*Updates to the orginal Ruby CMZ were made in 2017 as part of the Clear Creek CMZ.
Please also see the Clear Creek CMZ Report and the Upper Missouri Headwaters CMZ Summary Report.

Final Report

November 30, 2010*

Ruby River
Channel Migration Zone Mapping

Prepared for:

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1.0 Introduction

This report describes the development of a Channel Migration Zone (CMZ) map for the Ruby River from Ruby Reservoir downstream to the Beaverhead River. The project was performed under a contract dated May 19, 2010 between Ruby Valley Conservation District (RVCD) and Applied Geomorphology, Inc. AGI teamed with DTM Consulting, Inc. (DTM) to perform this work.

The contracted Scope of Work is "to perform a Channel Migration Zone Study and develop maps to assess channel migration and river bank erosion for the main stem of the Ruby River, from the outlet of the Ruby Dam to the confluence with the Beaverhead River. Additionally, the purpose of this project is for the Contractor to provide an educational opportunity for the TAC, county officials, and interested community members to learn about the Ruby River Channel Migration Zone Study and maps for potential local uses."

The following report describes the process used in developing a final map product, including data acquisition, data development, analysis, interpretation, map formulation, and recommendations for further analysis in support of management efforts in the Ruby Valley.

1.1 Channel Migration and Avulsion Processes

Along the majority of its extent, the Ruby River is an ***alluvial*** river, meaning it flows through sediment that has been deposited by the river itself (versus bedrock, concrete, etc.). As a result, the river is in a constant state of sediment reworking, as it builds point bars, erodes banks, and conveys sediment downstream. On meandering rivers such as the Ruby, these geomorphic processes are critically important for riparian vegetation communities, as the new bar surfaces provide areas for vegetative colonization by young trees including cottonwoods (Figure 1). Bank erosion also results in the recruitment of woody debris, which contributes to fish habitat quality and complexity.

Over a given timeframe, the Ruby River occupies a corridor that extends beyond its current channel boundaries (Figure 2). The width of this corridor reflects rates of lateral migration. Some banklines migrate relatively slowly due to low stream energy or erosion-resistant perimeter materials. Conversely, some banks migrate rapidly where the stream energy and sediment loads are relatively high and the erosion resistance of the channel perimeter is low (Figure 3).

Figure 1. Bar formation, wood recruitment, and riparian vegetation succession, Ruby River.

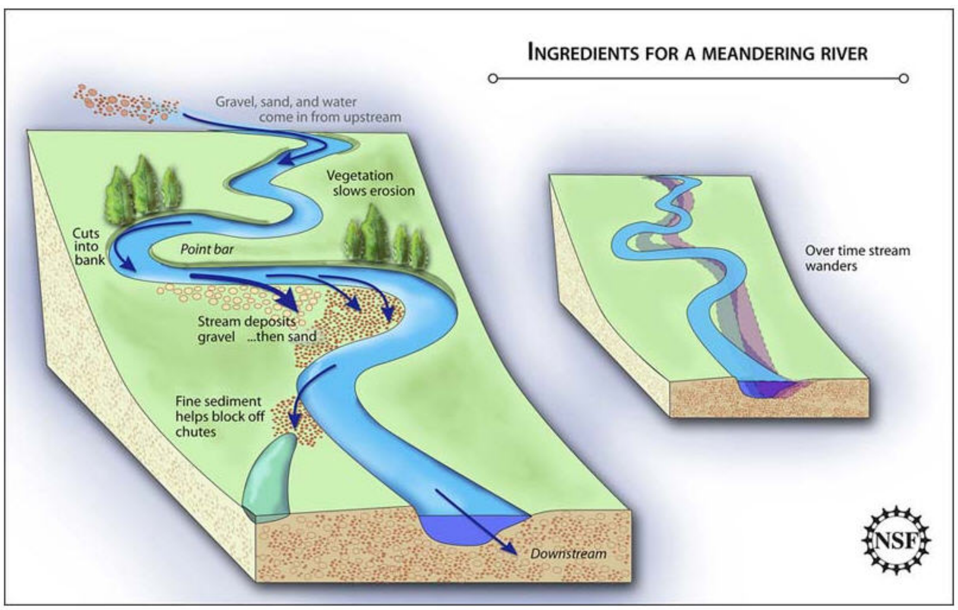

Figure 2. Schematic drawing showing the meandering river migration concept (www.berkeley.edu).

Figure 3. Active bank erosion and channel migration, Ruby River (Spring, 2010).

Whereas channel migration refers to the process of progressive lateral channel movement, ***avulsion*** refers to the capture of flow by a newly formed or previously abandoned channel segment. This process typically occurs during flood events, when overbank flows occupy and rapidly develop a new channel course. One common example of avulsion on the Ruby River is meander bend cutoff (Figure 4). Meander bends can cut off either due to migration, where the two limbs of a bend intersect through migration ("neck cutoff"), or by avulsion, where a new channel is excavated through the neck of the bend ("chute cutoff").

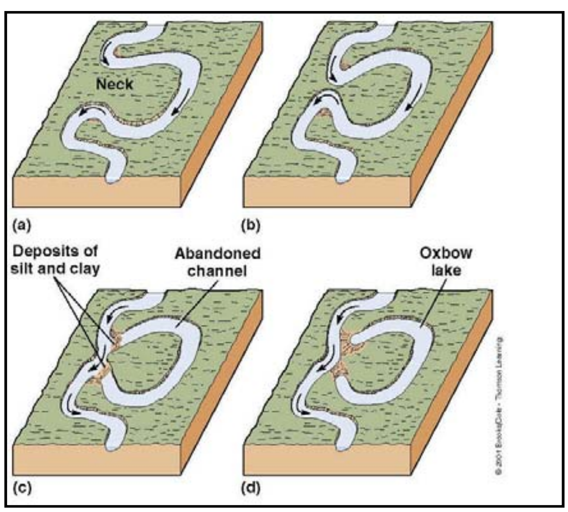

Figure 4. Schematic diagram of meander cutoff (www.uwsp.edu).

The photo shown in Figure 5 was taken from a helicopter by DNRC staff during the 2008 flood on the East Gallatin River near Bozeman, Montana. The photo shows a typical bendway on the East Gallatin, with floodwaters flowing over the core of the bend. On the downstream end of the bend (left side of photo), the overflows re-enter the main channel over a steep bank edge, creating a headcut. If the flood is large enough, or of long enough duration, the headcut will migrate up-valley through the core of the bend and excavate a cutoff channel. On this particular bend, the flood dissipated before cutoff occurred, resulting in a "failed avulsion". Numerous bendway cutoffs have occurred on the Ruby River since 1955 (Figure 6). During spring runoff of 2010, the Ruby River was out of bank for several weeks, creating avulsion hazards across the cores of bendways (Figure 7).

Figure 5. Example of the avulsion process, East Gallatin River May 2008 (DNRC).

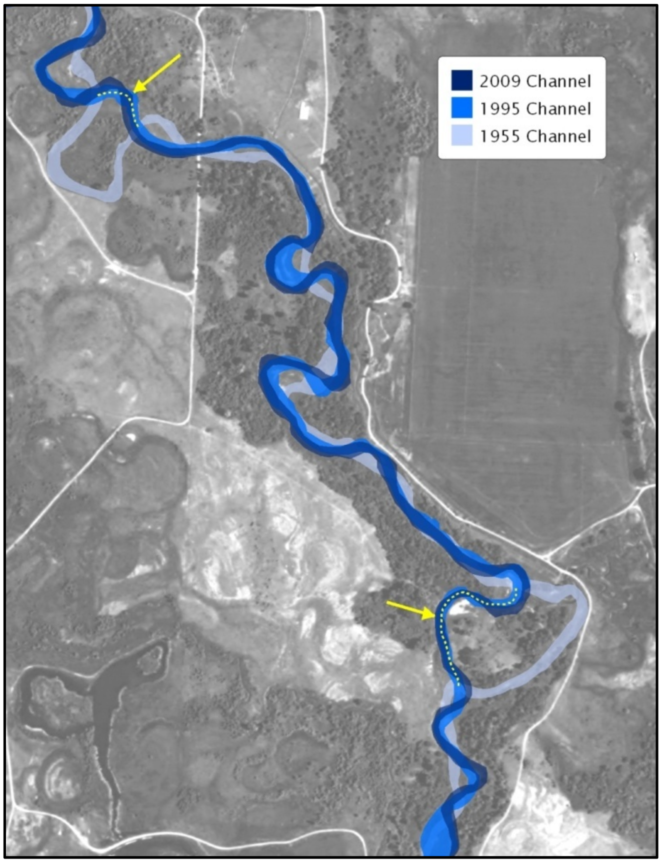

Figure 6. Example of two avulsions that occurred between 1955 and 1995 (yellow arrows).

Figure 7. Spring 2010 overbank flows creating avulsion hazard on Ruby River (S. Gillilan).

In addition to bendway cutoffs, avulsions occur where long segments of channel relocate to new areas on the floodplain. These relocations may reflect capture of an abandoned channel, a tributary channel, or creation of an entirely new channel in the floodplain. In evaluating the avulsion history of the Ruby River, it appears that the lower seven miles of the river avulsed between the 1870 General Land Office Survey and 1955. The upper end of the avulsion is located just downstream of Lewis Lane. Ground disturbance evident on the 1955 air photos suggest that this channel relocation was at least in part engineered. Notably, the National Hydrography Dataset (NHD) channel course, which was digitized from topographic maps, follows the same course as the centerline mapped in the 1870s (Figure 9). The date of the topographic maps used to digitize the NHD line is unknown, however as the NHD line is generally based on best available topographic mapping, one may surmise that the avulsion occurred not long before the 1955 photo flight.

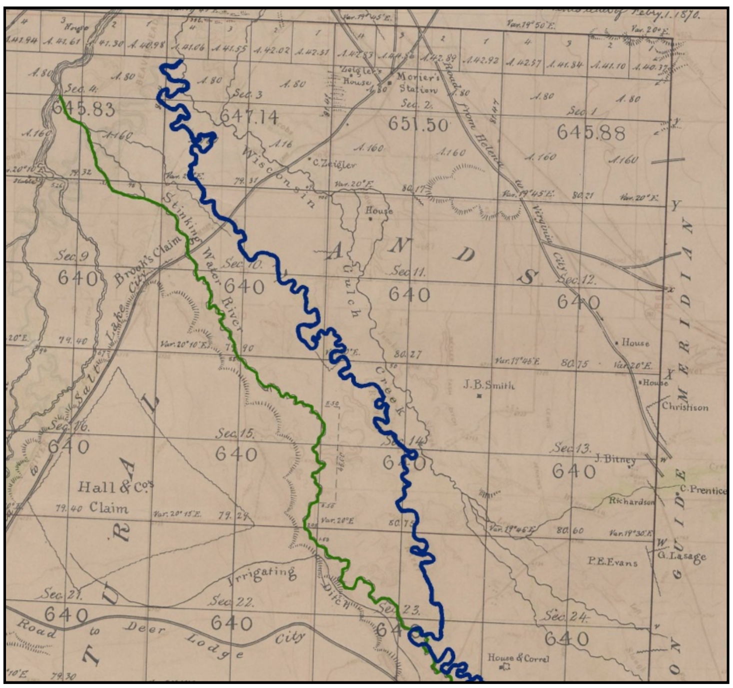

Figure 8. General Land Office Survey map of lowermost Ruby Valley showing river course as mapped in 1870 (green) and 2009 (blue).

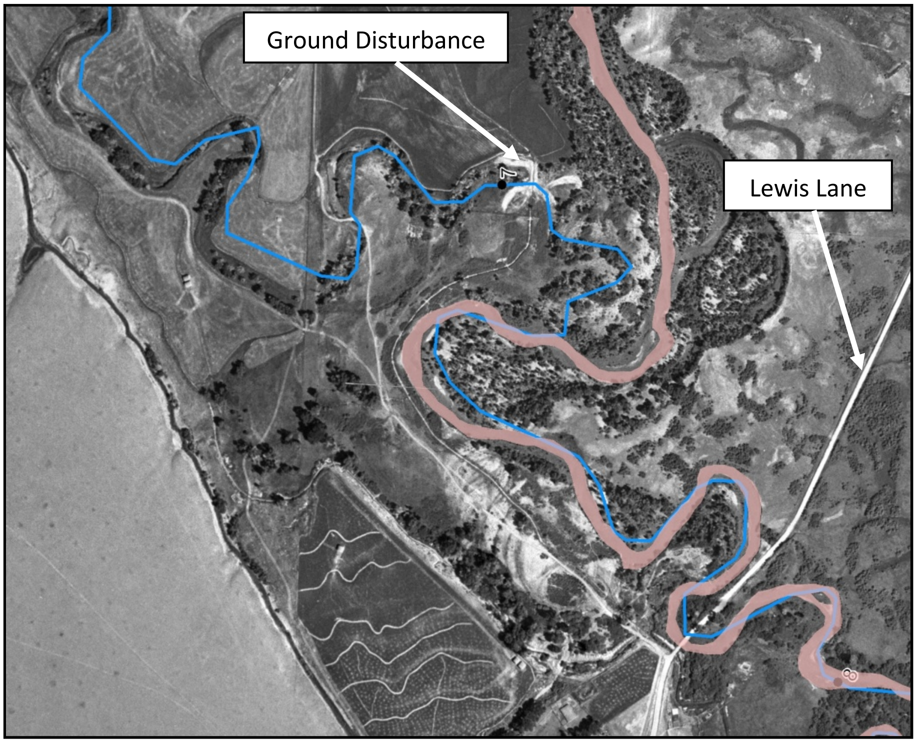

Figure 9. 1955 aerial image of Ruby River just downstream from Lewis Lane showing NHD line (blue) and 1955 channel course (pink); note ground disturbance near RM 7.

1.2 The Channel Migration Zone Mapping Concept

Channel Migration Zone mapping is based on the understanding that rivers are dynamic and move laterally across their floodplains through time. As such, over a given time period, rivers occupy a corridor area whose width is dependent on rates of channel shift. The processes associated with channel movement include lateral channel migration and more rapid channel avulsion. The fundamental concept of 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. For this study, a 100-year CMZ was developed.

In general, a Channel Migration Zone is composed of the following:

- ***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 or mass wasting.
- ***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 (also known as the Disconnected Migration Area, or DMA).

Rapp and Abbe (2003) define the CMZ as:

CMZ =HMZ + AHZ + EHA – RMA

This general definition allows for some flexibility in terms of both component definitions and the component inclusion in the CMZ. For example, one approach identified by the State of Washington is to use meander belt width and bendway amplitude to define the EHA, rather than measured erosion rates. This approach would be appropriate in channelized reaches where natural migration is largely inhibited. In addition, whether or not the RMA is included in the CMZ requires a decision as to whether bank armor should be considered effectively managed, stable, and permanent. In our experience, project stakeholders have been inclined to highlight the RMA, but not to exclude it from the CMZ as Rapp and Abbe (2003) propose. This is why the areas behind armor are called “restricted” migration areas rather than “disconnected” migration areas.

1.3 Uncertainty

The adoption of a 100-year period to define the migration corridor on a system as dynamic as the Ruby River requires the acceptance of a certain amount of uncertainty regarding those discreet 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 Ruby is a laterally dynamic stream that flows through a broad alluvial valley, and floodplain channels such as Mill Creek, Wisconsin Creek, and Clear Creek run parallel to its course. As a result, the Ruby River is naturally susceptible to both lateral migration and avulsion into floodplain channels. With potential contributing factors such as woody debris jamming, sediment slugs, or ice jams, dramatic change could potentially occur virtually anywhere in the floodplain. The goal of this mapping effort is to highlight those areas most prone to either migration or avulsion based on specific criteria developed from an assessment of historic channel behavior.

As predicted future migration is based on an assessment of historic channel behavior, the historic influences affecting channel migration are assumed to continue over the next century. In the event that the conditions experienced by the Ruby River over the last 50 years change significantly over the next century, uncertainty regarding the proposed boundaries will increase. These conditions include influences imposed by system hydrology, climate, reservoir management, riparian vegetation densities and extents, and channel stability. Bank armor and floodplain modifications, such as bridges, dikes, levees, could also affect map boundaries.

1.4 Relative Levels of Risk

Bankline migration and channel avulsion processes both present some level of risk to property within stream corridors. Although the quantitative probability of any area experiencing either migration or an avulsion during the next century has not been determined, their association with specific river process allows some relative comparison of the type and magnitude of associated risk. In general, the ***Erosion Hazard Area*** delineates areas that have a moderate to high risk of channel occupation due to channel migration over the next 100 years. Such bank erosion can occur across a wide range of flows. As such, the risk is not solely associated with flood events, as channel migration commonly occurs as a relatively steady process. Avulsion tends to be a flood-driven process, and as such, risks identified by the ***Avulsion Hazard Zone*** are typically associated with infrequent, relatively rapid shifts in channel course that are commonly very difficult to predict.

1.5 Potential Applications

The CMZ maps developed for the Ruby River are intended to support a myriad of applications. Potential applications for the CMZ maps include the following:

- Proactively identify future problem areas through documentation of active bankline migration;
- Identify restoration opportunities where bank armor has restricted the natural Channel Migration Zone;
- Provide a background tool to assess channel dynamics within any given area;
- Assist in the development of river corridor best management practices;
- Improve stakeholder understanding of the geomorphic behavior of this river system;
- Support planning decisions at local and county levels by identifying relative levels of erosion risk;
- Identify areas where channel migration easements would be appropriate;

- Facilitate productive discussion between regulatory, planning, and development interests active within the river corridor; and,
- Help define long-term sustainable river corridor boundaries.

1.6 Disclaimer and Limitations

The boundaries developed on the Channel Migration Zone maps are intended to provide a basic screening tool to help guide and support management decisions within the Ruby River 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, 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 sight-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 evolution, and evaluation of influences such as vegetation and land use on channel migration.

1.7 Acknowledgements

This project was performed for the Ruby Valley Conservation District (RVCD) through a contract between the district and the Applied Geomorphology/DTM Consulting Project Team. Rebecca Mayfield Ramsay was instrumental in providing contract management and facilitating communication between the authors and project sponsors. Jeremy Miller, Steve Wood, Neil Barnosky, John Anderson, Shirley Galovic and Tom Miller all took time to map locations of bank armor in the project reach, and that information has been incorporated into the project GIS.

The RVCD and the RVCD Technical Advisory Committee (TAC) provided feedback throughout the project, and Matt Jaeger of Montana Fish Wildlife and Parks provided a thoughtful review of the draft document. The project team extends its sincere gratitude to everyone who facilitated this effort and improved the final product.

2.0 Physical Setting

The following summary of the Ruby River geomorphology provides basic context regarding the physical conditions within the river corridor and the 54-mile project reach in the Ruby River Valley below the Ruby Reservoir. Because of the reach-scale approach to this project, it is important to consider the variability in physical conditions that control river form and process.

The Ruby watershed is located in Madison County, Montana, and encompasses approximately 623,000 acres. At its headwaters, the Ruby flows northward through a valley defined by the Gravelly Range to the east and the Snowcrest Range to the west (Figure 10). At Ruby Reservoir, the river enters a narrow bedrock canyon carved through the eastern edge of the Ruby Range; this canyon section comprises the uppermost portion of the CMZ mapping project reach (Figure 11). Within the canyon, the river corridor is approximately 500 feet wide. At the mouth of the canyon, the river valley rapidly widens to over 2 miles in width (Figure 12). Major diversion structures in the canyon section convey irrigation water down the valley; the Vigilante and West Bench Canals have a collective diversion capacity of 355 cfs (MTDEQ, 2006).

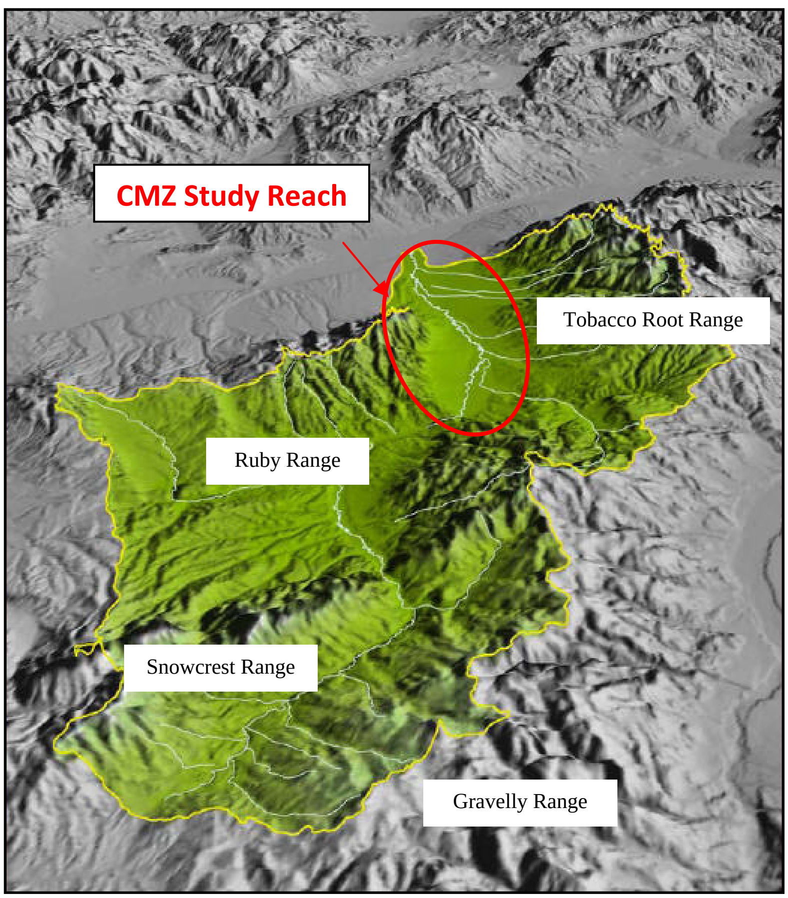

Figure 10. Ruby River Watershed (MTDEQ, 2006)

Figure 11. Ruby River canyon section below Ruby Reservoir.

Figure 12. Unconfined floodplain of the Ruby River Valley.

2.1 Geology

Upstream of the reservoir, the Tertiary Bozeman Group forms much of the river valley margin (Figure 13). The Bozeman Group consists of tuffaceous sandstone and siltstone with interbeds of limestone and conglomerate (Ruppel, et. al, 1993). The upper part of the Bozeman Group contains the Sixmile Creek fanglomerate, which contains cobble and boulder-sized clasts of schist. The Bozeman group has been estimated to be between 3,700 and 8,000 feet thick in the upper Ruby Basin (St. Jean and Teeter, 2004). On the east side of the river above the reservoir, landslides mapped in Cretaceous-age shales form a dip-slope towards the Ruby River. These landslide deposits are a major natural source of fine sediment to the Ruby River (MTDEQ, 2006).

Just below the reservoir, the Ruby River flows through a confined canyon that is bounded by Archean-age amphibolites, quartzites, and marble (Figure 11). These rocks are extremely old, having formed over 2.5 billion years ago (St. Jean and Teeter, 2004). These rocks confine the river within a ~500 ft-wide corridor for the first several miles of the project reach.

The Ruby Range and the Tobacco Root Mountains bound the lower river valley. Distinctly arcuate alluvial fan deposits that have formed on the flanks of the Ruby Range extend into the river valley (Figure 13 and Figure 14). The alluvial fans consist of poorly sorted silty sand and gravel, and include gravel veneers on pediment surfaces (Ruppel et al., 1993). These deposits have been identified as potentially providing placer resources for garnets (Van Gosen et al., 1998). The fan deposits locally overly Tertiary-age Bozeman Formation rocks. Landslides and glacial deposits are also common on the valley margins. The active stream corridor is underlain by Quaternary-age alluvium, which consists of silt, sand, and gravel within channel and floodplain environments.

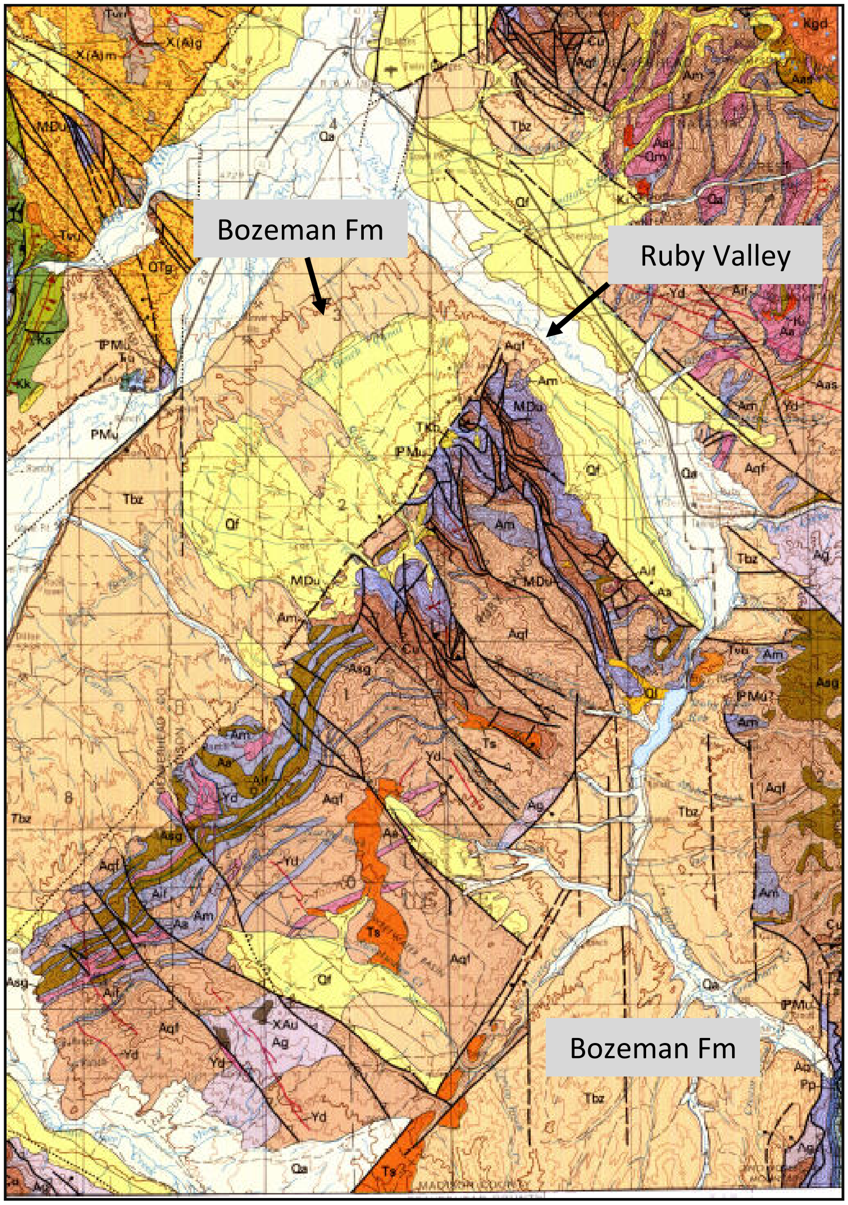

Figure 13. Geologic map of the Ruby Valley; note extent of alluvial fans (Qf) and Bozeman Formation (Tbz) (Ruppel and others, 1993).

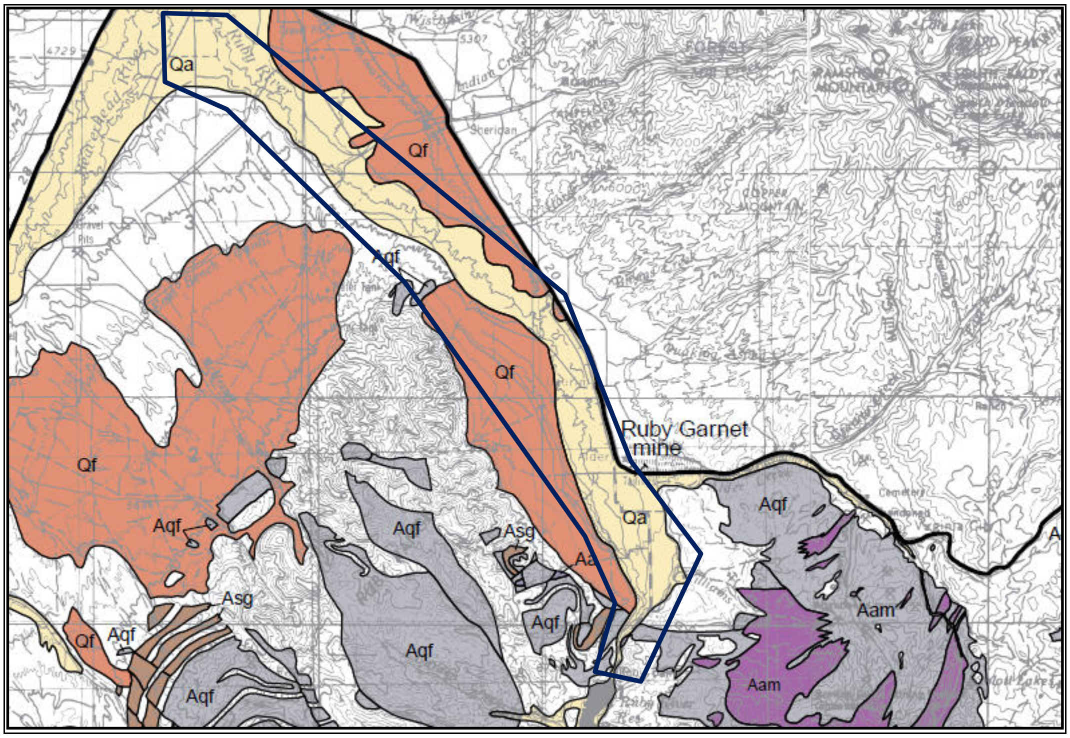

Figure 14. Geologic map of the project reach (outlined in blue) showing alluvial fan extents (orange) in Ruby Valley (Van Gosen, et al, 1998).

2.2 Geomorphology

For approximately 2.5 miles downstream of Ruby Reservoir, the Ruby River flows through a narrowly confined valley that constrains lateral migration processes. Downstream of this confined section, the river flows onto a largely unconfined floodplain where the channel sinuosity is notably high and floodplain irrigation is extensive. There are several areas of split flow, such as near Alder. In some cases, historic side channels appear to have been converted to ditches (e.g. Clear Creek) and lose definition in the downstream direction. Numerous meander scars record historic meander bend cutoffs. Some tributaries, such as Mill Creek, appear to occupy historic Ruby River channels on their lower segments.

The river tends to become finer-grained in the downstream direction. In the upper reaches, coarse gravel bars form discreet point bar features (Figure 1). The lower river is markedly finer grained, with a notable lack of point bars (Figure 15). An inventory of the Ruby River performed by the RVCD (Alvin, 1998) indicates that the system hosts coarse gravel deposits in the upper portions of the project area, and fines in the downstream direction below Alder (Figure 16).

Figure 15. Lower Ruby River showing low floodplain and lack of coarse bar features.

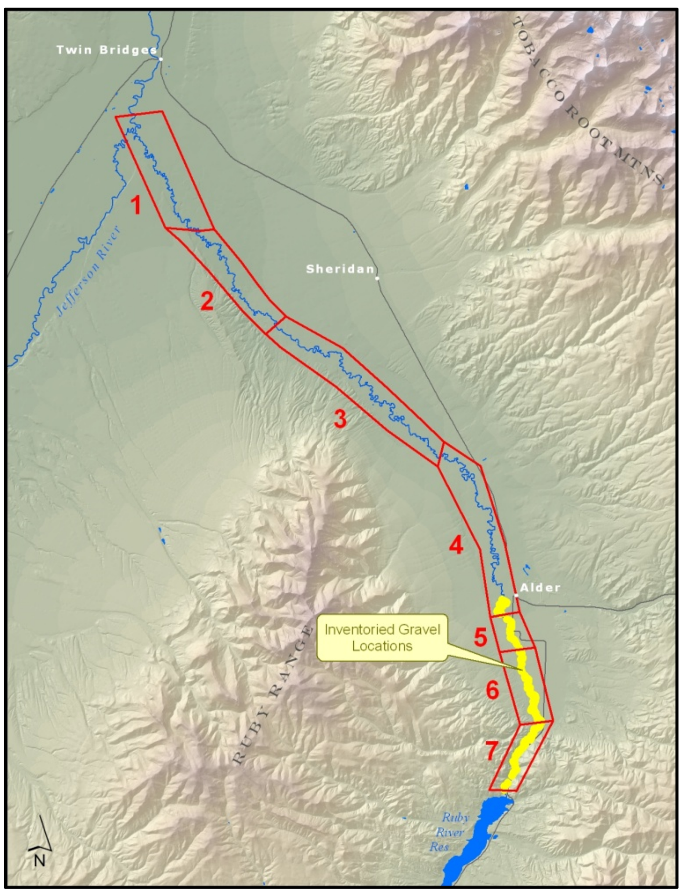

Figure 16. Results of Ruby River inventory (Alvin, 1998) showing observed locations of unvegetated gravel bars (yellow).

2.3 Hydrology

The hydrology of the project reach largely reflects the managed flow releases through the Ruby Dam, a 111 ft high structure that was completed in 1939 (State of Montana Natural Hazards Mitigation Plan, 2001). Ruby Dam is a state-owned water project that impounds Ruby Reservoir, a 38,000 acre-foot impoundment managed primarily for irrigation water storage and flood control (Figure 17). The following is a brief summary of project reach hydrology, including average flow conditions as well as flood history.

Figure 17. Ruby Reservoir.

2.3.1 Mean Daily Flows

Mean daily flows at Sheridan measured from 1941-2009 show a typical snowmelt hydrograph, with a slight increase in March reflecting lowland snowmelt, and a peak discharge in June (Figure 18). Minimum flows are typically experienced in August.

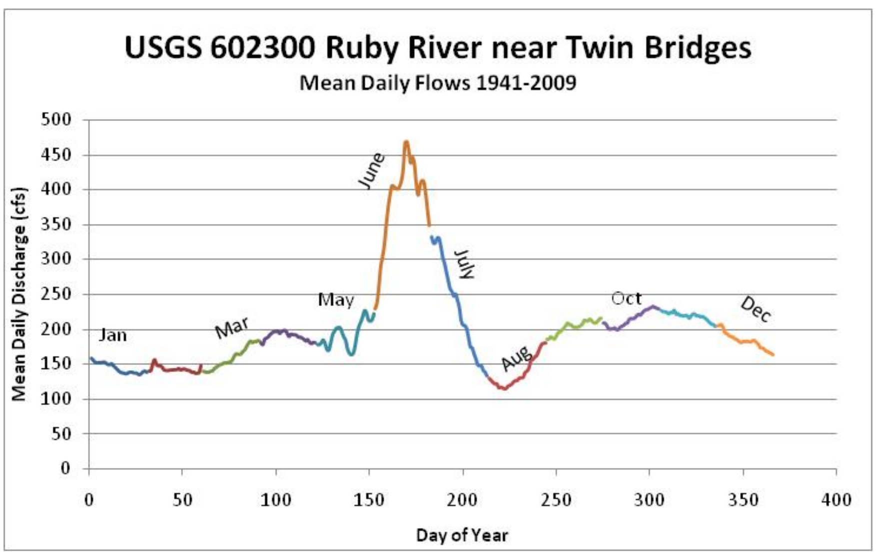

Figure 18. Mean daily hydrograph for the Ruby River at Sheridan, 1941-2009.

2.3.2 Flood History

USGS stream gage data for the Ruby River exist at the reservoir outlet (USGS 06020600) near Alder (06021000), and near Twin Bridges (USGS 06023000)(Figure 19). These discontinuous flow records collectively depict the general flood history of the area. The gage at the reservoir has the most complete peak flow record, extending from 1963 to 2007. At this location, the 10-year discharge is 1,740 cfs and the 5-year flood is 1,450 cfs (www.mt.water.usgs.gov). Since 1962, the 10-year event has been exceeded once, on May 16, 1984, when the discharge measured at the gage was 3,010 cfs. This event, which is the flood of record on the Ruby River, exceeded the 200-year discharge of 2,900 cfs (www.mt.water.usgs.gov). The 5-year flood discharge (1,450 cfs) was exceeded in 1964, 1970, 1973, 1975, and 1995. The other gages both recorded flood events in 1947 and 1948.

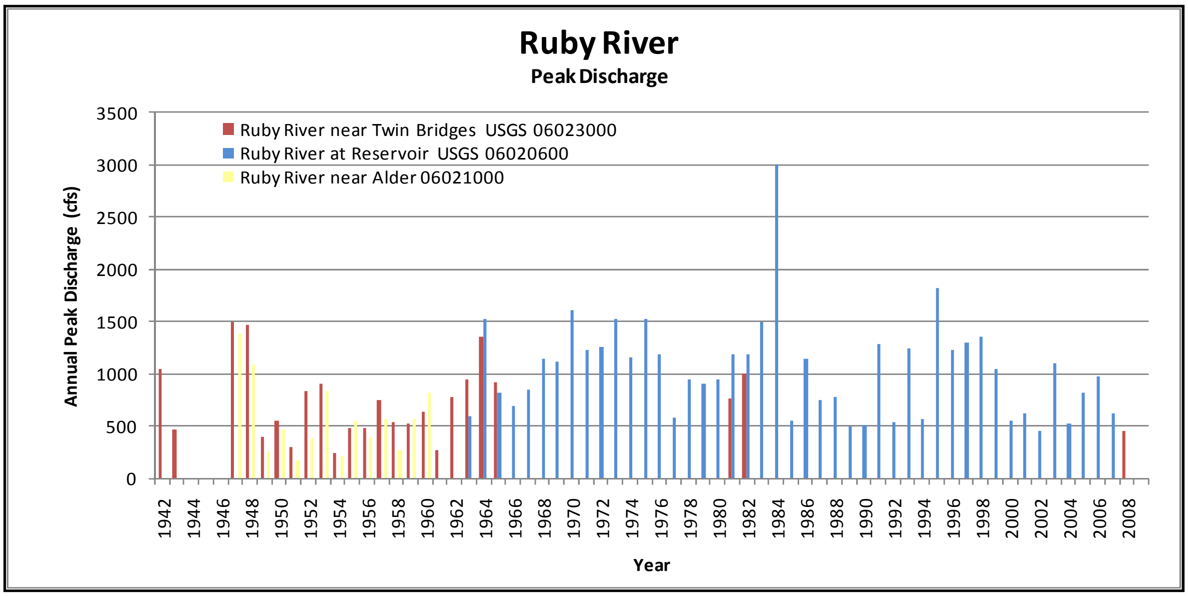

Figure 19. Annual peak discharges, Ruby River.

The flood of record on the Ruby River flood peaked on May 16, 1984. This event has been associated with extensive flooding in the Missouri River basin due to intermittent heavy rainstorms that occurred during the months of May and June (NOAA, 2010). On the scale of the Missouri River basin, the 1984 flooding is considered the most severe since previously disastrous flooding in the basin in 1952. In 1984, millions of acres of land in the Missouri basin were flooded or damaged by erosion. Agriculture was dealt a severe financial blow, as thousands of acres of cropland were not planted due to the magnitude and timing of the flood. Besides the Ruby, other tributary basins that had severe flooding in 1984 include the Beaverhead River in Montana, the Vermillion River, James River, and Big Sioux River basins in South Dakota; the

Big Sioux River, Little Sioux River, and Nishnabotna River basins in Iowa; and the Salt Creek, Papillion Creek, Elkhorn River, and North Platte, and Platte River basins in Nebraska.

2.4 The 1994 "Sediment Event"

In the fall of 1994, the Ruby Reservoir was nearly drained, resulting in extensive erosion of accumulated sediments in the reservoir, and the consequent delivery of a large pulse of sediment downstream (Oswald, 2006). This caused a major fish kill below the reservoir and resulted in the implementation of a minimal storage pool of 2,600 acre-ft. The spring following this event produced a 5 year flood (1,820 cfs at Alder), which likely caused significant reworking of the sediment pulse.

3.0 Methods

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

The primary methods employed in developing the maps include air photo acquisition and incorporation into a GIS environment, bankline digitization, migration rate measurements, and data analysis. The mapping information and measured rates of channel shift are then utilized to define historic channel locations and apply an erosion buffer to allow for future erosion. Once this buffer is established, areas beyond the buffer prone to avulsion are mapped in the GIS, using supporting information derived from air photos, GLO mapping, and inundation modeling results.

3.1 Imagery

Imagery from 1955, 1995, and 2009 were used to develop the CMZ maps (Table 1). These suites were selected due to their dates, quality, and overall coverage. This 1955-2009 timeframe includes one extreme flood event (1984), and numerous events that exceed the 5-year flood (1,450 cfs), including the floods of 1964, 1970, 1973, 1975, and 1995.

Table 1. Imagery suites used in this study.

Date	Source	Scale	Notes
1955	USDA APFO	1:20,000	36 frames, orthorectified by MapCon
1995 - DOQ	NRIS	~5 meter resolution	Digital Download
2009 NAIP	NRIS	~ 1 meter resolution	Digital Download

Several additional sets of aerial photography are available through other sources. Most notably, the APFO has imagery from a 1979 flight at a scale of 1:40,000 (Note: this suite was not acquired due to budget constraints). Additionally, the National Archives may have imagery from the 1930s that would be useful for understanding the large avulsion in the lower seven miles of the river (see Section 4.3), Orders through the National Archives require a custom search to identify potential imagery, followed by a custom order, a process that can take over two months to complete.

The 1955 flight was ordered from the USDA Aerial Photography Field Office (APFO) and consists of 36 black and white frames, providing complete stereographic coverage of the project area at a scale of 1:20,000. These were orthorectified by MapCon Mapping of Salt Lake City using the 10-meter National Elevation Dataset and SocetSet software. The resulting mosaic provides spatially accurate (estimated 3 meter accuracy) seamless coverage of the project area.

The 1995 DOQ black and white and 2009 Color NAIP mosaics were downloaded from the Montana State Library (NRIS) and are assumed to have similar spatial accuracies to the orthorectified 1955 imagery.

3.2 GIS Project

The orthorectified air photos were compiled within an ArcMap GIS project to provide the basis for CMZ mapping. Other data included in the GIS project include a 10-meter National Elevation Dataset DEM, digitized banklines, migration vectors, roads, stream courses as depicted in the National Hydrography Dataset, scanned General Land Office Survey Maps obtained from Bureau of Land Management, and USGS topographic maps.

The project GIS utilizes the Montana State Plane 1983 HARN spatial reference, in accordance with the Best Practices and Standards defined by the Montana Association of Geographic Information Professionals (www.magip.org, 2009). A list of GIS data layers can be found in Appendix C.

3.3 Banklines

Banklines representing bankfull condition were digitized for each year of imagery at a scale of 1:2,500. Bankfull is defined as the stage above which discharge commences to flow out onto the floodplain. There are many possible ways to delineate bankfull, including morphometric, sedimentary and discharge approaches (Riley, 1972). Despite the advantages offered by these methods, CMZ development requires identification of bankfull for past time periods where the historic ground condition can no longer be measured. Therefore, we typically rely on the extent of the lower limit of perennial, woody vegetation to define channel banks (Mount & Louis, 2005). The bankfull extent reflects those portions of channels that are likely to convey typical spring runoff, thereby preventing the establishment of woody vegetation. In addition, terrace margins and bedrock valley walls are used as boundaries. Fortunately, shrubs, trees, terraces and bedrock generally show distinctive signatures on both older black-and-white as well as newer color photography. These signatures, coupled with an understanding of riparian processes, allow for consistent bankline mapping through time and across different types of imagery. Additionally, the acquisition of modern-day banklines via field-based methods such as surveying or GPS, aside from not being feasible under typical time and budget constraints, would yield results that are not consistent with the accuracy of banklines obtained from historic photographs.

3.4 Project Reaches

The project area extends approximately 54 miles from Ruby Reservoir Dam, downstream to the Beaverhead River confluence near Twin Bridges. In order to define erosion potential on the channel margins, it is helpful to subdivide this project area into stream reach segments of similar geomorphic character. To assist in defining reach breaks, a channel centerline and valley axis centerline were stationed at one tenth mile increments in the GIS. The stationing points were then intersected with Digital Elevation Model (DEM) data to create a channel profile and a valley profile. Collectively, this information allows the assessment of channel sinuosity (channel length/valley length), and slope (both channel and valley). Based on this information, as well as geologic data, and tributary confluences, a total of seven reaches were defined (Figure 20, Table 2).

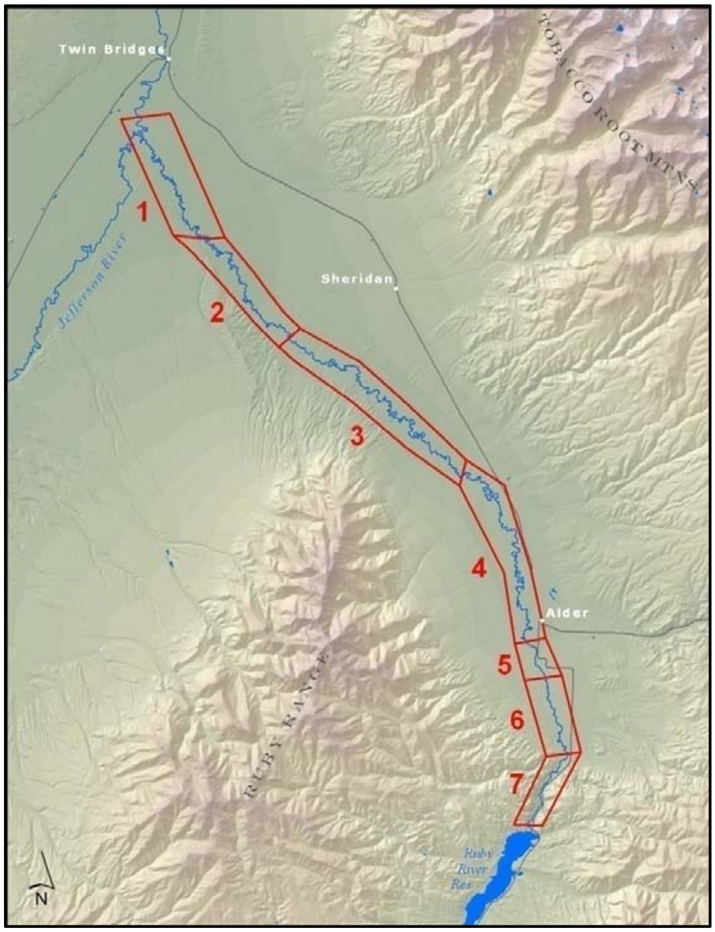

Figure 20. Project reaches, Ruby Valley CMZ development.

A series of air photos showing the extents of each reach are contained in Appendix A.

Table 2. Ruby River Reach Descriptions

Reach	*Location*	*River Mile (lower end)*	*River Mile (upper end)*	*Length (mi)*	*Sinuosity*	*Slope*
1	Mouth upstream to Lewis Lane	0	7.2	7.2	1.95	0.24%
2	Lewis Lane to Duncan District Rd	7.2	17.3	10.1	2.73	0.19%
3	Duncan District Rd to just below mouth of Clear Creek	17.3	32.4	15.1	2.29	0.19%
4	Just below mouth of Clear Creek to just above Clear Creek Diversion	32.4	46.1	13.7	2.85	0.21%
5	Head of Clear Creek to upper end of channelized reach	46.1	47.5	1.4	1.17	0.35%
6	Upper end of channelized reach to mouth of canyon	47.5	51	3.5	1.46	0.44%
7	Mouth of canyon to Ruby River Reservoir	51	53.7	2.7	1.29	0.47%

These reaches reflect differences in channel sinuosity and channel slope. In general, sinuosity increases in the downstream direction, and slope decreases as a result. In the lower four reaches, the channel length is typically over two times the valley length (sinuosity exceeds 2.0; Figure 21).

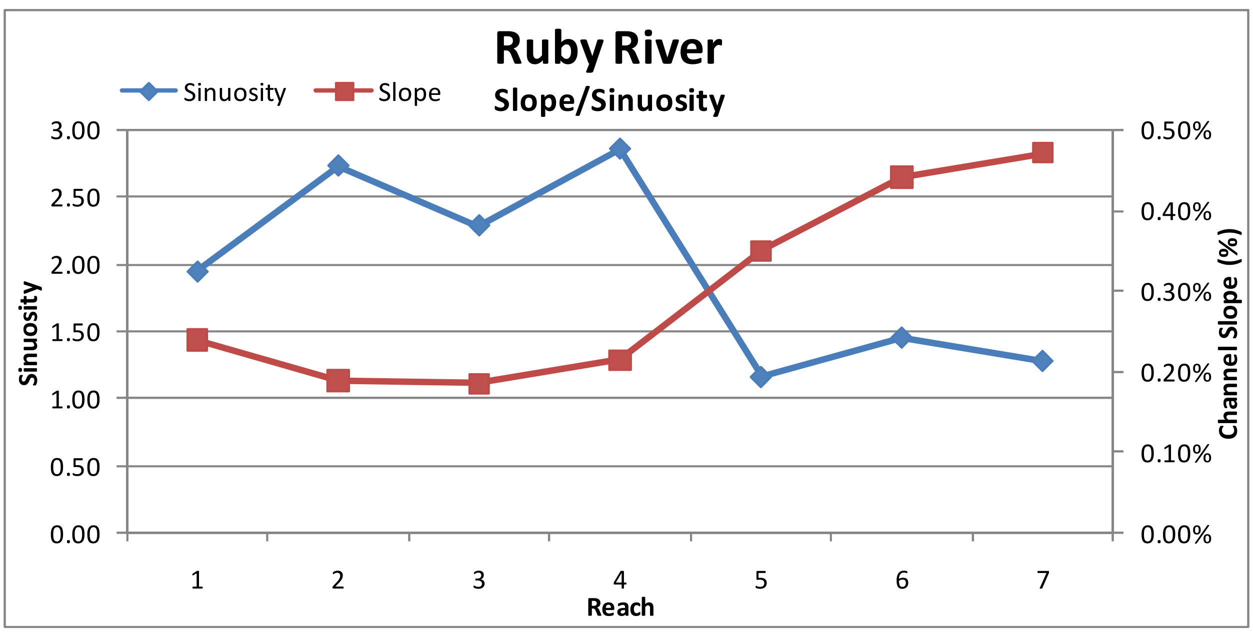

Figure 21. Reach slope and sinuosity, Ruby River.

3.4.1 **Reach 1**

Reach 1 consists of the lowermost 7.2 miles of the Ruby River. In this area the valley is broad and dissected by numerous channel remnants including Jacob's Slough to the northeast and an abandoned channel segment to the southwest. The reach has a moderately high sinuosity of 1.95, and channel slope of 0.24% (12.6 ft/mile). Several bendways upstream of Seyler Lane have been armored (RM 2.8-RM 3.7). Between RM 1.6 and RM 2.8, five large cutoffs occurred between 1955 and 2009. Wisconsin Creek enters the Ruby River at RM 5.6.

3.4.2 **Reach 2**

Reach 2 extends from near Lewis Lane at RM 7.2 to Duncan District Road at RM 17.3. Reach 2 consists of a highly sinuous channel with extensive bendway development, some following 1955-2009 cutoffs (e.g. RM 9.2- RM 9.5). Migration distances of over 100 feet since 1955 are common in this reach. Several large bends in this reach are significantly overlengthened and appear highly prone to cutoff (e.g. RM 10.5). One section within Reach 2, extending from RM 14.6 to RM 16.4, shows notably active meander migration.

3.4.3 **Reach 3**

Reach 3, which extends from Duncan District Road to just below the mouth of Clear Creek, has a lower density of erosion sites than downstream reaches. There are fewer avulsion hazards bounding the channel, and historic cutoffs are less common than downstream.

3.4.4 **Reach 4**

Through Reach 4, Clear Creek flows parallel to the Ruby River. As such, it constitutes an avulsion hazard, which is most accessible downstream of RM 42, where erosion hazards indicate a potential capture of Clear Creek. There is substantial bank armor and relatively few cutoffs in this channel segment.

3.4.5 **Reach 5**

Reach 5 has the lowest sinuosity of all seven reaches due to substantial river channelization sometime prior to 1955. The reach is extensively armored. Migration rates are consequently low in this reach due to armoring, thus empirically derived migration measurements do not reflect a natural condition. Because of the armoring and channelization in this reach, the natural, unimpeded migration area is based on migration and meanderbelt characteristics of the adjacent upstream and downstream reaches.

3.4.6 **Reach 6**

Reach 6, which is located at the mouth of the canyon, has a relatively high density of identified erosion sites. The reach is characterized by relatively low sinuosity, relatively steep slopes, and a gravel bedload. The highest migration rates measured in the entire project area are in Reach 6, where a maximum 1955-2009 migration distance of 228 feet was measured. Bank armor is common in Reach 6.

3.4.7 **Reach 7**

Reach 7 is located in the canyon section below Ruby Dam. Migration is limited by the erosion-resistant valley walls, and the erosion site density is low. Extensive irrigation infrastructure parallels the river course (e.g. West Bench Canal), restricting much of the migration area.

3.5 Migration Rate Measurements

Within the GIS, the digitized banklines were evaluated in terms of discernable channel shift since 1955. Where migration was identifiable, vectors were drawn in the GIS to record that change. At each site of bankline migration, three measurements were collected, and the vectors were attributed with reach, eroding site identification, and line length. These measurements were then summarized by site and by reach to determine appropriate reach-specific buffer widths to accommodate future shifts in channel location.

3.6 Bank Armor Extents

By design, bank armor restricts the natural movement of a channel. In order to map those areas where migration is restricted (“Restricted Migration Area”, or RMA), a bank armor inventory is required. Initially, there was no bank armor inventory available for this project. In the fall of 2010, however, the RVCD requested local residents to assist with an armor mapping effort. In response to that request, mapped extents of bank armor were drawn on hard copies of stream corridor maps. This mapping has not been field checked or spatially located using GPS. As a result, their locations and extents should be considered approximate. Even as an approximation, however, the mapped extents are useful and thus included in the GIS project.

3.7 Inundation Modeling

Inundation modeling is a static model of inundation potential based upon Digital Elevation Modeling (DEM) data. The general technique involves creating a flood surface based on cross section elevations extracted from the DEM. This model surface is then intersected with the DEM to create a surface representing inundation depth. This is often used to approximate flood prone areas (e.g. areas where the flood surface elevations at a given stage are higher than the underlying DEM ground surface elevations are identified as flood-prone), but it also is a useful tool for identifying areas prone to avulsion. Areas of low elevation such as swales that may be reactivated through avulsion are highlighted in the resulting model. While anomalies in the DEM data, local structures, and the highly variable terrain complicate the model outputs, compelling results can still be developed.

For this study, 34 cross sections were defined along the study area. These were then intersected with the 10-meter DEM and the minimum elevation of each cross section was used to create the model surface at each cross section. Section 4.3 goes into further detail of how the Inundation Model is used in this study.

4.0 Results

The channel migration zone (CMZ) developed for the Ruby River is defined as a composite area made up of the existing channel, the historic channel since 1955 (Historic Migration Zone, or HMZ), and an Erosion Buffer that encompasses areas prone to channel erosion over the next 100 years (Erosion Hazard Area, or EHA). Areas beyond the Erosion Buffer that pose risks of channel avulsion are identified as Avulsion Hazard Zones (AHZ). And lastly, those areas within the AHZ that have been restricted by structures are identified as Restricted Migration Area (RMA).

4.1 The Historic Migration Zone (HMZ)

The HMZ for the Ruby River consists of the collective footprint created by the 1955, 1995, and 2005 bankfull channel polygons (Figure 22). All islands are included within the HMZ. Any future integration of additional intermediate air photo suites (e.g. 1979) may alter the footprint of the HMZ, however, it is most likely that these changes will be entirely masked by the overlying EHA (Section 4.2).

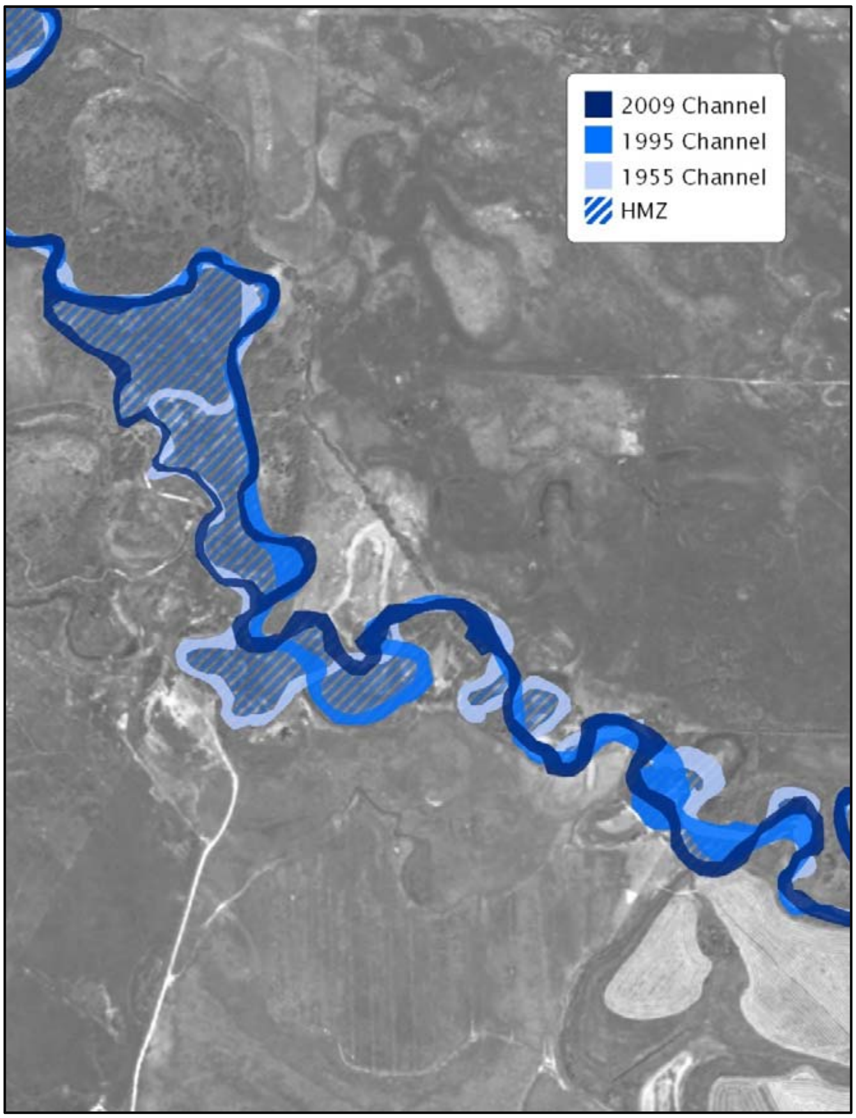

Figure 22. Ruby River Historic Migration Zone (HMZ), a composite of 1955, 1995, and 2009 channel locations.

4.2 The Erosion Hazard Area (EHA)

The Erosion Hazard Area consists of an erosion buffer that allows for 100-years of future erosion based on average historic movement measured using the 1955 and 2009 banklines. This buffer is placed on the outside (landward) margins of the 2009 banklines to allow for a century of future (average) migration. On a reach-scale analysis such as this, a single buffer is used for the entire reach, and the buffer underlies the HMZ layer. Because of this overlapping, the EHA buffer can be masked out by the HMZ where the historic footprint of the channel is relatively wide.

The general approach to determining the Erosion Buffer (100 times the mean annual migration rate) is similar to that used 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).

Bank movement was measured in the GIS directly using the digitized 1955 and 2009 banklines. From Ruby Reservoir to the mouth, a total of 362 erosion sites were identified as having channel movement between 1955 and 2009 in excess of 20 lateral feet, which was defined as the minimum measurement unit for the project. For each site, three linear measurements were made, for a total of 1086 migration measurements. All erosion site locations are shown in Appendix A and mean and maximum migration rates measured at each of these sites are tabulated in Appendix B.

Although the statistic utilized in developing the Erosion Hazard Area is the reach-scale mean migration rate, it is also instructive to consider the distribution of measured values relative to the mean. To that end, a series of statistics have been developed for each suite of migration rate measurements. These statistics for each data series are presented in graphical form as a box and whisker plots which reflects the following statistics for each dataset: minimum, 25th percentile, mean, 75th percentile, and maximum (Figure 23). Additionally, the 90th percentile value has been added to help identify the range of the most extreme (top 10%) of rate measurements. The box can be used to visually assess the concentration of data about the mean (50% of all measurements are within the box).

The results of this analysis show that a reach-averaged value of the maximum site measurement effectively depicts overall historic migration trends. Summary statistics for the measurements were made to develop an average 100-year migration distance for each reach (Figure 24, Figure 25, and Table 3). The box and whisker plot (Figure 24) shows the range of values measured within each reach for the 1955-2009 timeframe. The mean migration distance for each reach is shown as red triangles in the box. EHA buffers have been developed by converting that mean migration distance to feet per year, and extrapolating that rate to a 100-year buffer (blue diamonds). For the EHA, these buffers (Figure 25) are placed against the 2009 banklines to allow for a century of potential lateral movement (Figure 26).

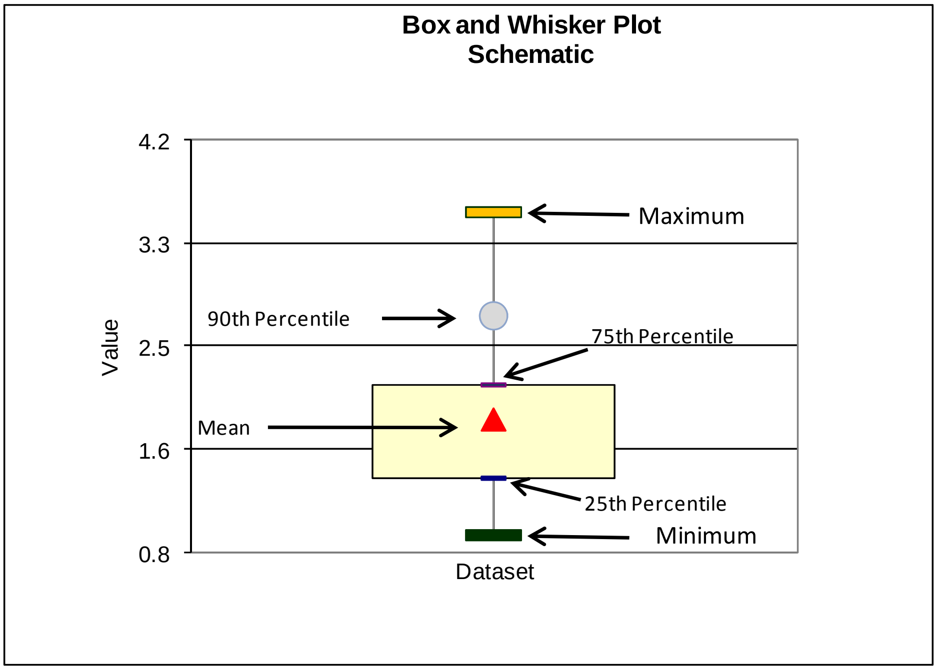

Figure 23. Box and whisker plot schematic.

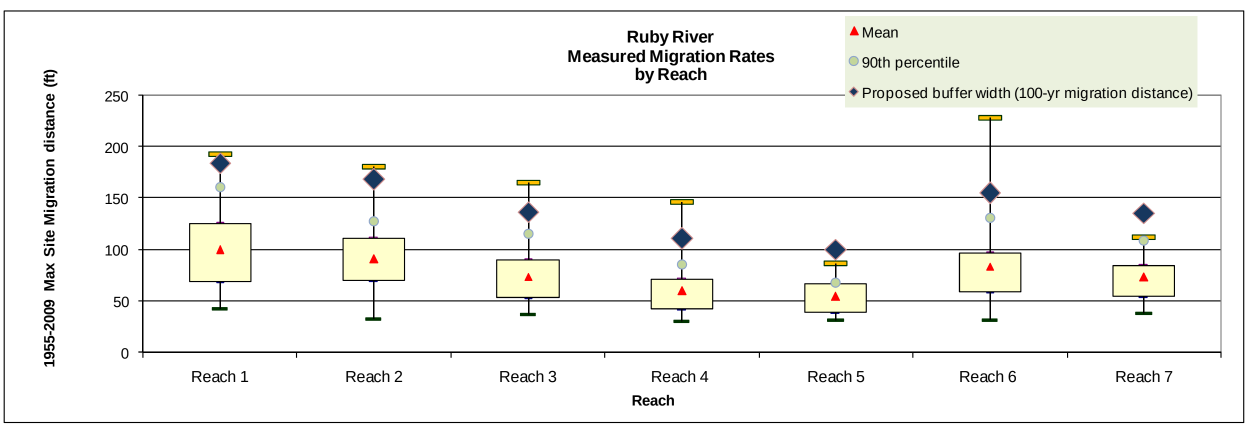

Figure 24. Box and whisker plots showing statistical summary of migration measurements, Ruby River.

Table 3. Statistical summary of migration measurements in feet, Ruby River.

Statistic	***Reach***						
	1	***2***	***3***	***4***	***5***	***6***	***7***
25th Percentile	69	70	53	42	39	59	55
Min	43	32	37	30	31	32	38
Median	89	90	64	55	52	73	72
Max	193	180	165	146	87	228	112
75th Percentile	125	110	90	71	67	97	85
N	56	73	96	102	11	32	9
90th Percentile	160	127	115	85	68	130	109
Mean	99	91	74	60	54	83	73
Mean Rate (ft/yr)	1.8	1.7	1.4	1.1	1.0	1.5	1.4
Mean 100 year Migration Distance (feet)	184	168	137	110	100	155	136

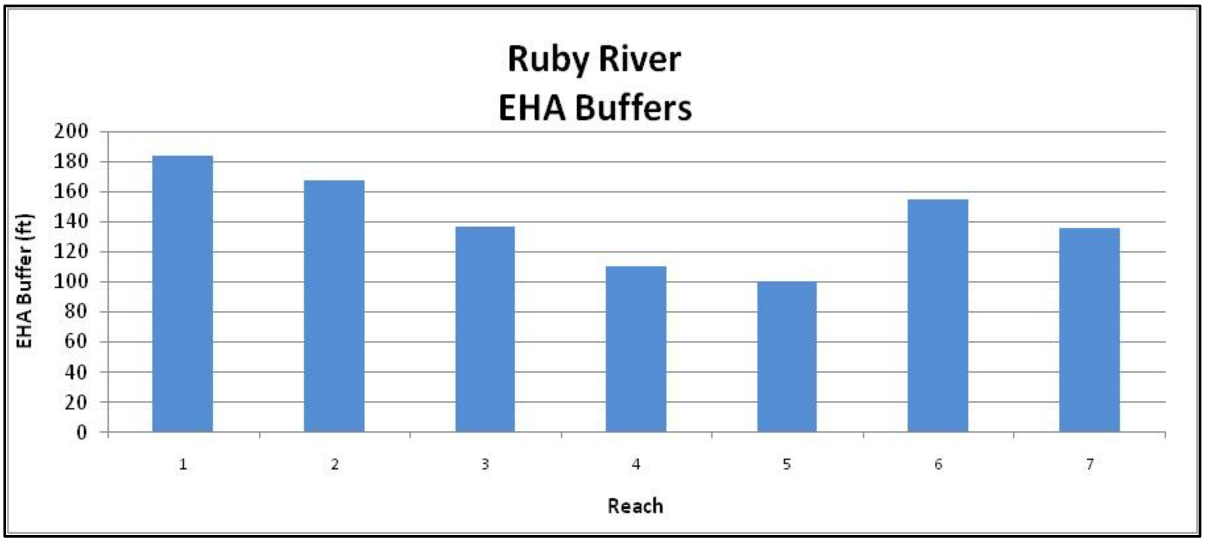

Figure 25. Erosion Hazard Area (EHA) buffers, Ruby River.

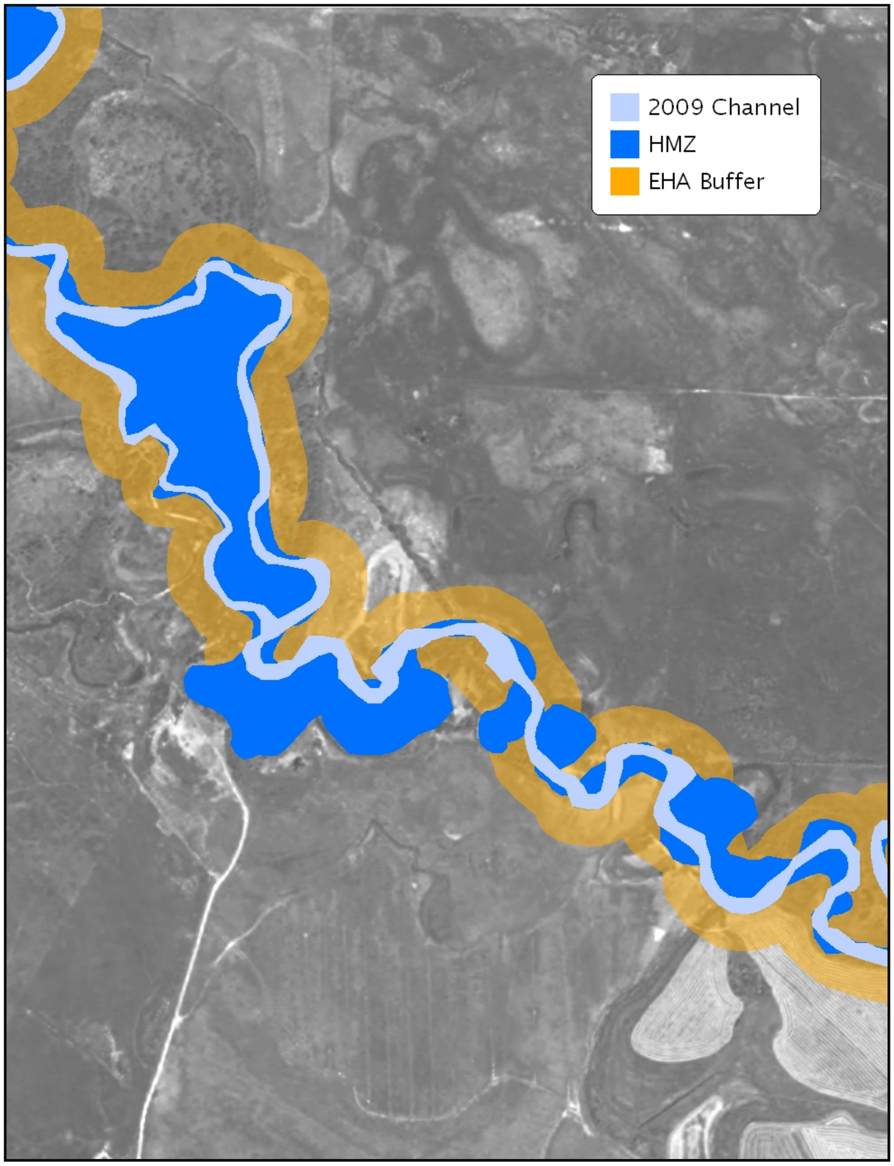

Figure 26. Historic Migration Zone (blue) with Erosion Hazard Area (EHA) buffers (orange) and 2009 channel (light blue).

4.2.1 Data Stratification

The mean 1955-2009 migration distance in Reach 1 is 99 feet, and that of Reach 2 is 91 feet (Table 3). The similarity in both mean values and the total range in values (Figure 24) suggests that the reaches may not exhibit major differences in typical rates of movement. As the reach delineations are based primarily on sinuosity and channel slope, strong stratification between reaches would suggest that sinuosity and slope exert strong influences on migration rate. The results suggest that other parameters influence migration rates, such as bendway radius of curvature, land use, riparian density, soils, etc. Further analysis of this data may reveal those site characteristics that affect rates of channel movement. Recommendations for this analysis is provided in Section 5.0. For this mapping effort, the reach breaks have been retained to reflect calculated rates within geomorphically similar channel segments, even if the resulting EHA buffer widths are similar.

4.2.2 Outliers

A comparison of the proposed buffer widths to the maximum migration measured in each reach demonstrates a critical aspect of CMZ mapping (Figure 24). For the Ruby River, the application of a mean migration rate to develop a 100-year buffer accommodates most, ***but not all,*** of the 1955-2009 movement. The plot demonstrates that the proposed buffer (blue diamonds) exceed the 90th percentile values of the measurements in every reach, indicating that over 90% of the sites measured are accommodated by the mean-derived buffer. This is not the case with maximum values. In Reaches 1, 2, 3, 4, and 6, the maximum migration distance ***exceeds*** the proposed buffer width. This result is common on dynamic streams where a few sites experience extremely rapid erosion, and thus become statistical outliers. In a practical sense, it indicates that a small number of sites are likely to exceed the buffer width on a 100-year timeframe.

4.2.3 Reach 5 Buffer

Reach 5 of the Ruby River is highly channelized and armored. As a result, the historic footprint of the river is very narrow within this reach, and channel migration rates are very low. Because the natural processes have been arrested in this reach, the EHA buffers applied to Reach 5 have been modified based on typical belt widths of upstream and downstream reaches. This modification provides a sufficient corridor within Reach 5 to reflect a natural meanderbelt configuration. This results in a modified buffer of 230 feet (increased from 100 feet) in this channel segment.

4.2.4 Buffer Performance

This effort included developing and applying buffers on a reach scale rather than the scale of a single migrating site of bank erosion. The reach-scale approach provides a more generalized long-term depiction of channel movement relative to approaches that apply buffers on the scale of individual sites. In the near-term, this reach scale averaging is likely to overestimate channel movement in places where active migration is currently slow or nonexistent, and potentially underestimate the short-term migration rates of areas in active phases of movement. However, due to the active planform of the Ruby River and the 100-year projected timeframe, reach scale buffer development should produce a more realistic depiction of the active channel corridor over 100 years. Empirical observations of aerial photography indicate that over the past 50 years, there are areas where erosion sites have developed in that time, and areas where actively migrating banklines have slowed down, changed direction, or cut off. Predictive modeling of these processes over 100-years is beyond the scope of this project, and likely impossible, which further supports the reach-scale mapping approach.

An important empirical test of the buffer widths is the application of the calculated buffers to the 1955 banklines, and determination of the number of sites that would have migrated through the buffer by 2009, 54 years later. In other words, if we had created these EHA buffers in 1955, how would they have performed by 2009? For Reaches 1 through 7, no more than 4% of the erosion sites would have reached the buffers edge between 1955 and 2009 (Figure 27). These sites are statistical outliers that demonstrate the fact that where bank erosion is exceptionally rapid, banklines may locally exceed the buffer over the next century. An area of extremely rapid migration in Reach 4 (just upstream of Clear Creek) where the buffers would have been exceeded is shown in Figure 28.

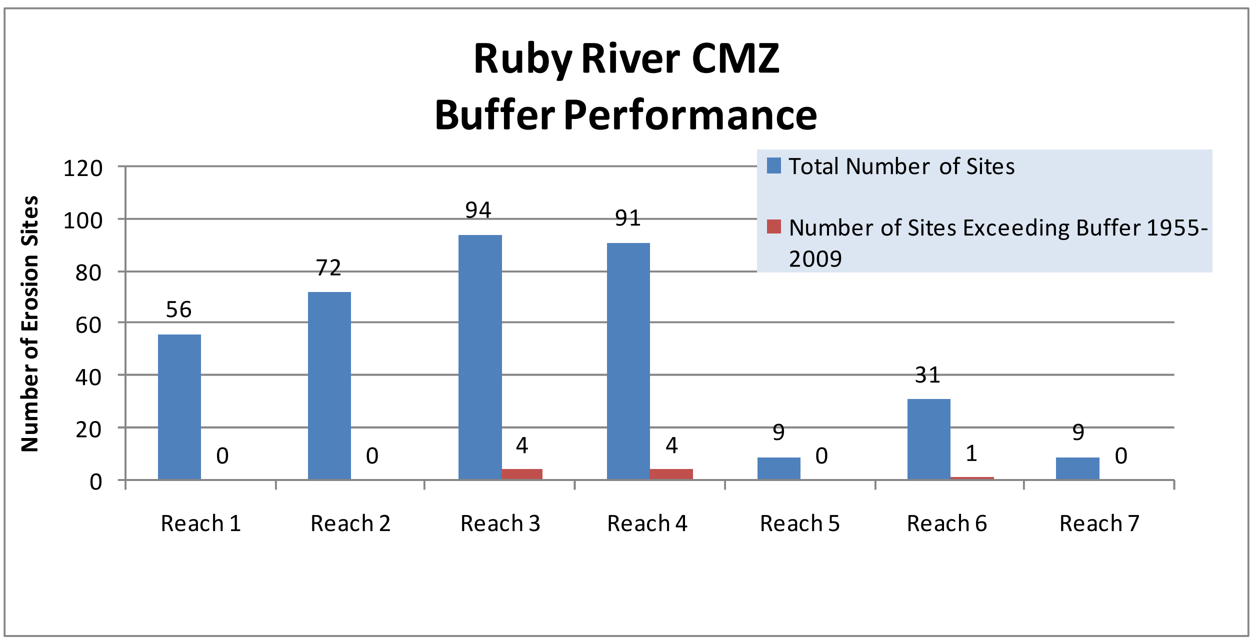

Figure 27. Number of erosion sites that would have exceeded the EHA buffer width from 1955-2009.

Figure 28. Example of locations where 1955-2009 migration would have exceeded buffers.

4.2.5 Geologic Controls on Migration Rate

Through the vast majority of the project area, the Ruby River flows through recent alluvial deposits that become finer grained in the downstream direction. The reach boundaries address these shifting downstream trends in sediment load and bank materials. In a few locations, however, the CMZ overlaps onto valley wall colluvium or alluvial fan margins. As we have no empirical measurements of channel movement through these features, their erodibility has not been documented in this effort. As a result, these geomorphic units have been clipped from the CMZ, and thus any erosion concerns in these areas should include a site specific assessment of channel migration potential.

4.3 The Avulsion Hazard Zone (AHZ)

Avulsion hazards can be difficult to identify on broad floodplains, because an avulsion could occur virtually anywhere on the entire floodplain if the right conditions were to occur. Our approach to defining avulsion pathways is to develop criteria that identify a relatively high propensity for such an event. These criteria include bendway cores that are prone to cutoff, as well as relic floodplain channels that concentrate flow during floods. General Land Office

Survey maps from the late 1800s, as well as inundation modeling results were used to help identify floodplain channels.

The types of avulsions that are most common on the Ruby River are bendway cutoffs. These cutoffs typically reflect planform change within the river's meanderbelt. As these processes are relatively common, the areas where bendway cutoff is likely as the buffers are encroached, are mapped as ***high avulsion hazards***. In contrast, the wholesale relocation of the river into floodplain channels appears relatively rare, however such avulsions do appear to have occurred since 1870. Because they are less common than meander cutoffs, avulsions associated with reactivation of floodplain channels are mapped as ***moderate avulsion hazards***.

The moderate avulsion hazards locally encompass relative wide swaths of the Ruby River floodplain. One large avulsion hazard is present in the lowermost 7 miles of river where the 1870 river course was approximately ½ mile west of its current location (Figure 29). The margin of this avulsion hazard follows an abandoned channel on the 2009 imagery, and approximates the mapped location of the Ruby River (called the Stinking Water River) in 1870.

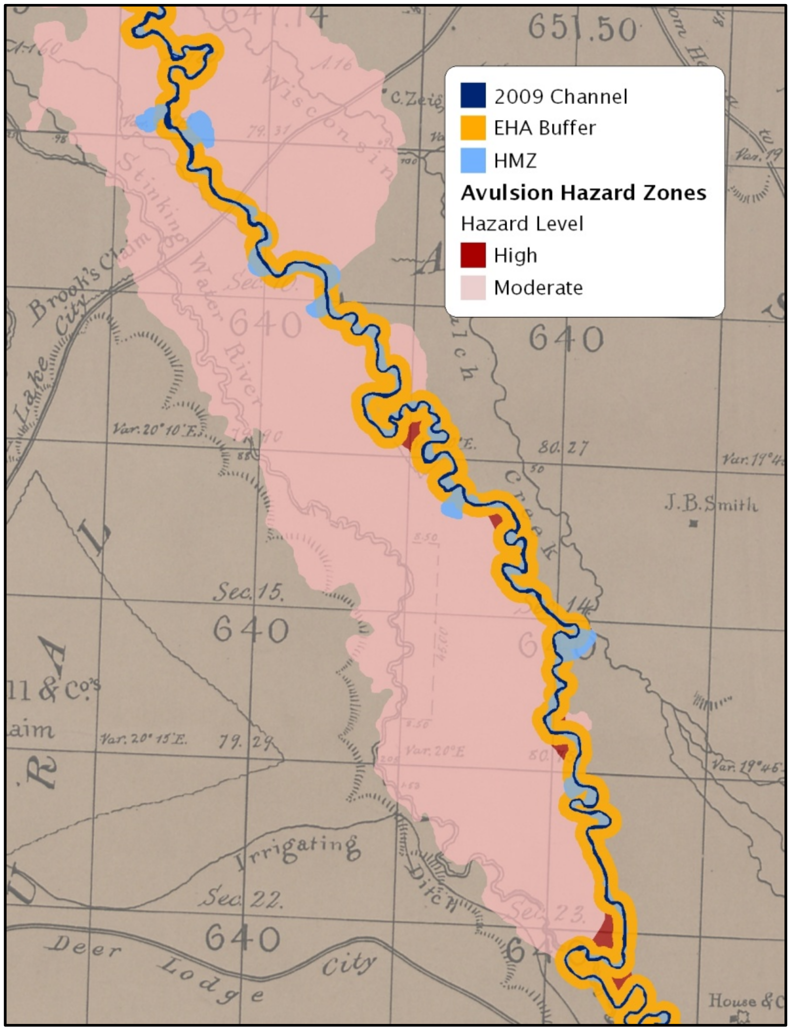

Figure 29. Lower Ruby Valley moderate avulsion hazard (light pink), showing 1870 mapped location of the "Stinking Water River".

The inundation modeling results provide additional means of mapping avulsion hazards (Figure 31). The modeling highlights several floodplain swales that are difficult to see on the imagery; one example which has been mapped as an avulsion hazard is shown in Figure 30.

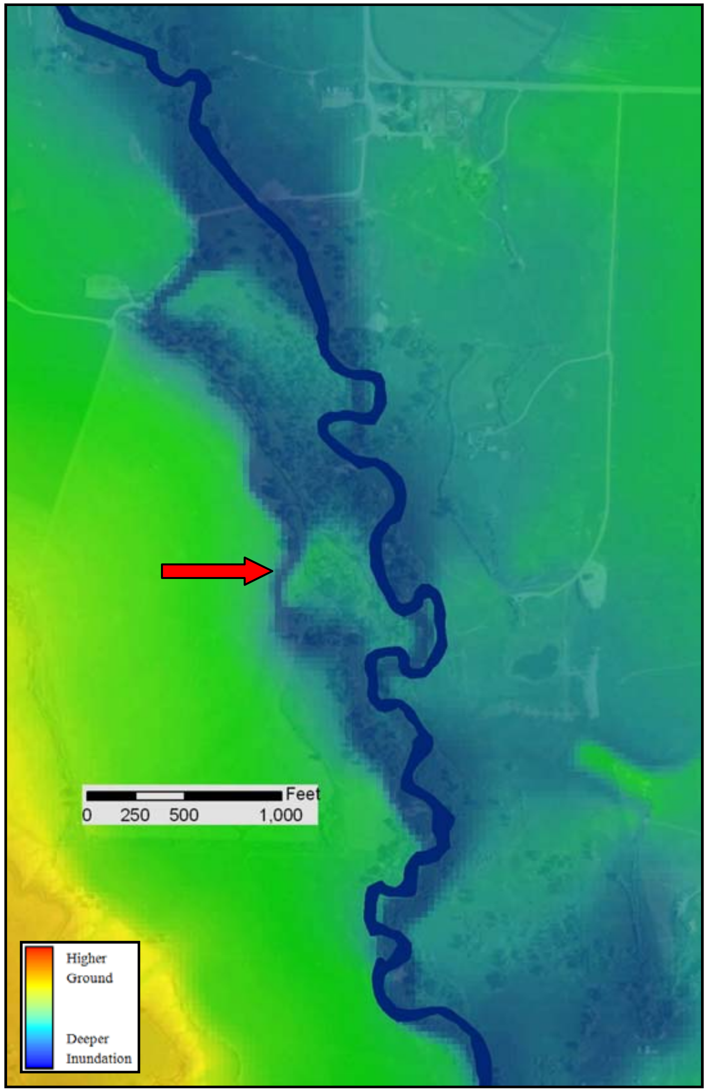

Figure 30. Inundation modeling results showing 2009 channel (dark blue), and avulsion hazard area to west (arrow).

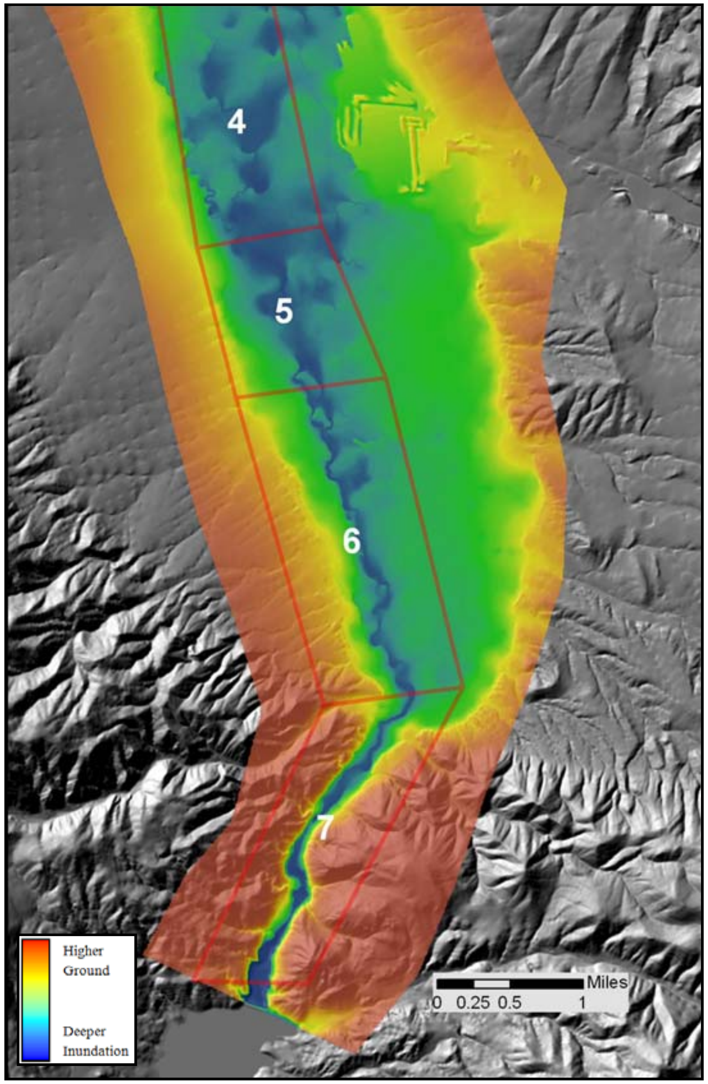

Figure 31. Inundation modeling results for upper portion of study reach.

4.4 The Restricted Migration Area (RMA)

The bank armor inventory for the project reach is currently incomplete. Since data are not available to consistently identify CMZ areas restricted by bank armor, this map unit has not been developed. As more detailed information becomes available, these areas can be identified on the maps, and highlighted as restricted. Although the RMA is not identified in relation to bank armor, all mapped armor segments contained within the GIS project are shown on the maps.

4.5 The Restricted Avulsion Hazard Zone

In numerous areas, overflow channels that have been mapped as part of the Avulsion Hazard Zone have been blocked by flood control features such as dikes and levees. Where these features clearly block channels and thus prevent their activation, the Avulsion Hazard Zone has been cross-hatched to indicate that it is restricted (Figure 32 and Figure 33). An interesting AHZ example is located approximately 1.2 miles northwest of Alder where the Erosion Hazard Area on the mainstem Ruby overlaps the current course of Clear Creek. This indicates a potential for the capture of lower Clear Creek over the next century. As a result, the upper (southern) part of Clear Creek is restricted Avulsion Hazard Area (cross-hatched) due to irrigation infrastructure at the main diversion, but the lower part is not restricted due to its risk of capture (Figure 32).

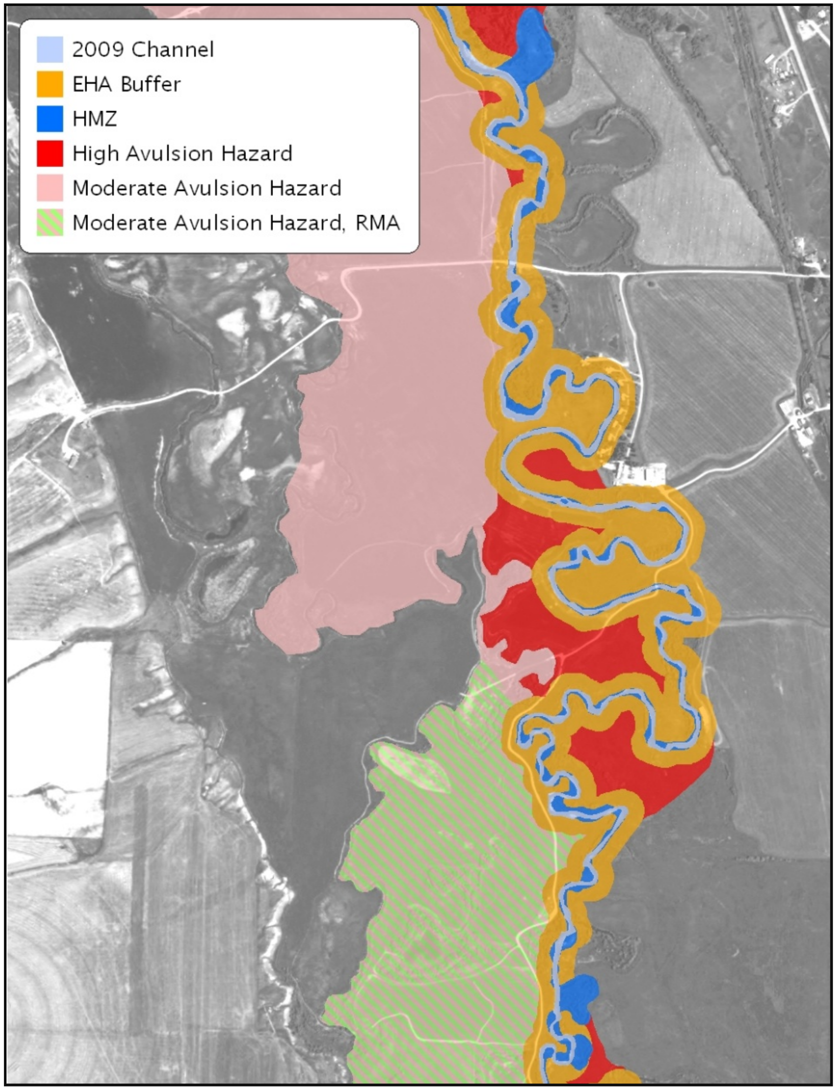

Figure 32. Clear Creek avulsion hazard, showing the upper restricted area (cross-hatched), and the lower unrestricted area (pink).

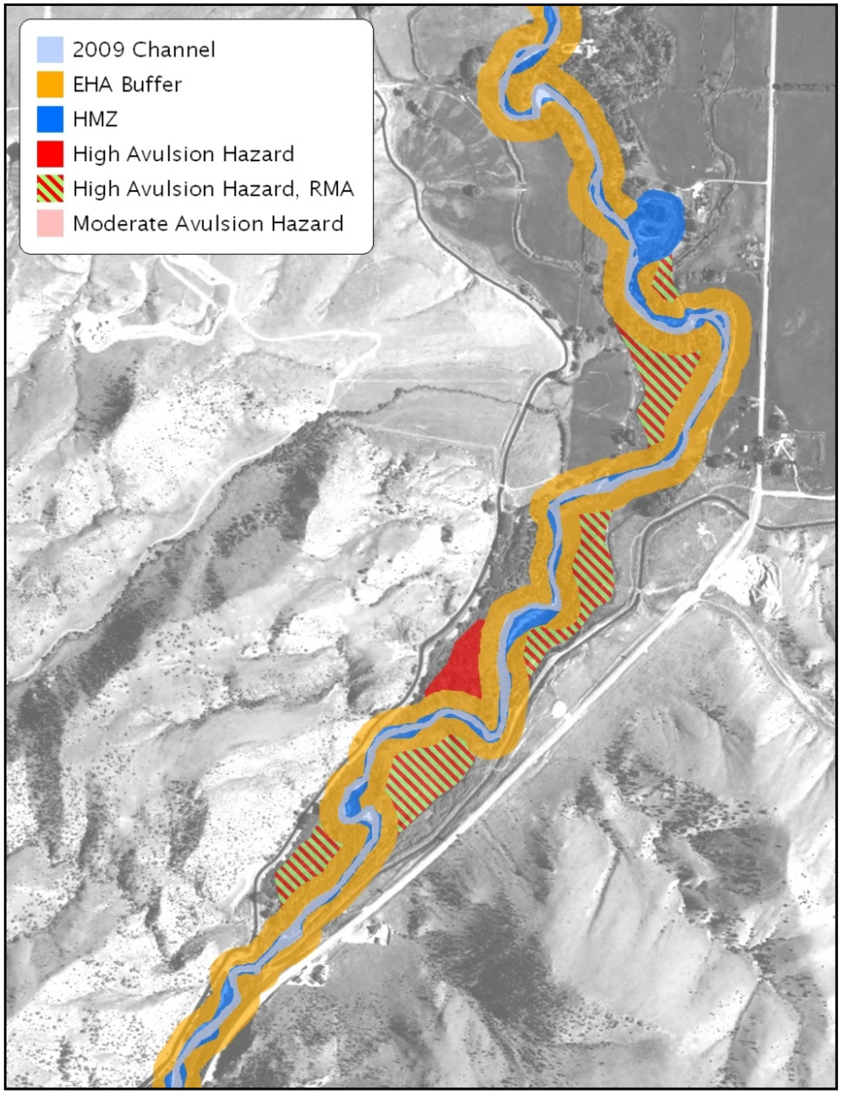

Figure 33. Canyon section (Reach 7) showing restricted avulsion hazard areas (cross-hatched).

4.6 Composite Map

An example portion of the composite CMZ map for a section of the Ruby River project reach is shown in Figure 34. The accompanying deliverable maps for the project reach are included on the project CD as PDF files. The final CMZ boundary includes the Historic Migration Zone (HMZ), Erosion Hazard Area (EHA), and areas of High Avulsion Hazards (AHZ). Avulsion hazards considered of moderate risk are not included within the CMZ boundaries.

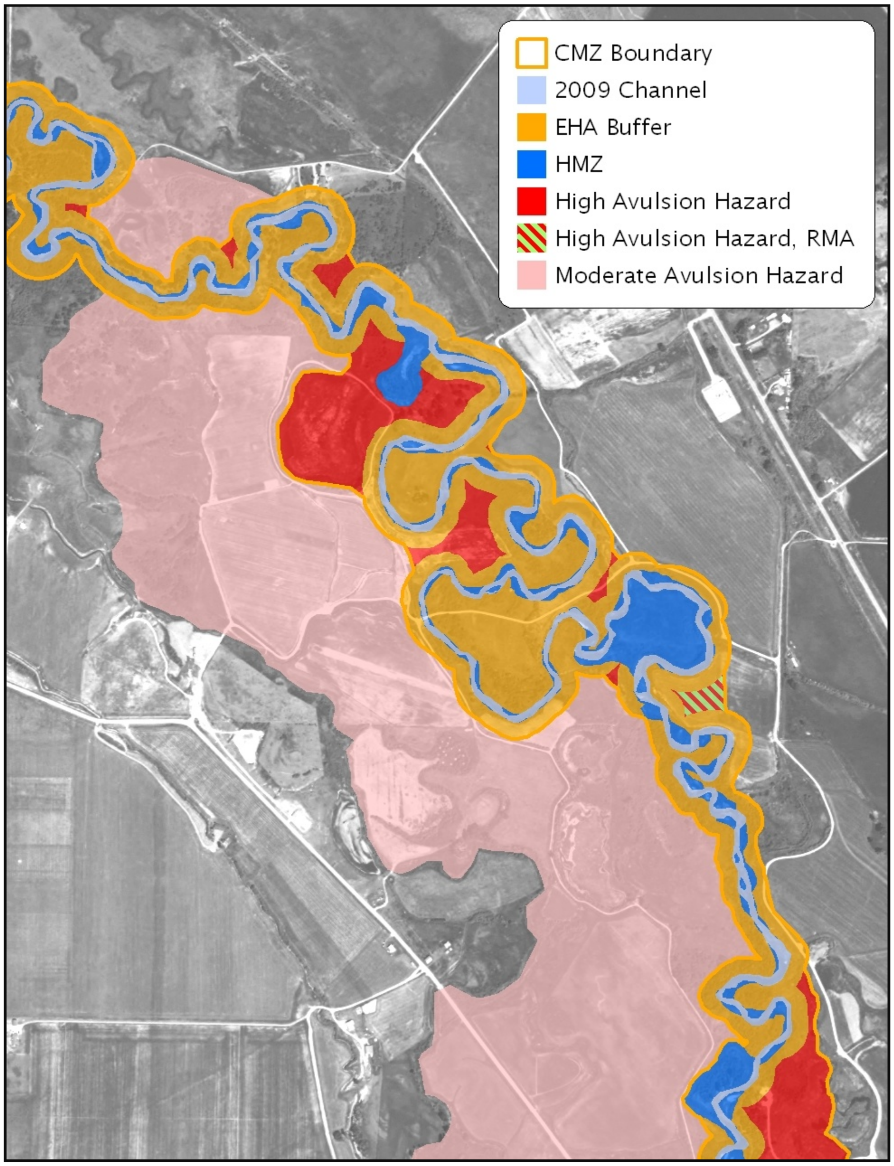

Figure 34. Composite Channel Migration Zone on 2009 imagery.

4.7 Deliverables

In addition to this report, CMZ mapping products for this effort consist of a project data CD and a map that delineates the Channel Migration Zone for the Ruby River from Ruby Reservoir to the Beaverhead River. All new project data are supplied on DVD in an ESRI Personal Geodatabase, along with PDF versions of the map. Each Feature Class is accompanied by appropriate FGDC compliant metadata. All data utilize the Montana State Plane 1983 HARN meters spatial reference. A list of GIS data layers can be found in Appendix C.

5.0 Recommendations

The reach-scale CMZ boundaries are based on average migration rates within a given channel segment. In order to allow 100-years of corridor change, sites are not treated specifically in terms of their recent migration rates; rather, all banklines are considered capable of an average migration distance over the next century. As a result, the CMZ boundaries are limited in terms site-specific applications, such as the evaluation of 310 permit applications. Based on feedback provided by the Ruby Conservation District, the local advising FWP fish biologist, and others, we have summarized recommendations for using the maps and associated data in site specific applications below. Additionally, opportunities for future work are provided, with coarsely estimated costs.

5.1 Individual Site Assessment using Existing Information

Because the widths of the erosion buffers are based on the average migration rate for an entire reach, the boundaries themselves do not reflect detailed, site-specific migration predictions. At a single location, migration rates will vary with time due to changes in channel planform, flow conditions, materials exposure, land use, and riparian conditions. Predicting these conditions at every eroding bank over the next century and developing site-specific rates that will accommodate those conditions is beyond the scope of this project. However, the GIS project that accompanies this report contains data generated in this effort that can assist managers in making decisions regarding the appropriateness of bank armor in a given location. With the GIS, the user can focus on an individual area and assess historic land use, planform change, and migration rates. This can be achieved using the orthorectified air photos in the project (1955, 1995, 2009) to assess overall site change. Migration vectors in the project are attributed with the 1955-2009 migration distance. With this information in hand, a better understanding of individual site conditions can support 310 permit decisions.

Additionally, this final report includes maps of all erosion sites and corresponding migration measurements in Appendix A and Appendix B.

5.2 Incorporation of 1970s Imagery

The inclusion of the pre-1981 flood imagery in the project GIS would help define the role of the 1981 flood on channel form. This imagery, from the 1970s, would provide a snapshot of the Ruby River just before that event. There has been some discussion that this event caused significant change in the river system which is difficult to discern with the existing suite of air photos.

The incorporation of the 1970s imagery would include photo acquisition from the USDA APFO, orthorectification, bankline digitiziation, and at a minimum, incorporation of the 1979 channel course into the HMZ. The estimated cost for these tasks is $3,000. These costs do not include the interpretation or analysis of the digitized banklines; that effort is included in Section 5.3.

5.3 Additional Analysis to Support Individual Site Assessment

Individual factors that influence migration rates on the Ruby River are not identified in this mapping effort. Migration rates naturally vary in any river system due to influences of materials, riparian condition, hydrology, land use, etc. In order to develop a more rigorous analysis of migration rates, it would be appropriate to further attribute the migration vectors in terms of site conditions, and then a statistical analysis of those results may shed light on rate influences. This effort would require segmenting the vectors into time steps based on the suites of photography, and then attributing each time step with parameters such as geology, land use, riparian density, and hydrologic history. If the results stratify sufficiently, it would be appropriate to map these features in the valley bottom and adjust migration rate projections accordingly. However, this will require extensive mapping of historic and existing land uses and riparian cover, additional information on soils, and will not be able to accommodate future land use change. We recommend that this assessment include the analysis of the 1979 imagery, to help characterize the response of the Ruby River to the 1981 flood.

If this effort is undertaken, it would be critical to define the criteria that are used in evaluating 310 permit application appropriateness, so that these factors can be considered in the analysis.

We recommend that this analysis be undertaken as a pilot study on select channel segments. The current migration measurement database for the Ruby River is robust, and the further analysis of the baseline information that is in hand could be performed for approximately $10,000.

5.4 Incorporation of a Bank Armor Inventory

Once a bank armor inventory is finalized, these line features can be incorporated into the GIS by digitizing line features on banklines mapped as armored. The line features can also be attributed with information such as armor type, condition, etc. If the RVCD is interested in identifying the Restricted Migration Areas associated with bank armor, the CMZ area behind each armor length can be cross-hatched in a similar fashion to the restricted avulsion hazard areas.

5.5 Short-Term CMZ Boundaries

If recent migration rates are major criteria in the consideration of 310 permit applications, then it may be appropriate to use short-term, recent migration rates to predict future movement over the next decade or so. This can best be achieved by site specific assessment of the GIS data as described in Section 5.1, or by considering historic rates that are mapped and tabulated in Appendix A and Appendix B.

5.6 Jurisdictional Boundaries

In the event that Conservation Districts desire to define 310 jurisdictional boundaries that extend behind the active bankline, such that projects such as trenched rock revetments can be reviewed, the CMZ boundaries as completed would be highly appropriate.

5.7 Investigate Lower River Avulsion

The avulsion in the lower seven miles of the river is a significant event in that it represents the largest channel shift in entire project area. The timing and factors behind this avulsion are currently unknown. As such, it would be appropriate to further investigate when the avulsion occurred, whether it was partly or fully due to human influence, and whether the historic channel noted in the GLO mapping actually was the primary Ruby River channel.

6.0 References

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7.0 Appendix A: Mapped Erosion Sites, Ruby River

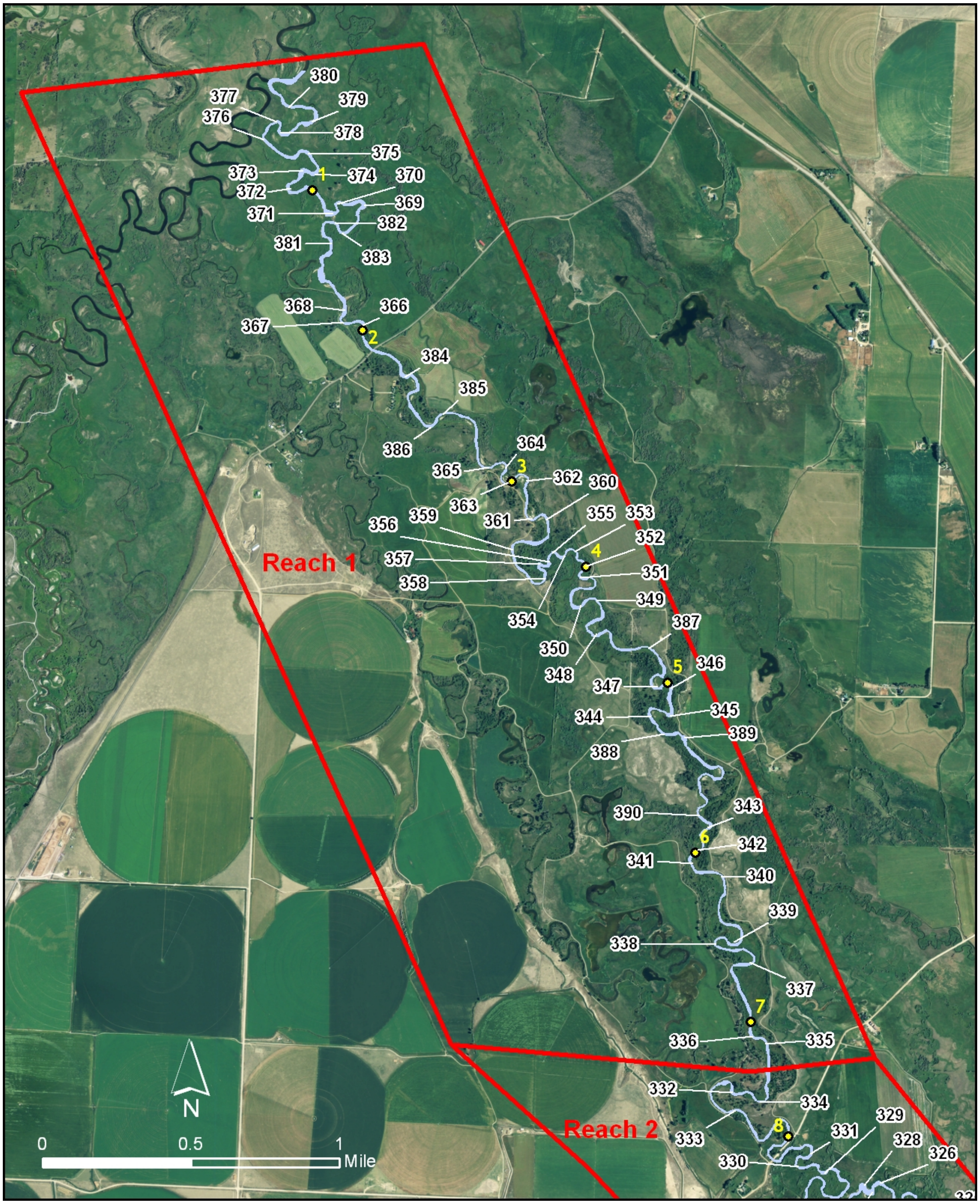

Figure 35. Erosion sites measured in support of CMZ analysis, Reach 1.

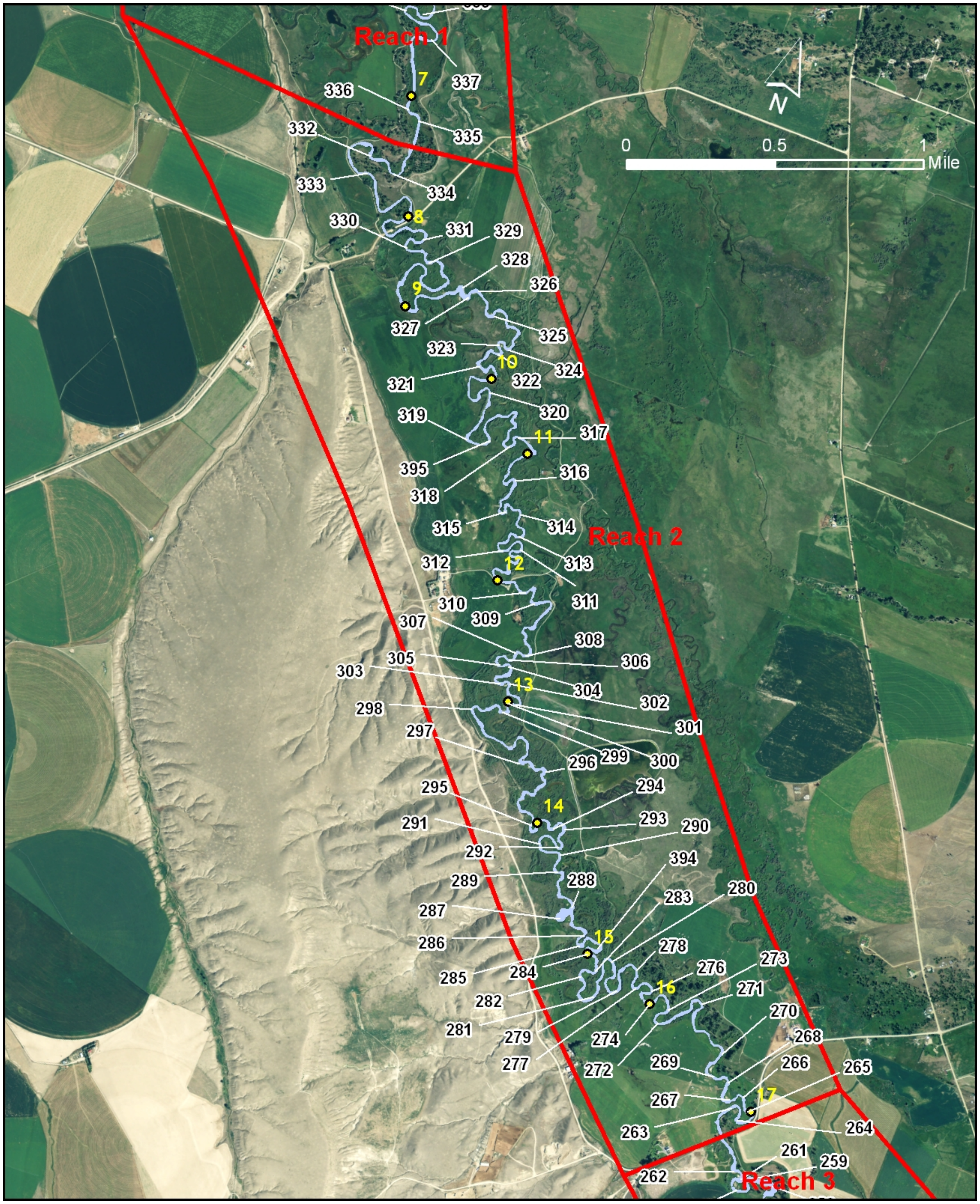

Figure 36. Erosion sites measured in support of CMZ analysis, Reach 2.

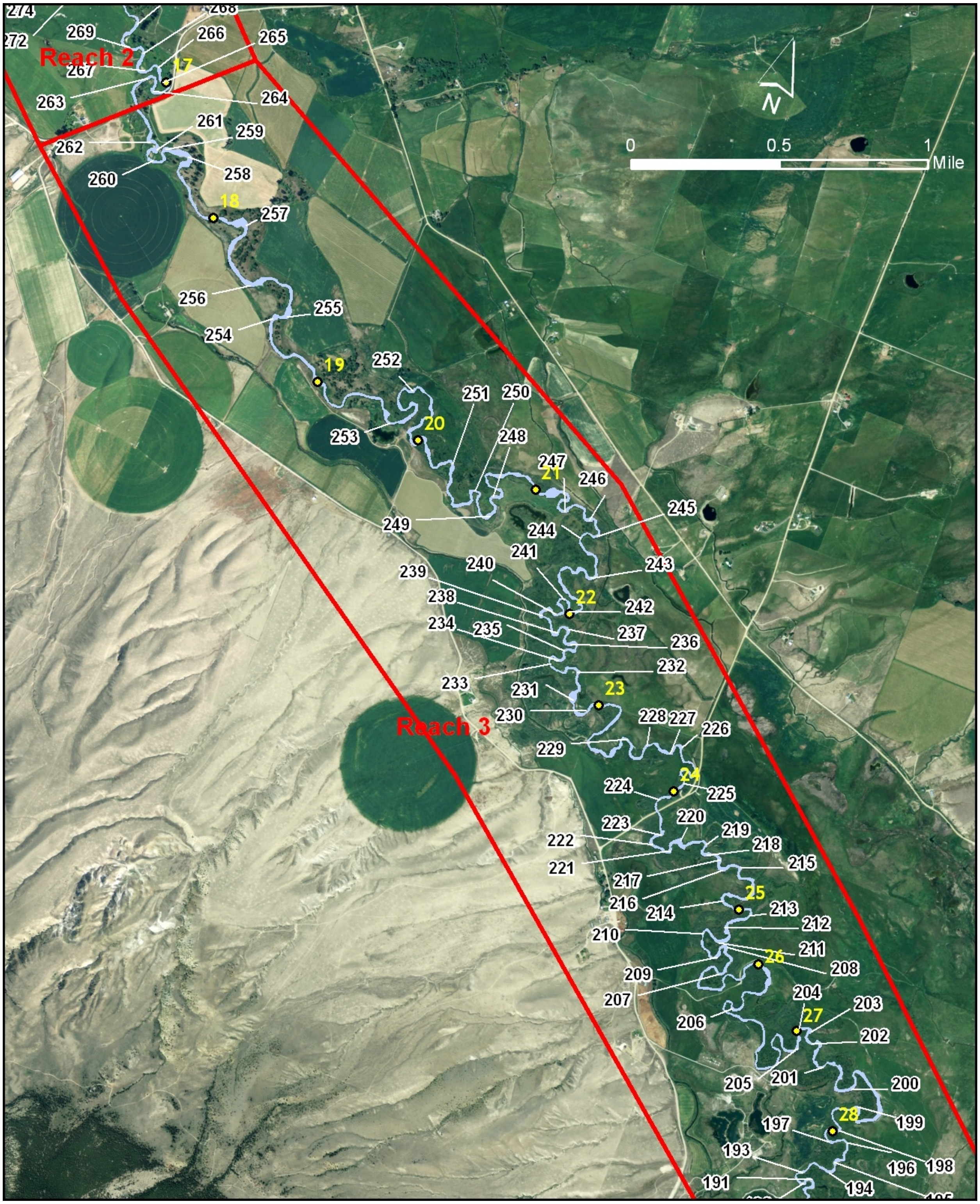

Figure 37. Erosion sites measured in support of CMZ analysis, Upper Reach 3.

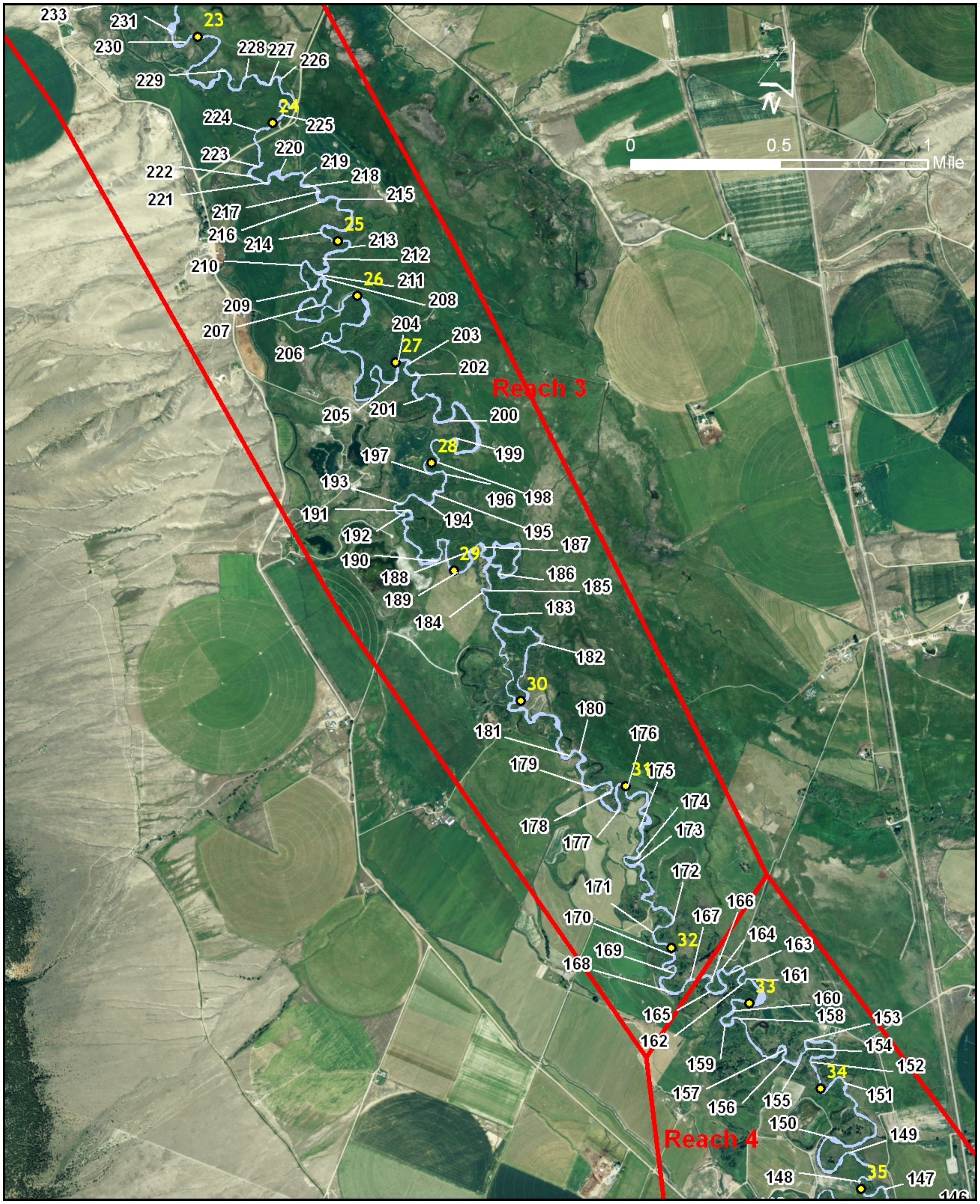

Figure 38. Erosion sites measured in support of CMZ analysis, Lower Reach 3.

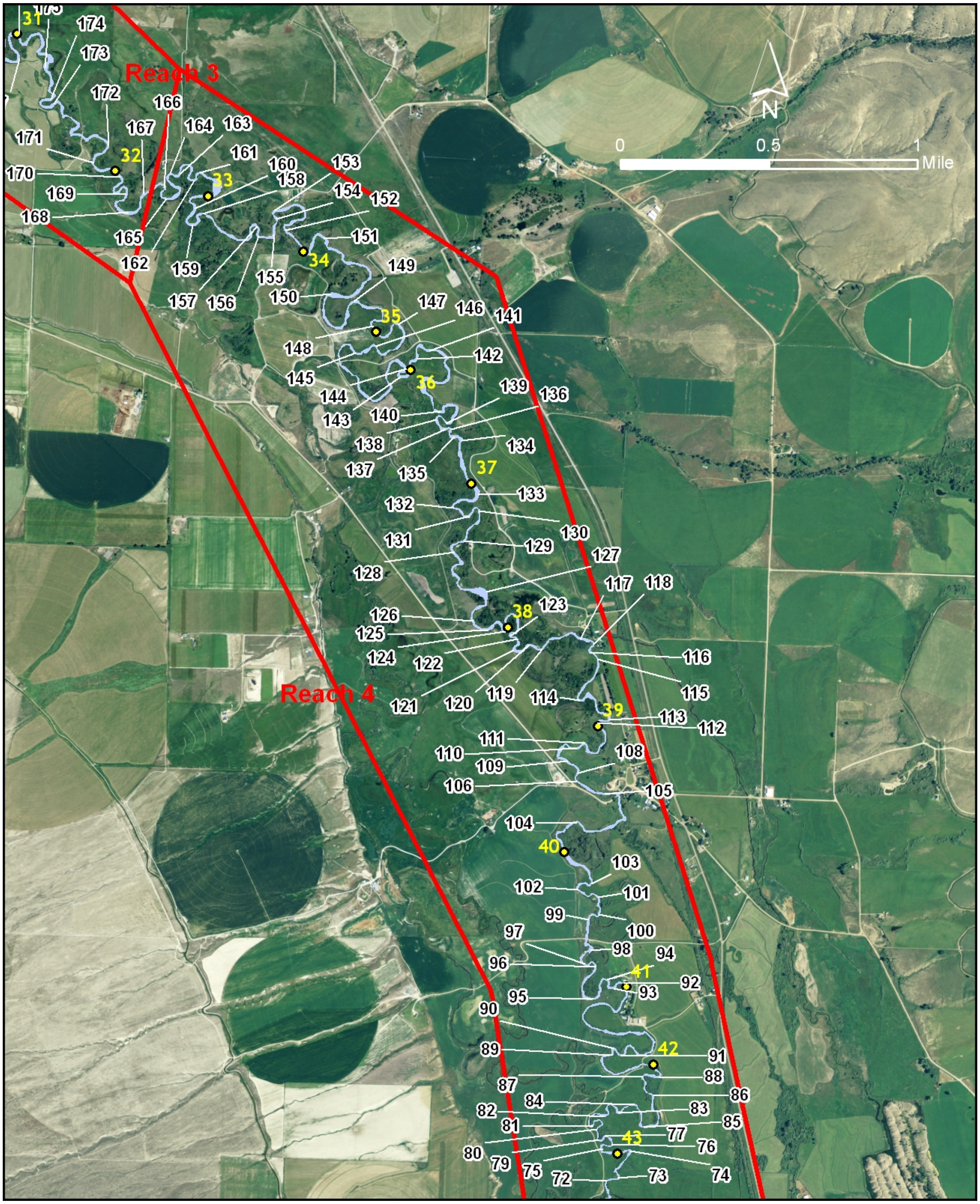

Figure 39. Erosion sites measured in support of CMZ analysis, Upper Reach 4.

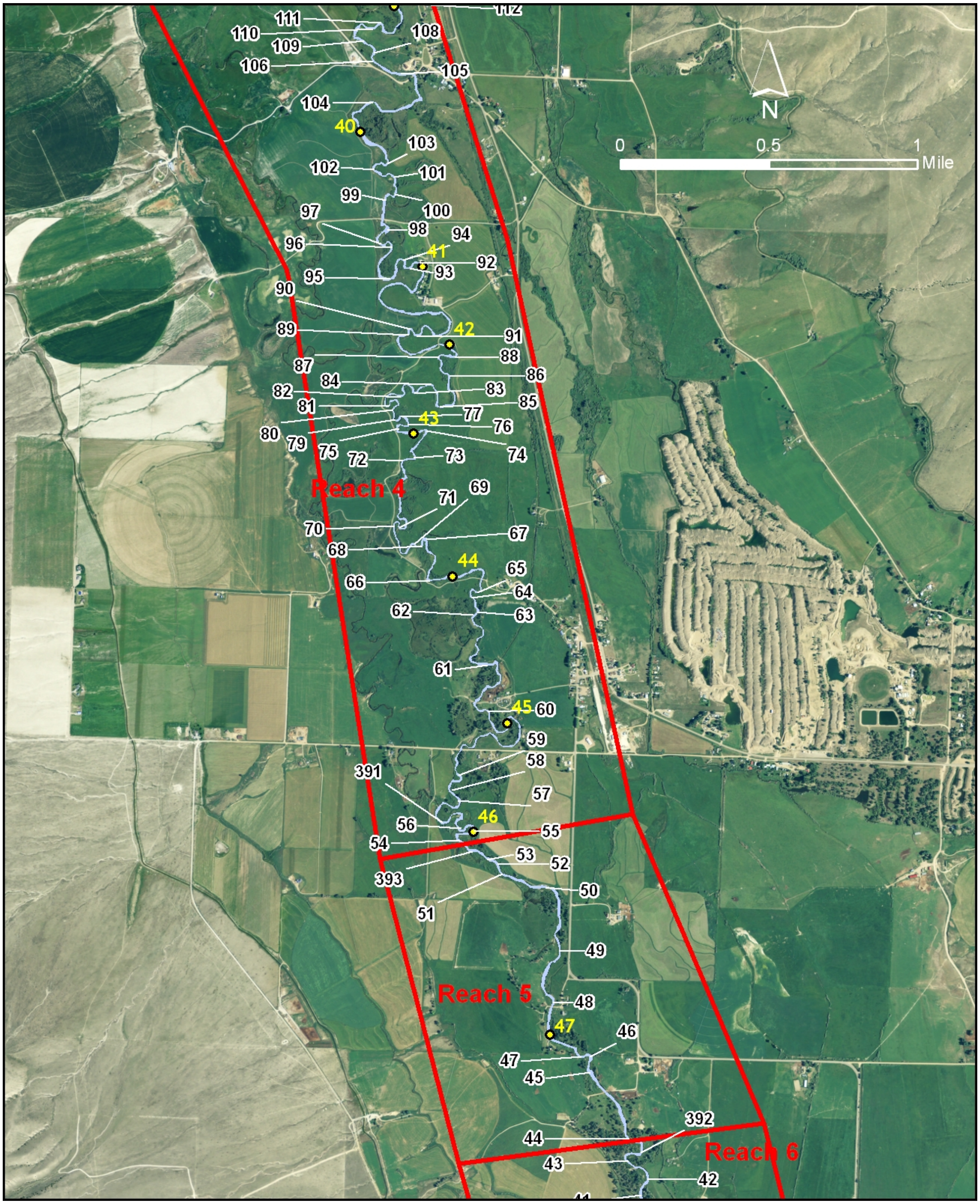

Figure 40. Erosion sites measured in support of CMZ analysis, Lower Reach 4 and Reach 5.

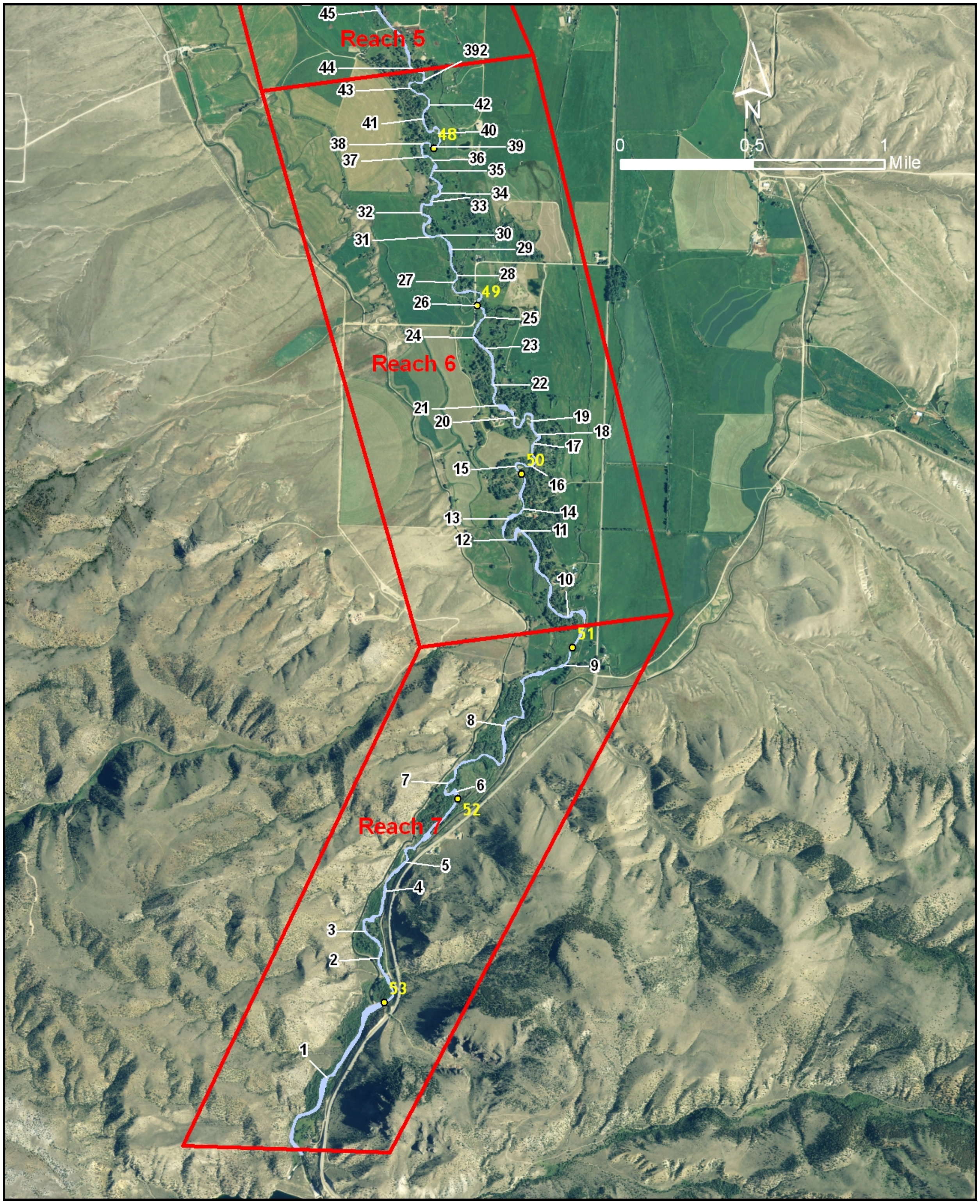

Figure 41. Erosion sites measured in support of CMZ analysis, Reach 6 and Reach 7.

8.0 Appendix B: Migration Rate Measurements

Ruby River Migration Rate Measurements				
1955-2009				
Reach	***Site ID***	***River Mile***	***Mean Migration Distance (ft)***	***Max Migration Distance (ft)***
1	380	0.09	54	62
1	379	0.22	100	127
1	378	0.36	76	92
1	377	0.42	75	90
1	376	0.49	54	61
1	375	0.67	99	113
1	374	0.76	67	96
1	373	0.82	64	84
1	372	0.91	144	171
1	371	1.10	81	109
1	370	1.17	70	81
1	369	1.26	96	105
1	383	1.40	38	43
1	382	1.45	59	62
1	381	1.56	56	62
1	368	1.85	93	97
1	367	1.89	57	71
1	366	1.96	94	120
1	384	2.22	56	65
1	386	2.48	41	50
1	385	2.53	56	71
1	365	2.82	77	88
1	364	2.90	121	145
1	363	2.97	100	123
1	362	3.05	134	152
1	361	3.20	113	131
1	360	3.28	112	136
1	359	3.48	73	84
1	358	3.66	79	101
1	357	3.74	53	55
1	356	3.78	94	110
1	355	3.82	42	47
1	354	3.86	65	75
1	353	3.91	52	61
1	352	3.99	78	83
1	351	4.05	81	101
1	350	4.25	114	157
1	349	4.34	65	70
1	348	4.49	150	164
1	387	4.74	71	81
1	347	4.92	148	173
1	346	5.01	116	137
1	345	5.11	67	80
1	344	5.20	144	188
1	388	5.29	50	56
1	389	5.36	42	49
1	390	5.81	41	46
1	343	5.87	113	135
1	342	5.97	105	124
1	341	6.03	82	101

Ruby River Migration Rate Measurements				
1955-2009				
Reach	**Site ID**	**River Mile**	**Mean Migration Distance (ft)**	**Max Migration Distance (ft)**
1	340	6.15	70	74
1	339	6.43	167	193
1	338	6.54	76	84
1	337	6.70	157	182
1	336	7.04	60	65
1	335	7.10	78	87
2	334	7.31	56	71
2	332	7.43	57	62
2	333	7.69	55	73
2	331	8.29	84	100
2	330	8.38	59	70
2	329	8.50	48	56
2	328	9.26	66	80
2	327	9.29	117	135
2	326	9.34	82	106
2	325	9.45	116	131
2	324	9.67	41	47
2	323	9.73	109	122
2	322	9.78	95	120
2	321	9.88	66	91
2	320	10.23	61	75
2	319	10.42	42	49
2	395	10.50	37	39
2	318	10.83	85	111
2	317	10.89	56	66
2	316	11.17	72	81
2	315	11.32	103	118
2	314	11.41	56	73
2	313	11.50	72	84
2	312	11.63	92	110
2	311	11.72	76	90
2	310	12.10	76	93
2	309	12.19	74	92
2	308	12.50	48	57
2	307	12.55	48	56
2	306	12.59	61	70
2	305	12.65	76	101
2	304	12.71	85	97
2	303	12.80	60	77
2	302	12.85	49	57
2	301	12.94	94	104
2	300	13.00	82	101
2	299	13.04	91	111
2	298	13.17	52	60
2	297	13.54	51	57
2	296	13.64	62	72
2	295	13.96	100	114
2	294	14.06	69	79
2	293	14.12	71	89
2	292	14.21	80	96
2	291	14.29	44	47
2	290	14.40	58	68
2	289	14.46	103	117

Ruby River Migration Rate Measurements				
1955-2009				
Reach	**Site ID**	**River Mile**	**Mean Migration Distance (ft)**	**Max Migration Distance (ft)**
2	288	14.64	84	100
2	287	14.68	115	137
2	286	14.77	48	55
2	285	14.81	66	85
2	394	14.89	122	163
2	284	14.99	89	98
2	283	15.06	69	101
2	282	15.13	98	125
2	281	15.26	101	128
2	280	15.44	89	111
2	279	15.60	76	114
2	278	15.74	30	32
2	277	15.82	47	60
2	276	15.89	57	70
2	274	15.97	73	97
2	273	16.08	84	107
2	272	16.17	81	93
2	271	16.36	67	83
2	270	16.60	62	66
2	269	16.70	107	144
2	268	16.78	83	107
2	267	16.86	147	180
2	266	16.92	68	86
2	265	16.98	58	66
2	264	17.08	77	89
2	263	17.14	116	146
3	262	17.41	73	78
3	261	17.45	87	101
3	260	17.52	94	108
3	259	17.62	87	101
3	258	17.69	108	122
3	257	18.10	117	153
3	256	18.37	61	65
3	255	18.62	76	86
3	254	18.67	76	93
3	253	19.38	54	60
3	252	19.67	54	63
3	251	20.19	46	61
3	250	20.45	73	100
3	249	20.57	67	86
3	248	20.66	62	80
3	247	21.19	73	89
3	246	21.33	74	86
3	245	21.42	45	57
3	244	21.48	44	48
3	243	21.65	71	82
3	242	21.99	92	111
3	241	22.04	67	83
3	240	22.13	82	105
3	239	22.21	100	115
3	238	22.32	92	117
3	237	22.37	50	62
3	236	22.43	82	102

Ruby River Migration Rate Measurements				
1955-2009				
Reach	Site ID	River Mile	Mean Migration Distance (ft)	Max Migration Distance (ft)
3	235	22.52	56	69
3	234	22.56	64	69
3	233	22.62	77	104
3	232	22.73	100	117
3	231	22.85	135	164
3	230	22.92	122	165
3	229	23.42	46	61
3	228	23.57	46	54
3	227	23.66	57	63
3	226	23.73	32	40
3	225	23.94	60	64
3	224	24.05	48	56
3	223	24.18	51	62
3	222	24.23	66	83
3	221	24.30	63	74
3	220	24.36	90	107
3	219	24.46	58	71
3	218	24.51	93	117
3	217	24.56	62	66
3	216	24.60	57	72
3	215	24.66	45	50
3	214	24.92	48	53
3	213	25.05	51	59
3	212	25.15	34	37
3	211	25.21	37	46
3	210	25.30	53	61
3	209	25.41	56	67
3	208	25.47	41	46
3	207	25.58	54	62
3	206	26.26	42	45
3	205	26.92	44	47
3	204	27.00	36	49
3	203	27.05	55	62
3	202	27.09	38	48
3	201	27.24	42	56
3	200	27.40	45	51
3	199	27.81	42	44
3	198	27.97	30	42
3	197	28.04	41	48
3	196	28.12	40	48
3	195	28.22	45	58
3	194	28.26	36	45
3	193	28.37	37	42
3	192	28.44	56	61
3	191	28.48	40	46
3	190	28.74	55	66
3	189	29.00	56	62
3	188	29.11	34	38
3	187	29.17	50	65
3	186	29.29	49	66
3	185	29.35	51	58
3	184	29.39	50	59
3	183	29.49	50	65

Ruby River Migration Rate Measurements				
1955-2009				
Reach	Site ID	River Mile	Mean Migration Distance (ft)	Max Migration Distance (ft)
3	182	29.72	63	93
3	181	30.43	81	108
3	180	30.48	51	63
3	179	30.64	129	151
3	178	30.75	45	62
3	177	30.88	39	52
3	176	30.99	35	44
3	175	31.27	54	67
3	174	31.39	63	78
3	173	31.51	40	57
3	172	31.82	28	38
3	171	31.89	33	37
3	170	32.00	93	115
3	169	32.14	103	131
3	168	32.24	97	105
3	167	32.37	35	41
4	166	32.45	59	65
4	165	32.49	49	74
4	164	32.64	26	30
4	163	32.68	42	58
4	162	32.80	49	58
4	161	32.84	40	58
4	160	33.09	58	75
4	159	33.16	51	69
4	158	33.23	42	59
4	157	33.49	36	45
4	156	33.53	40	49
4	155	33.58	40	57
4	154	33.64	36	46
4	153	33.67	42	53
4	152	33.89	54	64
4	151	34.09	90	121
4	150	34.51	44	58
4	149	34.77	33	34
4	148	34.96	91	114
4	147	35.10	53	65
4	146	35.29	30	33
4	145	35.37	37	42
4	144	35.90	27	29
4	143	35.94	45	60
4	142	36.04	32	39
4	141	36.13	62	75
4	140	36.49	81	100
4	139	36.65	40	49
4	138	36.70	37	42
4	137	36.74	60	82
4	136	36.77	39	48
4	135	36.80	68	81
4	134	36.84	44	49
4	133	37.03	55	64
4	132	37.15	52	71
4	131	37.21	51	63
4	130	37.26	60	76

Ruby River Migration Rate Measurements				
1955-2009				
Reach	Site ID	River Mile	Mean Migration Distance (ft)	Max Migration Distance (ft)
4	129	37.39	45	55
4	128	37.45	92	124
4	127	37.70	43	53
4	126	37.82	48	55
4	125	37.89	26	32
4	124	37.98	34	41
4	123	38.16	44	47
4	122	38.18	32	37
4	121	38.23	30	38
4	120	38.29	33	39
4	119	38.33	51	63
4	117	38.49	42	48
4	118	38.55	27	34
4	116	38.58	70	76
4	115	38.62	57	61
4	114	38.78	36	43
4	113	38.94	42	49
4	112	38.98	32	36
4	111	39.16	28	31
4	110	39.20	71	90
4	109	39.33	57	71
4	108	39.38	69	85
4	106	39.42	23	25
4	105	39.52	54	71
4	104	39.84	46	54
4	103	40.15	32	37
4	102	40.21	41	49
4	101	40.29	56	61
4	100	40.35	44	48
4	99	40.40	65	84
4	98	40.52	66	79
4	97	40.58	65	73
4	96	40.64	43	53
4	95	40.78	51	62
4	94	40.88	39	53
4	93	40.93	28	33
4	92	40.97	17	19
4	91	41.69	46	61
4	90	41.72	35	39
4	89	41.75	55	61
4	88	42.05	48	52
4	87	42.10	31	37
4	86	42.19	27	29
4	85	42.33	23	26
4	84	42.43	30	36
4	83	42.50	30	35
4	82	42.60	28	30
4	81	42.69	40	45
4	80	42.77	35	38
4	79	42.81	40	42
4	77	42.84	23	28
4	76	42.88	43	56
4	75	42.93	74	76

Ruby River Migration Rate Measurements				
1955-2009				
Reach	Site ID	River Mile	Mean Migration Distance (ft)	Max Migration Distance (ft)
4	74	43.05	47	59
4	73	43.16	49	58
4	72	43.20	19	27
4	71	43.48	35	42
4	70	43.52	64	74
4	69	43.69	25	27
4	68	43.71	34	38
4	67	43.75	46	59
4	66	43.91	38	46
4	65	44.19	37	39
4	64	44.24	19	21
4	63	44.30	38	48
4	62	44.32	19	24
4	61	44.58	31	35
4	60	44.86	32	39
4	59	45.50	63	80
4	58	45.55	102	118
4	57	45.63	83	93
4	391	45.76	36	52
4	56	45.90	129	146
4	55	45.98	96	114
4	54	46.06	104	145
5	393	46.13	32	37
5	53	46.19	26	31
5	52	46.23	35	41
5	51	46.26	28	35
5	50	46.42	48	68
5	49	46.66	55	61
5	48	46.87	42	52
5	47	47.12	42	49
5	46	47.17	73	87
5	45	47.22	60	68
5	44	47.48	56	66
6	392	47.55	79	96
6	43	47.63	96	131
6	42	47.73	65	80
6	41	47.80	46	60
6	40	47.91	119	140
6	39	47.99	94	104
6	38	48.04	43	53
6	37	48.10	28	32
6	36	48.14	53	60
6	35	48.18	41	55
6	34	48.27	95	130
6	33	48.34	56	70
6	32	48.42	69	80
6	31	48.53	60	89
6	30	48.60	24	27
6	29	48.66	34	40
6	28	48.77	24	28
6	27	48.83	52	68
6	26	48.99	41	55
6	25	49.04	61	66

Ruby River Migration Rate Measurements				
1955-2009				
Reach	Site ID	River Mile	Mean Migration Distance (ft)	Max Migration Distance (ft)
6	24	49.14	49	58
6	23	49.23	34	46
6	22	49.35	50	60
6	21	49.43	57	64
6	20	49.54	129	160
6	19	49.65	160	228
6	18	49.76	68	92
6	17	49.81	69	76
6	16	49.88	54	76
6	15	49.95	75	99
6	14	50.12	48	56
6	13	50.20	54	62
6	12	50.27	25	29
6	11	50.37	79	111
6	10	50.75	53	75
7	9	51.06	31	43
7	8	51.45	95	108
7	7	51.92	74	85
7	6	51.97	79	112
7	5	52.32	60	72
7	4	52.47	48	55
7	3	52.63	54	64
7	2	52.81	37	38
7	1	53.36	73	82

9.0 Appendix C: GIS Datasets

Layer Name	*Description*
Avulsion_Areas	Topographic features identified as potential avulsion areas.
Bank_Armor	Mapped bank armor locations (incomplete).
banklines_1955	1955 banklines.
banklines_1995	1995 banklines.
banklines_2009	2009 banklines.
CMZ	Composite Channel Migration Zone, including avulsion zones and restricted areas.
CMZ_boundary	Channel Migration Zone outer boundary only.
EHA_max_2009	EHA buffer using maximum measured vector statistic.
EHA_mean_2009	EHA buffer using average measured vector statistic.
HMZ	Historic Migration Zone
Migration_Vectors	Lines representing measured migration from 1956 to 2009.
Reach_Boundaries	Project reaches.
RM_integer	Integer river miles.
RM_tenths	Tenths of river miles.
Ruby_centerline_2009	2009 channel centerline.