uncertainty also stems from the general paradigm that "the past is the key to the future." As predicted future migration is based on an assessment of historic channel behavior, the drivers of channel migration over the past 50 years are assumed to be relatively consistent over the next century. If conditions change significantly, uncertainty regarding the proposed boundaries will increase. These conditions include system hydrology, sediment delivery rates, climate, valley morphology, riparian vegetation densities and extents, and channel stability. Bank armor and floodplain modifications, such as bridges, dikes, levees, or sand and gravel mining could also affect map boundaries.

1.5 Potential CMZ Map Applications

The CMZ mapping is intended to support a range of applications, but the mapping should be primarily viewed as a tool to support informed management decisions throughout a river corridor. Potential applications for the CMZ maps include the following:

- Identify specific problem areas where migration rates are notably high and/or infrastructure is threatened.
- Develop project priorities, timelines, and funding mechanisms.
- 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.
- Improve stakeholder understanding of the risks and benefits of channel movement.
- Identify areas where channel migration easements may be appropriate.
- Facilitate productive discussion between regulatory, planning, and development interests active within the river corridor.
- Help communities and developers integrate dynamic river corridors into land use planning.
- Assist long-term residents in conveying their experiences of river process and associated risk to newcomers.

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.

1.6 Other River Hazards

The CMZ maps identify areas where river erosion can be expected to occur over the next century. It is important to note that river erosion is only one of a series of hazards associated with river corridors.

1.6.1 Flooding

The CMZ maps do not delineate areas prone to flooding. The difference between mapped flood boundaries and CMZ boundaries can be substantial. In cases where the floodplain is broad and low, the CMZ tends to be narrower than the flood corridor (left schematic on Figure 4). In contrast, where erodible terrace units bound the river corridor, the CMZ is commonly wider than the floodplain, because the terraces may be high enough to escape flooding, but not resistant enough to avoid erosion (right schematic on Figure 4). This is a common problem in Montana because of the extent of high glacial terraces that are above base flood elevations, but not erosion-resistant.

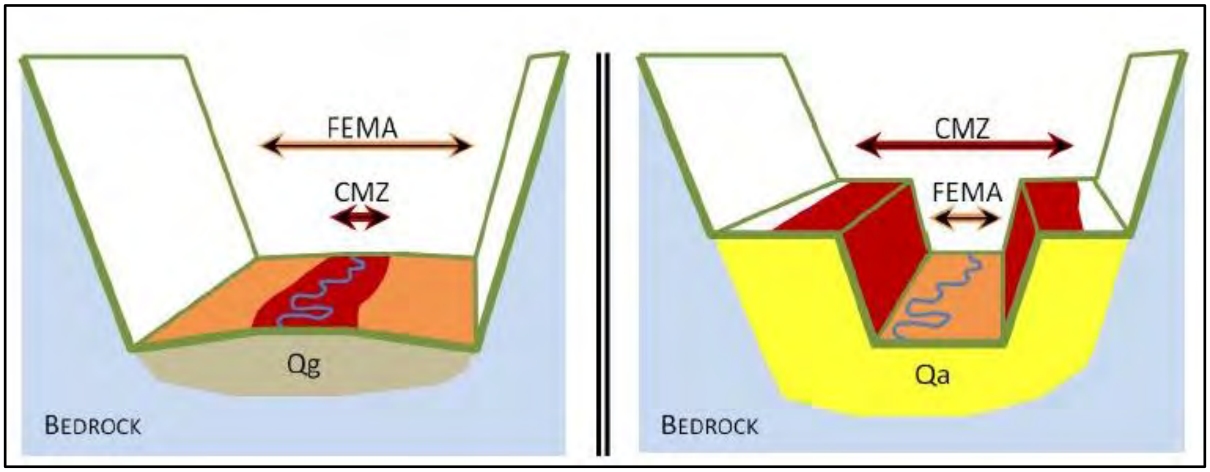


Figure 4. Schematic comparisons between CMZ and flood mapping boundaries (Washington Department of Ecology).

Figure 5 shows a property on the Yellowstone River in Park County that was progressively undermined during the 1996-1997 floods, prompting the owner to burn it down to prevent any liability associated with the structure falling into the river. This has been a chronic problem in river management, as landowners assume that if their home is beyond the mapped floodplain margin, it is removed from all river hazards. After experiencing massive 2005 flood damages in Saint George Utah (Figure 6), several property owners reflected on this issue (www.Utahfloodrelief.com):

We knew the river was there. We were 3 feet above the 100-year flood plain and made sure we were well above the flood plain. It was surveyed and the engineers told us where we had to put it and no, we don't have flood insurance or any kind of insurance that is going to reimburse us for anything.

Our property was not located within the 500-year flood plain or was it adjacent to it. The river simply took a new route that went right through our property.

I knew we were in big trouble. The river was raging and making a sharp "S" turn right behind our home. Our property seemed to take the full force of the river turning against the bank. Large chunks of earth were being swallowed up into the river. We watched 20 feet erode in less than two hours. We knew if it continued at that pace, we'd lose our house. Our contractor contacted an excavation company early that morning, but they said there was nothing they could do for us. We were also informed that our contractor's insurance was not covered for floods.

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

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

An example floodplain map for the Sun River upstream of Vaughn is shown in Figure 7. The floodplain boundaries cover much of the valley bottom, and the regulatory floodway, which is crosshatched in red, identifies the area of river and adjacent land areas that “must be reserved in order to discharge the base flood without cumulatively increasing the water surface elevation more than a designated height” (www.fema.gov). Communities are responsible for prohibiting encroachments including fill and new construction in floodway areas unless hydrologic and hydraulic analyses show that it will not increase flood levels in the community. On the Sun River, the floodway footprint envelops depict a complex series of active channels, gravel pits, and floodplain areas. The combined risks of flooding and channel migration on the Sun river should both be considered threats to human health and safety.

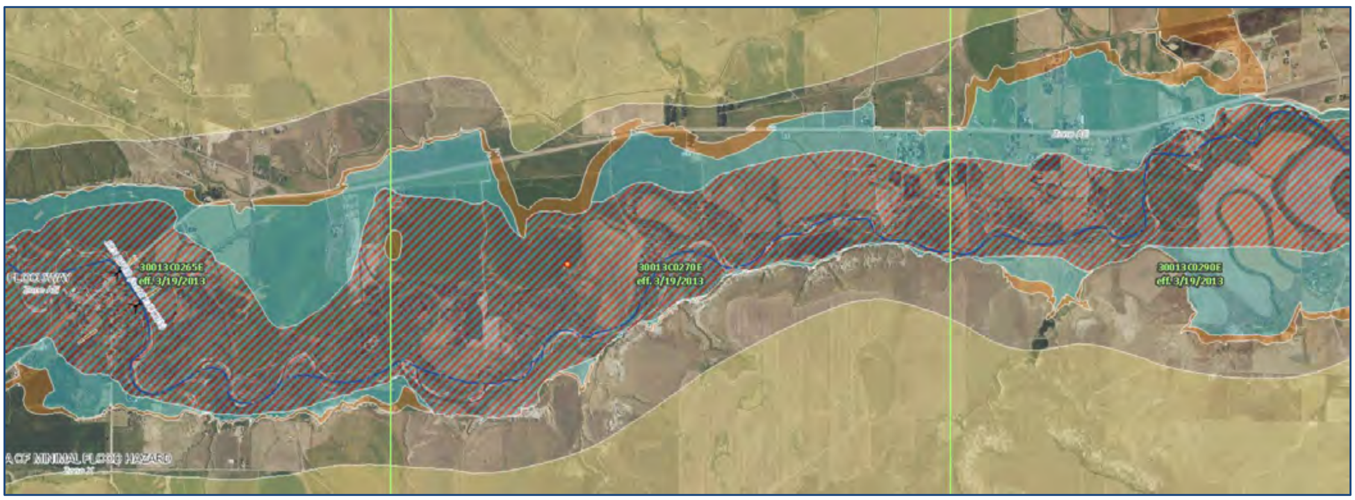


Figure 7. FEMA flood map for area between Sun River Bridge (left) and Vaughn (right).

1.6.2 Ice Jams

Another serious river hazard, especially in Montana, is ice jamming. Over 1,780 ice jams have been recorded in Montana, which is the most of any of the lower 48 states (http://dphhs.mt.gov/). Ice jams are most common in Montana during February and March. 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.

The Sun River and Elk Creek do not appear to be particularly prone to ice jamming, as they are not listed as having had 10 or more reported jams (Figure 8). They are not unheard of, however; in March of 2019 for example, the Cascade County Sheriff’s office reported that ice jams on the Sun River were starting to break up, creating flash flood concerns (Figure 9).

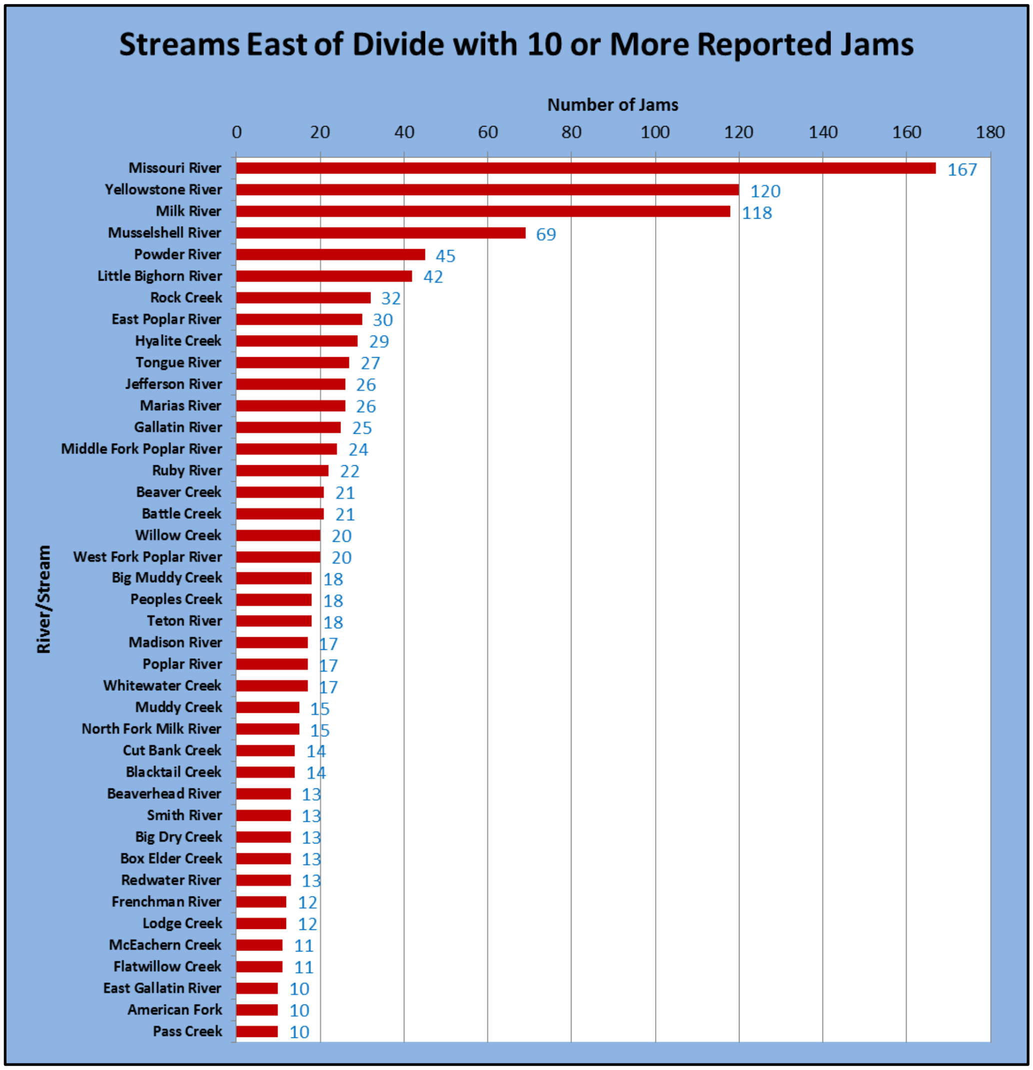


Figure 8. Montana rivers east of the continental divide with 10 or more reported ice jams (wrh.noaa.gov).

Figure 9. 2019 ice jam on the Sun River near Muddy Creek (ktvm.com)

1.6.3 Landslides

There are no mapped landslides adjacent in the project area. Upstream, however, landsliding in the upper watershed could impact stream process in the project reach by impounding and then releasing massive volumes of water and sediment. Just downstream of the Highway 287 bridge, a hillslope failure against the Floweree Canal caused the canal to breach, forming a large deposit on the Sun River floodplain (Figure 10). This demonstrates that, where canals are close to the river, breaches could create new floodplain channels or depositional features that may affect Sun River dynamics.

Figure 10. Google Earth photo showing Floweree Canal hillslope failure causing canal breach (left); Sun River is to right.

1.7 Disclaimer and Limitations

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

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

1.8 Acknowledgements

We would like to extend our gratitude to Tracy Wendt of the Sun River Watershed Group and Tenlee Atchison of the Cascade Conservation District for their assistance in Phase 1 contract management, scheduling, and draft document review. In the summer of 2020, during difficult days of Covid-19, Tracy and Tenlee sponsored a highly effective and organized public meeting outside the Sun River Methodist Church using creative technology and a solid sense of humor.

Funding provided by the Lewis and Clark Conservation District allowed us to extend the mapping into Elk Creek and address some specific issues on the Sun River in more detail. We would like to thank Chris Evans of LCCD for managing this contract, and Tracy Wendt's continued assistance in executing Phase 2. In late April 2021, still in Covid, we had another stakeholder meeting in Augusta, which was again remarkably productive and well-attended. As part of this work Tanner Tompkins of Montana Map Works captured drone imagery from the Adobe Creek/Rocky Reef Spring Creek area near Fort Shaw. His work products have been incredibly useful in our evaluation of recent changes in this area.

We would especially like to thank those stakeholders who showed up to learn about our work and describe their experiences living and working in these stream corridors. The community members who attended were essential in helping us strengthen our work product to address specific issues that they highlighted. Many provided invaluable historic context. We deeply appreciate your engaged and welcoming attitude, as we feel strongly that this work is much more effective if it is carried out collaboratively with the local community.

2 Physical Setting

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

2.1 Geography

The Sun River Watershed is 1875 square miles in size (1.2 million acres), originating as two forks (North and South Forks of the Sun River) within the core of the Bob Marshall Wilderness and flowing eastward off of the Rocky Mountain Front to its confluence with the Missouri River in Great Falls. Major tributaries include Willow Creek, Elk Creek, Dry Creek, Simms Creek, and Muddy Creek (Figure 11). Major communities in the river corridor include Simms, Fort Shaw, Sun River, Vaughn, Sun Prairie, Augusta, and Manchester. For much of its length in the upper watershed, the river forms the boundary between Lewis and Clark and Teton counties. Below Simms the river is entirely within the boundaries of Cascade County.

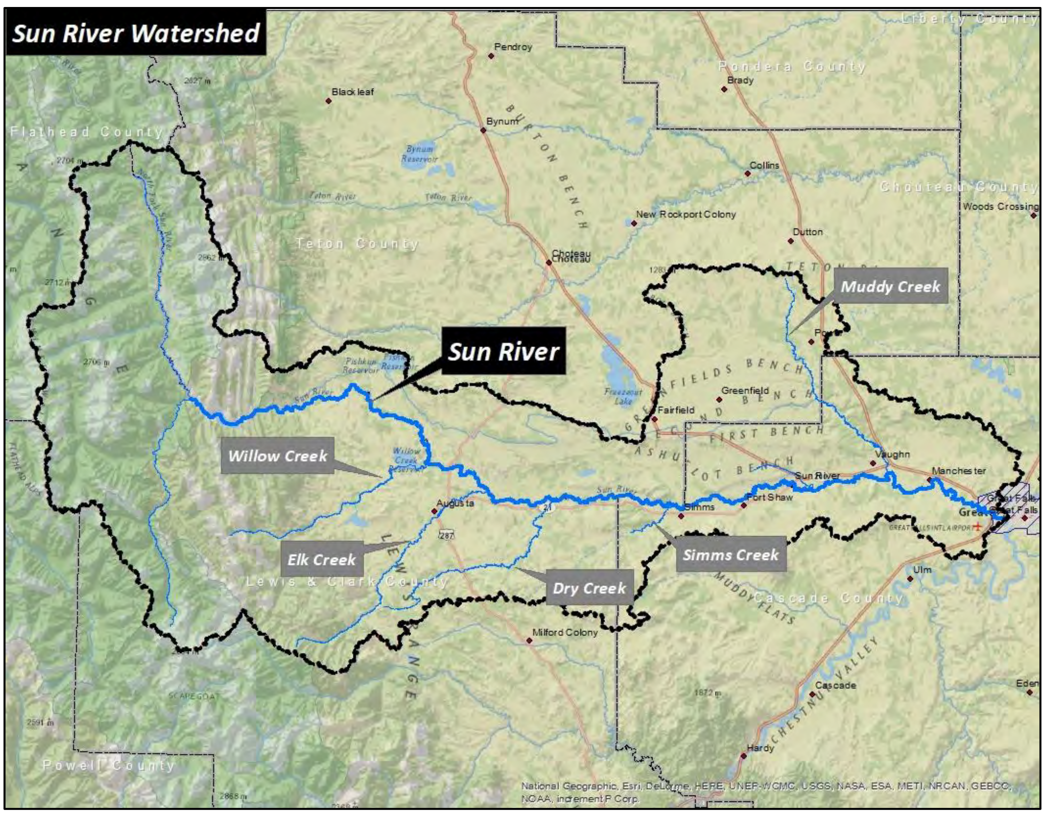


Figure 11. Sun River Watershed.

The Sun River watershed encompasses about 28 linear miles of the Rocky Mountain Front, extending from Castle Reef on the northern portion of the watershed to Steamboat Mountain to the south. Ivan Doig effectively described the Rocky Mountain Front in *This House of Sky*:

> *We came up over the crest and were walled to a stop. The western skyline before us was filled high with a steel-blue army of mountains, drawn in battalions of peaks and reefs and gorges and crags as far along the entire rim of the earth as could be seen. Summit after summit bladed up*

thousands of feet as if charging into the air to strike first at storm and lightning, valleys and clefts chasmed wide as if split and hollowed by thunderblast upon thunderblast.

The peaks, reefs, gorges, and crags described in *This House of Sky* capture the unique grandness of scale in this area (Figure 12). The Rocky Mountain Front ("The Front") in the Augusta-Choteau area has long been recognized by geologists as a classic example of thin-skinned, fold- and thrust-type mountain forming processes, and universities commonly base structural geology field camps in Sun Canyon. East of the canyon mouths, the combination of mountain building processes with subsequent glaciation has created a spectacular landscape where steep scarps on the eastward edge of limestone thrust sheets grade to rolling prairie hills comprised of outwash gravels that transition into a glacial lake environment near Vaughn.

Figure 12. View to the west showing Castle Reef (right); Sun River flows about ¾ mile to the left of this photo.

The Elk Creek watershed is 193.4 square miles in size, and major streams include Elk Creek, Smith Creek, Goss Creek, and Ford Creek (Figure 13). Elk Creek itself, which is sometimes called the South Fork of the Sun River, is about 32 miles long, originating on the north flank of Steamboat Mountain and flowing northeast to its confluence with the Sun River about five miles northeast of Augusta, Montana.

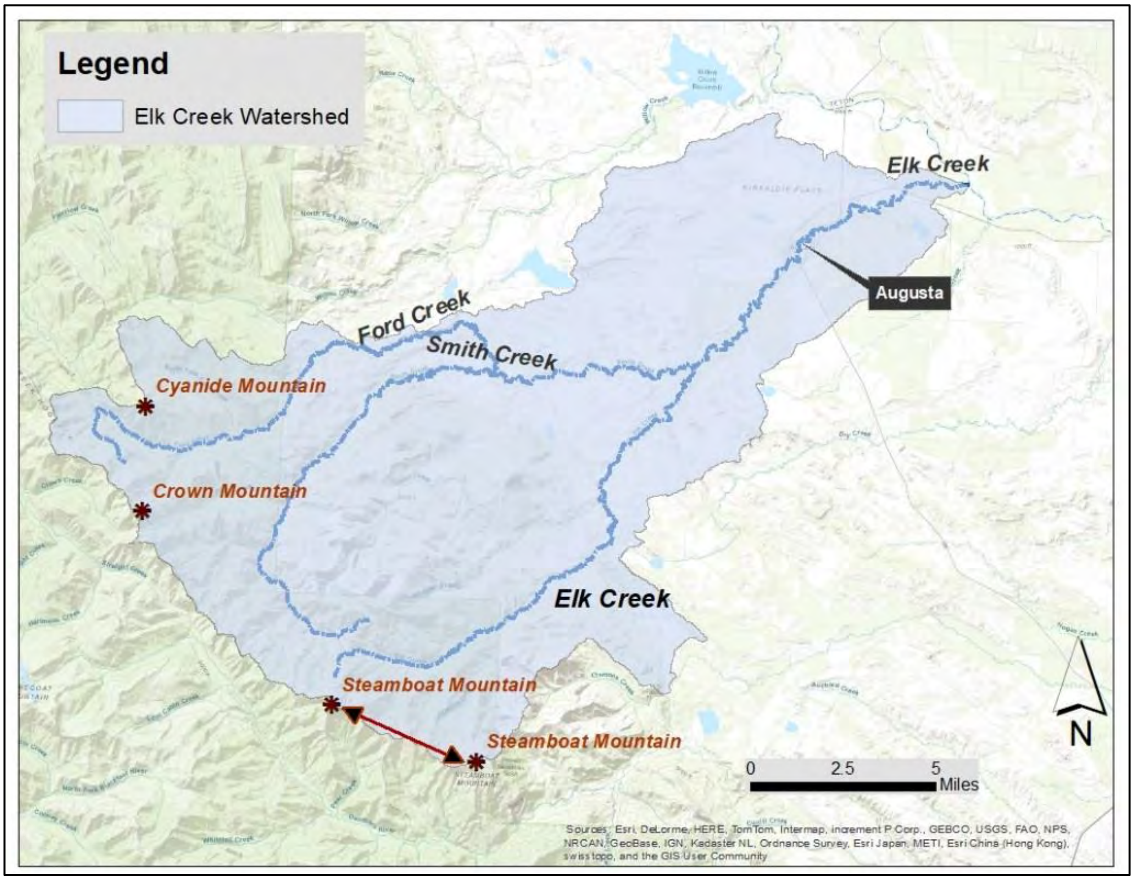


Figure 13. Map of Elk Creek watershed near Augusta, MT.

2.2 Geology and Glacial History

Limestone cliffs are the defining feature of the Rocky Mountain Front. Erosion through the thrust sheets has created unique stream systems that flow north-south through repeating sequences of limestones. These tributaries feed the Sun River, which flows eastward across the prairie where it joins the Missouri River at Great Falls. Figure 14 and Figure 15 shows how the Sun River cuts perpendicularly through a series thrust sheets in Sun Canyon. On Figure 15 the thrust faults are depicted as black lines that show how the faults dip to the west. The map shows that the thrust sheets have been pushed eastward, which is what forms the cliffs of Castle Reef and Sawtooth Mountain at the mouth of Sun Canyon.

Figure 14. Northward view of thrust sheets dissected by the Sun River near Augusta (www.formontana.net).

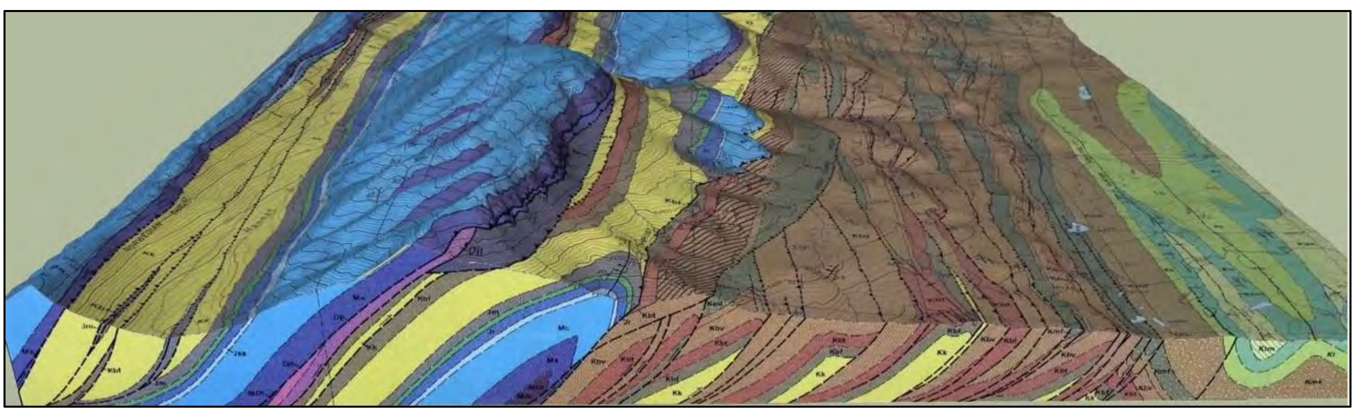


Figure 15. Geologic cross section showing northward view of Castle Reef (blue ridge in center) and dense fault system just to the east (right) (Karabinos, 2017).

As the Rocky Mountain Front was uplifted, the drainage network became controlled by that geology. Figure 14 shows how tributary streams in Sun Canyon enter the river from right angles, controlled by a series of gulches formed along the more erodible layers of the thrust sheets.

The bedrock geology is one major aspect of the watershed conditions that affect the dynamics of the Sun River as if flows out of the Bob Marshall Wilderness towards Great Falls. A second major control is the younger sediments, many of which are glacial deposits. Well after the uplift of the mountains, the Cordilleran Ice Sheet intermittently covered the western edge of Montana up until about 10,000 years ago. During that period, the ice made several advances and retreats; two distinct glacial periods in this area were the Bull Lake Glaciation (200,000 to 130,000 years ago) and the Pinedale Glaciation (~30,000 to 10,000 years ago). The Bull Lake ice is thought to have extended as far east as Choteau.

In Montana, the glacial advance to the south created ice margin lakes across Montana (Figure 16). Part of this study areas lies within the footprint of Glacial Lake Great Falls, and those deposits are exposed in some eroding banklines (Kellogg, 2014).

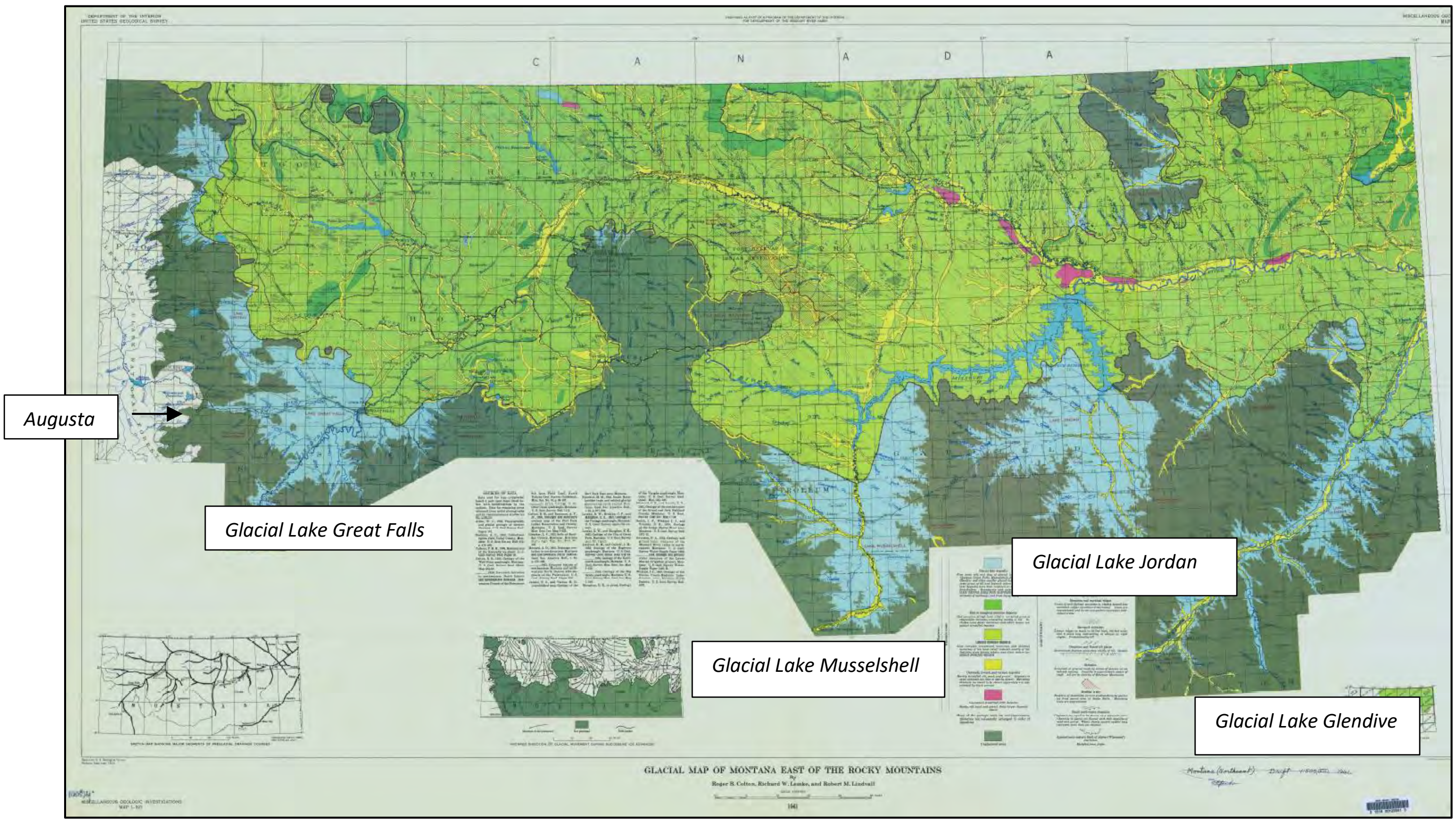


Figure 16. Map of northern Montana showing extent of glacial deposits (light green) and glacial lakes (light blue) that formed south of those deposits. These include Lake Choteau and Lake Great Falls (left); Lake Musselshell (center), and Lake Jordan (center right). The lake shown on the lower right follows the current path of the Yellowstone River and was called Lake Glendive (Colton, et. al., others, 1961).

Figure 17 shows a map from the 1930s, showing the glacial ice sheet extending to the edge of Great Falls. Glacial Lake Great Falls formed at the toe of the ice sheet, inundating much of the lower Sun River watershed. Separate smaller glaciers formed in the mountains; Figure 17 shows the Sun River Glacier flowing beyond the toe of the mountains to Augusta. This valley glacier was four miles wide near the mouth of Sun Canyon and spread out towards Augusta for 18 miles, reaching a maximum width of about 15 miles. It covered more than 200 square miles of the plains west of Augusta. On the edges of the ice, it appears to have been over 200 feet thick, and about 1,500 feet thick at the mouth of the canyon (Alden, 1934). Figure 18 and Figure 19 show 1930s photos of large limestone blocks that were carried by the Sun River Glacier onto the prairie near Augusta. A smaller glacier due south of the Sun River Glacier covered parts of the upper Elk Creek watershed southwest of Haystack Butte.

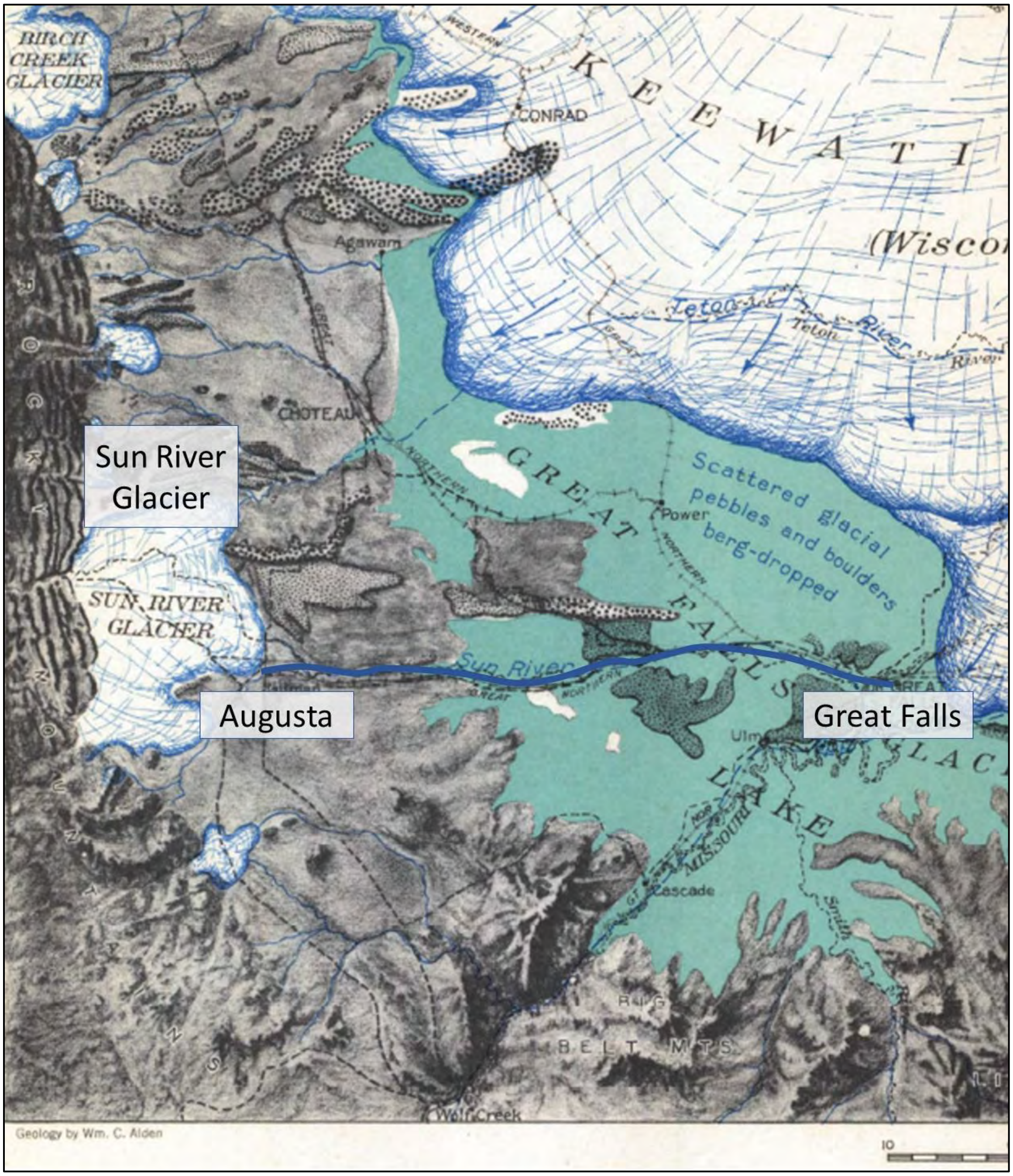
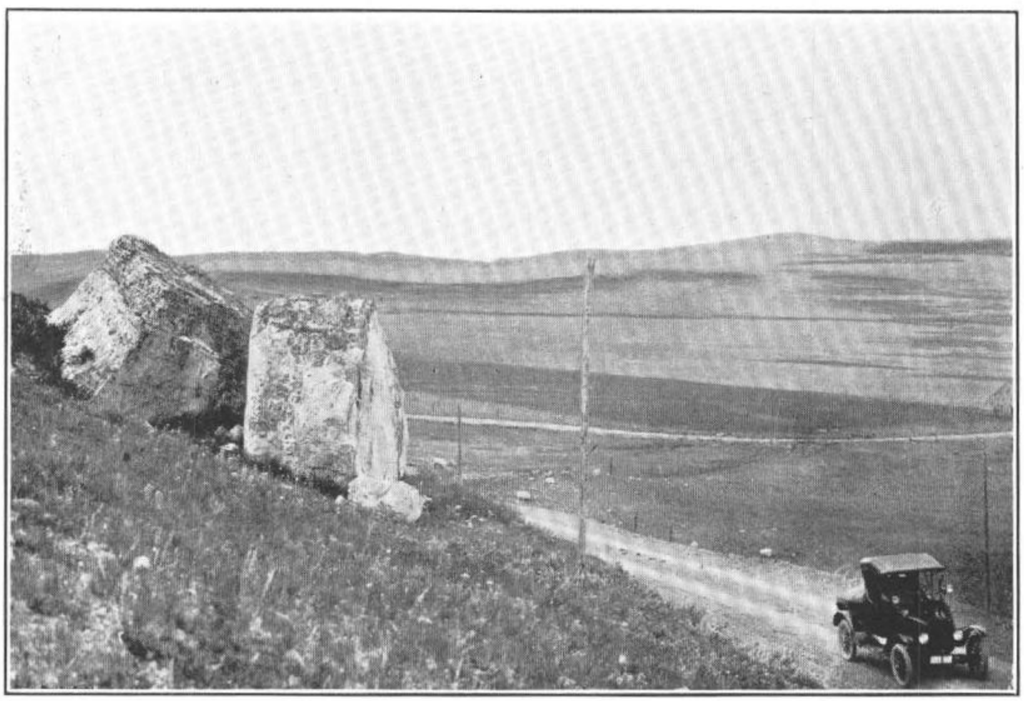


Figure 17. Map of Sun River Glacier extending from the Sun Canyon to Gilman near Augusta (Alden, 1934).

B. BLOCKS OF PALEOZOIC LIMESTONE TRANSPORTED BY SUN RIVER GLACIER, ON THE PLAIN 8 MILES EAST OF THE MOUTH OF THE SUN RIVER CANYON

The blocks are 10 by 13 by 30 feet.

Figure 18. Mid-1930s photo showing glacial erratic on plains east of Sun River Canyon (Alden, 1934).



C. BLOCKS OF PALEOZOIC LIMESTONE TRANSPORTED BY SUN RIVER GLACIER 4 MILES NORTHWEST OF AUGUSTA, MONT.

On moraine 15 miles southeast of the mouth of the Sun River Canyon. The blocks are 15 to 20 feet long.

Figure 19. Mid-1930s photo showing glacial erratic on what appears to be modern Highway 287 hillslope (Alden, 1934).

The geologic and glacial histories of this area are both important to one's overall understanding of the behavior of the Sun River and its upper tributaries. The Rocky Mountain Front provides a major source of both flow and sediment to the river, as do glacial outwash sediments that extend into the project area (Figure 20). As the river continues eastward towards Great Falls, it enters a glacial lake environment characterized by much lower slopes. This setting, where a large coarse-grained sediment load progressively encounters flatter slopes (reduced transport energy), makes the Sun River especially prone to major changes, especially during flood events when high volumes of sediment are mobilized. A simplified modern geologic map of the watershed is shown in Figure 21, with the project area shown in a black polygon. The map shows glacial tills in the upper end of the project area, and near Simms and Fort Shaw gravel terraces along the river that have glacial origin as outwash deposits formed by braided streams at the toe of the glaciers (Figure 20). The light blue color reflects older rocks such as the Two Medicine Formation, that form bluffs along the river. The Two Medicine sandstone is relatively resistant to erosion, whereas the glacial gravels are highly erodible. As a result, the valley margins affect river behavior in terms of both sediment contributions and channel migration rates.

Figure 20. Gravel deposits on terrace adjacent to Sun River—river corridor is in cottonwood gallery in background.

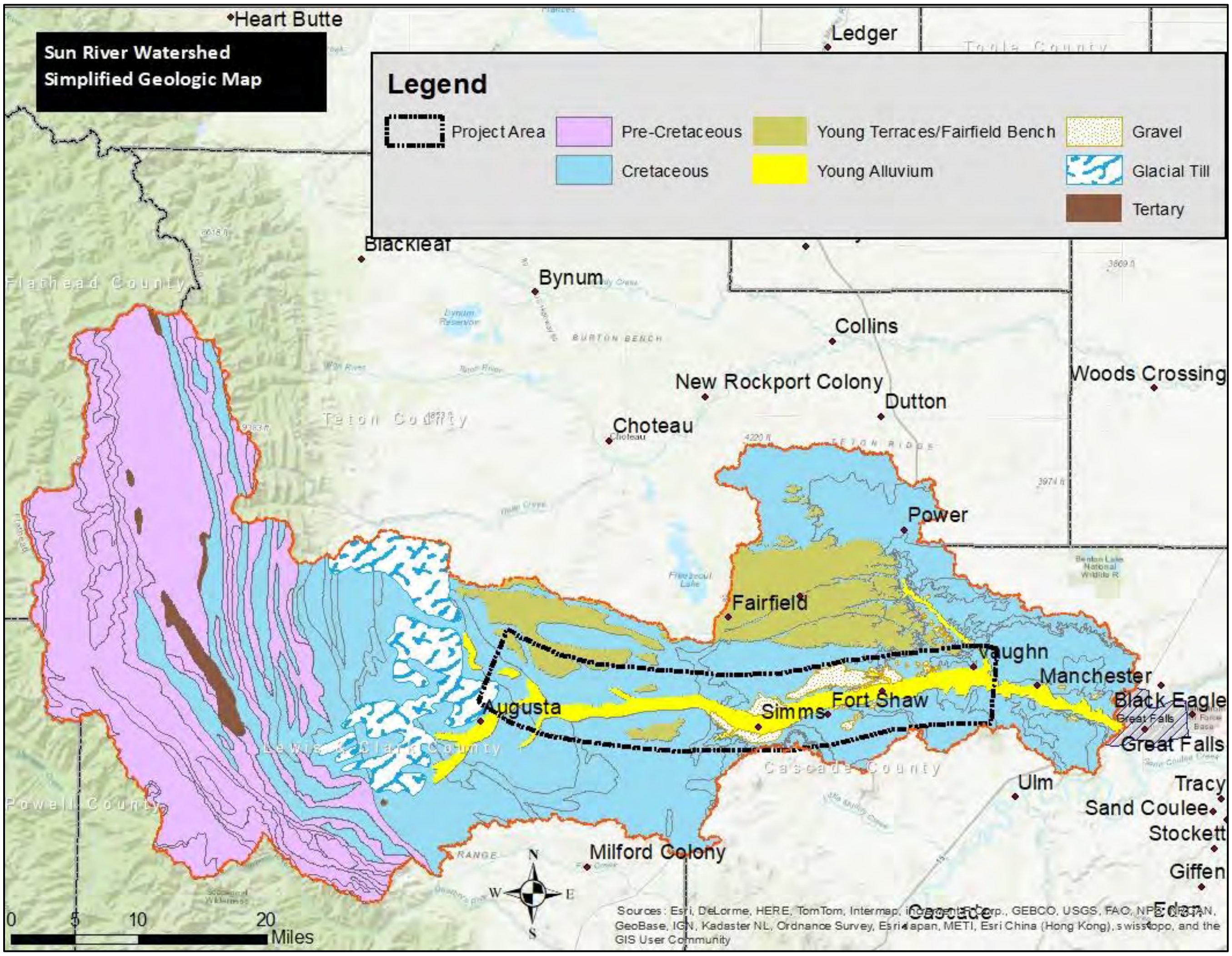


Figure 21. Simplified USGS geologic map of the Sun River Watershed.

2.3 Hydrology and Flow Management

The hydrology of both the Sun River and Elk Creek reflects a typical snowmelt system, with peak flows occurring between late May and early July.

2.3.1 Water Development

The biggest and oldest water development project in the watershed is the Sun River project. This project launched in 1907 when the U.S. Reclamation Service approved the construction of the Greenfields and Fort Shaw divisions, each with its own irrigation district. The project includes three storage reservoirs, two diversion dams, 131 miles of main canals, 562 miles of smaller side canals, and 265 miles of drain canals (Kellogg, 2014). Additional irrigation projects include Nilan Water Users, Broken O Ranch, Rocky Reef, and the Sun River Valley Ditch Company. According to Kellogg (2014), the eight-mile reach from Lowry bridge to the mouth of Big Coulee is especially susceptible to dewatering during droughts, although recent cooperative actions by water users have resulted in improved in-stream flows in recent years.

2.3.2 Flood History

Between 1953 and 1975, major floods typically occurred every 11 years on the Sun River (1953, 1964, and 1975). From 1975 until a few years ago, floods were relatively rare, with only two 5-year floods (1981 and 2011) occurring over 41 years. Over the last two years (2018 and 2019), flooding has been the rule rather than the exception. These patterns are important when considering channel form and resilience, as floods can have a major, long-term influence on stream stability and rates of change.

The annual flood record for the Sun River near Vaughn is shown in Figure 22, and flood frequency estimates for the gage are shown as horizontal lines on the plot. The flood of record was in 1964, although there is general agreement amongst hydrologists that the 1964 flood flows were probably substantially lower than reported (M. Downey, DNRC, pers comm).

The 1975 flood is the second largest on record and exceeded a 100-year event. Then, for several decades, there was little flooding on the Sun River. This dry pattern changed in 2011, when substantial flooding occurred across much of the state. And most recently, two major floods occurred back-to back, with the 2018 and 2019 floods exceeded 25-year and 5-year events, respectively.

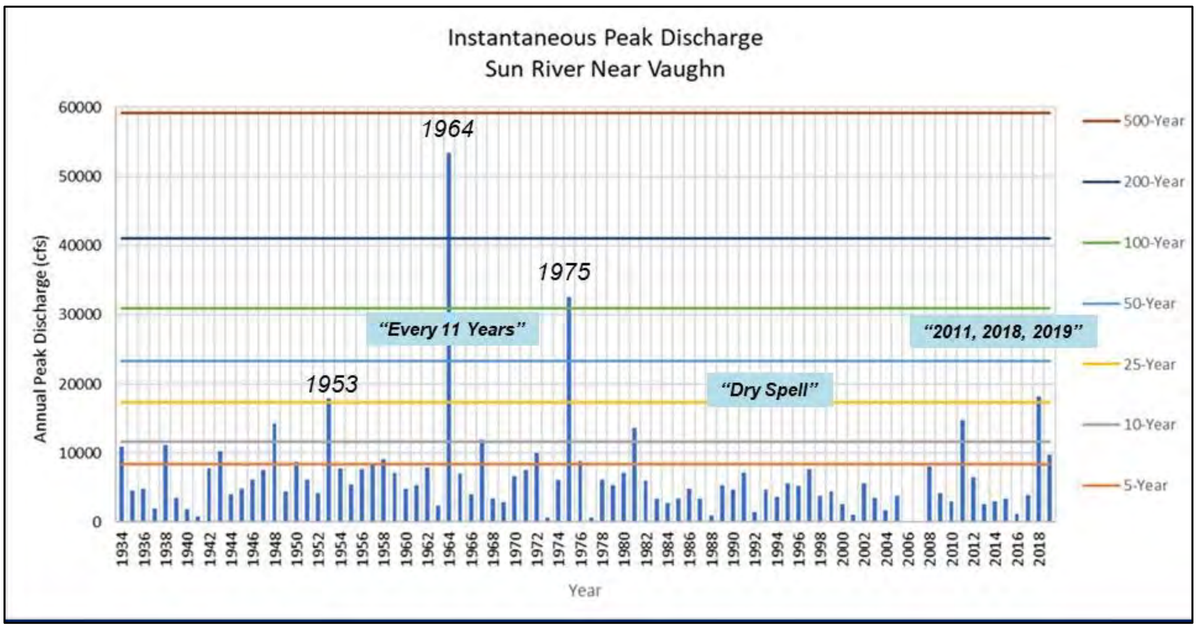


Figure 22. Annual Instantaneous Peak Discharges from 1934-2017, Sun River near Vaughn (USGS 06089000).

2.3.3 Channel Forming Flows

In snowmelt-driven stream systems, rivers are largely formed by spring runoff. The size of a typical runoff, or what is commonly referred to as a river's "channel forming flow", is commonly estimated by a 2-year discharge ("Q2"), or that flow that occurs every other year on average. The number of days over which a 2-year flow is exceeded can also be used to estimate how much "channel forming" energy was exerted on a stream during any given event or series of events. This in turn can shed light on the geomorphic drivers of change seen in any given stream, as increased durations of flows over Q2 typically reflect higher rates of sediment transport and sorting, and associated channel change.

Each major flood described above is plotted in Figure 23, showing how many days flows exceeded a 2-year discharge during that flood season at Vaughn. This in turn can be used as a rough indication of how much work was performed on the channel. The results show that 1953 and 2018 had the longest duration of channel forming flows, and thus these floods have the potential to impart major channel change. In contrast, the 2019 event had the shortest duration of flows over a 2-year event. What is perhaps most relevant to this work is the long duration of the 2018 event; clearly this flood had the potential to drive high rates of channel change.

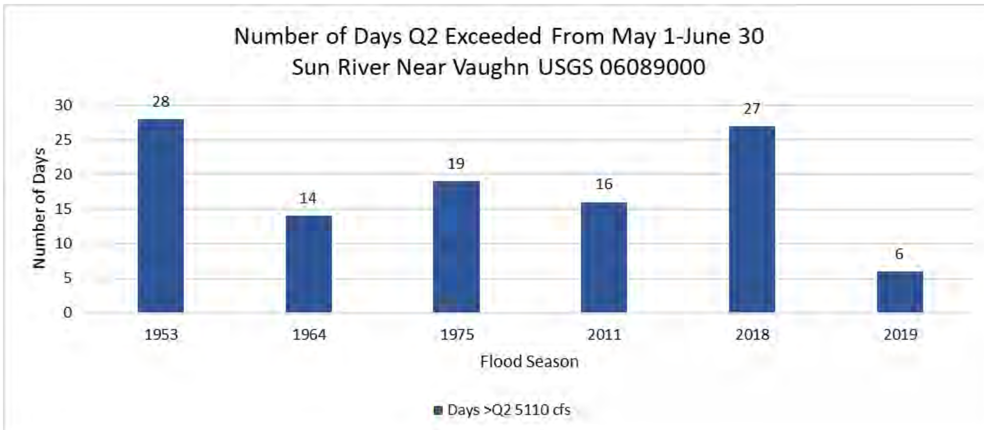


Figure 23. Number of days a 2-year discharge was exceeded during major flood events, Sun River near Vaughn.

When taken in broader context, it is important to recognize that work is performed on channels all the time, not just during major floods. Figure 24 shows the number of days the 2-year discharge was exceeded during any year (not just flood years) on the Sun River near Vaughn. What is striking about this graph is the lack of channel forming events since the 1975 flood. This is also shown on Figure 25 as a cumulative plot. The line shows a distinct break in slope, with conditions that would support much more work occurring prior to 1976.

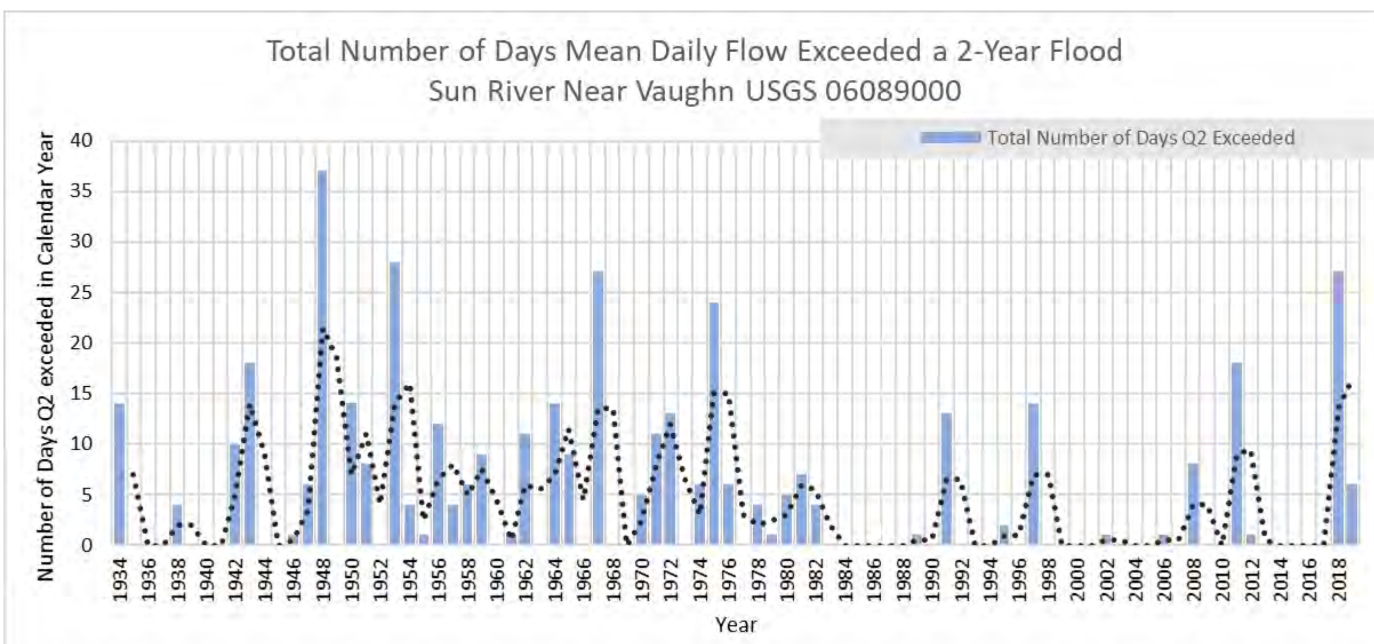


Figure 24. Number of days a 2-year discharge was exceeded annually since 1934 on the Sun River near Vaughn.

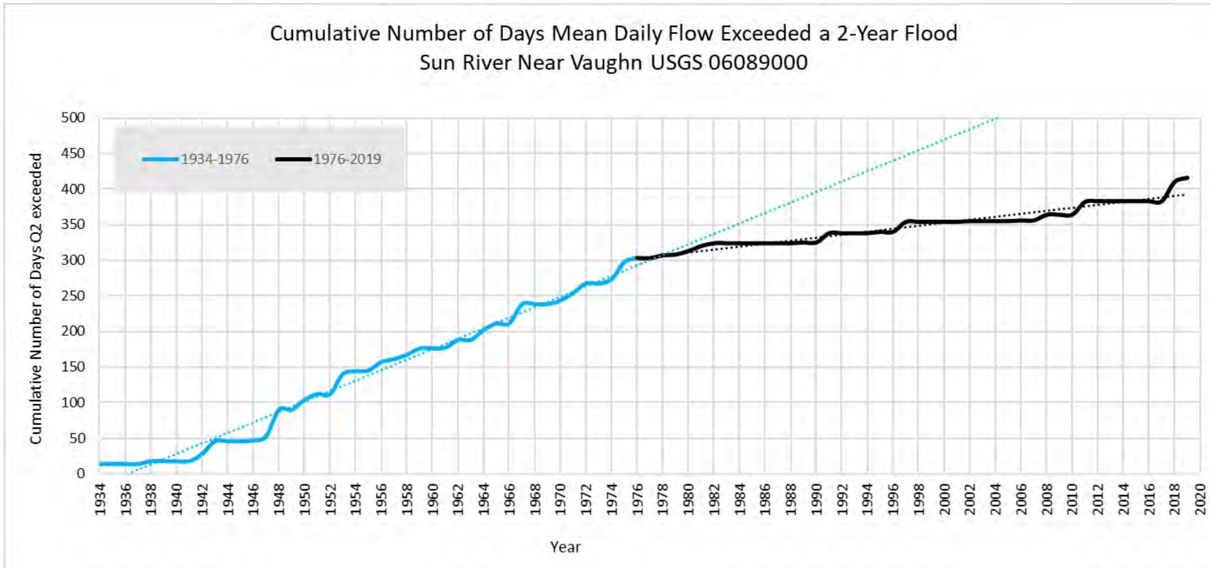


Figure 25. Cumulative number of days that Sun River flows have exceeded a 2-year flood event since 1934.

The data shown in Figure 25 shows an important aspect of the Sun River's geomorphic history. From 1976 to 2018 (or to 2011 in some areas), the river was quiet in terms of flood-driven change. The Sun River and its tributaries such as Elk Creek narrowed and grew in with vegetation. An example of this is shown in Figure 26, where open gravel bars near Lowry grew in between 1978 and 2011. Vegetation encroachment reduces channel capacity, making that channel especially prone to dramatic change during the next long flood event. This is a common phenomenon across the state; it wasn't only the drought years of the early 2000s that caused our rivers to atrophy, but a much longer period of minimal flooding that began in the late 1970s.

2.4 Dikes and Levees

The Vaughn Levee, shown in Figure 27, is the only major flood control structure we identified in the study area. The levee is about 2.5 miles long, built in 1969 in response to the 1964 floods. The levee protects 250 households from Sun River floodwaters (Kellogg, 2014). A second levee separates the river from an old gravel pit on the south bank about four miles upstream of Vaughn.

Figure 26. Sun River at RM 44 (just below Lowry Bridge) showing broad open bars in 1977 (top) and more dense riparian stands in 2011 (bottom).

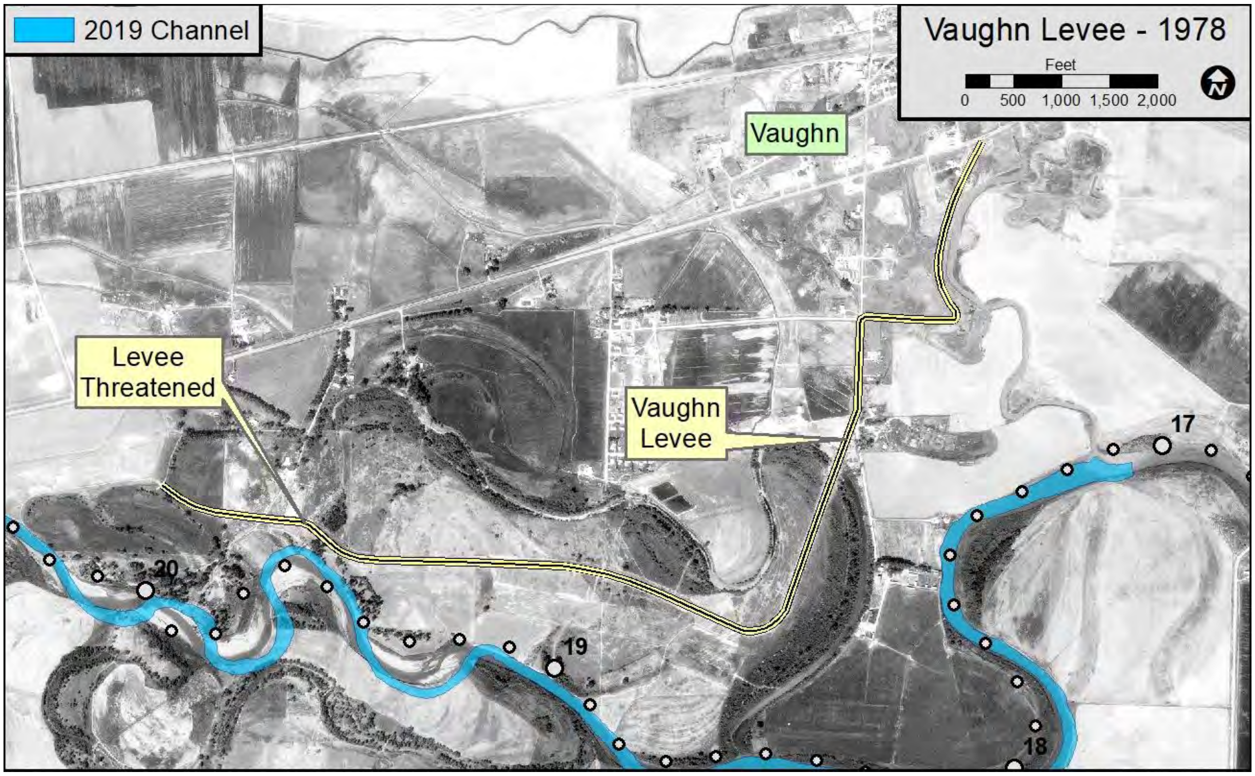


Figure 27. Vaughn Levee showing conditions a decade after it was built (1978 air photo); blue shows 2019 Sun River course and highlights large meander approaching and threatening levee.

2.5 Bank Armor

Bank armor was mapped where visible on air photos, Google Earth, or oblique photographs. Since there was no ground inventory, the mapping probably captures a conservative estimate of the extent of bank armor on current and historic channels. Additionally, the bank armor inventory has no assessment of condition or functionality. Along the length of the Sun River, we mapped 4.7 miles of bank armor which covers about 5% of the total bankline. The bank armor consists of rock riprap, barbs, and other revetments such as root structures, and potentially concrete rubble. On Elk Creek, about 3,400 feet of bank armor were mapped.

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

2.6 Transportation Infrastructure

Transportation infrastructure commonly follows stream corridors and encroaches into the CMZ. This is uncommon in the project area, with the exception of local impacts at bridge crossings.

2.7 Sand and Gravel Mining

A total of 41 gravel pits were mapped in the Sun River project area, and all of them are downstream of the town of Sun River in Reach SR1 (Figure 28). There are currently four permitted open cut sites within or adjacent to the stream corridor, indicating that most pits are non-operational. Figure 29 shows the number of new pits visible on each suite of imagery; the rate of development was fairly constant from the 1950s until 2011 but has dampened since then. Prior to 2011, about six new pits per decade were established.

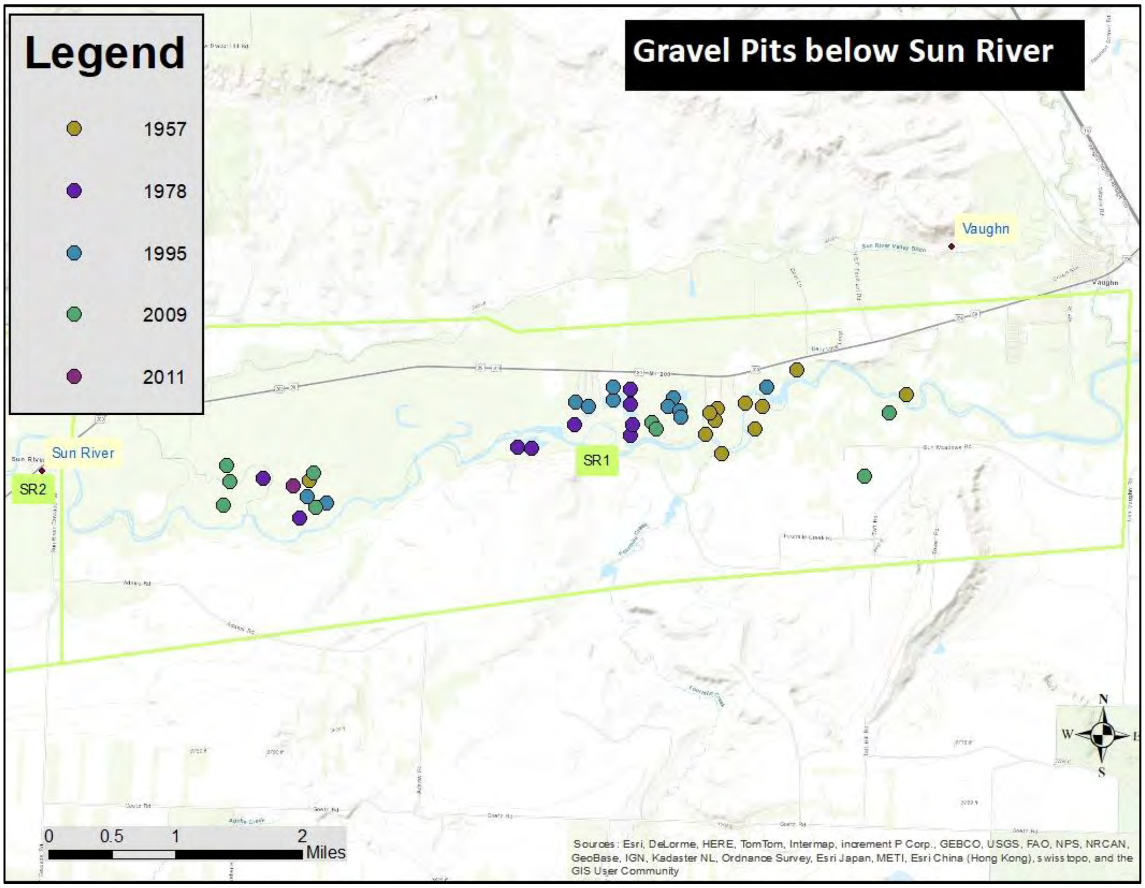


Figure 28. Gravel pits visible on imagery showing first year of visible activity.

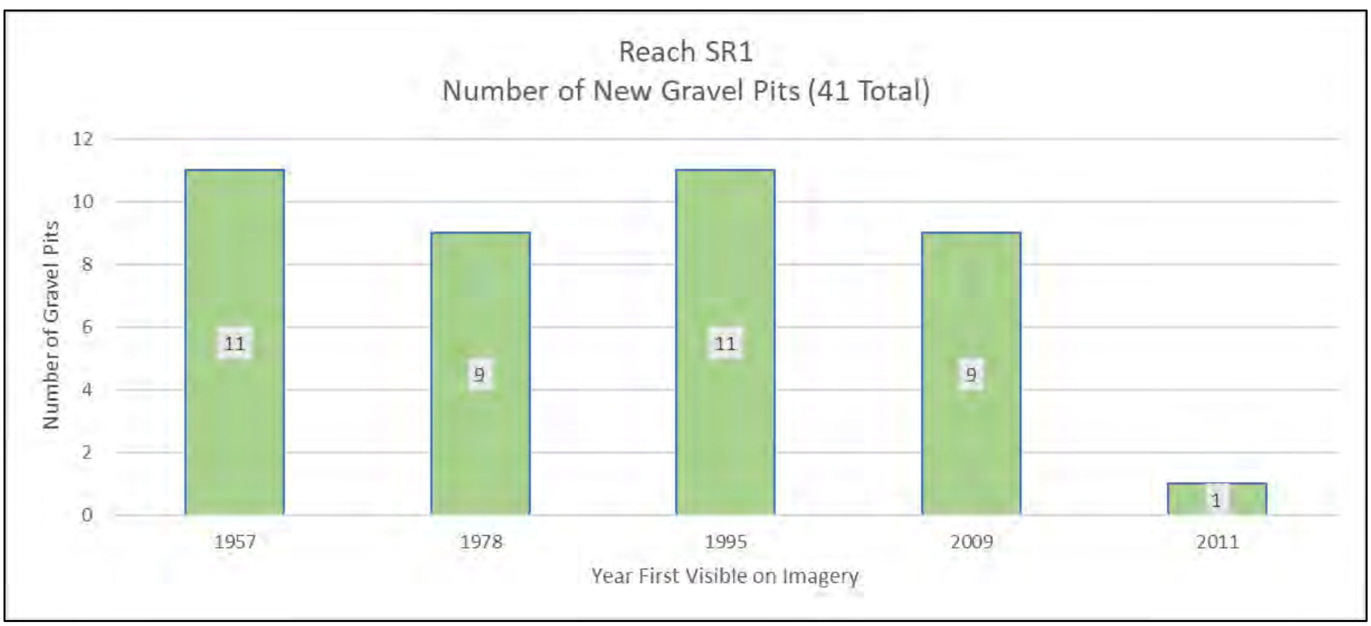


Figure 29. General rate of gravel pit development shown as first time pits were visible in imagery.

3 Methods

The development of the Sun 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 1,200 miles of rivers in Montana.

3.1 Aerial Photography

CMZ development from historic imagery is dependent on the availability of appropriate imagery that covers the required time frame (50+ years), the spatial coverage of that imagery, and the quality of the photos. It is important to use imagery with the best possible quality, scale, extent, and dates so that historic and modern features can be mapped in sufficient detail. Several imagery sources are available for the Sun River study area. The most recent sources, starting around 1995 with the black-and-white Digital Orthophoto Quad imagery (DOQ) and continuing through the current NAIP (National Agriculture Imagery Program) imagery, are freely available in GIS-compatible format. The quality of these images, both spatially and resolution, ranges from good to excellent and they cover the entire project area.

Imagery older than 1995 must be acquired from various archival services as digital scans, and then mosaiced into a single spatially-referenced image for use in the GIS. For this project, the historic imagery scans were ordered from the United States Department of Agriculture (USDA) Air Photo Field Office (APFO) in Salt Lake City, Utah.

A total of 79 individual images were ordered from the APFO to cover two time periods for the Sun River (57 for 1957 and 22 for 1977/78) and 19 images for Elk Creek (13 for 1955 and 6 for 1978). The 1970s imagery for the Sun River was collected in two different years, with 10 images from 1978 covering the river upstream of Simms and 12 images dated 1977 covering the river downstream. No significant flood events occurred between the image suites, so they could be combined as single time period. The USDA scans were delivered as high-resolution (12.5 micron) TIFF images, each approximately 330 MB in size. They were then orthorectified by Aerial Services, Inc. (ASI) in Cedar Falls, Iowa, using NAIP imagery as the spatial reference, providing identifiable ground control points. Table 1 lists imagery used for this project from the USDA and archives of current GIS data sets. Examples of the imagery used in the analysis are shown in Figure 30 through Figure 34. The examples are from the Sun River, but the Elk Creek imagery shows the same characteristics.

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

Year	Source	Scale	Number of Images	Image Date	Notes
1957 (Sun) **1955 (Elk)**	USDA APFO	1:20,000	57 13	7/10 to 7/18/1957	High-resolution Scans (black-and-white)
1977/78 (Sun) **1978 (Elk)**	USDA APFO	1:40,000	22 6	8/17/1977 8/3/1978	High-resolution Scans (black-and-white)
1995 DOQ (Sun/Elk)	USDA	~3 meter resolution	NA	7/1 to 8/9/1995	Digital Download, individual quad tiles (black-and-white)
2013 NAIP (Sun/Elk)	USDA	~ 1 meter resolution	NA	Mostly 8/9/1995, with remaining 7/1 to 8/5/1995	Digital Download, Compressed County Mosaics (color)
2017 NAIP (Sun/Elk)	USDA	~ 1 meter resolution	NA	7/3 to 7/17/2017	Digital Download, Compressed County Mosaics (color)
2019 NAIP (Sun/Elk)	USDA	~ 1 meter resolution	NA	7/27 to 7/30/2019	Digital Download, Compressed County Mosaics (color)

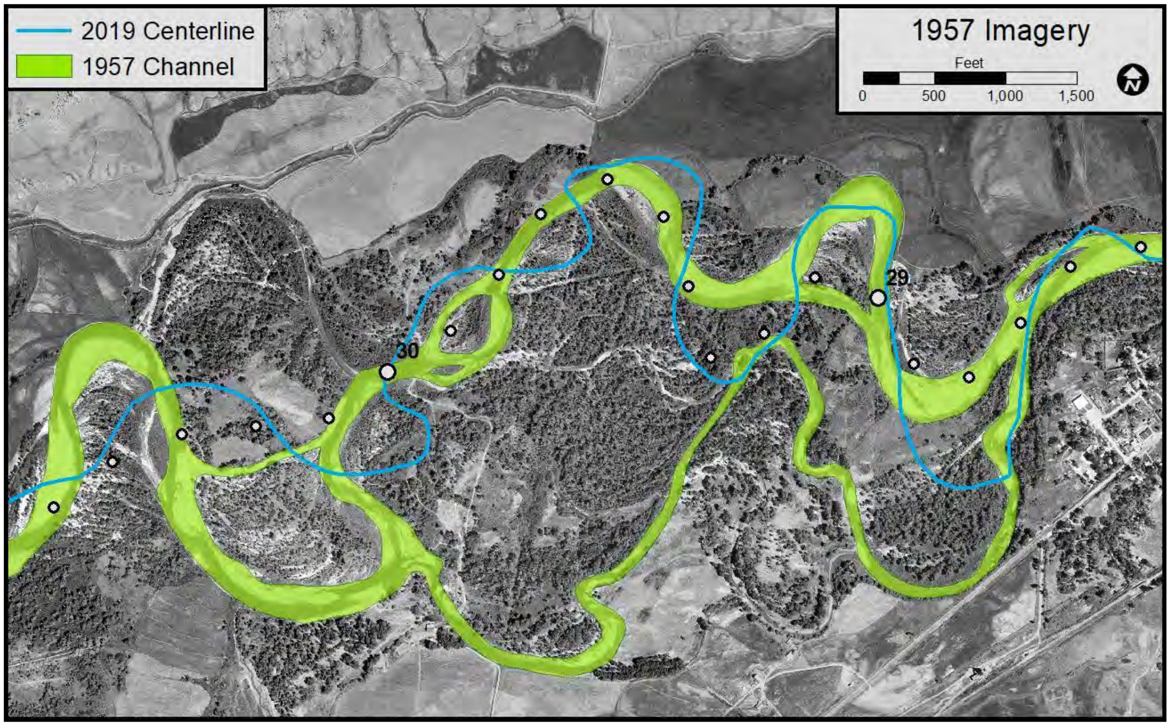


Figure 30. Example 1957 imagery upstream of Sun River.

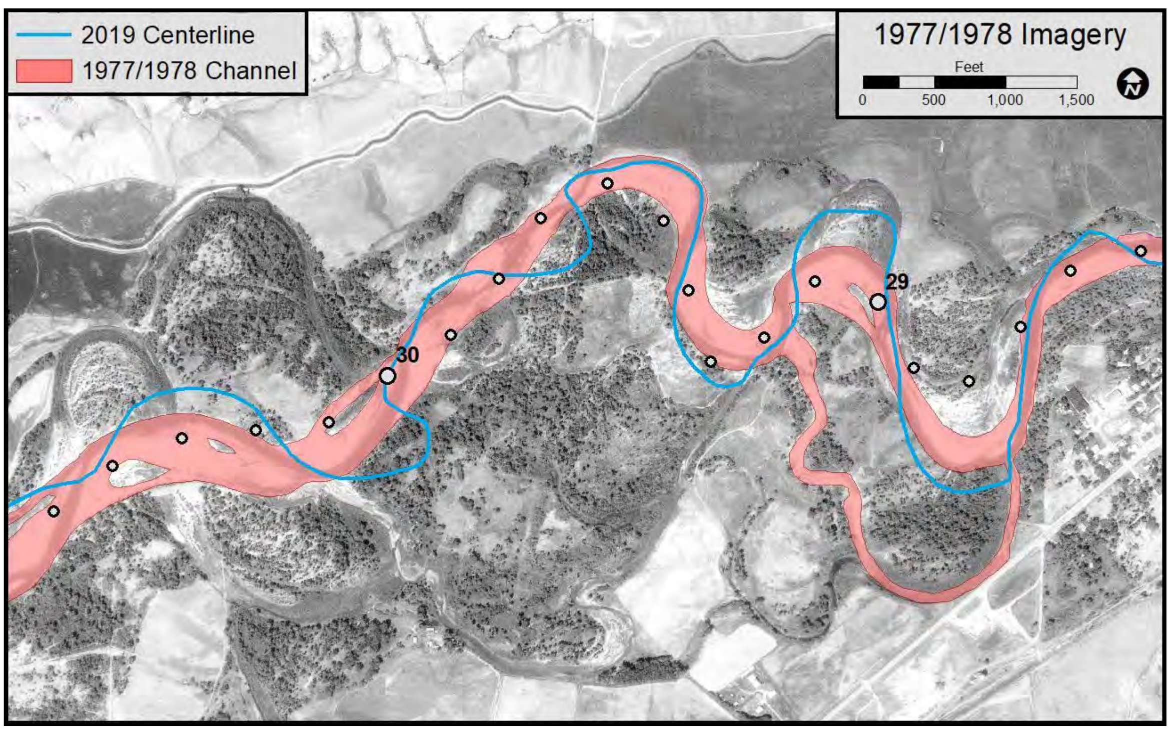


Figure 31. Example 1977/78 imagery upstream of Sun River.

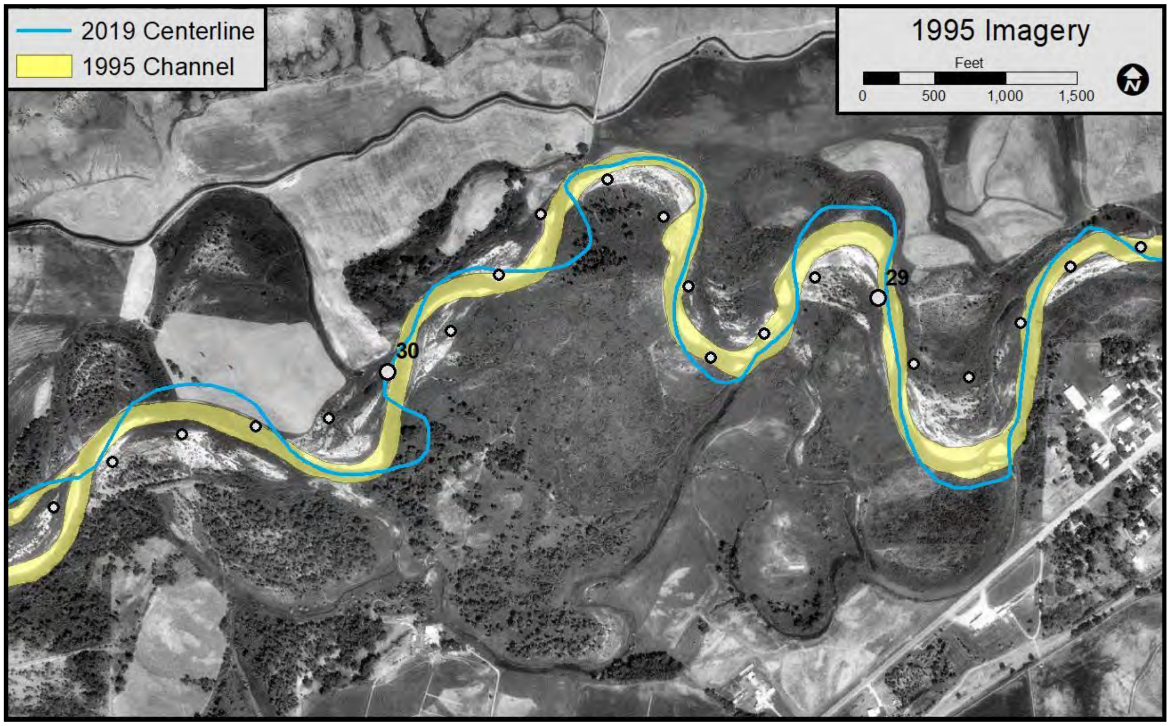


Figure 32. Example 1995 DOQ imagery upstream of Sun River.

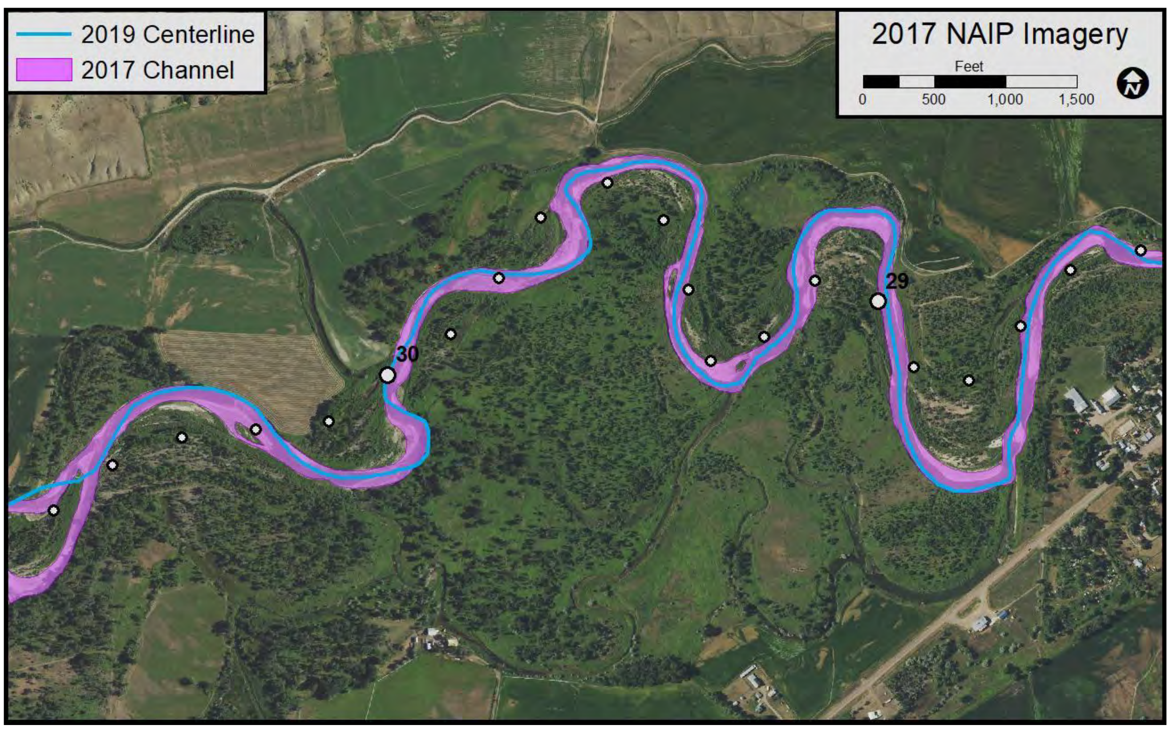


Figure 33. Example 2017 NAIP imagery upstream of Sun River.

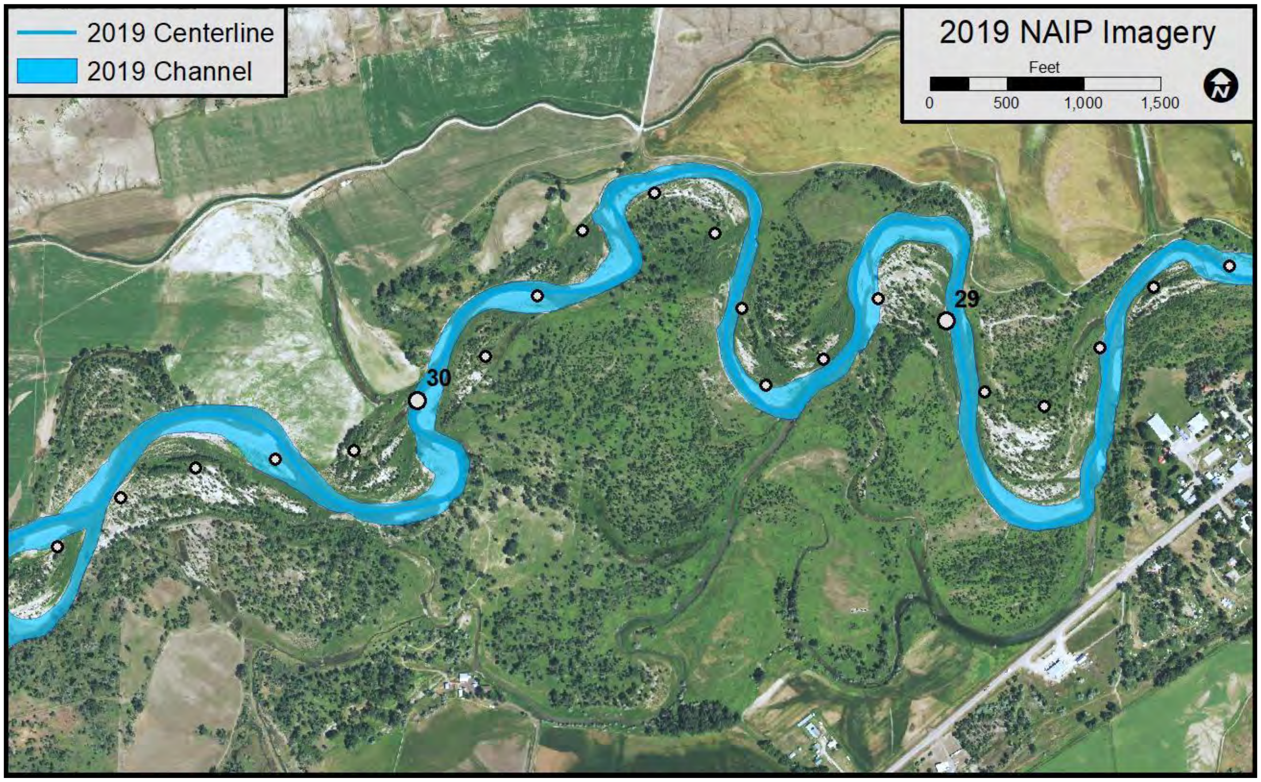


Figure 34. Example 2019 NAIP imagery upstream of Sun River.

Figure 35 shows how the dates of the imagery relate to the flood history of the Sun River. The 1957 imagery captures conditions shortly after the 1953 flood; in many locations, extensive braiding the 1957 imagery suggests that that event left a strong signature channel form. The 1978 photos capture the two largest recorded floods (1964 and 1975), and similarly shows broad open bars and a relatively large channel cross section. Numerous avulsions and extensive channel movement occurred during the 1957-1978 window. In contrast, 1995 captures a period of quiescence as vegetation encroached onto open gravel bars. And lastly, the 2017/2019 images bracket the two most recent floods of 2018 and 2019.

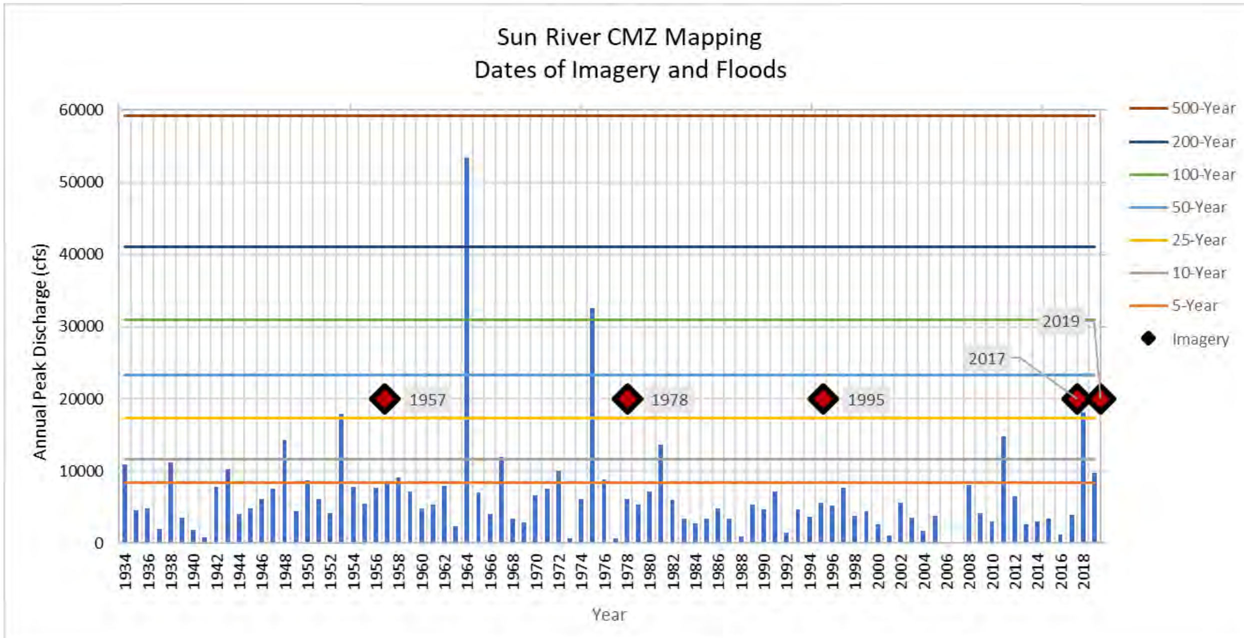


Figure 35. Dates of imagery (diamonds) showing their relationships to flood events.

3.2 LiDAR Elevation Data

During Phase 1 of this project (Sun River CMZ mapping), high-resolution LiDAR data was unavailable. More recently however, LiDAR data for the area was released for the Sun River, and we have used it in Phase 2 (evaluating site-specific issues). We were also able to acquire raw 2018 LiDAR (LZW) data for all but the lower 2 miles of the Elk Creek study area. This data was processed to extract the ground data points and create a bare earth digital elevation model. Using the LiDAR data, we generated Relative Elevation Models (REMs) for Elk Creek and the Rocky Reef Spring Creek/Adobe Creek areas.

3.3 GIS Project Development

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

3.4 Bankline Mapping

Banklines representing bankfull margins were digitized for each year of imagery at a scale of ~1:2,000. A tablet computer running ArcGIS and using a pen stylus was used to trace the banklines using stream mode digitizing. This methodology allowed us to capture a much more detailed bankline than using a mouse. Bankfull is defined as the stage above which flow starts to spread onto the floodplain. Although that boundary can be identified using field indicators or modeling results (Riley, 1972), digitizing banklines for CMZ development requires the interpretation of historic imagery. Therefore, we typically rely on the extent of the lower limit of perennial, woody vegetation to define channel banks (Mount & Louis, 2005). This is based on the generally accepted concept that bankfull channels are inhospitable to woody vegetation establishment. Fortunately, shrubs, trees, terraces, and bedrock generally show distinct signatures on both older black-and-white as well as newer color photography. These signatures, coupled with an understanding of riparian processes, allow for consistent bankline mapping through time and across different types of imagery. For Elk Creek, the banks of the primary channel and smaller side channels are often masked by vegetation. In these areas, we relied on photo interpretation skills and comparison of earlier/later data sets, as well as LiDAR elevation data to help refine masked bank lines.

3.5 Migration Rate Measurements

Once the banklines were digitized, they were evaluated in terms of discernable channel migration since 1957 for the Sun River and 1955 for Elk Creek. Where migration was clear, vectors (arrows with orientation and length) were drawn in the GIS to record that change. At each site of bankline migration, measurements were collected approximately every 30 feet (Figure 36). A total of 757 migration vectors were generated for the Sun River and 429 for Elk Creek at a scale of ~1:2,000. These measurements were then summarized by reach. The results were then used to define a reach-scale erosion buffer width to allow for likely future erosion. Results of this analysis are summarized in Sections 4.2 for the Sun River and Section 7.2 for Elk Creek.

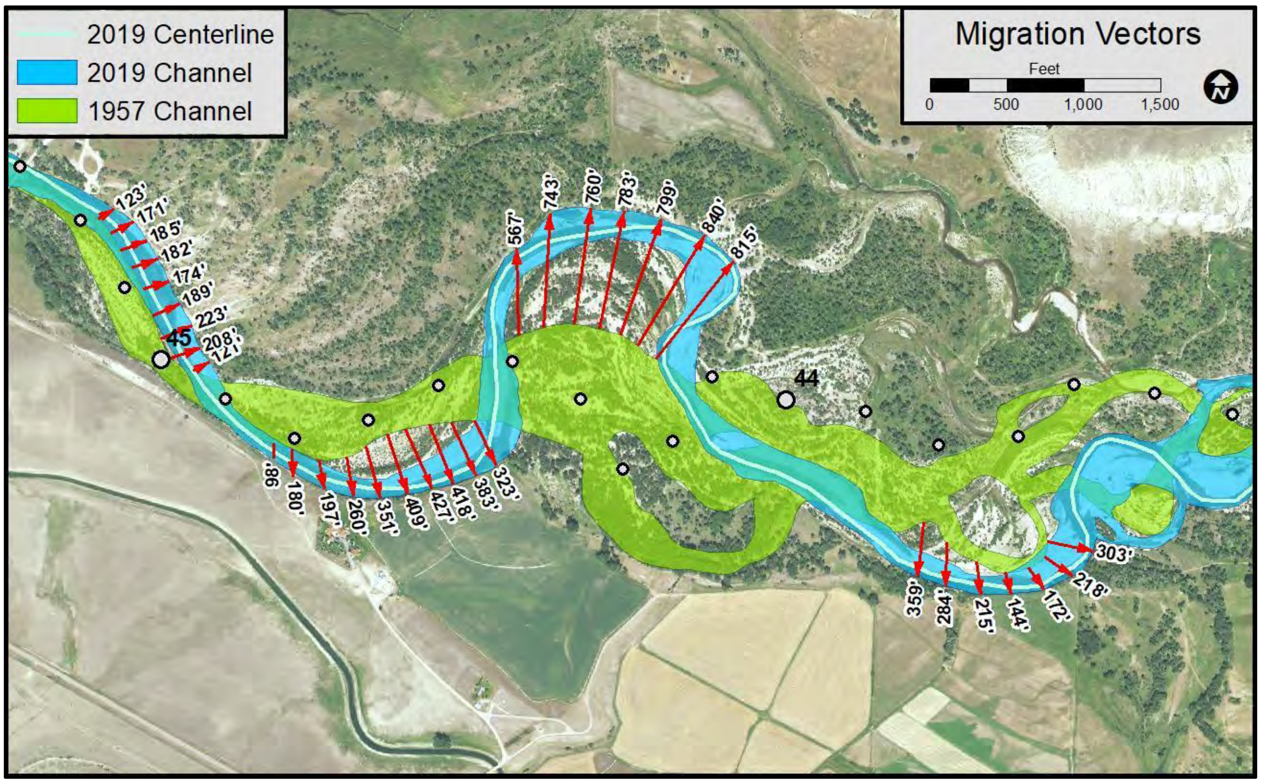


Figure 36. Example of migration measurements between 1957 and 2019 (migration distance in feet).

3.6 Avulsion Hazard Mapping

Avulsion pathways were mapped using criteria that indicate a relatively high risk of such an event. These criteria usually include the identification of high slope ratios between the floodplain and channel, tributary channels at risk of capture, and the presence of relic channels that concentrate flow during floods. Figure 37 shows several potential avulsion paths including a meander core, high flow channel, and remnant older channel (from left to right on image).

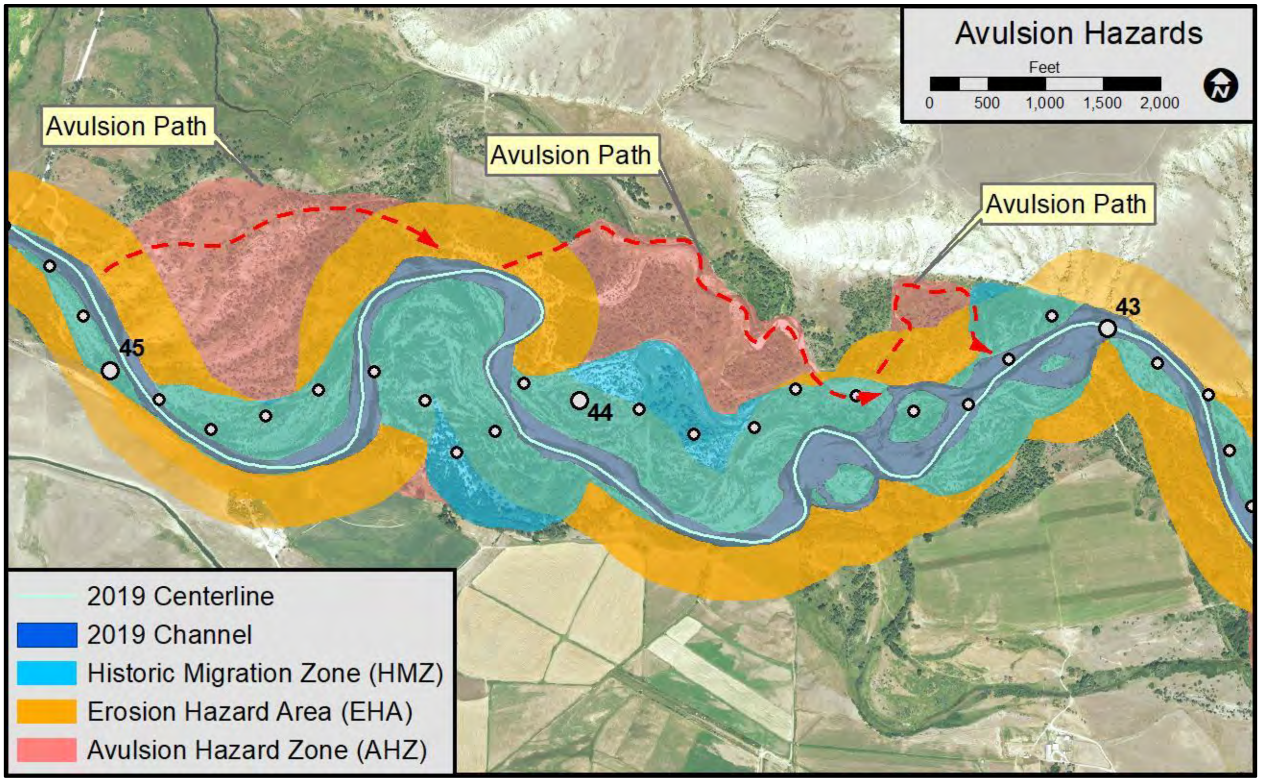


Figure 37. Example floodplain channel indicating an avulsion pathway.

4 Sun River Results (Phase 1)

The Channel Migration Zone (CMZ) developed for the Sun River is defined as a composite area made up of the existing channel, the historic channel since 1965 (Historic Migration Zone, or HMZ), and an Erosion Hazard Area (EHA) that encompasses areas prone to channel erosion over the next 100 years. Areas beyond the EHA that pose risks of channel avulsion comprise the Avulsion Hazard Zone (AHZ). Lastly, those areas where migration has been restricted are highlighted as Restricted Migration Area (RMA).

4.1 Project Reaches

The approach to CMZ mapping used here includes a reach-scale evaluation of channel migration rates. For the 51 miles of project length, the river was broken into six reaches based on geomorphic character such as river pattern, rates of change, and geologic controls (Figure 39). The reaches range in length from 4.2 to 13.2 miles (Table 2). Average channel slope for each reach flattens in the downstream direction, with a clear drop in slope below Reach SR4 which ends at Lowry Bridge (Figure 38).

Table 2. Sun River CMZ mapping project reaches.

Reach	General Location	Upstream RM	Downstream RM	Length (mi)
SR1	Sun River to Vaughn	28.2	17.2	11
SR2	Rocky Reef Diversion to Sun River	36.8	28.2	8.6
SR3	Lowry Bridge to Rocky Reef Diversion	45.3	36.8	8.5
SR4	Just above Fort Shaw Canal to Lowry Bridge	49.5	45.3	4.2
SR5	Dry Creek to just above Fort Shaw Canal	54.9	49.5	5.4
SR6	Highway 287 to Dry Creek	68.1	54.9	13.2

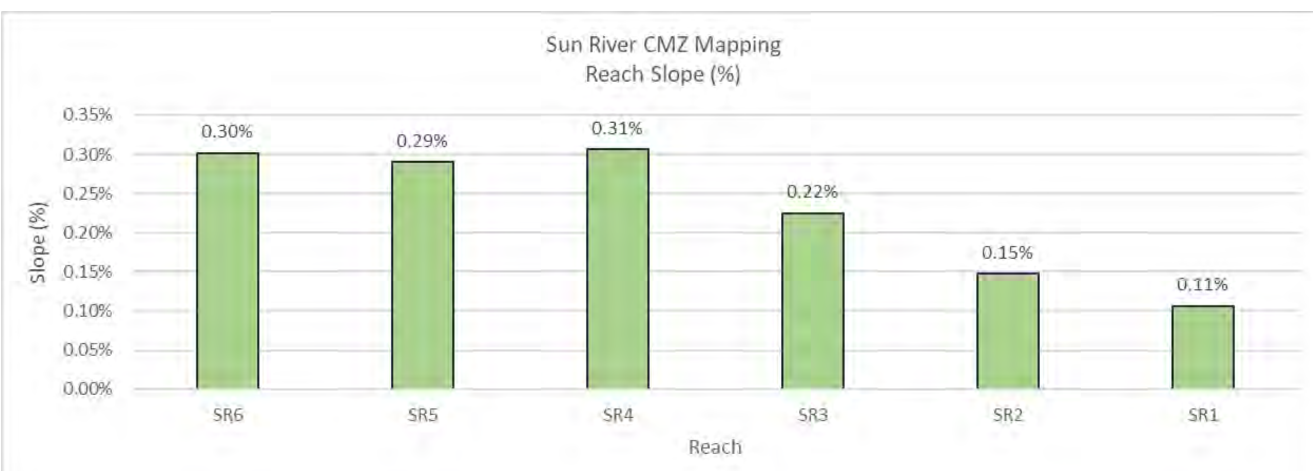


Figure 38. Average channel slope for project reaches plotted from upstream (SR6) to downstream (SR1) showing progressive loss of gradient below Reach SR4 (Lowry Bridge)

Figure 39. Sun River CMZ mapping project reaches.

4.2 The Historic Migration Zone (HMZ)

The Historic Migration Zone (HMZ) is created by combining the bankfull channel polygons into a single HMZ polygon. The bankfull channels commonly split and rejoin, creating a mosaic of channel courses with intervening islands, some of which are seasonal. The HMZ footprint includes all channels as well as any area between split flow channels. By including islands, the HMZ captures the entire footprint of the active river corridor from 1957-2019. In some settings where island areas are non-erodible, it may be appropriate to exclude these features from the CMZ. In the case of the Sun River, however, these areas have been retained in the CMZ since they are made up of young alluvial deposits that are prone to reworking or avulsion and are thus part of the active meander corridor.

Any side channels that have not shown perennial connectivity to the main channel since 1957 were not mapped as active channels and are not included in the HMZ.

For this study, the Historic Migration Zone is comprised of the total area occupied by Sun River channel locations in 1957, 1977/78, 1995, 2017 and 2019 (Figure 40). The resulting area reflects 62 years of channel occupation for the length of the Sun River study area.

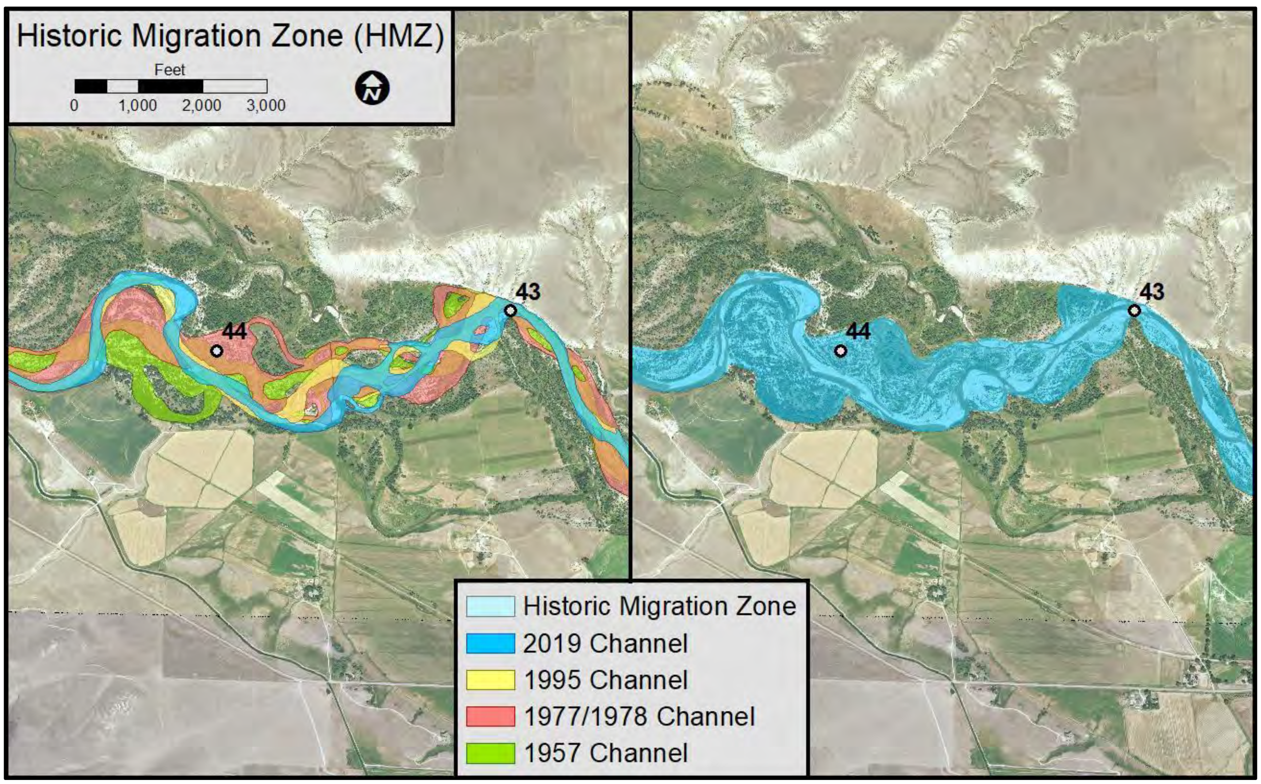


Figure 40. The Historic Migration Zone (HMZ) is the combined footprint of all mapped channel banklines.

4.3 The Erosion Hazard Area (EHA)

The Erosion Hazard Area (EHA) is based on measured migration rates, which are derived from measured migration distances. Migration distances were measured where it was clear that the channel movement was progressive lateral movement and not an avulsion. A total of 757 measurements were collected on the Sun River. The minimum distance measured is 20 feet, which proved to be an easily measurable distance that is not compromised by the resolution or spatial accuracy of the data. The 1957-2019 measured migration distances are summarized in Figure 41, and migration rates are shown in Figure 42. Migration into terraces was summarized separately, to allow the application of an erosion hazard buffer specifically to that geologic unit. Mean migration rates and EHA buffer widths are shown in Table 3 and Figure 43. The buffer width is calculated as that distance the river would move over a century's time at the mean annual rate.

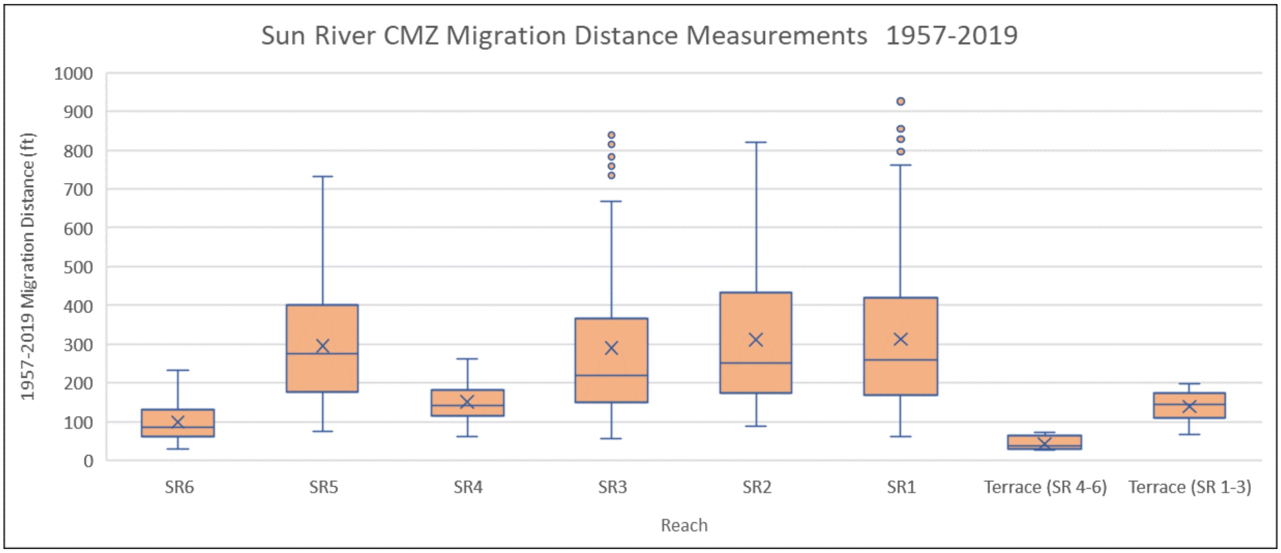


Figure 41. Box and whisker plot showing measured 1957-2019 migration distances by reach and for terraces -- reaches are plotted from upstream (left) to downstream (right). Mean values are denoted by "X".

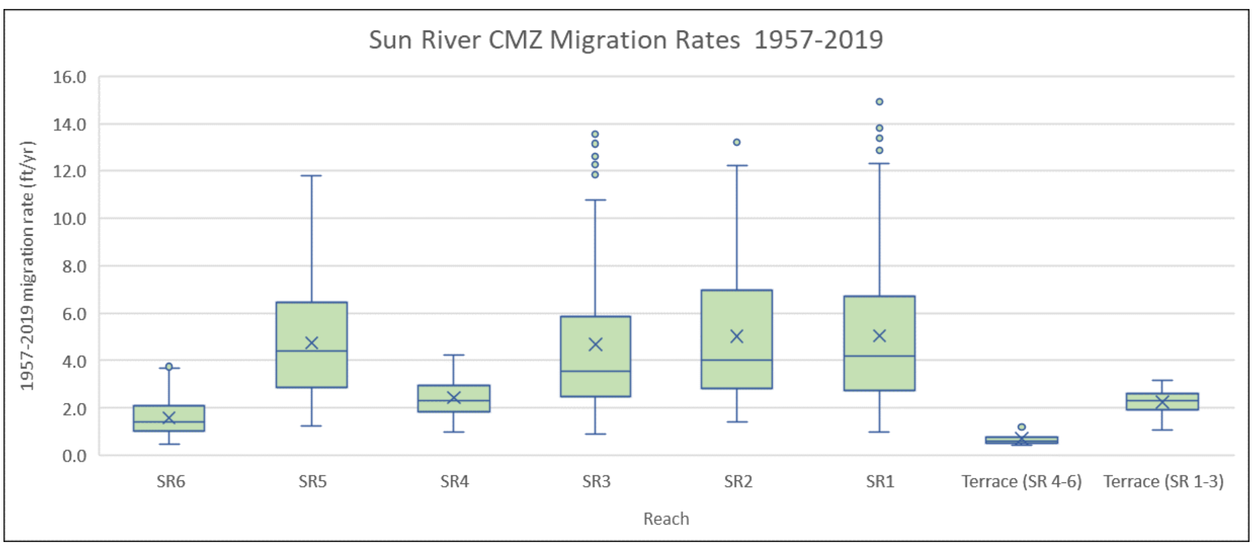


Figure 42. Box and whisker plot showing measured 1957-2019 migration rates by reach and for terraces -- reaches are plotted from upstream (left) to downstream (right). Mean values are denoted by "X".

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

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

Reach	Number of Measurements	Maximum Migration Distance (ft)	Average Annual Migration Rate (ft/yr)	100- Year Buffer Width (ft)
SR1	144	928	5.0	503.7
SR2	118	831	5.0	502.8
SR3	110	840	4.7	468.2
SR4	35	263	2.4	244.4
SR5	125	732	4.8	475.4
SR6	212	232	1.6	159.1
T (SR1-3)	11	188	2.2	224.8
T (SR4-6)	2	35	0.7	69.7

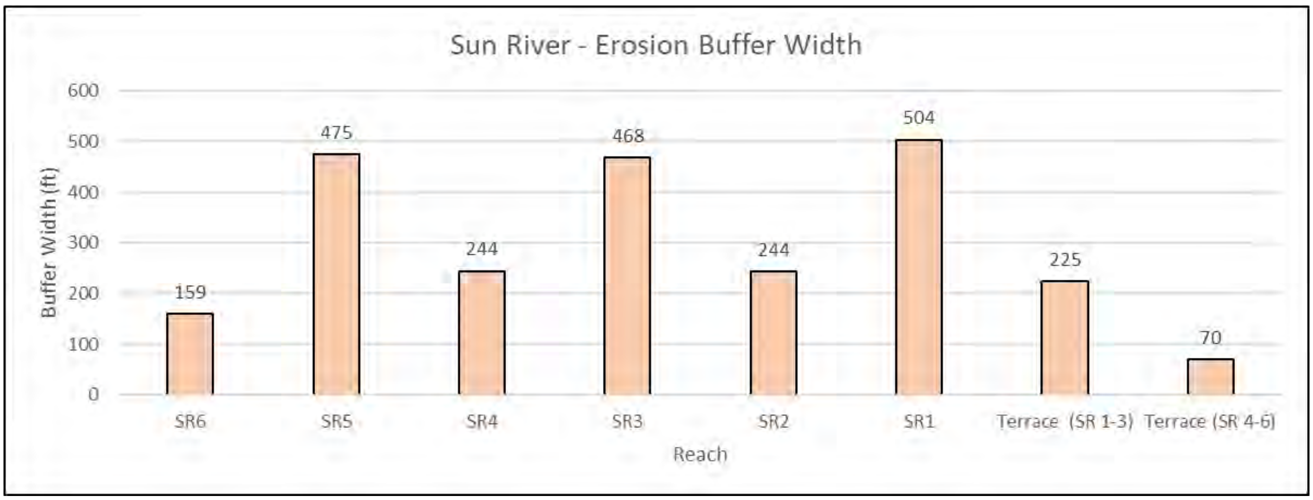


Figure 43. Mean migration rate-based EHA buffer width, Sun River-- reaches are plotted from upstream (left) to downstream (right).

The location and intensity of rapid streambank erosion shifts with time. Over a century, areas that currently show no erosion may become more active. Predicting these shifts is difficult due to the number of drivers that can cause these shifts (ice, woody debris, floods, cutoffs, etc.). As such, the erosion buffer is assigned to all banks, even those not currently eroding, to allow future bank movement at any given location. This is consistent with the Reach Scale approach outlined by the Washington State Department of Ecology (WSDE, 2010). The general approach to determining the Erosion Buffer (using the annual migration rate to define a 100-year migration distance) is similar to that used in Park County (Dalby, 2006), on the Tolt River and Raging River in King County, Washington (FEMA, 1999), and as part of the Forestry Practices of Washington State (Washington DNR, 2004).

An example of EHA mapping is shown in Figure 44. If the EHA extends into the Historic Migration Zone, it is masked by the HMZ so that areas of historic channel locations are prioritized in the mapping hierarchy. As a result, the EHA is typically discontinuous along the river.

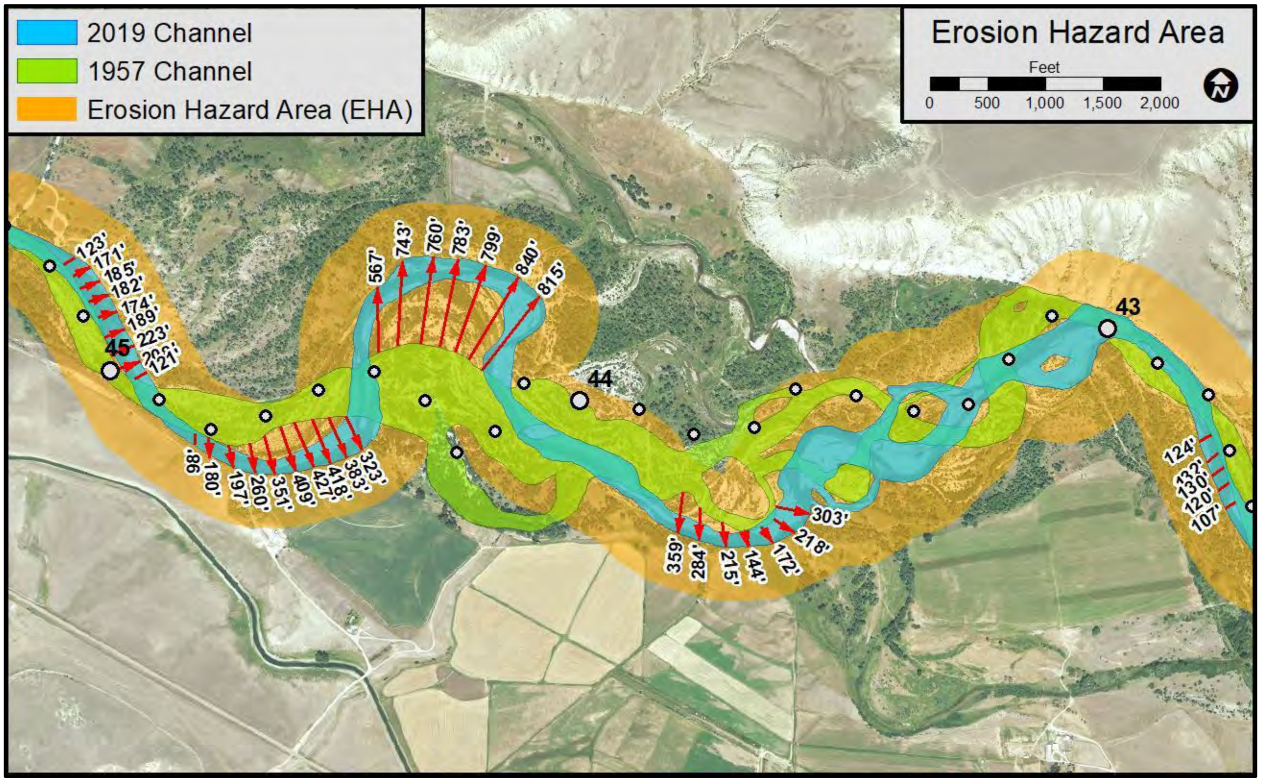


Figure 44. The Erosion Hazard Area (EHA) is a buffer placed on the 2019 banklines based on 100 years of channel migration for the reach.

4.4 The Avulsion Hazard Area (AHZ)

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

A total of 10 avulsions were mapped on the Sun River. The majority (6) of them occurred between 1957 and 1978, and two are in process. One active avulsion is shown in Figure 46; the river has migrated eastward and captured an old swale at RM 38.9 about a mile above Big Coulee. The other is the capture of Adobe Creek, which is described in Section 5.5.1. The major types of avulsion processes on the Sun River are meander cutoffs and capture of old channels, tributaries, or floodplain swales.

The majority of avulsions mapped on the river happened between 1957 and 1978, which would be expected due to the major floods that occurred during that time. Reach SR2 (Rocky Reef to Sun River) experienced the bulk of those avulsions.

This report refers to the flow split at the head of an avulsion as an "avulsion node".

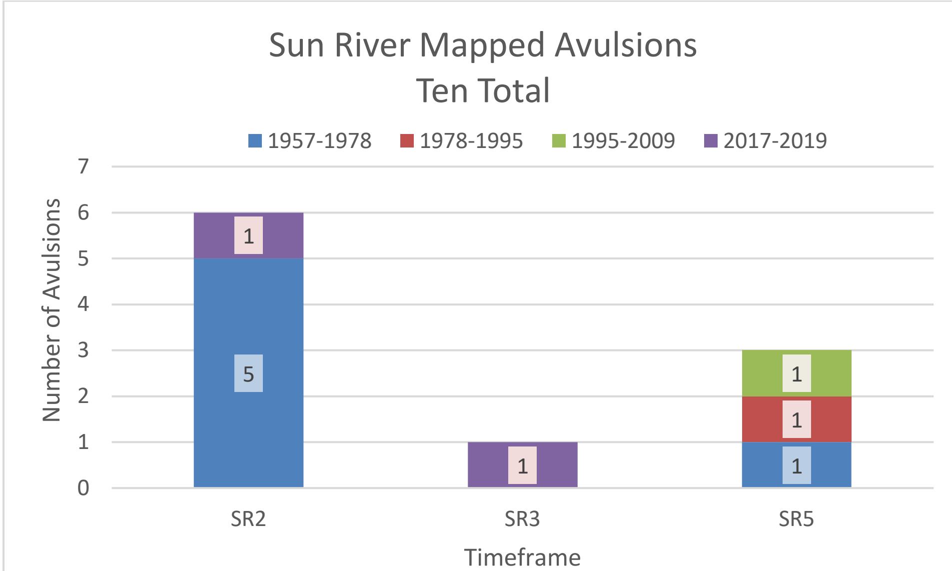


Figure 45. Number of mapped avulsions by reach, Sun River.

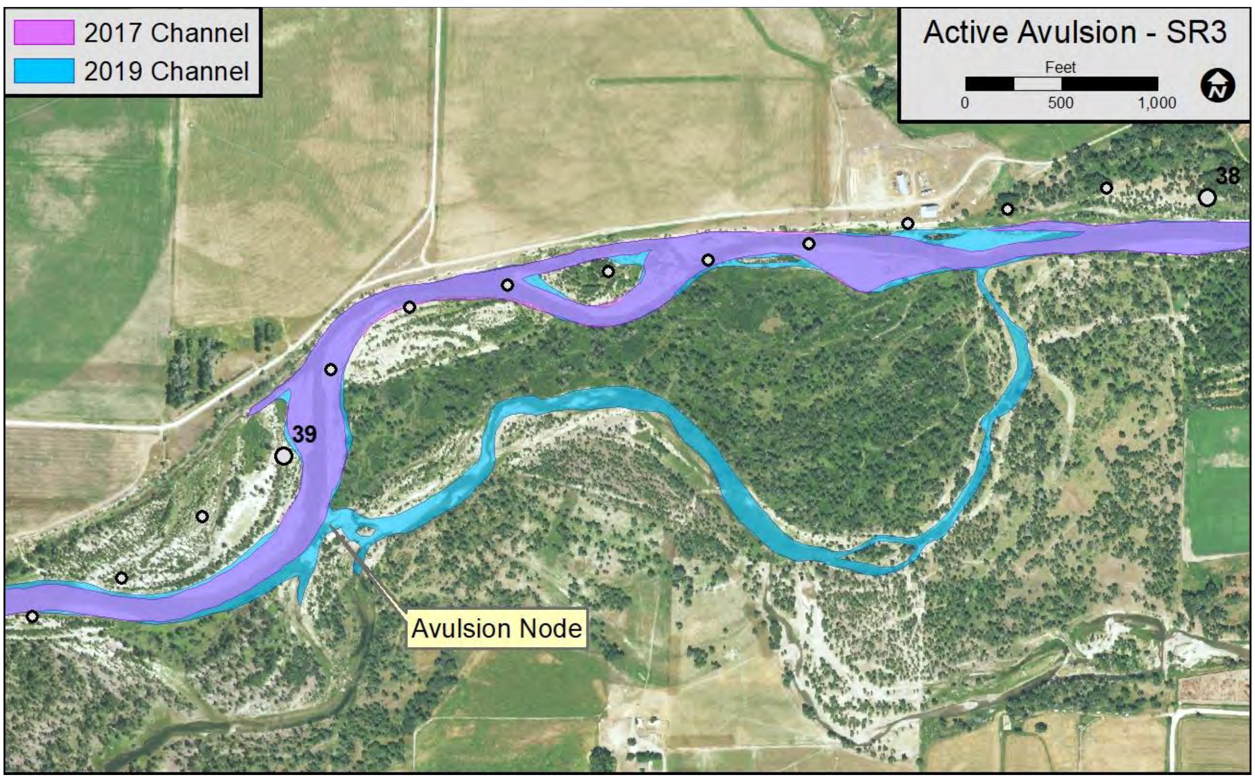


Figure 46. Active avulsion at RM 39, Reach SR3.

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

4.5 The Restricted Migration Area (RMA)

The Restricted Migration Area largely reflects bank protection associated with major diversions and bridges. Downstream in reach SR1 residential and suburban development begins to play a substantial role in bank armoring extents. Two dikes/levees have also restricted areas that would be otherwise exposed to channel movement.

A total of 4.7 miles of bank armor were mapped on the 51 miles of project length. Figure 47 shows that the extent of armored banks ranges from 2% to 12% of the main channel length. The densest armor is in Reach SR2, where about 10,690 feet or almost 12% of the total bankline is armored to protect agricultural fields, diversions, and other developed areas. In terms of areas restricted by levees, one major 2.5-mile long levee exists at Vaughn (See Section 2.4) with a smaller levee (~2600 feet) associated with a gravel pit on the south side of the river at RM 23.5.

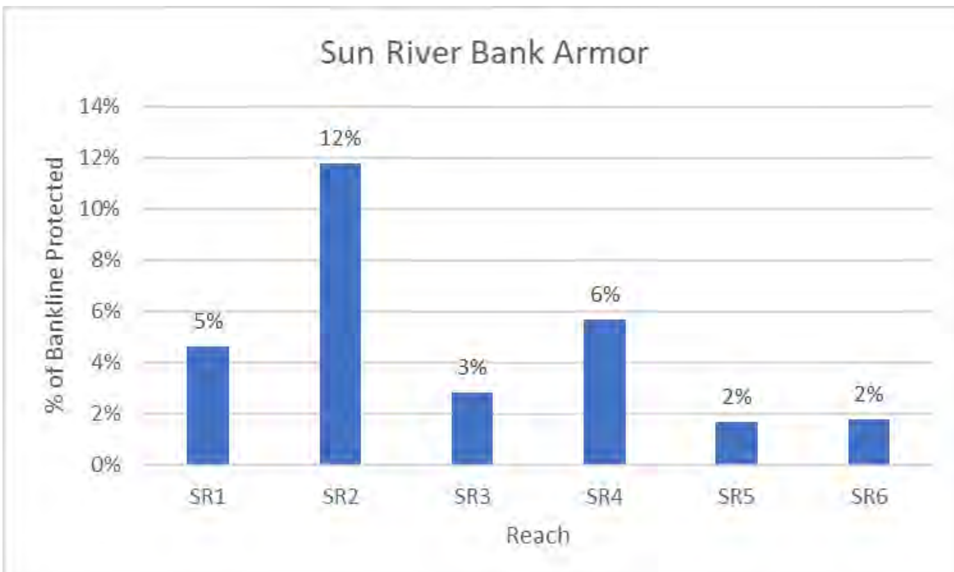


Figure 47. Percentage of bankline protected by armor by reach.

Figure 48 shows an example of Restricted Migration Areas at the city of Sun River.

Bank armoring currently restricts access to approximately 494 acres of the Channel Migration Zone. The majority of this armor is protecting irrigated agricultural land and key irrigation infrastructure at the major diversions, with the exception of approximately 159 acres of land behind levees in SR1. The amount of restricted area generally increases downstream as the river becomes less confined and development pressures promote bankline stabilization. This is especially true in reach SR1 where residential and suburban development begins to take on a major role in bank armoring and levees in the communities of Sun River and Vaughn.

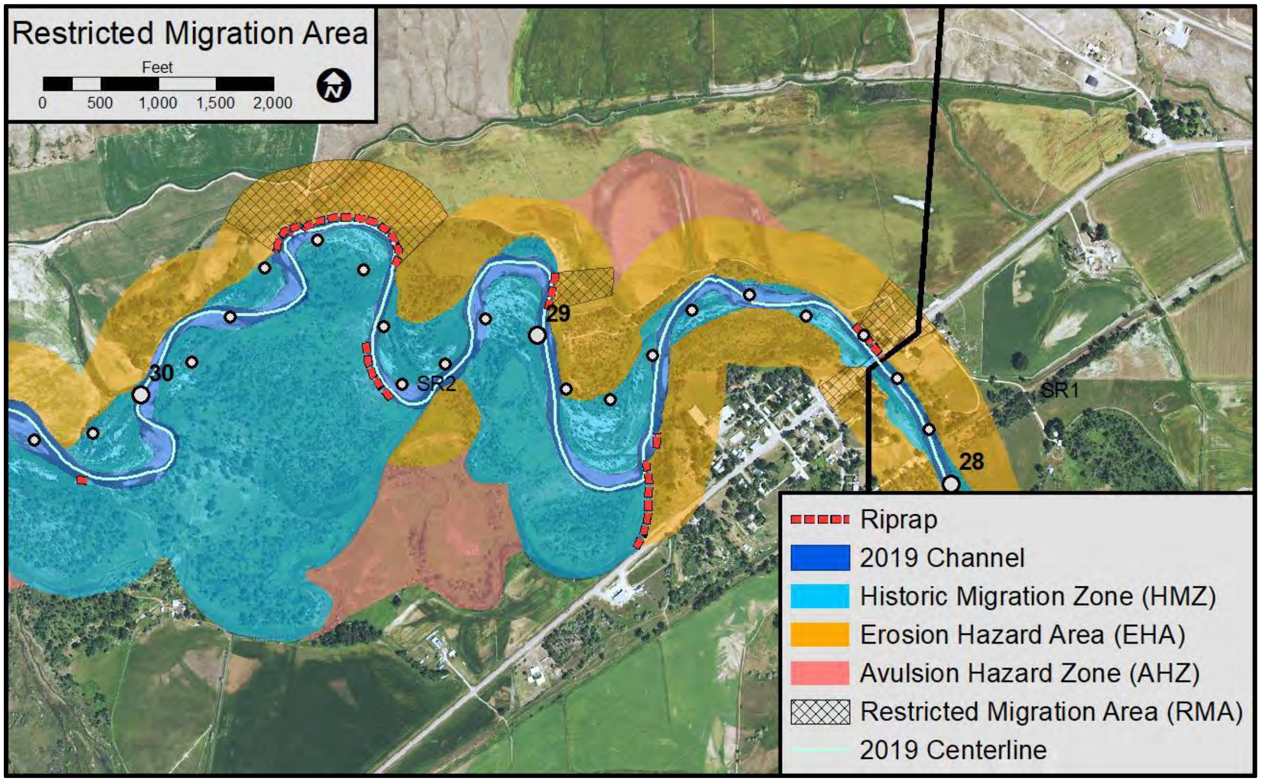


Figure 48. Restricted Migration Areas at Sun River.

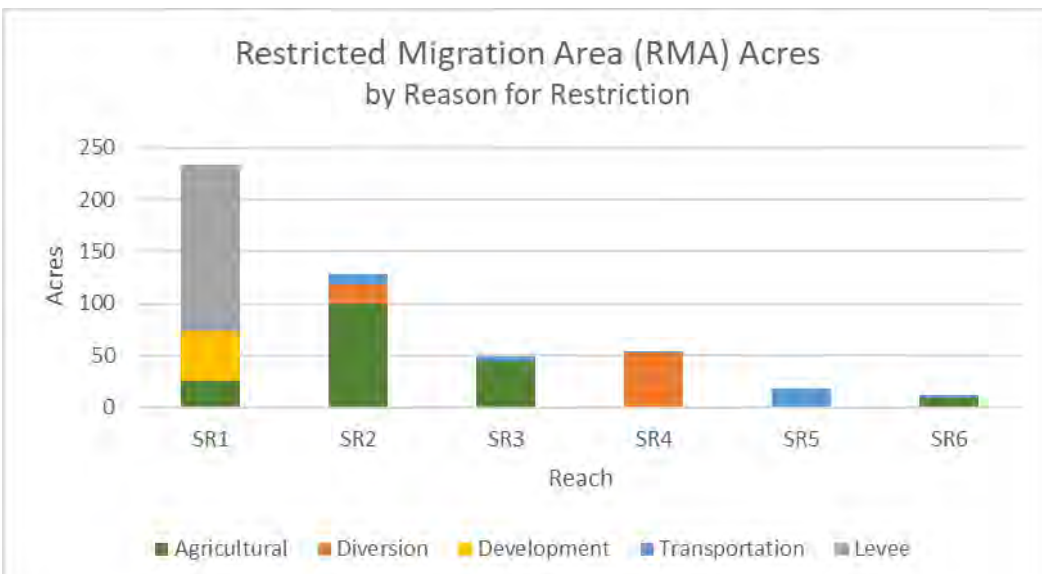


Figure 49. Acres of the CMZ mapped as restricted by reach.

4.6 Composite Map

An example portion of a composite CMZ map for a section of the Sun River project area is shown Figure 50. Each individual mapping unit developed for the CMZ has its own symbology, so that any area within the overall boundary can be identified in terms of its basis for inclusion. Over the 51 mile project reach, a total of 9,819 acres of land form the CMZ, or about 193 acres per mile. The mean width of the CMZ is about 1,600 feet, ranging from 730 feet in Reach SR6 upstream to 2,300 feet in Reach SR2 (Rocky Reef to Sun River).

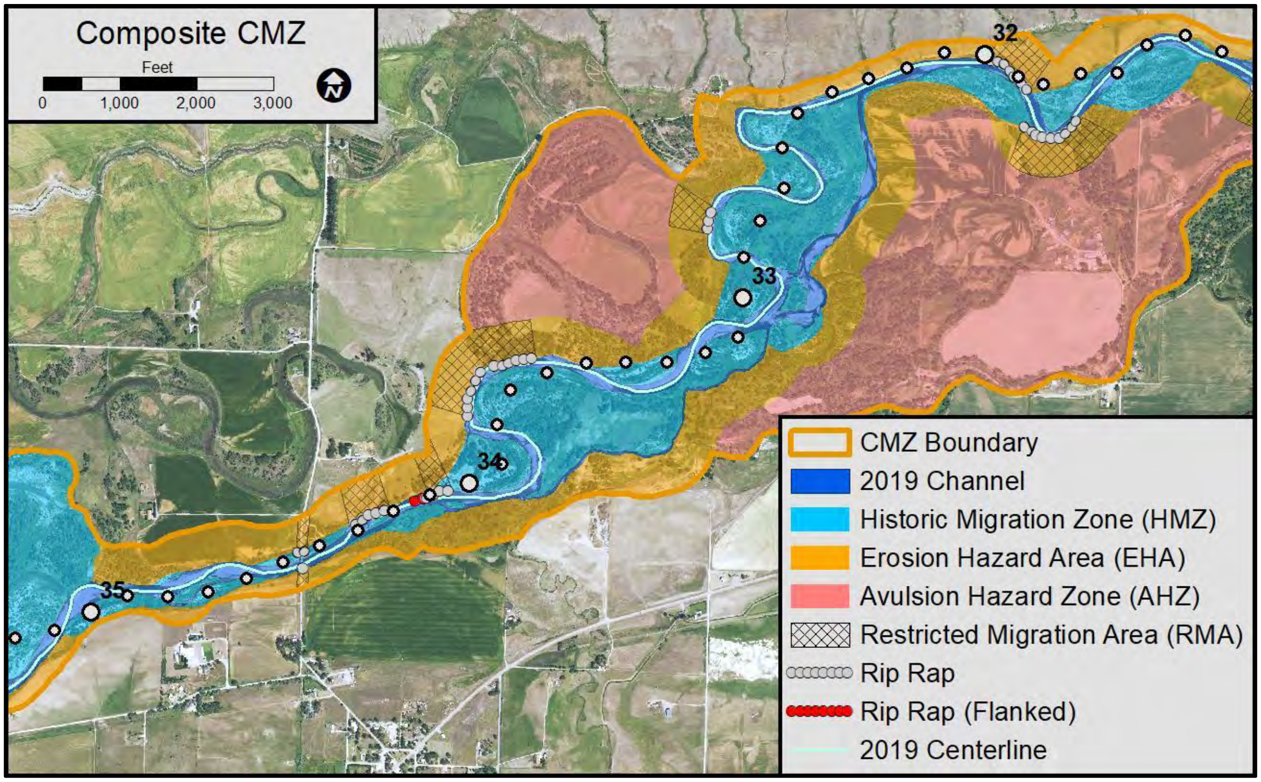


Figure 50. Composite Channel Migration Zone map.

4.7 Geologic Controls on Migration Rate

Between the Highway 287 Bridge and Vaughn, the margins of the active Sun River floodplain consist of both erodible and non-erodible terraces. The non-erodible terraces are generally comprised of Cretaceous-age sandstone overlain by a younger alluvial cap. The erodible terraces are more consistently non-bedrock, comprised of younger sediments that were shown to erode, but typically at a lower rate than the floodplain alluvium. As a result, the erosion buffer assigned to these units was narrower than those of active floodplain alluvium.

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

5 Sun River Reach Descriptions

The following sections describe mapping results for each reach of the Sun River. They are described below from upstream to downstream, starting with Reach SR6 just above the Highway 287 Bridge, and ending with Reach SR1 at Vaughn. The maps can be found in Appendix A. All references to River Miles (RMs) reflect the Fish Wildlife and Parks data layer that begins in Great Falls (RM0) and extends upstream to the confluence of the North and South Forks at the head of Gibson Reservoir (RM 102.3). River Miles are labeled on the maps in Appendix D. Wherever streambanks or floodplain areas are described as “right” or “left”, that refers to the side of the river as viewed in the downstream direction. For example, “RM 16.4R” refers to the right streambank located 16.4 miles upstream of the river’s mouth.

5.1 Reach SR6—Highway 287 to Dry Creek

Reach SR6 is 13.2 miles long, extending from just upstream of the Highway 287 bridge north of Augusta to the mouth of Dry Creek (Figure 51). Within this reach the river is moderately confined by bedrock and glacial outwash bluffs that limit channel movement. Bedrock outcrops are also common in the bed of the river.

Reach SR6		
Upstream/Downstream RM	68.1	54.9
Length (miles)		13.2
General Location	Highway 287 to Dry Creek	
Mean Migration Rate (ft/yr)		1.6
Max 62-year Migration Distance (ft)		232
100-year Buffer (ft)		159
100-year Terrace Buffer		70

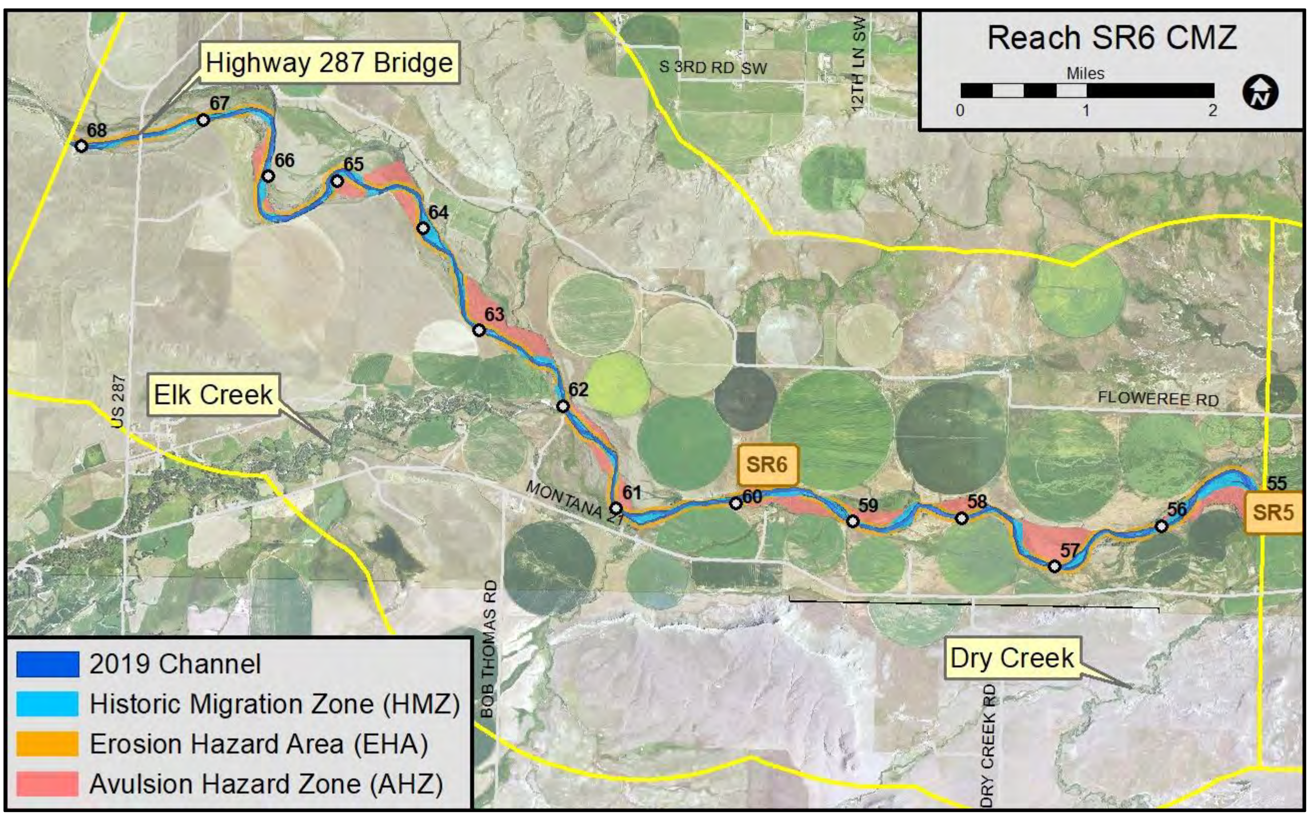


Figure 51. CMZ map for Reach SR6.

The river corridor tends to be relatively narrow in Reach SR6, and migration rates are low. Avulsion hazards are present through meander cores and where channel remnants parallel the river. Most of the bluff line in the upper portion of Reach SR6 has been clipped out of the CMZ as it appears to be highly erosion resistant, consisting of Cretaceous-age rocks overlain by outwash gravels (Figure 52). Further downstream there is no evidence of a hard rock toe on the terrace edge, and in these areas the terraces have been given a 70' wide erosion buffer width based on measured migration rates into the outwash.

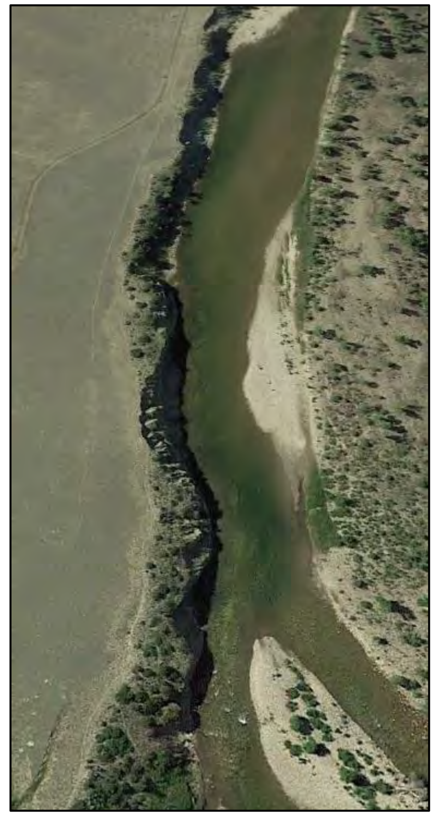


Figure 52. Sandstone bluffline clipped out of CMZ in Reach SR6 (Google Earth)

The Floweree Canal closely parallels the river in the upper few miles of Reach SR6, and sometime between 2011 and 2014 there was a substantial hillslope failure along the canal that caused it to breach at RM 66.6, forming a distinct alluvial fan on the Sun River floodplain (Figure 53). Canal seepage supports numerous wetlands on the floodplain as well. In some areas such as just below the mouth of Spring Creek, the stream corridor is tightly confined between pivot fields, and in several locations the streambanks have been armored to protect those pivots (Figure 54).

The geologic confinement in Reach SR6 has resulted in a narrow CMZ with an erosion buffer width of 159 feet.

Figure 53. View downstream showing Floweree Canal breach forming alluvial fan on Sun River floodplain (Google Earth).

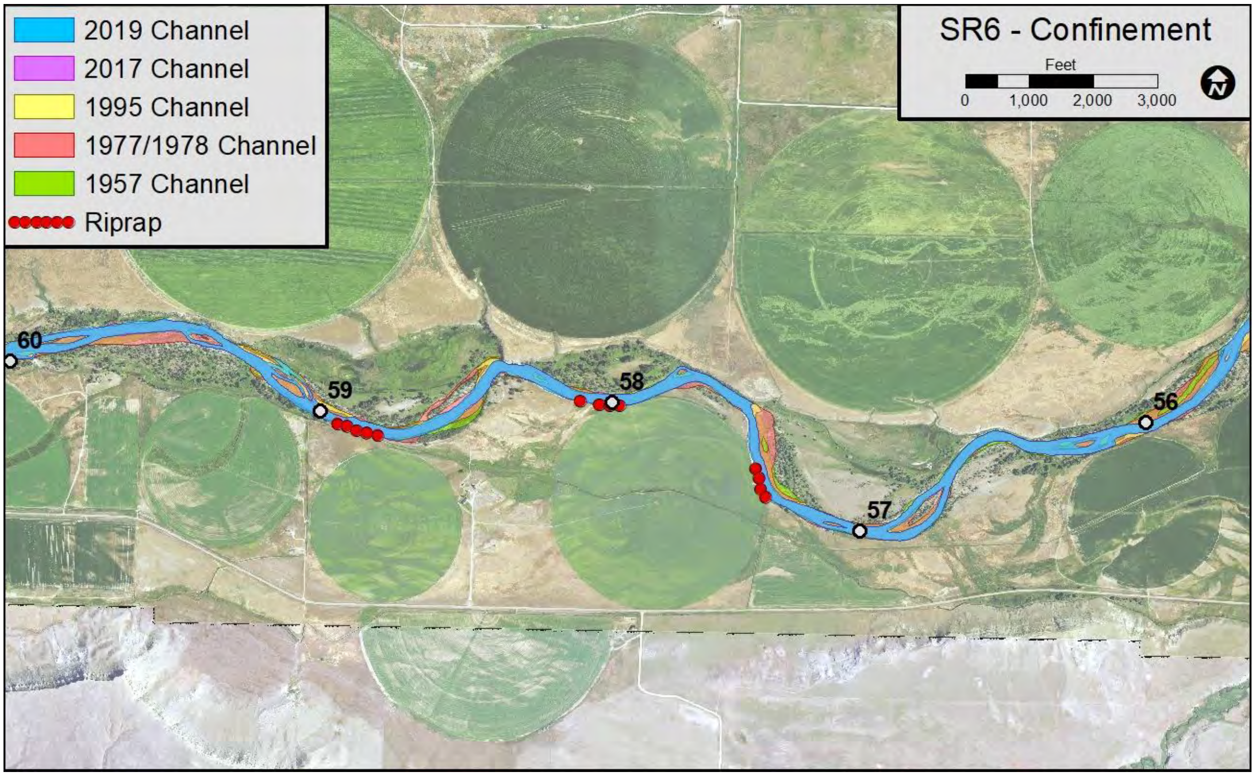


Figure 54. Bankline mapping showing armor and minimal channel movement between pivots in Reach SR6.

5.1.1 CMZ-Related Issues in Reach SR6

Issues identified with respect to infrastructure performance in this reach include the following:

1. A diversion structure at RM 60R, which is about a mile below the mouth of Spring Creek, appears to have some sedimentation issues at its entrance. A large bar has formed but it appears that the flow split into the ditch has been effectively managed by hardening the upper face of the bar to form a deflector (Figure 55). In 1978, a rock weir extended into the river to deflect flows towards the ditch, this is probably what drove the sedimentation just downstream. The bar has been established since at least 1995. A return flow channel at the headgate will be important to maintain so the ditch is not overrun in high water. The ditch itself poses an avulsion hazard as it flows parallel to the river across a low meander, it should be monitored for that risk.

Figure 55. Bar formation at diversion, RM 60.

5.2 Reach SR5--- Dry Creek to Fort Shaw Canal

Reach SR5		
Upstream/Downstream RM	54.9	49.5
Length (miles)	5.4	
General Location	Dry Creek to just above Fort Shaw Canal	
Mean Migration Rate (ft/yr)	4.8	
Max 62-year Migration Distance (ft)	732	
100-year Buffer (ft)	475	
100-year Terrace Buffer	70	

About a mile and a half upstream of the Freeman Road Bridge at the mouth of Dry Creek, the Sun River transitions to an actively meandering channel that forms broad bendways that have migrated on the order of 500 feet since the 1950s (Figure 56 and Figure 57). This marks the shift from the relatively confined condition of Reach SR6 to a much more dynamic reach in Reach SR5. Reach SR5 is just over five miles long, extending the mouth of Dry Creek to RM 49.5 just above the Fort Shaw Canal Diversion. Within this reach, channel migration rates increase rapidly relative to upstream, with the erosion buffer width expanding from 159 feet in Reach SR6 to 475 feet in Reach SR5. Three avulsions were mapped in this reach; one of them occurred around 1999 where the river captured a swale that was carrying the lower portion of School Section Coulee (Figure 58).

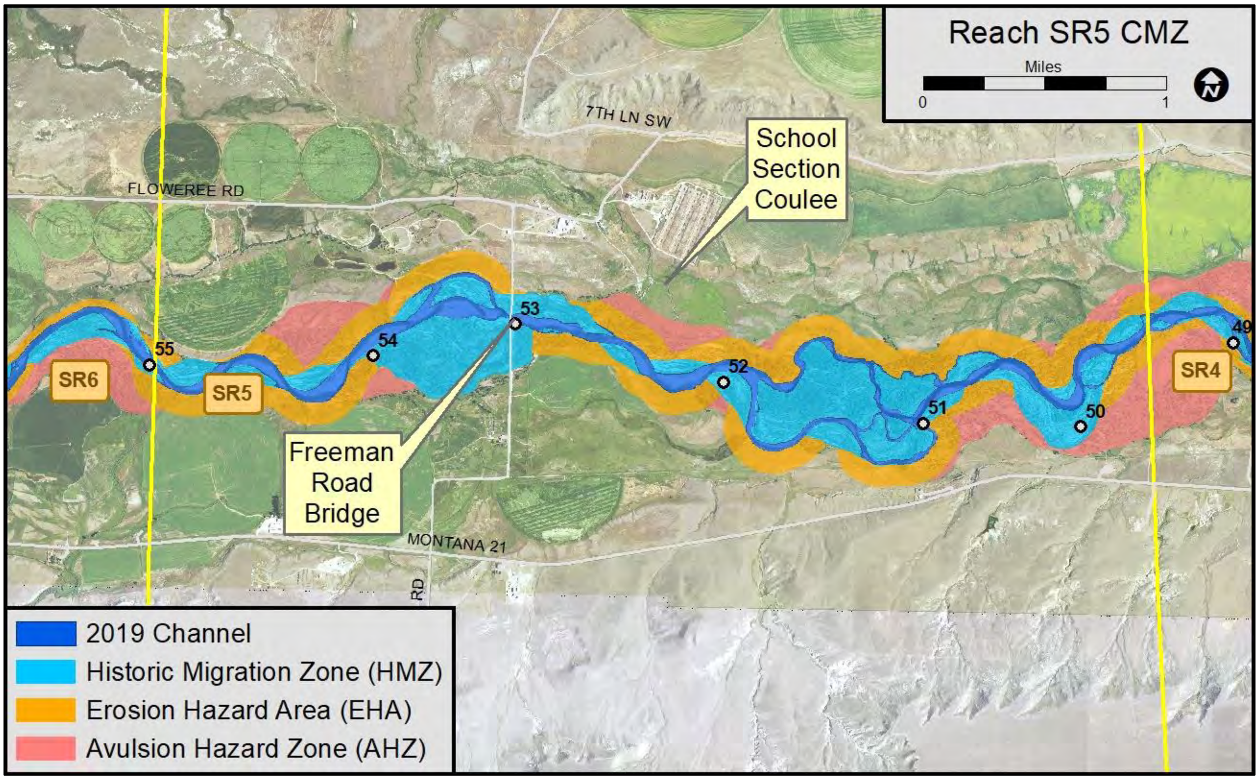


Figure 56. CMZ map for Reach SR5.

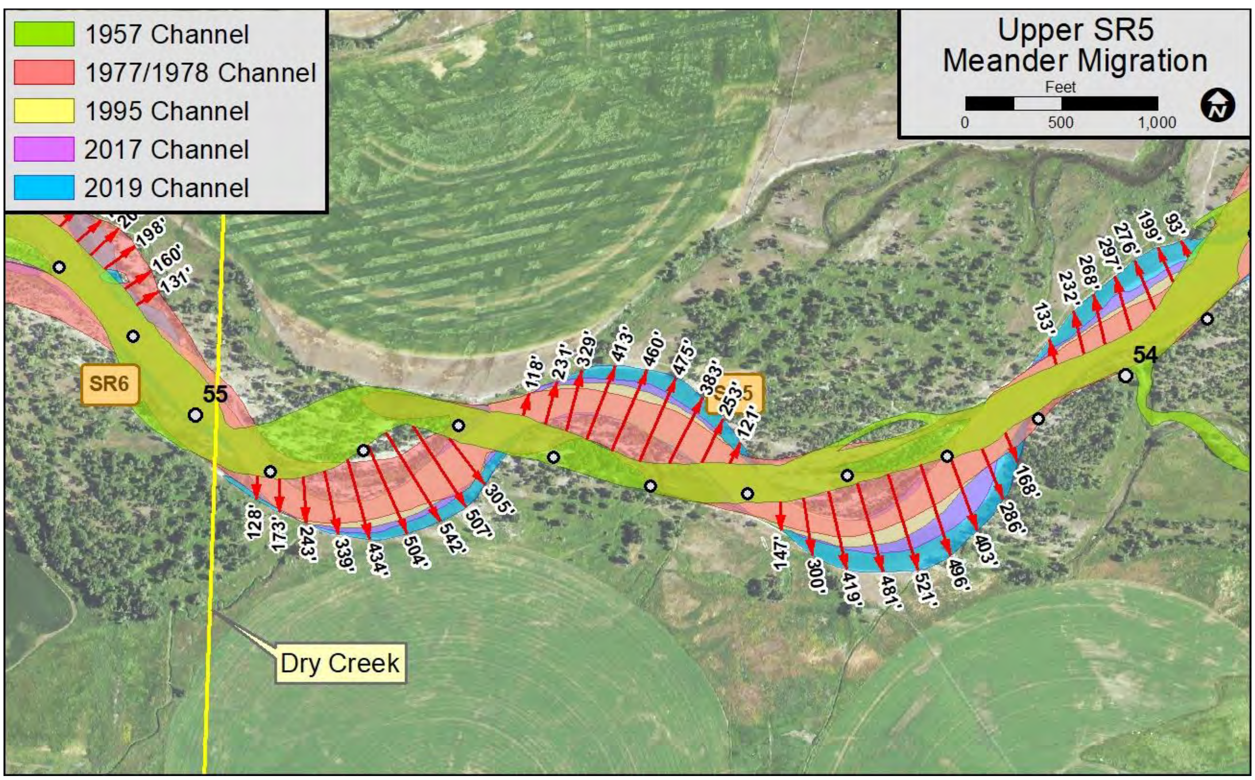


Figure 57. Meander migration in upper SR5 near the mouth of Dry Creek.

Figure 58. Sun River capture of swale that routed School Section Coulee in 1995.

5.2.1 CMZ-Related Issues in Reach SR5

1. Progressive southward bank movement immediately downstream of the mouth of Dry Creek at RM 54.8 is threatening a pivot field (Figure 57). The river was about 60 feet from the edge of the field in 2019. The banklines show that the most rapid erosion is on the downstream limb of the bend as it translates down valley to the east. This will reduce the erosive pressure on the field with time. As the river is pinned on the north side by a bluff, it will be important to provide some room for channel adjustment in this area to prevent a need for perpetual bank armor expansion. About 9 acres of the pivot field are within the mapped CMZ of the Sun River.

2. Freeman Road Bridge narrowly constricts the CMZ from over a mile wide upstream to about 250 feet at the bridge. These “hourglasses” within the CMZ can create challenges when trying to maintain a high angle approach to the bridge that is least destructive to both the bridge and road prism. It appears that the 2018 flood started to flank the right (south) bank armor at the bridge, necessitating the extension of the armor upstream (Figure 59). This project consists of a rock toe overlain by coir fabric and hundreds of willow stakes, and it performed well during recent floods (R. Sain, pers comm). Maintaining a good channel alignment is a common problem at bridges, and the best performance we have seen at such locations is a gentle tapering of the CMZ into the bridge opening. To that end, this site will require continued monitoring to ensure the upper extent of the project remains functional as the head of the taper.

3. About a half-mile downstream from Freeman Road Bridge (RM 52.4) the river has recently migrated southward into a pivot field. It appears the management response has been to reduce the pivot swing rather than to armor the river, which can be a cost-effective approach to CMZ management. That said, the pivot tower itself is at high risk of damage due to channel migration (Figure 60). Bankline maps can be used to help producers lay out pivot fields in a way that minimizes river erosion issues and associated costs.

Figure 59. Bank armor expansion above Freeman Bridge between 2017 (top) and 2019 (bottom) showing continued flanking risk south of armor.

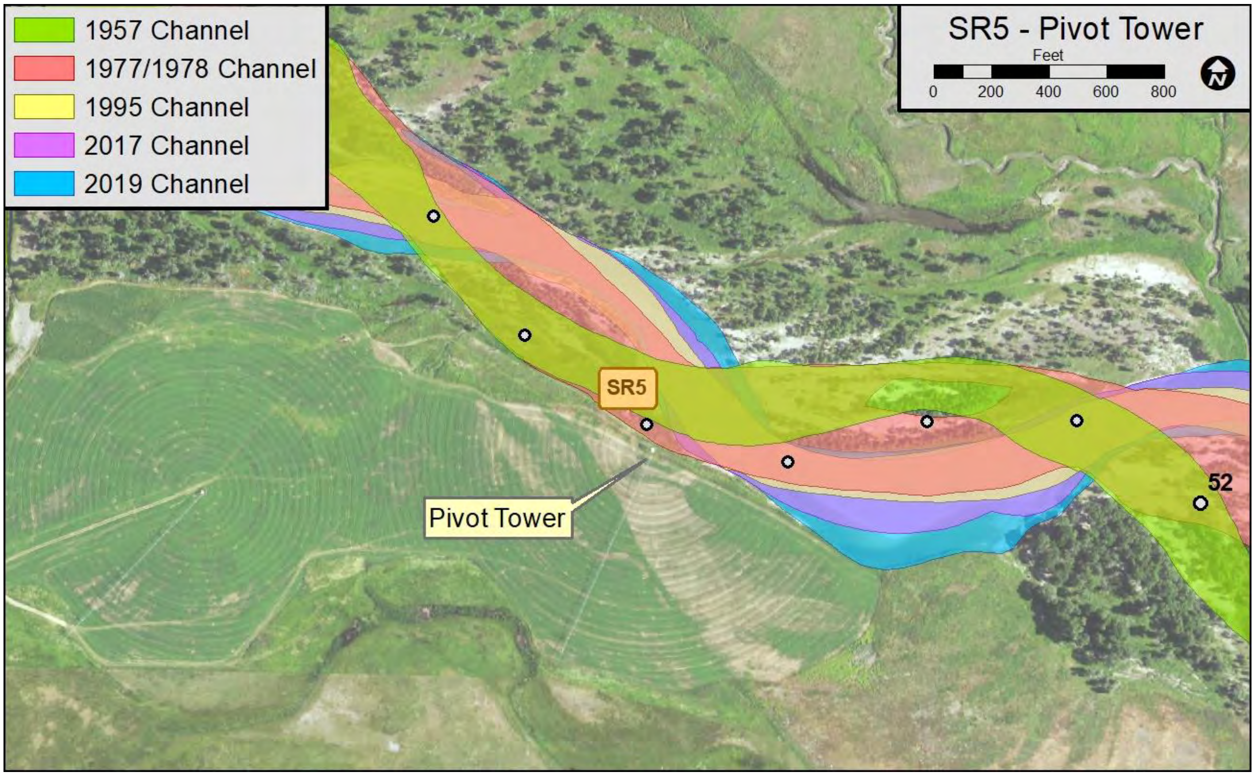


Figure 60. Pivot tower at RM 52.4R at high risk of damage due to channel migration.

5.3 Reach SR4—Fort Shaw Canal to Lowry Bridge

Reach SR4 extends from just above the Fort Shaw Canal diversion down to Lowry Bridge. The reach is 4.2 miles long. Migration rates drop in this reach relative to upstream, as the river has tended to maintain a relatively straight course with low rates of channel movement. Although the Historic Migration Zone is relatively narrow in this reach, a network of floodplain swales creates avulsion hazards on the floodplain that widen the CMZ boundaries (Figure 61).

Reach SR4		
Upstream/Downstream RM	49.5	45.3
Length (miles)	4.2	
General Location	Just above Fort Shaw Canal to Lowry Bridge	
Mean Migration Rate (ft/yr)	2.4	
Max 62-year Migration Distance (ft)	263	
100-year Buffer (ft)	244	
100-year Terrace Buffer	70	

On the order of 6% of the banklines are armored in Reach SR4, and this armor is concentrated upstream of the Fort Shaw Canal Diversion.

The maximum migration distance measured in Reach SR4 was 263 feet, and the CMZ buffer width is 244 feet.

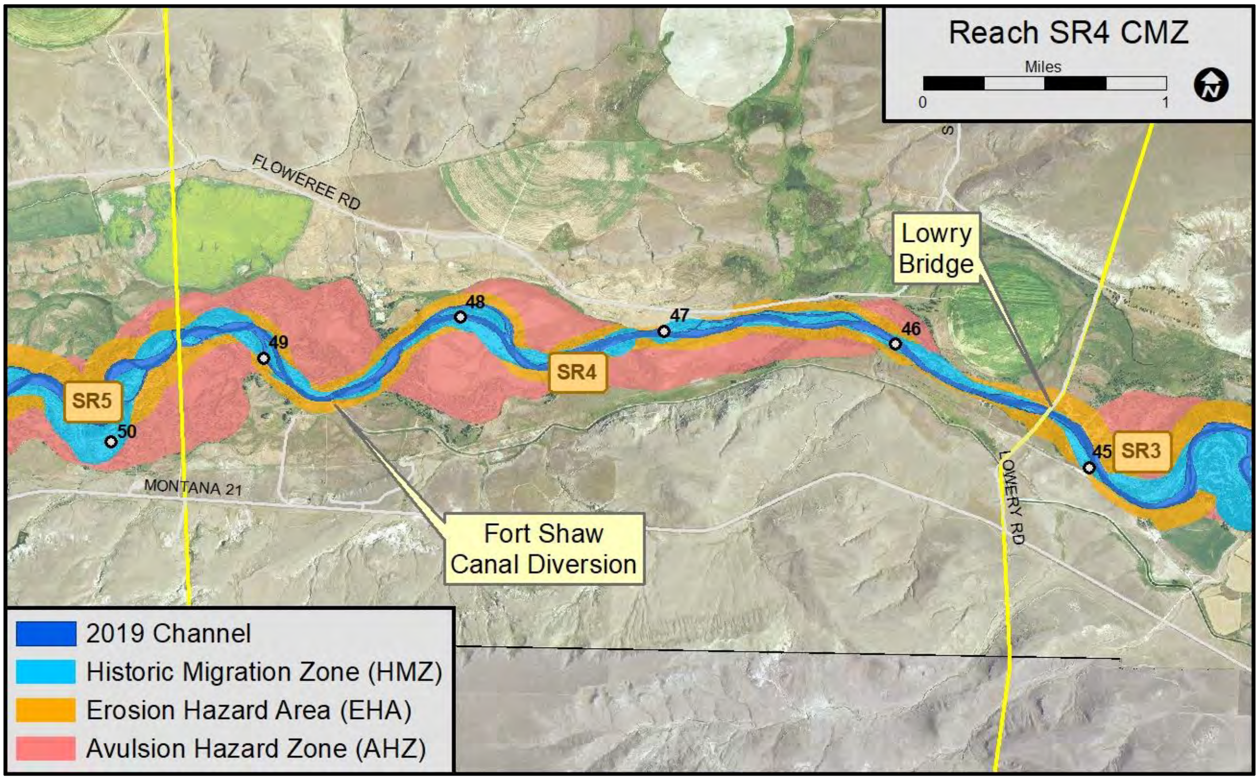


Figure 61. CMZ map for Reach SR4.

5.3.1 CMZ-Related Issues in Reach SR4

No major issues were identified in Reach SR4. There is a fair bit of bedrock control in this reach, resulting in relatively low migration rates. At the Fort Shaw Canal Diversion, the river location has changed very little since at least the 1950s due to bank armoring upstream. It appears that the river was dredged in 1957 just upstream of the diversion, probably in response to the 1955 flood. Both banks have since seen some armoring upstream of the diversion; some of that armor now sits in the floodplain about 200 feet south of the active river channel. Left bank armoring upstream of the diversion at RM 49.1 appears stable but does have some risk of flanking on its upstream end. Just below the canal there is a growing risk of an avulsion south of the river, where the channel is progressively migrating into an avulsion path made up of a well-defined historic swale of the Sun River (Figure 62).

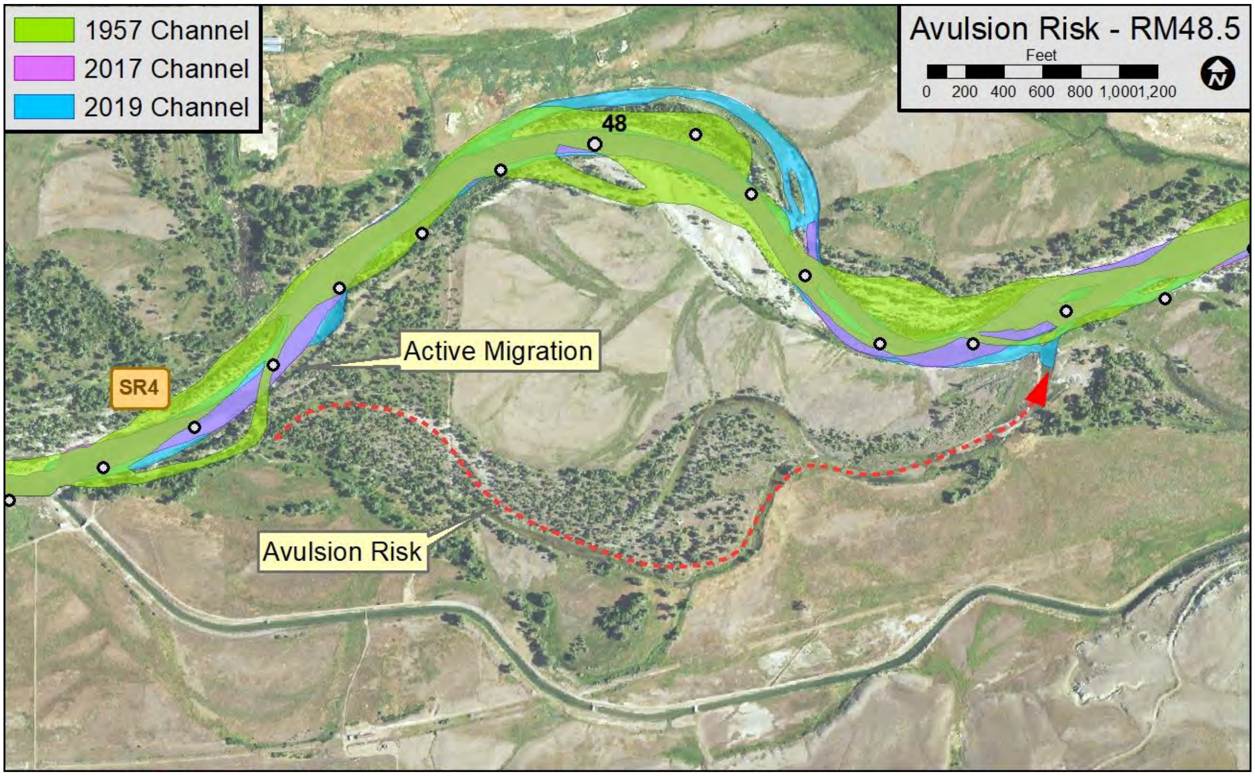


Figure 62. Example avulsion hazard through floodplain swale below Fort Shaw Canal Diversion; note how river has migrated towards upper end of avulsion path in recent years.

5.4 Reach SR3—Lowry Bridge to Rocky Reef Diversion

Reach SR3		
Upstream/Downstream RM	45.3	36.8
Length (miles)		8.5
General Location	Lowry Bridge to Rocky Reef	
Mean Migration Rate (ft/yr)		4.7
Max 62-year Migration Distance (ft)		839
100-year Buffer (ft)		468
100-year Terrace Buffer		225

Reach SR3 starts at Lowry Bridge and extends to the Rocky Reef Diversion structure (Figure 63). The reach is 8.5 miles long. A total of 110 migration measurements were collected in this reach, and the maximum 1957-2019 migration distance measured was 439 feet. Bedload remains coarse, and just below Lowry Bridge recent deposits of coarse gravel/cobble was evident on the north floodplain (Figure 64). Coarse dredge spoils just upstream of the bridge suggest that the reach is prone to aggradation (sediment deposition in the streambed). The 1957 imagery shows that, at that time, the river was locally highly braided with a large overall channel footprint. Since then, the river has continued to evolve, creating a notably wide historic migration zone in areas (Figure 65). This wide HMZ is likely driven by the ~30% reduction in channel slope relative to upstream. In addition to a wider HMZ, the buffer width in this reach is almost double that of upstream.

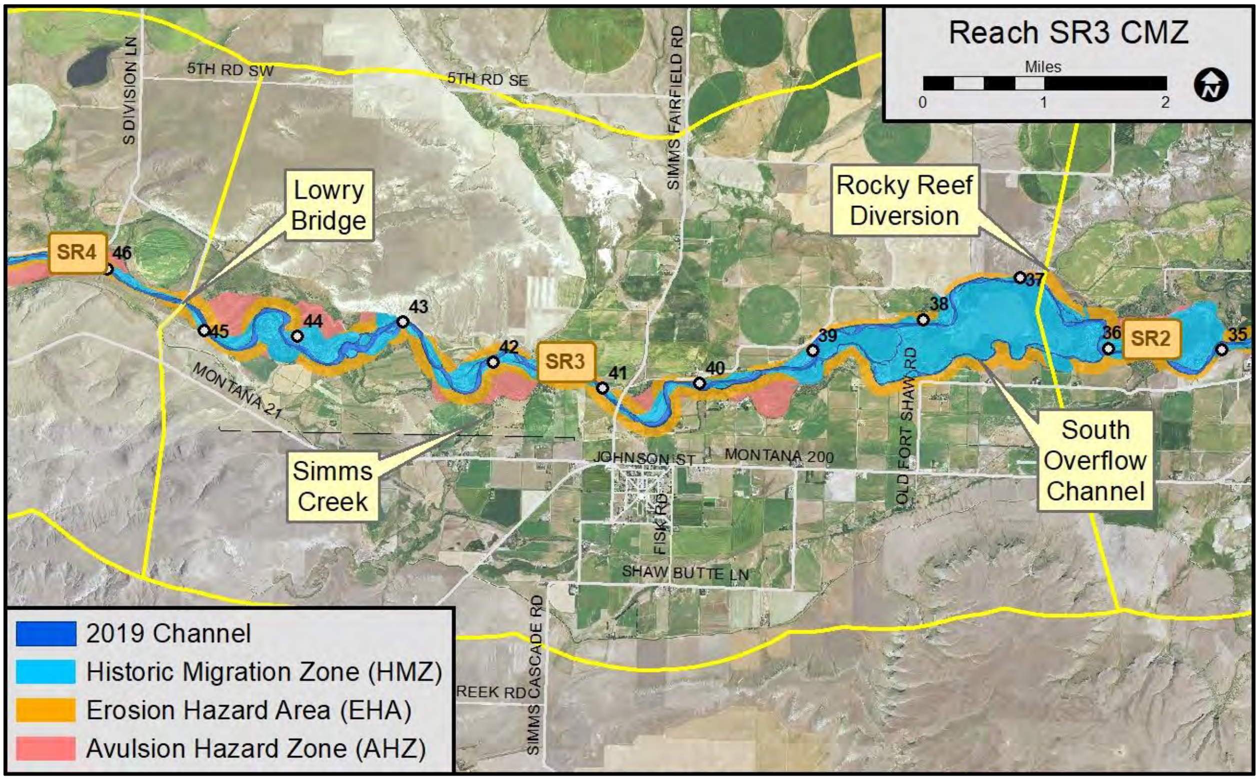


Figure 63. CMZ map for Reach SR3.

Figure 64. Coarse bedload deposition on floodplain just below Lowry Bridge.

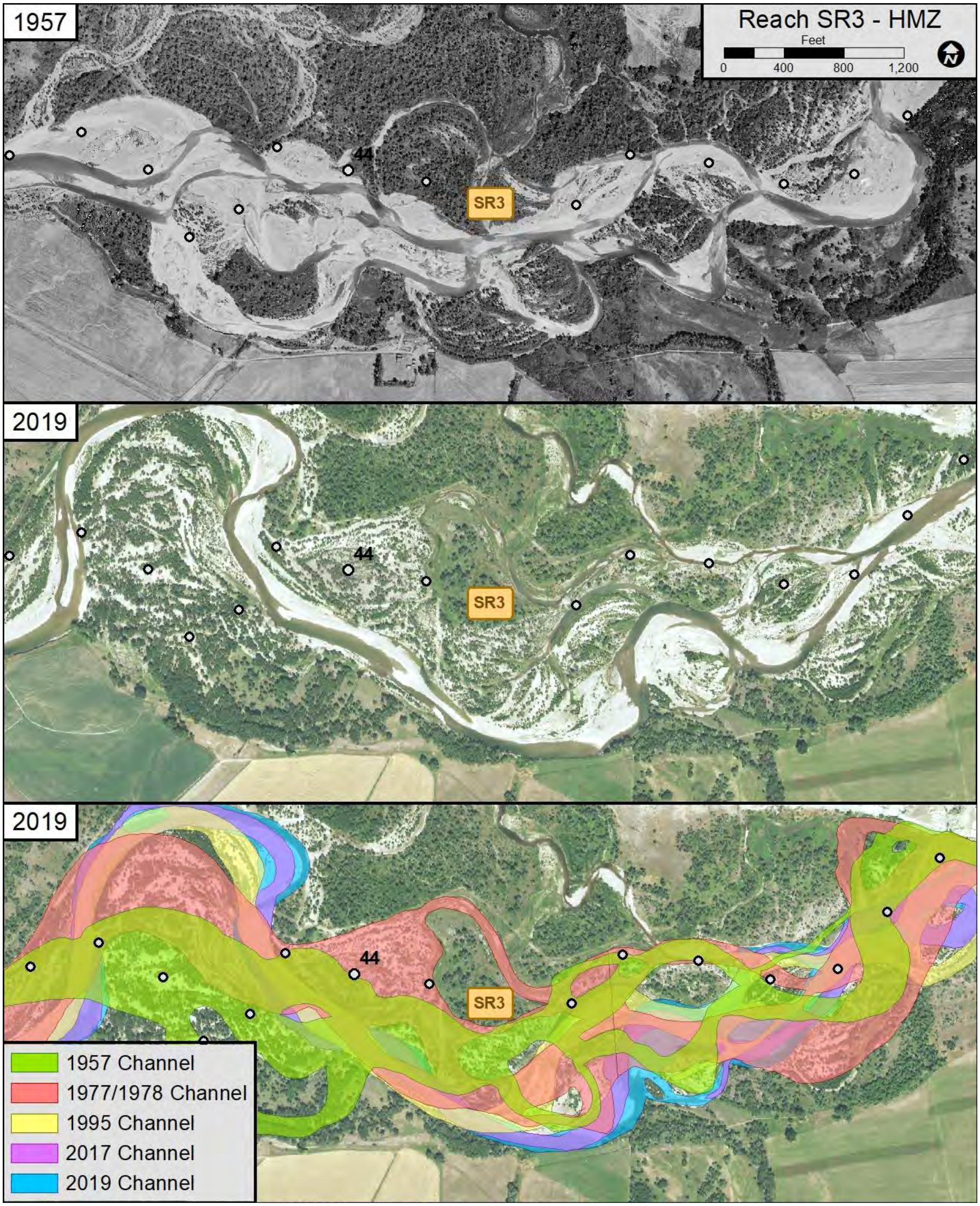


Figure 65. Upper Reach SR3 showing braided conditions in 1957 (top), some vegetation recovery by 2017 (middle), and complex composite footprint of mapped banklines (bottom).

5.4.1 CMZ-Related Issues in Reach SR3

Kellogg (2014) started his assessment at Lowry Bridge which marks the start of Reach SR3. He identified Lowry Bridge as a "No Action" site, and the CMZ mapping supports that recommendation.

1. About a half-mile downstream of Lowry Bridge, there are flanked barbs on the right bank where the river has eroded into a terrace (Figure 66). Kellogg (2014) described the bank protection project at this site as follows:

   A high terrace was shaped, nine rock flow deflectors installed, and erosion fabric laid along 1,000 feet of south river bank in late 1997. The project purpose was to stabilize the terrace and protect an irrigated hay field. Two deflectors on the upper end are intact, a third deflector is close to being flanked, and the other six have washed out. Rock from one of the flanked deflectors is exposed in mid-channel. Another deflector is buried in a large gravel point bar on the opposite side of the river. Cottonwood saplings were planted along the bank on the upper third of the project and appear to be doing well. An additional 600 feet of river bank, downstream from the flow deflectors, was shaped and covered with erosion fabric. It has subsequently washed out.

   During the 2011 flood, the river migrated 40 – 100 feet into the downstream end of the terrace bank. A gravel point bar on the opposite bank nearly doubled in size and is pushing the river channel into the terrace, increasing sheer stress along the terrace toe.

Recommendations for this site (Kellogg, 2014) included salvaging rock from flanked deflectors to reinforce remaining structures, monitoring for avulsions, and bank plantings.

Since 1957 about 12 acres of land have eroded at this site, the majority of which occurred between 1957 and 1978, during which time the river migrated about 410 feet to the southeast. The bank has continued to erode since the 2014 assessment, and that erosion is concentrated on the downstream end of the hayfield (Figure 66). This erosion will likely continue into the riparian corridor and lower end of the field. As this bank trends at a right angle to the river corridor (due north) it will probably require substantial maintenance and extension with time. The bendway just downstream will probably cut off in coming flood years, so the alignment in this area will be dynamic for some time. As a result, the recommendations provide by Kellogg (2014) are still valid; we would not recommend heavy bank armor investment at this location due to reach-scale dynamics.

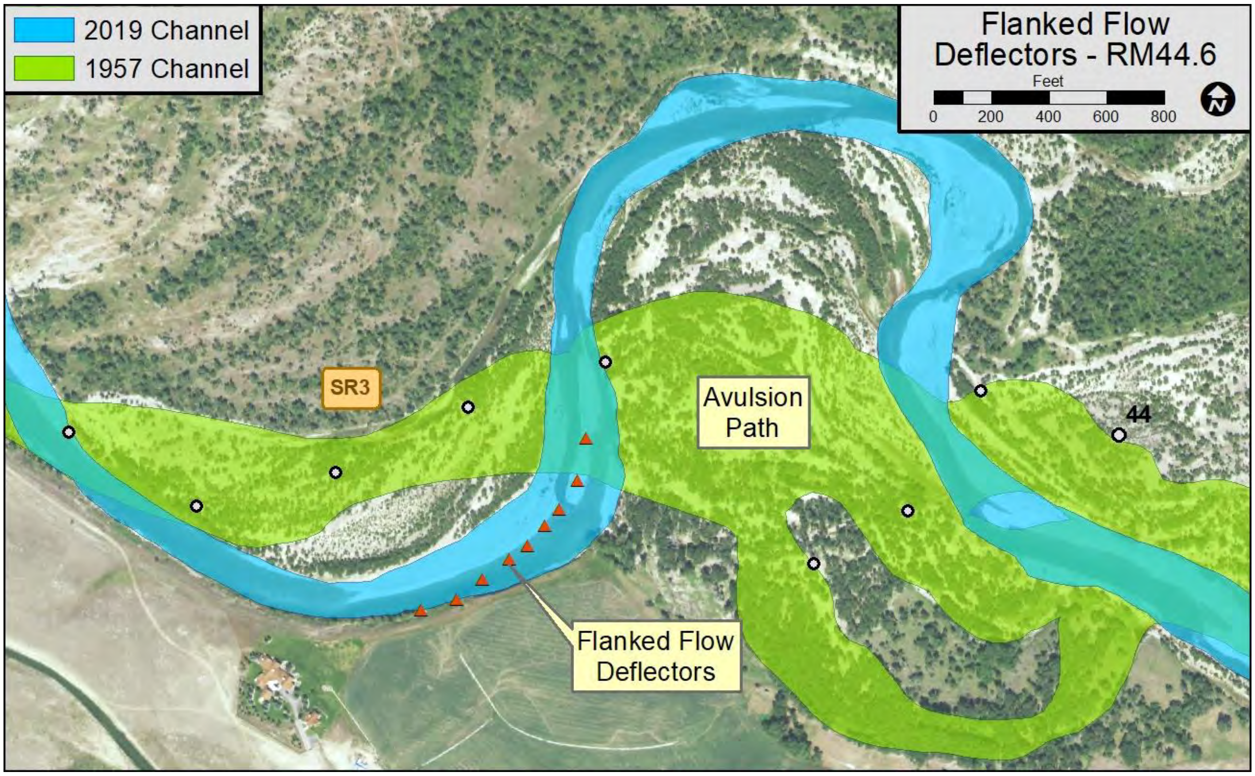


Figure 66. Channel migration at RM 44.7, site of Kellogg (2014) Site SR-3; at least five barbs have been flanked on the right bank; note avulsion path following 1957 channel route just downstream.

2. Channel migration towards the south at RM 42.3 has created a high potential for an avulsion into the lower end of Simms Creek (Figure 67).

3. At RM 41.8, a house sits on a high terrace that has actively eroded in recent years (Figure 68). This is referred to as Site SR-5 by Kellogg (2014), who described the bank stratigraphy as alluvial deposits overlying glacial lake sediments. His recommendations included water management on the terrace to reduce seepage and potentially slope stabilization. Recent bankline mapping corroborates Kellogg's 2014 observation that the river is trending essentially parallel to the bank, reducing erosive pressure at the site. Regardless, this site is a good example of how high terraces are not immune to bank erosion. Although structures on high terraces are typically perched above the river's floodplain, they can still be in the Channel Migration Zone and thus at risk of undermining.

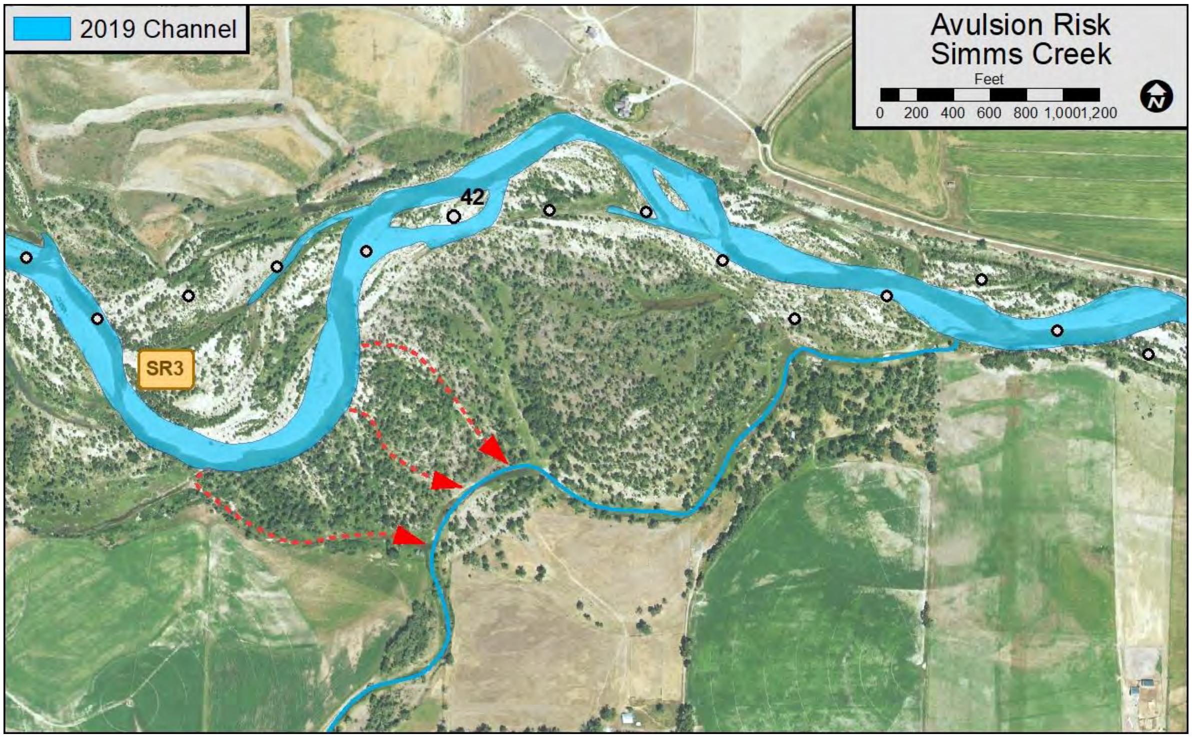


Figure 67. Multiple avulsion paths have developed from an outside bend towards Simms Creek, creating a high avulsion risk in this area.

Figure 68. Home on high terrace, RM 41.8L.

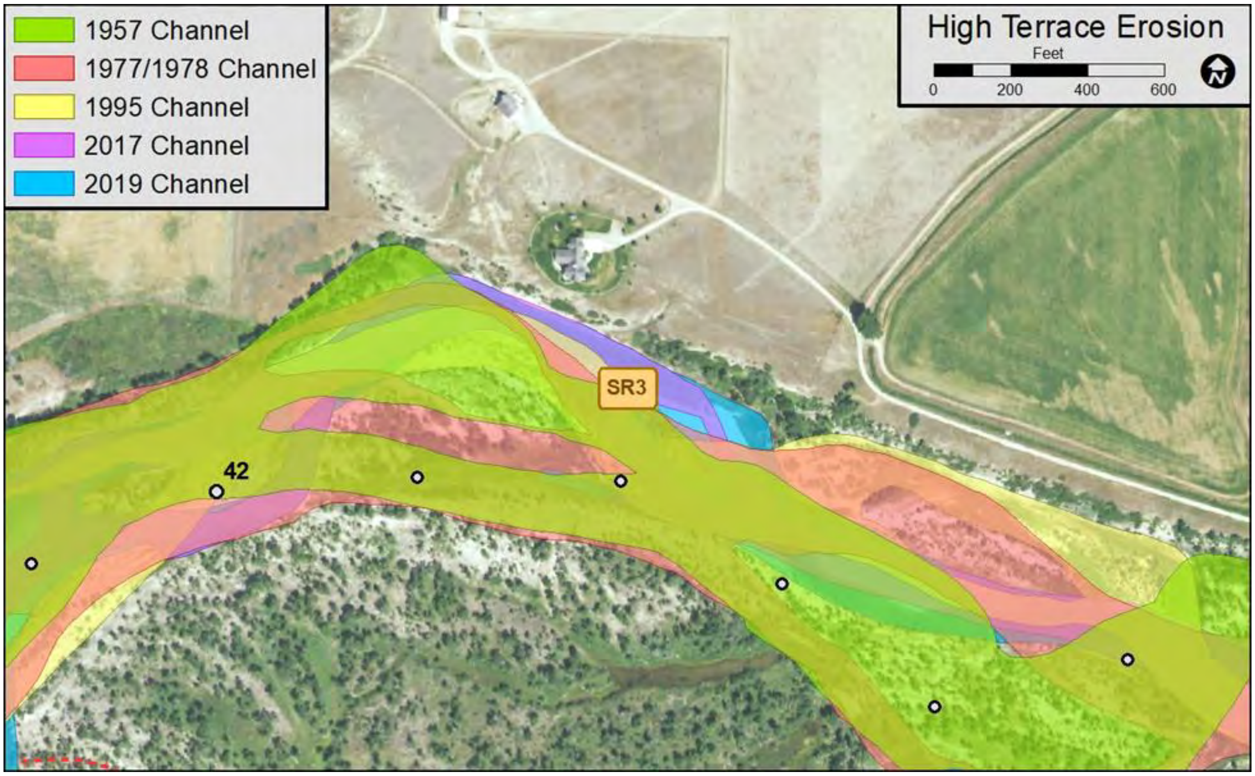


Figure 69. 1957-2019 migration pattern against high terrace at RM 41.8.

4. An active avulsion is underway at RM 38.5 (Figure 70). This avulsion is re-activating a 1957 channel route. Evidently there were efforts to prevent this from happening, including a rootwad project constructed just upstream of the avulsion node (where the river splits at the entrance to the avulsion path), and placement of a sills/berms across the relic channel to prevent its capture (Kellogg, 2014). All of these projects appear to have eroded out (Figure 71). Although a major channel relocation here will not directly bypass any major infrastructure, there is some potential of this flow shift to reactivate what Kellogg (2014) referred to as the "South Overflow Channel". If this channel were to capture a substantial portion of the river's flow it could impact water availability at the Rocky Reef Diversion at RM 36.8.

Recommendations by Kellogg (2014) for this site included armoring the bank at the avulsion node (flow split at avulsion) to prevent the river from breaching into the avulsion path; this breaching has since occurred. In order to prevent activation of the South Overflow Channel, Kellogg (2014) recommend evaluating the head of that channel to see if structures should be built to prevent its activation. Those recommendations are still valid.

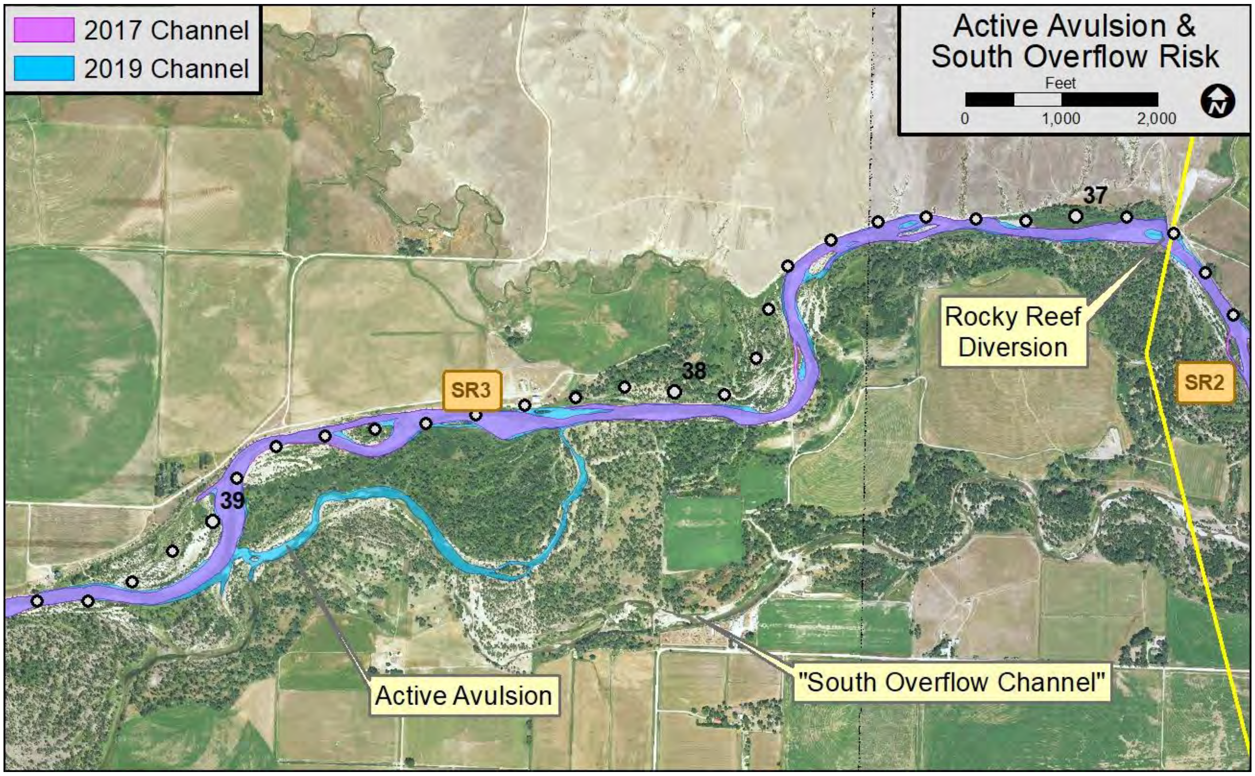


Figure 70. Active avulsion (blue 2019 path) at RM 38.5 showing potential for reactivation of South Overflow Channel that would bypass Rocky Reef Diversion.

Figure 71. Activating channels on south floodplain about 1.5 miles upstream of Rocky Reef Diversion showing breaching of cross-channel berms between 2009 and 2019.

5.5 Reach SR2—Rocky Reef Diversion to Sun River

Reach SR2 extends from Rocky Reef to the community of Sun River, a distance of 8.6 miles (Figure 72).

Figure 73 shows an example of an avulsion in Reach SR2 that occurred between 1957 and 1977. The original meander has been abandoned as an oxbow, and about a half mile of new channel has formed to the south, through a field. These types of avulsions tend to be more common through fields than in riparian areas, because riparian forests support floodplain integrity better than hay or other herbaceous crops.

Reach SR2		
Upstream/Downstream RM	36.8	28.2
Length (miles)	8.6	
General Location	Rocky Reef to Sun River	
Mean Migration Rate (ft/yr)	5	
Max 62-year Migration Distance (ft)	831	
100-year Buffer (ft)	503	
100-year Terrace Buffer	225	

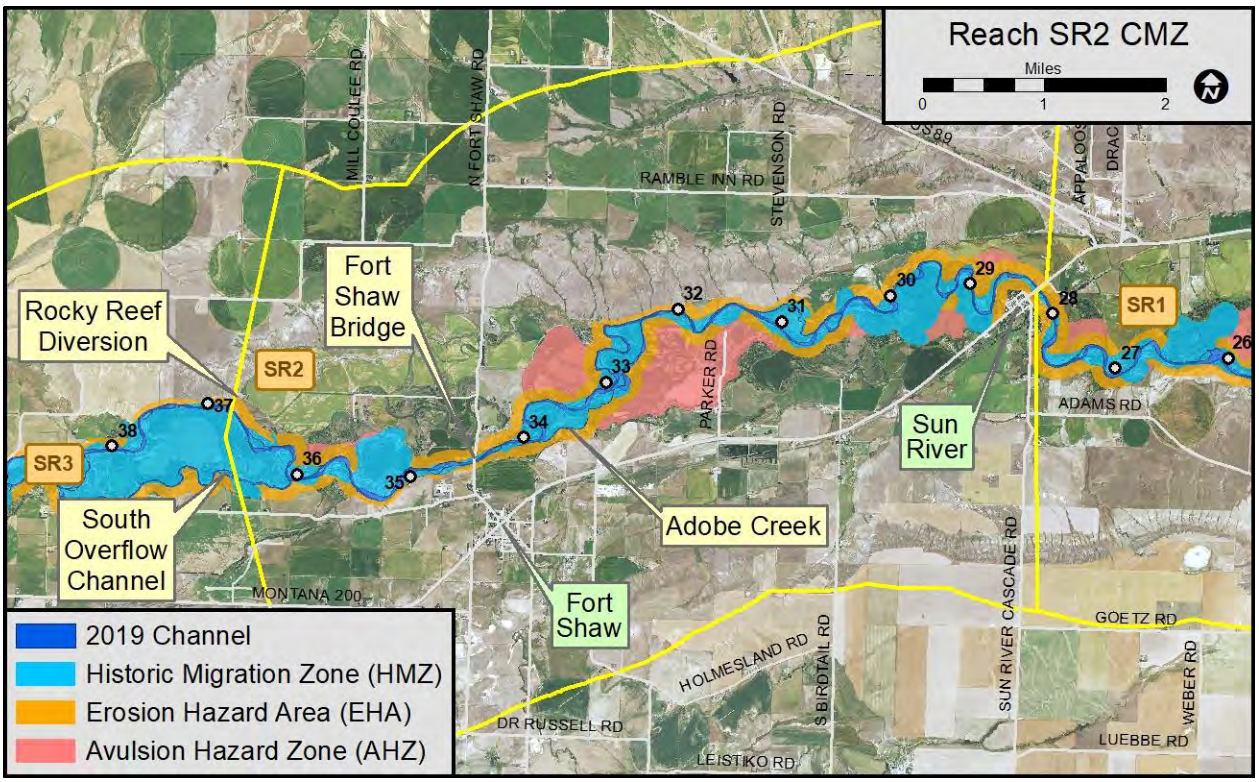


Figure 72. CMZ map for Reach SR2.

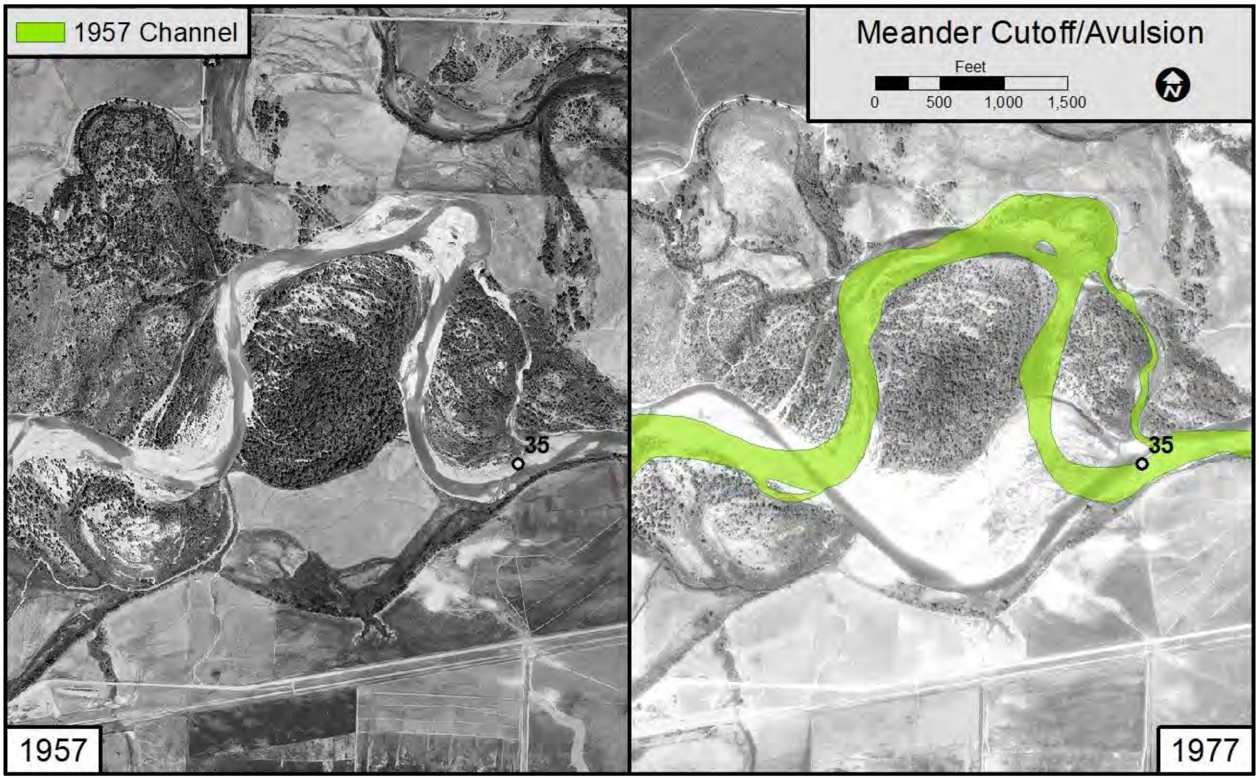


Figure 73. Meander cutoff/avulsion in Reach SR2 between 1957 and 1977.

5.5.1 CMZ-Related Issues in Reach SR2

1. An active avulsion in Reach SR2 on Adobe Creek is a current concern to adjacent landowners, as the river has migrated into a connector channel that conveys Sun River flows into Adobe Creek. From the avulsion node there is about 4,300 feet of lower Adobe Creek that has activated. It is important to note that the avulsion path is about 3,500 feet shorter than the current path of the Sun River, indicating a strong topographic advantage (steeper route) for the Adobe Creek path rather than the current route of the main channel. This site is discussed further in Section 6.2.

2. Another avulsion has established below the mouth of Adobe Creek through what is an old Sun River high flow channel (Figure 78). This was described as High Priority Site SR-16 by Kellogg (2014) who indicated that root wads and riprap were installed over ten years ago on the right bank to prevent the river from breaching into the side channel/tributary (this may have been described as "lower Adobe Creek" in 1995). Recommendations were to reinforce all likely breach locations with rock riprap and flow deflectors. All treatments that were in place in recent years failed, and headcuts that had established between the river and side channel grew and allowed the river to breach into the channel. This site is also discussed further in Section 6.2.

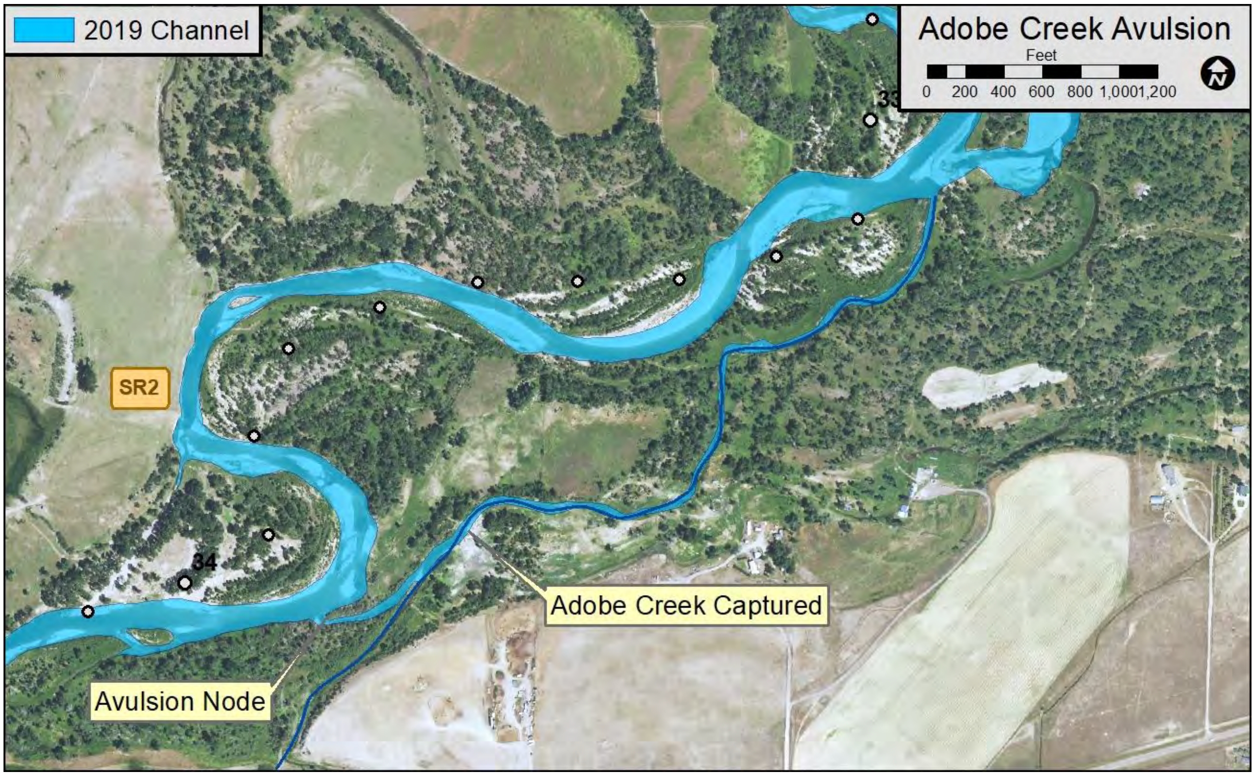


Figure 74. 2019 image showing active avulsion into lower Adobe Creek; avulsion path is about 2,000 feet shorter than the main river.

Figure 75. View down Adobe Creek above avulsion point.


Figure 76. View of Adobe Creek below avulsion point; the Sun River has captured the creek (June, 2020).

Figure 77. View downstream from avulsion node showing breach in right bank that captured swale feeding Adobe Creek (June, 2020).

Figure 78. Avulsion into an older Sun River side channel) between 1995 and 2019 showing channel capture/reactivation due to bank erosion at avulsion node.

5.6 Reach SR1—Sun River to Vaughn

Downstream of the town of Sun River Reach SR1 is characterized primarily by a long history of gravel extraction (Section 2.7). In the 1950s, the gravel mining was intensive in braided reaches, which may have been a direct response to the 1953 flood (Figure 80).

Reach SR1		
Upstream/Downstream RM	28.2	17.2
Length (miles)		11
General Location	Sun River to Vaughn	
Mean Migration Rate (ft/yr)		5
Max 62-year Migration Distance (ft)		928
100-year Buffer (ft)		504
100-year Terrace Buffer		225

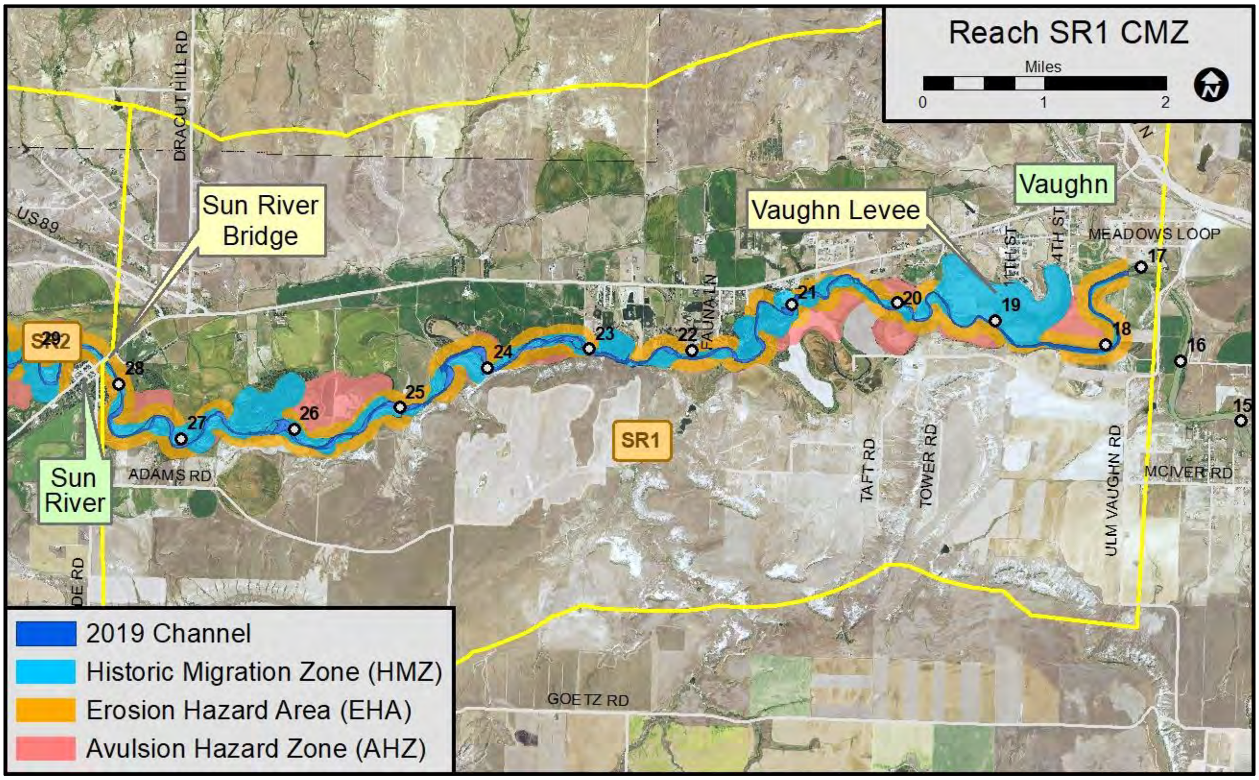


Figure 79. CMZ map for Reach SR1.

Figure 80. In-stream sand and gravel mining in 1957, Reach SR1.

5.6.1 CMZ-Related Issues in Reach SR1

The CMZ mapping shows one place of special concern in Reach SR1. It is an area of high terrace erosion on the left (north) bank at RM 20.5. The terrace has old car bodies and scrap metal strewn along 1,000 feet of bank (Kellogg, 2014). Kellogg recommended that the car bodies be removed and salvaged/disposed of.

Gravel pit capture will remain an issue in Reach SR1 unless the old pits are remediated. This may not pose a major problem for channel stability, but it can create serious fisheries concerns if a breach releases non-desirable species from the pond to the river.

Figure 81. Terrace erosion at RM 20.5; green polygon shows channel location in 1957.

Figure 82. High terrace erosion at RM 20.5 (Kellogg, 2014).

6 Site Specific Issues on the Sun River –Rocky Reef Spring Creek and Adobe Creek (Phase 2)

As part of the Phase 2 component of this work, we were requested to specifically evaluate the area where Rocky Reef Spring Creek and Adobe Creek enter the Sun River just downstream of North Fort Shaw Road. This is an area where the Sun River crosses across the valley from the south to the north valley wall, and as a result it is minimally confined and highly dynamic.

This is a difficult situation, especially with regard to ongoing bank erosion associated with recent major changes in channel course. The concepts provided here are initial recommendations for consideration, although this area will require a much more detailed feasibility analysis and costing effort prior to any project implementation. In order to leverage our data and CMZ mapping efforts, however, some general management strategies are provided below.

6.1 Recent Changes and Current Conditions

Figure 83 shows a general Relative Elevation Model (REM) map of the area located just downstream of North Fort Shaw Road. In this area, Adobe Creek flows into the Sun River valley from the south. When it enters the valley, it parallels the general trend of the Sun River. Any time a tributary runs parallel to a dynamic, major river, that tributary is prone to capture and enlargement. This process has been ongoing on lower Adobe Creek, as several flow connections between the two have developed in recent years. Most recently, in spring of 2021, a new connection labeled “Avulsion Node #1” in Figure 83 began routing a major portion of Sun River flows into lower Adobe Creek as well as an older Sun River side channel. The river is actively migrating into this channel and will likely cause it to further enlarge and become claimed as a perennial side channel of the Sun River. It could also become the primary thread, as the route down Adobe Creek is currently shorter and steeper than that of the Sun. Downstream, a location marked as “Avulsion Node #2” marks where the Sun River has recaptured an old river channel. This avulsion node was blocked by a gravel berm in 2020. There is another Avulsion Node (#3) just below, that currently contributes flow into the older channel, which, in recent years, has captured the entire Sun River, abandoning the portion shown as a red line in Figure 83. The main issues with these changes are high velocities and intense erosion along the fields that form the right bank of the expanding main thread of the Sun River below Avulsion Node #3.

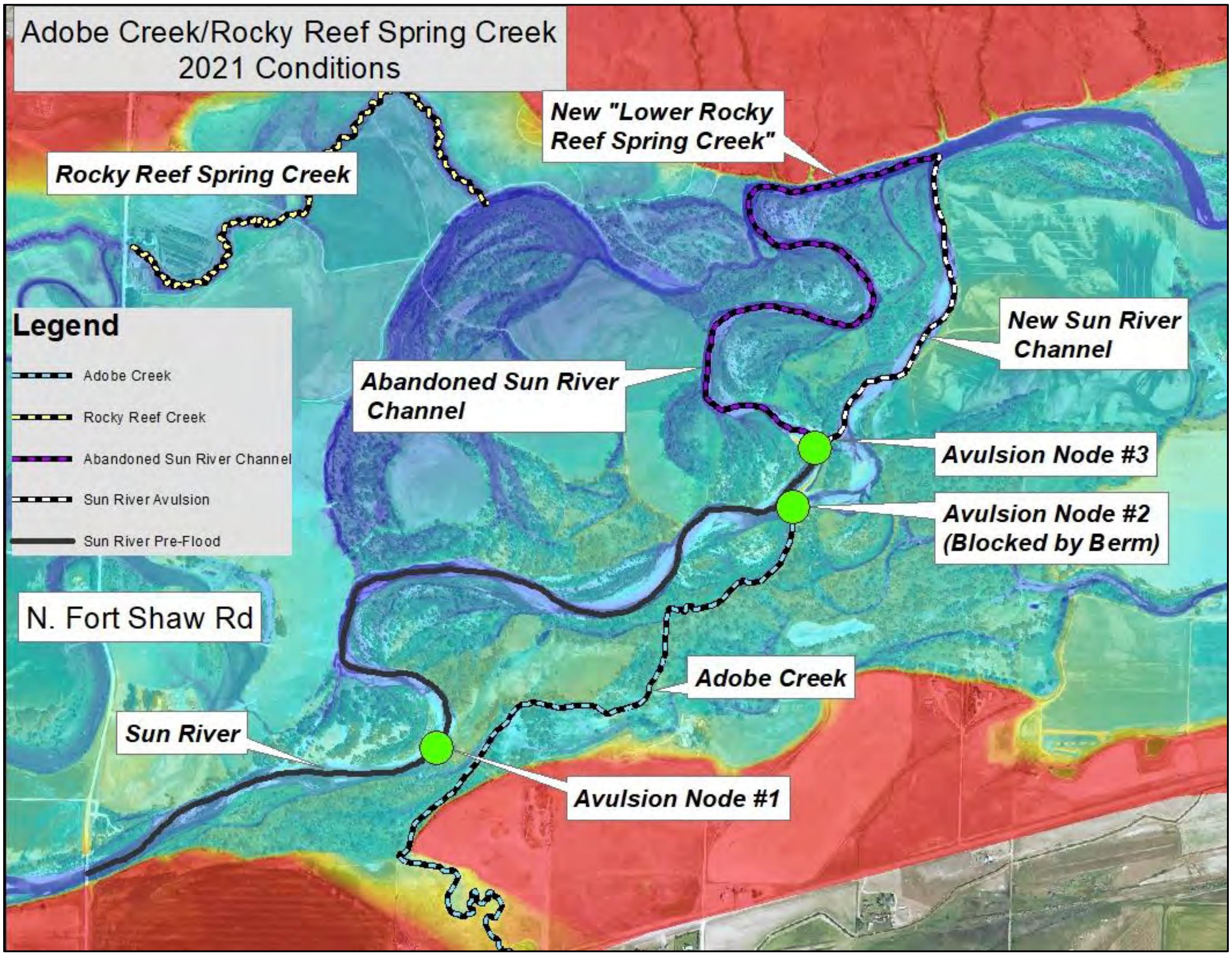


Figure 83. REM of the Adobe/Rocky Reef Spring Creek area near Fort Shaw showing avulsion path of Sun River (yellow line) and resulting abandoned channel segment that also forms lower end of Rocky Reef Spring Creek (red line).

The following time series shows how the imagery used in the CMZ mapping captures the major changes at this site. In the late 1950s, some work had been done in the river, probably in response to the 1955 flood (Figure 84). Gravel berms are evident on the imagery and there are still pockets in the floodplain where some berm material appears to have been excavated. The 1957 imagery shows a scoured avulsion path to the right (east) of the main channel, although this route does not support the main thread. The main channel appears to have been graded and straightened, probably to prevent the avulsion from happening. The inset map on the photo shows an excavated return flow channel extending from the avulsion path back to the river; the flood channel may have been blocked to support pooling and irrigation of the fields on the right floodplain.

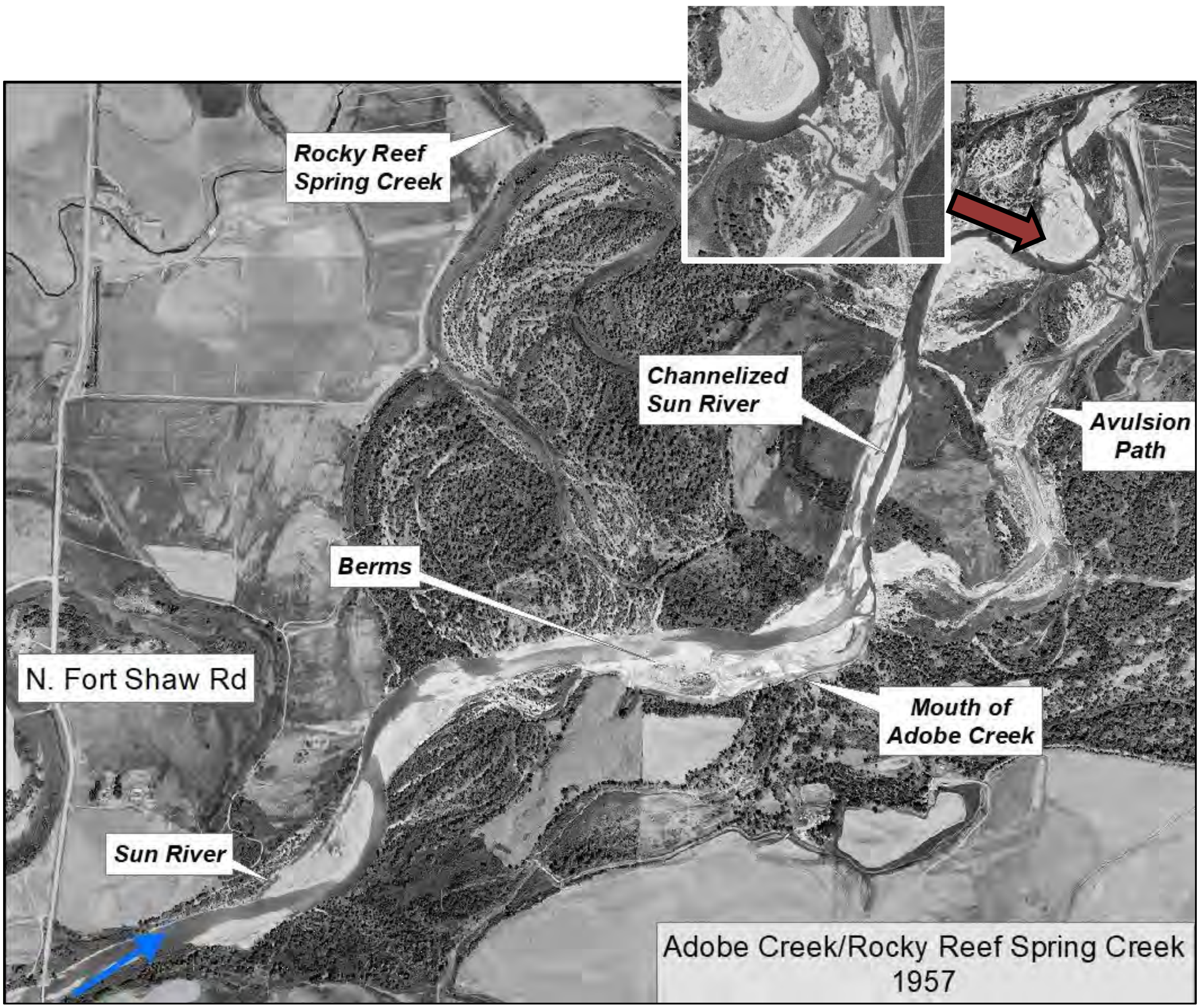


Figure 84. 1957 image of Adobe Creek area showing failed avulsion path on right. At this point there are berms in the channel and a portion of the river appears channelized away from the avulsion path. Inset photo on upper right shows "bleed channel" excavated through floodplain between avulsion path and river.

By 1978, the straight channelized segment of the Sun River had regained substantial length by forming a series of large sweeping meanders through the middle of the river corridor (Figure 85). The avulsion path to east of this main thread had healed, as a well vegetated side channel. It appears that the head of this eastern side channel may have been intentionally kept open to get irrigation water to the fields to the east. Based on available imagery, it is difficult to tell if this channel was ever actually lower Adobe Creek, or if it has always had some Sun River connection near the avulsion nodes, making it a Sun River side channel.

Figure 85. 1978 image of Adobe Creek area showing longer, more sinuous sun river and established side channel to the east.

By 2011, the meanders that formed along the straightened segment lengthened enough to come within about 120 feet of breaching through Avulsion Node #3 downstream of the mouth of Adobe Creek (Figure 86). Since then, floods have caused the river to migrate fully into the old avulsion route/side channel. The 2019 image shown in Figure 87 shows the avulsion in process, but by fall of 2020 it had become complete, with low flows heading down the new channel and the old channel that had lengthened so much since the 1950s becoming completely abandoned.

Figure 86. 2011 image of Adobe Creek area showing longer, more sinuous sun river and established side channel to the east.

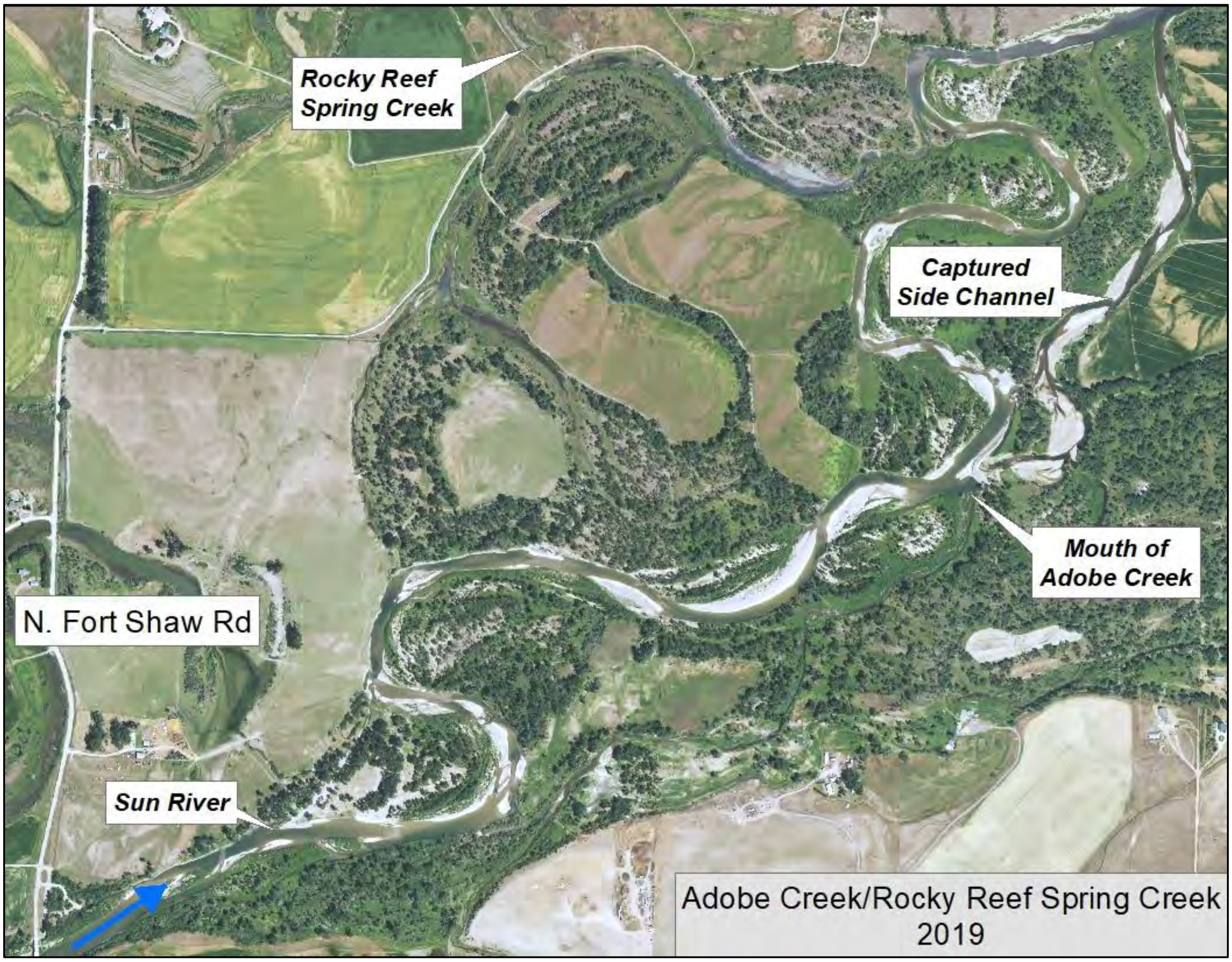


Figure 87. 2019 image of Adobe Creek area showing breach into side channel and creation of large open bars. Note how much shorter side channel route is relative to main thread. The side channel has since captured all flow.

Figure 88 shows the conditions at Avulsion Nodes #2 and #3 in the fall of 2021. The image shows how Avulsion Node #2 was blocked by a gravel berm, but Node #3 is sending all water into the side channel that flows along the farmed fields. The head of the abandoned channel has filled in with sediment, reducing its frequency of activation and thereby sending more flow down into the captured channel.

Figure 88. Drone flight image showing downstream view that captures mouth of Adobe Creek just above Avulsion Node #1 which has been blocked by a berm. Downstream, Avulsion Node #2 has successfully captured the channel to the right and abandoned the long sinuous Sun River channel that persisted until recently. Image captured by Tanner Tompkins, Montana Map Works, December 2020.

The main issue associated with the avulsion is the rapid geomorphic evolution of the new channel. The new channel is about 3,500 feet shorter than the channel it abandoned, and as a result it is twice as steep (0.29% versus the abandoned channel at 0.14%--Figure 89). The channel carries more flow, it has widened substantially, and right bank erosion has removed most of the woody riparian vegetation as well as a pump site (Figure 90).

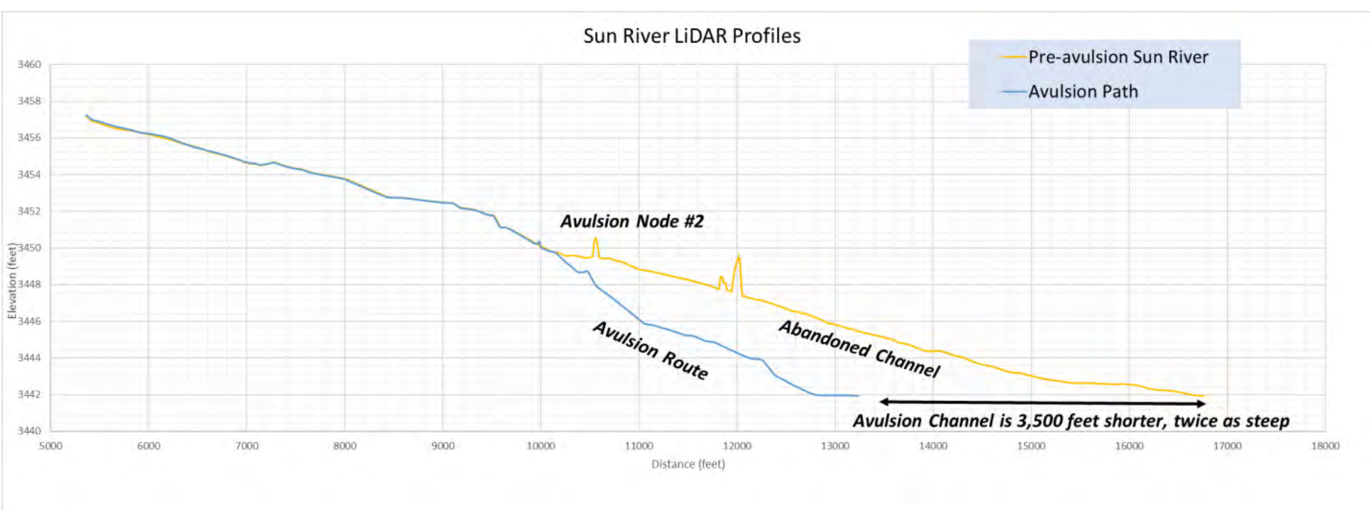


Figure 89. LiDAR profiles showing Sun River profiles for recently abandoned segment of Sun River and actively developing avulsion route.

Figure 90. Pre- and post- flood photos showing enlargement of channel against fields and loss of pump site (lower photo was taken in December 2020).

6.2 Flood Rehabilitation Alternatives: Adobe Creek

The biggest apparent issues with the recent relocation of the main thread of the Sun River into a side channel (Adobe Creek) include the following:

- Rapid channel expansion of the Adobe Creek channel that has destroyed a pump site and discontinuous riparian buffer.
- Growth of mid-channel bars.
- Strong evidence of rapid migration rates in coming years as the steep channel lengthens to restore an equilibrium grade condition, which will erode substantially into existing irrigated ground.
- A potential risk of the river bypassing the Sun River Valley Ditch Company Diversion at River Mile 32.

This is a difficult situation that will be costly to remediate. In terms of concepts, a few ideas that may help promote collaborative discussion of treatment alternatives are described below. These are highly conceptual in nature and would require additional feasibility analysis and cost/benefit considerations. Landowners should also reach out to permitting agencies prior to embarking on any project concept to ensure the project is feasible from a regulatory perspective. The concepts developed herein include the following:

NOTE: Any project work at this site will require permitting, and there is no guarantee that the concepts described below will ultimately meet permitting requirements by the local Conservation District, County Floodplain Administrator, or Corps of Engineers.

Alternative #1: No Action

Alternative #2: Fully Reactivate Abandoned Segment of Sun River: This alternative would basically build on existing efforts to block the flow paths at each of the avulsion nodes and send water back down the section of the Sun River that has become abandoned.

Alternative #3: Partially Reactivation Abandoned Segment of Sun River: This is a modification of Alternative #2 that is intended to maintain the side channel functionality of the avulsion path to support habitat rejuvenation, floodwater spreading, and irrigation.

Alternative #4: Armor the Right Bank Along the Avulsion Path: This consists of a long armoring project on the right bank of the avulsion path along the irrigated fields.

Alternative #5: Consider a Channel Migration Easement Concept: This is a developing concept in Montana that compensates landowners for allowing natural migration to occur to a certain extent in support of natural processes. Landowners can then let the system "settle down" and save the funding for a project at a future date once the land under easement has been eroded out.

6.2.1 Alternative #1: No Action

No Action should be a strong consideration in any river engineering alternatives discussion. This is certainly one course of action, however if No Action is pursued, local landowners should expect high erosion rates and loss of irrigated ground in coming years. The current avulsion path of the Sun River, because it is so steep and straight, will rapidly develop meanders in coming years to dissipate energy, consuming adjacent ground in the process. In addition, the lower end of Rocky Reef Spring Creek, which is discussed more specifically later in this section, would remain a challenge for fish passage into the main portion of the tributary. If a No Action approach is taken, we would recommend that landowners shift to a portable pump along the right bank fields, to allow water rights to be met on the evolving channel. This was a common approach on the Musselshell River following the 2011 floods, which caused the channel to become unstable and dozens of pump sites to become inoperable.

6.2.2 Alternative #2: Fully Reactivate Abandoned Segment of Sun River

Another concept to consider is the reactivation of the abandoned segment of the Sun River. This would require, at a minimum, reconstructing the right bank and floodplain areas avulsion nodes #2 and #3, and excavating the entrance of the abandoned channel, which shows substantial new deposition at its entrance (Figure 91). In our experience with these types of meander reactivation projects, we have generally converted the newly formed channel to a high-flow channel/wetland complex, with low vegetated berms along its course to dissuade re-capture of the channel. One drawback with this approach is that if the avulsion nodes are completely blocked, limited water will flow against the irrigated fields below, where a pump site was operational prior to the flood. It may also be appropriate to address Avulsion Node #1 in this alternative (Figure 91), as most streamflow is now flowing down this portion of Adobe Creek, which if left unchecked will dramatically enlarge Adobe Creek and affect any project implemented downstream (Figure 92).

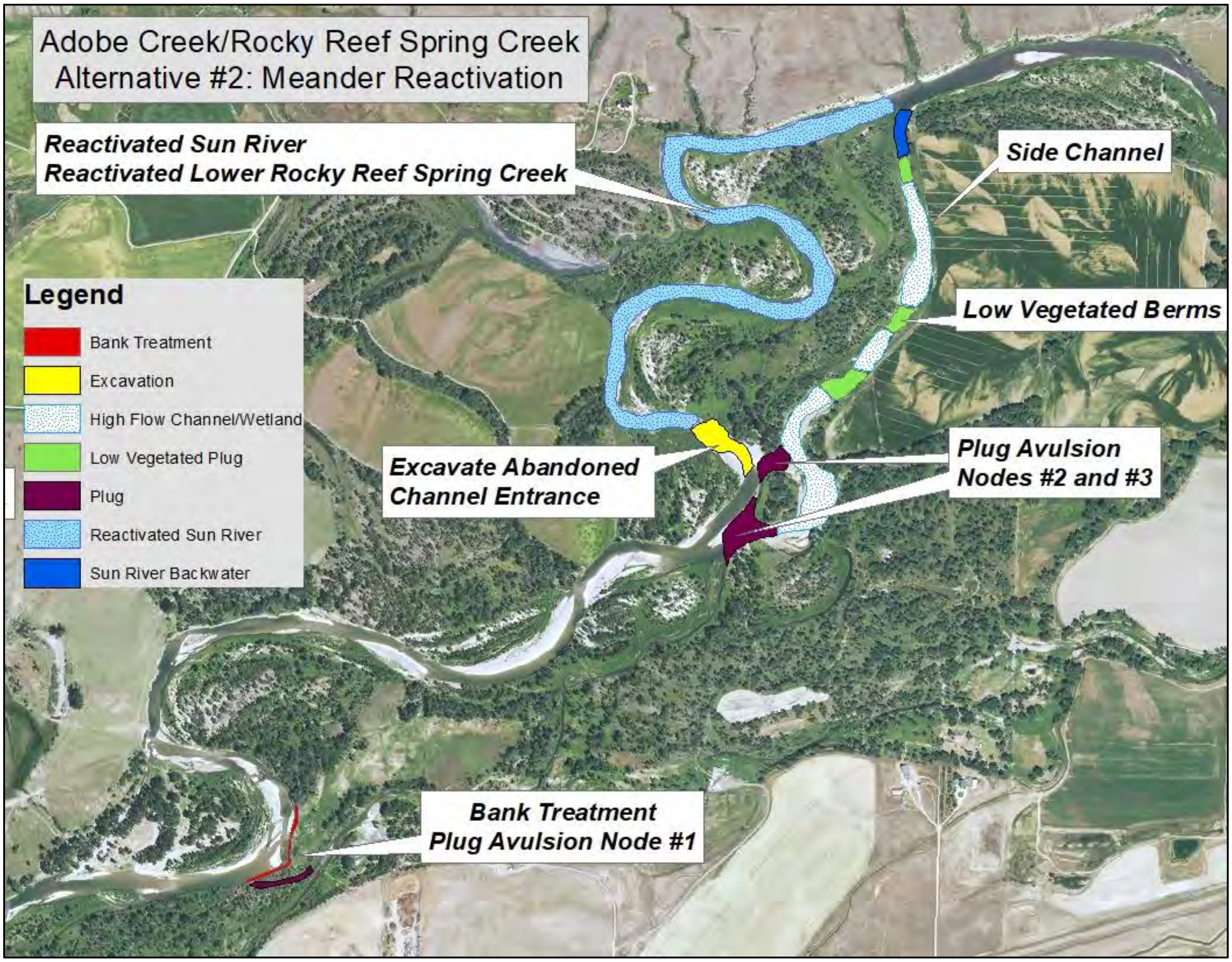


Figure 91. Alternative #2 concept that plugs all three avulsion nodes and re-routes Sun River back to pre-2019 path.

Figure 92. View downstream showing water flowing from Sun River into Adobe Creek via Avulsion Node #1; note minimal flows in older Sun River Channel (Tanner Tompkins, August 2021).

6.2.3 Alternative #3: Partially Reactivate Abandoned Segment of Sun River

If one objective of any project in this area would be to maintain a low flow condition along the fields where the pump site was, it would be worth considering partially reactivating the abandoned Sun River channel and designing a long-term split flow condition that would essentially simulate pre-flood conditions. This would likely entail completely plugging Avulsion Nodes #1 and #2, and stabilizing the flow split at Avulsion Node #3 (Figure 93). Similar to Alternative 2, this would reactivate the abandoned segment of the Sun River which would alleviate issues on lowermost Rocky Reef Spring Creek.

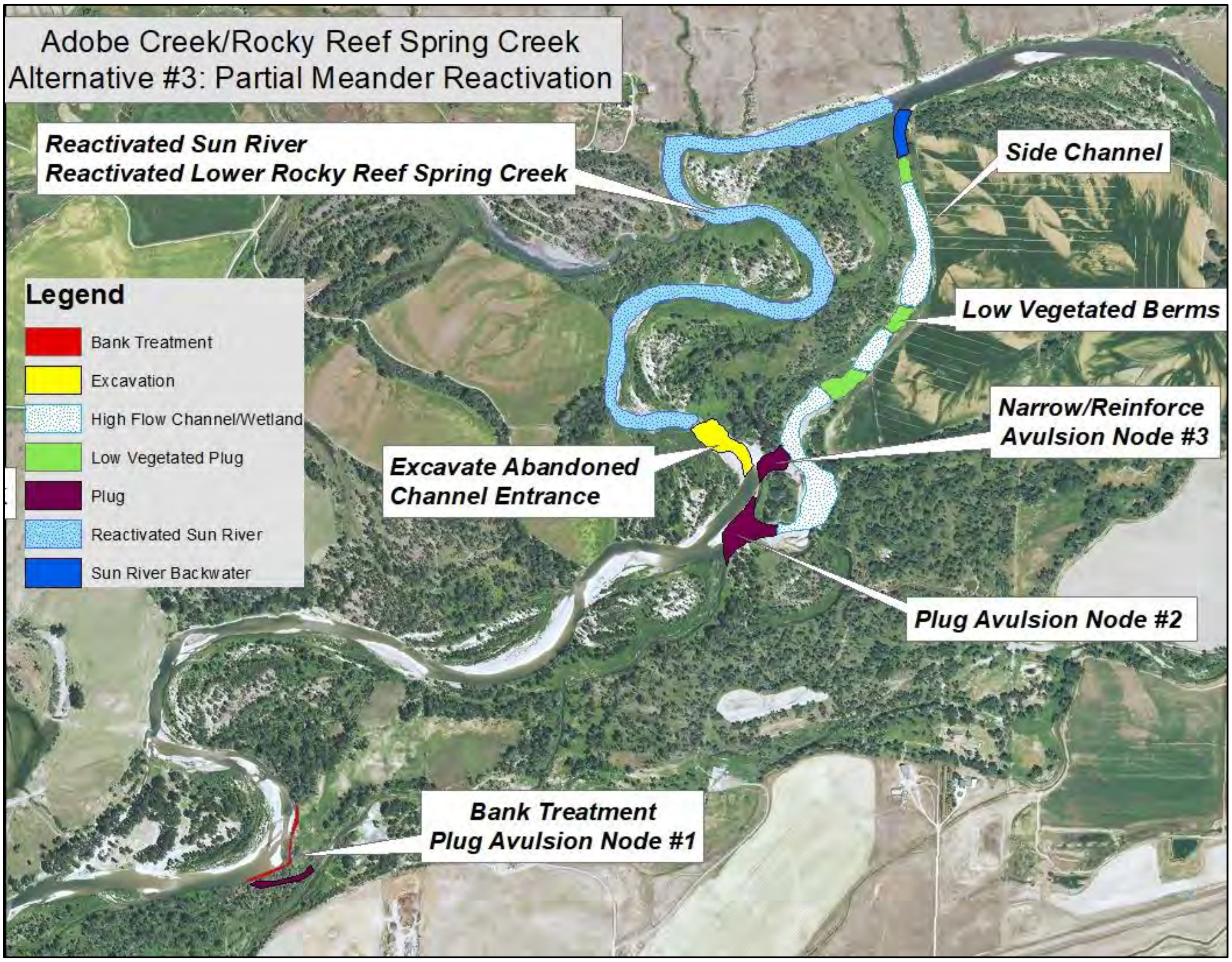


Figure 93. Schematic diagram showing Sun River reactivation and conversion of avulsed channel to a smaller side channel.

6.2.4 Alternative #4: Bank Armor

A fourth alternative is to armor the right bank along the agricultural fields that are currently eroding badly. The channel follows the fields for about a half mile in this area, making this a very large bank armor project that would be costly and would require mitigation. Additionally, the armor would be running almost due north in a largely southwest-northeast trending river valley, meaning the armor would be at a high angle to the stream corridor. It would also be on the down-valley (east) side of the river corridor, making it prone to continued high erosive pressure in coming decades. As a result, the armor would require careful design and construction, and substantial maintenance costs should be anticipated.

In the event an armoring project is considered the best approach, and if it is considered permittable, we would recommend that the landowner consider techniques that incorporate concepts such as inset floodplain benches and integrated riparian vegetation to help recover the riparian buffer on the right bank. An example schematic for a bank armoring project with these elements integrated is shown in Figure 94.

Erosion control professionals may recommend using barbs at this site versus riprap. Barbs can be quite effective, but in our experience, in a dynamic system such as this, they can be especially prone to flanking and scalloping between barbs, which commonly results in the need for riprap between the barbs. This is especially the case where the planform of the river is adjusting such that the angle of attack on the bank can change dramatically with time (Figure 95).

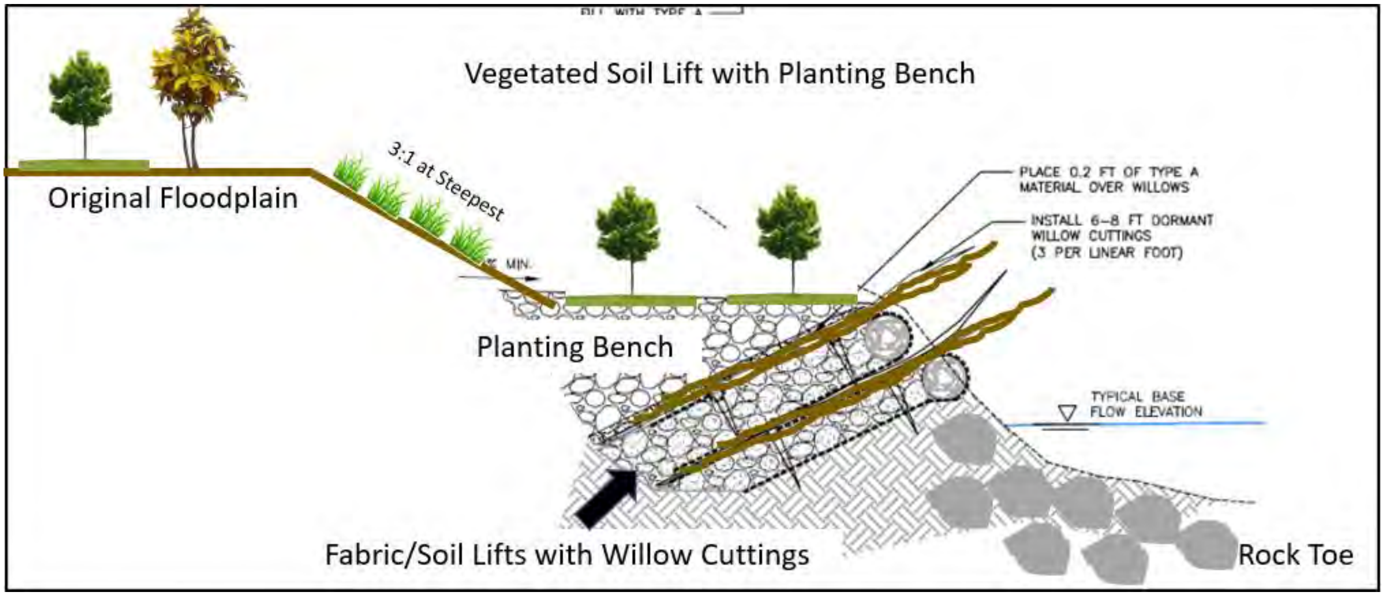


Figure 94. Example schematic drawing for vegetated soil lift design.

Figure 95. Erosion control barbs on Musselshell River (left) and Yellowstone River (right) showing orientation to flow, and erosion between structures.

6.2.5 Alternative #5: Consider the Potential for Securing a Channel Migration Easement (CME) for Land Anticipated to be Lost to Erosion

In the event that the concepts provided above prove too costly or are otherwise unfeasible, we would recommend the landowner along the eroding right bank consider securing a Channel Migration Easement (CME) if the program can be employed here. A CME is a special form of conservation easement where a landowner continues to use their land while allowing the river to erode and move across the floodplain within the easement boundaries. CMEs have been established on the Yellowstone River where landowners were compensated to essentially dedicate portions of their property as river bottom that can be freely accessed by the river. The landowner essentially sells the right to armor the bank in exchange for the financial compensation. The goal of the program is to provide dynamic rivers some freely accessible valley/bottom floodplain areas to maintain their ecological health and resiliency. In previous CME agreements, the landowner has retained all rights to manage the acres in the CME for agricultural production, irrigation, recreation, and other uses. For more information on this program, see https://montanaaquaticresources.org/cme/.

Figure 96 shows that there are about 60 Erosion Hazard Area acres in CMZ map for this location that could provide a good starting point for any CME boundary discussion.

Note: It is our understanding that there is currently no funding available for CMEs in this area, however the project sponsor (Montana Freshwater Partners) hopes to continue project development and expansion.

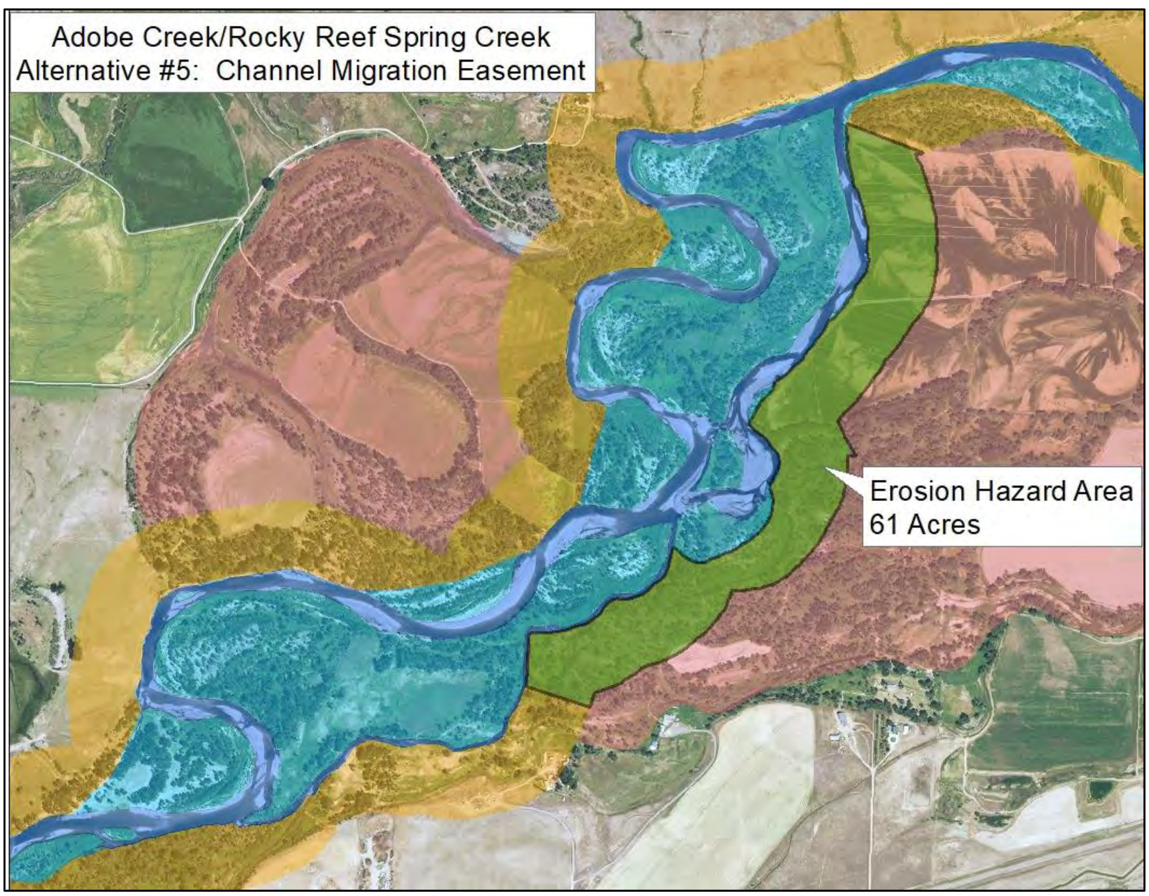


Figure 96. CMZ map highlighting erosion hazard area through project area.

6.3 Flood Rehabilitation Alternatives: Rocky Reef Spring Creek

The changes that have affected lower Adobe Creek have also impacted a tributary on the north side of the Sun River floodplain called Rocky Reef Spring Creek (Figure 83). This creek originates in a center pivot field about 8,000 feet west of North Fort Show Road and flows several miles eastward as a small, highly sinuous constructed channel (Figure 97). About 3,000 feet east of the Fort Shaw Bridge, the creek flows into an old, atrophied swale of the Sun River (Figure 98). Prior to the floods, it followed this channel for about a half mile, then it entered the active Sun River Channel. Evidently, at that time the creek supported salmonid reproduction, with brown trout swimming from the main Sun River channel, up the old swale feature, and into Rocky Reef Spring Creek to spawn. Because of the avulsion described above, however, the creek now flows from the atrophied swale into a recently abandoned segment of the Sun River, which is massively oversized for the Rocky Reek Creek flows, resulting in very shallow flows over a wide channel bottom (Figure 99). This section of channel has likely become a barrier to brown trout movement at low flows, as reports include stacking of brown trout at the lower end of the channel in the fall when they would normally move up the channel to spawn. Because of the value of Rocky Reef Spring Creek to the Sun River fishery, we were asked to develop concepts to address the passage barrier, which is basically an oversized channel that doesn't maintain swimmable water depths for brown trout. Whereas some of the alternatives directly integrate into the Adobe Creek alternatives previously described, others are independent.

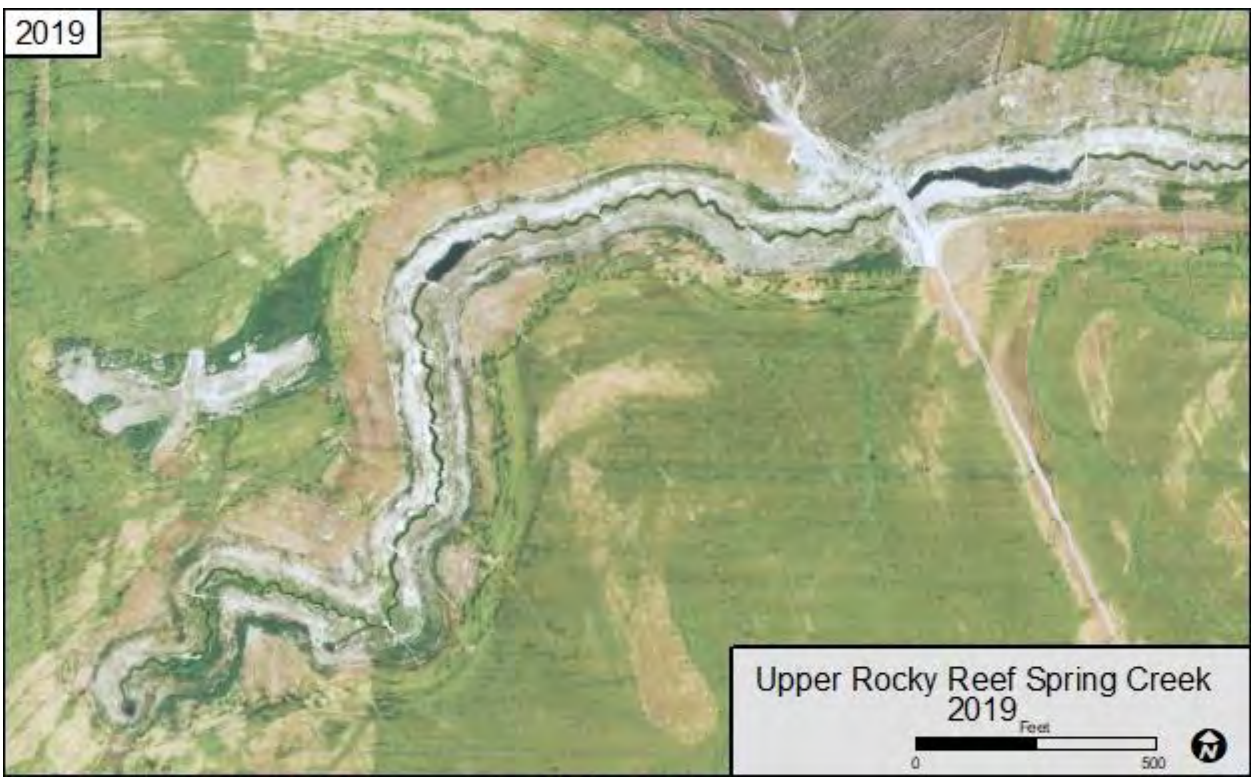


Figure 97. Uppermost end of Rocky Reef Spring Creek showing small, sinuous, constructed channel through pivot fields.

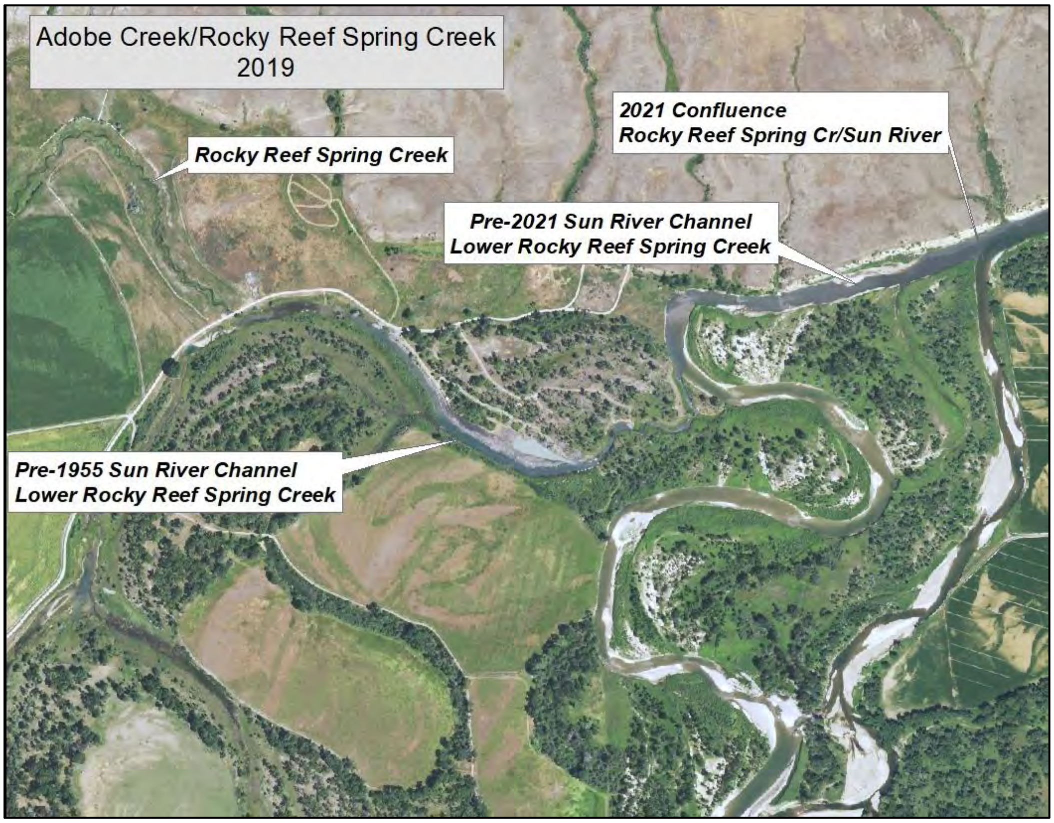


Figure 98. General overview showing Rocky Reef Spring Creek flow path through a small, constructed channel (left), pre-1955 abandoned swale of Sun River (center) and recently abandoned lower Sun River channel. The routing of Rocky Reef Spring Creek through these older swales has increased its length by almost a mile, and the swales are oversized for the creek.

Figure 99. View upstream of shallow Rocky Reef Spring Creek flows in Sun River channel (labeled "pre-2021 Sun River Channel" in Figure 98).

The following concepts have been developed for the lowermost Rocky Reef Spring Creek fish passage barrier:

Alternative #1: No Action

Alternative #2: Fully Reactivate Abandoned Segment of Sun River - This alternative is the same as Alternative #2 described for Adobe Creek. It would essentially restore primary Sun River flows through the old channel, restoring the pre-flood connectivity between Rocky Reef Spring Creek and the Sun River.

Alternative #3: Narrow Abandoned Segment of Sun River to Appropriate Dimensions for Rocky Reef Spring Creek Flows - This alternative would consist of the restoration of the abandoned segment of the Sun River to essentially convert it to a smaller creek channel.

Alternative #4: Construct a New Connection between Rocky Reef Spring Creek and the Primary Thread of the Sun River - This alternative consists of the construction of a new segment of Rocky Reef Spring Creek across the Sun River floodplain that is passable to fish.

6.3.1 Alternative #1: No Action

A No Action approach will not address the passage problems that currently exist, but with time the abandoned Sun River channel will narrow and the barrier condition will ease.

6.3.2 Alternative #2: Reactivate Abandoned Sun River Segment

This alternative is the same as the alternative described in Section 6.2.2.

6.3.3 Alternative 3: Narrow Abandoned Sun River Channel to Provide for Fish Passage

As the main issue with lowermost Rocky Reef Spring Creek is that the channel is much too large to maintain water depths amenable to fish passage, one alternative is simply to narrow the channel. This will eventually occur naturally as the channel begins to accumulate fine Sun River sediment during floods, as Rocky Reef Spring Creek will maintain a channel through those sediments, resulting in passive narrowing into a slough. A faster, more active approach to that end game is to either excavate a pilot channel or to construct a floodplain bench in the oversized channel. The excavation of a pilot channel may first appear to be the most cost-effective strategy, but drone imagery shows bedrock reefs in the depth-limited channel that will probably be difficult to work with. Figure 100 shows an example channel narrowing project, where a floodplain bench was constructed to narrow and deepen flows. This is a common approach to restoring over-widened channels, but because of the length of this project, (~2,000 feet) it would require major dirt moving and sod sourcing for the top of bank, making it an expensive option. For example, if the channel were narrowed to a 20 ft top width with a 2.5 ft inset floodplain bankline, it would require about 13,000 cubic yards of fill. In addition to that, the project would likely require bank treatments and floodplain bench sodding/vegetating as shown in Figure 100.

Figure 100. Example channel narrowing project near Driggs, Idaho (postregister.com).

6.3.4 Alternative 4: Reconstruct lowermost Rocky Reef Spring Creek through Sun River floodplain.

The final alternative for lower Rocky Reef Spring Creek is to reconstruct its lower end through the Sun River floodplain at an appropriate dimension and planform for the creek. Figure 101 shows a potential example route, where the creek would cross the abandoned Sun River swale and then flow within an existing narrow swale to the Sun River. The profile for this channel is shown in Figure 102; the profile indicates about 2-4 foot excavation depths on the floodplain, although a formal channel design could include components such as compound slopes to better fit the existing ground and reduce costs. As the creek would cross the abandoned Sun River channel, that design element would need careful consideration to maintain stability during high water when Sun River flows may intersect the creek.

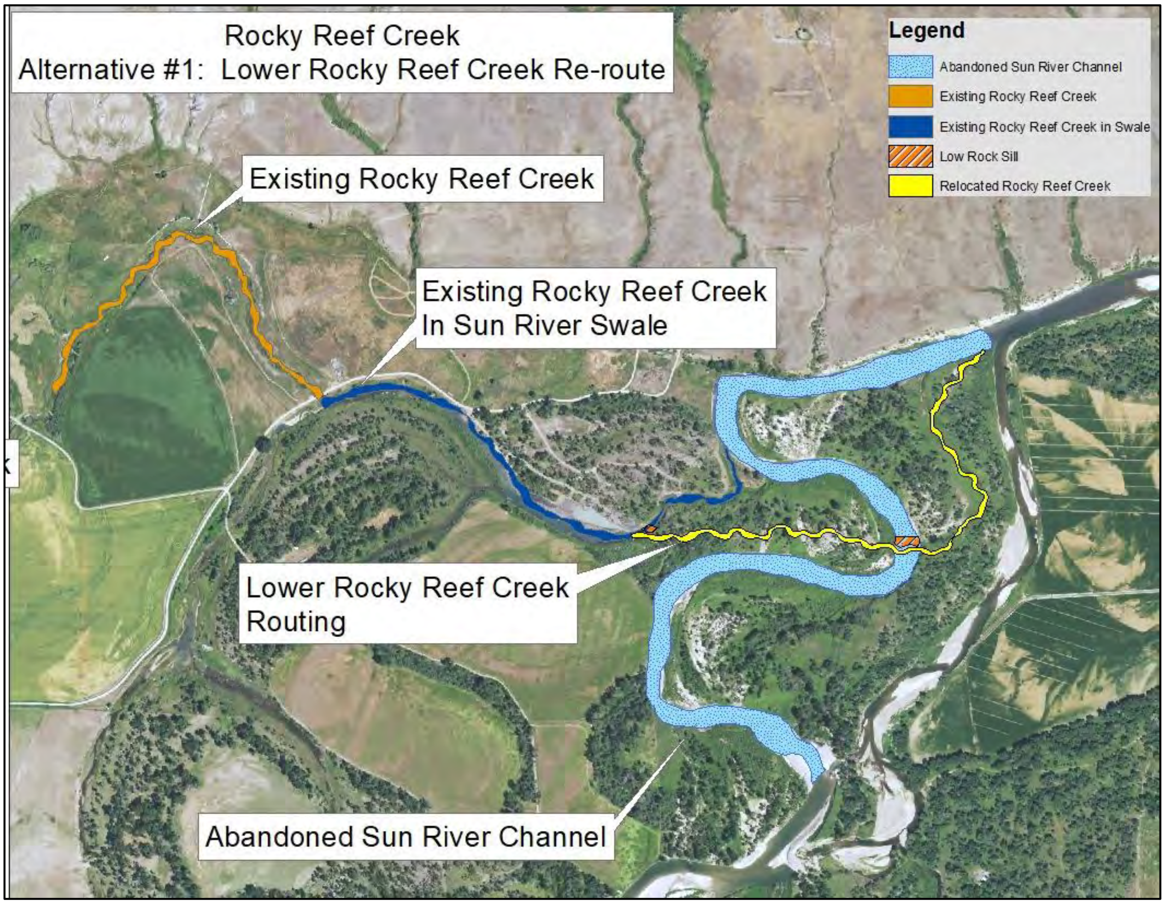


Figure 101. Example potential reconstruction route for lower Rocky Reef Spring Creek.

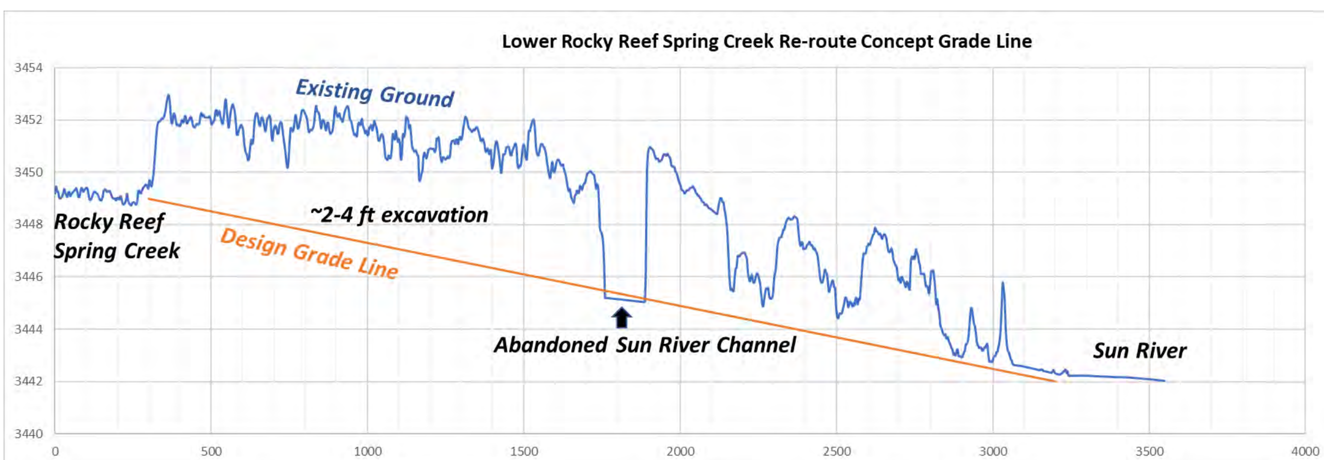


Figure 102. LiDAR profile showing depth of floodplain excavation required to reconstruct lower Rocky Reef Spring Creek-

Figure 103 shows a similar project example on Jefferson Slough near Cardwell, where the creek was relocated from an old Jefferson River slough channel into a more appropriate creek dimension, in this case to increase flow velocities to dissuade the expansion of Eurasian Water Milfoil in this area.

These projects can create excellent fish habitat. On Elk Creek, for example, a small channel constructed within a larger swale (Figure 104) maintains a low width to depth ratio, bank cover, and spawning gravel substrates.

Figure 103. Jefferson Slough reconstruction as smaller creek near Whitehall MT; flow direction is left to right.

Figure 104. Small creek channel construction project in older swale of Elk Creek near Augusta.

7 Elk Creek Results (Phase 2)

This section will summarize the results of the key analyses that feed into the CMZ map generation for Elk Creek. The maps can be found in Appendix B.

7.1 Project Reaches

From the mouth of Smith Creek to the Sun River, Elk Creek was broken into five reaches ranging in length from 1.4 to 4 miles long (Table 2).

Table 4. Elk Creek CMZ mapping project reaches.

Reach	General Location	Upstream RM	Downstream RM	Length (mi)
EC1	Railroad Grade to Mouth	2.2	0	2.2
EC2	Eberly Lane to Railroad Grade	5.4	2.2	3.2
EC3	Lovers Lane to Eberly Lane	8.6	5.4	3.2
EC4	Augusta Clemons Rd to Lovers Lane	10.1	8.6	1.5
EC5	Smith Creek to Augusta Clemons Rd	14.1	10.1	4

The Historic Migration Zone on Elk Creek consists of a composite footprint of river locations from 1955 to 2019.

7.2 The Erosion Hazard Area (EHA)

A total of 429 measurements were collected on Elk Creek. The minimum distance measured is 20 feet, which proved to be an easily measurable distance that is not compromised by the resolution or spatial accuracy of the data. The 1955-2019 measured migration distances are summarized in Figure 41, and migration rates are shown in Figure 42. Migration into the terrace bankline was summarized separately, to allow the application of an erosion hazard buffer specifically to that geologic unit. Mean migration rates and EHA buffer widths are shown in Table 3 and Figure 43. The buffer width is calculated as that distance the river would move over a century's time at the mean annual rate.

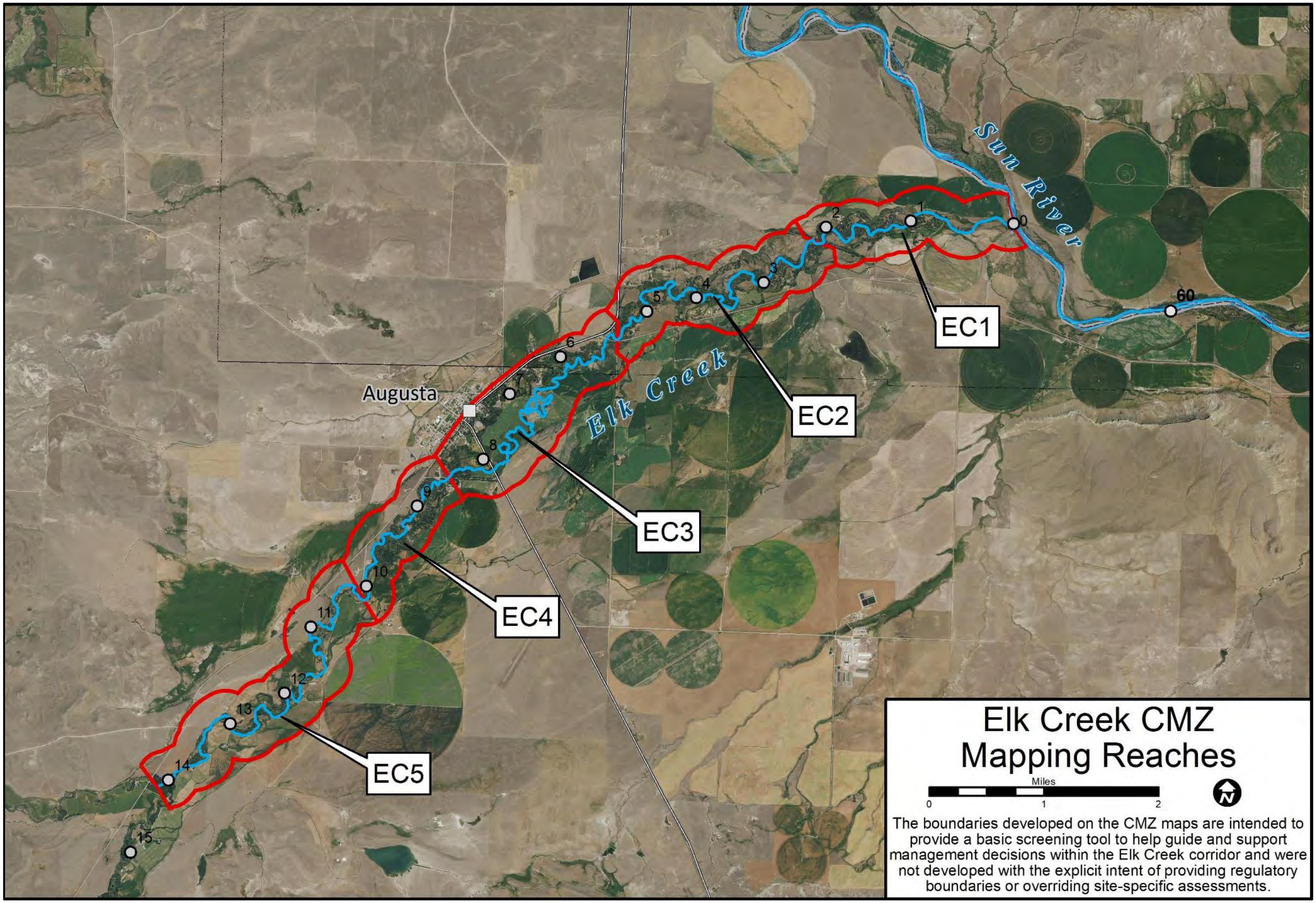


Figure 105. Elk Creek CMZ mapping project reaches.

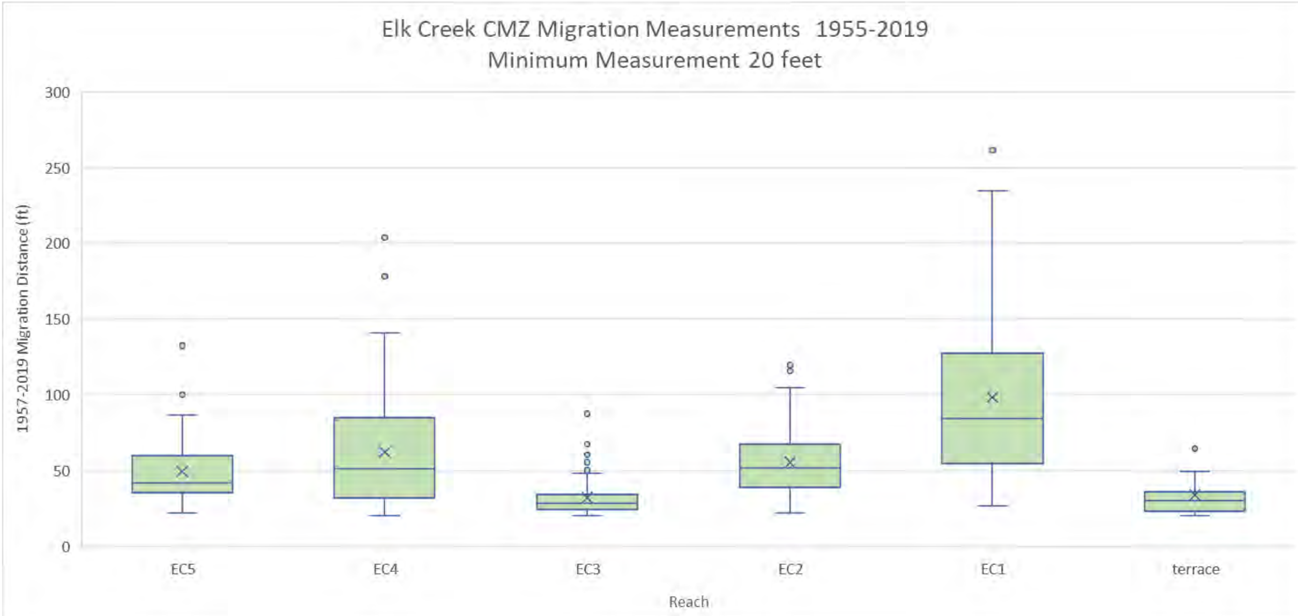


Figure 106. Box and whisker plot showing measured 1955-2019 migration distances by reach and for terraces -- reaches are plotted from upstream (left) to downstream (right). Mean values are denoted by "X".

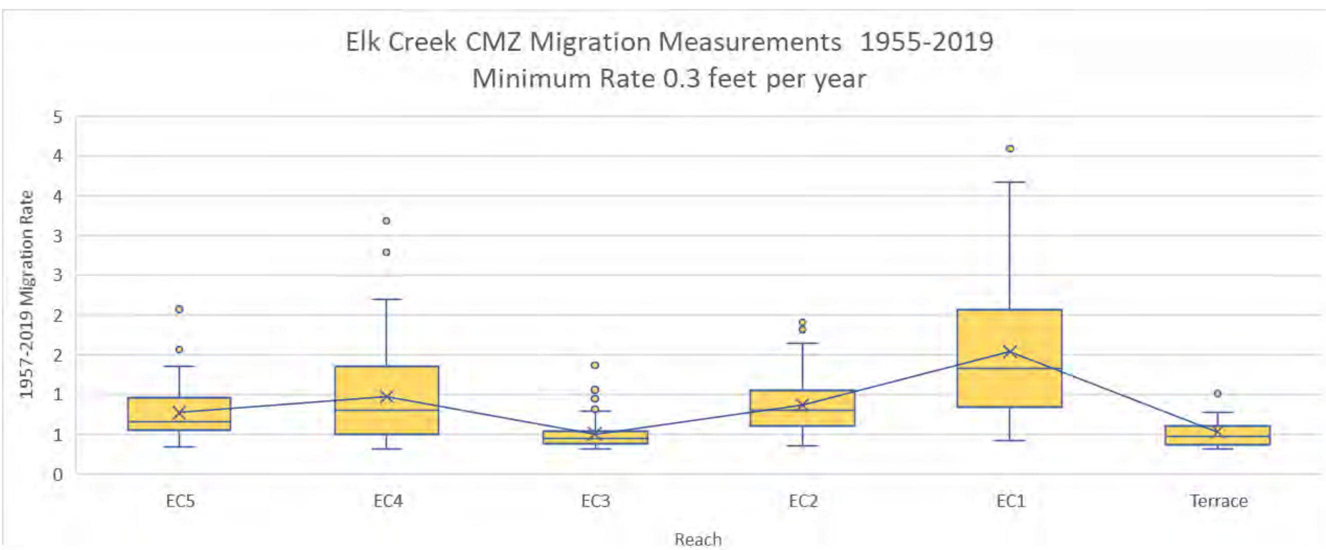


Figure 107. Box and whisker plot showing measured 1957-2019 migration rates by reach and for terraces -- reaches are plotted from upstream (left) to downstream (right). Mean values are denoted by "X".

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

Table 5. Average migration rate and 100-year EHA buffer by reach.

Reach	Number of Measurements	Maximum Migration Distance (ft)	Average Annual Migration Rate (ft/yr)	100- Year Buffer Width (ft)
EC1	58	262	1.5	154
EC2	110	122	0.9	87
EC3	97	89	0.5	50
EC4	70	204	1.0	97
EC5	76	132	0.8	77
Terrace	18	66	0.5	53

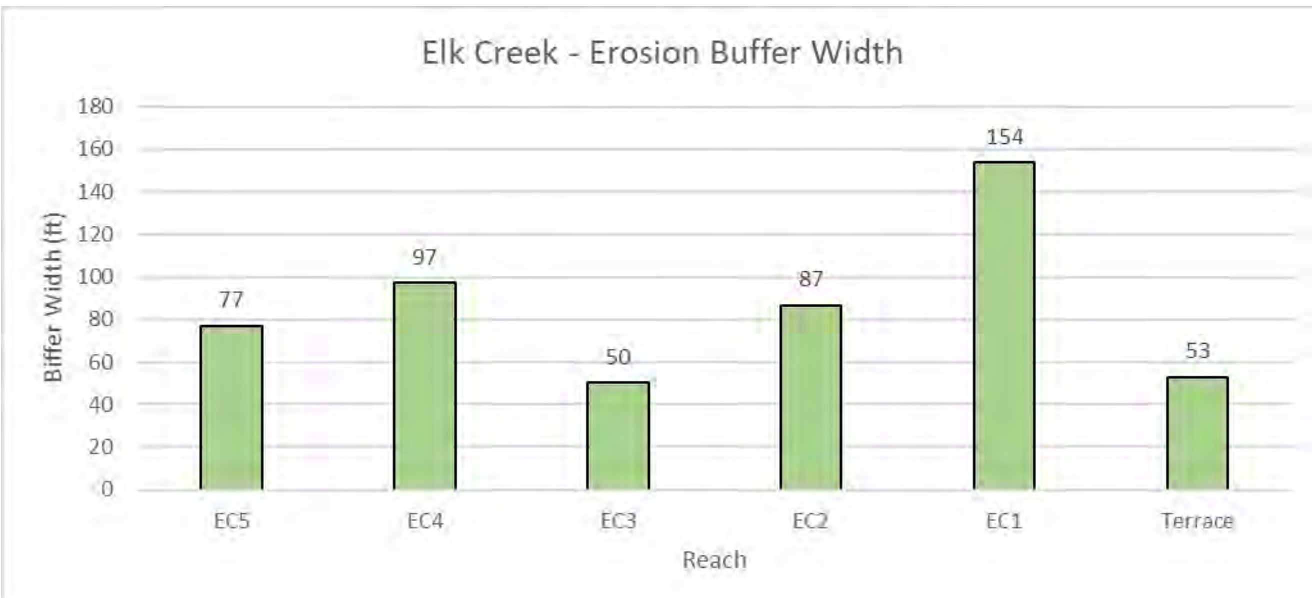


Figure 108. Mean migration rate-based EHA buffer width, Sun River-- reaches are plotted from upstream (left) to downstream (right).

Similar to the Sun River, the erosion buffer is assigned to all banks, even those not currently eroding, to allow future bank movement at any given location.

A total of 16 avulsions were mapped on Elk Creek. The majority (9) of them occurred between 1957 and 1978, and four occurred during the recent floods of 2018/2019.

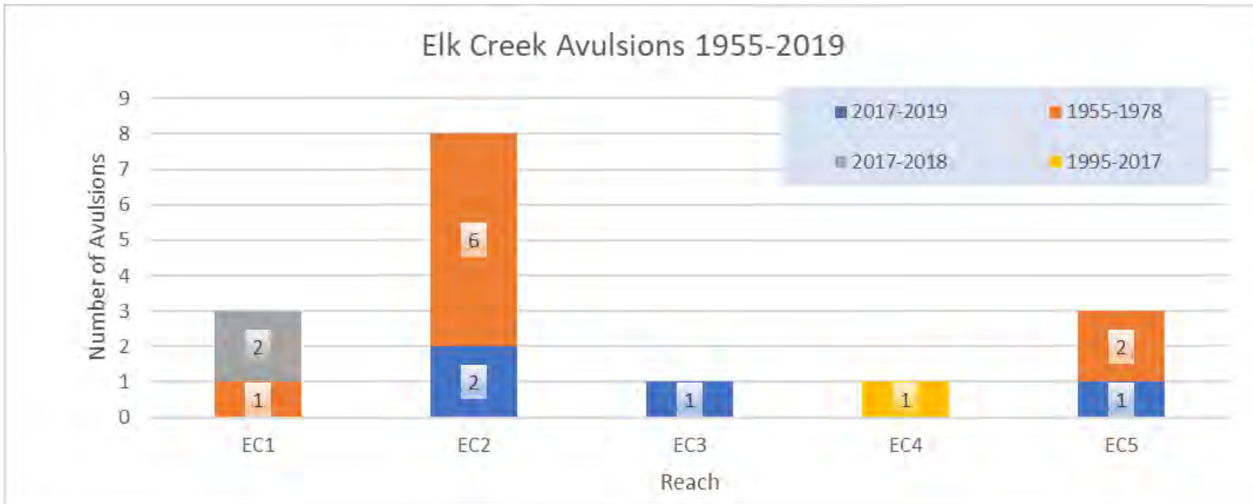


Figure 109. Number of mapped avulsions by reach, Elk Creek.

7.3 The Restricted Migration Area (RMA)

The Restricted Migration Area largely reflects bank protection associated with diversions, agricultural land, roadways, and bridges. It is largely concentrated in reach EC3 and the town of Augusta. Bank armor mapping was performed through a review of available imagery and Google Earth. As much of the bankline is heavily-vegetated, the mapping likely represents only a portion of the armor in place along Elk Creek. A field inventory of the banklines would be required to develop a complete inventory of armor.

A total of 3,400 feet of bank armor were mapped on the 14 miles of project length. Figure 110 shows that the extent of armored banks ranges from 3% to 8% of the main channel length. The densest armor is in Reach EC4, where about ~1,200 feet or almost 8% of the total bankline is armored to protect agricultural fields, diversions, roadways, and developed areas. Below the Hwy 21 bridge in reaches EC2 and EC1, no armor was mapped.

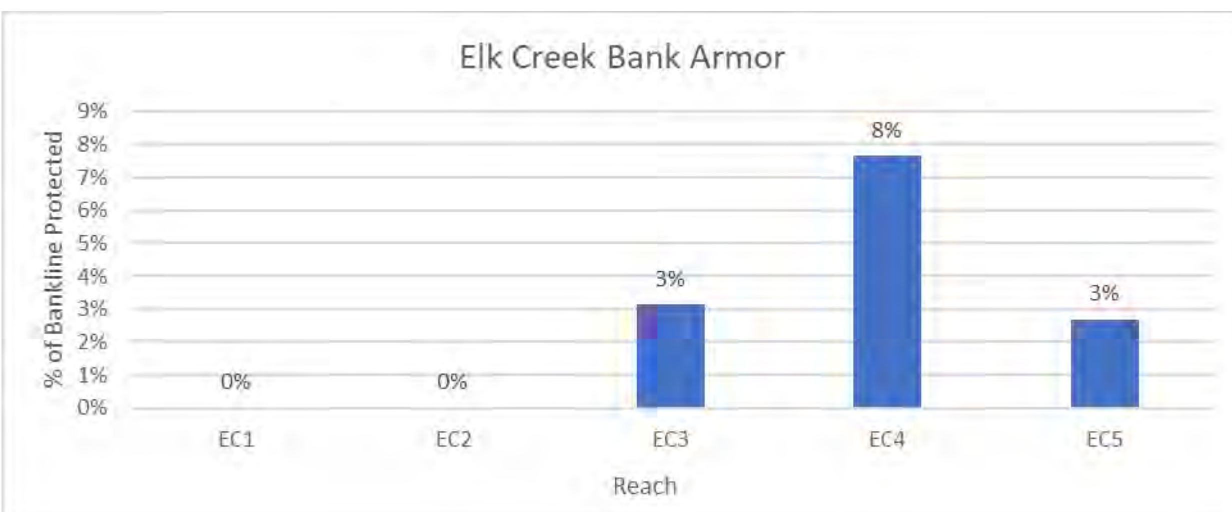


Figure 110. Percentage of bankline protected by armor by reach.

Figure 111 shows an example of Restricted Migration Areas (RMA) on Elk Creek below the Smith Creek confluence.

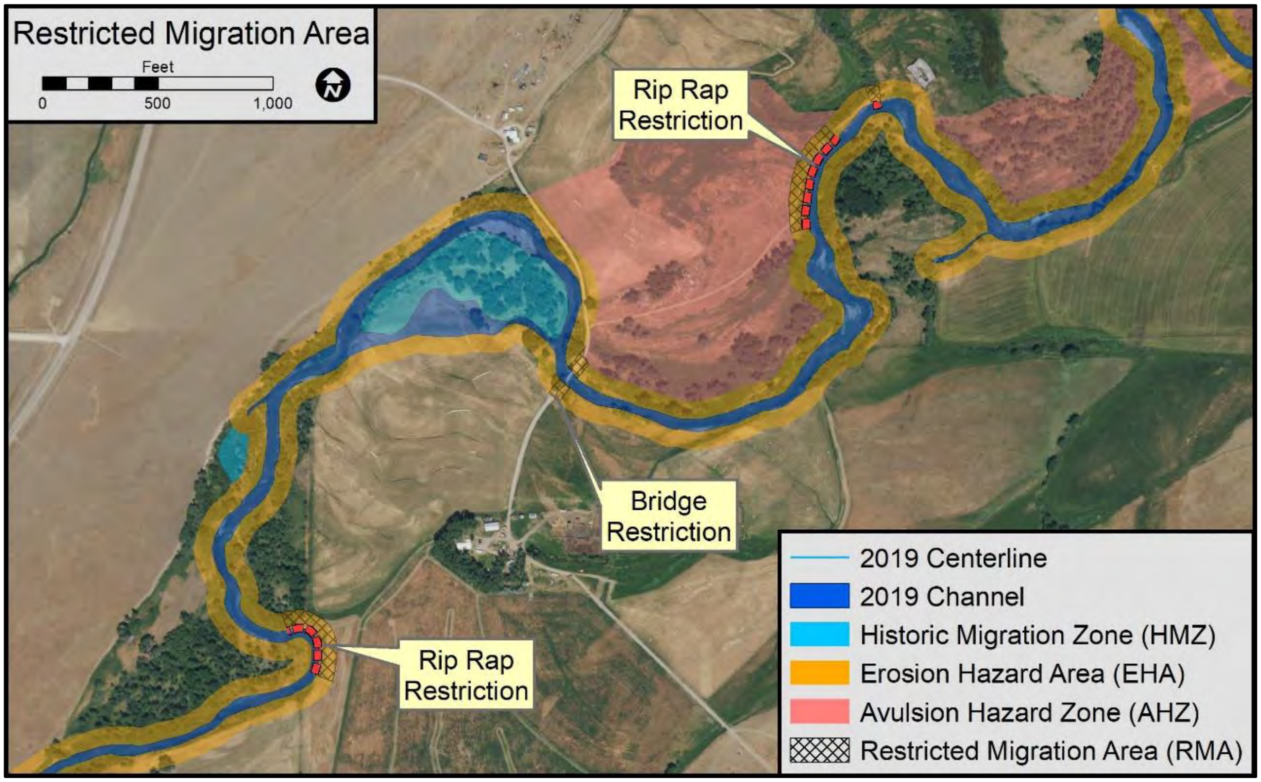


Figure 111. Restricted Migration Areas on Elk Creek.

Bank armoring currently restricts access to approximately 18 acres of the Channel Migration Zone. The majority of this armor is protecting irrigated agricultural land and transportation infrastructure, including six bridges. The amount of restricted area is greatest in reach EC3, with HWY 287 contributing the majority of the area. Again, due to the restrictions on mapping armor, there is likely a greater amount of restricted migration area throughout the Elk Creek corridor.

7.4 Composite Map

An example portion of a composite CMZ map for a section of the Elk Creek project area is shown Figure 113. Each individual mapping unit developed for the CMZ has its own symbology, so that any area within the overall boundary can be identified in terms of its basis for inclusion. Over the 14 mile project reach, a total of 1,082 acres of land makes up the CMZ, or about 77 acres per mile. A disproportionate amount of the CMZ area is due to large split flow areas and avulsion areas in reaches EC2 and EC3 (Lovers Lane to the abandoned railroad grade) which result in large areas of Historic Migration Zone between the mapped channels. This also results in a highly variable CMZ width ranging from 150 feet to over 2,000 feet.

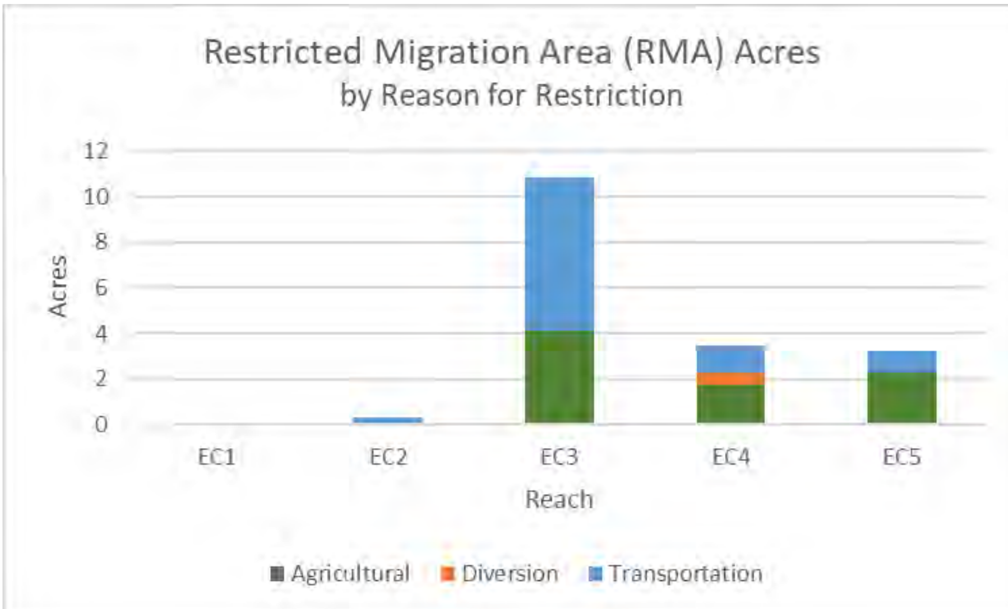


Figure 112. Acres of the CMZ mapped as restricted by reach.

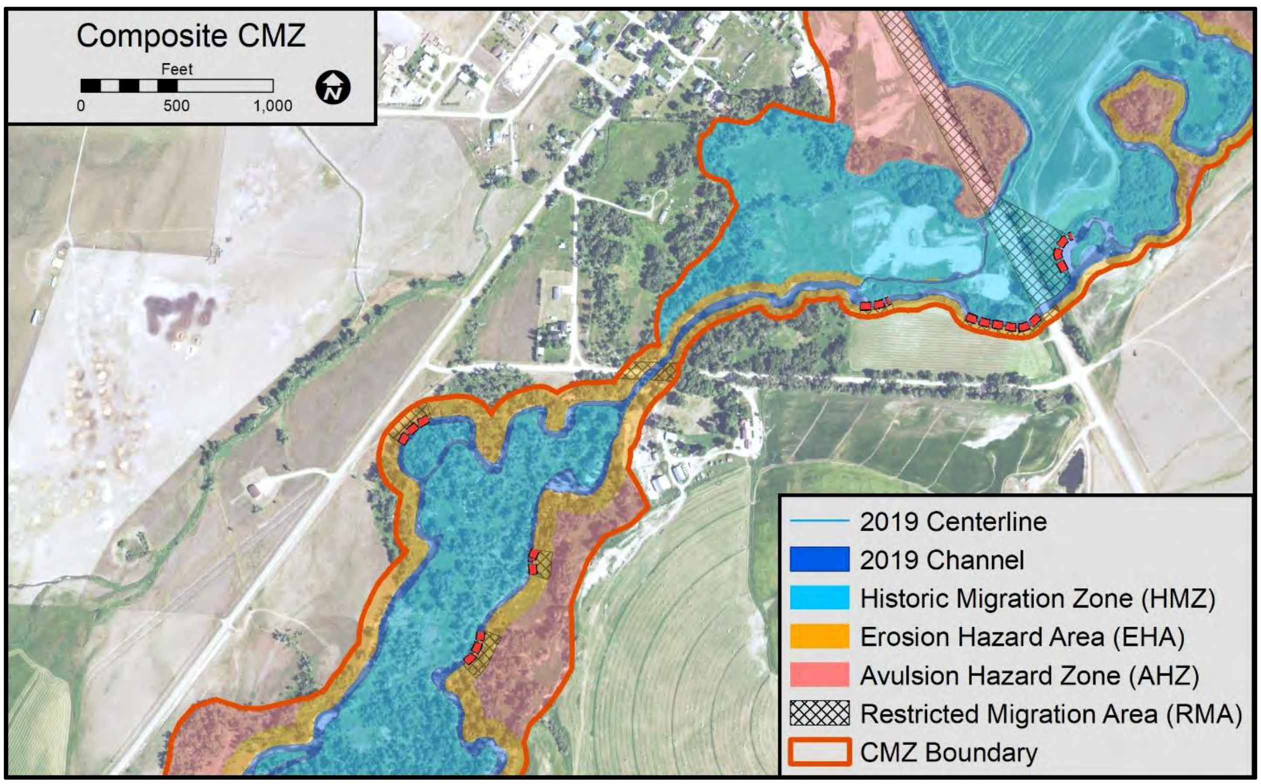


Figure 113. Composite Channel Migration Zone map at HWY 287 near Augusta.

7.5 Elk Creek Reach Descriptions (Phase 2)

The following descriptions extend from the upper portion of the project reach near Smith Creek (EC5) down to the confluence of Elk Creek with the Sun River (EC1). Descriptions are provided in the upstream to downstream direction. The CMZ maps can be found in Appendix B.

Elk Creek is typically on the order of 30-40 feet wide in this area. The valley bottom consists of a mosaic of cottonwood galleries and agricultural fields. Diversions are common. The lateral rates of channel migration are not particularly high as it is a relatively small creek, but the creek is clearly responsive to flooding, with complex flow paths being generated and avulsions commonly occurring.

General Land Office maps and notes of this area describe the area along the creek around the town of Augusta as a “swamp”. Considering the size of this channel, it probably hosted beaver colonies that were largely trapped out during the fur trade that flourished after Lewis and Clark passed through and then crashed in the mid-1800s. Beaver removal from our stream systems in Montana has become increasingly recognized as an agent of major geomorphic change, with broad stream/wetland complexes converting to single thread entrenched channels with less floodplain access and more stream power within the channel itself.

7.5.1 Reach EC5—Smith Creek to Augusta Clemons Road

Reach EC5 is 4 miles long, extending from the Elk Creek/Smith Creek confluence down to the Augusta Clemons Road (Figure 114). The erosion buffer width for this reach is 77 feet, and the highest migration rate measured is 132 feet just downstream of the Highway 435 Bridge at the upper end of the reach. This bendway located immediately downstream of the bridge is in the process of cutting off. There is no apparent issue with this bend cutting off, it is in a dense riparian area and there are no diversion structures nearby. In this case, the avulsion will likely rejuvenate fish habitat and riparian succession as trees enter the creek and new bars form to support seedling establishment.

Reach EC5		
Upstream/Downstream RM	14.1	10.1
Length (miles)	4	
General Location	Smith Creek to Augusta Clemons Rd	
Mean Migration Rate (ft/yr)	0.8	
Max 64-year Migration Distance (ft)	132	
100-year Buffer (ft)	77	
100-year Terrace Buffer	53	

In general, bank erosion tends to be along bendways that have growing point bars that drive opposite bank erosion. Much of the erosion is into cleared hayfields where root reinforcement of the banks is minimal (Figure 115). Several bendways have developed chute channels through their cores, which increases their propensity for cutoff during future floods (Figure 114).

Three avulsions were mapped in this reach, two occurred between 1955 and 1978, and another occurred in 2019 at RM 13.1 on the Converse Ranch (Figure 116). Just below the Highway 435 Bridge an avulsion is underway on a small tight meander bend.

While at a stakeholder outreach meeting in Augusta on April 30, 2021, local landowners in this reach described issues at the Augusta-Clemons Road, which marks the downstream reach boundary. The road crosses the river corridor essentially perpendicularly, and near the creek it blocks several overflow channels that evidently used to have some culvert connectivity (Figure 117). Local landowners feel strongly that the lack of culverts at this location dramatically worsens flooding in the area. They also felt that additional culverts should be added both north and south of the CMZ boundary on the Augusta Clemons Road to alleviate flooding in Augusta and road washouts.

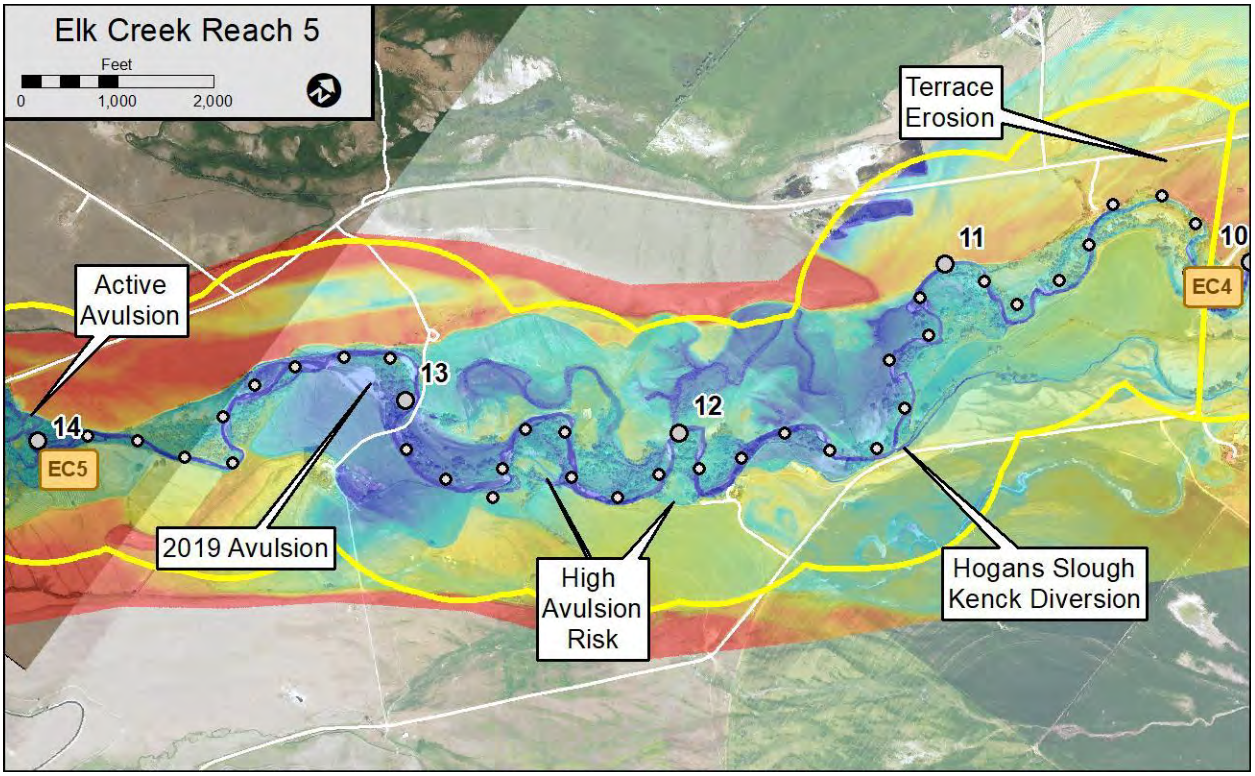


Figure 114. Relative Elevation Model (REM) map for Reach EC5; blue shows areas of relatively low ground whereas red depicts higher surfaces such as terraces on the north side of the corridor.

Figure 115. Typical bank erosion into hayfield, Reach EC1.

Figure 116. View downstream of 2019 eroded floodplain/erosion path on Converse Ranch at RM 13.1

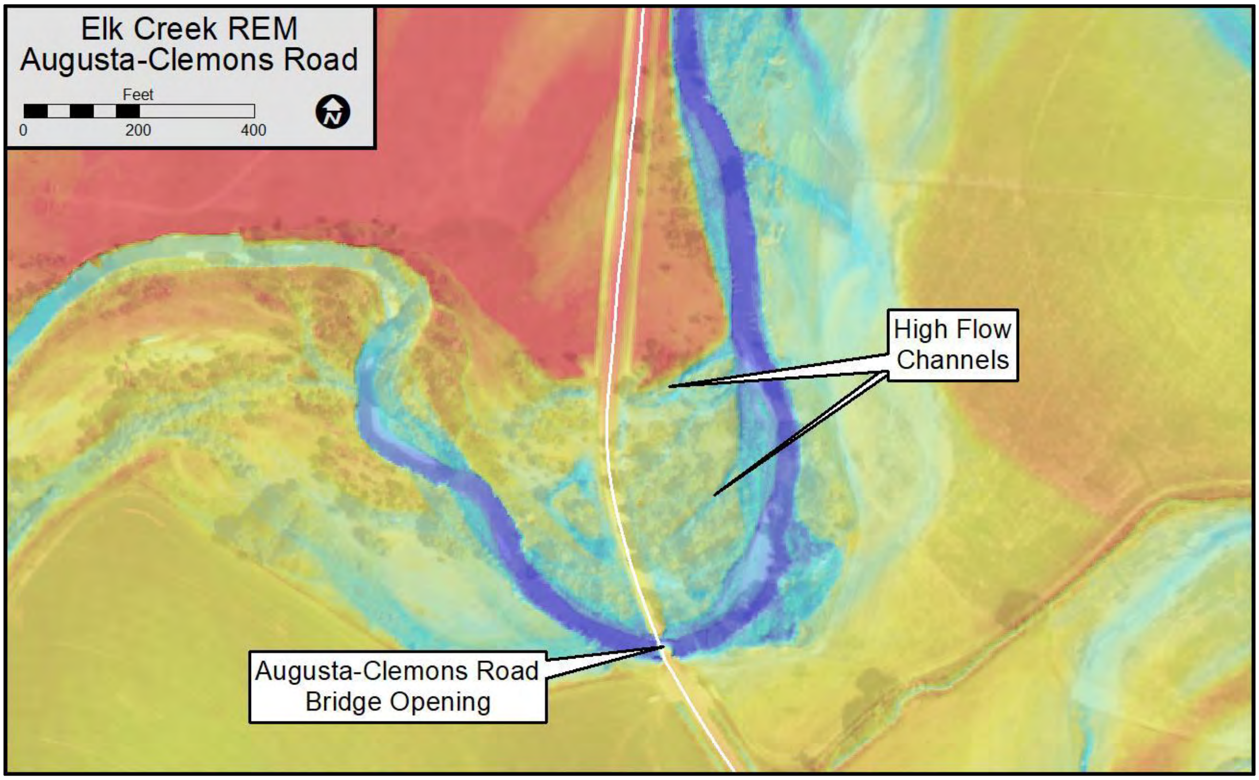


Figure 117. Relative Elevation Model (REM) map the Augusta Clemons Road Bridge crossing, showing floodplain confinement and blocking of high flow channels in meander core.

7.5.2 Reach EC4—Augusta Clemons Road to Lovers Lane

Reach EC4 extends from the Augusta Clemons Road to Lovers Lane, a distance of 1.5 river miles. The erosion buffer width for this reach is 53 feet. Within this reach the Elk Creek corridor widens as the glacial terrace described above becomes less prominent. Some of the stream patterns, which include capillary channels, suggest that groundwater upwelling occurs in this reach. Split flow and avulsions are common, which may be a consequence of the capillary channel development (Figure 118).

Reach EC4		
Upstream/Downstream RM	10.1	8.6
Length (miles)	1.5	
General Location	Augusta Clemons Rd to Lovers Lane	
Mean Migration Rate (ft/yr)	1.0	
Max 62-year Migration Distance (ft)	204	
100-year Buffer (ft)	97	
100-year Terrace Buffer	53	

In the upstream portion of the reach at about RM 9.6 there is a major swale east of the creek that is in the process of reactivating. This swale follows the 1871 channel course mapped in the General Land Office Survey. Currently it appears that this swale functions as a primary overflow/wetland complex.

A major flow split at RM 9.3 marks a significant avulsion node in Reach EC4 (labeled “avulsion node” in Figure 118). This is a complex area where avulsions appear to be a dominant geomorphic process, and this condition carries on downstream past Augusta. The node marks a split between two major channels; the left channel ultimately feeds a diversion, and the right channel flows through a narrow thread that has some old riprap and levees on its banks (Figure 119).

The survey notes from 1871 do not describe the left channel at all, indicating that it formed since then (as it crosses a surveyed section line). By 1955 things had changed substantially as the newly formed left channel was the primary thread, with the right channel becoming discontinuous but apparently collecting groundwater. This condition appears to have been fairly stable through the mid-1990s. By 2011, however, the creek reactivated about 3,500 feet of the previously atrophied right channel, maintaining split flow at the avulsion node (Figure 120). Shortly after, there were attempts to block off the right channel to satisfy water demands at the diversion down the left channel (Pat Troy, pers. comm). This has been difficult to manage, however, as the 2018/2019 floods re-opened the right channel, which caused serious problems downstream. It appears that a debris jam formed on the upper end of the right channel, forcing flows eastward along the edge of a pivot and then through the outbuildings at the Young Ranch just upstream of Lover's Lane. The secondary avulsion was blocked with hay bales and alluvium.

This history suggests that the left channel, which was not even there in 1871, may have been a ditch that was captured by the creek sometime prior to 1955. Since then, the flow split has been a problem as the creek appears to find preferential flow paths in the right channel. LiDAR data indicate that the left channel is perched about five feet above the right channel, which would support the tendency for flow to preferentially occupy the lower right channel.

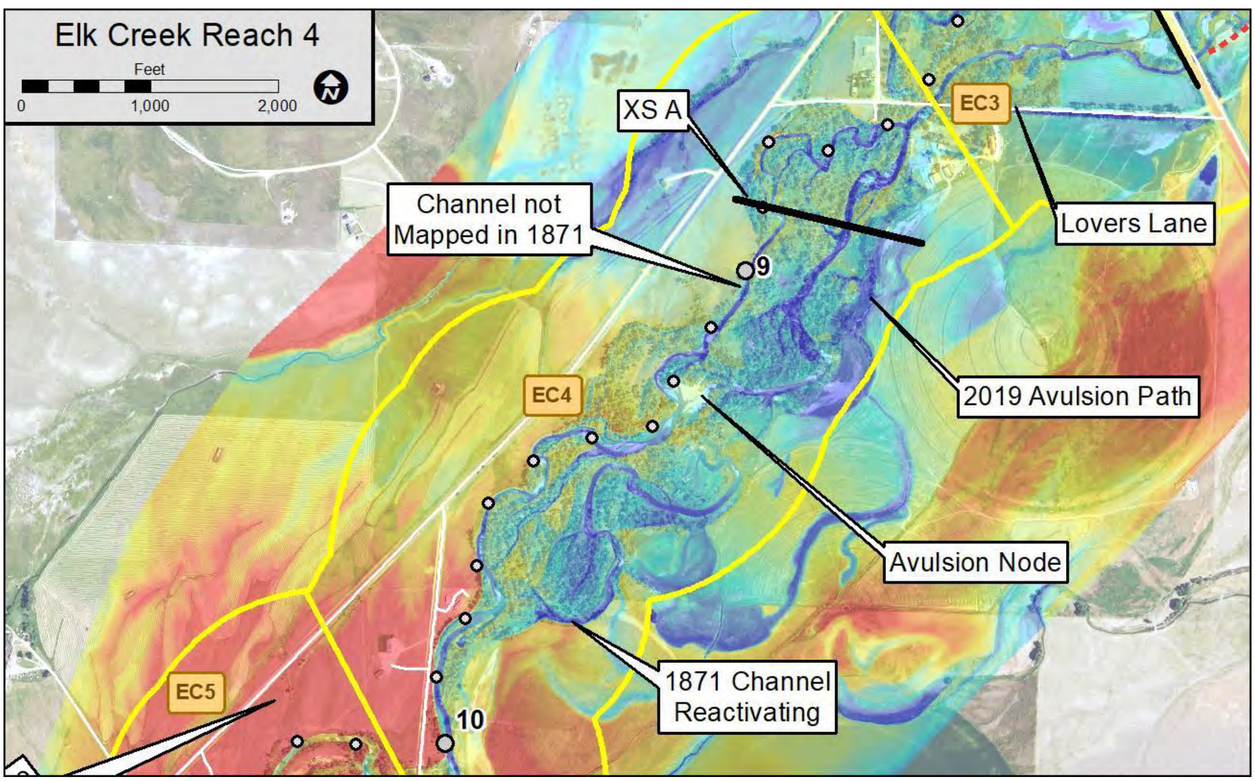


Figure 118. Relative Elevation Model (REM) map for Reach EC4; blue shows areas of relatively low ground whereas red depicts higher surfaces. Cross Section A plot is shown in Figure 121.

Figure 119. View downstream showing riprapped banks in Reach EC4 avulsion channel (right channel).

Figure 120. Photos from 1995 (left) and 2011 (right) showing avulsion into high flow channel remnant.

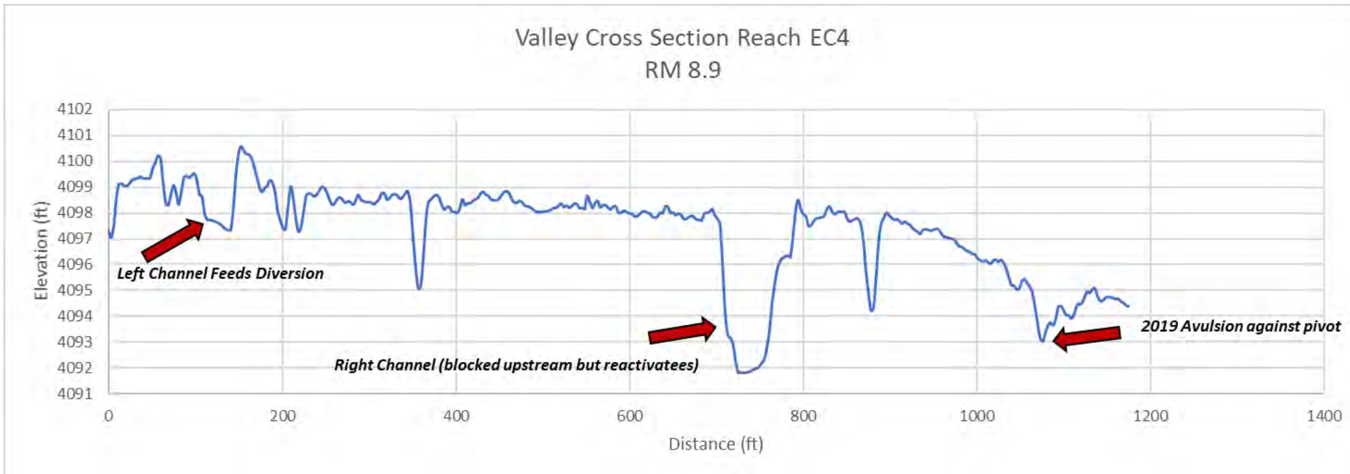


Figure 121. View downstream of Cross Section A labeled in Figure 118 showing perching of left channel over right channel and 2019 avulsion path.

7.5.3 Reach EC3—Lovers Lane to Eberly Lane

Reach EC3 is located in the Augusta area proper, extending 3.2 miles from Lovers Lane to Eberly Lane (Figure 122). The erosion buffer width for this reach is 50 feet. The highest migration distance measured in this reach is 89 feet.

Reach EC3		
Upstream/Downstream RM	8.6	5.4
Length (miles)		3.2
General Location	Lovers Lane to Eberly Lane	
Mean Migration Rate (ft/yr)		0.5
Max 62-year Migration Distance (ft)		89
100-year Buffer (ft)		50

This reach is complicated by split flow, perched channels, avulsions, and a history of manipulation. Recent flood mapping of the area shows that much of the stream corridor is located within the mapped floodway (Figure 123).

In the summer of 2019, Confluence Consulting performed a post-flood assessment of Elk Creek in this segment (Confluence, 2019). They evaluated several avulsions on the properties of the Young and Mills families above and below Highway 287. They noted that a headgate washed out just downstream of Lovers Lane that led to the delivery of higher water than normal to the “overflow channel” next to town.

The tendency for water to flow northward across the Elk Creek floodplain towards Augusta reflects the fact that the floodplain slopes in that direction. At the 287 bridge, for example, a cross section extracted from the LiDAR data shows that the channels that flow through two culverts just west of the rodeo grounds are about 10 feet lower than Elk Creek where it crosses 287 about a half-mile south (Figure 124). The General Land Office Survey map shows that, at that time, the channel close to town was the main thread (Figure 125).

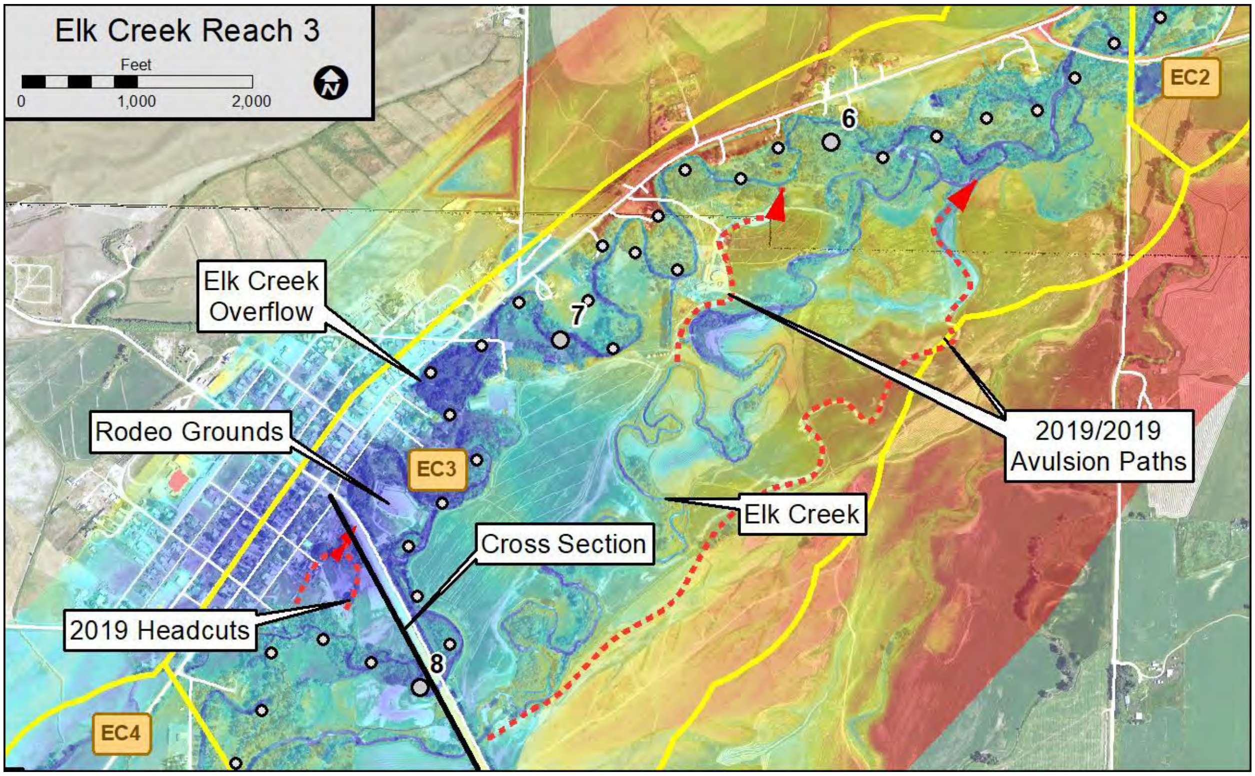


Figure 122. Relative Elevation Model (REM) map for Reach EC3; blue shows areas of relatively low ground whereas red depicts higher surfaces. Cross Section Plot is shown in Figure 124.

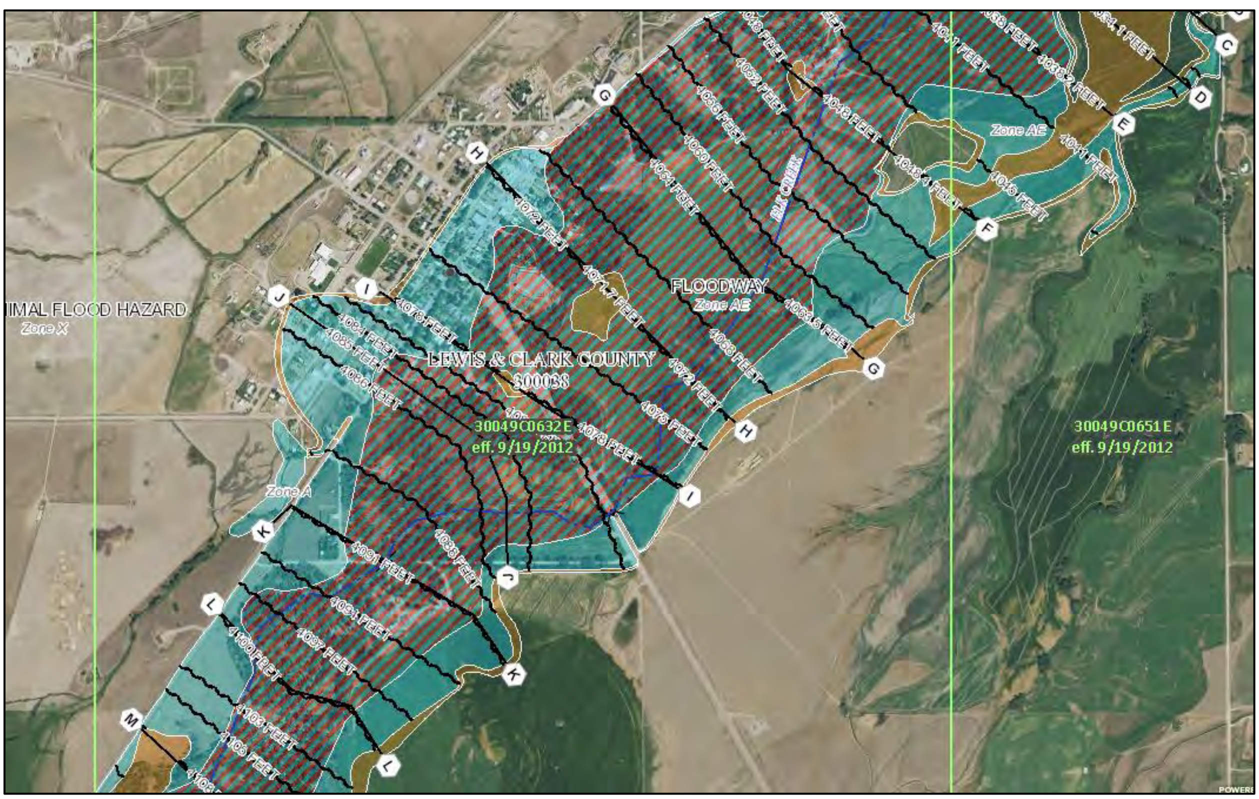


Figure 123. FEMA flood map showing much of Reach E3 as floodway (cross-hatched).

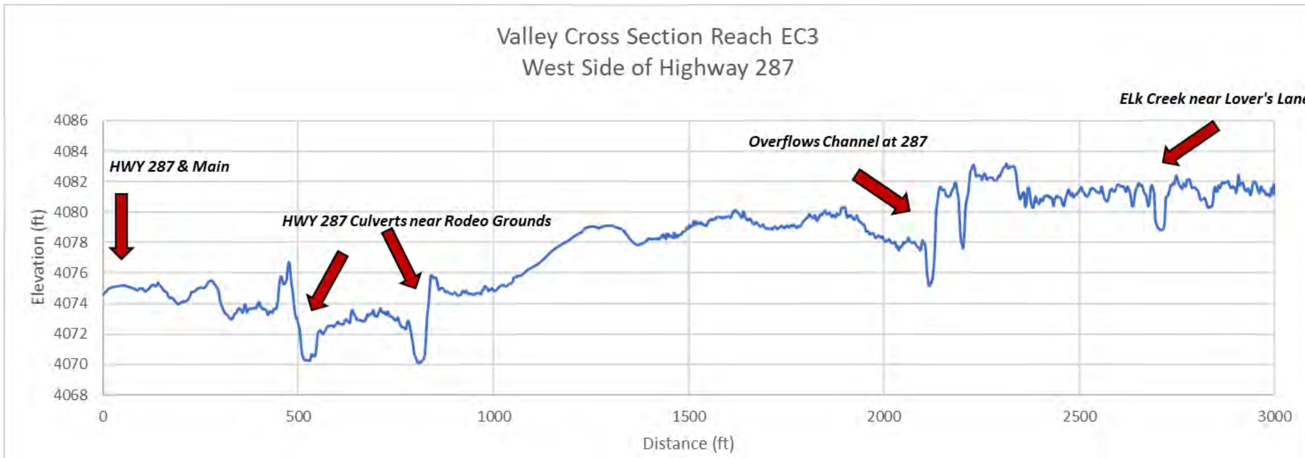


Figure 124. View downstream showing cross section pulled from just upstream of Highway 287; note lowest channels near rodeo grounds and perched modern Elk Creek near Lover's Lane.

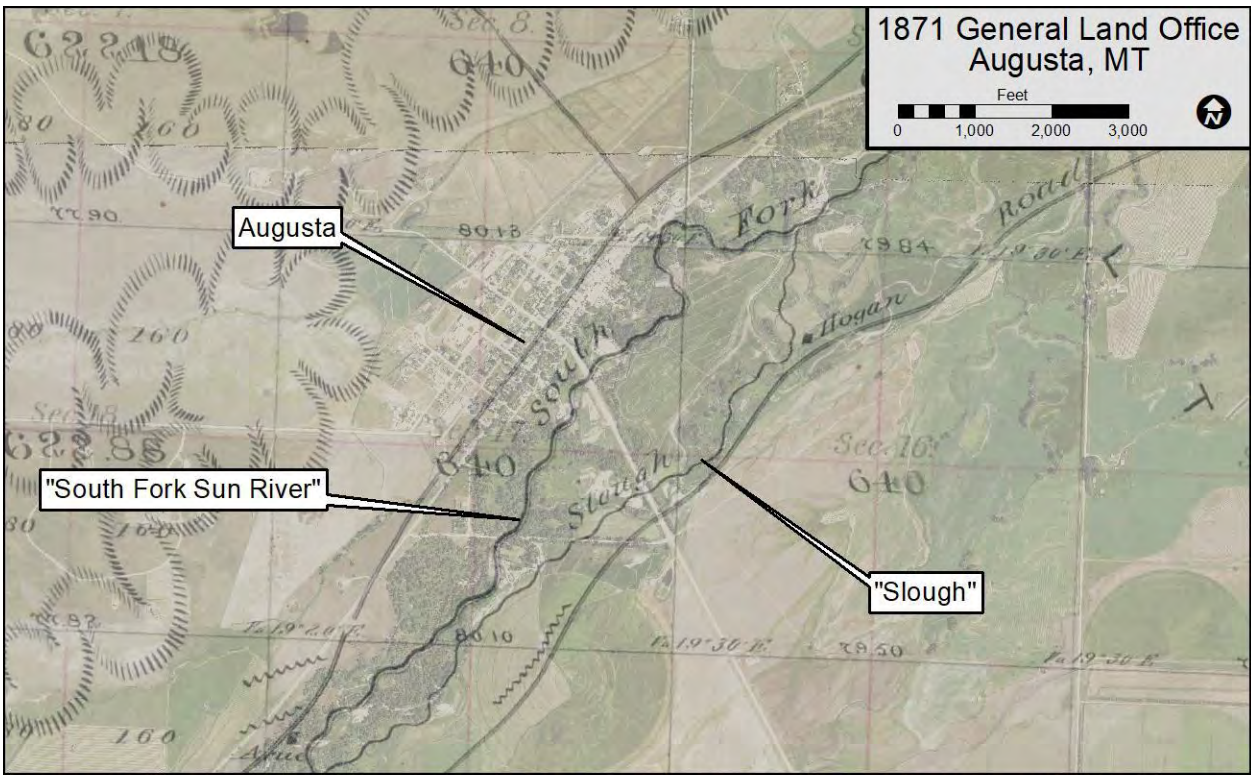


Figure 125. 1871 General Land Office Survey map showing main thread of Elk Creek ("South Fork of Sun River") flowing through what is now referred to as the Overflow Channel near Augusta, and modern Elk Creek following what was described as a slough in 1871.

The Relative Elevation Model clearly shows historic channel routes in this area. It appears that when Highway 287 was built, it crossed Elk Creek channels several times (Figure 126), including three crossings over what is now referred to as the "overflow channel". In several locations the creek was channelized to re-route flows. Just southwest of the Rodeo Grounds, the two culverts appear to follow the path of an older channel that are the lowest in elevation along 287. The route shown in Figure 126 shows how those channels may be the lowest, as they were the furthest downstream when the road was built, hence they are lower. Currently overflows tend to be drawn towards these two culverts near the Rodeo Grounds; in 2019 major headcuts developed due south (upstream) of the two culverts (Figure 127 and Figure 128).

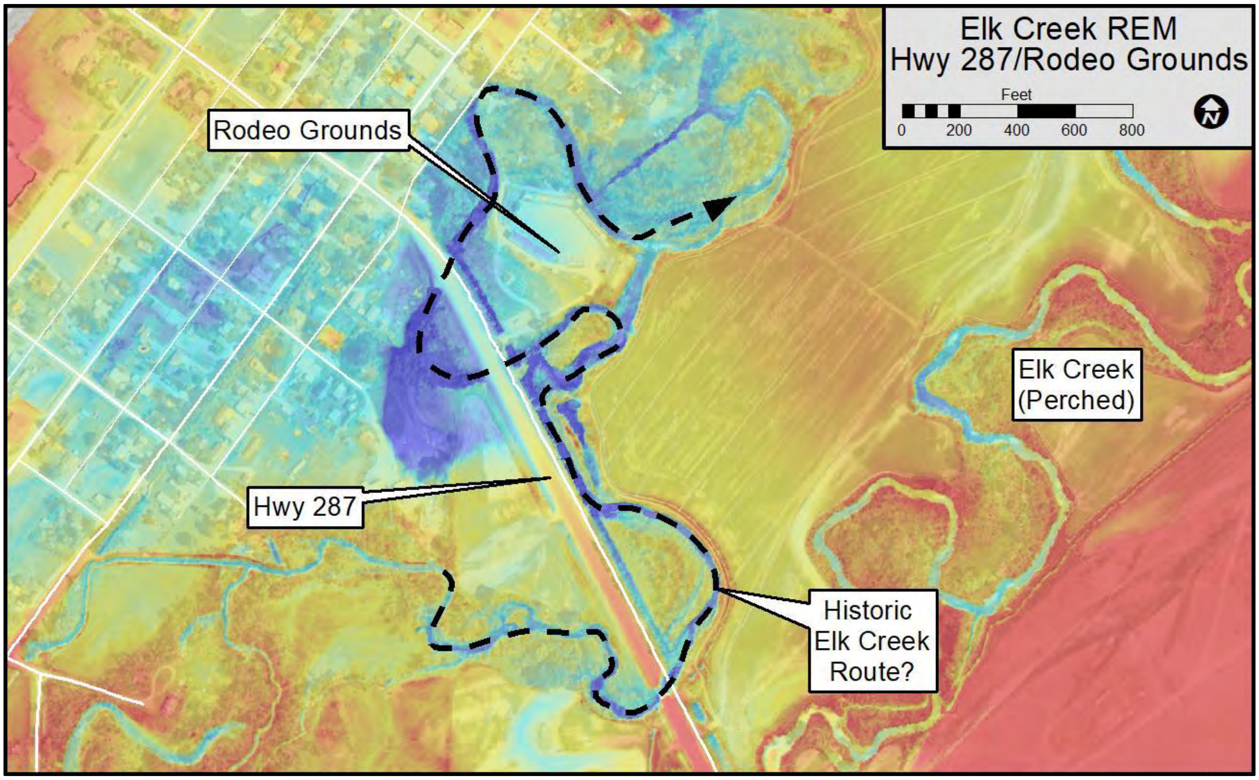


Figure 126. Potential historic route of Elk Creek that would explain why the lowest channels at Highway 287 are located at the blue arrows near rodeo grounds.

It appears that Elk Creek has been channelized and re-routed near Augusta in an attempt to simplify flow paths and to move the main channel away from town and into what was mapped in 1871 as a slough. This appears to work fairly well most of the time, however topographic gradients still pull water towards the rodeo grounds and Main Street through the high flow channel during floods. This will make this reach especially prone to avulsion and floodplain channel formation during high water. As a result of both split flow and avulsion risk, this segment of Elk Creek has the widest mapped Channel Migration Zone footprint in the project area.

At a stakeholder outreach meeting in Augusta on April 30, 2021, local landowners expressed concern that culverts through the highway embankment are undersized and contributing to flooding problems in town.

Figure 127. 2019 flood photo taken by Scott Gasvoda showing potential historic flow path of Elk Creek.

Figure 128. Headcut formed during the 2019 property upstream of Highway 287 (Confluence, 2019).

7.5.4 Reach EC2—Eberly Lane to Railroad Grade

Reach EC2		
Upstream/Downstream RM	5.4	2.2
Length (miles)		3.2
General Location	Eberly Lane to Railroad Grade	
Mean Migration Rate (ft/yr)		0.9
Max 62-year Migration Distance (ft)		122
100-year Buffer (ft)		87

Reach EC2 extends 3.2 miles from to Eberly Lane to the abandoned railroad grade below town. The erosion buffer width for this reach is 87 feet. This reach includes a broad riparian corridor and floodplain that has experienced the most avulsions of any project reach on Elk Creek. A total of 8 avulsions were mapped, 6 of which occurred between 1955 and 1978, and another two avulsions took place since 2017. One major recent channel reactivation happened over the past few years where the river migrated through a small berm and re-accessed a historic swale, causing extensive floodplain erosion downstream (Figure 129). According to local landowners, this channel was still flowing as of late April 2021.

This reach fared well during recent flooding, although high water marks record several feet of floodplain inundation (Figure 130) and some erosion against hayfields (Figure 131). Overall, however, the flood rejuvenated riparian and aquatic habitats without causing extensive damage (Figure 132 and Figure 133). The presence of a robust riparian corridor in this reach may be contributing to its flood resilience.

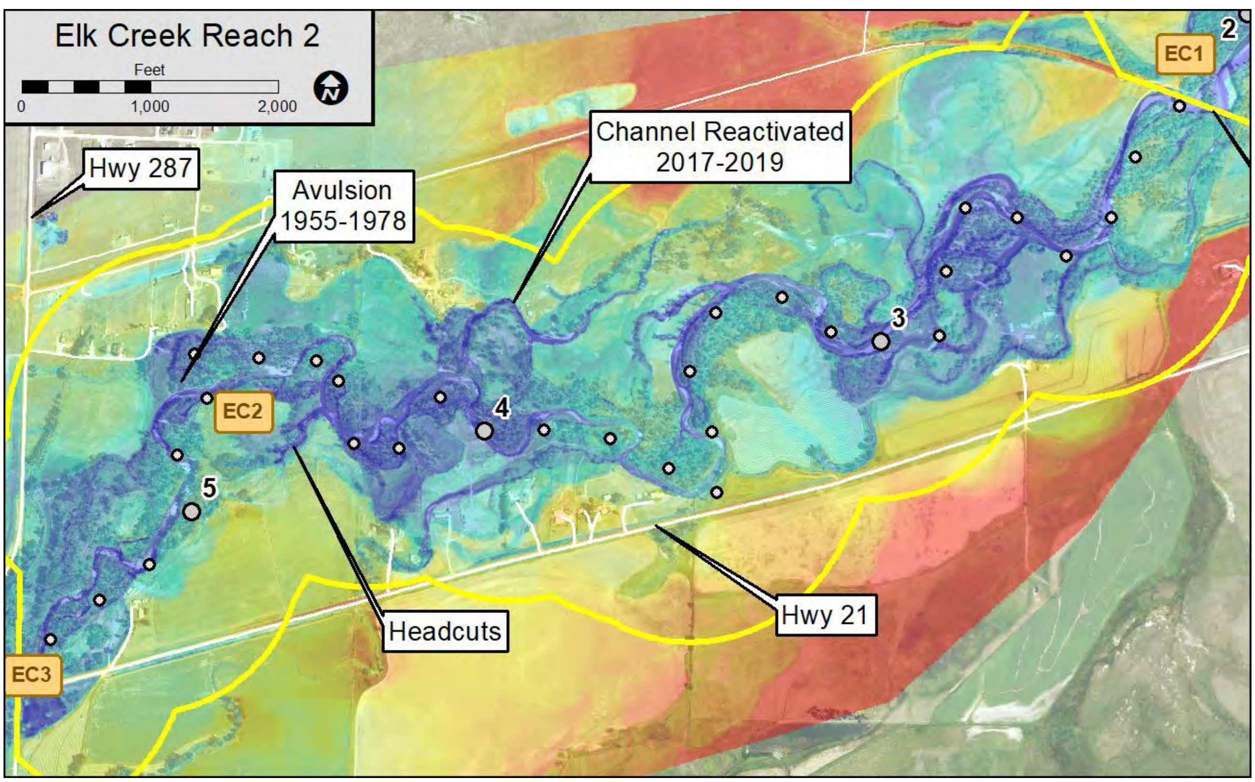


Figure 129. Relative Elevation Model (REM) map for Reach EC2; blue shows areas of relatively low ground whereas red depicts higher surfaces.

Figure 130. Racked flood debris on Elk Creek floodplain, Reach EC2.

Figure 131. View downstream of right bank erosion against hayfield, Reach EC2.

Figure 132. View downstream showing coarse bedload and post-flood habitat complexity common in Reach EC2, 2020.

Figure 133. Exposed cottonwood roots currently sprouting in failed avulsion path, Reach EC2. Note young cottonwood establishment on point bar in center background.

7.5.5 Reach EC1—Railroad Grade to Mouth

Reach EC1 consists of the lowermost 2.2 miles of Elk Creek below the abandoned railroad grade (Figure 134). The erosion buffer width for this reach is 154 feet. The largest migration vector measured in this reach is 262 feet, measured in an area of rapid change near River Mile 1 that is described below.

Reach EC1		
Upstream/Downstream RM	2.2	0
Length (miles)	2.2	
General Location	Railroad Grade to Mouth	
Mean Migration Rate (ft/yr)	1.5	
Max 62-year Migration Distance (ft)	262	
100-year Buffer (ft)	154	

This lowermost reach of Elk Creek appears to be a "response reach" in that it is prone to substantial change due to inputs from upstream. This may be due to reduced slope as the creek approaches its confluence with the Sun River at RM 0. One reason for a higher level of response in this reach may be due to the progressive erosion of the abandoned railroad embankment at the top of the reach that has delivered large quantities of sediment downstream (Figure 135). Downstream of the grade, a large floodplain channel reactivated in 2019, and the entrance to the reactivation was subsequently graded and plugged by a wood/gravel berm (Figure 136 and Figure 137). Further downstream at River Mile 1, there have been major changes in channel location and form, which appears to have started with major floodplain erosion during the 1964 and 1975 floods (Figure 138). The left side of the railroad embankment appears to be imminently prone to breaching, however continued sediment contributions from this area will likely persist for some time, keeping this reach prone to point bar formation, bank erosion, floodplain channel activation, and avulsion.

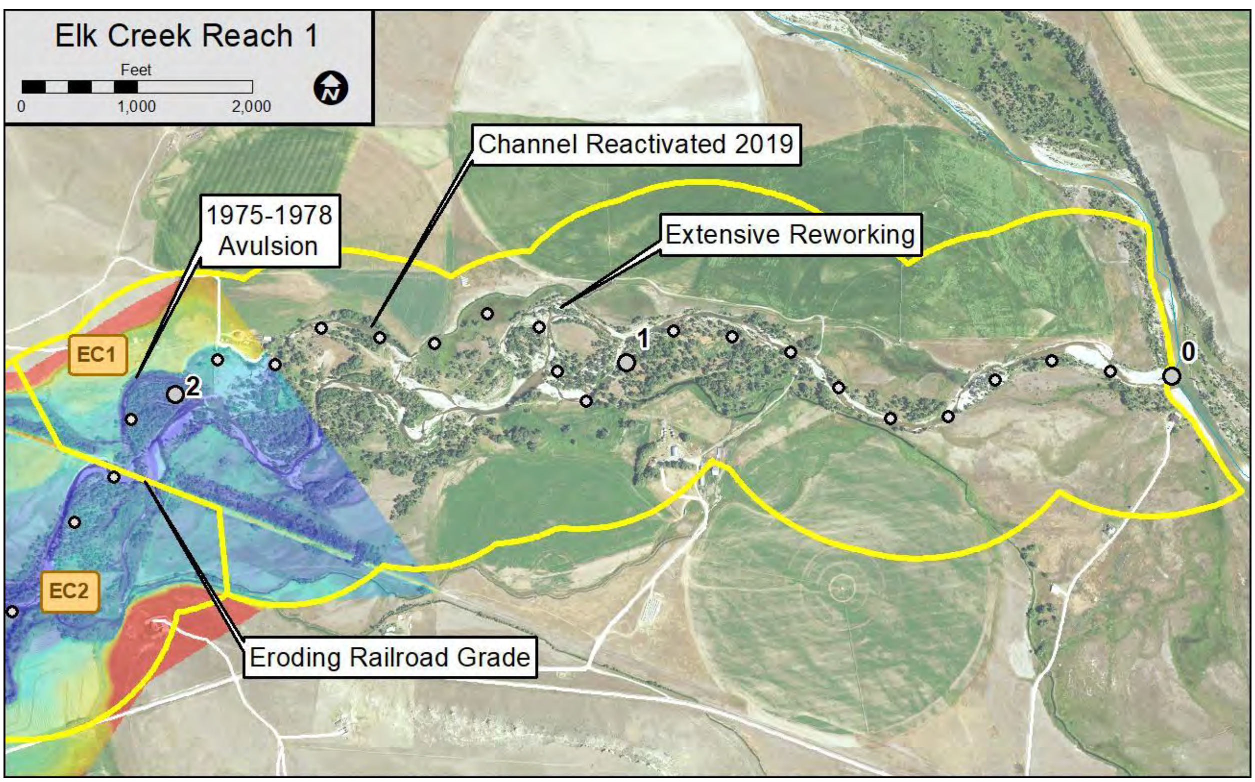


Figure 134. Air photo of Reach EC1 showing major features (LiDAR data was only available for the upper portion of this reach).

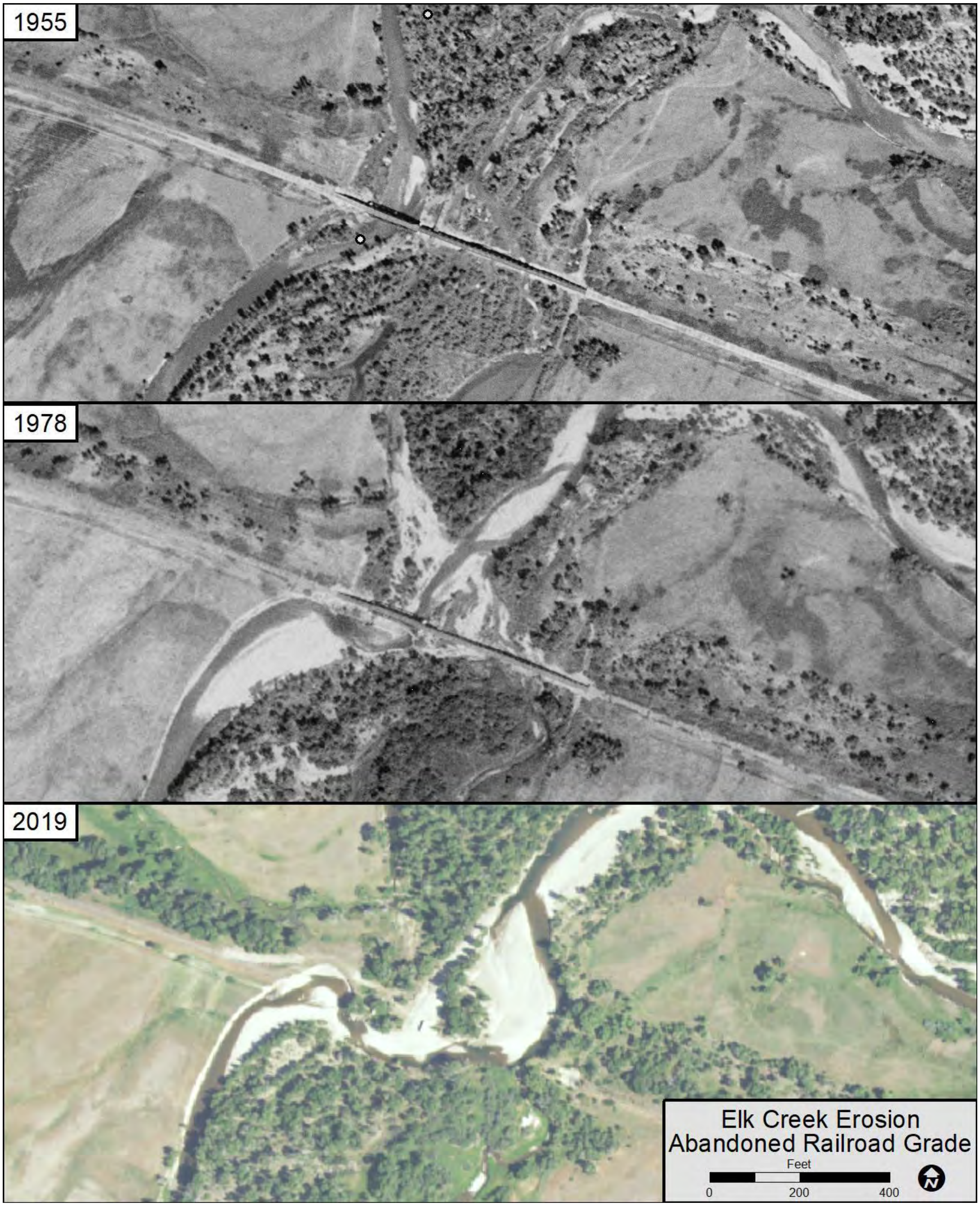


Figure 135. Time series showing progressive erosion at abandoned railroad grade at top of Reach EC1.

Figure 136. View downstream of flood channel reactivation route.

Figure 137. View upstream of berm constructed to block reactivation route.

Figure 138. Time series from RM 1.0 showing dramatic changes in Elk Creek since 1955.

8 CMZ-Related Management Considerations for the Sun River and Elk Creek

The following section summarizes several management strategies applicable to Channel Migration Zones.

8.1 CMZ Management and Stream Corridor Resiliency

Perhaps one of the most important results of this study is the clear documentation that the Sun River below the Highway 287 Bridge is a dynamic river corridor that naturally experiences high rates of change due to coarse sediment delivery, a flattening slope, a propensity for large rain-on-snow flood events, and a wide valley floor. The Sun River is more than a channel, it is a mosaic of active and abandoned channels on a wide floodplain that experiences major changes through time. The upper watershed delivers high volumes of coarse bedload sediment, and as the river loses slope it loses the capacity to transport that material. This deposition drives point bar formation and meander migration which will lead to bank erosion, meander cutoffs, and floodplain avulsions. Loss of sediment transport capacity in the lower project area explains in part why sand and gravel mining has been so persistent near Vaughn, where the slope of the river is about one third of that of the river upstream above Lowry Bridge.

One of the most important considerations in Sun River management is therefore how to integrate the protection of fixed infrastructure while allowing the river to naturally respond to floods, changes in sediment delivery (e.g., pulses), and topographic imbalances on the floodplain. Allowing the river to naturally adjust is important from a resiliency perspective, as local slope adjustments will help prevent chronic deposition and perching of the river above its floodplain. This means meanders will continue to grow and cut off, and the river will change its location on the floodplain, reworking sediments and minimizing topographic disparities.

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

- 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 pivot towers beyond the margins of the Erosion Hazard Area to reduce the need for near-term bank armoring.
- Carefully taper the CMZ to bridge openings using bank armor approaches that gradually narrow the stream corridor to the bridge opening.
- As possible, minimize bank armoring projects that run perpendicular to the axis of the CMZ. Any channel segments that trend across the CMZ (typically north/south) will have increased erosive pressure on the down-valley (east) 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. While the Sun River has been impacted by development pressures of transportation, irrigation water delivery and residential expansion, its inherent dynamism has limited human encroachment into the CMZ footprint. As a result, there are sections on the river that show largely unimpeded channel movement and resulting complex channel forms, both spatially and temporally. The Sun River CMZ corridor is commonly over 3,000 feet wide and supports broad riparian forests of diverse age classes. The continual turnover of floodplain forest supports long term riparian health as the woody vegetation is constantly regenerating (Figure 139 and Figure 140). Wood recruitment in more dynamic reaches is common, and entrainment of both wood and sediment through bank erosion supports to aquatic habitat development and sustenance. These conditions clearly contribute to the long-term viability of our willow/cottonwood corridors and provide geomorphically deformable river channels that can adjust to changing inputs in the future.

Figure 139. Riparian succession below Lowry Bridge; channel movement has prompted establishment of smaller cottonwood seedlings on open gravel bars on the river's edge.

Figure 140. Black cottonwood seedlings establishing on new post-2019 flood gravel bar, Elk Creek.

8.2 Gibson Dam Operations

At one of the outreach meetings for this effort, a discussion focused on how reducing flood peaks by storing additional water in Gibson Reservoir could dampen rates of change and associated economic impacts downstream. Currently, irrigation is the only federally authorized purpose for the dam (HRC&RMS, 2013). It is common for reservoirs to provide floodwater storage and changing the water delivery patterns downstream can influence rates of river movement. This should be carefully considered on the Sun River, however, as reducing peak flows may reduce the amount of time the floodplain is inundated, but it will lengthen the time the river channel is running full. Longer durations of moderate flood levels may result in higher long-term bank erosion rates but will likely reduce avulsion frequency.

8.3 Roads and Bridges

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

8.4 Irrigation Infrastructure

Irrigation infrastructure can be challenging to maintain on dynamic channels where diversion dams, headgates, or pumping systems are in fixed locations. Avulsions can completely bypass diversions, and there is some concern that will happen with the active avulsion occurring on Adobe Creek on the Sun River. In general, however, many diversion structures on these streams are well-placed and well-functioning. Structures that are placed on the downstream limbs of bendways that show low rates of movement tend to perform best. Figure 141 and Figure 142 show an example of such a diversion on Elk Creek—it diverts water on downstream limb of a bendway that follows terrace margin that is relatively erosion-resistant. This diversion also has a rock drop structure that survived the 2018/2019 flooding intact, while effectively diverting flows.

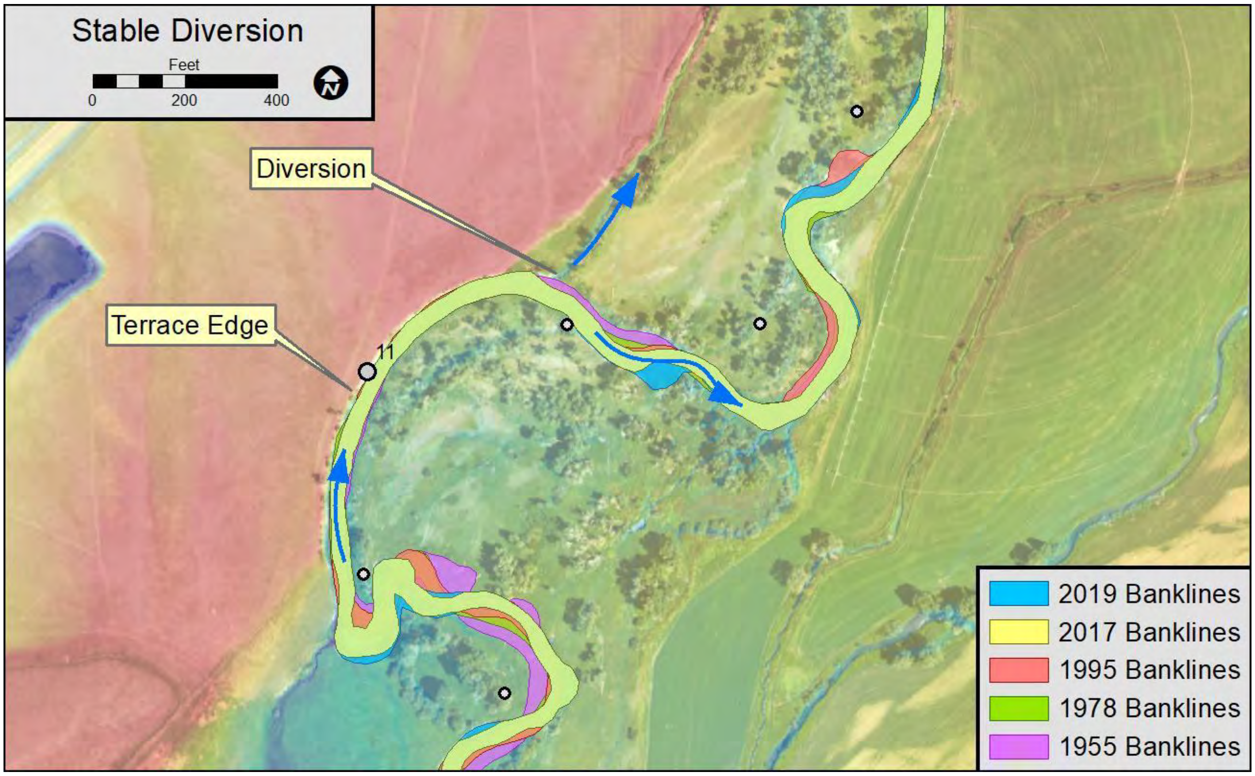


Figure 141. Stable diversion location on Elk Creek, RM 11.

Figure 142. View downstream from left bank terrace of stable diversion structure, Elk Creek RM 11.

8.5 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 our public outreach meetings, both for this study and throughout Montana, 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, one landowner moved his house 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.

8.6 Riparian Clearing

The CMZ mapping has revealed some riparian degradation on the Sun River. The cause of this degradation is probably active clearing to improve agricultural lands (Figure 143). However, the continued persistence of a robust riparian corridor on segments of the Sun River indicates that riparian restoration could be an effective means of improving floodplain/bankline resilience, and possibly reducing bank migration rates.

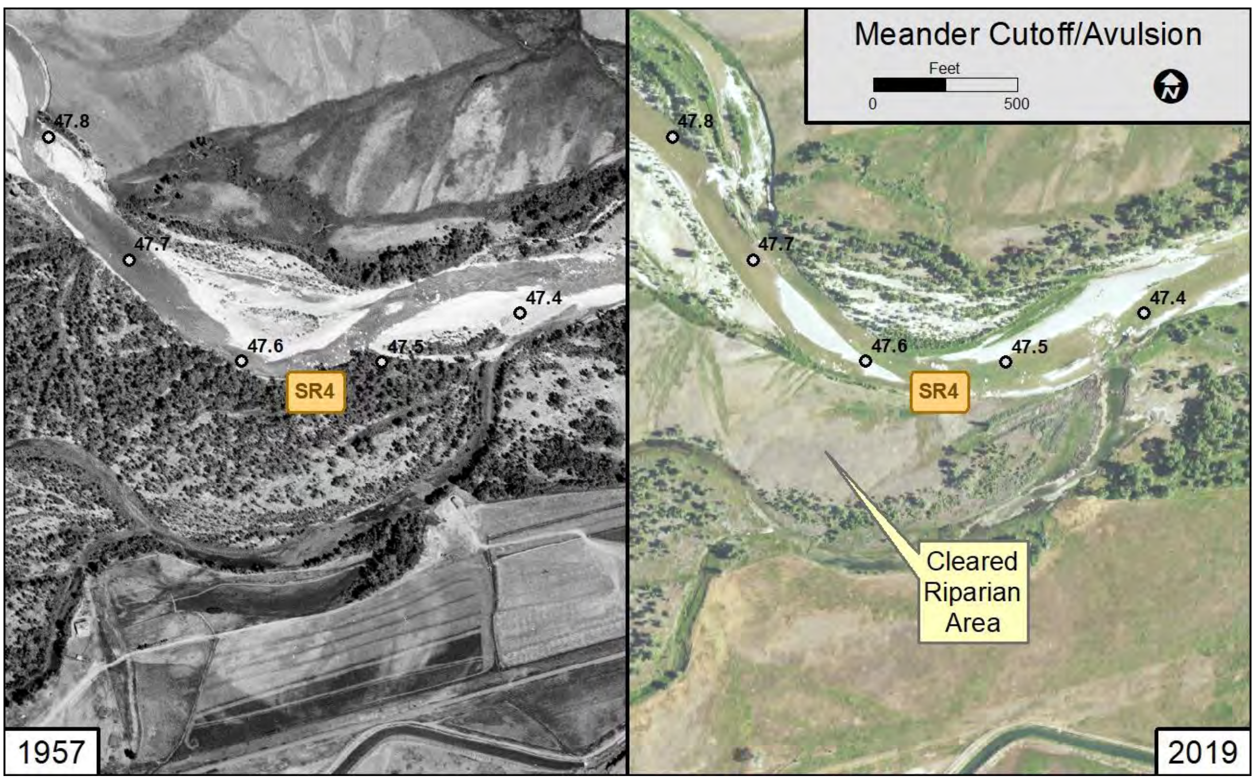


Figure 143. Riparian clearing on Sun River floodplain between 1957 (left) and 2019) right, Reach SR4.

9 CMZ-Related Project Considerations for Specific Issues

This section describes some mitigation strategies for CMZ-related issues on the Sun River and Elk Creek. These issues include avulsions, accelerated bank erosion, terrace erosion, and failed infrastructure that is in the channel.

9.1 Avulsions

An avulsion is the creation of a new river channel away from the main thread. On both Sun River and Elk Creek, this may occur where the river captures a tributary, due to a meander cutoff, or where an old swale is captured. It may relocate the whole river or create a secondary channel. Avulsions commonly 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. Although avulsions typically occur during floods, they can also be driven by meander migration into an old swale, which is common on the Sun River. The following recommendations relate to managing avulsions:

1. ***Preventing Avulsions:*** In many locations on the Sun River, avulsion risks have been managed by building berms across swales where high flows are likely to channelize and convert the swale to a perennial channel. This may reduce the energy in the swale, but these berms have been shown to erode out if they are some distance down the erosion path. If an avulsion is to be prevented, it should be addressed at the upper flow split, known as the "avulsion node". This will require plugging and reconstructing the bankline where flows enter the avulsion path.

2. ***Managing Avulsions:*** In some cases, preventing an avulsion is nearly impossible, since they can occur unexpectedly during high water. If an avulsion occurs it may be optimal to manage the new flow path as an active channel. This may involve relocating/replacing infrastructure on the avulsion path or protecting infrastructure as the new channel develops.

3. ***Reversing Avulsions:*** It is not uncommon to re-route a channel back to its original path following an avulsion, although this can be difficult if the avulsion route is much shorter/steeper than the original channel. This type of project generally requires rebuilding a bank and floodplain at the point of avulsion, putting intermediate plugs on the avulsion path to prevent recapture, and excavating any new deposition from the original channel.

4. ***Accommodating Avulsions:*** Allowing avulsions to occur where there is no direct threat to infrastructure can rejuvenate aquatic and riparian habitats while allowing slope adjustments to progressively occur. This can help prevent wholesale perching of the river over its floodplain and negate the high costs typically necessary to entirely prevent an avulsion.

It is important to secure cooperation between neighbors in managing avulsions. Stopping an avulsion in an area where the avulsion path provides a more efficient route than the main channel can be an expensive venture that requires long-term vigilance.

9.2 Accelerated Bank Erosion

Probably the most common complaint with channel migration is bank erosion. As a result, bank armoring is typically the most common means of managing river locations and rates of change. On the Sun River, Kellogg (2014) noted the following:

> *River volatility makes it difficult and expensive to keep existing bank armor intact and functional. Several sections along this reach are in jeopardy of being flanked by the river. The best long-term management approach is to maintain healthy riparian vegetation and limit infrastructure development along the river. Bank stabilization may only be worthwhile where high value infrastructure (i.e. roads, buildings, irrigation structures, etc.) requires protection.*

We support this recommendation. Table 6 lists the bank armor sites described by Kellogg (2014) in terms of condition and priority for additional work. His workup, only included sites below Lowry Bridge, indicates that bank armor on the Sun River is highly prone to progressive damage or complete failure. Several projects have been completely lost, including flow deflector and rootwad projects. Riprap is highly prone to flanking. Of the 24 bank armor projects he reviewed, only 9 appear to be performing as intended. Based on these observations, it appears that flow deflectors and bioengineering treatments such as rootwads have not performed well on the Sun River.

Table 6. Bank armor sites below Lowry Bridge described by Kellogg (2014) describing current performance.

Kellogg (2014) Site Reference	River Mile	Treatment	Priority (2014)	Condition (2014)	Condition (2020)	Performing?
SR-3	44.6	Rock Flow Deflectors	Medium	Seven of nine deflectors flanked	Same	**No**
SR-7	39.2	Root Wads/Rocks	High	Washed out	~85 feet erosion behind treatment; high avulsion hazard	No
SR-8	37.9	Riprap	No Action	Some repairs	Lower 130 feet eroded out	Upper portion
SR-14	34.3	Riprap	No Action	Upper portion intact; lower end flanked	480 feet eroded out; upper end flanking	Partially
SR-15	33.7	Riprap/Jetties	Medium	Flanking on ends of treatment	Upper end flanking	Partially
SR-17	32.8	Root Wads/Rocks	Medium	Upper 80' washing out	Upper end flanking	Partially
SR-18	32	Riprap/Rootwads	Low	Some sloughing	Lower ~230 feet eroded out	Upper portion
SR-19	31.8	Riprap	No Action	In need of minor repair	Lower ~40 feet eroded out	Upper portion
SR-21	30.1	Flow Deflector	No Action	In need of repair	Repaired	Yes
SR-22	29.8	Riprap/Jetties	Medium	Prone to flanking	Jetty removed	Yes
SR-23	29.3	Riprap	No Action	Prone to flanking	Lower end eroded out	Yes

Kellogg (2014) Site Reference	River Mile	Treatment	Priority (2014)	Condition (2014)	Condition (2020)	Performing?
SR-24	29.1	Riprap	Low	Erosion just upstream	Continued erosion upstream	Yes
SR-25	28.8	Riprap	No Action	Performing well	Performing well	Yes
SR-26	28.5	Rock Jetty	Medium	Prone to flanking	Jetty flanked	No
SR-29	27.7	Riprap/Jetties	No Action	Performing well	Severe erosion between jetties; risk of upper jetty flanking	Partially
SR-30	26.3	Riprap	No Action	Performing well	Performing well	Yes
SR-32	24.5	Riprap/Jetties	Medium	Prone to flanking; upper 30' in need of repair	Completely flanked; ~100 feet of erosion behind	No
SR-35	23.2	Rootwads/Rubble	Medium	Rootwads okay, rubble non-functional, public hazard	Lower 100 feet eroded out since-2017	Upper portion
SR-38	21.2	Rootwads/Riprap	Medium	Rootwads from 2002 washed out.	Jetty and rootwads eroded out; 160 feet of migration since 1995	No
SR-39	21	Root Wads	No Action	Performing well	Tight bend; performing ok	Yes
SR-40	21	Car Bodies	No Action	Performing well	Performing well	Yes
SR-41	20.5	Car Bodies	High	Public hazard	Public Hazard	No
SR-42	20.4	Car Bodies	Medium	Public hazard	Public Hazard	Yes
SR-43	19.6	Riprap	High	Failed barbs/riprap disrepair	Performing well	Yes

9.3 Accelerated Terrace Erosion

High terrace erosion is a distinct characteristic of the Sun River due to the erodible nature of the terrace deposits below Lowry Bridge. The erosion mechanism for these units can be related to several factors, including river erosion, mass wasting/slumping of a high vertical bank, and saturation of those terrace sediments due to irrigation on top. For the purposes of this study, the geotechnical aspects of the terraces were not individually assessed, and as such factors such as geotechnical failure or saturation-driven failure should be considered carefully at each site. As far as river erosion goes, however, the primary technique generally applied to high banks is to construct a low armored bench at the base of the terrace to provide a buffer between the river and the high valley margin, and to densely vegetate that surface to provide some erosion resistance.

9.4 Debris in Channel

Kellogg (2014) noted several locations were old man-made features are sitting in the middle of the channel (Figure 144). These features were commonly identified as public hazards. These features can also cause unusual locations and rates of channel movement due to the complex hydraulic fields they create at high water. As a result, removing these features from the active channel is recommended as funding allows.

Figure 144. Bridge abutments in channel approximately 1.5 miles downstream from Largent's Bend Fishing Access Site (Kellogg, 2014).

10 Discussion

Prior to human development, the Sun River and Elk Creek probably hosted a complex mosaic of active channels flowing within a densely vegetated floodplain. These conditions, which were typical of major Upper Missouri River tributaries, allow floodwaters to spread through multiple channels and across a rough floodplain surface. The first major human impact to the river was likely beaver trapping. In the early 1800s beaver trappers explored the Upper Missouri watershed and beaver populations plummeted. Beaver eradication 200 years ago has been generally recognized across Montana as a profound driver of change in our rivers and streams. This change was dominated by a conversion from multi thread channel/wetland complexes to much more efficient and energetic single thread channels. Further development of stream corridors beginning in the late 1800s generally included consolidation of river channels to facilitate water use and riparian clearing to expand agricultural lands.

It is difficult to say if the Sun River was more active historically than it is today. The consolidation of flows into larger channels would tend to increase stream power and associated bank erosion over the last 150 years. However, the system has also been altered by flow diversions and reservoirs, which would tend to reduce stream power and associated bank erosion rates. Gibson Dam was built in the upper watershed in the 1920s, no doubt altering natural patterns of flow and sediment delivery to the river. Imagery used in this analysis shows broad expanses of open gravel bars in the 1950s and 1970s; these features may reflect short-term influences of floods, or alternatively may reflect a historically typical condition. As the influence of Gibson Reservoir includes starving the river of coarse sediment, the impacts would be initiated below the dam and then extend downstream with time. It is possible that sediment loads to the reach were naturally higher into the 1970s and that those loads are beginning to drop off as the project reach begins to experience the influence of sediment trapping upstream. An assessment of these broader historic trends was generally beyond the scope of this effort but considering them may provide some insight as to the state of the river today.

This assessment of channel migration rates and patterns on the Sun River indicates that this system has maintained a strong propensity for rapid lateral migration as well as avulsions (wholesale channel relocations). This is due to the combination of coarse bedload delivery and flattening slopes, amplified by occasional large rain-on-snow driven floods. As the river flows off of the glaciated Rocky Mountain Front towards the low gradient areas around Great Falls, stream energy naturally drops and coarse sediment is deposited as point bars and in stream deposits. This sediment drives lateral bank erosion through point bar/meander development as well as avulsions via channel perching and breaching into older swales. As a result, the floodplain currently hosts a complex mosaic of active and inactive channels, all of which have the potential for some level of dynamism.

Considering the costs associated with managing lateral migration on a river such as the Sun, stakeholders in this river corridor are relatively fortunate due to the use of a larger bench canal system to support irrigation needs. As a result, there are only a few primary diversion structures on the river and development encroachment into the stream corridor has been relatively tepid. The fairly low concentration of key infrastructure elements on the river is commendable and, if maintained, will both save money and preserve important stream functions into the future. Our attempt with this analysis is to document/demonstrate the nature of channel movement on the Sun River and Elk Creek, to help develop effective management strategies that both support local economies while minimizing river corridor impacts that prove to be costly and ineffective.

Elk Creek has recently experienced dramatic change due to sequential years of major flooding. Landowners have been adaptive in restoring their land uses in the stream corridor. That said, the floodplain asymmetry near Augusta will likely result in continued tendencies for flows to travel north out of the channel across the floodplain, potentially carving new avulsion paths that will need to be managed.

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Appendix A: 11X17 CMZ Maps for the Sun River (Separate Document)

Appendix B: 11X17 CMZ Maps for the Elk Creek (Separate Document)