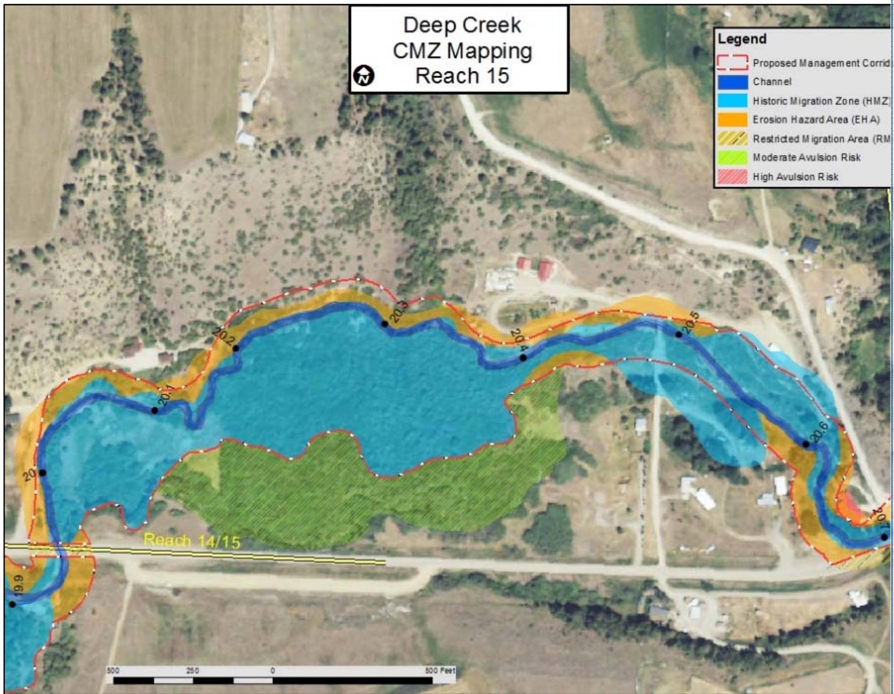
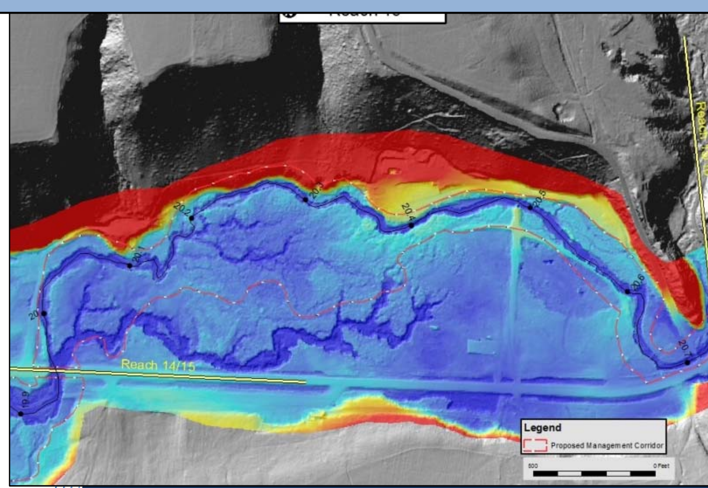


Final Report

January 25, 2016

Deep Creek

Channel Migration Zone Mapping



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Glossary

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

Avulsion - A sudden cutting off or separation of land by a flood or by abrupt change in the course of a stream, as by a stream breaking through a meander or by a sudden change in channel location whereby the stream deserts its old channel for a new one. The result is often the formation of a straighter channel pattern characterized by an increase in channel bed slope and decrease in channel length.

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. The stage just before over bank flow begins.

Channel Migration – The process of a river or stream moving laterally (side to side) within its floodplain. This process can be slow or fast and the rate is usually affected by the type of soils present in the banks, land use, the volume of water and its power to erode the banks.

Channel Migration Zone – An area enveloping a stream that reflects the corridor the stream is likely to occupy over some given period of time.

Erosion Buffer—An area beyond the active river banks where future erosion is likely based on historic rates of change.

Flood frequency – The statistical probability that a flood of a certain magnitude for a given river will occur in a certain period of time.

Floodplain- A flat or nearly flat land adjacent a stream or river that stretches from the banks of its channel to the base of the enclosing valley walls and experiences flooding during periods of high discharge

Fluvial - Formed or produced by the action of flowing water; of, pertaining to, or inhabiting a river or stream.

Geomorphology - The study of landscape evolution including shape, form and process through space and over time. It is the earth science that focuses on understanding the processes of erosion, weathering, transport, and deposition, with measuring the rates at which such processes operate, and with quantitative analysis of the forms of the ground surface and the materials of which they are composed (Goudie et. al. 1994).

GIS – Geographic Information Systems: 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).

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) - Functional wood in streams is called *large woody debris*. The definition of large woody debris varies. However, for the purposes of this study, the typical size of LWD are 18-36 inches in diameter and 12 – 32 feet in length.

Management Corridor: A proposed stream corridor that integrates CMZ mapping and land use into a practical corridor for river management.

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.

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

Riparian: Relating to or inhabiting the banks of a natural course of water. Riparian zones are ecologically diverse and contribute to the health of other aquatic ecosystems by filtering out pollutants and preventing erosion.

Return Interval- The likely time interval between floods of a given magnitude.

Riprap – Rocks placed to stabilize banks and provide other types of protection, such as from erosion.

Sinuosity - The measurement of a channel's relative straightness or curving configuration. It is the ratio of channel length to downward valley length; for example, a value of one 1.0 is a straight channel pattern, whereas a sinuosity of 1.5 is considered meandering.

Stream competency - The ability of a stream to mobilize its sediment load; refers to the maximum size of particles of given specific gravity, which, at a given velocity, the stream will move.

Terrace - A step-like surface, bordering a valley floor or shoreline, that represents the former position of a floodplain, or lake or sea shore. Practically, terraces are considered to be generally flat alluvial areas above the 100 year flood stage.

Wetland – Areas that possess unique types of vegetation and soils resulting from their frequent inundation or saturation by water.

Forward

A New Approach for Managing Deep Creek

Ron Spoon, Montana Fish Wildlife and Parks

Information presented in this report is a result of decades of attempting to manage the stream channel of Deep Creek. Many activities along Deep Creek since the 1940's have attempted to control the stream's location and movement. In addition, a variety of people have made their living along Deep Creek. Beaver were trapped, vegetation was removed, crops were planted, livestock was grazed, and roads were built along the waterway. The response of the stream to these activities seems logical now, but for decades folks along Deep Creek including agency professionals believed the stream could be reined-in with dikes, rip-rapped, and controlled other aggressive methods. Lots of rip-rap was placed along the streambanks of Deep Creek from approximately 1950 to 1980.

Some of this old rock work still exists today, but the stream generally continued to migrate, erode and degrade during the years of extensive armoring. Streamside vegetation was limited to a narrow corridor, and the downcut, incised, entrenched channel exposed eroding banks that were often higher than 4 to 6 feet from the water.

From 1991 to 1997, an alternative approach to managing erosion and instability of Deep Creek was attempted by agencies and cooperating landowners. A large-scale attempt to use soft streambank treatments to slow erosion and promote streamside vegetation was implemented in 1996-97. Over 13,000 feet of streambank was sloped, stabilized with juniper revetments, and planted with willow. Miles of riparian fence was built. Streamside vegetation visibly improved after this project, and the quantity of actively eroding streambank was reduced. The longevity and persistence of this work was unknown.

During 2010 and 2011, Deep Creek experienced two significant spring run-off events. The 2011 event was particularly noteworthy because of the long duration of high water. Stream channel movement was extensive in some areas during these floods, and landowners were beginning to plan their response. It appeared there was risk that some landowners were considering a return to the practice of installing expensive, un-vegetated rip-rap to define the margin of the stream and the agricultural operation.

After two years of inventory and reviewing options with the Deep Creek Landowner Advisory Group, a consensus emerged. The more experienced residents along the waterway saw the futility and expense of going back to the 1960's when placing large rock along streambanks was common. The notion of simply getting away from the stream was an idea that gained traction.

How far should a landowner keep fences, barns, roads, and other important infrastructure away from the dynamic waterway? The Deep Creek Landowner Advisory Group, Broadwater Conservation District, Department of Fish, Wildlife & Parks, and others directed grant funds from DEQ and DNRC to answer this question about stream migration over time.

The intention of conducting this Channel Migration Zone evaluation, and for developing maps to understand where the steam has been and where it might go over time, is to improve our decision making along Deep Creek. This report is not intended to be a regulatory tool, but rather, an educational tool to guide management actions. Natural process that allow Deep Creek to heal over time might take a little more space near the stream, but this space or buffer will likely improve the experience of people living and working near this Montana trout stream.

1 Introduction

This report describes the development of a 100-year Channel Migration Zone (CMZ) map for the portion of Deep Creek that extends from the US Forest Service Boundary in Deep Creek Canyon downstream to its confluence with the Missouri River (Figure 1-1). The purpose of this write-up is to summarize the project methodology and provide some interpretation in regards to river process, management challenges, and restoration opportunities. Although the mapping results are presented in a discussion of each reach, the complete CMZ map is provided as a separate PDF document.

Figure 1-1. General project location (from Skidmore Restoration Consulting and AGI, 2013).

1.1 What is Channel Migration Zone Mapping?

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

The Channel Migration Zone (CMZ) developed for Deep Creek is defined as a composite area made up of the existing channel, the collective footprint of mapped historic channel locations since 1947 (Historic

Migration Zone, or HMZ), and an Erosion Buffer (Erosion Hazard Area or EHA), that encompasses areas demonstrably prone to channel erosion over the next 100 years. Areas beyond the Erosion Buffer that pose risks of channel avulsion are identified as Avulsion Hazard Areas or AHZ. These mapping components are discussed in more detail in the results section of Section 4.

1.2 CMZ Mapping on Deep Creek

This project was performed in support of recommendations made in the report titled ***Deep Creek Watershed Restoration Plan – Assessment and Recommendations*** (Skidmore Restoration Consulting and AGI, 2013). That document, referred to in this document as the ***Skidmore Watershed Restoration Plan*** (to avoid its confusion with the Watershed Restoration Plan developed by the Broadwater Conservation District), contains a summary of project reach conditions with regard to land use and historic issues of channel stability. The reader is referred to that document for more site-specific background information. This report focuses on the development of a Channel Migration Zone (CMZ) map for the reach, which was recommended in the Watershed Restoration Plan as follows:

> We suggest a two-step corridor delineation procedure. First, a CMZ is mapped with consideration of historic channel migration trends, anticipated future migration erosion buffers, channel avulsion potential, meander belt widths, and flood inundation mapping, among other geologic or hydrologic considerations. And second, the corridor is modified to accommodate existing infrastructure and landowner concerns. For example, a modified CMZ will typically be bounded where roads and railroads are established and pinch at road crossings. A modified CMZ can be delineated to accommodate existing property concerns that may be unreasonable to compromise.

In support of this recommendation, we have developed CMZ boundaries and an accompanying Recommended Management Corridor using the process described above. The Management corridor is described in more detail in Section 2.8.

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

1.3 The Project Team

This project 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 a number of rivers in Montana, in an attempt to provide rational and scientifically sound tools for river management. It is our overall goal to facilitate the understanding of rivers regarding the risks they pose to infrastructure, so that those risks can be managed and hopefully avoided. Furthermore, we hope to stress the benefits of managing rivers as dynamic, deformable systems that provide resilience to flooding, economic benefit through ecological sustainability, and reduced capital costs of engineered solutions.

1.4 Acknowledgements

We would like to extend our gratitude to Denise Thompson of Broadwater Conservation District for her assistance in contract management and scheduling. Ron Spoon of Montana Fish Wildlife and Parks collected field data that were used in the assessment, and he also provided the foreword to this document which provides excellent context. We also appreciate the oblique aerial photography shot by Chris Boyer of Kestrel Aerial Services, as those images provide a perspective of the creek that can't be made with conventional air photos. Draft review comments from Denise Thompson, Ron Spoon, Robert Ray (DEQ) and Katie Mumford (Big Sky Watershed Corps) were appreciated and integrated into the document.

2 Methods

The methodology applied to the CMZ delineation generally follows the techniques outlined in Rapp and Abbe (2003) as well as Washington Department of Natural Resources (2004). The Channel Migration Zone (CMZ) developed for Deep Creek is defined as a composite area made up of the existing channel, the historic channel since 1947 (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 (an abrupt channel relocation) are identified as having either high or moderate avulsion risk.

The basic steps used to develop the maps include acquiring air photos, digitizing the channel, measuring migrating rates, analyzing the results, and using all of the results to map each CMZ component.

2.1 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. For relatively small streams like Deep Creek, 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 were available for Deep Creek. 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 ranges from good to excellent and they cover the entire project area.

Imagery older than 1995 had to be acquired from various archival services as digital scans. For this project, the historic imagery scans were spatially referenced in the GIS using 2nd and 3rd degree polynomial fit georeferencing. The 2013 NAIP imagery was used as a spatial reference, providing identifiable ground control points. The individual georeferenced images were then clipped to create a tiled data set for each archival year.

Table 1 lists imagery used for this project from the USGS and archives of current GIS data sets. The rows in green are the image sets primarily used in the analysis. Examples of the imagery used in the analysis are shown in Figure 2-1 through Figure 2-4.

Table 1. Available aerial photography for the Deep Creek corridor. The series in green were used in CMZ development.

Date	Source	Quality	Notes
1947	USGS	Moderate	High Resolution scans Digital Download
1980	USGS	Moderate	Medium Resolution scans Digital Download
1995 - DOQ	USGS	Good	Digital Download
2005 NAIP	NRIS	Excellent	Digital Download
2009 NAIP	NRIS	Excellent	Digital Download
2011 NAIP	USDA	Excellent	Digital Download
2013 NAIP	USDA	Excellent	Digital Download

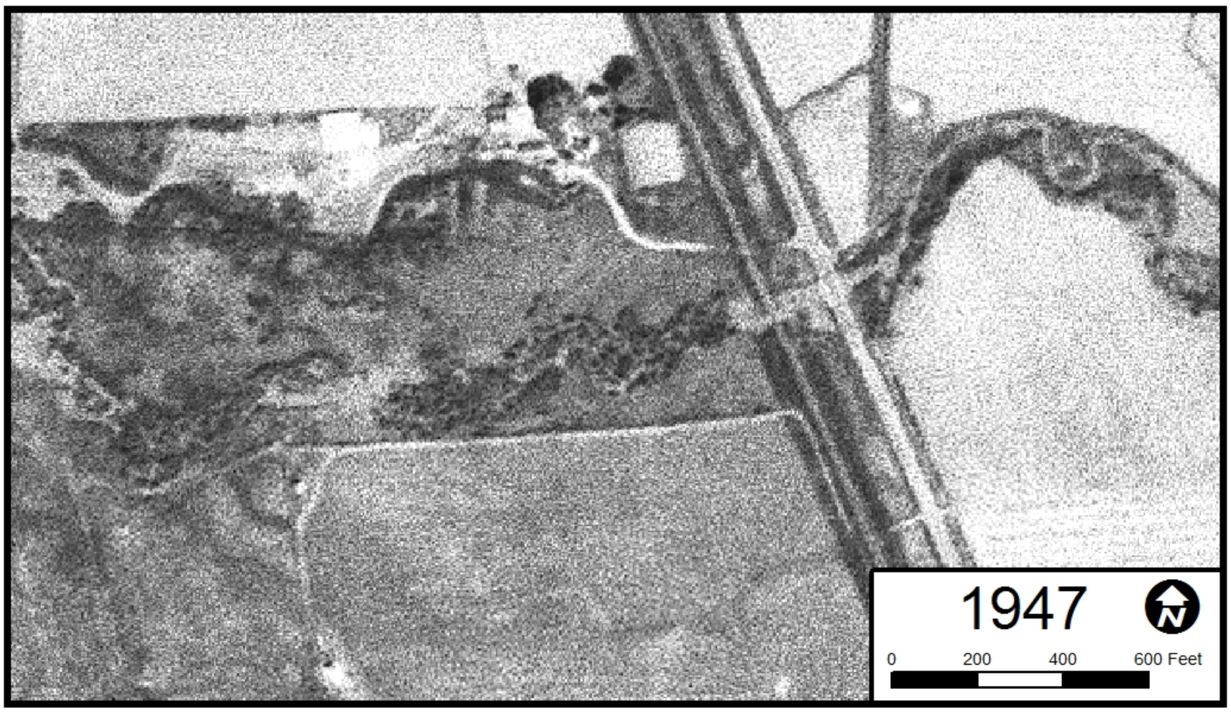


Figure 2-1. Example 1947 imagery, Deep Creek CMZ development (Hwy 287, Reach 1-2 boundary).

Figure 2-2. Example 1980 imagery, Deep Creek CMZ development (Hwy 287, Reach 1-2 boundary).

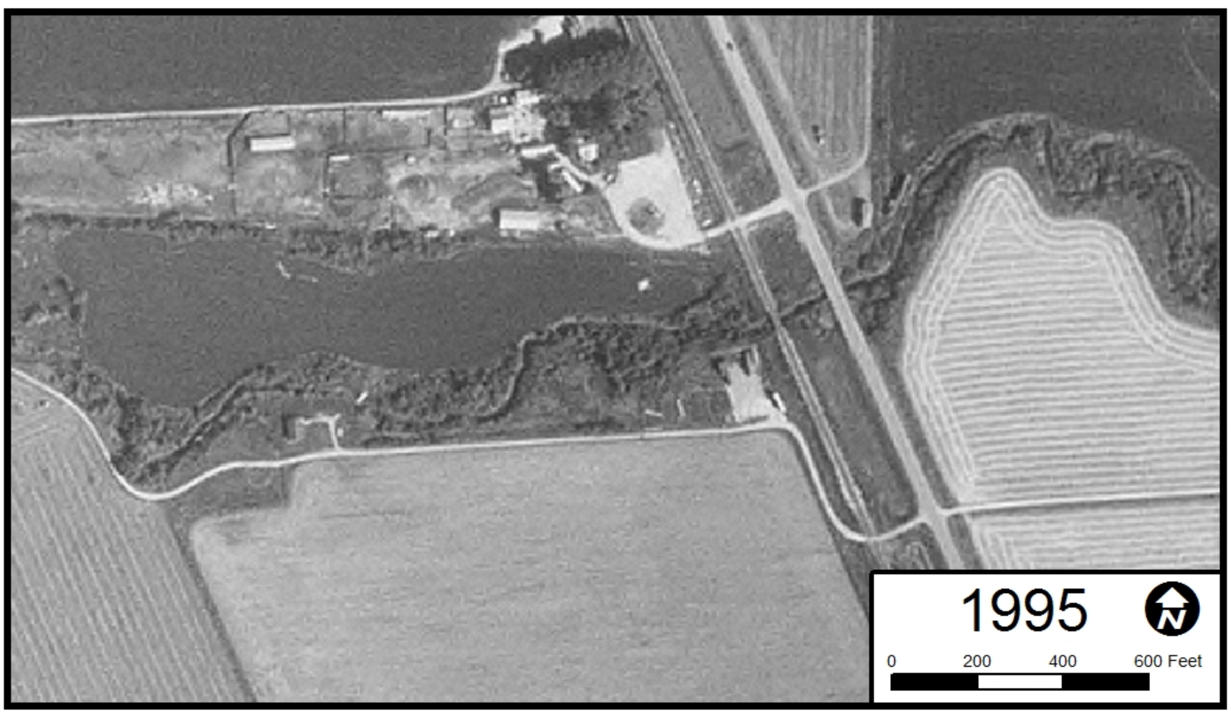


Figure 2-3. Example 1995 imagery, Deep Creek CMZ development (Hwy 287, Reach 1-2 boundary).

Figure 2-4. Example 2013 imagery, Deep Creek CMZ development (Hwy 287, Reach 1-2 boundary).

2.2 LiDAR Data

High resolution LiDAR (LIght Detection and Ranging) elevation data were made available by the Broadwater Conservation District and used extensively in this effort. The LiDAR dataset was used in inundation modeling, as well as to help identify topographic features such as terraces, floodplain channels, and dikes/levees by cutting cross sections and reviewing hillshaded data.

2.2.1 Inundation Modeling

Inundation Modeling is an effective way to visually compare floodplain elevations to channel elevations, and is useful in identifying floodplain features such as historic channels that are prone to frequent flooding and avulsion.

Inundation modeling is a static model of inundation potential based upon Digital Elevation Model (DEM) data. The general goal of the modeling is to identify areas that may be prone to flooding as the water surface of the stream is raised. The general technique involves using cross sections to create a water surface profile down the stream corridor. This profile is then transformed into a series of ramped planes down the stream corridor that match the down-valley slope of the water surface. The ground surface is then subtracted from this planar water surface, so that a relative depth can be assigned at each LiDAR data point. The resulting surface coarsely represents relative inundation potential (Figure 2-5). This is often used to approximate flood prone areas, but it also is a useful tool for identifying low topographic features or channels that may pose an avulsion risk (Figure 2-5).

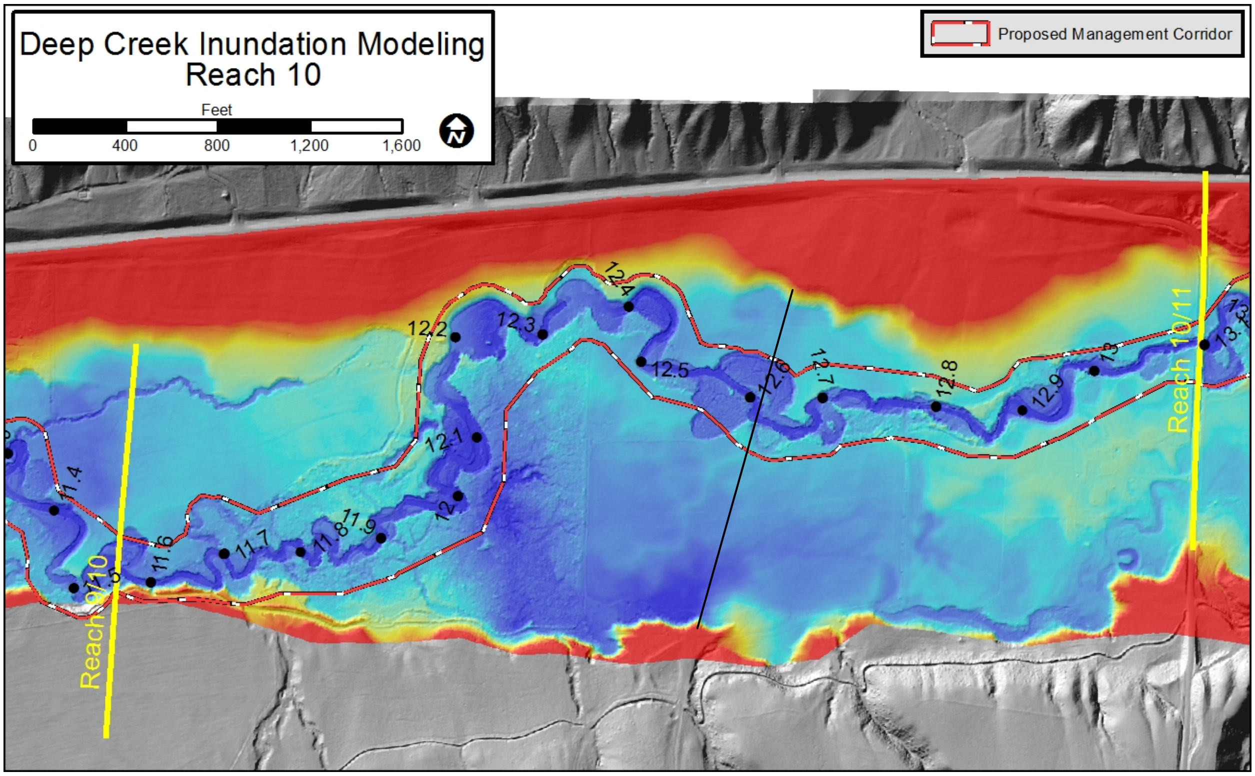
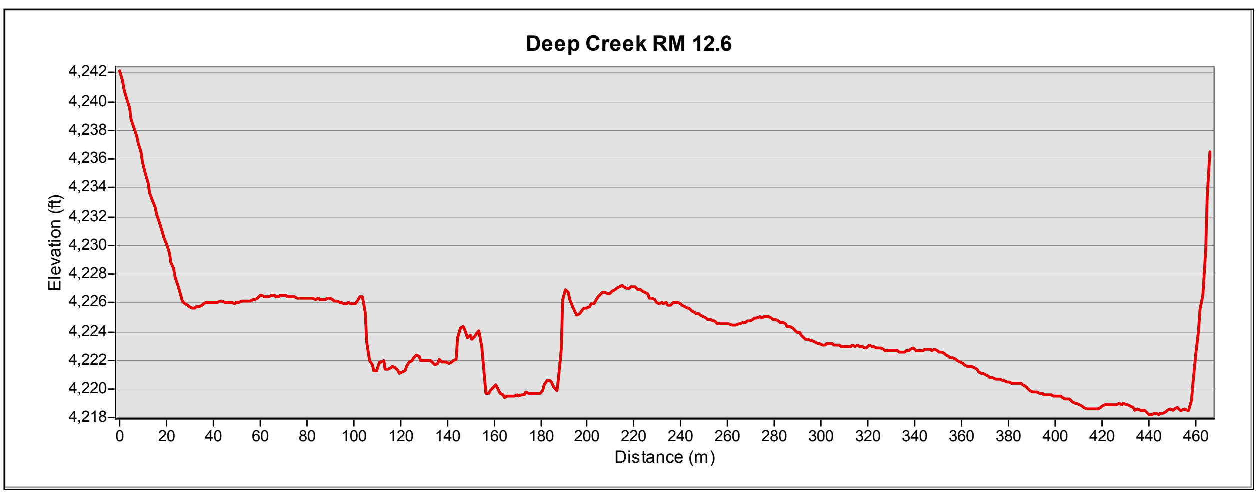


Figure 2-5. Example Inundation Modeling Results, Reach 10 (cross section location in black). Colors represent elevations relative to the elevation of the main channel. Dark blue areas are equal to or lower than the channel. Yellows and reds are significantly higher than the adjacent main channel.



2-6. Cross section at River Mile 12.6.

2.3 **Centerline Digitizing and Buffering**

The traditional approach to CMZ mapping involves mapping the channel banklines seen on each set of historic imagery. The visibility of the banks depends on the size of the stream, the stream setting (e.g., heavy vegetation vs. open fields), and the quality of the imagery. Larger streams and rivers in open settings are easier to map and can be supported by poorer quality imagery.

The Deep Creek project reach is challenged by all three issues: a small stream, locally dense vegetation, and moderate image quality. In some areas, especially in the 1947 and 1980 imagery, the stream almost completely disappears into dense vegetation or is otherwise not clearly visible, perhaps due to low flows not maintaining a clear channel. In other areas, though the course of the stream is visible, there is no clear left and right bank line. As such, the traditional approach of mapping bank lines has been altered in favor of mapping centerlines. Centerlines were digitized on the air photos from 1947, 1980, 1995, and 2013. The centerlines were then buffered on either side to generate a 28-foot wide channel (Figure 2-7), which is the approximate average channel width (Skidmore Restoration Consulting and AGI, 2013). The results were checked for each year of the imagery and as a team we agreed that they provided sufficient detail for the analysis.

2.4 **Mapping the Historic Migration Zone**

The Historic Migration Zone is the overall footprint that the creek occupied in 1947, 1980, 1995, and 2013 (Figure 2-7). The method for delineating the HMZ is to overlay the digitized polygons for the channel for each time series, and union those polygons into a single HMZ polygon. All islands are included with the merged HMZ polygon.

The HMZ mapping can provide a useful management tool on its own, as it shows the locations of Deep Creek over the past 66 years. People commonly don’t recognize when they are investing capital in high risk areas where the channel has recently been flowing. The HMZ is a very straightforward depiction of that high risk area, and that depiction can be very is compelling to stakeholders.

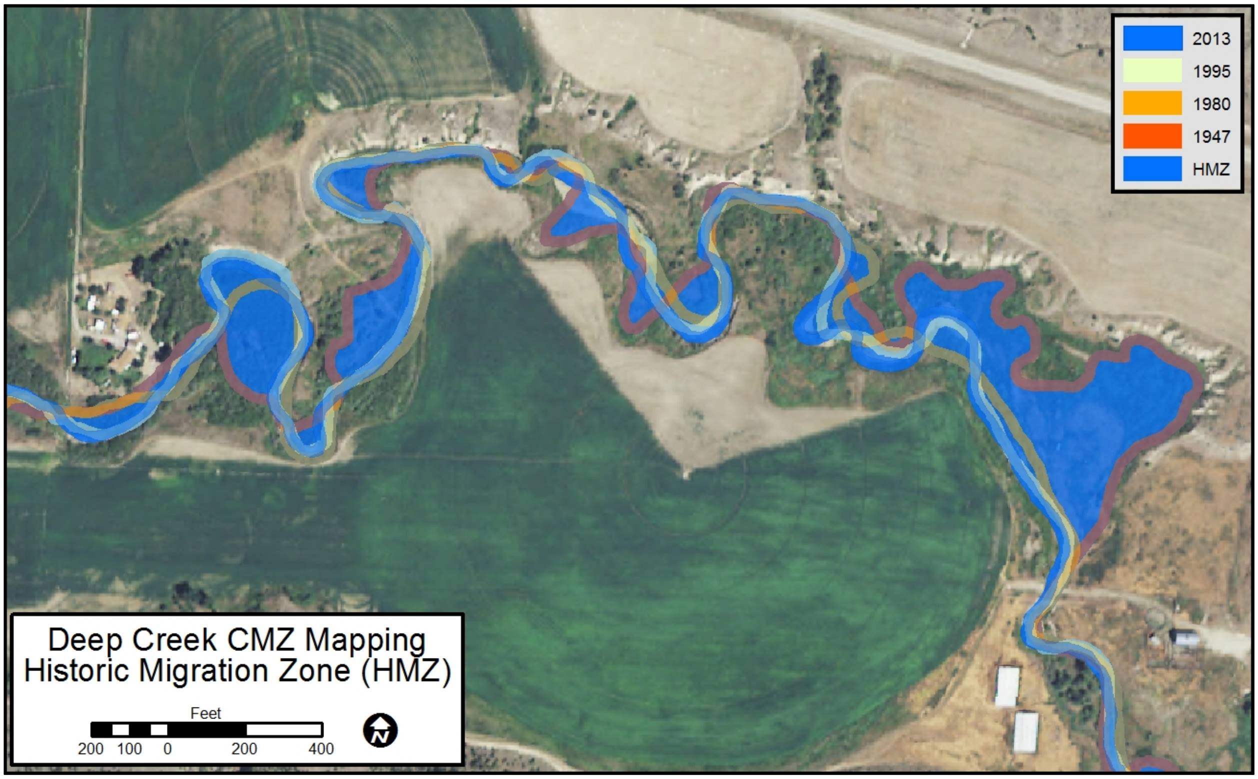


Figure 2-7. Example of mapped channel courses and composite Historic Migration Zone (HMZ).

2.5 Migration Rate Measurements

Once the HMZ was developed, the banklines were evaluated in terms of discernable channel migration since 1947. 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 at approximately 30 foot intervals (Figure 2-8). These measurements were then summarized by reach to estimate how much more room the creek needs for future erosion. The results define the width of the erosion buffer.

There are several areas throughout the corridor where the stream is actively eroding into high terraces on the edge of the valley. Migration into the terraces is typically slower than in the valley bottom. As a result, these measurements were kept separate, and the erosion buffer assigned to the terraces reflects just those measurements.

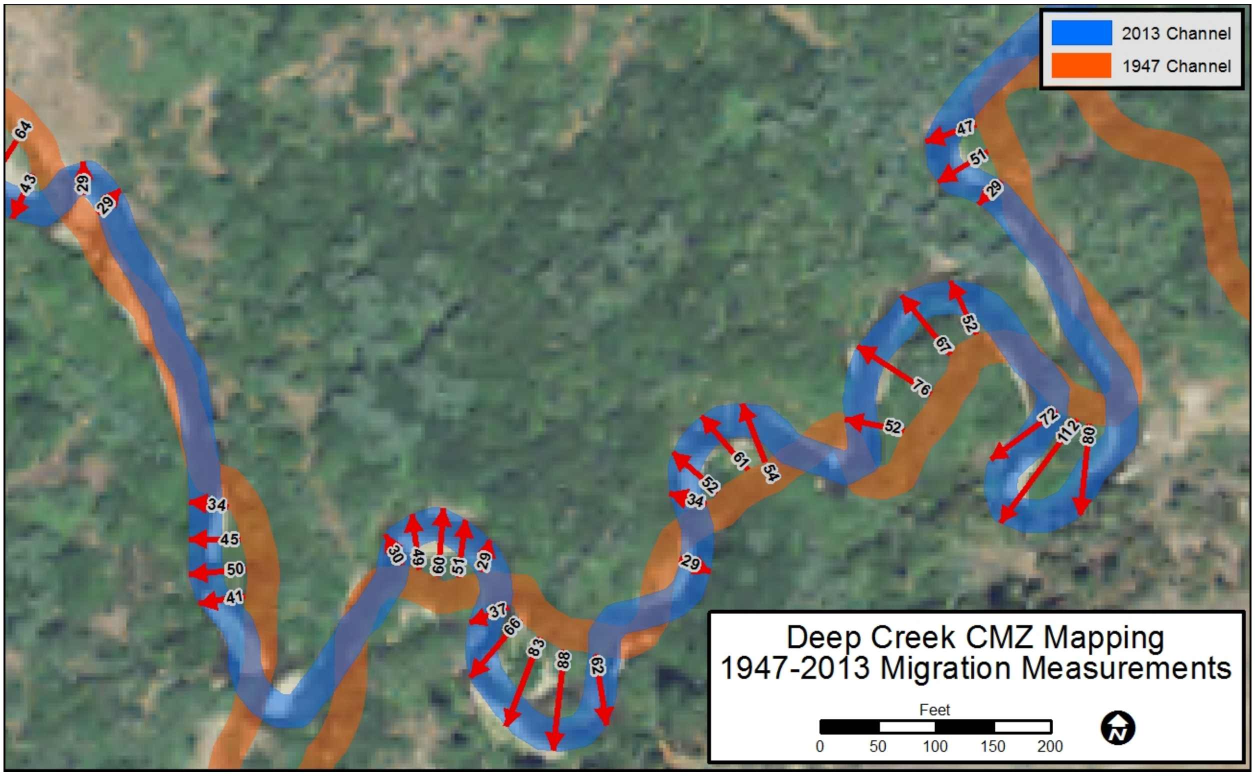


Figure 2-8. Example of migration measurements.

2.6 **Avulsion-Prone Area Mapping**

An avulsion is the sudden relocation of a channel into a new course. When water flows away from a primary channel, it will follow the most efficient course available. Sometimes, these overflows can channelize and create a whole new channel, potentially abandoning the original one. Three types of avulsion-prone areas were mapped on Deep Creek including meander cores, floodplain areas where the channel is perched, and distinct floodplain relic channels (Figure 2-9).

In general, the risk of a channel reoccupying a relic floodplain channel is low relative to a meander cutoff or abandonment of a perched channel segment. Avulsions tend to be rare events caused by a combination of channel instability (aggradation), channel migration, high flows, debris jamming, or ice jamming. Using the LiDAR, we have highlighted areas where low-elevation overflows become channelized on the floodplain, and thus may result in an avulsion.

Some of the greatest avulsion risk on Deep Creek is where the channel has been leveed and is perched above (topographically higher than) the adjacent floodplain. For this effort, two categories of avulsion risk were identified. Moderate risk avulsion areas are those where continuous floodplain channels exist that could feasibly experience partial or total reactivation, or within broad meander cores. High risk avulsion areas are those where the channel is currently unstable and especially prone to relocation, especially during a large flood event. The only high risk avulsion area in the project area is in Reach 8, where Deep Creek is perched above the surrounding floodplain (Chapter 4).

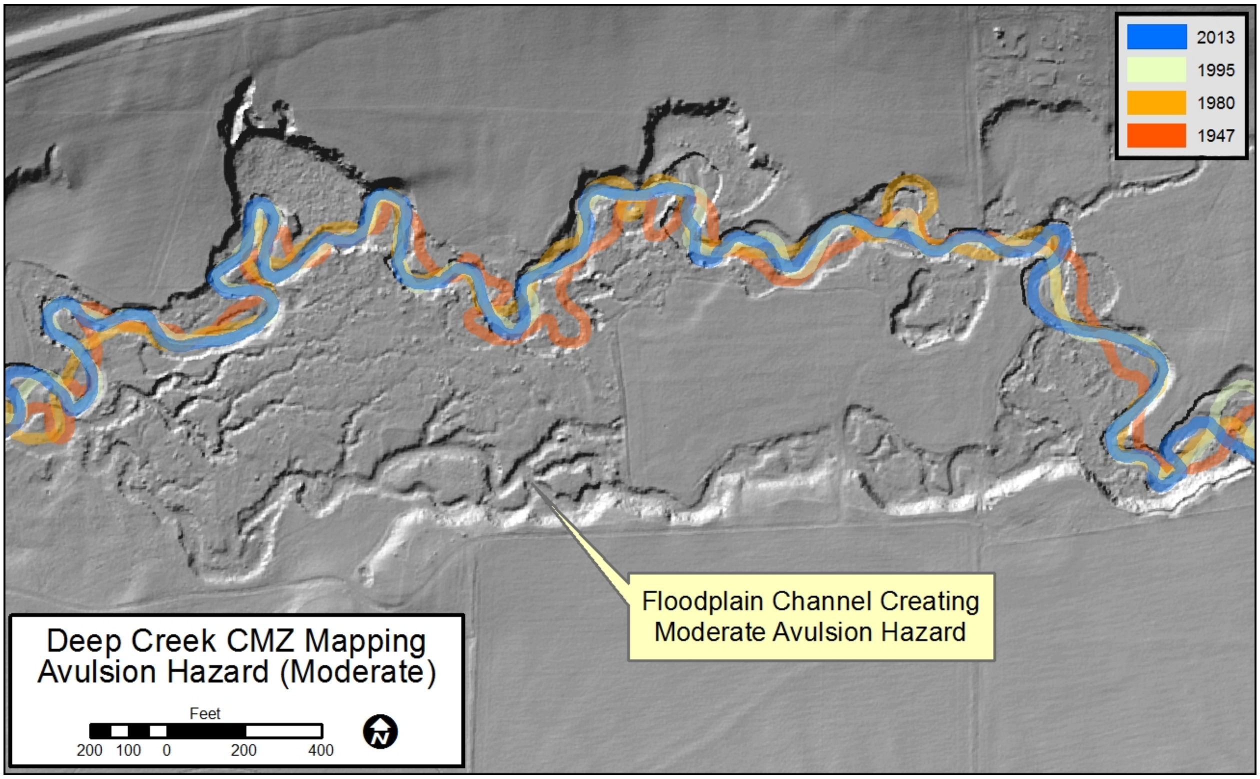
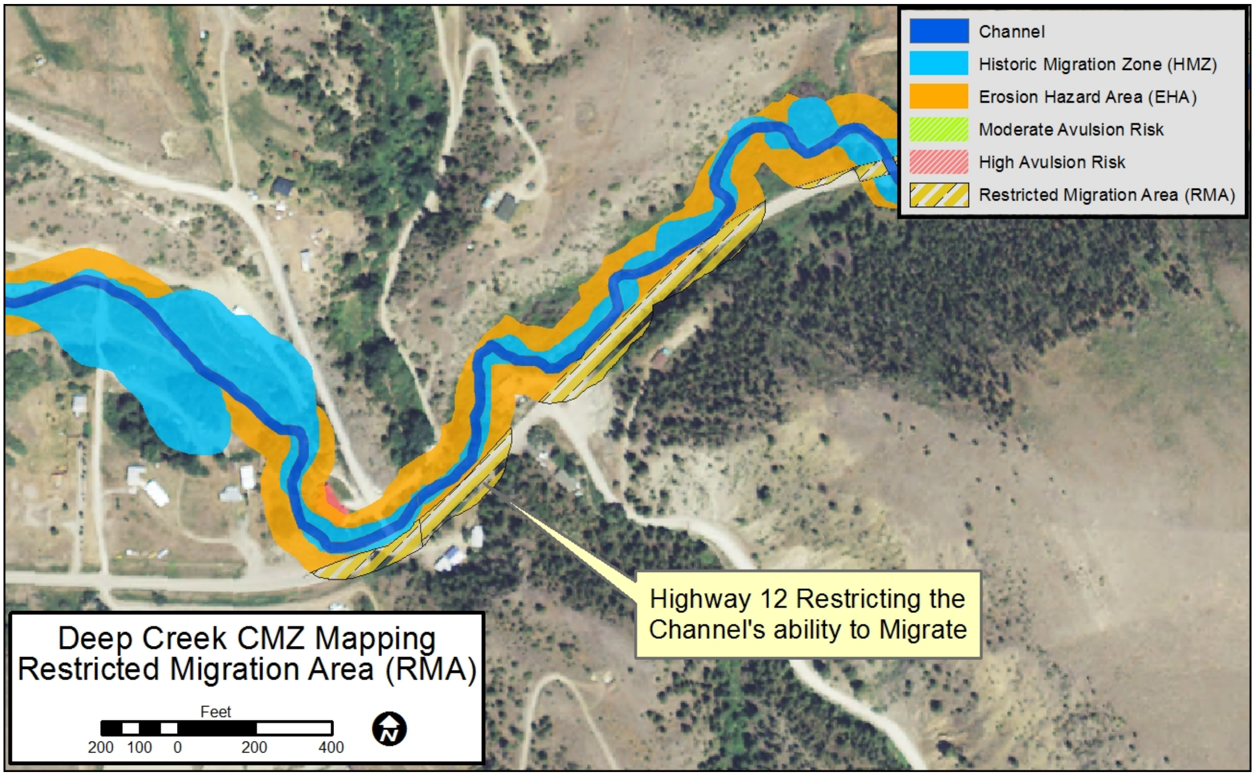


Figure 2-9. Example of floodplain channel south of main channel that creates a moderate risk avulsion hazard (risk of reactivation).

2.7 Restricted Migration Area Mapping

Restricted Migration Areas (RMAs) are those areas that, although mapped within the CMZ, are essentially removed from the active migration corridor due to infrastructure such as highway prisms. These areas are highlighted as restricted in the CMZ mapping.



2-10. Restricted Migration Areas (RMA) in the Deep Creek corridor are limited to where Highway 12 encroaches on the CMZ.

2.8 Management Corridor Delineation

Because the CMZ boundaries are developed on a reach scale, they are blind to site-specific land uses such as buildings or irrigated hayfields that are close to the creek. The mapping can be useful in that regard as it shows which of those investments are demonstrably at risk. On the other hand, if those banks are armored, the natural CMZ will be narrowed which will adversely affect the long-term function of the creek unless that narrowing is compensated for elsewhere. To address this issue, a Management Corridor boundary is provided as a means of integrating existing land uses in the corridor with the CMZ mapping results. The goal was to maintain the integrity of the CMZ while allowing for appropriate activities within the boundary. The boundary was also shaped with straight edges where possible to provide potential riparian fencing layouts.

As far as fencing strategies go, FWP provided the following general guidelines:

For fencing, three criteria must be considered: (1) A 30 foot setback (NRCS), a 50 foot setback (DEQ), and the Management Corridor defined in this study. Recommendations regarding activities in relation to the Management Corridor include:

1) Outside of the Management Corridor is the safest location to install fences, define irrigated boundaries, or install relatively permanent, expensive structures.

2) Fences located approximately 30 to 50 feet from the outside of bends (and inside the Management Corridor) may have relatively low risk depending on terrain and vegetation. If problems occur, fence relocation, rather than stream stabilization, is recommended.

2.9 GIS Project Creation

All of the information described above were compiled into a single GIS project and accompanying ESRI GeoDatabase to provide the basis for CMZ mapping. Other data included in the GIS project include bank armor inventory maps, datasets generated in support or the Skidmore Watershed Restoration Plan, and geologic maps produced by the Montana Bureau of Mines and Geology (Vuke, 2009).

2.10 Error Discussion

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

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

3 Data Analysis

The migration rate measurements were analyzed on a reach scale, so we could characterize typical rates of movement over similar sections of creek. For example, migration rates in Deep Creek Canyon are very low due to the bedrock controls on channel movement. Further downstream, migration in some places has exceeded 200 feet since 1947. It is therefore important to assign predicted erosion extents to geomorphically similar stream segments so that results effectively capture different trends through the project area.

The reaches used in this analysis are the same as those defined in the Skidmore Watershed Restoration Plan, with one additional reach added in Deep Creek Canyon. The reaches are numbered sequentially from the Missouri River confluence upstream and are shown in Figure 3-1. The Skidmore Watershed Restoration Plan contains additional data analyses and management recommendations for each reach.

3.1 The Erosion Hazard Area

To address anticipated future migration beyond the historic corridor boundary, an erosion buffer has been added to the 2013 channel margin. This area is considered prone to channel occupation over the life of the CMZ (100 years) and is based on mean migration rates for a given channel segment or reach.

To determine the buffer distance, migration rates from 1947 to 2013 were measured throughout the corridor. A total of 762 measurements were made through the entire project length and these measurements were summarized statistically by reach. Figure 3-2 shows a schematic drawing for how statistics are shown on a box-and-whisker plot, and Figure 3-3 shows the Deep Creek results. The minimum channel migration distance measured was one channel width, or 28 feet; anything less than that was considered to be too small to measure given the resolution of the imagery. The 100 year buffer distance was calculated as 100 times the annual mean migration rate for each entire reach (Table 2 and Figure 3-4). Figure 3-3 shows that the 100-year erosion buffer in Reach 10, which is 128 feet, is less than the maximum migration distance measured in that reach. This shows that there are areas where very rapid bank migration has occurred, and that the Erosion Hazard Area may be locally eroded through over the next 100 years. Typically, however, these areas of rapid bankline movement are within the Historic Migration Zone, and thereby captured in the CMZ.

The general approach to determining the Erosion Buffer (using the annual migration rate to do 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).

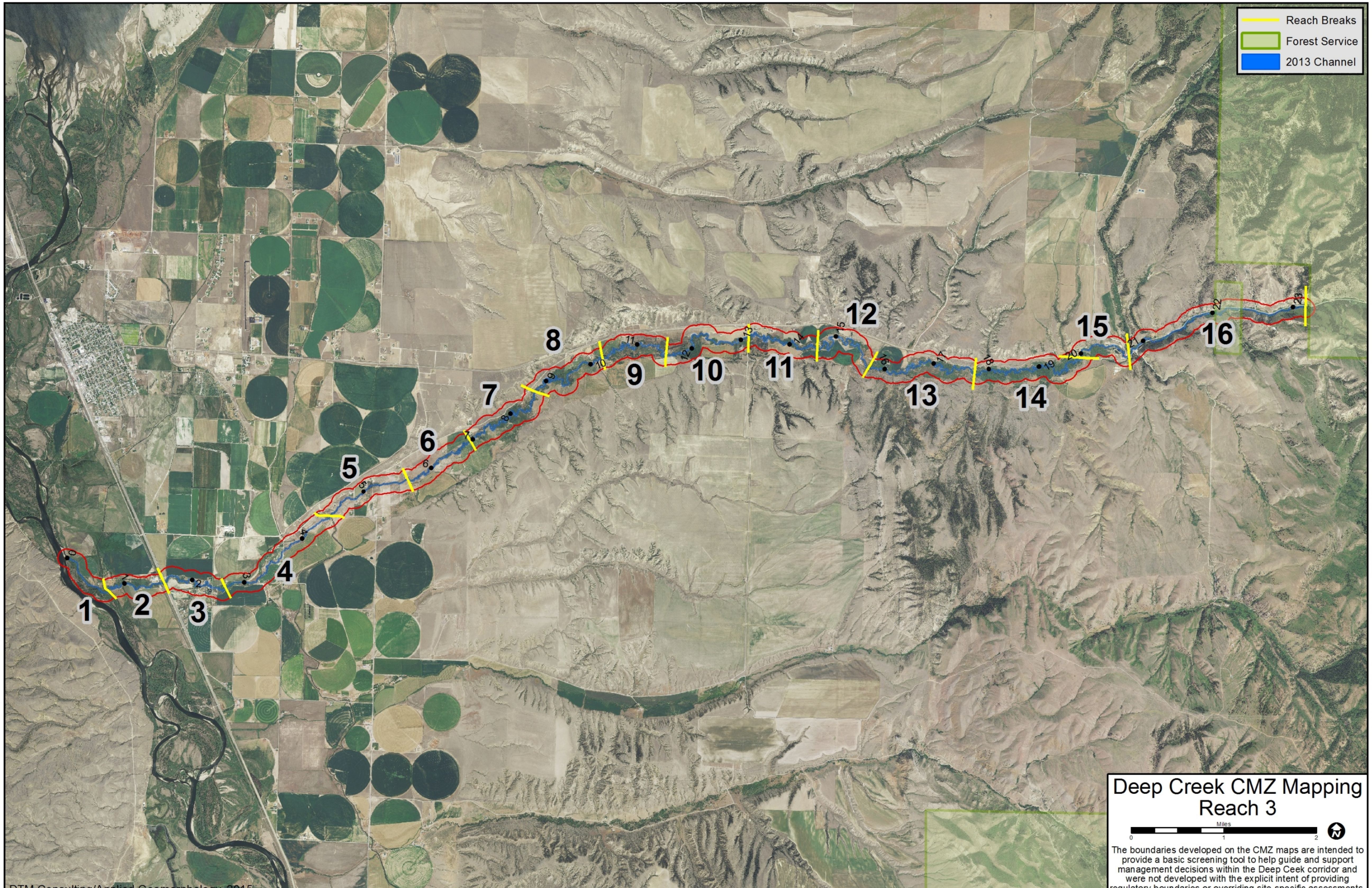


Figure 3-1. Deep Creek project reach delineation used in CMZ data analysis.

Table 2. Summary of migration data showing EHA Buffer distance in right column.

Reach	Number of Measurements	Mean Migration Distance (1947-2013)	Mean Migration Rate	Maximum Migration Distance (1947-2013)	Maximum Migration Rate (1947-2013)	EHA Buffer: 100-yr Migration Distance (Based on Mean Annual Rate)
		(ft)	(ft/yr)	(ft)	(ft/yr)	(ft)
R1	41	37.9	0.6	62	0.9	57
R2	28	39.8	0.6	74	1.1	60
R3	53	56.0	0.8	120	1.8	85
R4	103	54.7	0.8	166	2.5	83
R5	26	38.0	0.6	52	0.8	58
R6	20	64.3	1.0	137	2.1	97
R7	48	45.6	0.7	83	1.3	69
R8	47	61.7	0.9	117	1.8	94
R9	48	65.5	1.0	137	2.1	99
R10	52	84.4	1.3	219	3.3	128
R11	48	94.2	1.4	156	2.4	143
R12	35	89.3	1.4	169	2.6	135
R13	62	75.6	1.1	157	2.4	114
R14	101	52.4	0.8	112	1.7	79
R15	4	42.6	0.6	58	0.9	65
R16	46	50.1	0.8	99	1.5	76

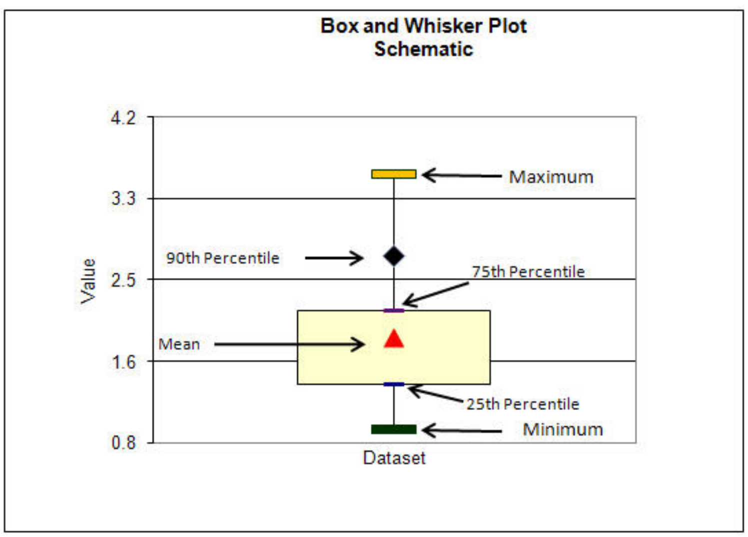


Figure 3-2. Schematic showing how values for a range of numbers are displayed on a Box and Whisker Plot.

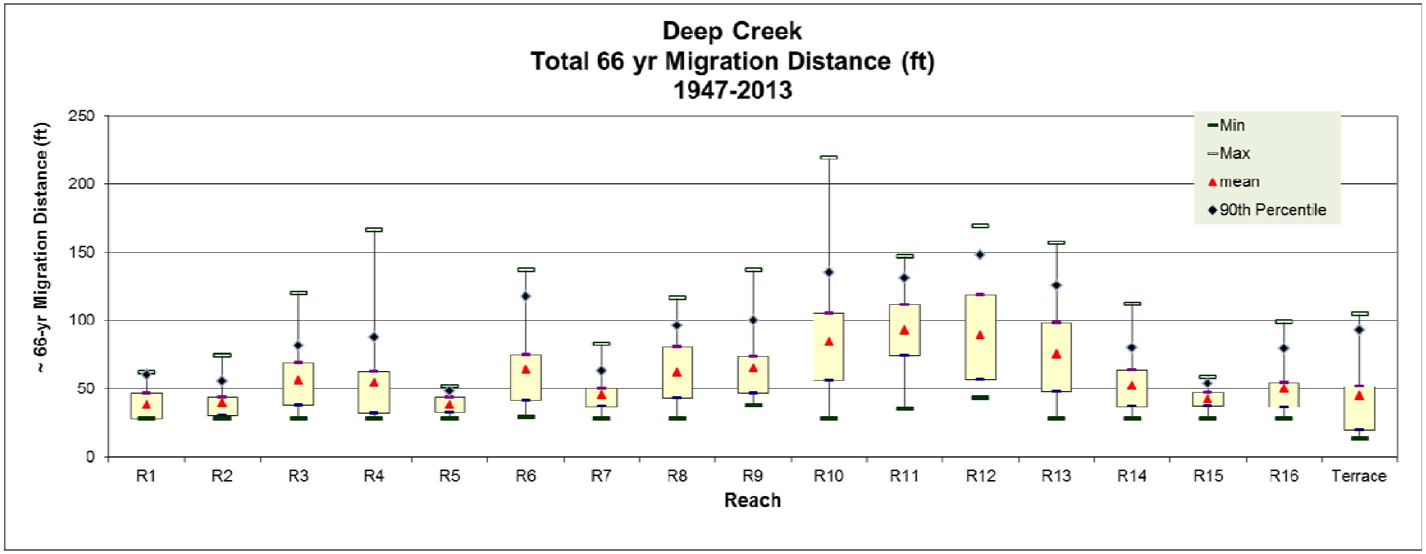


Figure 3-3. Box and Whisker plot showing data summary for Deep Creek Migration Measurements.

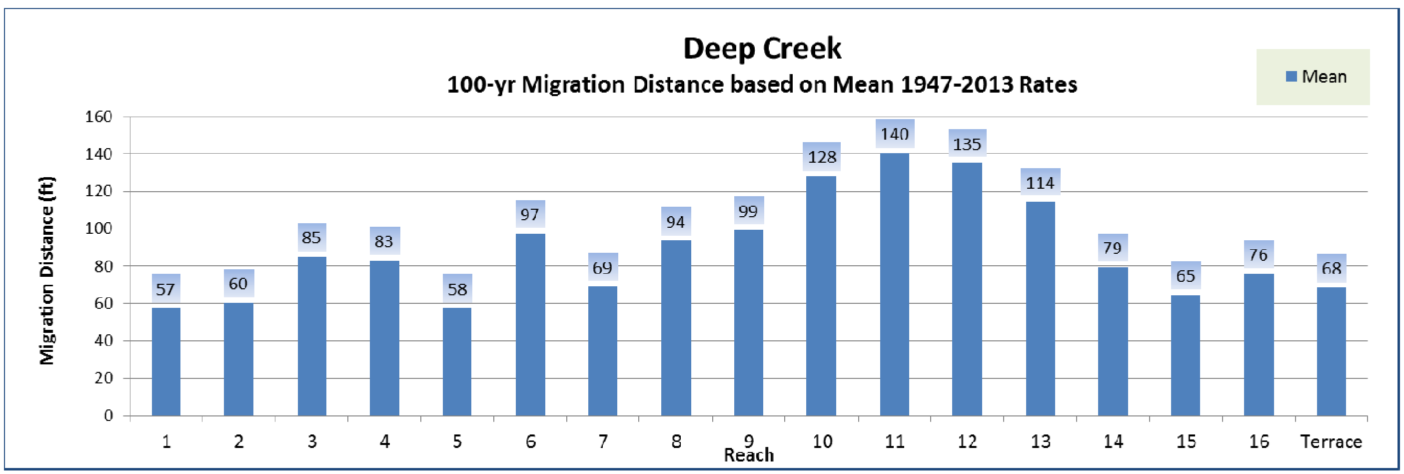


Figure 3-4. Erosion Hazard Area (EHA) buffers assigned to each reach.

Figure 3-3 and Figure 3-4 show that the highest rates of bank movement are in Reaches 10-13 (above Fautsch to Flume Gulch), where erosion buffers are over 100 feet wide. Most of the other reaches have 100 year buffer widths on the order of 60-100 feet. It is interesting to note that Reaches 10-13, which have the highest rates of bank movement, have also had quite of bit of riparian clearing along the creek. In contrast, upstream in Reach 14 migration rates are markedly lower where there is a wide, healthy riparian corridor against the stream. This suggests that riparian recovery in Reaches 10-13 will slow down bank erosion. We have seen this on other systems, where migration rates are higher in cleared fields than healthy riparian areas.

As noted earlier, there are several places within the corridor where the creek is actively eroding valley wall terraces. These features, because they are geotechnically different than the valley floor alluvium, received a unique buffer width. With only seventeen erosion measurements into terraces, a single buffer value of 68 feet was applied to all alluvial terraces regardless of reach (Figure 3-4). Also, areas where the CMZ extended into older geologic units, such as in Reaches 15 and 16, were clipped from the CMZ entirely due to their general non-erodibility.

4 CMZ Mapping Results by Reach

The Channel Migration Zone (CMZ) developed for Deep Creek is defined as a composite area made up of the existing channel, the collective footprint of mapped historic channel locations since 1947 (Historic Migration Zone, or HMZ), and an Erosion Buffer (Erosion Hazard Area or EHA), that encompasses areas demonstrably prone to channel erosion over the next 100 years. Areas beyond the Erosion Buffer that pose risks of channel avulsion are identified separately. We would recommend that areas of high avulsion risk be included in the core CMZ; areas of lower risk are not as critical.

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

1. ***Active Channel:*** The active channel is shown in DARK BLUE, and reflects the channel course in 2005.

2. ***Historic Migration Zone (HMZ):*** This unit is shown as LIGHT BLUE on the map, and reflects the area where active channels of Deep Creek have existed between 1947 and 2013.

3. ***Erosion Buffer:*** The erosion buffer is shown in ORANGE. This reflects a calculated erosion buffer based on over seven hundred measurements of channel migration.

4. ***Avulsion Hazard Zone (AHZ):*** These are areas where topographic conditions suggest potential channel relocation or reactivation. These units have a high level of transparency as they are beyond the CMZ Core.
    a. ***High:*** The areas of high avulsion risk areas are mapped in RED.
    b. ***Moderate:*** The areas of moderate avulsion risk mapped in GREEN.

5. ***Restricted Migration Area (RMA):*** These areas of the CMZ are located behind bankline features such as bank protection or levees and, thus, natural channel movement may be restricted. As there is no assessment of the effectiveness of the features, these areas are still considered to be within the CMZ.

6. ***Management Corridor:*** The maps all have a red boundary that is the proposed management corridor for Deep Creek. It was drawn to envelop the CMZ to the greatest extent possible, while taking into account developed land uses and infrastructure. The boundary was also shaped to dampen the curvature on the edge of the CMZ where possible, to facilitate implementation of management techniques such as fencelines or field boundaries.

The following sections present the CMZ maps by reach. We have included inundation maps at the same scale, as well as select photos of the area collected by Kestrel Aerial Services in support of the Skidmore Watershed Restoration Plan. Inundation modeling was only completed upstream of Highway 287.

Reach	StartRiver Mile (RM)	End River Mile (RM)	Description
1	0	0.65	Missouri River to Montana Ditch
2	0.65	1.55	Montana Ditch to Hwy 287
3	1.55	2.75	Hwy 287 to Above Carson
4	2.75	4.45	Above Carson Lane to B-M Canal
5	4.45	5.55	B-M Canal to Reider's Bridge
6	5.55	6.97	Reider's Bridge to McArthur's Bridge
7	6.97	8.72	McArthur's Bridge to Above Stock's Bridge
8	8.72	10.21	Above Stock's Bridge to Antonick's Bridge
9	10.21	11.55	Antonick's Bridge to Above Faust
10	11.55	13.1	Above Fautsch to Clopton Lane
11	13.1	14.47	Clopton Lane to Gobbs
12	14.47	15.8	Gobbs to MLBar Headquarters
13	15.8	17.8	MLBar Headquarters to Flume Gulch
14	17.8	19.95	Flume Gulch to Hwy 12
15	19.95	20.73	Hwy 12 to North Fork Deep Creek
16	20.73	23.15	North Fork Deep Creek to USFS boundary

4.1 Reach 1—Missouri River to Montana Ditch

Reach 1 is located in lowermost Deep Creek, where it parallels the Missouri River between the river and Montana Ditch (Figure 4-1 and Figure 4-2). Bank migration rates are low in this reach and the CMZ is narrow as a result. The Erosion Hazard Area buffer in Reach 1 is 57 feet wide. Reach 1 appears to have been channelized sometime prior to 1947 and the creek has remained essentially straight for at least 66 years. LiDAR data suggest that the lowermost half mile of Deep Creek is an historic side channel of the Missouri River. The Management Corridor closely follows the edge of the CMZ. Inundation modeling was not available for Reach 1.

Figure 4-1. View east showing lower reaches of Deep Creek in foreground (Kestrel Aerial Services).

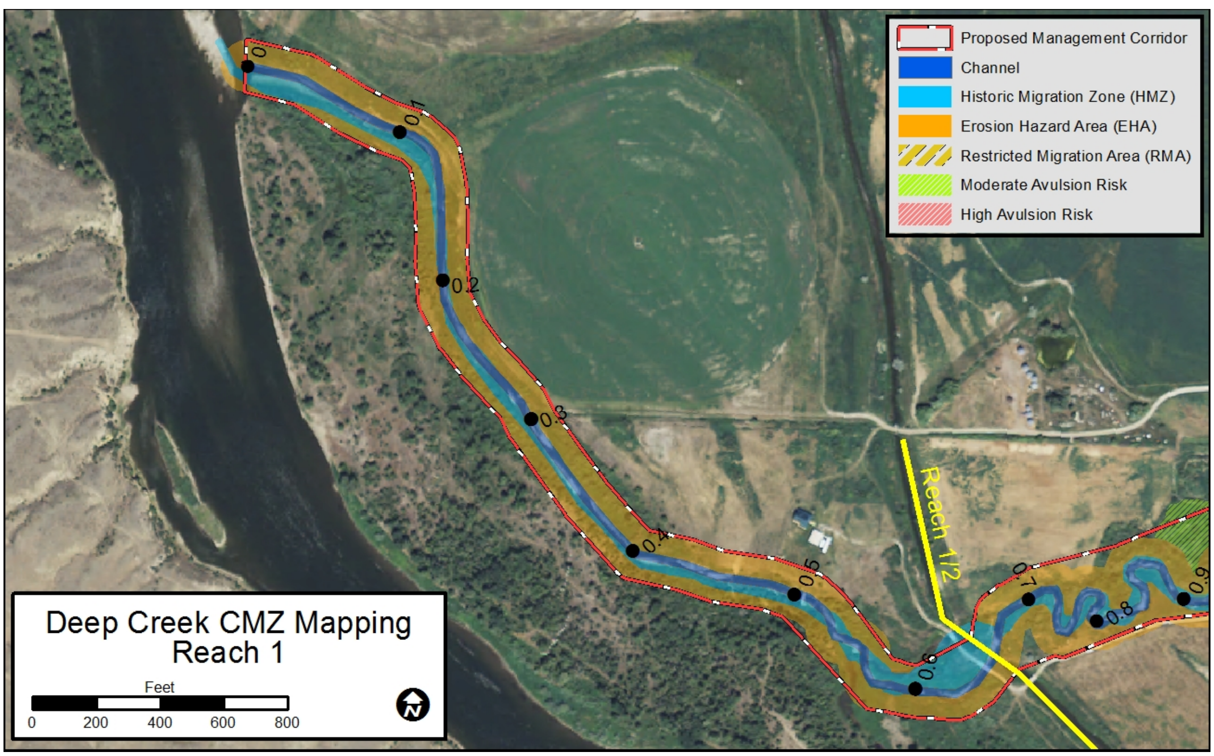


Figure 4-2. CMZ map for Reach 1.

4.2 Reach 2—Montana Ditch to Highway 287

Reach 2 extends from Montana Ditch to Highway 287, a distance of just over a mile. This reach has substantial more sinuosity than Reach 1, and as a result the river corridor is wider. The migration rates are similar to Reach 1 with an average rate of 0.6 feet per year on eroding banks. Reach 2 has an ~800 ft long meander cutoff at RM 1.05 that appears to have occurred sometime around 1947. There was no inundation modeling available for Reach 2.

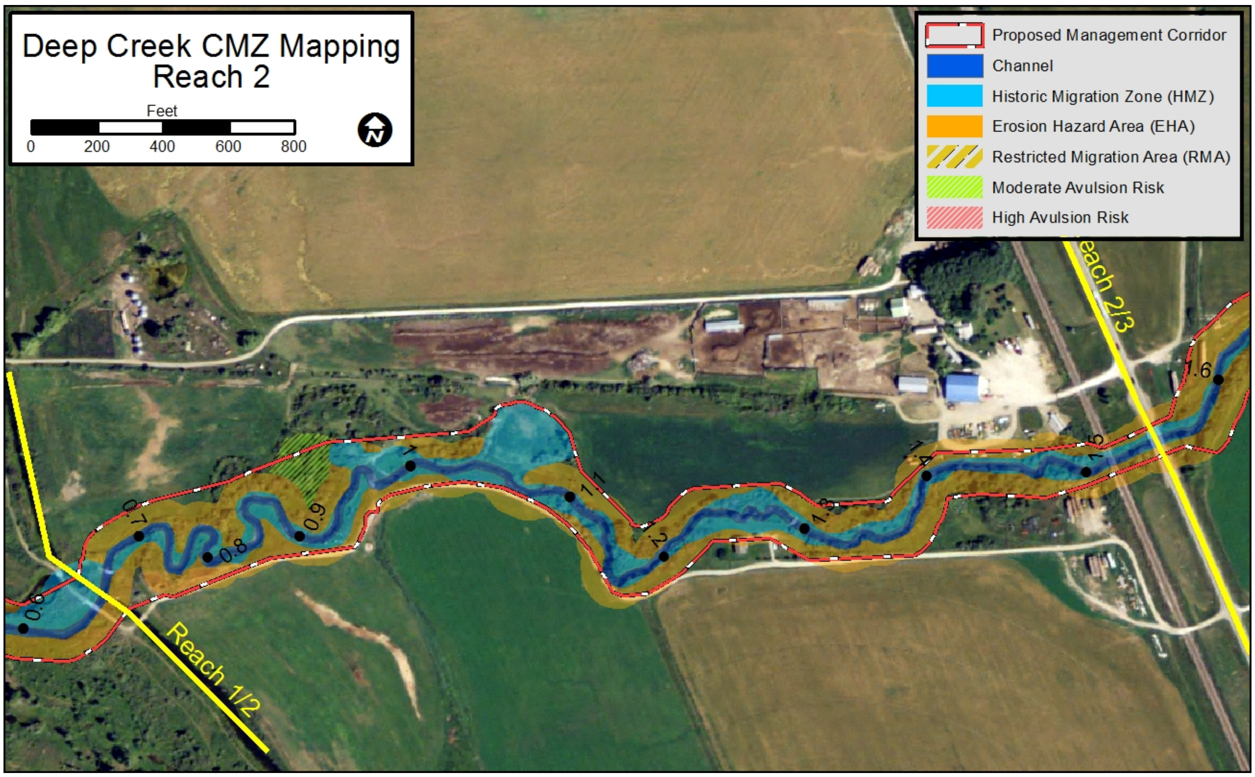


Figure 4-3. CMZ map for Reach 2.

4.3 Reach 3—Highway 287 to above Carson Lane

Reach 3 extends from Highway 287 upstream to just above Carson Lane (Figure 4-3). The mean migration rate on eroding banks in Reach 3 is 0.8 feet per year, which results in an erosion buffer width of 85 feet. About 600 feet upstream of the Highway 287 Bridge (RM1.7), there is a large meander in Reach 3 that cutoff between 1009 and 2011, probably during the 2011 flood. There are two additional meanders upstream at RM2.1 and RM 2.4 that appear poised for cutoff in the coming decades.

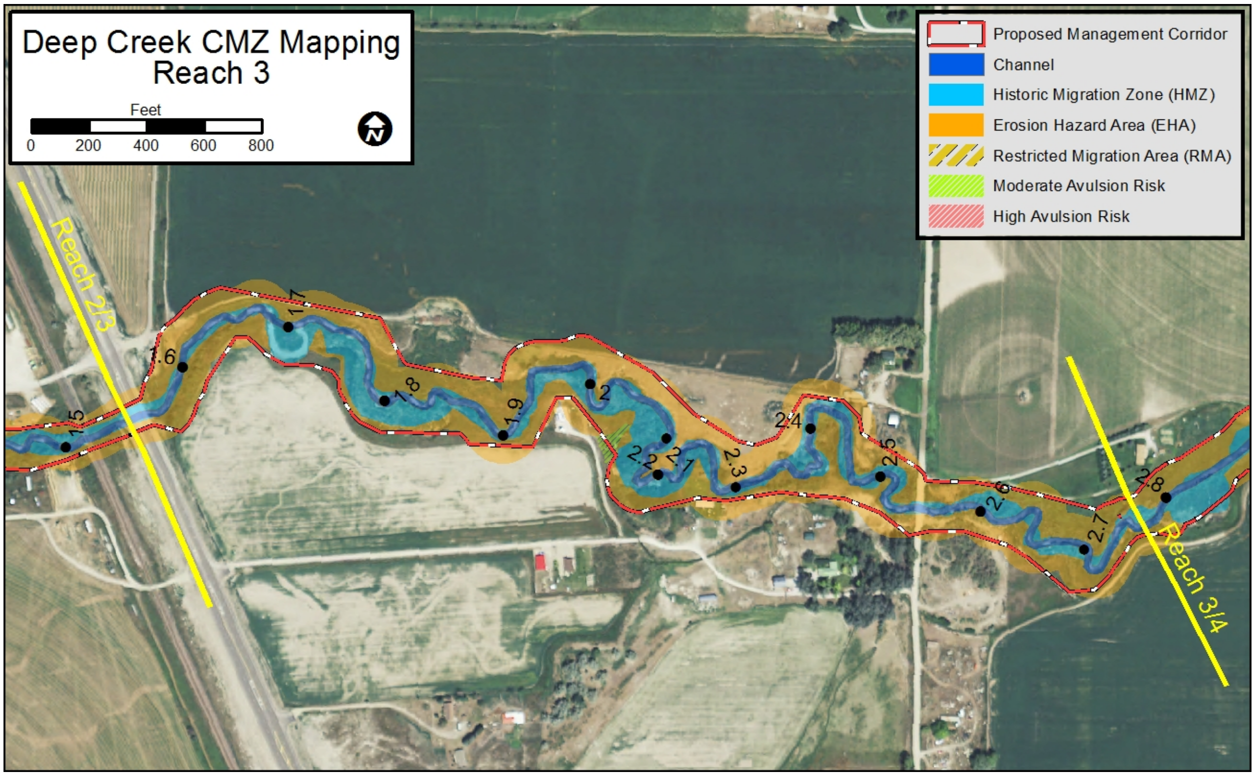


Figure 4-4. CMZ map for Reach 3.

4.4 Reach 4—Above Carson Lane to B-M Canal

Reach 4 is bordered by extensive irrigated lands, with multiple pivots reaching to the edge of the stream corridor. The CMZ is relatively narrow in this reach, with an EHA buffer width of 83 feet (Figure 4-5). The proposed Management Corridor tends to closely follow the field margins through much of Reach 4 (Figure 4-6); however in some areas such as at RM 4.4, development extends into the active stream corridor (Figure 4-7). In the lower portion of the reach, around RM 3.0, the Management Corridor excludes part of the Historic Migration Zone, where the 1947 channel was channelized and the historic channel area developed for irrigation on the north side of the creek (Figure 4-5 and Figure 4-8).

Inundation modeling shows some floodplain channels south of the current creek course; these areas were not included as avulsion hazards due to their subtlety and distance from the main channel thread (Figure 4-9).

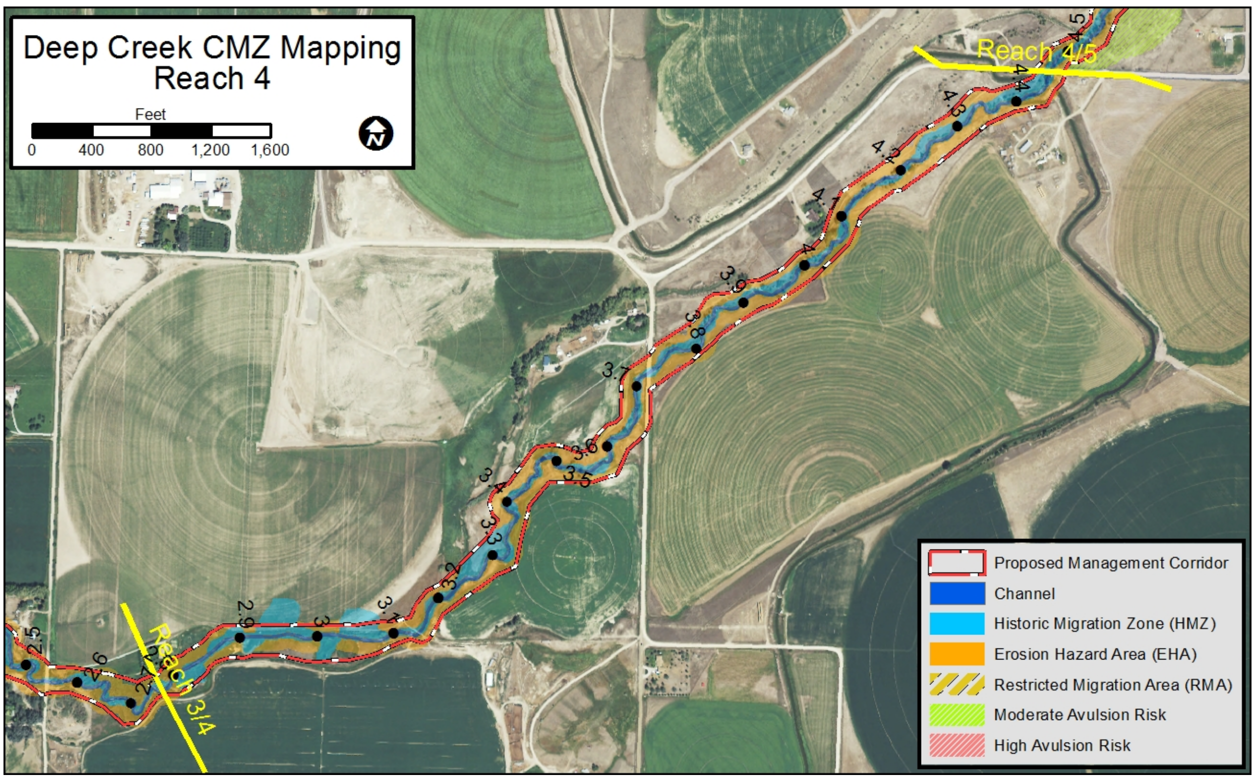


Figure 4-5. CMZ map for Reach 4.

Figure 4-6. View upstream at RM 3.5 showing agricultural fields adjacent to the Deep Creek corridor; the management corridor is about 200-250 feet wide in this area and closely follows the field edges (Kestrel Aerial Services).

Figure 4-7. View downstream of uppermost portion of Reach 4 (RM 4.4) showing encroachment of corrals into the stream corridor; about one half of the corral area is within the proposed management corridor boundary.

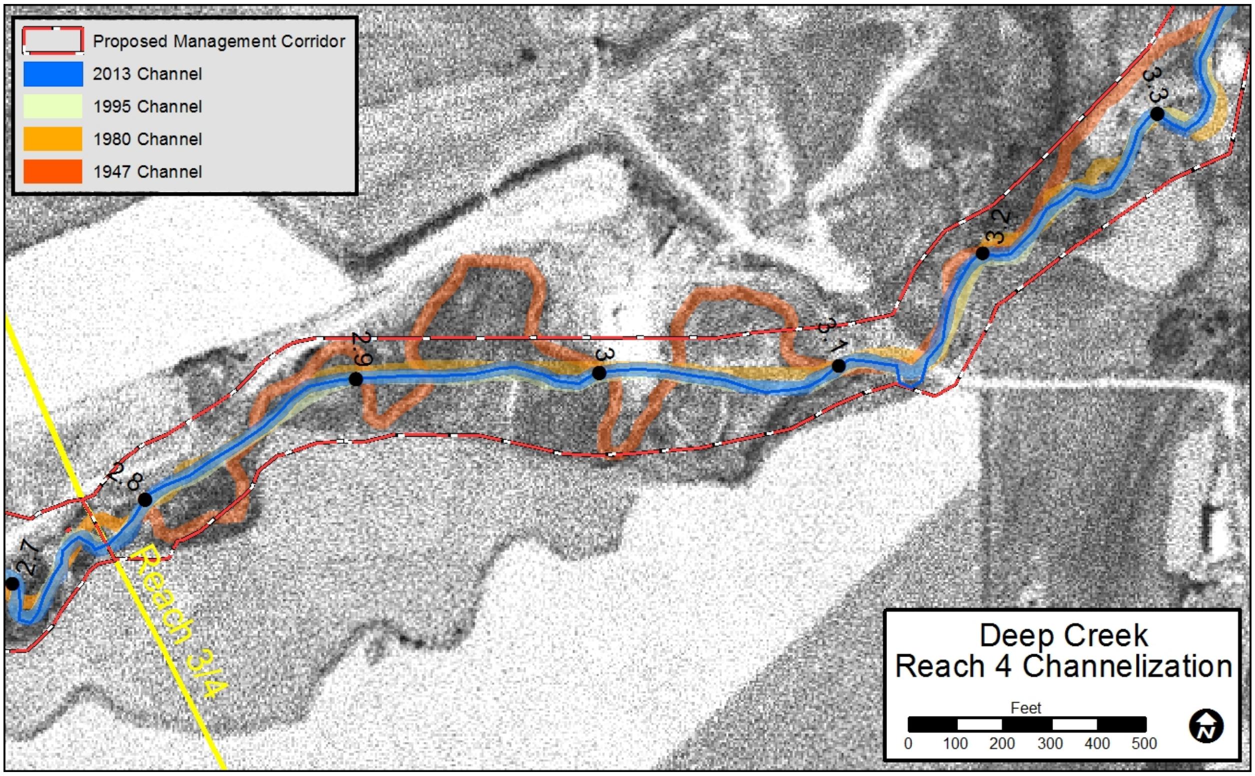


Figure 4-8. Historic channelization (post-1947) in Reach 4 at RM3; banklines are overlain on 1947 imagery.

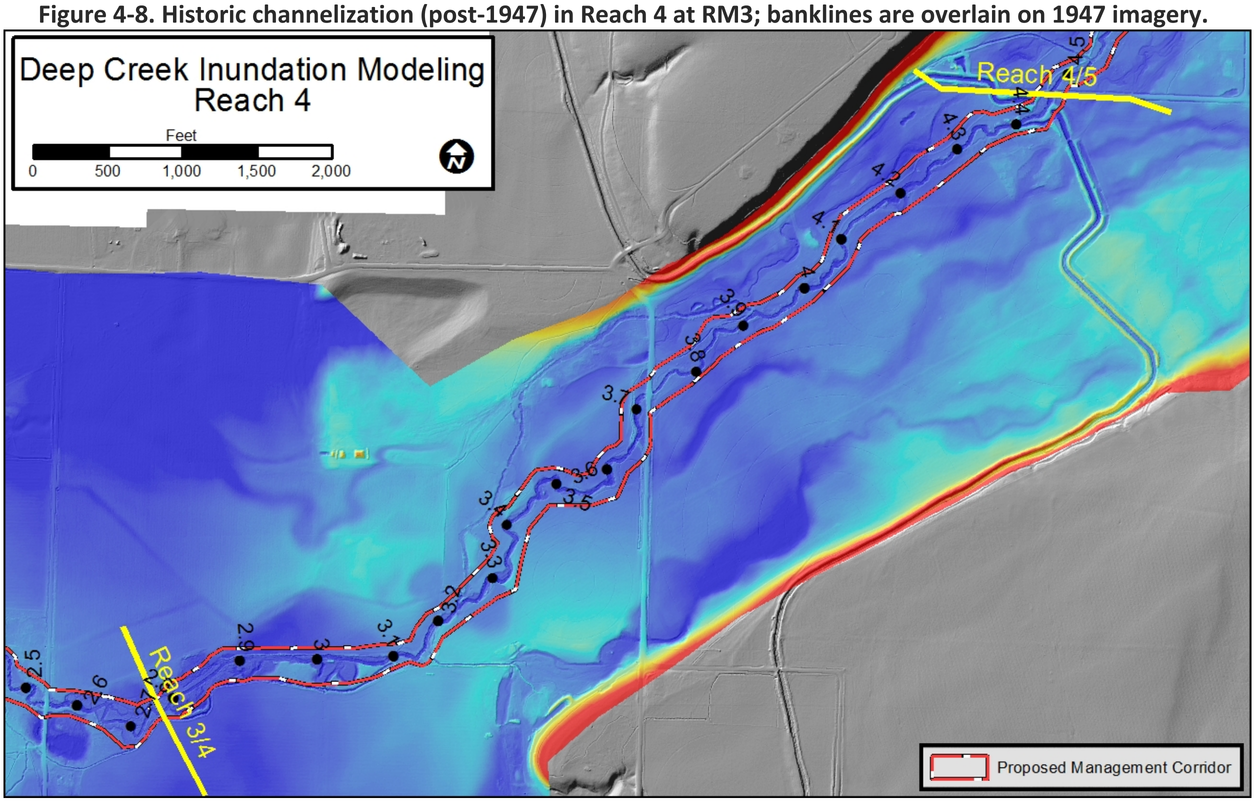


Figure 4-9. Inundation modeling results for Reach 4. Colors represent elevations relative to the elevation of the main channel. Dark blue areas are equal to or lower than the channel. Yellows and reds are significantly higher than the adjacent main channel.

4.5 Reach 5—B-M Canal to Reider's Bridge

Reach 5 is located just upstream of the Broadwater-Missouri Canal. Within this reach, the average migration rate is one of the lowest within the project reach. The Erosion Hazard Area buffer width in Reach 5 is 58 feet, creating a narrow CMZ similar to Reach 1 (Figure 4-10). Reach 5 does have markedly low floodplain areas to the south, however, and these surfaces have distinct channel features that have been mapped as a moderate avulsion hazard (Figure 4-10 and Figure 4-11). Only those channels closest to the creek were included in the Avulsion Hazard Zone. Although these relic channels have some potential to reactivate in the event of major flooding blockage of the main channel by debris or ice, since the risk is relatively low, these areas were not included in the proposed Management Corridor.

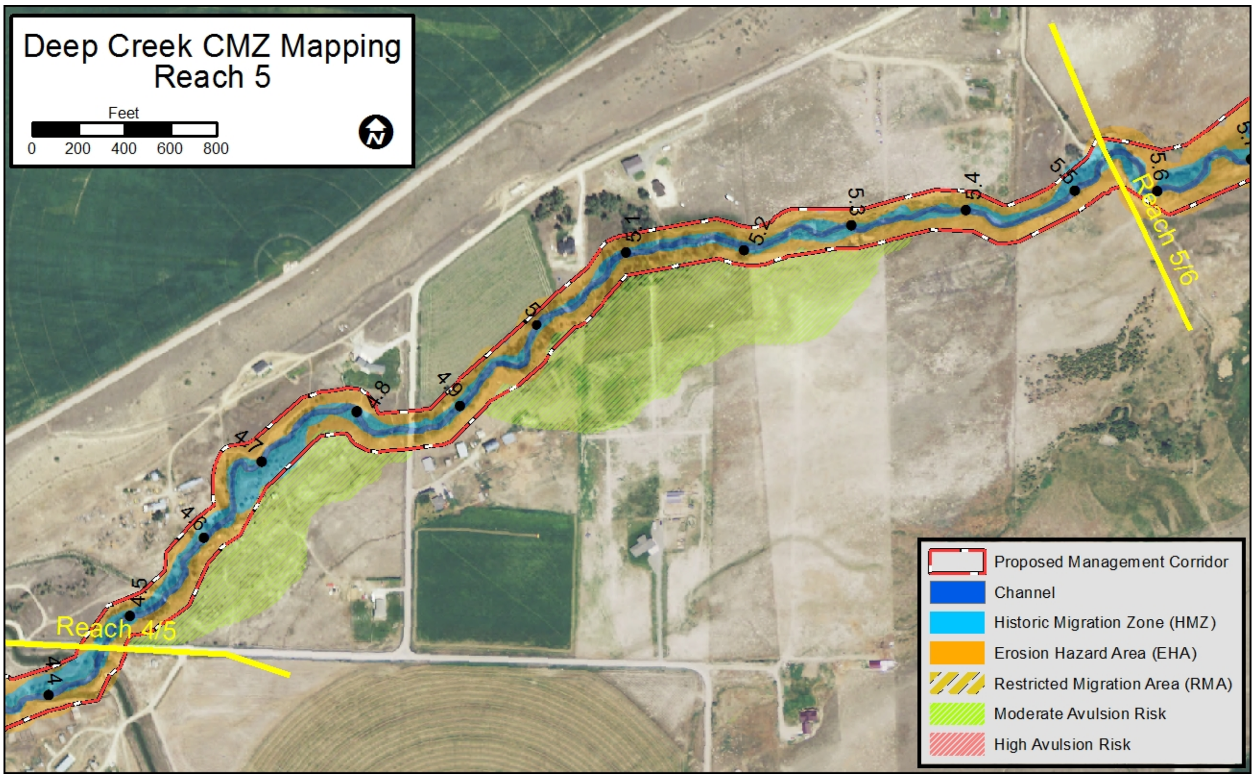


Figure 4-10. CMZ map for Reach 5.

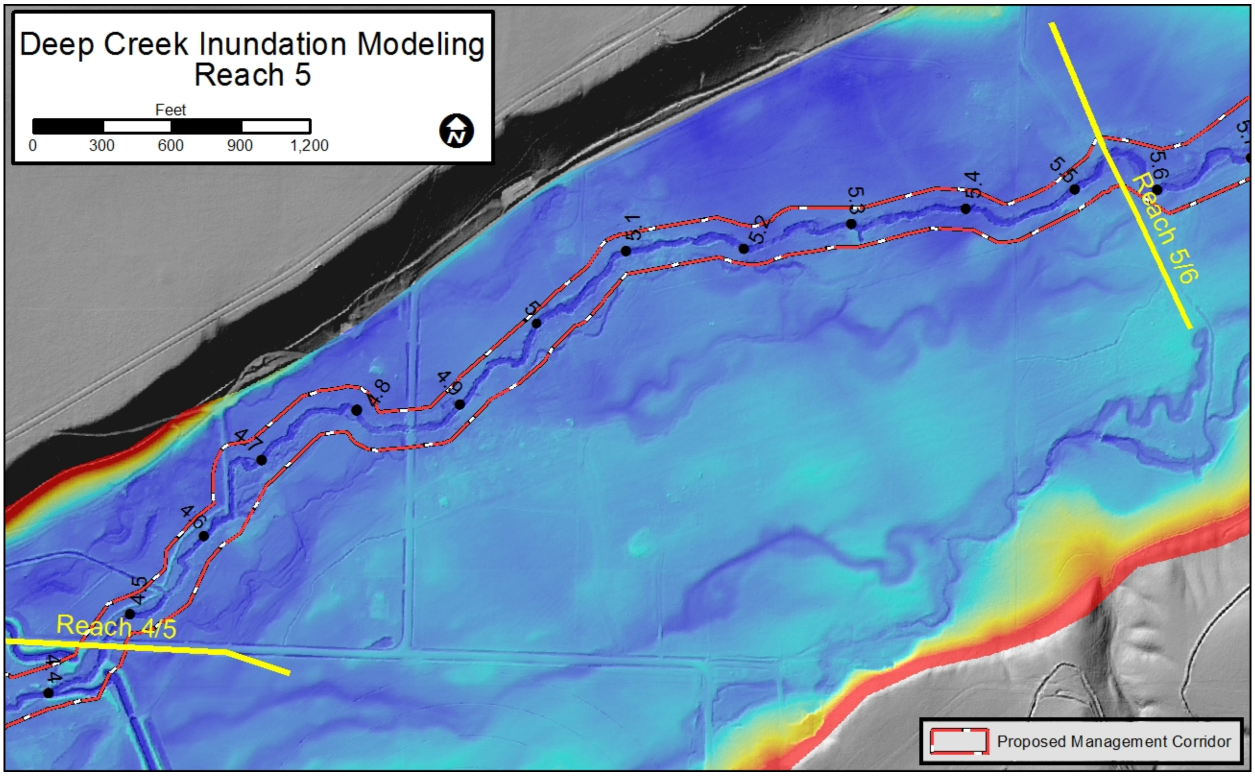


Figure 4-11. Inundation modeling results for Reach 5. Dark blue areas are equal to or lower than the channel. Yellows and reds are significantly higher than the adjacent main channel.

4.6 Reach 6—Reider's Bridge to McArthur's Bridge

Reach 6 is about 1.3 miles long, and similar to other reaches in lower Deep Creek, it is a narrow stream corridor with substantial riparian clearing and pivot irrigation development on the floodplain (Figure 4-12 and Figure 4-13). Similar to Reach 5 downstream, there are relic channels on the south floodplain area, some of which cross pivot fields (Figure 4-14 and Figure 4-12). These areas were mapped as having some risk of avulsion, indicating the potential for activation during flood events or in response to any blockage on the main channel. Since the risk of such an event is relatively low, these areas were not included in the proposed management corridor.

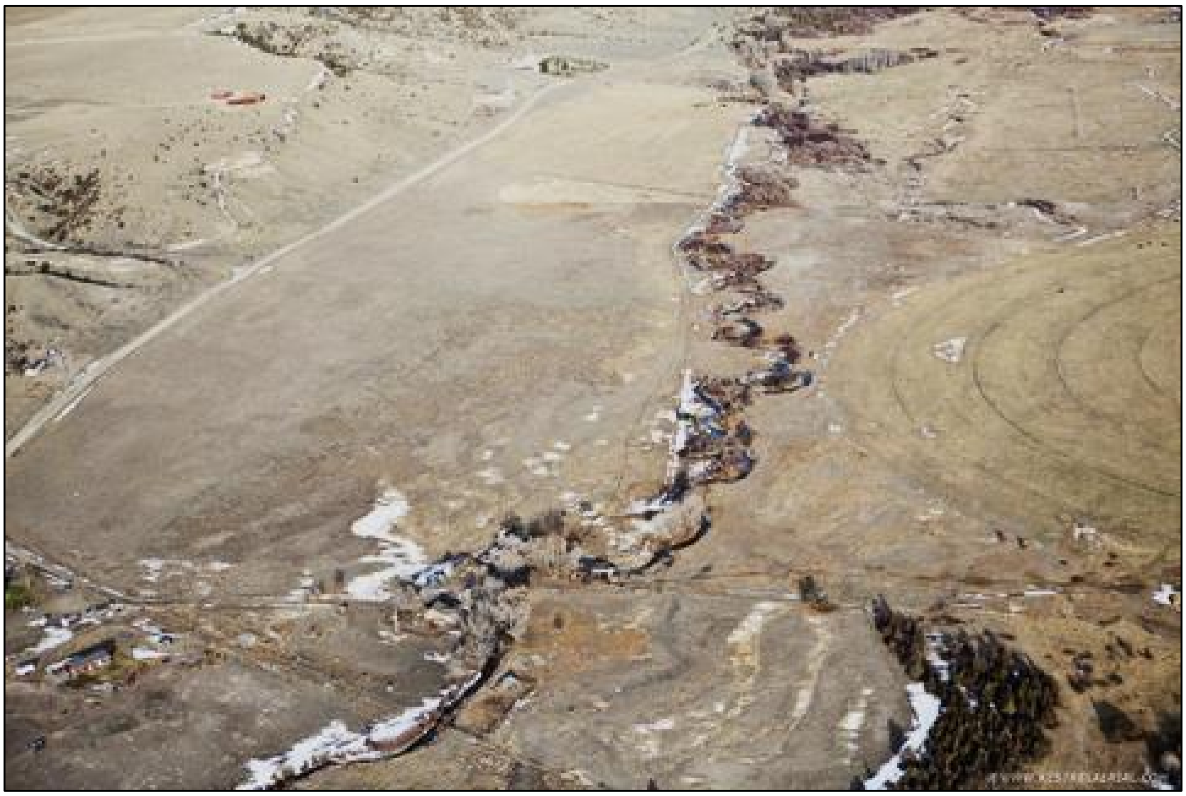


Figure 4-12. View upstream of Reach 6 showing narrow stream corridor with floodplain channels dissecting pivot ground in upper right portion of photo.

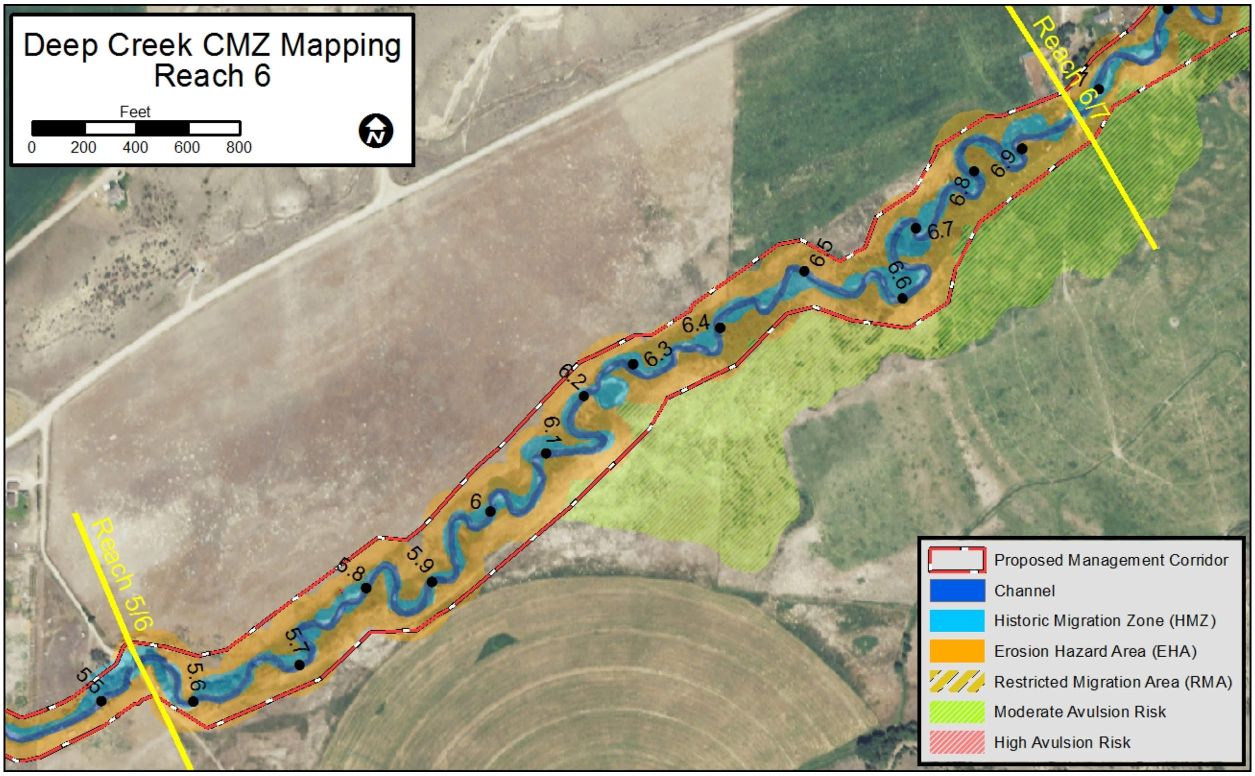


Figure 4-13. CMZ map for Reach 6.

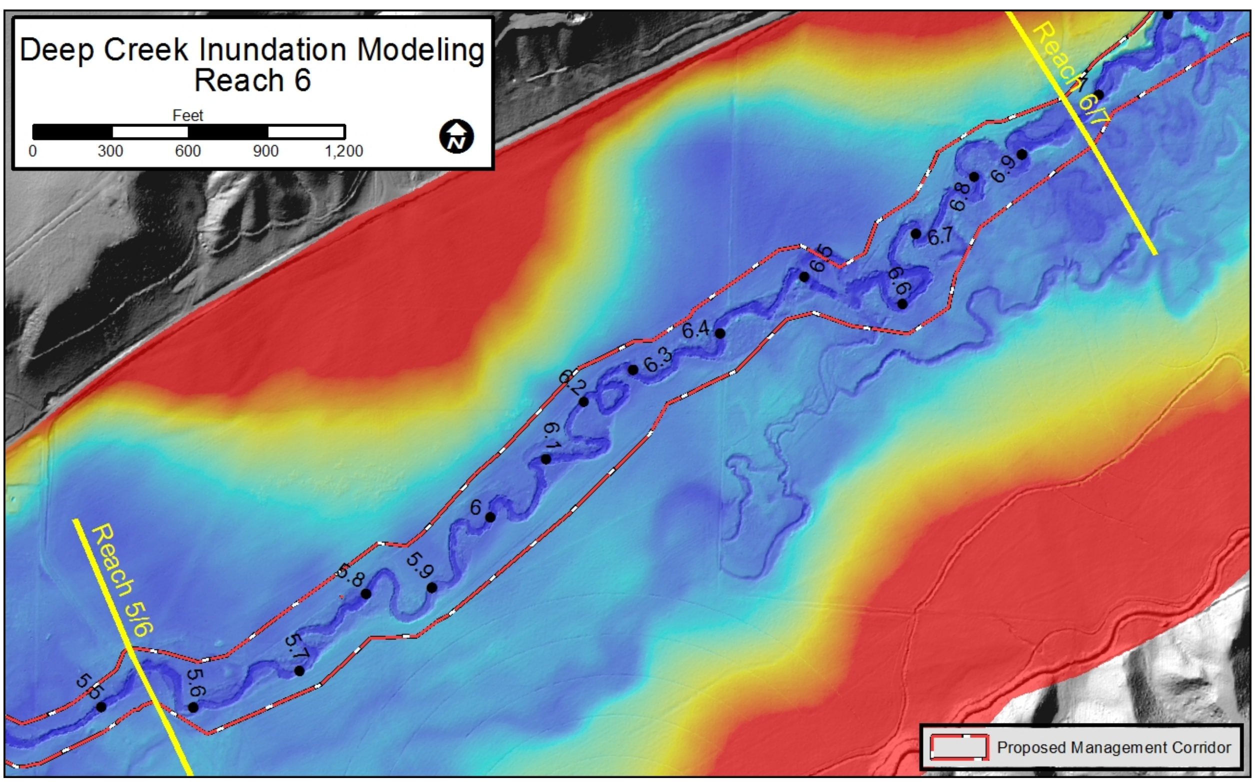


Figure 4-14. Inundation modeling results for Reach 6. Dark blue areas are equal to or lower than the channel. Yellows and reds are significantly higher than the adjacent main channel.

4.7 Reach 7—McArthur's Bridge to Above Stock's Bridge

Reach 7 marks a distinct change in the Deep Creek corridor relative to downstream reaches. The reach is sinuous, and supports a relatively robust riparian corridor (Figure 4-15). The Erosion Hazard Area buffer width is 69 feet, indicating moderate rates of channel migration relative to other reaches (Figure 4-16). The inundation modeling results show that in the upstream-most portion of the reach, the historic channel area has been diked on the south side of the river at RM 8.6 (Figure 4-17). The air photos show that this happened before 1947 and as a result this area is not within the mapped Historic Migration Zone. Although the proposed management corridor does not include this remnant floodplain feature, it could provide excellent opportunity for floodplain/wetland restoration.

Reach 7 also has extensive open bars and mapped bank erosion, indicating that it is actively migrating across its floodplain. One section of the reach from RM 8.2 to RM 8.5 has a high concentration of bank armor on the south side of the river protecting a hayfield. As the bank armor segments are discontinuous and relatively short (typically less than 100 feet), they have not been mapped as long-term restrictions of the CMZ.

Figure 4-15. View upstream of Reach 7 showing wide riparian corridor and sinuous channel.

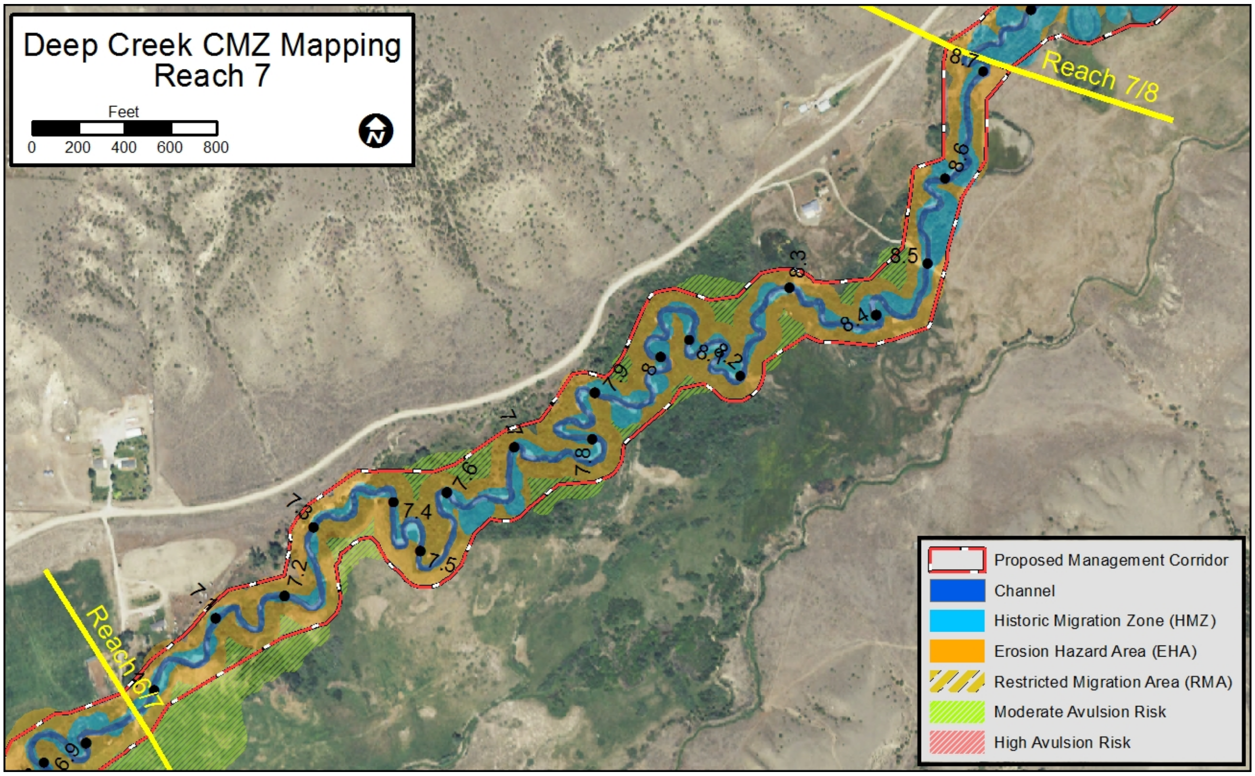


Figure 4-16. CMZ map for Reach 7.

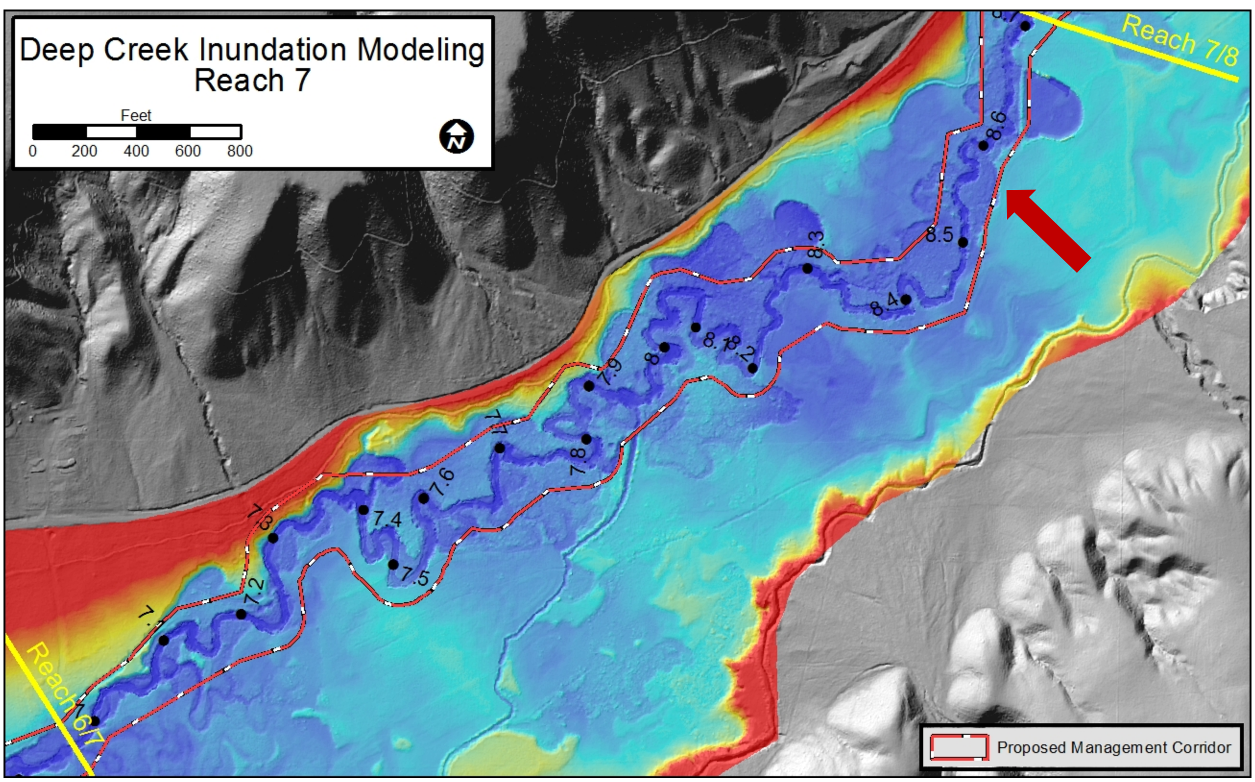


Figure 4-17. Inundation modeling results for Reach 7 showing the isolation of a historic meander in the upper portion of reach by a dike. (arrow). Dark blue areas are equal to or lower than the channel. Yellows and reds are significantly higher than the adjacent main channel.

4.8 **Reach 8—Above Stock's Bridge to Antonick's Bridge**

Reach 8 is a strikingly problematic section of Deep Creek (Figure 4-18). According to the Skidmore Watershed Restoration Plan, the reach has been characterized by a continual pattern of channelization, levee construction, and periodic dredging due to sedimentation within the leveed channel. Flooding has been a chronic problem on both the north and south sides of the channel. Recommendations for this reach have included realigning the channel or passively managing the corridor.

This analysis supports the observations and recommendations made in the Skidmore Watershed Restoration Plan. The CMZ map for Reach 8 shows a moderately wide Erosion Hazard Area that reflects a buffer width of 94 feet. This Historic Migration Zone in Reach 8 also shows a wide area of historic channel occupation especially in the downstream half of the reach. The Inundation Modeling results show that the floodplain is exceptionally low relative to the channel from RM 9.3 to RM 9.9 (Figure 4-19). The levees are also evident from RM 9.6 to RM 9.9. The levees appear to have been constructed sometime after 1947 (4-20). This section of Deep Creek is notably flat and prone to chronic deposition, even in a channelized and leveed condition. The Skidmore Watershed Restoration Plan indicates that there has been some observation of clay lenses in the stream banks of Reach 8 which may exert a control on overall grade.

Figure 4-21 and Figure 4-22 show the leveed reach as photographed obliquely from the air. There is evidence of active deposition within the stream channel, and saturated floodplain ground landward of the levees. This reflects the most striking issue in the reach, which is the perching of the creek above the adjacent floodplain. Figure 4-23 shows that Deep Creek is perched above both the north and south floodplain by two to four feet. This channel perching has created the highest avulsion risk within the entire project area. Avulsion out of the perched, leveed segment should be considered imminent should the levee overtop or fail.

As a result of the high avulsion risk, the low floodplain area is included in the Management Corridor of Reach 8. Furthermore, the recommendation made in the Skidmore Watershed Restoration Plan for an engineered realignment of the channel should be considered. Such a realignment would allow the redistribution of grade to try and optimize sediment transport through the currently perched, aggradational segment. This grade distribution would probably include cutting off the meander bend at RM 9.6 and carrying that grade upstream to about RM 9.9. Figure 4-24 shows the relatively low gradient in the leveed portion of Reach 8.

In the lower portion of Reach 8, the grade increases, as evidenced by both the channel profile, as well as the perching of meanders that were active channel in 1947 (Figure 4-25).

It is interesting to also note that there is a fault line that crosses Deep Creek in the upper portion of Reach 8 that could be affecting valley slopes and bedrock exposures in the valley.

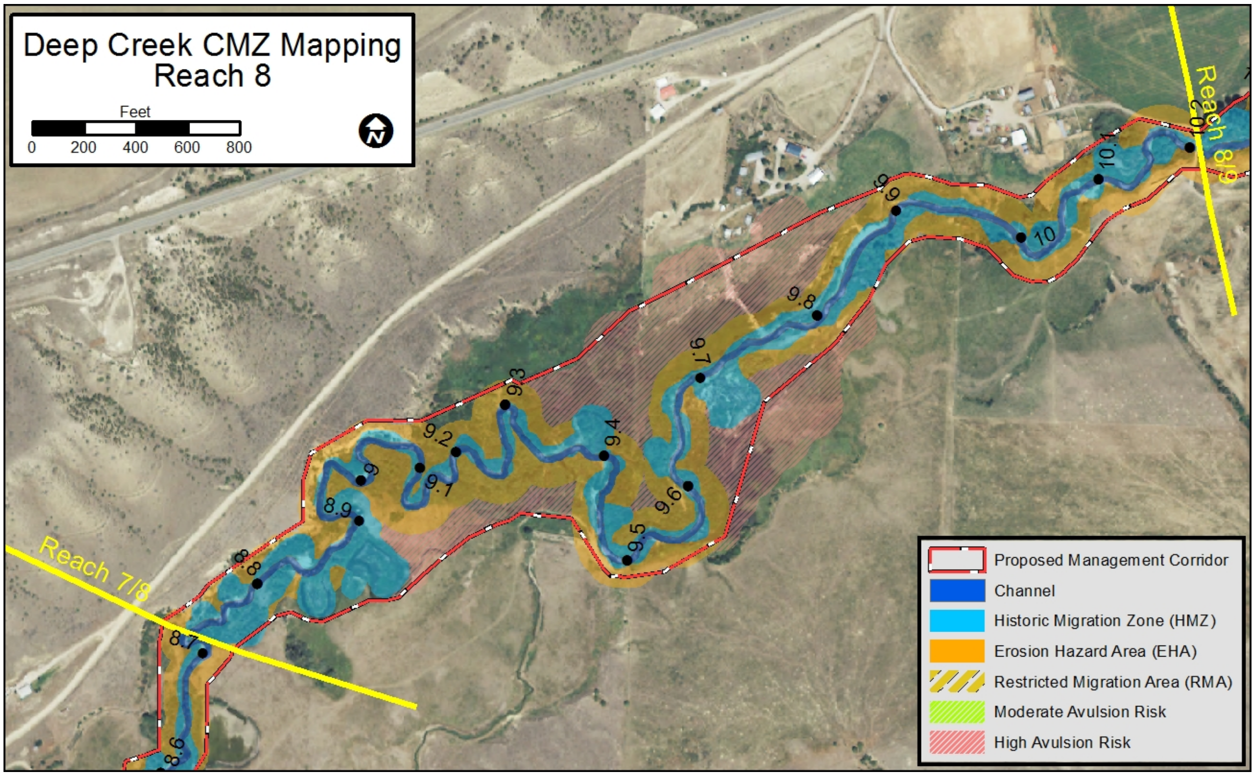


Figure 4-18. CMZ map for Reach 8.

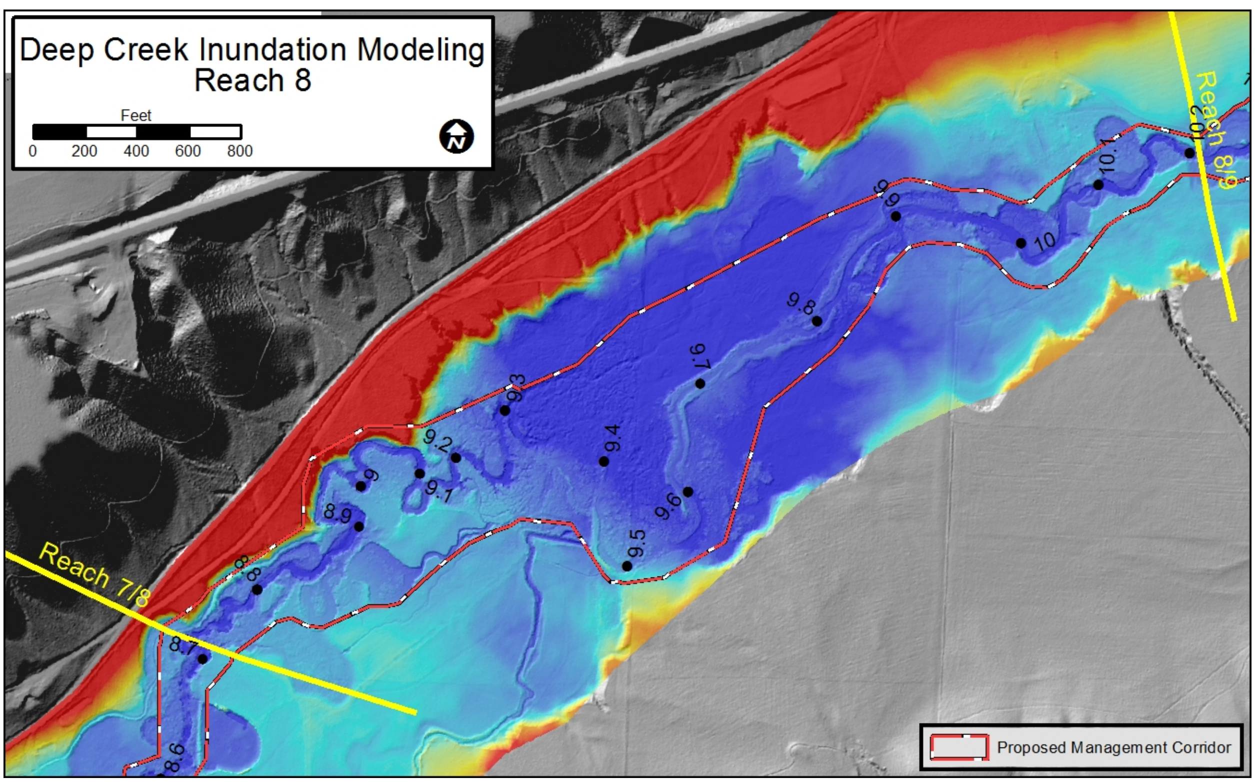
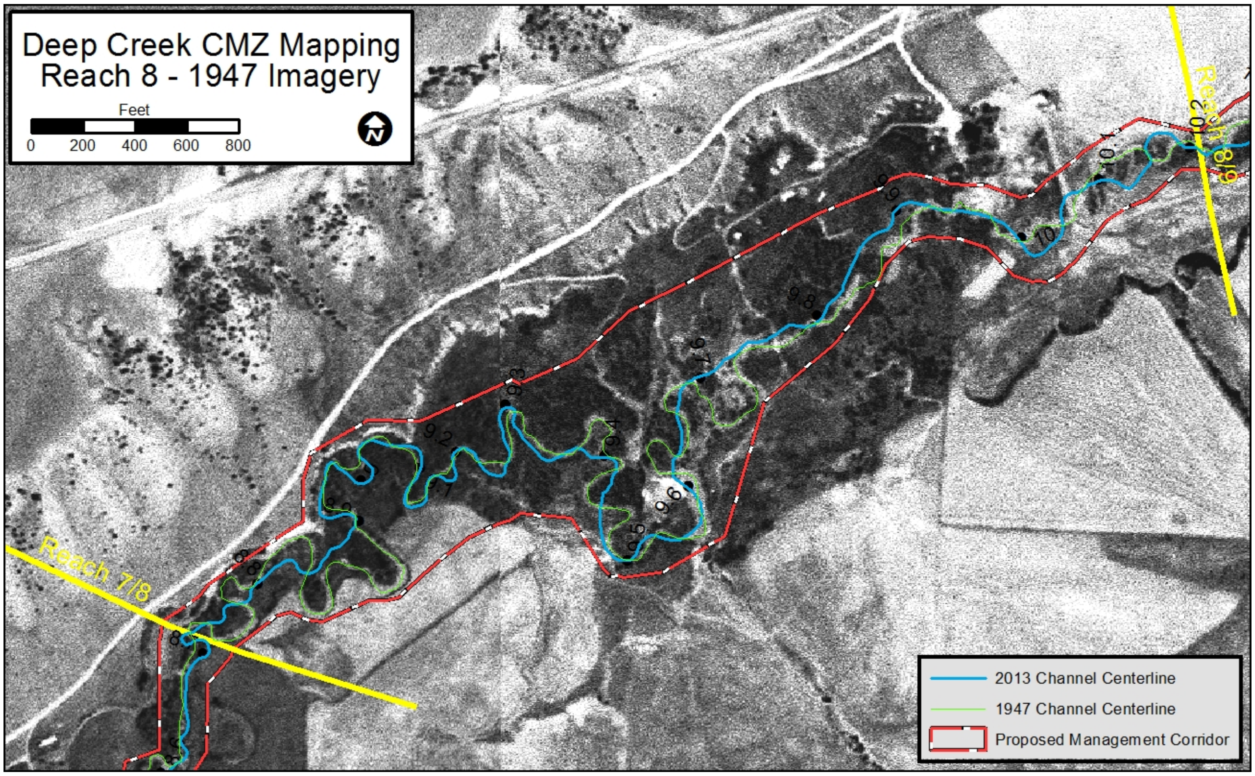


Figure 4-19. Inundation modeling results for Reach 8. Dark blue areas are equal to or lower than the channel. Yellows and reds are significantly higher than the adjacent main channel.



4-20. 1947 imagery for Reach 8, showing the 1947 and 2013 channel centerlines.

Figure 4-21. View downstream of Reach 8 showing a transition from the leveed section bounded by low floodplain to an open floodplain downstream.

Figure 4-22. View south of leveed and perched section of Deep Creek (left portion of photo).

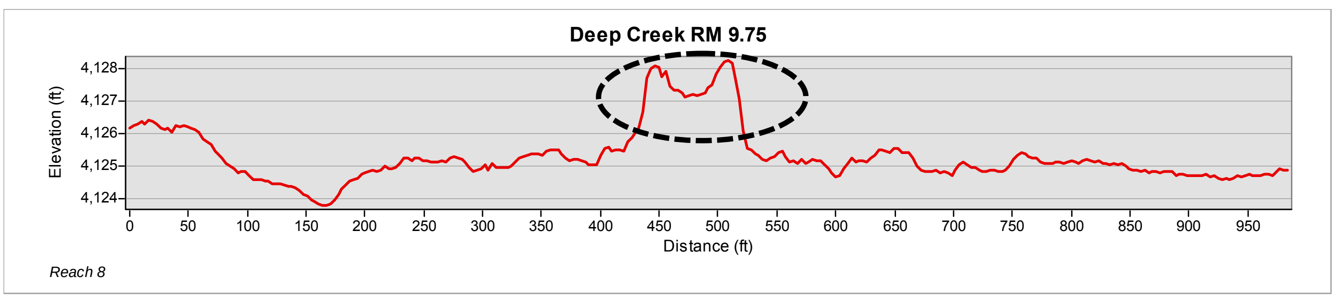


Figure 4-23. LiDAR-derived cross section at RM 9.75 in Reach 8 showing leveed, perched channel (circled); Deep Creek channel is at Station 150; low ground to left is northern floodplain.

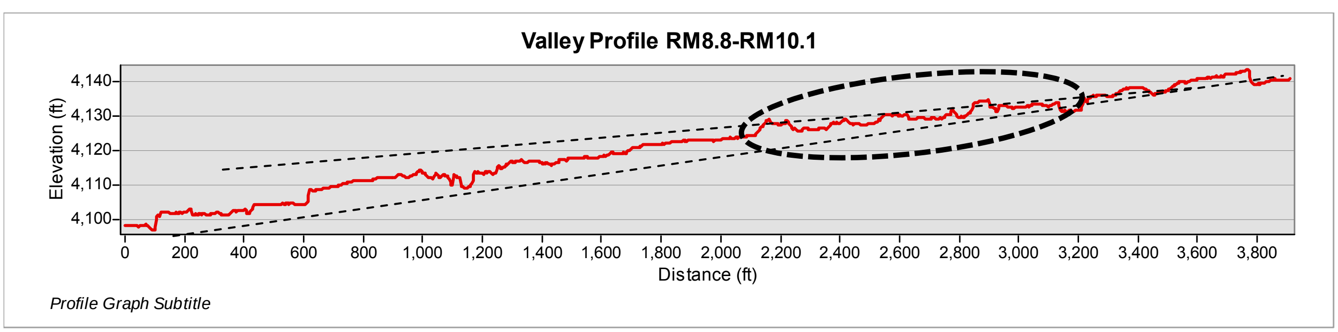


Figure 4-24. Valley profile from RM 10.1 (right) to RM 8.8 (left) showing grade variability in Reach 8; leveed section is from about Station 650 to Station 950 where slope is notably flat (circled).

Figure 4-25. View south of lower Reach 8 showing abandoned, moderately perched meanders that were active channels in 1947.

4.9 Reach 9—Antonick's Bridge to Above Fautsch

Reach 9 is characterized by a largely undeveloped stream corridor that has a fairly robust riparian corridor (Figure 4-26). Migration rates are moderate in Reach 9, which has a 99-foot Erosion Hazard Area buffer width. Reach 9 also has distinct vegetated floodplain channels on the south side of the corridor that pose a moderate risk of avulsion (Figure 4-27 and Figure 4-28). This south floodplain area has not been included in the Management Corridor, however with the largely undeveloped floodplain in this area, there is excellent opportunity to expand the corridor and allow for flow spreading and side channel activation. This may also help reduce sediment loading downstream in Reach 8.

Figure 4-26. View upstream of Reach 9 (Kestrel Aerial Services).

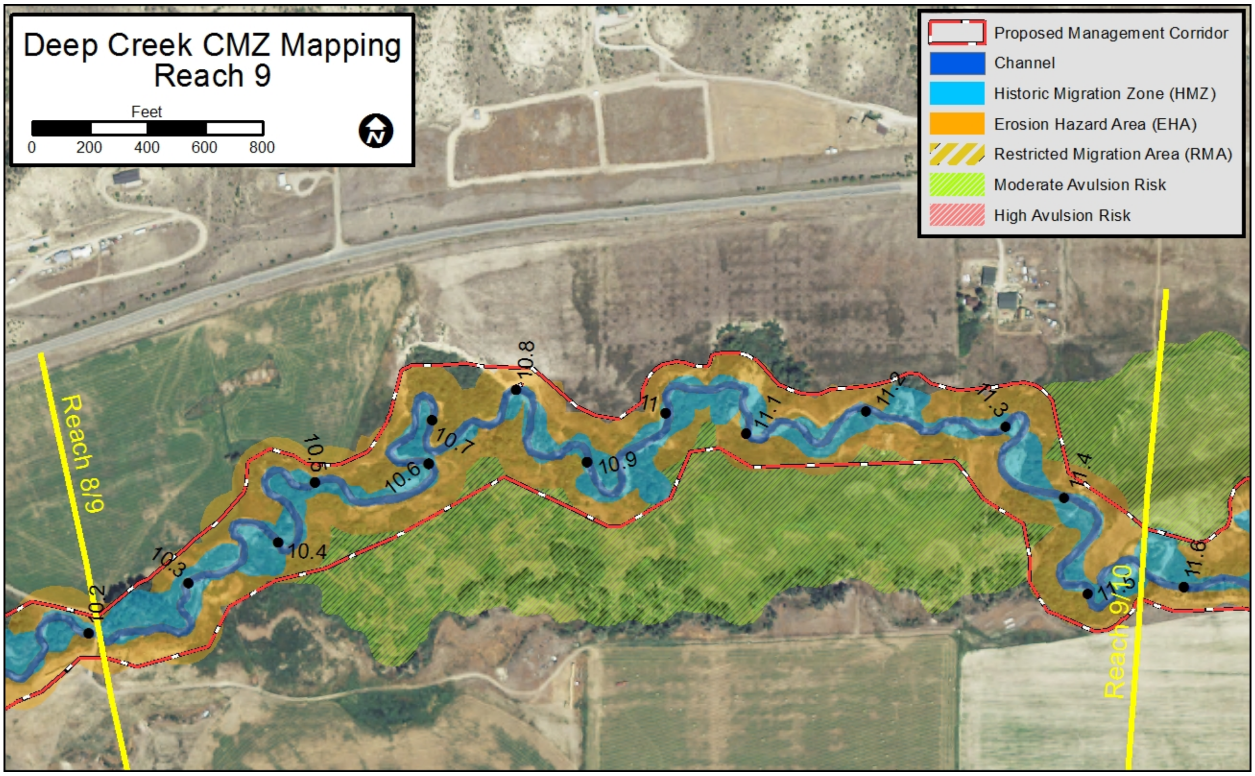


Figure 4-27. CMZ map for Reach 9.

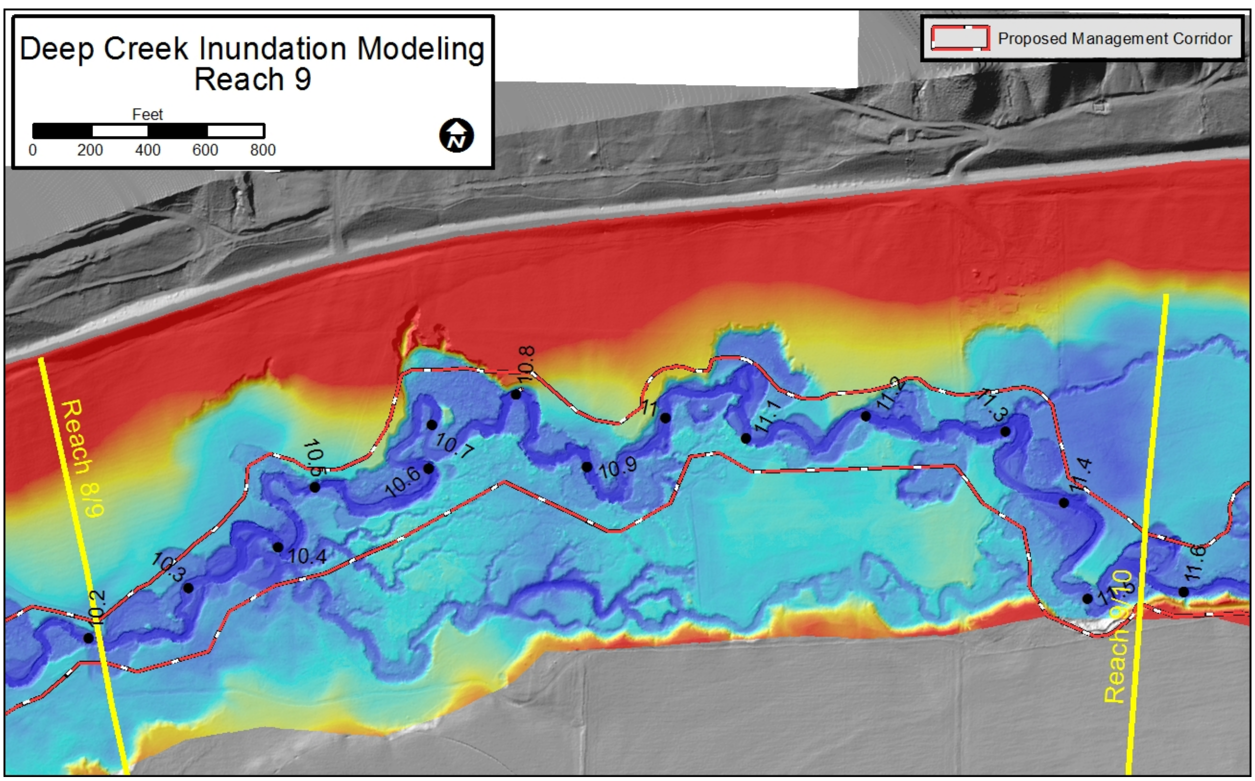


Figure 4-28. Inundation modeling results for Reach 9. Dark blue areas are equal to or lower than the channel. Yellows and reds are significantly higher than the adjacent main channel.

4.10 **Reach 10—Above Fautsch to Clopton Lane**

Reach 10 is about 1.5 miles long and shows the scale of riparian clearing that has taken place in the valley bottom (Figure 4-30). The CMZ map for Reach 10 reflects fairly high migration rates, with an Erosion Hazard Area buffer width of 128 feet. In the downstream portion of the reach, there is a distinct channel on the north floodplain that creates a moderate avulsion risk (Figure 4-31). This area is not included in the proposed Management Corridor.

The inundation modeling (Figure 4-31) shows that the area of dense riparian vegetation in the middle of Reach 10 is characterized by relatively low ground and a network of small dendritic channels which collectively suggest upwelling in the reach. If so, this area should be considered a high priority for riparian conservation and/or restoration due the apparent groundwater connectivity and associated high levels of ecological function.

Figure 4-29. Abrupt land use boundary showing riparian clearing and likely historic riparian extent.

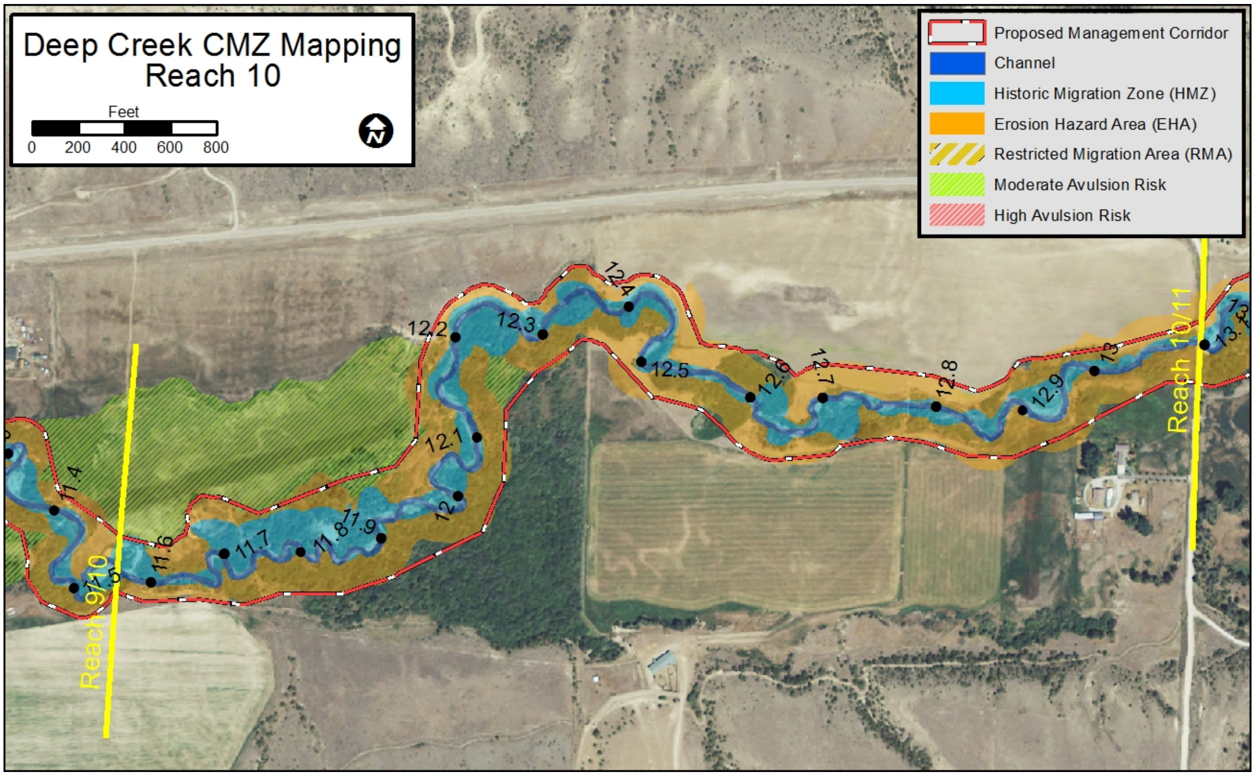


Figure 4-30. CMZ map for Reach 10.

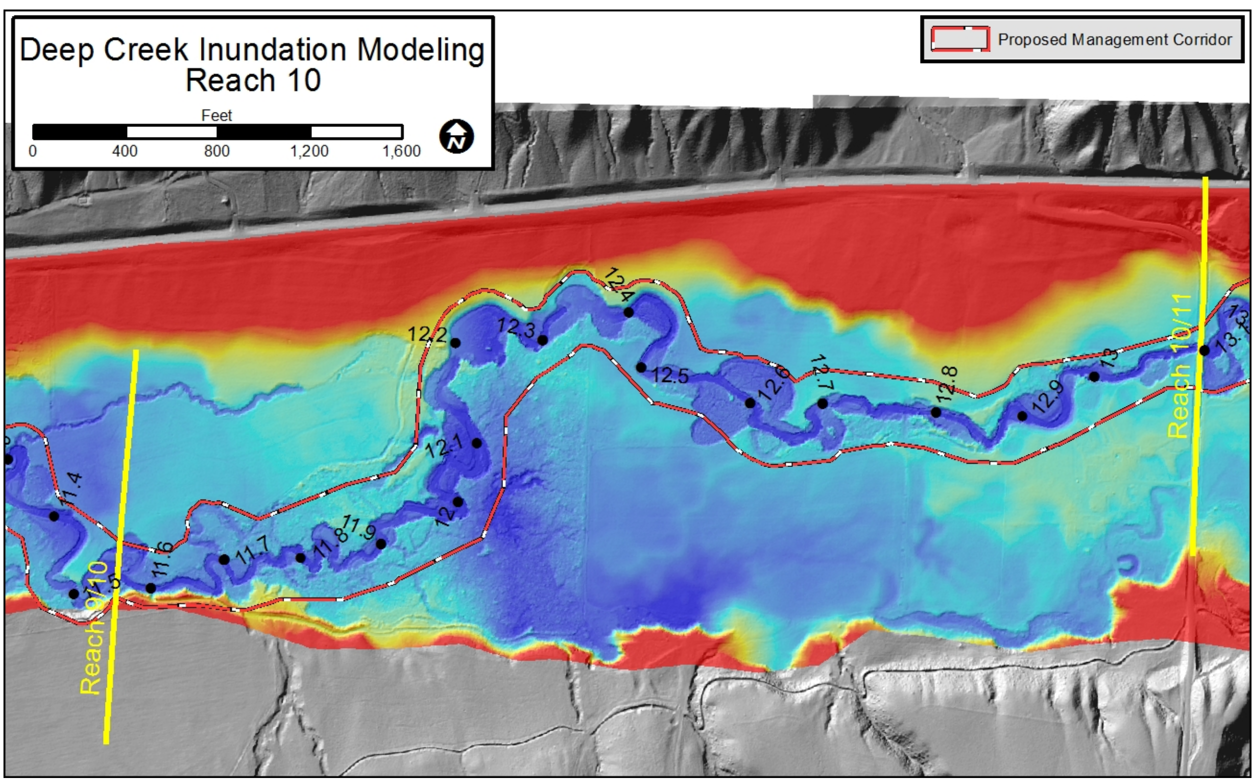


Figure 4-31. Inundation modeling results for Reach 10. Dark blue areas are equal to or lower than the channel. Yellows and reds are significantly higher than the adjacent main channel.

4.11 **Reach 11—Clopton Lane to Gobbs**

In Reach 11, Deep Creek flows mostly along the north side of the valley, with most of the floodplain to the south cleared and developed for irrigated agriculture (Figure 4-32). Reach 11 has the highest mean migration rate in the project reach, and the width of the Erosion Hazard Area buffer is 140 feet (Figure 4-33). Because of the encroachment of agriculture into the stream corridor coupled with high natural rates of channel migration in Reach 11, the proposed Management Corridor extends into some of the agricultural fields. This would be an excellent reach to consider the implementation of riparian buffers to potentially slow rates of bank erosion.

Inundation modeling results show that the river corridor is topographically well-defined, with a modern riparian zone nested within the surrounding floodplain surface (Figure 4-34). There are some remnants of historic channels on the south floodplain, but these appear to have been largely graded out with floodplain development.

Reach 11 has over 2,000 feet of bank protection, about half of which is rock riprap and the other half juniper revetments. Most of the riprap is concentrated on two bendways between RM 14.0 and RM 14.1.

Figure 4-32. View north of Reach 11 showing narrow riparian corridor; Deep Creek flow is right to left.

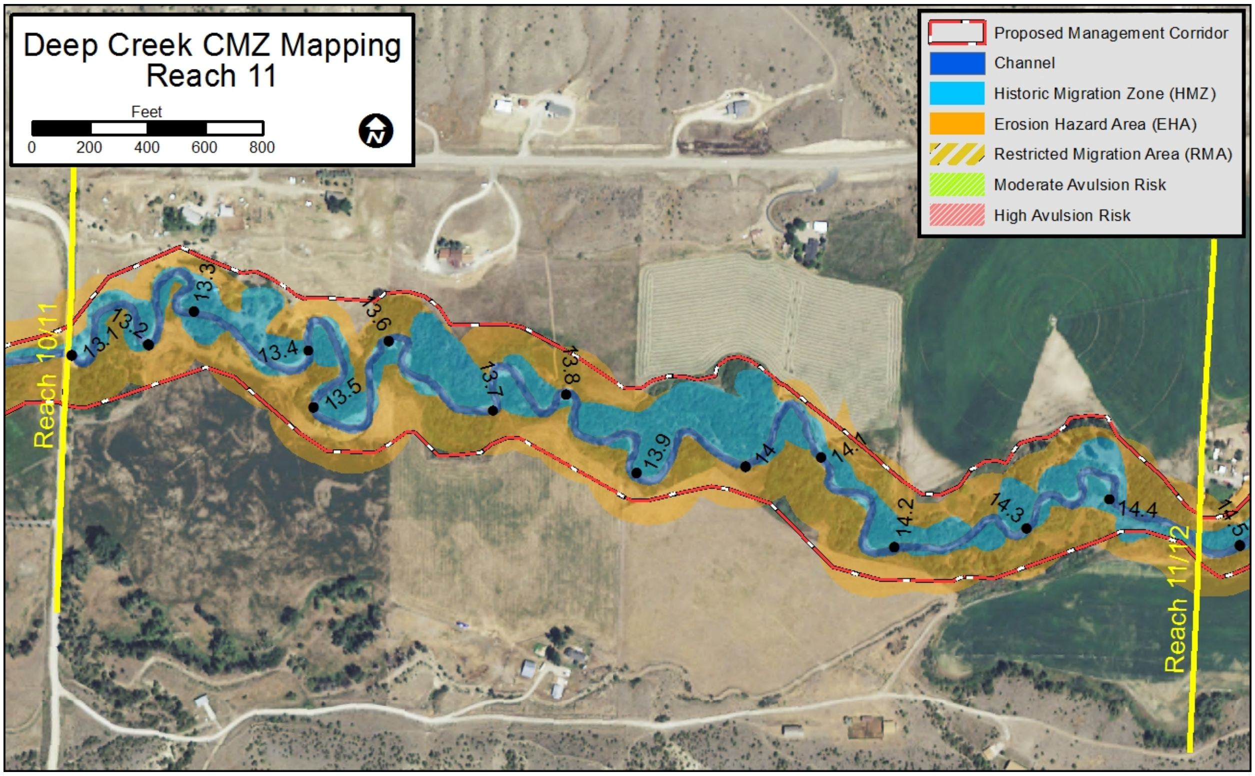


Figure 4-33. CMZ map for Reach 11.

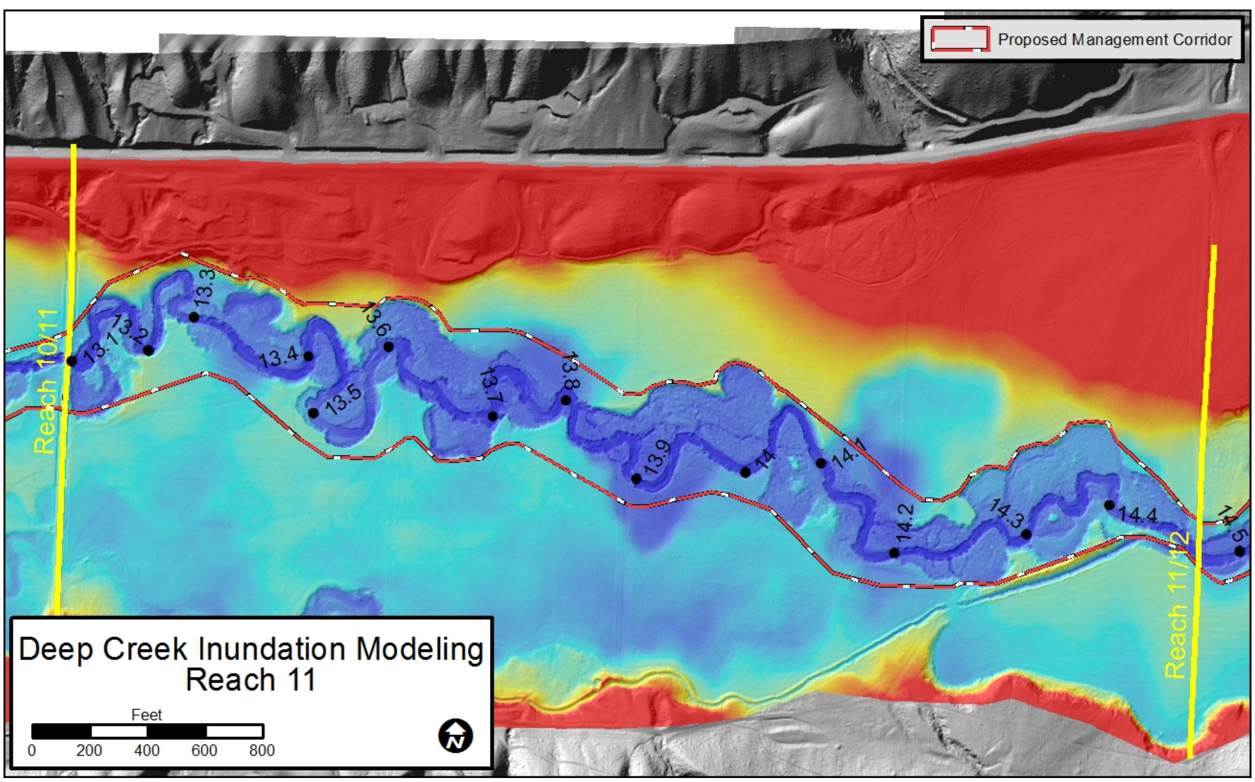


Figure 4-34. Inundation modeling results for Reach 11. Dark blue areas are equal to or lower than the channel. Yellows and reds are significantly higher than the adjacent main channel.

4.12 Reach 12—Gobbs to ML Bar Headquarters

Reach 12 is characterized most notably by a prominent bluff line north of the river where the channel has eroded into alluvial terraces that are prone to gullying (Figure 4-35). Extensive riparian clearing in the reach has limited the woody vegetation thread to the near stream environment, mostly meander tabs. Similar to Reach 11 downstream, migration rates are relatively high in Reach 12, which has an Erosion Hazard Area buffer width of 135 feet (Figure 4-36). Reach 12 is relatively sinuous, with numerous large meanders that will become increasingly prone to cutoff with time (Figure 4-37). The Historic Migration Zone has a relatively large footprint which reflects historic patterns of meander lengthening and cutoff. According to the Skidmore Watershed Restoration Plan, Reach 12 has gained almost 500 feet of channel lengths since 1995. The Plan also documents almost 1,900 feet of bank armor in the reach, about half of which is rock riprap. There is about 500 feet of rock riprap protecting the right bank both above and below the bridge at RM 15.65.

A good approach in Reach 12 would be to minimize further development against the creek and to allow riparian recovery on the streambanks and within the management corridor as land uses allow.

Figure 4-35. View to north over a portion of Reach 12 showing intensive cultivation of the floodplain and erosion of Deep Creek into alluvial terraces on the north side of the valley.

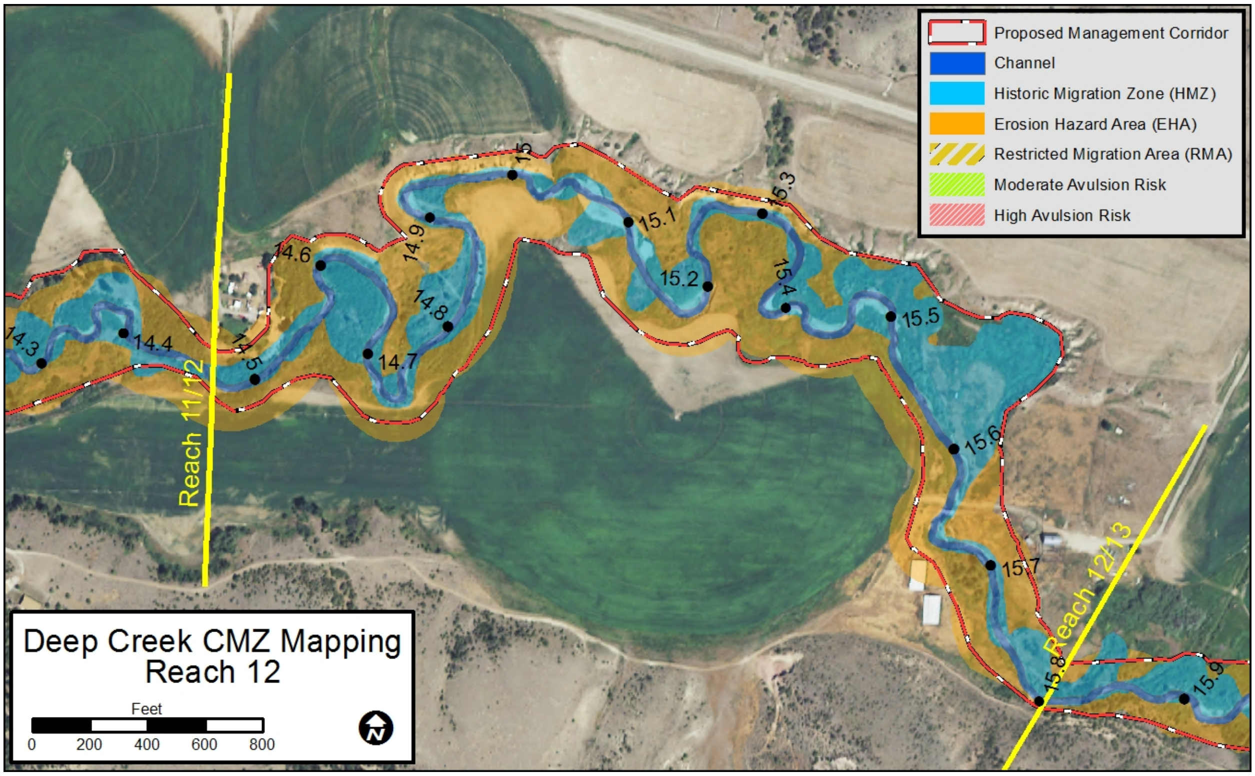


Figure 4-36. CMZ map for Reach 12.

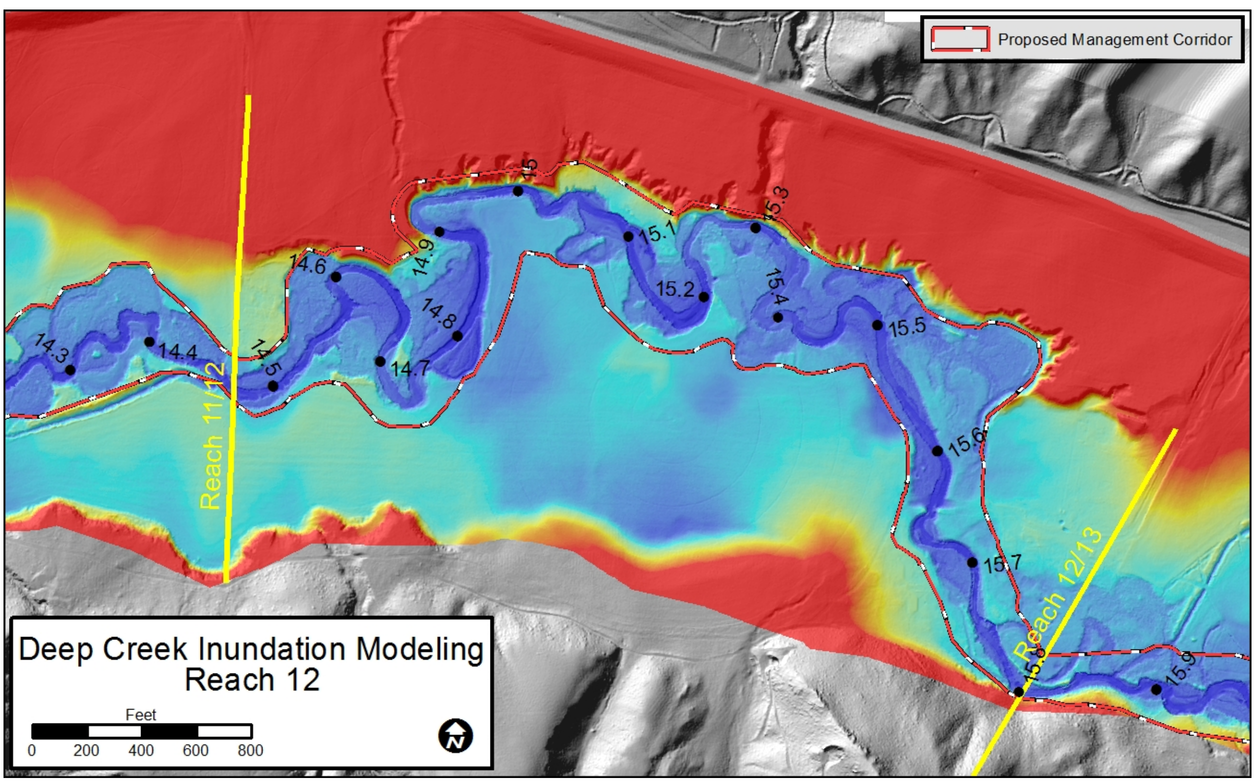


Figure 4-37. Inundation modeling results for Reach 12. Dark blue areas are equal to or lower than the channel. Yellows and reds are significantly higher than the adjacent main channel.

4.13 **Reach 13—ML Bar Headquarters to Flume Gulch**

In Reach 13, Deep Creek is a highly sinuous channel that has distinct meanders and meander cutoff remnants (Figure 4-38). The reach has experienced at least four meander cutoffs since 1995, and the Skidmore Watershed Restoration Plan reports that between 2009 and 2011, the reach lost 973 feet of length. Within this reach, Deep Creek has fairly high rates of bank migration which results in an Erosion Hazard Area buffer width of 114 feet (Figure 4-39). Inundation modeling shows that in the middle of the reach, there is a large channel that flows along the south valley wall (Figure 4-40). A LiDAR-derived cross section of the valley at this location shows that due south of the creek at RM16.7, the floodplain channel is much larger and about six feet lower than Deep Creek water surface. This channel does create a moderate avulsion hazard for Reach 13, which is mapped in the CMZ. It is not included in the proposed Management Corridor due to its distance from the main channel.

Figure 4-38. View upstream of Reach 13 showing main channel on north side of valley and avulsion risk to right of fields.

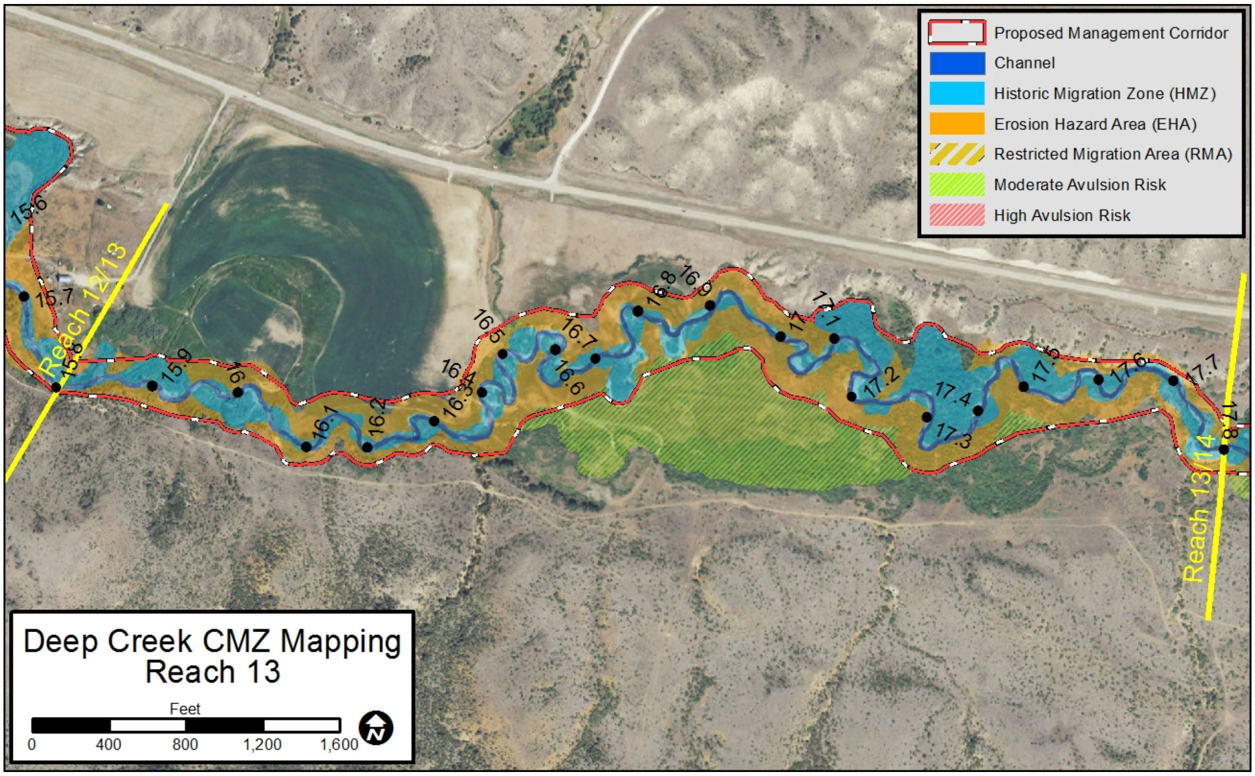


Figure 4-39. CMZ map for Reach 13.

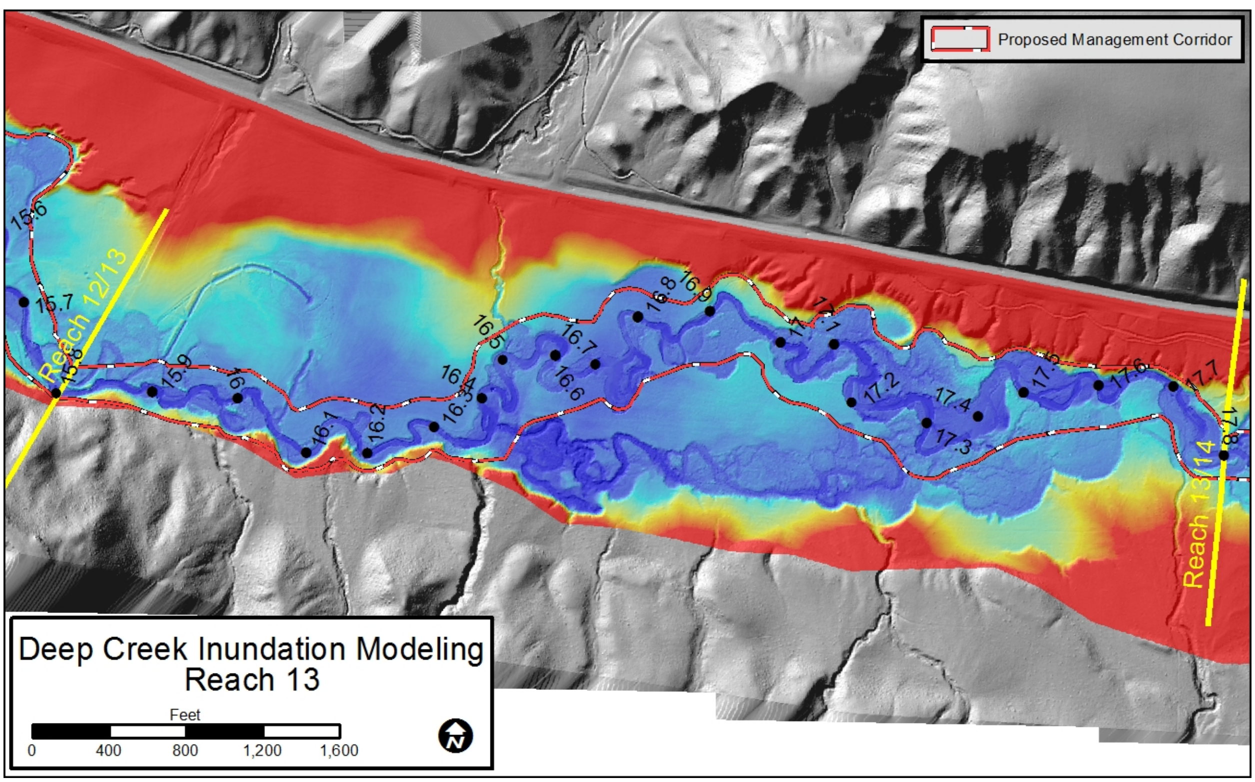


Figure 4-40. Inundation modeling results for Reach 13. Dark blue areas are equal to or lower than the channel. Yellows and reds are significantly higher than the adjacent main channel.

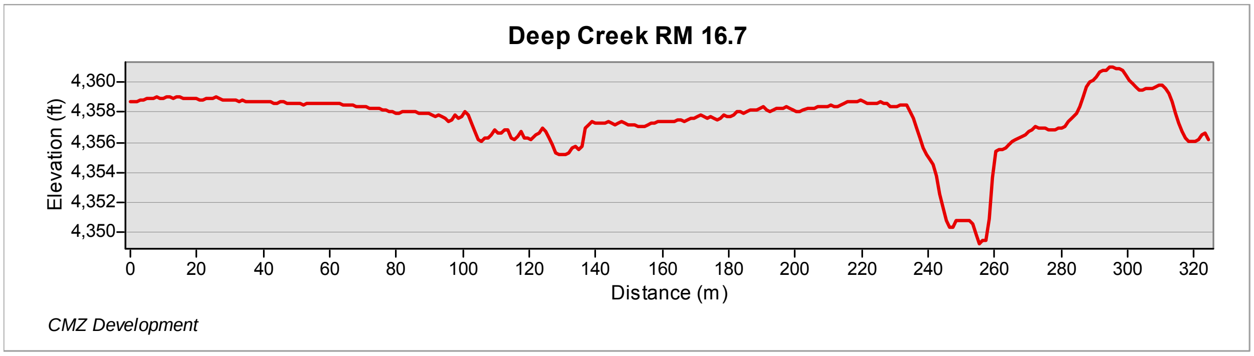


Figure 4-41. LiDAR-derived cross section from RM 16.7 in Reach 13 showing major channel feature on south side of valley (Station 250). The modern Deep Creek channel is at Station 120.

4.14 Reach 14—Flume Gulch to Highway 12

Reach 14 is characterized most prominently by a robust riparian corridor (Figure 4-42). This riparian zone spans a wide floodplain that hosts numerous small channels that could potentially be reactivated at high water. According to the Skidmore Watershed Restoration Plan, the reach gained almost 300 feet of length between 2009 and 2011. The reach tends to follow the north valley wall, and floodplain channels to the south have been mapped as moderate avulsion hazards (Figure 4-43 and Figure 4-44). These areas are not included in the Management Corridor but would be excellent areas of riparian conservation. The Skidmore Watershed Restoration Plan indicates that Reach 13 has about 2,300 feet of mapped bank protection, most of which is juniper revetment. With a meandering planform, low migration rates, and excellent habitat, Reach 14 could provide and excellent reference for downstream areas.

Figure 4-42. View downstream of Reach 14 showing expansive riparian corridor and sinuous channel.

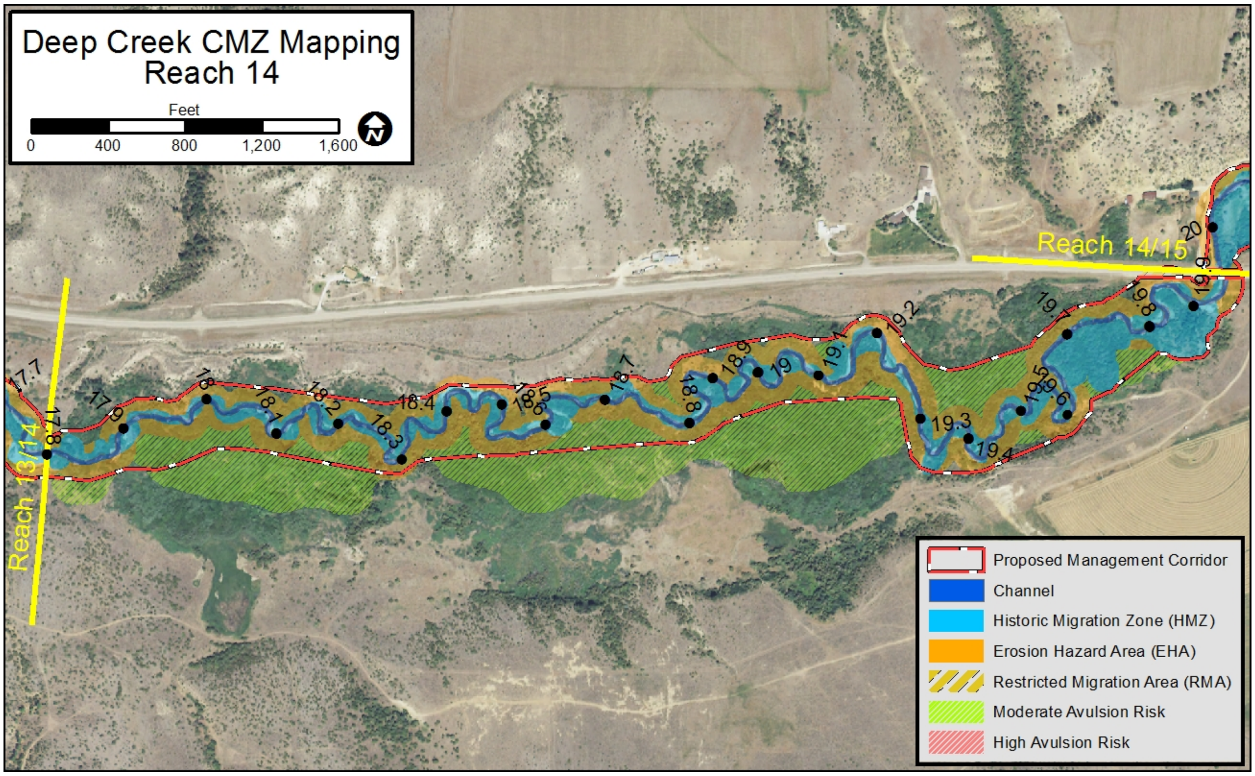


Figure 4-43. CMZ map for Reach 14.

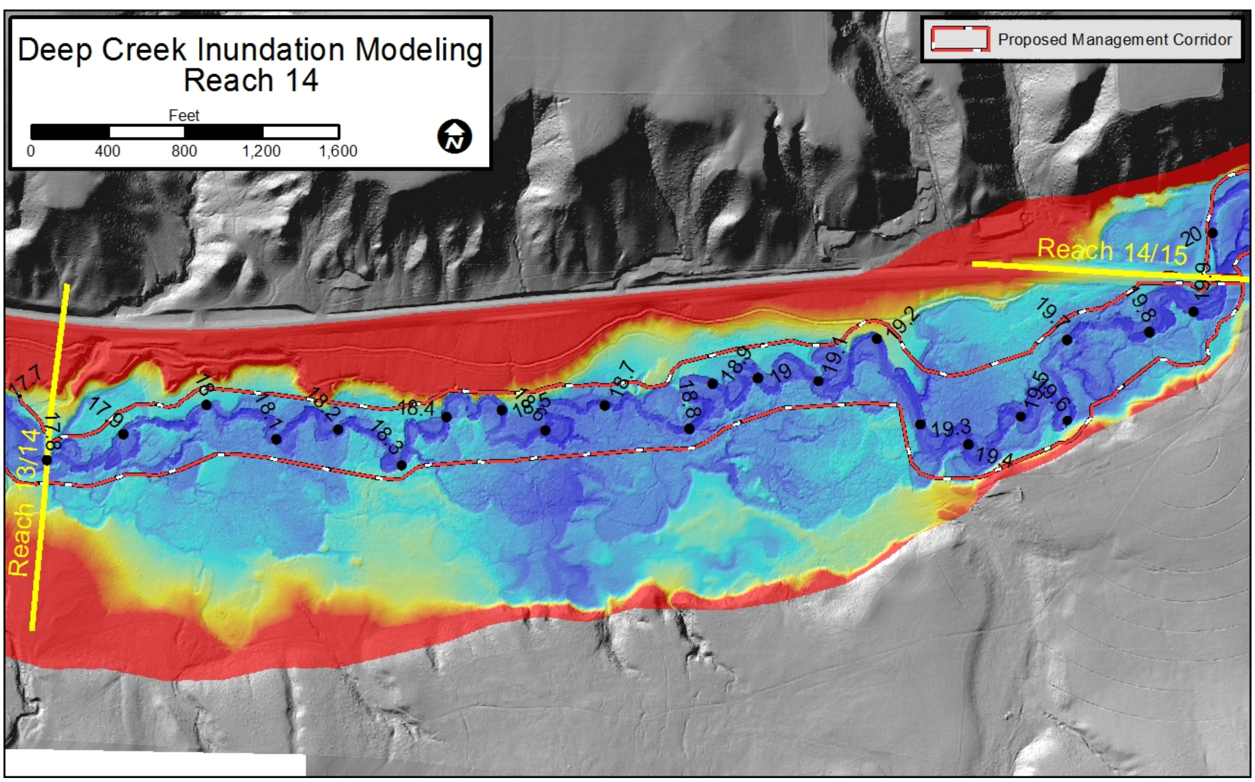


Figure 4-44. Inundation modeling results for Reach 14. Dark blue areas are equal to or lower than the channel. Yellows and reds are significantly higher than the adjacent main channel.

4.15 Reach 15—Highway 12 to North Fork of Deep Creek

Reach 15 is located just upstream of the Highway 12 Bridge and consists of a relatively short section of channel at the mouth of Deep Creek Canyon that supports a wide riparian corridor. The upper portion of the reach also has substantial residential development (Figure 4-45). Reach 15 has the widest Historic Migration Zone in the project area, because in 1947 the channel was about 500 feet south of its current location (Figure 4-46). Older channels to the south that are evident on the inundation modeling map are included as moderate risk avulsion hazard areas (Figure 4-47). The proposed Management Corridor contains the HMZ only.

Because of the old channels and dense vegetation in the reach, it would be a good idea to maintain this riparian area where Deep Creek leaves the mountains, so that the floodplain can continue to absorb floodwaters and sediment, which will help mitigate impacts downstream below Highway 12.

Figure 4-45. View upstream of Reach 15 showing broad riparian zone and moderate avulsion risk area to right (south) of main channel in foreground.

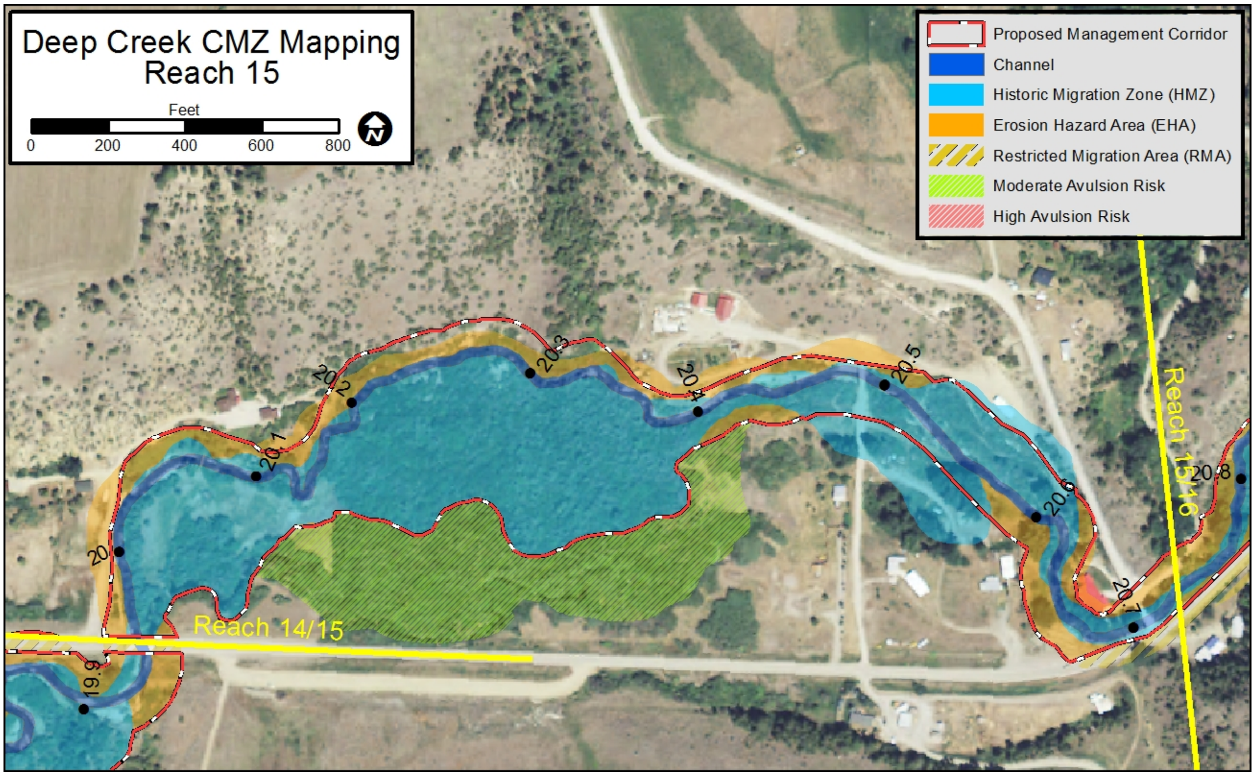


Figure 4-46. CMZ map for Reach 15.

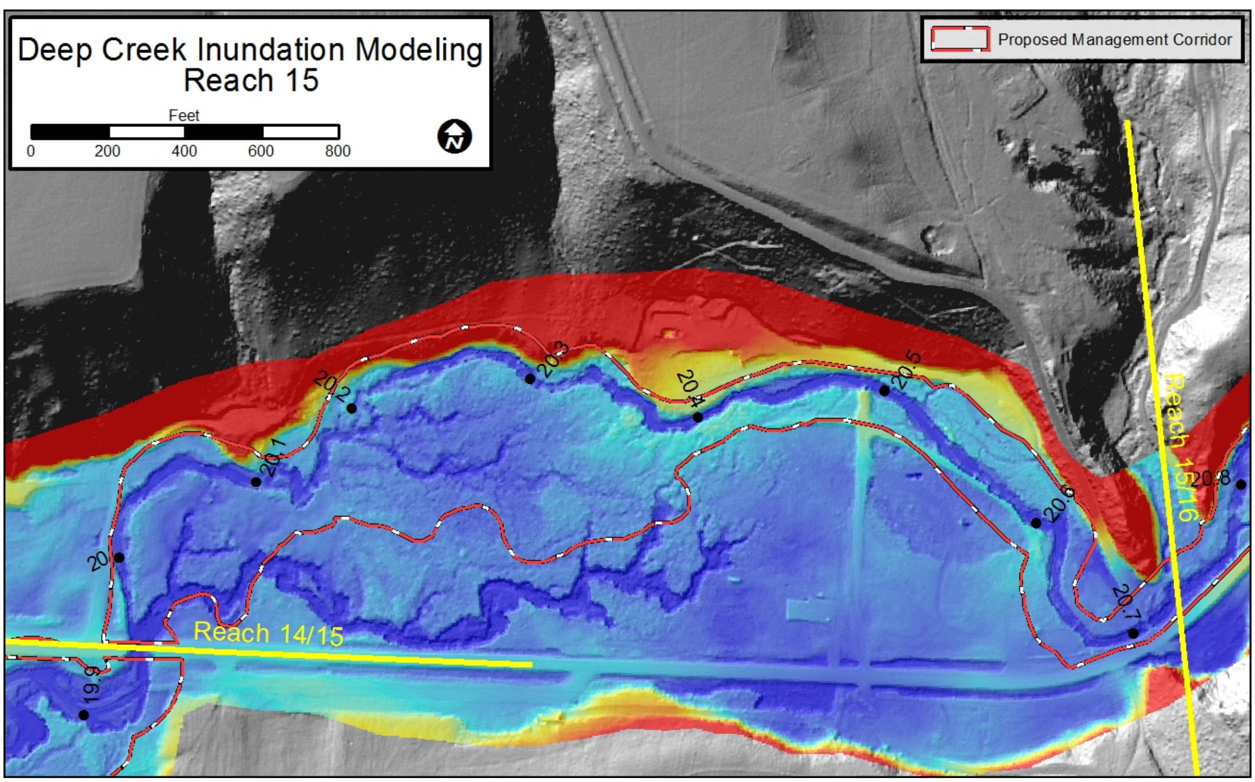


Figure 4-47. Inundation modeling results for Reach 15. Dark blue areas are equal to or lower than the channel. Yellows and reds are significantly higher than the adjacent main channel.

4.16 **Reach 16—North Fork of Deep Creek to USFS Boundary**

Reach 16 is located in Deep Creek Canyon which hosts Highway 12 East (Figure 4-48). As a result of highway construction in the bottom of the canyon, the stream channel confinement is even greater than that created by the bedrock canyon walls. As a result, the natural CMZ overlaps the Highway prism, but has been clipped out as "Restricted Migration Area" (Figure 4-49). The inundation modeling results show historic channel remnants on the north side of the highway (Figure 4-50). Because of its confinement by highway infrastructure and natural geology, there are no obvious restoration opportunities for Reach 16.

Figure 4-48. View upstream (east) of Deep Creek Canyon showing Highway 12.

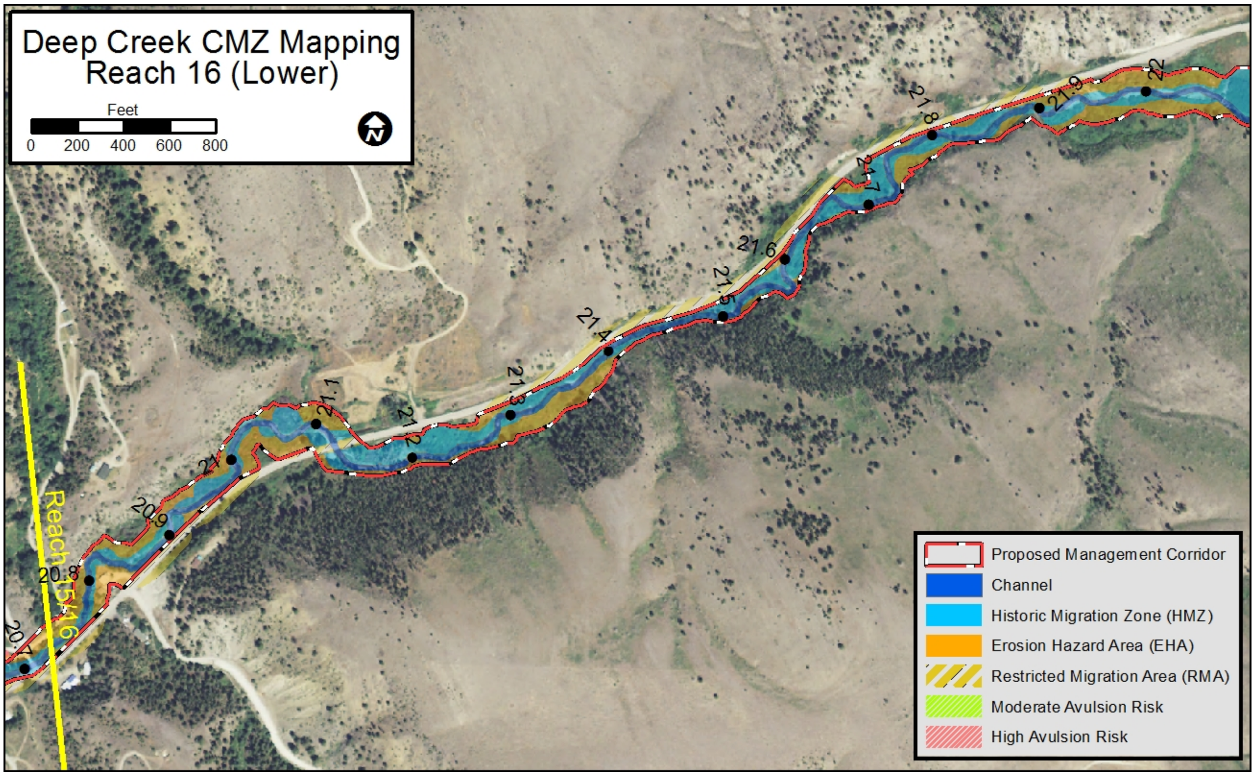


Figure 4-49. CMZ map for the lower portion of Reach 16.

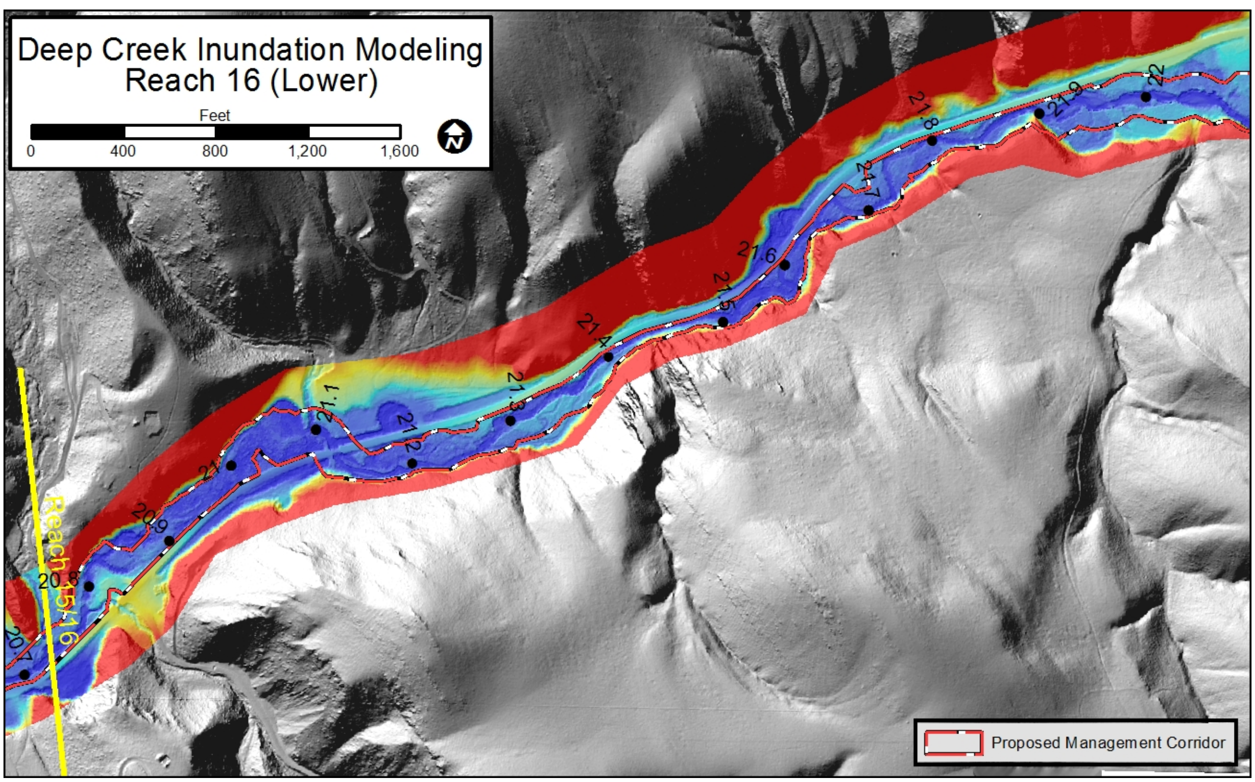
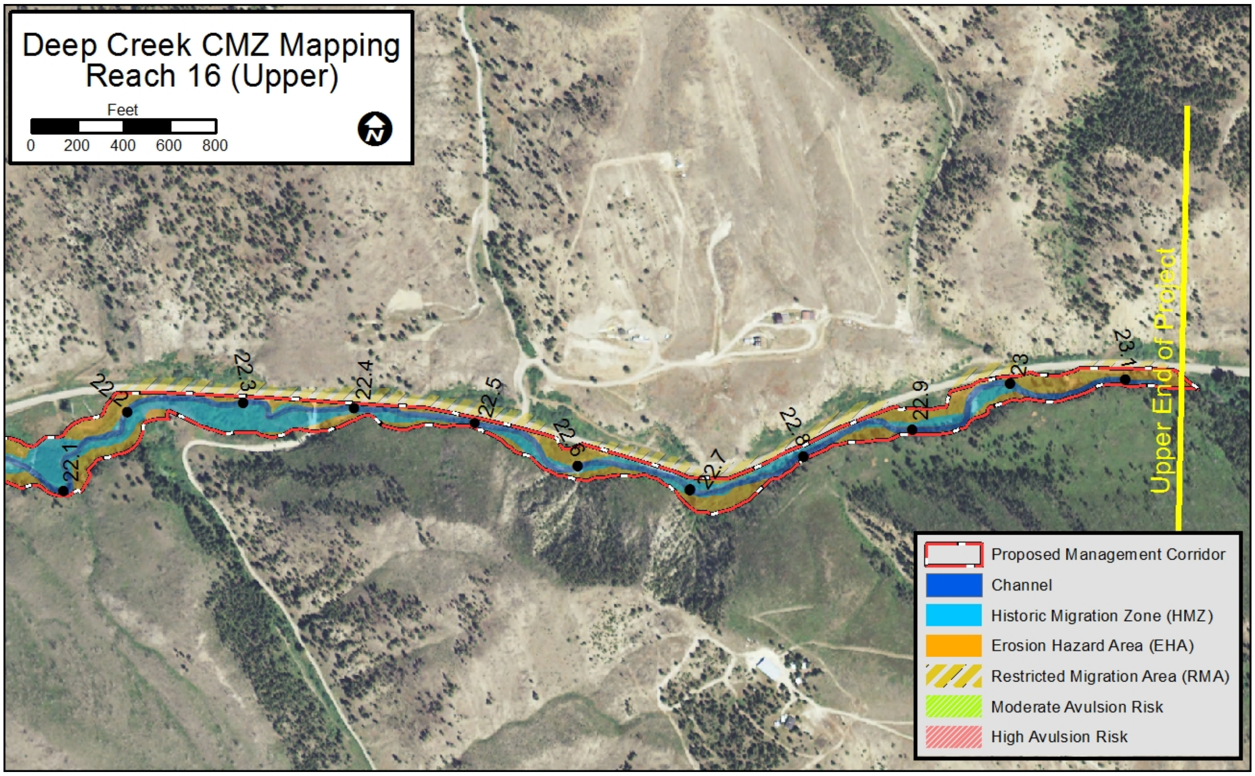
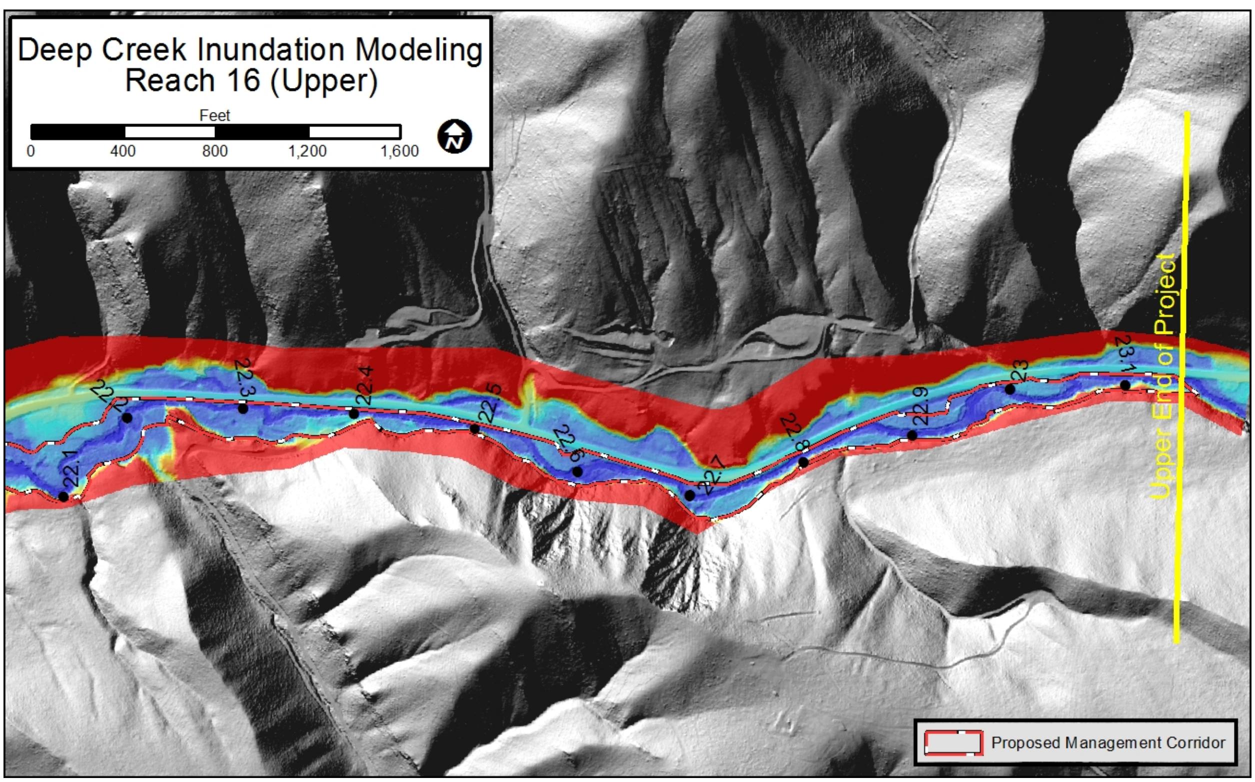


Figure 4-50. Inundation modeling results for a portion of Reach 16. Dark blue areas are equal to or lower than the channel. Yellows and reds are significantly higher than the adjacent main channel.



4-51. CMZ map for the upper portion of Reach 16.



4-52. . Inundation modeling results for the upper portion of Reach 16. Dark blue areas are equal to or lower than the channel. Yellows and reds are significantly higher than the adjacent main channel.

5 References

Dalby, C, 2006. Comparison of channel migration zones in plane-bed, pool-riffle and anabranching channels of the upper Yellowstone River: Poster Session delivered at the Montana Section AWRA annual meeting, October 12-13, 2006.

FEMA, 1999, River Erosion Hazard Areas—Mapping Feasibility Study: Federal Emergency Management Agency, Technical Services Division, Hazards Study Branch, 154p.

Rapp, C., and T. Abbe, 2003. A Framework for Delineating Channel Migration Zones: Washington State Department of Ecology and Washington State Department of Transportation. Ecology Final Draft Publication #03-06-027.

Skidmore Restoration Consulting and AGI, 2013. Deep Creek Watershed Restoration Plan—Assessment and Recommendations: Report prepared for Broadwater Conservation District, Townsend, MT, 52p.

Vuke, S.M., 2009. Geologic map of the Southern Townsend Basin, Broadwater and Gallatin Counties, Montana: Montana Bureau of Mines and Geology Open File Report 586.

Washington Department of Natural Resources Forest Board Manual, 2004, Section 2: Standard Methods for Identifying Bankfull Channel Features and Channel Migration Zones, 69p.