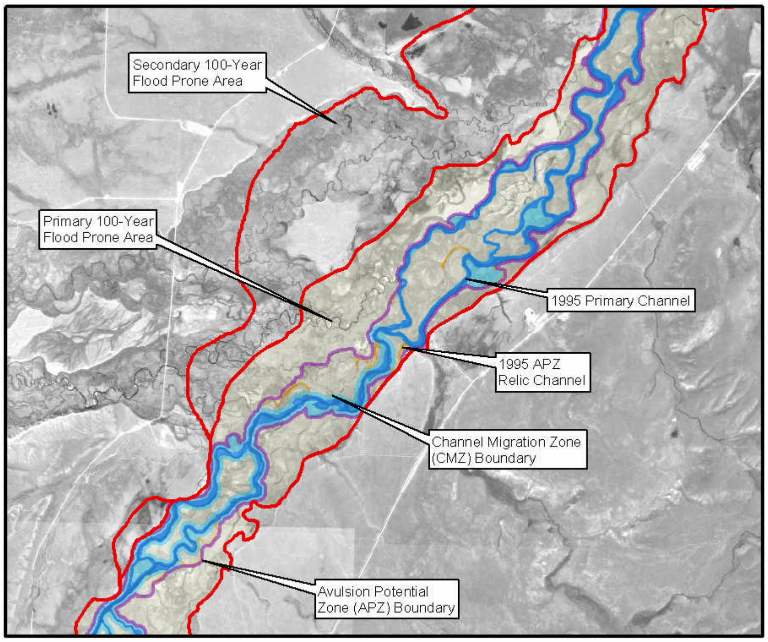
Flood Inundation Potential Mapping

and

Channel Migration Zone Delineation

Big Hole River, Montana



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1. Introduction

1.1. Goals and Objectives

Rural counties face unique challenges when providing for public safety and other critical services. Specific to this study, rural counties that contain major river corridors typically find it difficult to secure sufficient funding to define regulatory flood boundaries. As a result, rural floodplain managers and resident stakeholders commonly have few tools available to guide river corridor development and provide for associated public safety. The Big Hole River Valley exemplifies a rural river corridor that is facing increased development pressure. Floodplain mapping in the region is limited. However, in an effort to address the anticipated risks associated with development, the counties that contain and border the Big Hole are collaboratively addressing the hydrologic hazards inherent to the river system.

This project has two primary goals. The first is to produce approximate 100-year floodplain maps for the main stem of the Big Hole River. This goal is part of a locally led, four-county[1] effort to coordinate land use planning in the Big Hole Basin. The second goal is to describe physical and vegetative conditions of stream reaches for the Middle and Lower Big Hole River and several tributaries using available aerial photography and other available digital data sources. This aerial assessment is part of ongoing TMDL planning for all impaired water bodies in the Middle and Lower Big Hole TMDL Planning Areas.

This report presents the results of the floodplain mapping. The results present an application of GIS modeling and geomorphic assessment techniques to define a series of hydrologic hazard corridors for the main stem Big Hole River. The composite corridor includes an inundation corridor that approximates the 100-year floodplain, a Channel Migration Zone (CMZ) that identifies areas in terms of risk of channel occupation, and an Avulsion Potential Zone (APZ) that identifies areas at risk of large-scale relocation of primary river channels. These zones are based on available data, supplemented by geomorphic and hydrologic analysis.

A separate document, “Aerial Assessment of the Middle and Lower Big Hole TMDL Planning Area; Pintlar Creek to the Beaverhead River,” (AGI/DTM 2005) presents the results of the aerial assessment.

1.2. Project Area

The Big Hole River flows for approximately 160 miles from its headwaters on the Montana/Idaho border of southwest Montana to its mouth near Twin Bridges, Montana (Figure 1). The convoluted course of the Big Hole River is attributable to the geologic controls provided by surrounding mountain ranges. The Big Hole River originates as a high-altitude mountain stream in the Beaverhead Mountains south of Jackson, flowing approximately 10 miles northward through the northern flank of the Beaverhead

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[1] Annaconda/Deerlodge, Beaverhead, Butte/Silver Bow, and Madison Counties are currently coordinating efforts to produce a uniform development setback ordinance for the Big Hole River.

Mountains into the Upper Big Hole Valley. From that point it flows northward for approximately 50 miles through a broad high elevation valley that lies on the western margin of the Pioneer Mountains. Between Pintlar Creek and Fishtrap Creek, the river turns northeastward and enters a canyon that wraps around the northern portion of the Pioneer Range. Near Divide, the river turns southward and flows through a series of canyons and open valleys, past Melrose and Glen, until it swings eastward along the south flank of McCartney Mountain, wrapping around its southern and southeastern edges, and following its margin northeastward to its ultimate confluence with the Beaverhead River, near Twin Bridges. Twin Bridges marks the confluences of the Big Hole, Beaverhead, and Ruby Rivers, which combine to form the Jefferson River.

The hazard zones developed in this project include the entire main stem of the Big Hole River from its confluence with Pioneer Creek at the upper end, to its mouth near Twin Bridges.

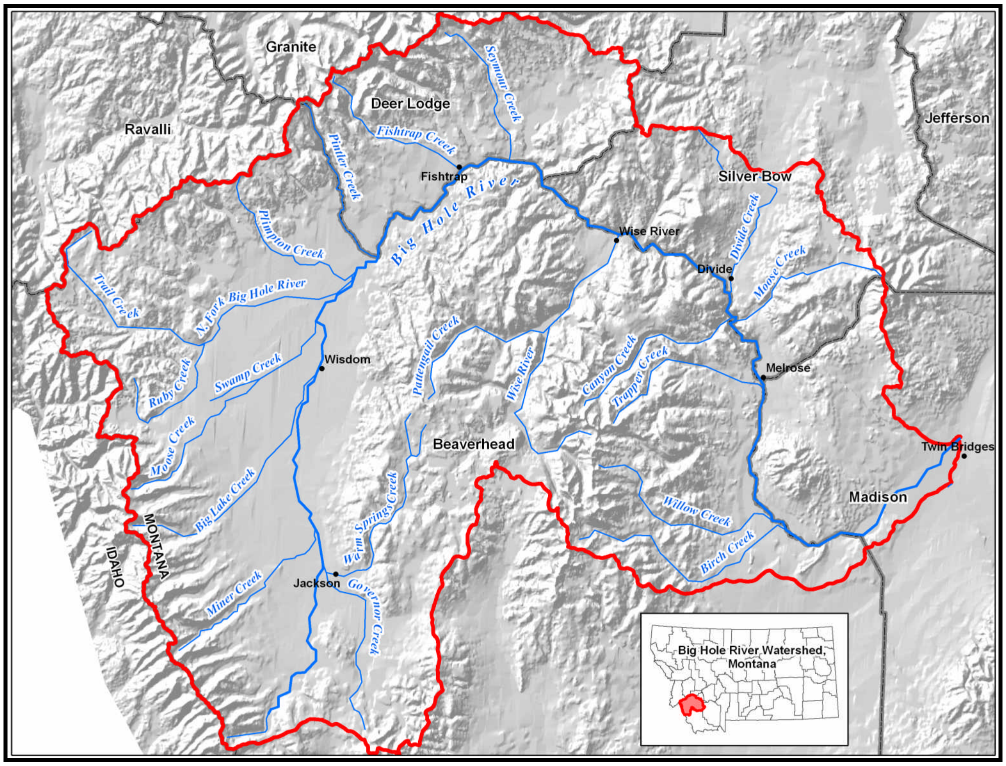

Figure 1. Location map, Big Hole River watershed and study reach.

1.3. Assessed Geomorphic and Flood Hazard Zones

The primary goal of this study is to identify the hazards associated with active river processes along the main stem of the Big Hole River. The project team evaluated three types of potential hazards:

- floodwater inundation/flood prone areas,
- channel migration, and
- channel avulsion.

The following is a brief description of each zone and its logistical basis for determination. Subsequent chapters define the actual methodologies used for defining the boundaries of each zone in detail.

1.3.1. Inundation Potential Zone

Within the Federal Emergency Management Agency (FEMA), the Mitigation Division manages the National Flood Insurance Program (NFIP). The NFIP has three components: flood insurance, floodplain management, and flood hazard mapping. Thousands of communities within the United States participate in the NFIP by adopting and enforcing floodplain management ordinances to reduce flood damages. In exchange, the NFIP backs flood insurance for community members.

Flood hazard boundaries developed to NFIP standards rely on detailed hydraulic models that predict inundation areas for a defined base flood. These models include one and two dimensional steady/unsteady flow models and floodway analysis models (http://www.fema.gov/fhm/en_hydra.shtm). Hydrologic analysis typically requires single event modeling that models rainfall/runoff or route measured flows to create flood hydrographs (http://www.fema.gov/fhm/en_hydro.shtm). The cost of developing NFIP flood hazard boundaries is typically on the order of several thousands of dollars per river mile. In many river corridor environments of Montana, sparse populations and limited funding preclude such topographic data acquisition and detailed analysis, resulting in undefined floodplain boundaries. Floodplain management in rural areas therefore poses unique challenges with respect to identifying the potential for flood inundation in a given area.

A pilot study by the Nebraska Natural Resources Commission (NNRC) in Nuckolls County demonstrated that it is possible to delineate approximate 100-year flood prone areas utilizing 30-meter Digital Elevation Models and GIS modeling techniques (Lear, et al, 2004). The methodology allowed for “rapid and efficient, limited-detail floodplain mapping over large rural areas.” The methodology used in this study is similar in nature to the Nebraska pilot project and shows similar results.

The primary objective of the Inundation Potential Corridor modeling is to provide a broad delineation of areas of the river valley that are most prone to inundation in the event of an approximate 100-year flood event (1% frequency flood).

1.3.2. Channel Migration Zone (CMZ)

River corridor environments are typically prone to hazards associated with bank erosion as well as flooding. FEMA has recognized the importance of this process with regard to floodplain management (FEMA, 1999):

> “The geomorphic complexity of alluvial streams creates difficulties for implementing Federal floodplain regulations that are based primarily on flooding. In fact, channel changes, such as meander migration and bank erosion, may constitute a greater hazard than overbank flow in some areas”.

Bank erosion reflects lateral shifting of a bankline. This natural process occurs as a stable stream channel migrates back and forth across its floodplain. If the stream is unstable, such that its channel pattern or cross section size is changing, amplified bank erosion rates and extents are possible. Where a river system has an adjustable boundary that allows for bank erosion, an erosion hazard area exists. Certain stream environments, such as bedrock canyons, have largely non-adjustable boundaries and very narrow hazard areas. Dynamic streams that are ***alluvial*** in nature (flowing through sediment deposited by the stream itself) can have very high lateral migration rates and extensive erosion hazard areas.

The threat caused by channel migration to buildings and infrastructure prompted FEMA, through the National Flood Insurance Reform Act (NFIRA) of 1994, to assess whether the mapping of Riverine Erosion Hazard Areas (REHAs) is technologically feasible (FEMA, 1999). FEMA defines an erosion hazard area as “an area where, based on erosion rate information and other available historical data, erosion or avulsion is likely to result in damage to or loss of buildings and infrastructure within a 60-year period.” The analysis, which includes a detailed review of methodologies applied in 12 case studies, concludes that it is technologically feasible to map riverine erosion hazard areas. The conclusions also state that there needs to be some flexibility in the choice of analysis techniques in order to address site-specific conditions.

In an effort to define erosion hazard areas, researchers have adopted the concept of a “migration zone” in assessing dynamic river systems (Rapp and Abbe, 2003, Skidmore, et al, 1999). The concept of a Channel Migration Zone (CMZ) refers to a river ***corridor*** that includes areas prone to natural channel occupation due to bank erosion. With regard to its application as a management tool, a guiding document on techniques for CMZ delineation by the Washington Department of Ecology (Rapp and Abbe, 2003) states the following:

> “The principal goal of delineating the Channel Migration Zone (CMZ) – the area where a stream or river is susceptible to channel erosion – is to predict areas at risk for future channel erosion due to fluvial processes. CMZ delineations help reduce risks to human communities by guiding development in and along river systems away from such areas. Limiting development within CMZs also reduces the costs of repairing or replacing infrastructure and major civil works that might otherwise be threatened or damaged by channel migration. Additionally, CMZ delineations can provide guidance in reducing degradation and loss of critical aquatic and riparian habitats, helping assure that fluvial process are accommodated and that the river landscape is not permanently degraded or disconnected from the river by development.”

The project reach of the Big Hole River ranges from conditions of highly erodible, dynamic channel margins, to very stable bedrock canyons. The purpose of the CMZ zone delineation is to generate a delineated corridor area that reflects these variable rates of natural channel activity, with the goal to identify relative risks of associated bank erosion.

1.3.3. Avulsion Potential Zone (APZ)

Numerous reaches of the Big Hole River have multiple stream channels. Because of this multi-channeled stream pattern, the river corridor hosts a mosaic of active side channels and abandoned floodplain channels that display a range of main channel connectivity. In some areas, split flow through multiple channels occurs at low flow conditions. In other areas, relic abandoned channels are not accessible by low flows and only convey river water during flood events. When minor channels convey water during floods, they are prone to enlargement and reactivation. Sometimes, a small channel can capture the main thread of the river and become the primary channel. This process of rapid channel shift into a new primary channel, called ***avulsion***, is different than that of lateral channel migration, and as such poses a different challenge in river management. According to FEMA (1999), the Erosion Hazard Area includes areas prone to avulsion. In their guiding document on Channel Migration Zone determinations, the Washington Department of Ecology states:

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

For this study, areas of high risk for avulsions are defined separately from areas at risk of channel migration. When the APZ and the CMZ are combined they define the composite erosion hazard area.

1.3.4. Corridor Limitations and Relative Levels of Risk

Floodwater inundation, bankline migration, and channel avulsion processes all present some level of risk to property within stream corridors. For this study, we developed each of these corridors independently. Although the statistical risk of each of these hazards has not been determined, their association with specific river process allows some relative comparison of the type and magnitude of risk (Table 1). In general, the ***Inundation Zone*** encompasses areas in the stream valley that, due to their low elevations, have a relatively high risk of site inundation during a ~100-year flood event. Here, the risk usually a short duration event, directly related to the overbank flow associated with periods of high magnitude flooding. In contrast, the ***Channel Migration Zone*** delineates areas that have a moderate to high risk of channel occupation due to channel migration over the next 50-60 years. Such bank erosion can occur across a wide range of flows. As such, the risk is not just associated with short-term flood events. In the short-term, the risk is gradational through the zone; it is highest at the active channel margin, and grades down through the buffer and historic channel zone. The ***Avulsion Potential Zone*** encompasses broad areas that display evidence for potential channel relocation, which, similar to the Inundation Potential Zone, is typically a flood-driven process.

1.4. Application of Results

The corridor delineations presented in this document are intended to provide a basic screening tool to help guide and support management decisions within the Big Hole River corridor. The expanse of the project area requires that the results are broad-scale in nature, and therefore less precise than highly detailed site-specific analyses. The inundation potential corridor identifies topographically low areas as defined by DEM data that are prone to floodwater inundation during a 100-year flood event. The results are unequivocally ***not*** *intended to replace or override flood boundary mapping that meets NFIP standards; conversely, they are intended to highlight areas that would warrant such mapping in the case of proposed development.*

Hazard Zone	***Basis of Delineation***	***Limitations***	***Relative Risk***
Inundation	Areas identified by inundation model to be below the flood water surface elevation and thus susceptible to overbank flow during 100-yr flood event.	May not include all floodplain structures that affect overbank flow access to floodplain area. Does not include backwater effects from bridges, embankments, etc.	Moderate to high risk during flood events.
Channel Migration	Areas showing 50-60 years of channel occupation, with modern channel buffered according to measured historic migration rates.	Does not include existing bank protection installations that may have arrested bank erosion. Assumes that all valley alluvium similarly is erosive.	Moderate to high risk during moderate to high flows.
Avulsion	Areas encompassing visible relict channels that appear to have sufficient access and continuity to pose a threat of channel capture.	Does not include human influences (e.g. diversion structures, ranch roads) that may effectively block side channels.	Low to moderate risk during flood events.

Table 1. Hazard Zone delineation basis, limitations, and relative level of risk.

1.5. Acknowledgements

This effort was performed through a contract between the Big Hole River Foundation and the DTM Consulting/Applied Geomorphology Project Team. Jeff Schahczenski, Executive Director of the Big Hole River Foundation was instrumental in providing contract management and facilitating communication between the authors and project sponsors. Planning representatives of four involved counties provided valuable input throughout the project process, including Doris Fischer and Ralph Hamler (Madison County), Rick Hartz (Beaverhead County), Russ Connole and John Sesso (Butte Silver Bow County) and Melinda Riley (Anaconda/Deer Lodge County). Noorjahan Parwana of the Big Hole Watershed Committee and Darrin Kron of Montana Department of Environmental Quality also provided valuable input. Mike Roberts of Montana DNRC provided cross section and flow data for use in the Inundation Model calibration. The project team extends its gratitude to all involved parties that facilitated this effort.

2. Geomorphic Setting

The hydrologic hazards associated with any given reach of the Big Hole River corridor directly relate to the geomorphic setting of that reach. The following description of the changing river conditions between the headwaters and Twin Bridges provides a context for correlating hazards with associated river processes. Unless otherwise noted, all of the graphics used to display examples of corridor conditions reflect 1995 aerial photography. The methods used to create the channel features shown on the figures are described in Chapter 4.1.

The headwater areas of the Big Hole River consist of relatively steep, historically glaciated drainages that flow through timbered uplands of the Beaverhead-Deerlodge National Forest. Approximately 10 miles south of Jackson, the river emerges into the upper Big Hole River Valley, which has been described is the "highest and widest of the broad mountain valleys of western Montana" (Alt and Hyndman 1986). Several major tributaries join the river in this valley, including Governor Creek, Warm Springs Creek, the North Fork Big Hole River, and Pintlar Creek. Through this broad, high elevation valley, the river flows through a sinuous willow corridor, commonly within a complex network of multiple low gradient channels. Numerous abandoned channel remnants are present on the floodplain, and some of these old channels have been converted to ditches. In many areas, such as just north of Wisdom, relic channels become more prominent in the downstream direction due to flow gains from tributaries, groundwater, and irrigation returns (Figure 2).

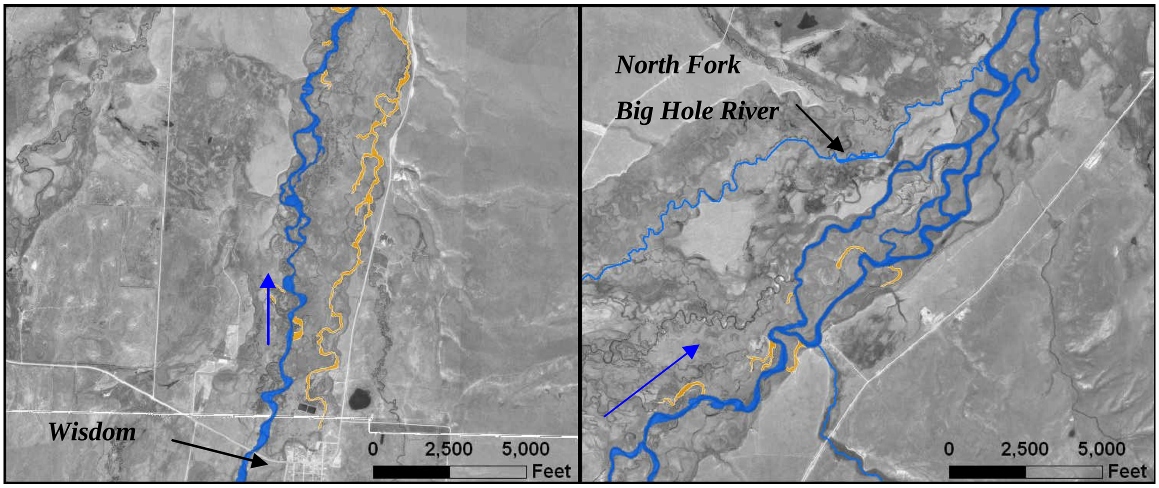

Figure 2. Big Hole River just north of Wisdom (left) and at the North Fork confluence (right) showing sinuous, multiple primary channel threads (blue) and relic channels (gold).

Between Mudd Creek and the Deep Creek confluence, the river turns northeastward, entering a narrow valley confined by Proterozoic rocks and Cretaceous granites. The southern valley walls are commonly densely forested (Figure 3, *left*). Highway 43 occupies the valley bottom and has locally isolated river floodplain areas. Where the valley locally widens, small, vegetated islands are common. The valley bottom widens to some extent between Deep Creek and Wise River. Within this reach, the river has increased floodplain access, although it is locally confined by bedrock as well as alluvial fans at the mouths of tributaries such as Alder Creek and Jerry Creek (Figure 3, *right*).

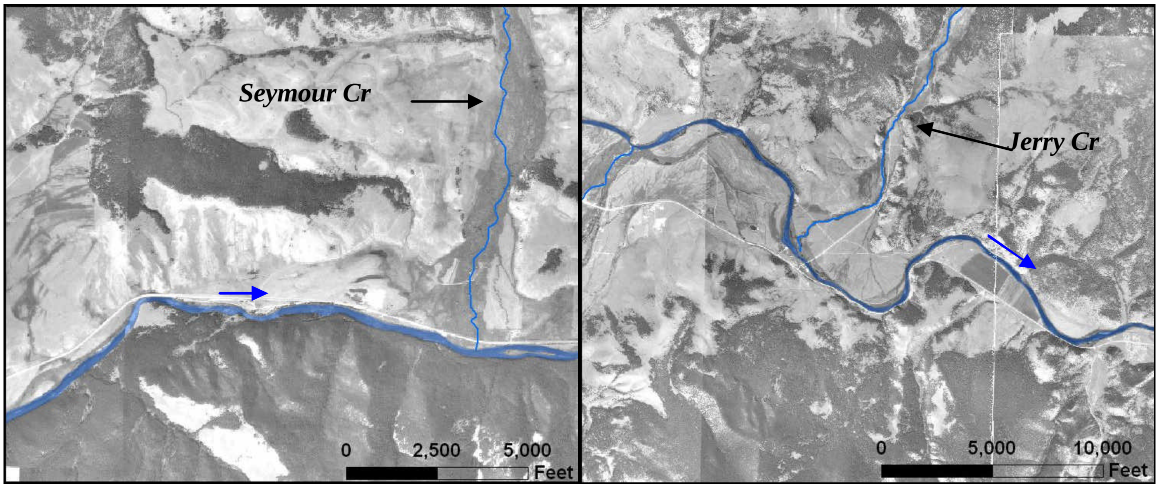

Figure 3 Confined reaches of the Big Hole River near Seymour Creek (left) and at the Jerry Creek confluence near Wise River (right).

Between Wise River and Divide, the river flows through a narrow canyon, in which there is much less floodplain access and irrigation extent relative to upstream. This reach is narrow with steep granitic valley walls (Figure 4, *left*). Highway 43 closely follows the river. Downstream of Divide Dam, just west of the town of Divide, the river remains moderately entrenched until it enters another narrow canyon section below the mouth of Divide Creek. This canyon reach has a narrow riparian corridor and dry, sparsely vegetated uplands (Figure 4, *right)*. Several mines in the canyon have historically supported underground phosphate mining and silica open pit mining. The canyon continues for several miles until the river valley abruptly broadens north of Melrose (Figure 5, *left*). Through Melrose, the Big Hole River flows through an open, heavily irrigated valley bottom that contains long sections of split flow through two main river channels.

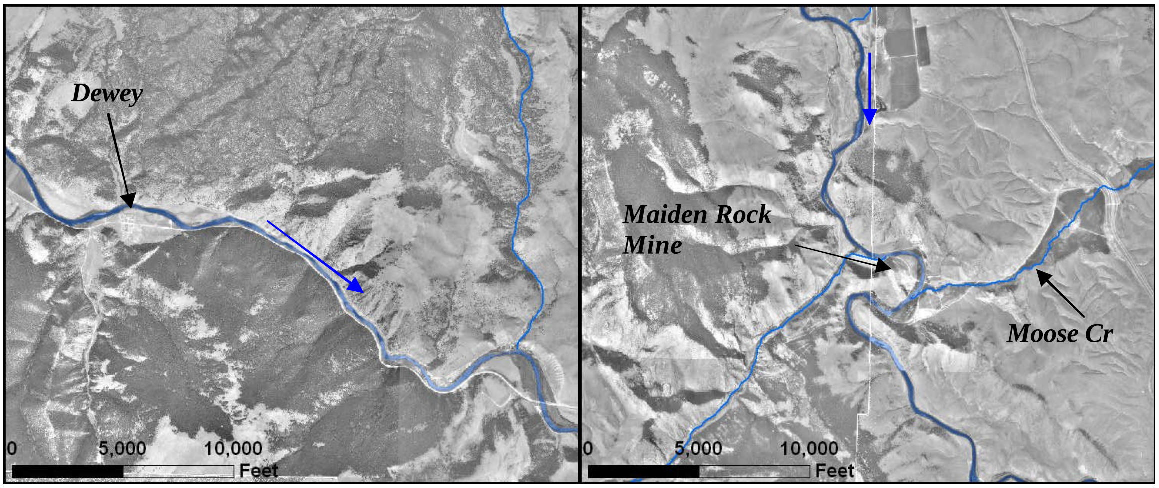

Figure 4. Big Hole River between Dewey and Divide (left) and south of Divide (right) showing channel confinement and single thread channel.

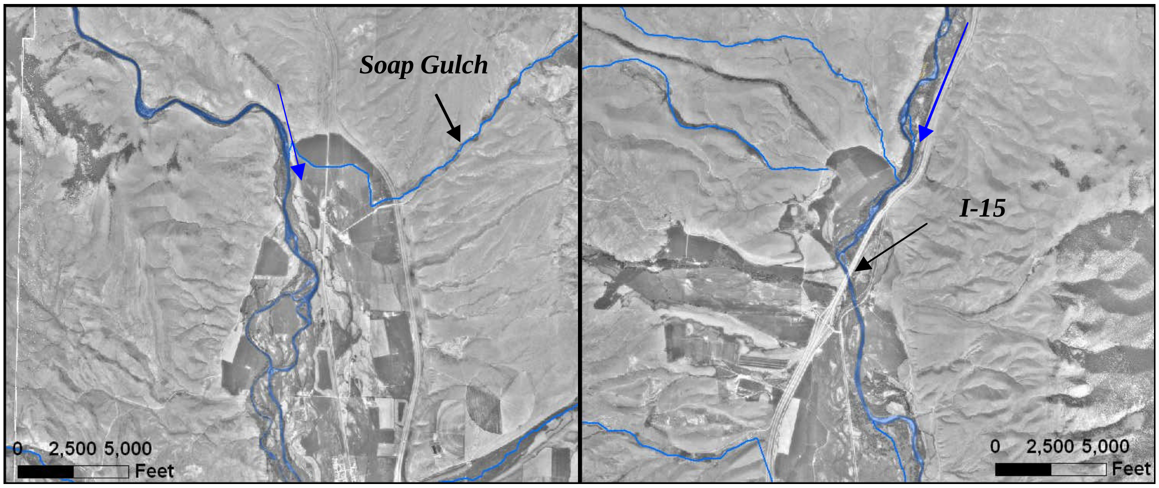

Figure 5. Big Hole River as it emerges from a canyon near Melrose (left) and as it widens downstream below I-15 (right).

South of Melrose, the Big Hole River flows through another confined, bedrock controlled reach to the I-15 Bridge (Figure 5, *right*). Within the reach, the river flows along volcanic rock outcrops on the margin of the narrow valley. From the interstate crossing to a prominent hogback ridge southeast of Glen, the river bottom is wide and multiple channel threads are common. This hogback ridge constitutes a major north/south geologic control that abruptly constricts the valley bottom (Figure 6). Upstream of this constriction, the Big Hole River corridor contains a network of channel threads and apparent groundwater sourced channels. This complex channel pattern potentially reflects the narrowing and shallowing of river alluvium at the constriction, and consequent upwelling of groundwater in the reach. Downstream of the geologic control, the river flows through a two broad valleys separated by similar, but less prominent geologic constrictions.

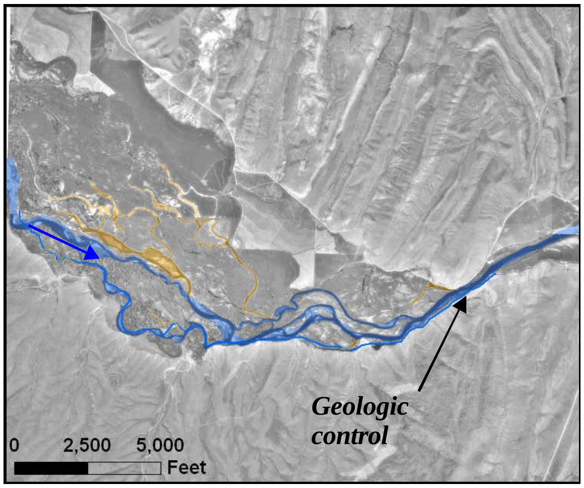

Figure 6 Big Hole River downstream of I-15 showing a major geologic structural control and resulting valley constriction.

From the lowermost geologic control, past Pennington Bridge to the High Road Fishing Access, the Big Hole River flows through a wide active meander belt with numerous floodplain channels and scars that reflect dynamic channel conditions. A network of sloughs parallels the channel as it approaches the Beaverhead confluence. Below the High Road Fishing Access, the Big Hole River is braided along its course to the Beaverhead River (Figure 7). Extensive split flows and unvegetated bars are present, and these conditions continue beyond the confluence, along the Jefferson River. Historic air photos indicate that the confluence with the Beaverhead was located several miles to the north of its current position in the early 1940's. Sloughs visible on topographic maps (e.g. Schoolhouse Slough, Owsley Slough) suggest that sometime prior to 1940, the Big Hole/Beaverhead confluence was located south of Twin Bridges. The complex channel patterns and recorded avulsions associated with the mouth of the Big Hole River indicate that the open, flat convergent zone between the Beaverhead and Big Hole River valleys has created a highly dynamic river environment.

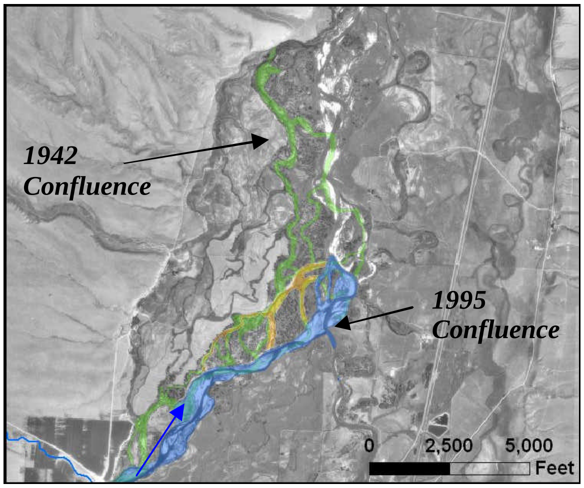

Figure 7. Mouth of the Big Hole River, showing a southerly shift in the confluence with the Beaverhead River from 1942 (green) to 1995 (blue).

Human influences on Big Hole River geomorphology are evident in the basin, especially where the valley bottom is wide and agricultural development is most extensive. Numerous diversion structures are present along and within the channels. Streambanks and floodplain areas have been cleared of riparian vegetation for agricultural use. Below Glen, several meanders appear to have been intentionally straightened to alleviate erosion problems on the valley margins (Figure 8). Along highways and at bridges crossings, the river corridor has been locally narrowed and fixed in place by erosion control measures.

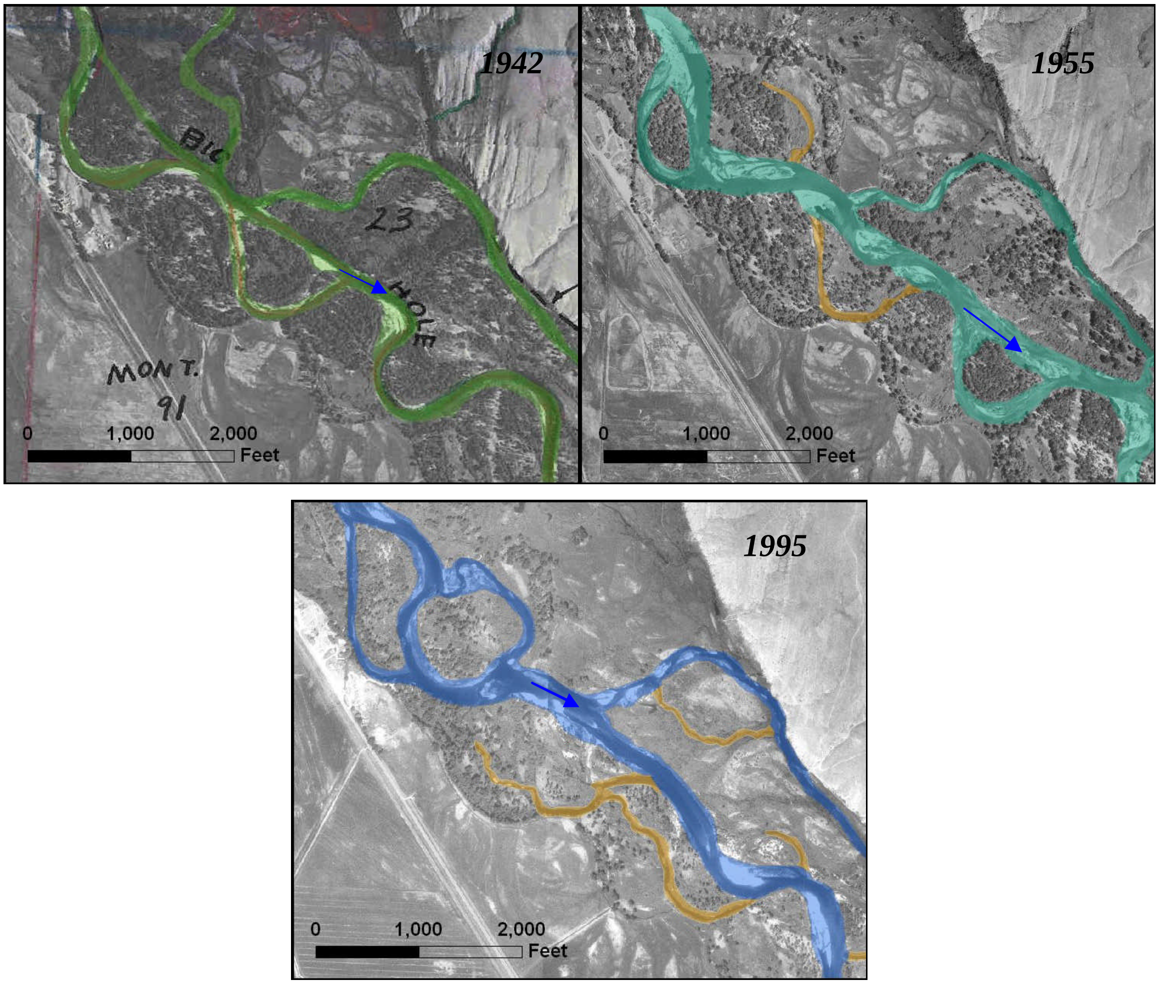

Figure 8. Big Hole River at Glen, showing 1942 bendway cutoffs (top left) and subsequent adjustment of channelized section from 1955 (top right) to 1995 (bottom). Primary channels are green/blue and relic channels are gold.

3. Inundation Corridor Development

An inundation model is a low-cost tool that can be used to identify flood-prone areas (Lear, et al, 2000). This study applies such a model to approximate the areas that are likely to be inundated during a 100-year discharge event. The model is not a replacement for a flood study performed to NFIP standards. In rural areas such as the Big Hole River, however, this approach can provide land use planners a screening tool to help identify areas where more detailed flood surveys are warranted.

The inundation corridor approach is a static model based upon digital elevation model (DEM) data. The general technique involves creating a flood surface based on cross sections extracted from the DEM, anticipated stage information from regional regression equations, and calibrating modeling results to existing data. Areas where the flood surface elevations exceed the underlying DEM ground surface elevations are identified as flood-prone. While anomalies in the DEM data, local structures, and the highly variable terrain complicate the model outputs, compelling results can still be developed.

3.1. Methods

The river course was segmented into coarse reaches based upon channel slope and confinement. This resulted in four primary model sections:

- Upper (North Fork to Pioneer Creek) – Broad valley bottom with little confinement. Genarally shallow slopes, except in the headwaters.
- Middle (North Fork to Silver Bow County Line) – Moderate confinement, with areas of wider floodplains. Generally shallow slopes.
- Silver Bow County – This section was previously mapped in the Flood Plain Management Study; Big Hole River; Silver Bow County, Montana (USDA, 1986). As such, it was primarily used to calibrate the model.
- Lower (Silver Bow County Line to mouth) – Generally broader valley bottom with local confinement. Some channel braiding, and lower average slope.

The sequential steps in the modeling process are as follows:

1. Define the model boundaries (e.g. valley wall)
2. Define cross section locations and generate 3-dimensional cross sections based on DEM data.
3. Estimate site-specific flood surface elevations from existing data.
4. Generate a continuous flood surface between cross sections using calculated flood surface elevations.
5. Intersect flood surface and DEM surface to identify areas of potential inundation.
6. Recalibrate the model to additional known data.

The model is based on intermittent empirical calibration of a planar surface rather than a step-backwater model such as HEC-RAS. As such, the results are limited in local areas of extensive backwatering, such as at bridges with extensive encroachment. However, the lateral extent of the model provides a highly cost-effective management tool for overall floodplain management efforts. The resulting inundation zone highlights areas that would potentially warrant more detailed NFIP-level hydraulic modeling in the event of proposed development.

3.1.1. Input Data Sources

The inundation model inputs include four kinds of data: Digital Elevation Models (DEM's), aerial photography, surveyed cross sections, and hydrologic data. The types, resolutions, and accuracy of the available data vary throughout the basin. Certain areas, such as the Silver Bow County section, have detailed cross section and hydrologic data. Upstream in the Big Hole Valley, only photographic and intermittent flow data exist. This creates a need to blend a variety of modeling techniques together to develop a composite flood prone area boundary. Each data source and its use are discussed below.

Digital Elevation Models (DEM)

DEMs serve as the primary elevation data source for this model. Three DEM sources exist for the Big Hole River. The most common is the USGS 30-meter DEM. These DEMs typically show a large number of processing errors and are often out of date, not showing recent development activity or topographic modifications. The second DEM source is the USGS 10-meter DEM. While the spacing of elevation points is much closer for these DEMs, they are still subject to the same errors as the 30-meter versions. In rural areas, the processing of the 10-meter DEMs often shows a distinctive 'stepping' of elevations in areas of low slope. This results in confusing artifacts that limit its use as an elevation data source. The final available DEM source is the SRTM (Shuttle Radar Topographic Mission) 30-meter DEM. The elevation data for this DEM comes from a single Space Shuttle mission in February 2000. The resulting DEM is very consistent, has few anomalies, and shows modern modifications to the topography.

This project evaluated each of the three DEM sources before adopting the SRTM data set for modeling purposes.

Using the relatively course 30-meter DEM data has certain disadvantages when modeling a river such as the Big Hole. Most importantly, in many areas the Big Hole River occupies topographically subtle channels in open valleys. There are often adjacent relic channels that have been recently abandoned. With the exception of the confined canyon reaches, the river leaves its banks at relatively common flow events and spills out onto the adjacent flat floodplain, commonly conveying floodwaters through historic channels (see Section 3.1.2).

Aerial Photography

1995 Digital Orthophoto Quads (DOQs) served as the primary photographic data source for the floodplain modeling. These were used to visually identify topographic features such as terraces, bedrock, and transportation infrastructure that define the river corridor margin. Where necessary, digital topographic maps were consulted to help identify that margin. The DOQs were also consulted to confirm the modeling results.

In June of 1997, the Big Hole River experienced an approximate 25-year flood event. This event was captured with black and white aerial photography just past the peak flow on June 12, 1997, from Twin Bridges to Sportsmans Park Campground. The water surface elevations between the 25-year event and the 100-year event amount to less than a foot in most areas of the Big Hole River (USDA, 1986). As such, the inundated and saturated areas captured in the 1997 flood photography serve as a preliminary approximation of a major flood event. These flood photographs were scanned and georeferenced in the project GIS. The floodwater extents were then digitized and used to help calibrate the inundation model for the lower river.

Cross Sections

Detailed cross section data was available for Silver Bow County, Meriweather Ranch, and several locations in the middle and upper sections of the river. These were critical for estimating flow depths along the river when creating the flood surface. The Silver Bow County data also includes calculated flood surface elevation for each cross section location. These elevations, as well as the analytical results discussed in Section 3.1.2 provide another means of calibrating the model.

Existing Flood Studies

In 1986, the USDA Soil Conservation Service, in cooperation with Silver Bow County, produced the Flood Plain Management Study for the Big Hole River in Silver Bow County. This study provides detailed flood surface elevations at various flows from Melrose upstream to near Dickie Bridge. The study also contains detailed 100-year Floodplain and Floodway boundaries and 500-year Floodplain boundaries. These boundaries were provided to the project team as a CAD file and imported into the GIS. The registration of this CAD data layer is suspect in some places and in some places does not match well with existing 1995 orthophotography. These boundaries, as presented in the 1986 report, are assumed to be more accurate than the inundation modeling in this study. As such, they are used to define the floodplain boundaries for the Silver Bow County portion of this study.

The other existing floodplain study that was available to the project team is a detailed study for the Meriwether Ranch north of Melrose. This study was conducted as part of the subdivision review process. The detailed floodplain boundaries were provided as a CAD data layer and brought into the GIS. These boundaries were adopted by this study as the best available and supercede the 1986 study discussed above.

The project team is aware of at least one other detailed floodplain study in the project area, though at the time of writing, this study was not available.

3.1.2. Estimation of Flow Depths at Surveyed Cross Sections

In the upper portion of the project area, we estimated the flow depth associated with a 100-year discharge event at five locations. This effort included acquiring and extending existing cross sections, estimating the flood frequency discharges at each cross section, and analyzing the cross section hydraulics. The hydraulic analysis results contain an estimation of the floodplain water depth for a broad range of discharge events.

The surveyed cross sections, provided by the Montana Department of Natural Resources and Conservation (DNRC), are located near the Little Lake Creek Bridge, Miner Creek Bridge, Wisdom Bridge, Mudd Creek Bridge, and Dickie Bridge. These cross sections included station/elevation data for the main channel, as well as a stage/discharge measurement at each cross section. The cross sections provided were typically surveyed to the top of bank and not onto the adjacent floodplain. In order to capture the floodplain area, the cross sections were extended laterally using coarse topographic data from USGS

1:24,000 topographic maps. In general, each cross section was extended as a relatively low, flat floodplain to provide a conservative estimate of inundation depths at high flow. The average slope of the cross section was derived from available maps and DNRC input (Mike Roberts, personal comm., 2005).

At each surveyed cross section location, the 100-year discharge was estimated based upon regional regression equations developed for the area (Parrett and Johnson, 2004). The equation utilized to estimate the 100-year discharge is as follows:

$$Q_{100} = 351A^{0.682}(E_{6000}+1)^{-0.476}\text{, where}$$

Q_{100} = 100-year peak flow
A= drainage area
E_{6000}= percentage of basin above 6,000 feet in elevation

The estimated 100-year discharges based on regional regression analysis range from 6462 cfs at Miner Creek Bridge near Jackson to almost 39,000 cfs at Dickie Bridge (Table 2).

In order to estimate the 100-yr flow depths at each cross section, an at-a-station hydraulics package (WinXSPRO) was used to estimate the discharge values associated with a range of flow depths. WinXSPRO performs a single cross section analysis using a resistance equation approach (e.g. Manning's equation), and hence does not address backwater effects caused by influences such as channel irregularities, road embankments or bridges. In areas of low slope where backwatering is likely, the depth/discharge relationships will tend to be conservative. The development of a relatively conservative water depth was considered appropriate for the inundation modeling to allow regional application of relatively consistent flow depths.

The hydraulic analysis requires an estimation of channel roughness (Manning's n value). For the channel environment, this value was derived from field discharge measurements provided by DNRC. Floodplain roughness values were estimated using methods defined in Arcement and Schneider (1990).

The results of the hydraulic analysis provide a general idea of 100-year flow conditions on the upper and middle reaches of the Big Hole River. Most importantly, results indicate that the channel capacity is significantly less than the 100-year discharge. At four of the five cross sections, the channel capacity is on the order of the 2-year flood event. These results show that at a 100-year flow event, the majority of river flow is out of bank and accessing floodplain area. Secondly, the results suggest that during an estimated 100-yr event, floodplain water depths are on the order of 4 feet. This estimate indicates that there is sufficient water spilled on the floodplain to apply the inundation model as a topographic assessment of flood prone area, rather than a hydraulic assessment of complex flow paths.

Site	***Drainage Area (sq miles)***	***Channel Capacity (discharge)***	***Channel capacity (return interval)***	***Estimated 100-year Discharge (cfs)***	***Estimated floodplain inundation depth (~100-yr flow)***
Miner Creek Bridge	116	1102	<Q10	6462	3.2
Little Lake Road Bridge	380	216	<Q2	14528	3.2
Wisdom Bridge	591	916	~Q2	19607	4.0
Mudd Creek Bridge	1274	1806	~Q2	33283	4.3
Dickie Bridge	1603	1942	~Q2	38971	8.0

Table 2. Estimated floodplain water depths at surveyed sections for a 100-year discharge.

3.1.3. Model Calibration

Model calibration is based on a variety of techniques, depending on site location and calibration data availability. The goal was to create a model that closely represented available existing data. The model cross sections were placed at approximately ¼-mile intervals and sized such that they extended slightly past the valley bottom margins. This ensured that the modeled areas of inundation were not artificially truncated by the model boundary (Figure 9). In areas such as the upper Big Hole Valley and the mouth, this resulted in long cross sections in order to capture slit flows and relic channels.

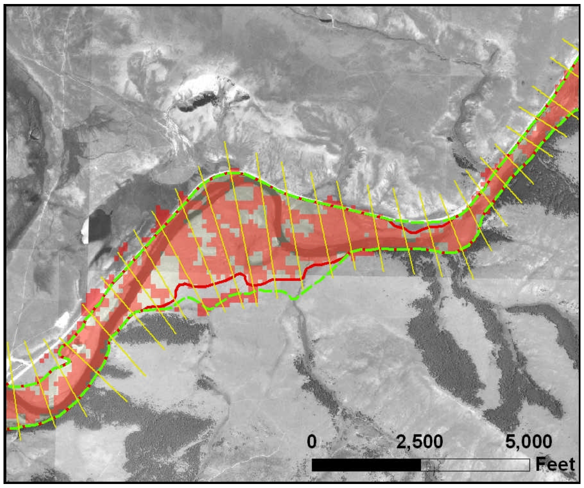

Figure 9. General model structure showing cross section locations (yellow) extending beyond the valley bottom margins (green).

In the upper basin, upstream from the confluence with the North Fork of the Big Hole River, the flow depths calculated from the DNRC cross sections (Section 3.1.2) were utilized to create the flood surface. This resulted in creating a flood surface that ranged from 3.5 to 5.1 feet above the base elevation for each model cross section location.

From the North Fork confluence to the Butte/Silver Bow County line, flow depths were also derived from the DNRC cross section data. Here the flood surface elevations were raised from 5.1 to 8.8 feet above the cross section base elevations. The greater depths generally equated to areas with increased channel constrictions from the valley walls.

Flood boundaries within Silver Bow County were previously mapped as part of the 1986 Flood Plain Management Study (USDA, 1986). This study contains the best available floodplain information for the Big Hole River, making it ideal for testing and evaluating the model results. A model was created for this section of river using water surface elevations provided in the 1986 report. The modeled areas of inundation developed for this study closely follow those identified as within the 100-year floodplain in the flood study (Figure 10).

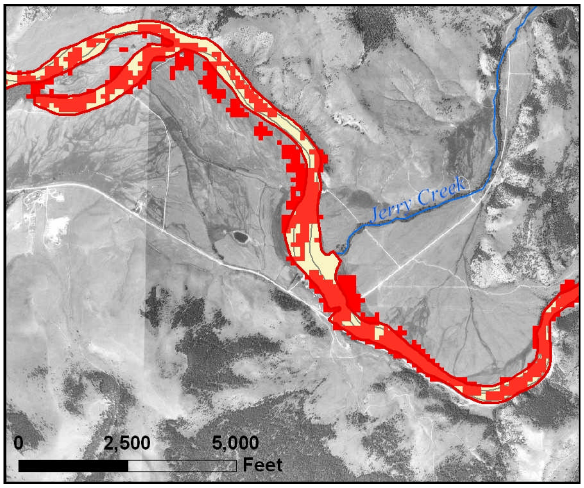

Figure 10. Model calibration below Dickie Bridge. Red areas represent modeled areas of inundation. Yellow polygon represents Butte/Silver Bow County Flood Plain Management Study floodplain.

The lower river, below Melrose, has very little available cross section information. The best source for model calibration for this section is the 1997 flood aerial photography. This section of river also shows the greatest variability in river form, open valley, split flows, and constricted areas. The lack of available empirical data and high variability necessitated numerous model runs in order to calibrate the model.

3.2. Results

The results of the Inundation Corridor development are presented in Map Sheets 1 and 2 included in this report. The corridor represents areas of likely inundation during a 100-year discharge event. The flood prone areas reflect three major types of flood hazard. First, much of the river is contained within well-defined valley walls, terraces, or infrastructure (Figure 11). In these areas, the river will experience increased flood depth, but very little flooding extent.

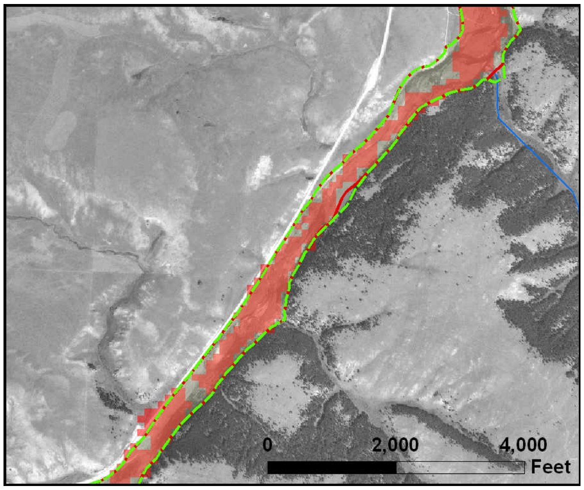

Figure 11. Confined river section showing well-defined inundation zone (red) within the valley bottom margins (green).

In the second type of hazard area, large sections of the river are poorly confined (Figure 12). In these areas, the river has historically occupied a variety of channels. Overbank flows occur at relative frequent, <5 year, flood events. These areas are subject to shallower flow depths, but will likely cover large horizontal extents during a major flood. Although the specific location of floodwater accumulation is difficult to pinpoint as one progresses away from the primary channel, the model does identify general areas of likely inundation.

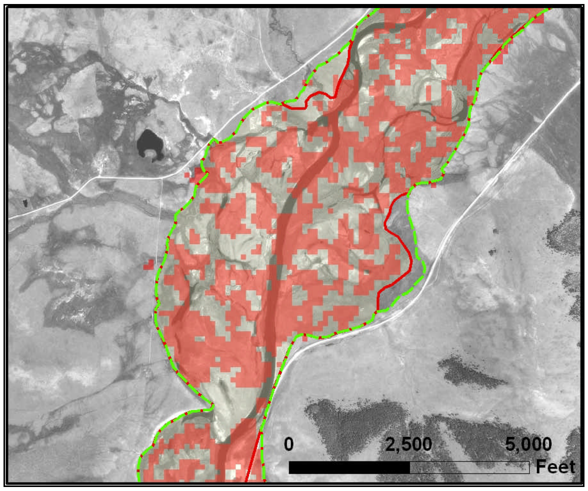

Figure 12. Unconfined river section showing a typical shallow inundation zone (red) loosely contained within the valley bottom (green).

Finally, in some areas, a secondary inundation zone was delineated where there is some indication of likely inundation, but the modeling results are more variable (Figure 13). These areas include several locations in the Upper Big Hole Valley, and the final section of river below Notch (Figure 14). These areas are associated with wide, flat valley bottoms where the river has historically occupied numerous channels. The relic channels are generally separated from the active channel by subtle topographic features, but may receive overbank flow in a large flood event. Some areas indicate elevated avulsion potential, because they appear to concentrate overflows into a historic or relic channel.

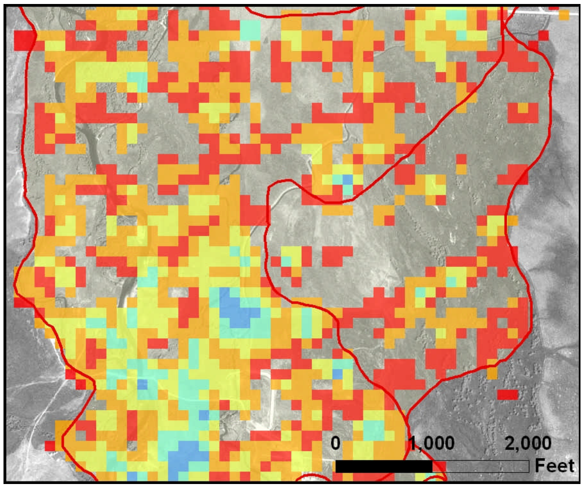

Figure 13. Secondary inundation zone (right), upper Big Hole Valley.

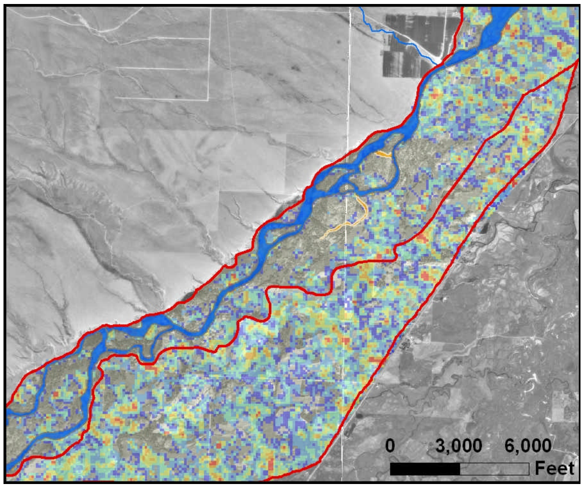

Figure 14. Subtle topography near river mouth creates potential for large scale river relocation into historic channels in the event of a major runoff event.

4. Channel Migration Zone (CMZ)

The Big Hole River Channel Migration Zone (CMZ) is a delineation of past, current, and anticipated zones of active bank erosion and channel movement. The Big Hole River CMZ is defined as the combined area that includes:

- the active channel location approximately 50-60 years ago;
- the 1995 channel location; and,
- a buffer width applied to the 1995 channel boundaries based on measured historic migration rates.

The result is a composite zone of historic channel locations, with variable buffer widths on the 1995 channel margins that reflect the relative lateral migration rates of individual river reaches.

4.1. Methods

The CMZ was developed in the GIS environment. Individual banklines were first digitized on the georeferenced aerial photography. Those banklines were then converted to zones (polygons) to show channel occupation areas. Buffers were developed to reflect measured historic rates of lateral migration within individual river reaches, and these buffers were added to the 1995 channel zone. Where the channel migration zone split into two or more active channels, the intervening “islands" were included in the zone if they were less than 10 acres in size. Larger islands were not included in the CMZ. Buffer areas extending beyond the valley margin were clipped from the CMZ. The composite CMZ was then merged into a single GIS polygon that includes the historic channel areas and the 1995 buffer zone.

4.1.1. Channel Boundary Digitization

The historic and modern (1995) positions of the Big Hole River were determined through a GIS-based analysis of aerial photography. The primary historic photo set utilized in the historic channel assessment was from 1955 (Figure 15). These photos were supplemented by 1942 and 1951 photos to fill a few gaps in coverage. All of the historic photographs were scanned and rectified into the project GIS. The modern channel was mapped using 1995 Digital Orthophoto Quads (DOQs), which are readily available for the entire project area.

Channel banklines were digitized to record the normal high water channel boundaries (Figure 16 and Figure 17). The 1942, 1955, and 1995 photos were digitized at a scale of 1:3,000; the 1951 photos were of lower quality, and were digitized at 1:5,000. The normal high water mark was typically identified by the transition from open bar area or water to woody riparian vegetation. Where woody riparian vegetation is not present in the river corridor, the boundaries were defined using supplemental indicators such as water lines, depositional bars and contrast changes in herbaceous vegetation.

The following features were digitized as ***active channels***, and are shown as ***green, teal, or blue*** in report figures:

- Continuous ***primary channels*** that convey the majority of flow during low flow conditions;
- Continuous ***side channels*** that constitute at least 1/3 of the main channel width;
- ***Active chute*** channels that reflect active meander cutoff through a secondary channel across a meander core; and,
- ***Oxbows*** (relict meander cutoffs) that maintain low flow continuity with the main channel.

The resulting mosaic of historic channel locations forms the foundation for the CMZ delineation. Additonally, ***relic channels*** were digitized to help identify floodplain swales, abandoned channels, and flood conveyance channels. These features were digitized only if they displayed continuous surface water segments that had some continuity with the main channel. These relic channels are depicted in ***gold*** (Figure 17) in report figures. Relic channels were not included in the CMZ, but were treated as areas of potential channel avulsion (Chapter 5).

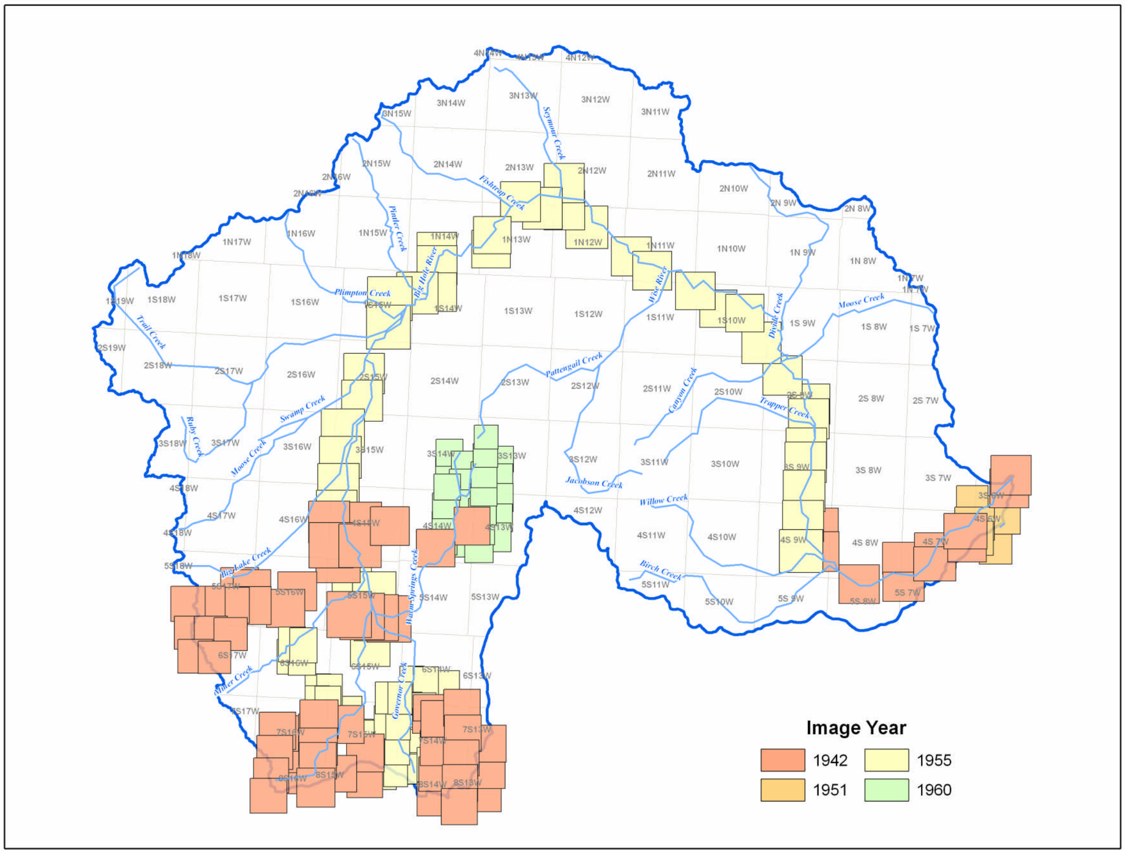

Figure 15. Index map of archived Big Hole River Historic Air Photos held by DTM Consulting, Inc.

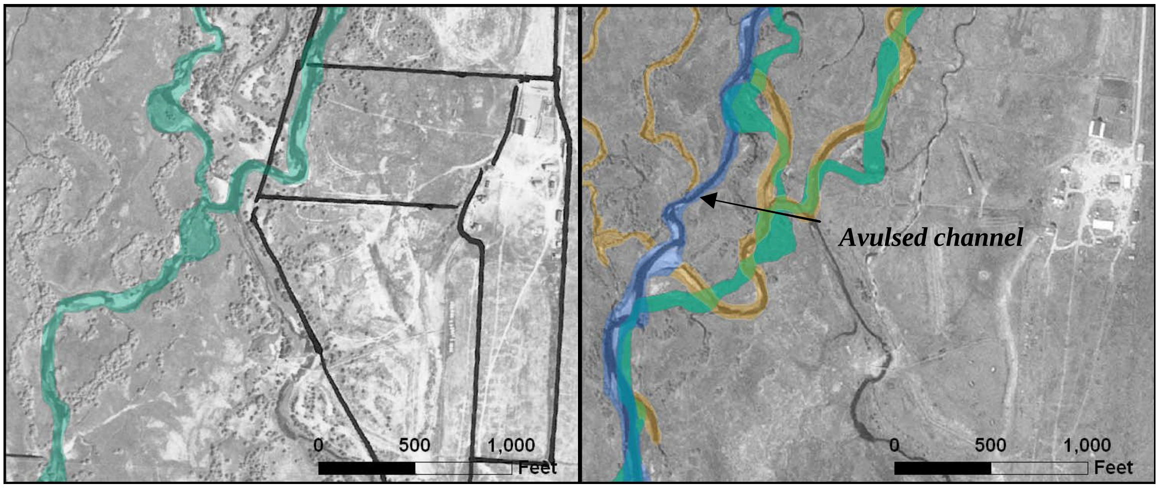

Figure 16. Big Hole River upstream of Wisdom showing 1955 channel in green (left) and 1995 channel in blue (right). Note new 1995 channel course caused by avulsion.

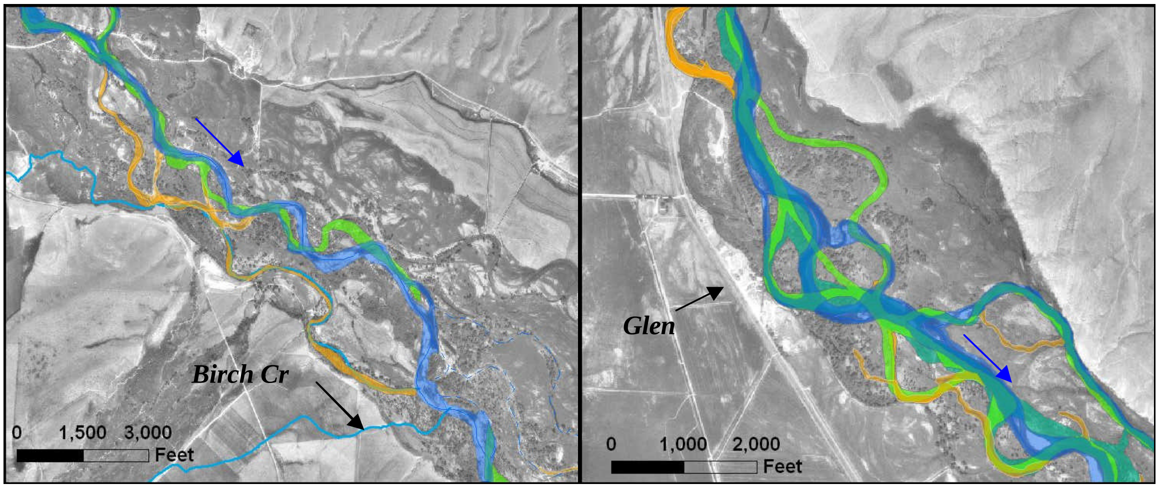

Figure 17. Big Hole River near Glen, showing digitized 1942 (green), 1955 (teal), 1995 (blue) active channels and relic (gold) channels.

4.1.2. Buffer Zone Development

The composite corridor that encompasses 50-60 years of channel occupation provides the foundation for the Big Hole River CMZ. However, in some places the channel is actively migrating beyond that corridor margin. As such, the future location of the CMZ will potentially change as the channel continues to move laterally. In order to address anticipated future migration beyond the historic corridor boundary, a supplementary buffer zone has been added to the 1995 channel boundaries. This buffer consists of an area beyond the 1995 channel boundary that is considered prone to channel occupation over the next 50 years. In determining the buffer widths, historic erosion rates are used to estimate future anticipated migration distances. As the erosion rates of the Big Hole River vary between areas, the buffer widths vary as well.

The development of a spatially variable buffer zone required the segmentation of the Big Hole River into geomorphic reaches and a geomorphic characterization of each reach. This effort built on previous TMDL-planning related efforts of the project team, which includes two aerial assessment reports on Big Hole TMDL Planning Areas (CCI, et al, 2003; AGI and DTM, 2005). As part of these aerial assessments, the main stem of the Big Hole River was subdivided into 50 reaches from upstream of Jackson to the river mouth. The reach breaks reflect changes in channel form, land use, riparian health, and potential indicators of stream impairment. Each reach was geomorphically classified, and described in terms of its geomorphic features, riparian condition, bounding geology, and land use.

The reach delineation developed in the aerial assessments was used to develop buffer zones. Within each reach, historic and recent channel locations were compared, migration distances were measured, and average annual rates of bank movement were calculated. Bankfull topwidths were also measured for each reach. Based on the relationship between migration rate and channel topwidth, each reach was categorized in terms of its severity of bank retreat. The erosion severity categories range from very low to very high. Buffers were then developed by applying a severity-based multiplier to the measured topwidth (Table 3). Relating the buffer to topwidth allows the buffer to increase in size in the downstream direction along with the channel. The multipliers range from 0.2 (20% of channel topwidth) to 2 (200% of the channel topwidth), and these values were developed to accommodate approximately 50 years of channel migration in a buffer zone. The results of these measurements are tabulated in Appendix A[2].

Where there is no measurable migration over the last 50 years, such as in the canyon above Divide, a minimal setback of 20% of the channel width was adopted to provide for bankline riparian integrity and associated maintenance of bank stability.

Relative Migration Rate	***Multiplier (Number of channel widths in buffer)***
Very Low	0.2
Low	0.5
Moderate	1.0
High	1.5
Very High	2.0

Table 3. Migration rate categories and associated buffer widths, Big Hole River

4.2. Results

The CMZ zone, in its entirety, is shown on the Map Sheets 1 and 2. The zone depicts the area that, based on historic channel location and migration rates, is susceptible to bank erosion over the next 50 years. In some areas of relatively active channel migration, the

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[2] For a complete discussion of reach locations and assessment, refer to the aerial assessment documents developed for TMDL planning efforts in the Big Hole River Watershed (CCI, et al, 2003; AGI and DTM, 2005).

buffer zones provide a relatively wide corridor to accommodate that activity (Figure 18). In some areas where bank line migration is not discernable from historic photos, there is little difference between the 1995 channel course and the ultimate CMZ (Figure 19). Although the CMZ includes the active channels and a calculated buffer, it does not necessarily include relic channels that show connectivity with the main channel (Figure 19 and Figure 20).

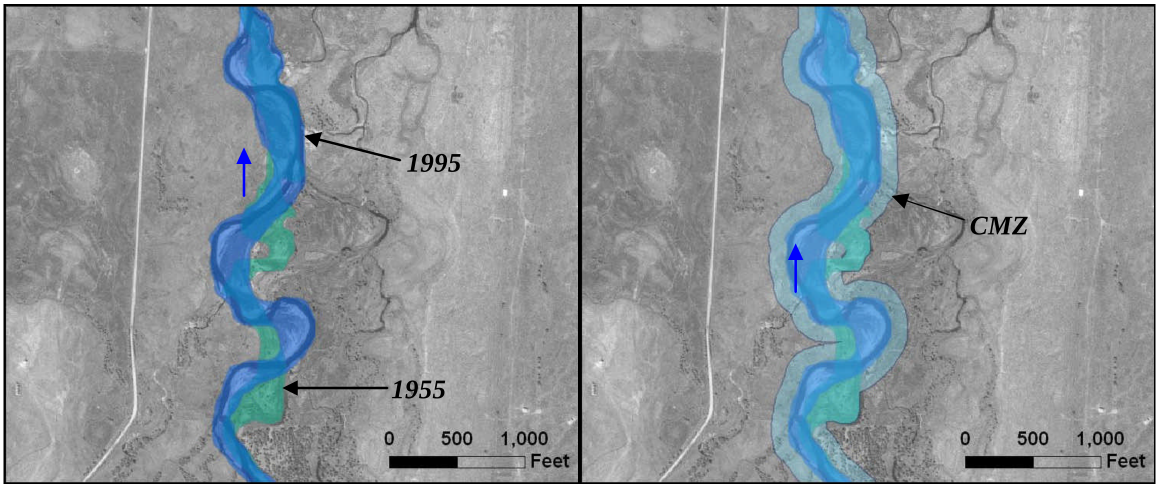

Figure 18. 1995 (dark blue) and 1955 (green) channels on the Big Hole River south of Wisdom. Image on right shows buffered 1995 channel and composite CMZ zone.

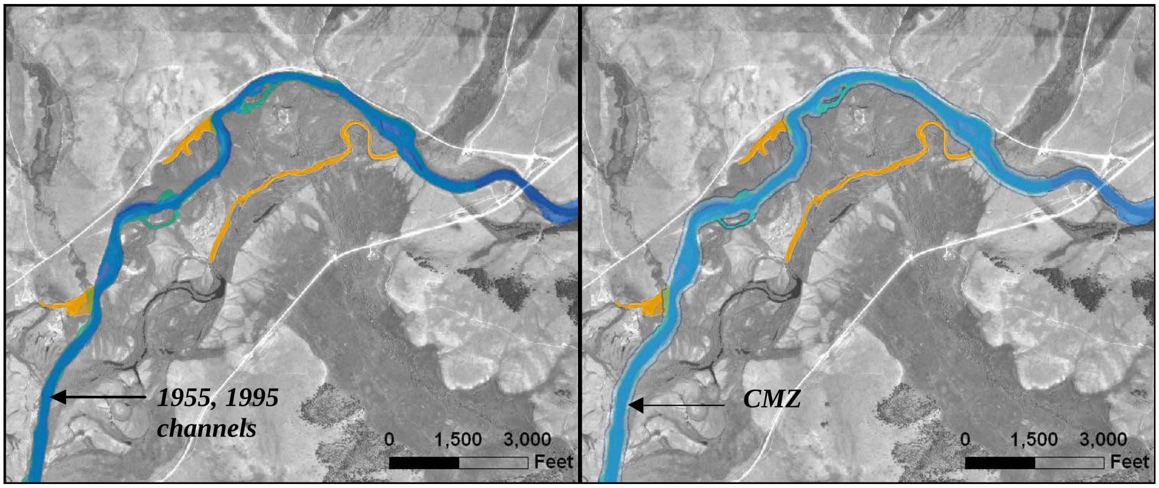

Figure 19. 1995 (dark blue) and 1955 (green) channels on the Big Hole River at Mudd Creek Bridge. Potentially avulsive channels are shown in gold. Image on right shows buffered 1995 channel and composite CMZ zone.

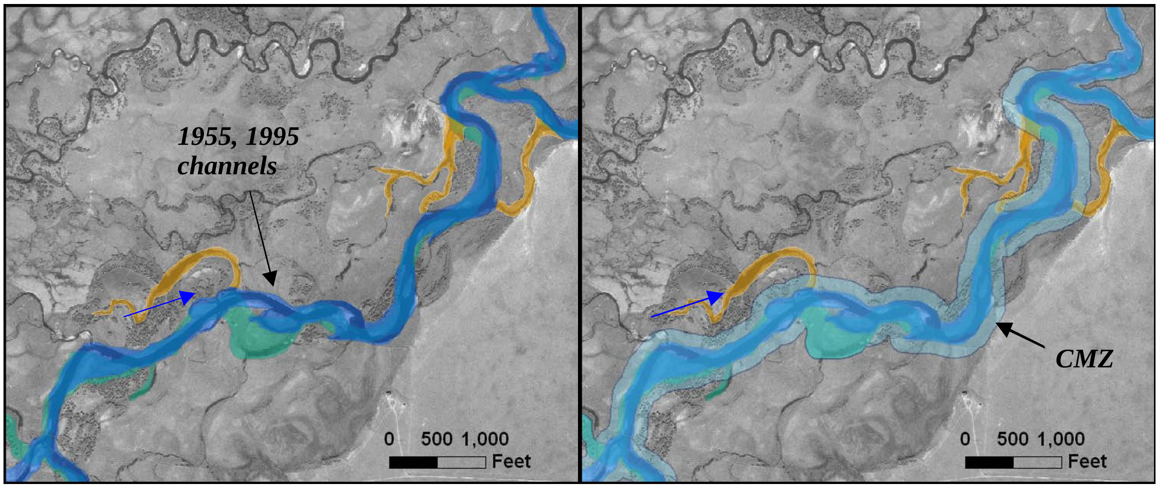

Figure 20. 1995 (dark blue) and 1955 (green) channels on the Big Hole River south of Wisdom. Potentially avulsive channels are shown in gold Image on right shows buffered 1995 channel and composite CMZ zone.

5. Avulsion Potential Zone (APZ)

The Big Hole River is a multi-channeled system along much of its length. The channel migration zone mapping shows that the river has historically "jumped" channels, or avulsed. This natural process creates additional risk of bank erosion within the river corridor. To address this risk, a separate Avulsion Potential Zone (APZ) has been delineated for the project reach.

5.1. Methods

The APZ was developed by modifying the CMZ boundary to incorporate floodplain channel features and CMZ island areas. Specific features included in the zone are:

- The CMZ;
- Areas within split CMZ zones ("CMZ islands");
- Discernable floodplain channel remnants that are within the inundation potential zone; and,
- Floodplain channels that appear to be used as ditches, but connect to the river on both their upstream and downstream ends.

In many areas, the floodplain area contains abandoned channel remnants that do not flow under normal conditions. Many of these relic channels are disconnected from the primary channel on their upstream end, but contribute flow to the mainstem on their downstream end. These relict channels commonly enlarge in the downstream direction due to groundwater gains, tributary input, and/or irrigation return flow (Figure 2). Where these channels gain flow from these sources, and do not have low flow continuity with the main channel on their upstream end, they were not included in the migration zone. However, these channels were included in the Avulsion Potential Zone.

5.2. Results

The APZ is shown on the Map Sheets 1 and 2. The zone depicts a relatively broad swath of valley bottom that commonly extends well beyond the CMZ (Figure 21). Where the channel is highly confined, the APZ is predictably narrow (Figure 22). Where the valley is wide, the APZ width may vary depending on the extent of visible floodplain features (Figure 23). At the mouth of the Big Hole River, the zone is especially wide to accommodate a multitude of side channels and sloughs (Figure 24).

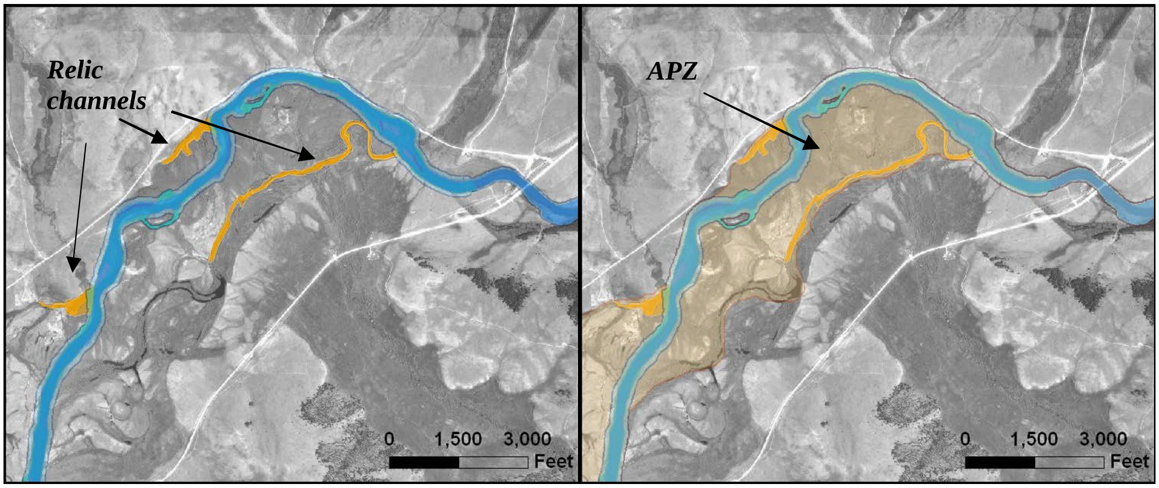

Figure 21. Big Hole River at Mudd Creek Bridge, showing CMZ (left) and APZ (right).

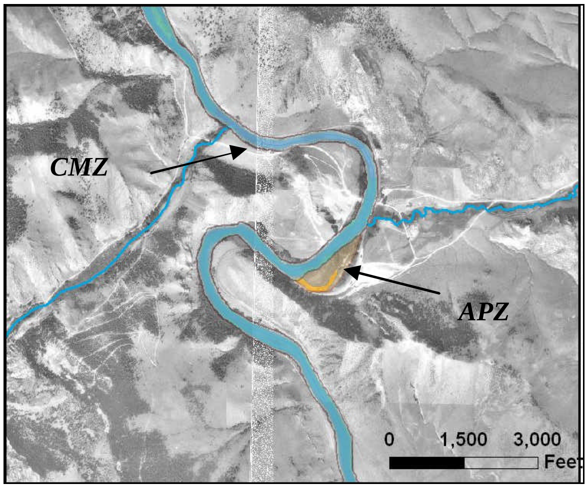

Figure 22. Big Hole River at Maiden Rock Mine, showing narrow CMZ and APZ.

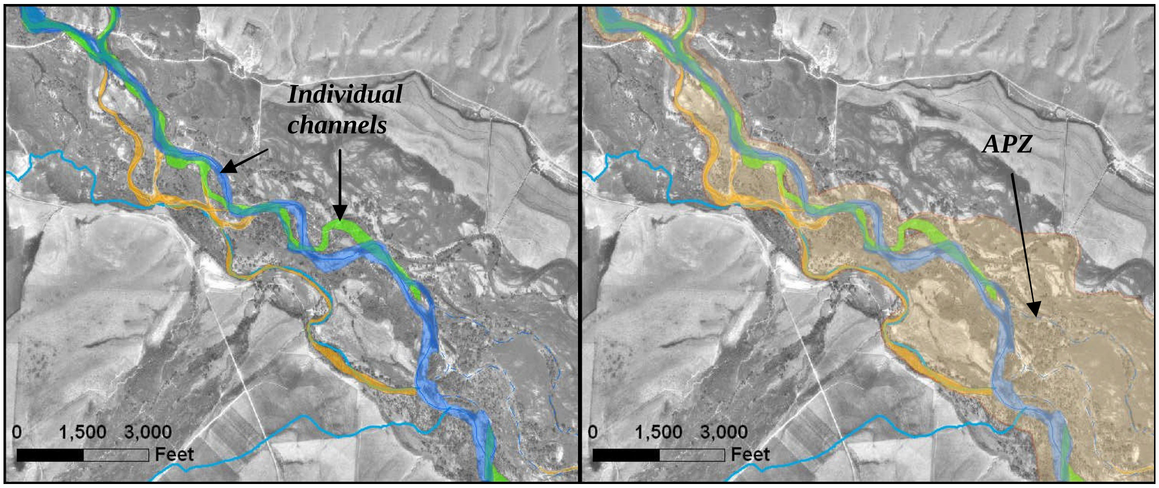

Figure 23. Big Hole River at Birch Creek confluence showing composite channels (left) and APZ (right).

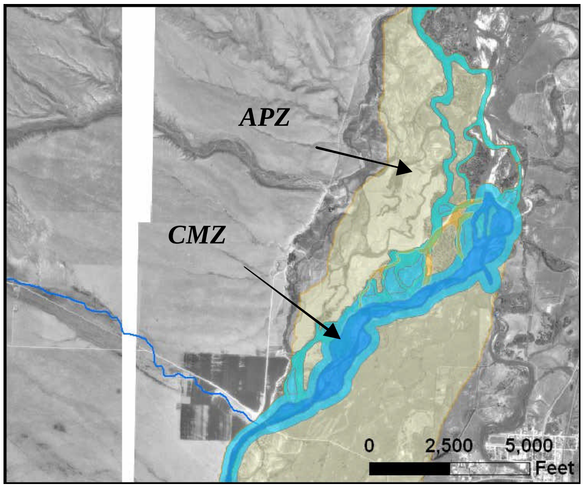

Figure 24. CMZ (blue) and APZ (yellow) at mouth of Big Hole River showing wide swath of continuous sloughs and side channels.

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Appendix A

Measured Migration Rates and Applied Buffer Widths

Reach locations are included in project GIS database.

Reach	*Stream Channel Type*	*Approximate Channel Width (ft)*	*Historic Bendway Migration Distance (ft)*	*Average Migration Rate (ft/yr)*	*Relative Average Migration Rate*	*Historic Photo Date*	*Recent Photo Date*	*Buffer Width Multiplier (widths)*	*Buffer Width (ft)*
BH12	C/E	20	40	1.0	High	1955	1995	1.5	30
BH13	C	20	40	1.0	High	1955	1995	1.5	30
BH14	C/E	20	30	0.8	High	1955	1995	1.5	30
BH15	C	20	40	1.0	High	1955	1995	1.5	30
BH16	C	20	40	1.0	High	1955	1995	1.5	30
BH17	C	50	90	2.3	High	1955	1995	1.5	75
BH18	Da/C	50	80	2.0	High	1955	1995	1.5	75
BH19	C	60	240	6.0	V. High	1955	1995	2	120
BH20	Da	60	120	2.3	V. High	1942	1995	2	120
BH21	C	60	230	4.3	V. High	1942	1995	2	120
BH22	Da	60	250	4.7	V. High	1942	1995	2	120
BH23	C/D	60	300	7.5	V. High	1955	1995	2	120
BH24	Da/C	60	175	4.4	V. High	1955	1995	2	120
BH25	C	60	160	4.0	V. High	1955	1995	2	120
BH26	Da/C	75	175	4.4	V. High	1955	1995	2	150
BH27	Da/C	75	150	3.8	V. High	1955	1995	2	150
BH28	Da	50	N/A	N/A	N/A	1955	1995	2	100
BH29	Da/C	75	175	4.4	V. High	1955	1995	2	150
BH30	C/Da	75	100	2.5	High	1955	1995	1.5	113
BH31	C	90	100	2.5	High	1955	1995	1.5	135
BH32	Da	100	20	0.5	V. Low	1955	1995	0.2	20
BH33	C/Da	150	20	0.5	V. Low	1955	1995	0.2	30
BH34	B	150	0	0.0	V. Low	1955	1995	0.2	30
BH 35	C	175	N/A	N/A	V. Low	1955	1995	0.2	35
BH 36	C/Da	180	100	2.5	Low	1955	1995	0.5	90
BH 37	C	150	0	0.0	V. Low	1955	1995	0.2	30
BH 38	F	150	0	0.0	V. Low	1955	1995	0.2	30
BH 39	C	150	50	1.3	Low	1955	1995	0.5	75
BH 40	F	200	0	0.0	V. Low	1955	1995	0.2	40

Reach	**Stream Channel Type**	**Approximate Channel Width (ft)**	**Historic Bendway Migration Distance (ft)**	**Average Migration Rate (ft/yr)**	**Relative Average Migration Rate**	**Historic Photo Date**	**Recent Photo Date**	**Buffer Width Multiplier (widths)**	**Buffer Width (ft)**
BH 41	F	200	0	0.0	V. Low	1955	1995	0.2	40
BH 42	C/Da	200	N/A	N/A	V. Low	1955	1995	0.2	40
BH 43	F	200	0	0.0	V. Low	1955	1995	0.2	40
BH 44	C	200	0	0.0	V. Low	1955	1995	0.2	40
BH 45	C/F	200	0	0.0	V. Low	1955	1995	0.2	40
BH 46	F	200	0	0.0	V. Low	1955	1995	0.2	40
BH 47	C/F	190	0	0.0	V. Low	1955	1995	0.2	38
BH 48	F	200	0	0.0	V. Low	1955	1995	0.2	40
BH 49	Da	140	90	2.3	Low	1955	1995	0.5	70
BH 50	C	150	210	5.3	Mod	1955	1995	1	150
BH 51	C	175	140	3.5	Mod	1955	1995	1	175
BH 52	Da	175	140	3.5	Mod	1955	1995	1	175
BH 53	C	175	500	9.4	V. High	1942	1995	2	350
BH 54	Da	150	340	6.4	V. High	1942	1995	2	300
BH 55	C	200	100	1.9	Low	1942	1995	0.5	100
BH 56	C	200	300	5.7	High	1942	1995	1.5	300
BH 57	C	175	150	2.8	Mod	1942	1995	1	175
BH 58	C	175	300	5.7	V. High	1942	1995	2	350
BH 59	Da	150	150	2.8	Mod	1942	1995	1	150
BH 60	C/Da	175	170	3.9	Mod	1951	1995	1	175
BH 61	D	250	200	3.8	Mod	1942	1995	1	250