RI

SPATIAL IMAGERY CONSOLIDATION AND CHANNEL FEATURE DELINEATION

PREPARED FOR:

BIG HORN RIVER ALLIANCE

THE RESEARCH INITIATIVE

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1 Introduction

A variety of spatial data compilation and analysis tasks, along with a reach-based review of trends were competed as part of the Bighorn River Alliance Research Initiative. These data layers form the basis for assessing changes in historic river conditions along the Bighorn River from the Afterbay Dam to its confluence with the Yellowstone River.

1.1 Study Area

The study area includes approximately 84 miles of river from the Afterbay Dam to the Yellowstone River (Figure 1). The river flows primarily through Big Horn County, with the lower 13 miles flowing along the Yellowstone/Treasure County boundary. Imagery datasets cover the active river corridor and adjacent uplands, while feature digitizing focuses on the historic active river corridor. Additionally, the study uses reach breaks to define specific sections of the river (Table 1, Figure 1).

Table 1. Project reach designations between Afterbay Dam and the Yellowstone River.

Reach	Miles	Up/Down RM*	Description
BH1	3.7	83.7 - 80	Afterbay Dam to Three Mile Fishing Access Site (FAS)
BH2	8.3	80 – 71.7	Three Mile FAS to Bighorn FAS
BH3	8.8	71.7 – 62.9	Bighorn FAS to Mallard's FAS
BH4	10.2	62.9 – 52.7	Mallard's FAS to Two Leggins Canal
BH5	10.8	52.7 – 41.9	Two Leggins Canal to Little Bighorn Confluence
BH6	17.8	41.9 – 24.1	Little Bighorn Confluence to General Custer FAS
BH7	24.1	24.1 - 0	General Custer FAS to Yellowstone River Confluence

*RM – Montana Fish Wildlife & Parks stream stationing. This varies from the 2017 river mileage of 86.6 miles.

1.2 Deliverables

The primary deliverables associated with this work scope include:

- GIS Data – All compiled GIS spatial data sets will be delivered on an external hard drive in ESRI Geodatabase, Shape File, or image formats. The LiDAR data is a very large data set and not easily transferable except on external hard drive.
- Summary Report – A short 3-page summary of tasks and results of this work scope.
- Full Report – This document represents a full documentation of this work scope.
- Reach Atlas – A PDF version of the Reach Atlas.

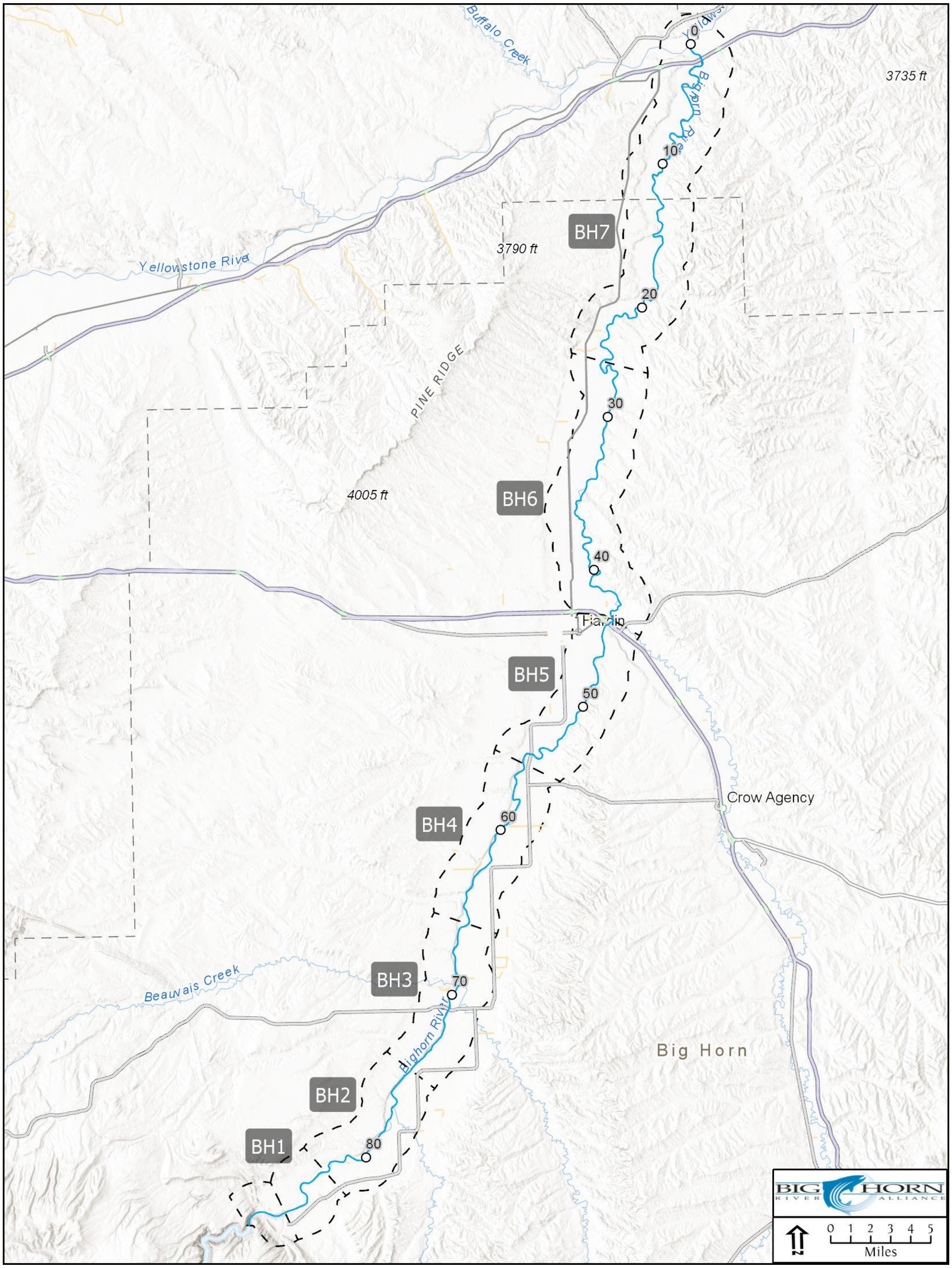

Figure 1. Study area boundaries and reaches.

2 Data

Key spatial data were compiled in ArcGIS for use in the study. Where possible, existing data were utilized, including historic and current imagery, base mapping data (roads, ownership, etc.) natural resource data (Russian olive, wetlands, etc.), and Public Land Survey System boundaries (township and sections). Other data sets were created specifically for the study, including older historic imagery and historic maps compiled and incorporated into the project GIS, and physical features and banklines digitized from imagery sources. The data are described in more detail below.

2.1 Primary Imagery Data Sets

Five time steps were chosen based on available imagery and significant events (e.g. Yellowtail Dam). Complete imagery coverage is available from Yellowtail Dam to the mouth for each of these times. While there is imagery covering additional time periods available from both the U.S. Geological Survey (USGS) and the U.S. Department of Agriculture (USDA), the coverage is either incomplete for the entire study area, or it is at an inappropriate scale for mapping (e.g., too small a scale resulting in poor resolution or too large a scale requiring an excessively large number or images to cover the study area). The earliest two data sets are made by combining a U.S. Army Corps of Engineers (COE) image mosaic for the area upstream from Mallard's FAS, with a newly created ortho-mosaic for the section below Mallard's. Utilizing the COE datasets for the upper river was chosen in order to reduce the costs associated with acquiring and georeferencing additional imagery for this section of river. Details for each data set are found below, along with the St Xavier gage stream flow at the time of imagery.

- 1954/1956 –
    - 1954 – Yellowtail Dam to Mallard's Fishing Access Site (FAS) – (Figure 2) This data set was provided from the COE. It was generated from scanned and likely georeferenced imagery. All imagery is black and white. The spatial accuracy is generally good along the river corridor, though it does lack some accuracy around the edges of the mosaic. The exact dates for the imagery are not available but flows during that summer of 1954 ranged from 2,000 to 4,000 cfs.
    - 1956 – St Xavier to the Yellowstone River – This data set was compiled from scanned stereo images acquired from the USGS Earth Explorer. The images were orthorectified by Aerial Services, Inc. into a single, seamless mosaic. The resulting mosaic has excellent spatial accuracy. All imagery is black and white. The imagery is entirely from August 9, 1956 (2,060 cfs).
- 1979/1980 –
    - 1980 – Yellowtail Dam to Mallard's FAS – (Figure 3) This data set was provided from the COE. It was generated from scanned and likely georeferenced imagery. All imagery is black and white. The spatial accuracy is generally good along the river corridor, though it does lack some accuracy around the edges of the mosaic and deviates significantly upstream of the Afterbay Dam. The exact dates for the imagery are not available but flows during that time period ranged from 3,000 to 4,000 cfs.

  - 1979/80 – St Xavier to the Yellowstone River – This data set was compiled from scanned stereo images acquired from the USDA Air Photo Field Office. The images were orthorectified by Aerial Services, Inc. into a single, seamless mosaic. The resulting mosaic has excellent spatial accuracy. All imagery is black and white. The imagery from Big Horn County is all from September 26, 1980 (3,980 cfs), while the lower approximate 13 miles are from August 9, 1979 (3,610).

- 1996 DOQ – (Figure 4) The Digital Orthophoto Quads (DOQ) were produced by the USGS and streamed from the Montana State Library GIS service. The dates for most of the Quads is August 26, 1996, with a few quads from August 8 (2,900 cfs) and August 19, 1996 (2,440 cfs). The imagery is all black and white, with excellent spatial accuracy.
- 2005 NAIP – (Figure 5) The 2005 National Agricultural Imagery Program (NAIP) imagery Compressed County Mosaic (CCM) was downloaded from the State of Montana Library. The imagery is color, with a near infrared band available. Spatial accuracy is excellent. The imagery is almost entirely from July 13, 2005 (4,410 cfs).
- 2017 NAIP – (Figure 6) The 2017 National Agricultural Imagery Program imagery Compressed County Mosaic (CCM) was downloaded from the State of Montana Library. The imagery is color, with a near infrared band available. Spatial accuracy is excellent. The imagery is from August 10 (3,990 cfs) and August 18, 2017 (3,140 cfs).

Figure 2. 1954 imagery example.

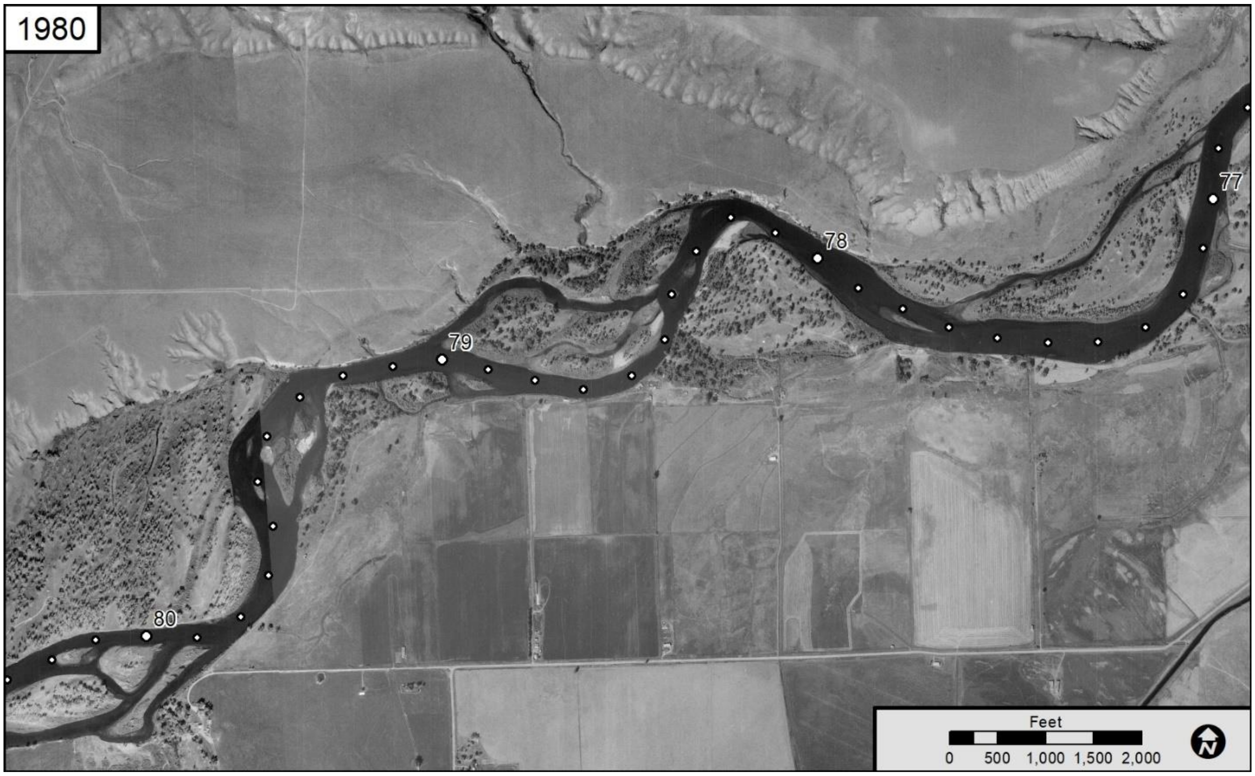

Figure 3. 1980 imagery example.

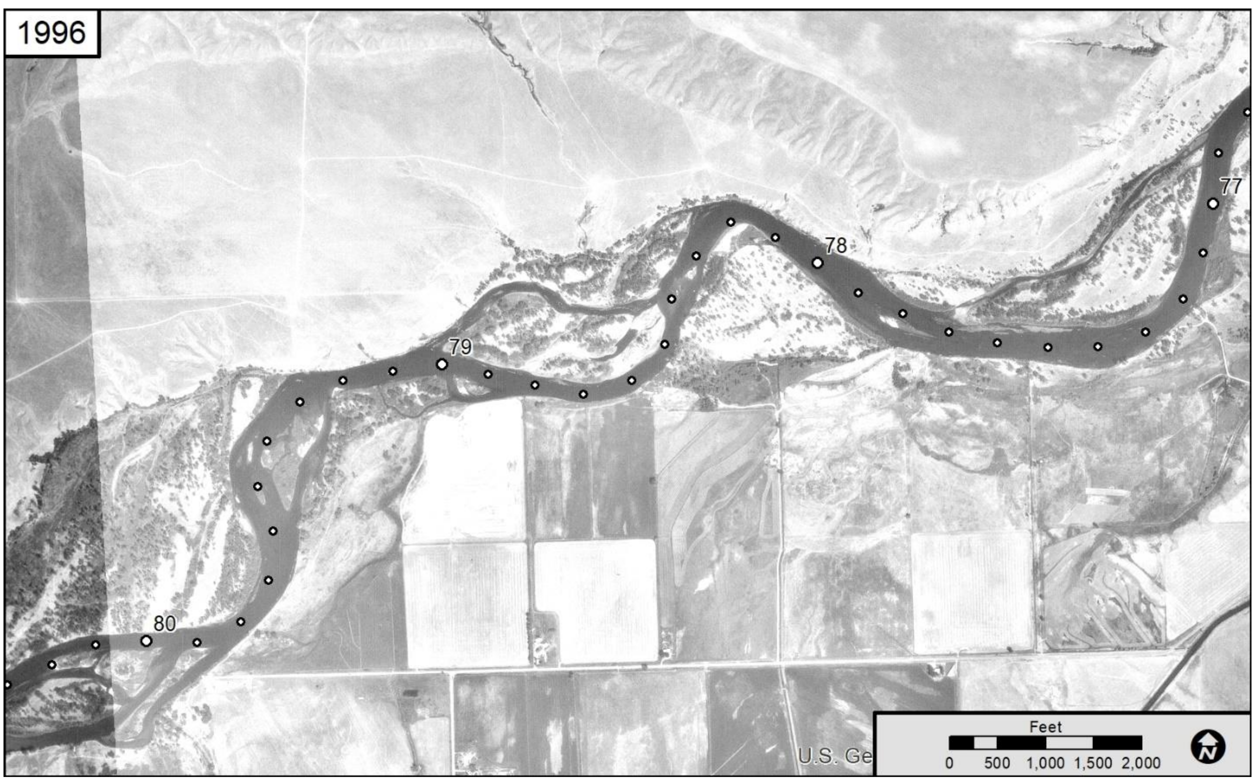

Figure 4. 1996 imagery example.

Figure 5. 2005 NAIP imagery example.

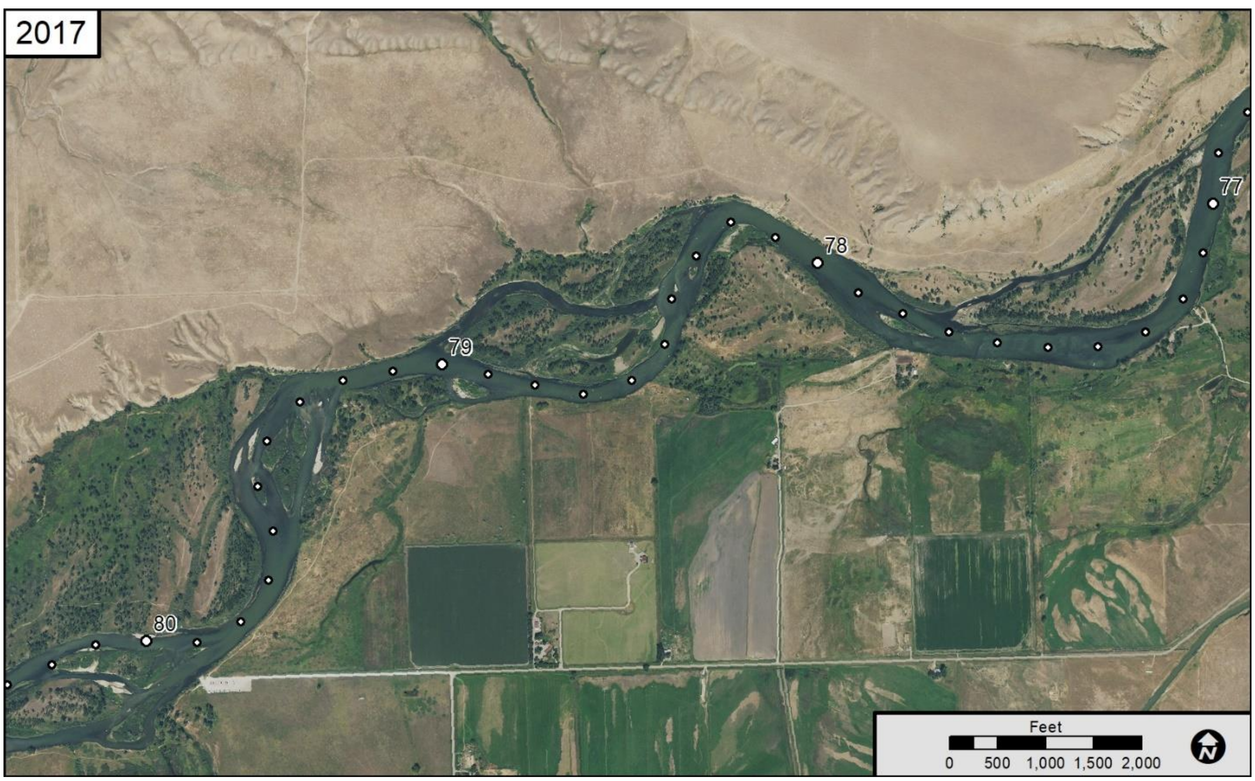

Figure 6. 2017 NAIP imagery example.

Additional Imagery Data Sets:

- Yellowtail Dam to Mallard's FAS – 1939, 1961, 1970, 1990 – Additional photo mosaics were provided by the COE for the upper river. They were generated from scanned and likely georeferenced imagery. All imagery is black and white. The spatial accuracy is generally good along the river corridor, though it does lack some accuracy around the edges of the mosaic. No additional work has been performed from these imagery sets. The 1939 imagery provides the earliest look at Bighorn River conditions and was used for developing reach descriptions. These images capture relatively pristine river conditions, as they were taken prior to the construction of Boysen Dam, which had a major impact on Bighorn River hydrology (Boyd, 2019).
- NAIP – Additional years of NAIP imagery are available (2009, 2011, 2013, and 2015), though they have not been assessed for this study. 2019 NAIP imagery is expected to be available spring 2020.

2.2 GLO Mapping

General Land Office (GLO) maps from the 1880s through 1920s often form the earliest available mapping along river corridors in the west. They are available as scanned imagers by township from the Bureau of Land Management (BLM). The key GLO maps from the current Yellowtail Dam location to the Yellowstone River were georeferenced to PLSS Section corners. In many cases, one bank of the river will have mapping from one survey effort, while the opposite bank is from another survey performed up to 40 years later. Additionally, the surveying for the GLO maps was conducted only along the Section lines. Thus, the location of river banklines shown on the GLO maps (as well as other features on the GLO maps) are only accurate for the date of the survey and only where it crosses a section line. The rest of the river banklines are interpreted between the section line crossing points and represent the approximate bankline shape and location noted by the surveyor. It is important to keep this in mind when viewing the GLO maps.

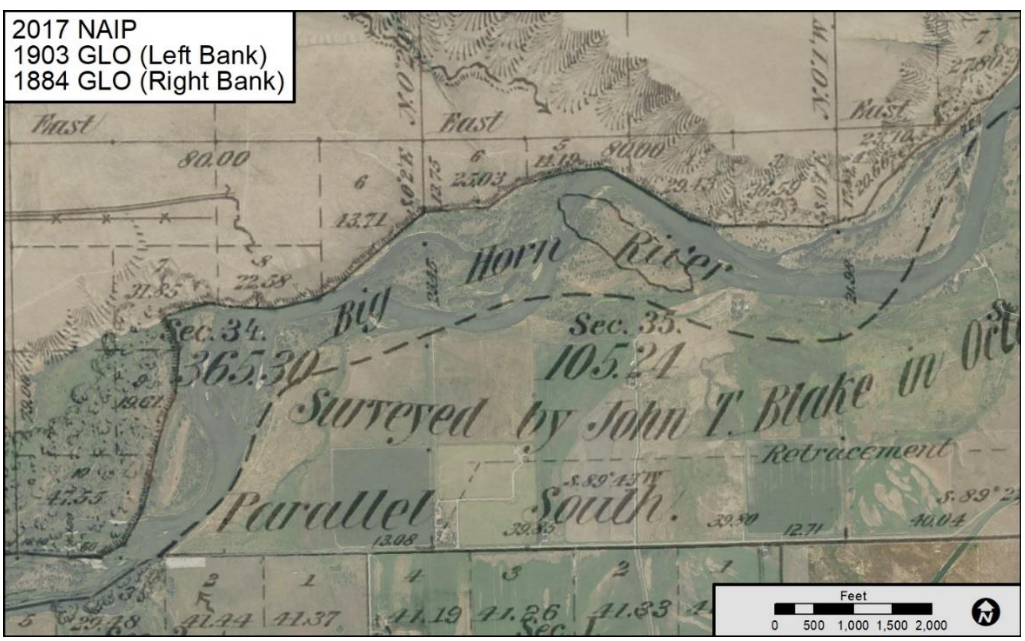

Figure 7. Example General Land Office Survey (GLO) map overlain on color imagery.

2.3 1978 Flood Imagery

The Montana Department of Transportation has limited imagery from the 1978 flood. These images were requested as scans through an interagency request from Fish Wildlife & Parks but have not been received. They are reportedly limited to four images for a short section of river near the Yellowstone River confluence. If these images become available, they could be georeferenced in the GIS and used to help coarsely correlate flood stage representation from the Relative Elevation Model (REM). Additional hard copy imagery may be available from the Big Horn County Conservation District, but due to the unknown usefulness or extent of the imagery, no effort has been made to acquire this imagery.

2.4 LiDAR/Relative Elevation Modeling (REM)

High-resolution LiDAR elevation data was collected in Fall 2018 by the NRCS for the Bighorn River corridor from Yellowtail Dam to the confluence with the Yellowstone River. LiDAR is a useful data set for a variety of analytical tasks, including hydraulic modeling, vegetation analysis, canopy mapping, change detection, automated feature mapping, and shoreline mapping, to name a few. For this work scope, LiDAR data was used to create a Relative Elevation Model (REM) of the active river corridor. The REM will be of immediate use to support the proposed Channel Migration Zone mapping effort.

A total of 891 hydro-flattened bare earth model data tiles covering the Bighorn River corridor and adjacent uplands from Yellowtail Dam to just above the Interstate-94 bridge were delivered by Catherine Maynard (USDA-NRCS). Each 1,000 ft x 1,000 ft tile contains a uniform grid of elevation values spaced at 1- meter intervals. 224 tiles covering the active river corridor were mosaiced into a single Digital Elevation Model (DEM) to allow for corridor-wide modeling. The DEM can be used to easily cut cross sections that can be used for a variety of management tasks such as assessing connectivity of side channels, assessing bankline configurations, or siting infrastructure (pumps, pivots, roads, etc.). For example, Figure 8 shows a topographic cross section from upland to upland and through the Juniper side channel (see Figure 9 for cross section location). The water surface (note that LiDAR does not penetrate the water surface and thus does not show channel bathymetry) for the main river channel and the smaller Juniper Channel, along with the ground surface for various perched historic swales are clearly visible.

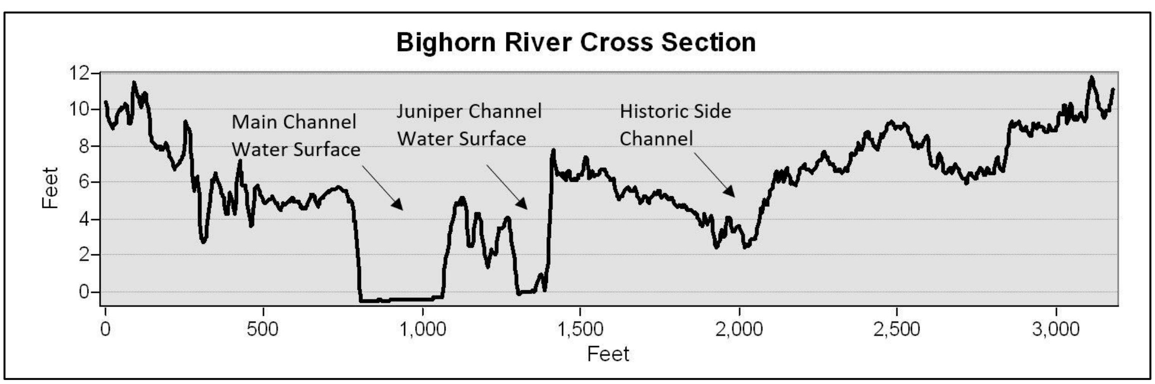

Figure 8. LiDAR cross section showing multiple current channels (water surface) and historic channels (ground surface) channels. Location of the cross section is shown in Figure 9.

The DEM was utilized to create a Relative Elevation Model (REM) for the study area. Relative Elevation Modeling is an analysis technique used to highlight the relative elevations of terrain adjacent to the river channel. This analysis and visualization technique helps identify perched or inset channels and potential avulsion pathways (e.g., historic sloughs or meander bendways where the river might abandon the current channel in favor of a new flow pathway). A REM can also be used to approximate the potential inundated area at a given flood stage by limiting the display of the REM to only display areas up to a selected flood stage. While this is not equivalent to detailed modeling of flood waters using a step-backwater model such as HEC-RAS, it can be a useful tool for understanding where water may end up as water levels rise.

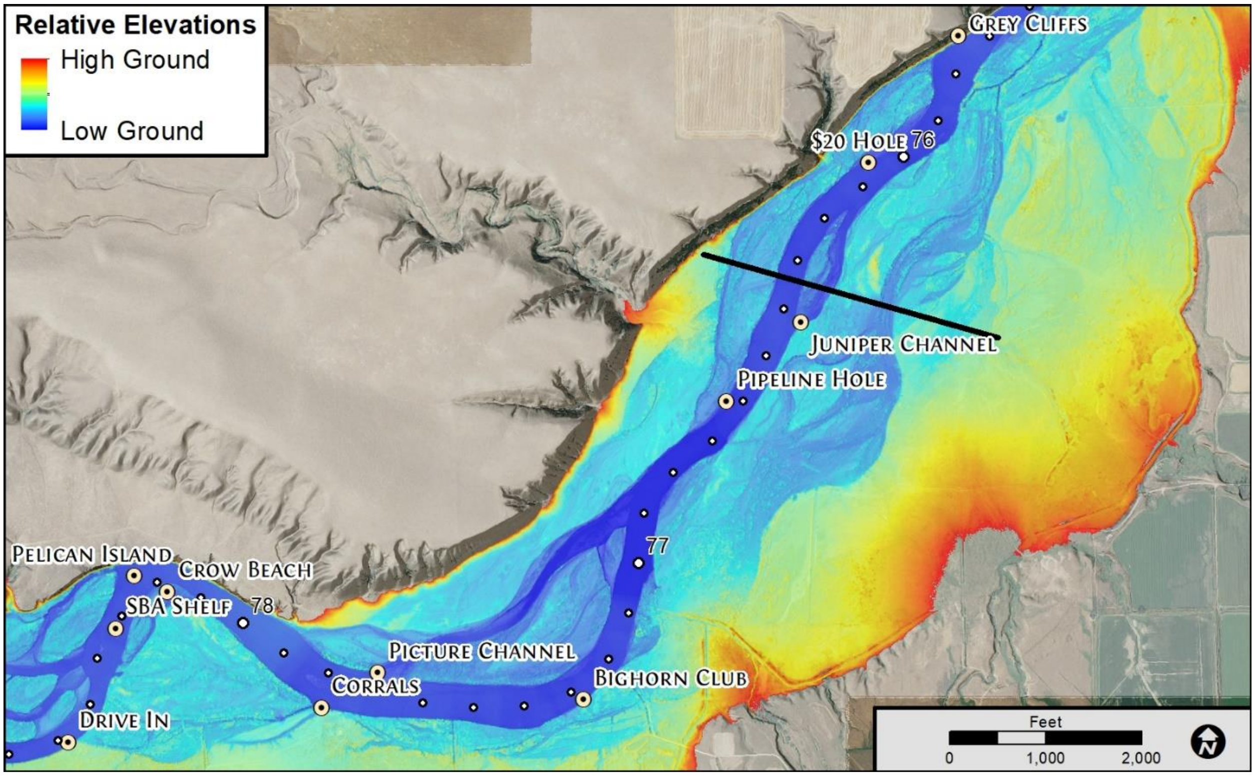

Figure 9. Relative Elevation Modeling (REM) using LiDAR elevation data with cross section location.

2.5 Base Data

A variety of existing core GIS base data has been compiled for use in the study. These include:

- River Stationing – The Montana Fish Wildlife & Parks (FWP) stream stationing is used for locational references in this study. This was defined from an older stream centerline data set (date unknown). Note that the river has migrated significantly from the centerline used for the FWP stationing. Approximately 34 percent of the FWP tenth-of-a-mile stationing is outside the 2017 bankfull channel mapping. Overall, the 2017 centerline is 2.9 miles longer than the FWP line, with the changes in length varying due to channel migration, avulsions, and primary flow splits.

- Geology – 100K geologic mapping was acquired from Montana Bureau of Mines and Geology. The 100K quads include: Hysham, Hardin, and Lodge Grass.
- Wetlands – National Wetlands Inventory (NWI) mapping was acquired from the Montana State Library. The mapping is derived from 1980 satellite imagery. The area was not remapped in the 2018 NWI update for Montana.
- Ownership – Ownership data for Big Horn, Yellowstone, and Treasure Counties were acquired from the Montana State Library as cadastral parcel boundaries. The attributes for the cadastral data include key information such owner and property type.
    - Public Lands – A stand-alone Public Lands data layer was acquired from the Montana State Library. This layer lists public lands according to responsible federal, state, or local agency.
    - Tribal Lands – A layer of Reservations was acquired from the Montana State Library. The utility of this layer is limited for the study as river upstream from Hardin is largely all part of the Crow Reservation.
- Land Cover – Land Cover data derived from 2017 satellite imagery was acquired from the Montana State Library.
- Russian Olive – The NRCS mapped Russian Olive in the Yellowstone River watershed using image analysis techniques from 2011 NAIP color-infrared imagery.
- Roads – The Montana Framework Data roads layer was acquired from the Montana State Library.
- Conservation Easements – Existing conservation easements from January 2019 was acquired from the Montana State Library. This layer contains known easements as of January 2019.
- PLSS – The Public Lands Survey Data (Townships and Sections) was acquired from the Montana State Library.

2.6 Digitize Banklines

Bankline mapping is complete from the Dam to the Yellowstone River confluence for the five primary imagery data sets (Figure 10) – 1954/56, 1979/80, 1996, 2005, and 2017. All digitizing was completed at a minimum scale of 1:4,000. A pen-based computer was utilized with stream mode digitizing with vertex spacing of approximately 40 feet. Banklines were defined as the approximate bankfull footprint as defined by presence/absence of established woody vegetation. Islands are digitized if they appeared to have established woody vegetation.

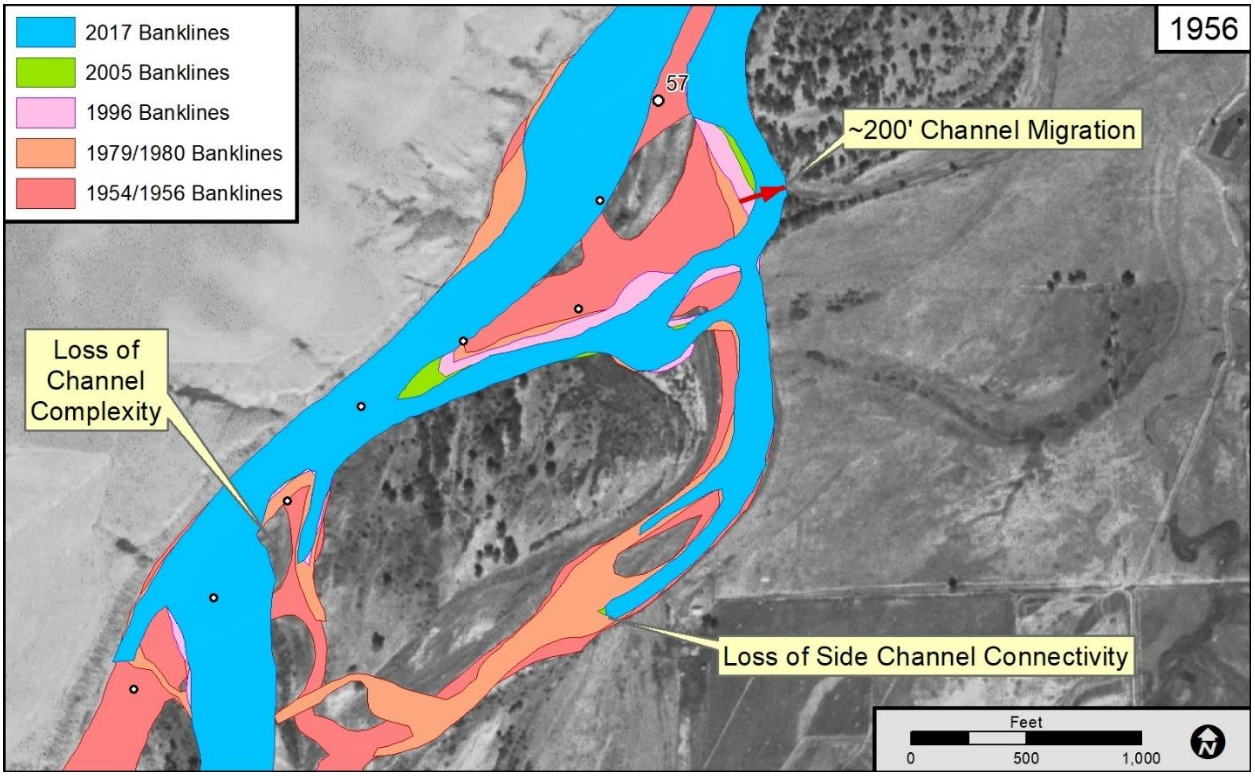

Figure 10. Five years of bankline mapping displayed on 1956 imagery.

2.7 Physical Features

All identifiable point and line physical features were mapped from Google Earth imagery and augmented with current NAIP imagery. This inventory is not comprehensive. Features that are hidden by vegetation or are otherwise not visible in the imagery are not included. Similarly, any features constructed after the 2017 NAIP imagery will not be included.

- Point Features include:
  - Flow Deflector
  - Boat ramp
  - Bridge
  - Headgate/Diversion
  - Fishing Access Site (FAS)
  - Landslide
  - Miscellaneous
  - Side Channel Plug
  - Pump
  - Irrigation Return
  - Tributary Confluence

- Line Features are currently limited to bank protection (rip rap)

The count of mapped point features and length of mapped bank armor are summarized in Table 2. This shows a significant increase in the number of bank protection features (barbs and armor) beginning in Reach 5 below Two Leggins and continuing to the Yellowstone River confluence.

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Table 2. Summary of mapped point features (count) and bank protection (ft) by reach.

Reach	Reach Length (mi)	Boat Ramp	Flow Deflector	Bridge	Canal	Diversion	FAS	Bank Protection (ft)	% Armored
BH1	3.7	2	3	0	1	0	1	443	1.1%
BH2	8.3	5	0	0	0	0	2	0	0.0%
BH3	8.8	7	8	1	0	0	1	1,050	1.1%
BH4	10.2	3	12	0	0	1	0	0	0.0%
BH5	10.8	4	4	6	1	1	1	4,939	4.3%
BH6	17.8	4	4	5	1	1	2	3,906	2.1%
BH7	24.1	3	27	5	3	3	1	9,674	3.8%

3 Bighorn River Atlas

The Atlas was created to provide a consistent spatial reference for the study. Core work included creating a consistent map tiling schema, adding known place locations (access sites, angler-based fishing holes, lodges, etc.), labeling features, and creating consistent symbology (Figure 11). Initial place locations were acquired from Doug Haacke and integrated into the GIS, and then refined after a review of the draft atlas. The Atlas is designed using Data Drive Pages within ArcMap to allow for easy updates as new data becomes available (e.g., new imagery, Relative Elevation Modeling, ownership, etc). Two versions of the Atlas from the Dam to the Yellowstone River were created in PDF format for review - one with parcel and ownership data and one without. Additionally, a demonstration on-line Atlas using ArcGIS Online was created for review.

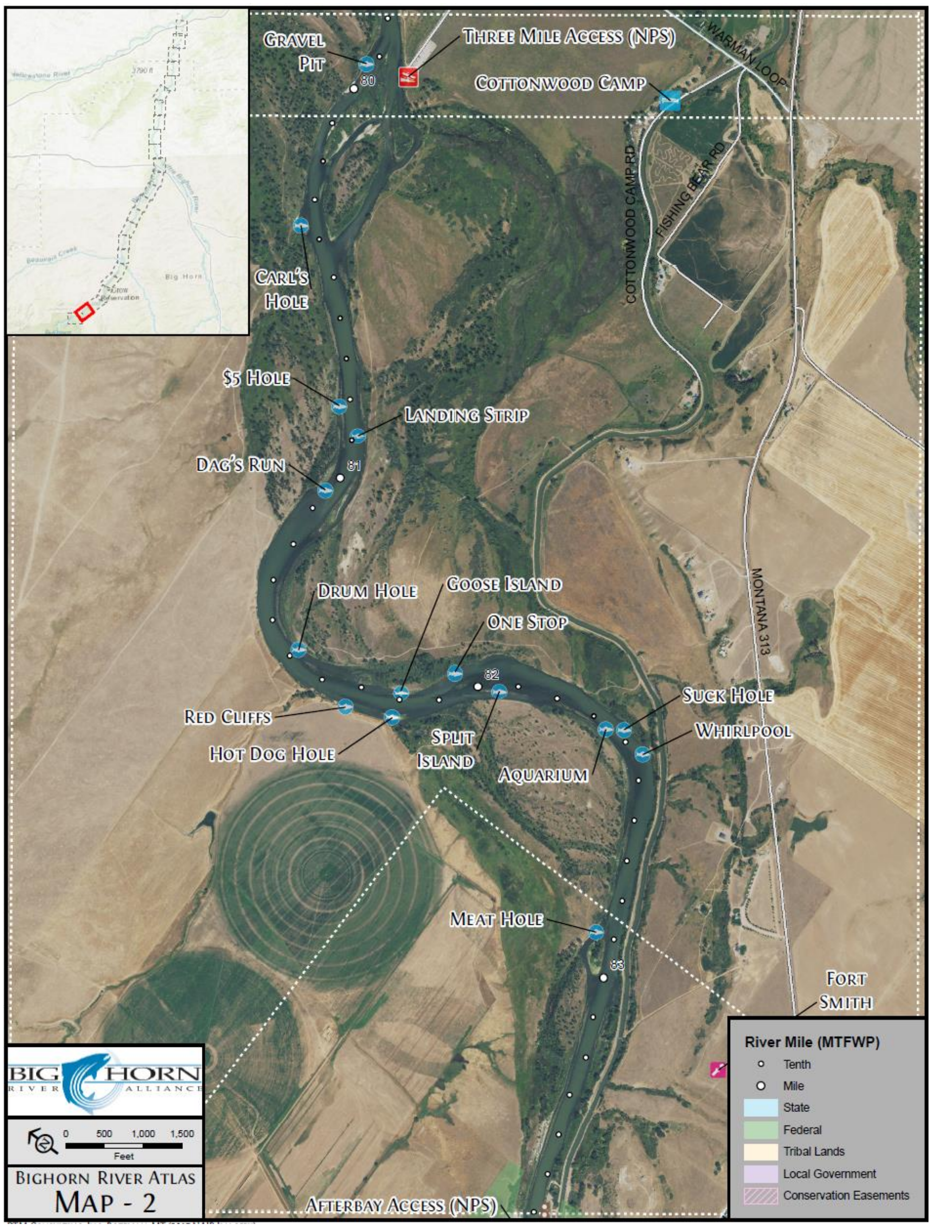

Figure 11. Example Bighorn River Atlas page.

4 Reach Summaries

In order to provide more context of future BHRA efforts, the following section summarizes each reach in terms of general trends and observations using the spatial data. The project area has been divided into seven reaches, most of which align with recreational float sections between Fishing Access Sites (Figure 12). The reaches range in length from 3.7 miles in Reach BH1 immediately below the Afterbay Dam to 25.3 miles in the lowermost portion of the project area below General Custer Fishing Access Site (Table 3). The following summaries include field observations made in the upper two reaches during a field visit in early September 2019 by Karin Boyd of Applied Geomorphology.

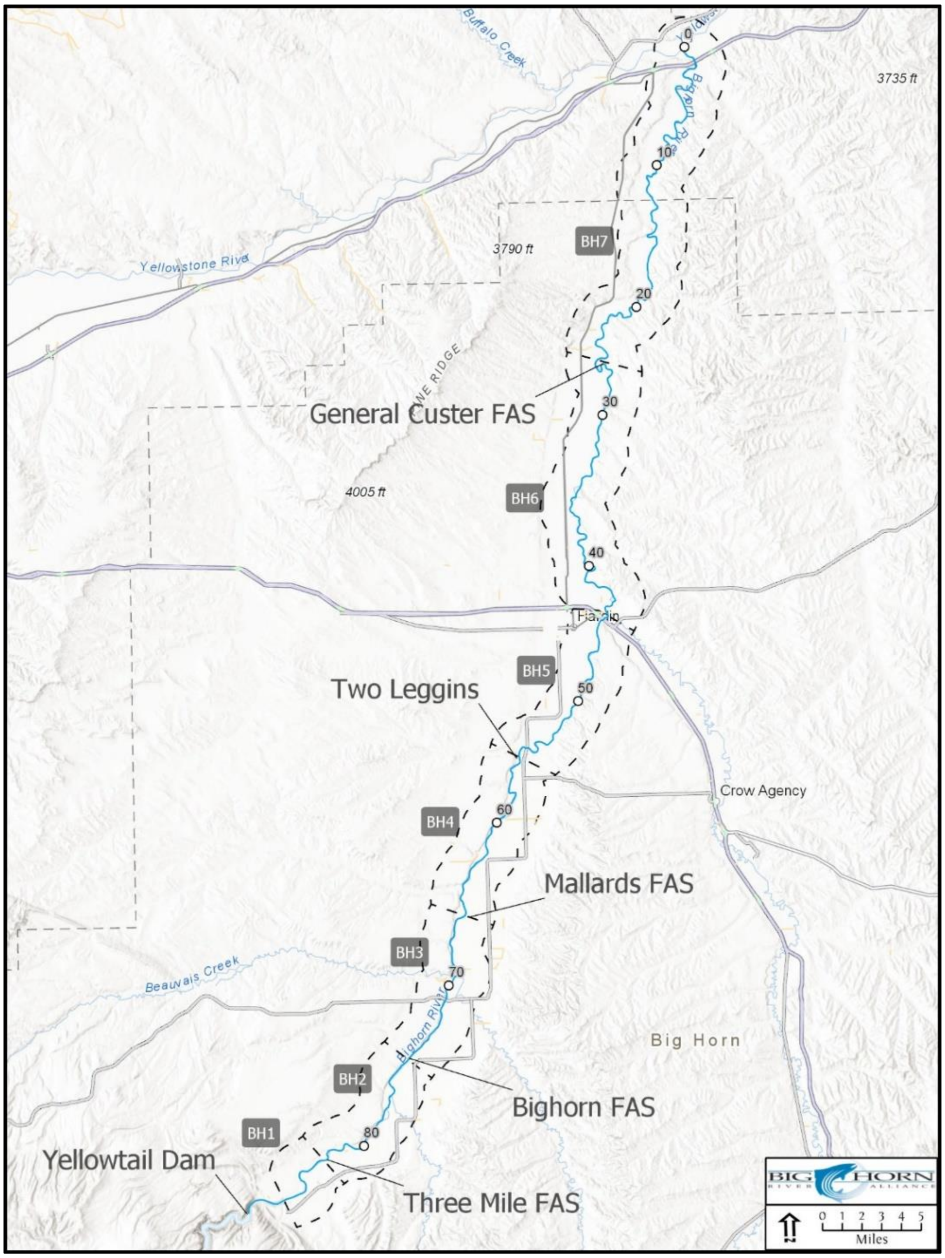

Figure 12. Project reach delineations.

Table 3. Bighorn River reach summary.

Reach	Location	Upstream RM	Downstream RM	Length (mi)	Description
BH1	Afterbay Dam to Three Mile	83.7	80	3.7	First few miles below Afterbay Dam; geomorphically simple and relatively stable/static
BH2	Three Mile to Bighorn FAS	80	71.6	8.4	Increasing complexity via side channels, wetlands, and sloughs, increased sediment transport and disturbance.
BH3	Bighorn FAS to Mallard's Landing FAS	71.6	63	8.6	River closely follows west bluff line. Loss of several miles of side channel at St Xavier since 1939
BH4	Mallard's Landing FAS to Two Leggins FAS	63	52	11	Continues to follow bluff line. Several complex island segments.
BH5	Two Leggins FAS to Little Bighorn River	52	42	10	River crosses valley to east bluff line; some persistent split flow segments.
BH6	Little Bighorn River to General Custer FAS	42	26.2	15.8	Increased meander development and channel migration below Little Bighorn River confluence. Increased armoring relative to upstream.
BH7	General Custer FAS to Yellowstone River Confluence	26.2	0.9	25.3	Some rapidly migrating bendways and threats to infrastructure/agricultural land.

General observations of the project area are dominated by a marked change in river conditions between the earliest available imagery (1939) and current conditions. The 1939 photos capture a much less controlled and wild river, with broad open sand bars and extensive split flow. As flows have become more managed, the sediment load has dropped and flow variability has waned, resulting in vegetation encroachment and landform stabilization. Another trend is from upstream to downstream; reaches below the Little Bighorn River confluence are inherently more dynamic than those above.

Figure 13 shows the total channel area of each reach normalized by river mile for three timesteps: Pre-Yellowtail Dam (1950s), early 2000s drought (2005) and recent (2017). The results show that all reaches show the same trend of channel contraction from pre-Yellowtail Dam to drought conditions, but that some of that channel area has been recovered since, as high flows have predominated in recent years (Boyd, 2019). This shows how the processes of vegetation encroachment and channel widening have the capacity to affect channel morphology through time in response to overall flow patterns. These changes have been notable in that the total amount of channel contraction across all reaches between the 1950s and 2005 was 26%, with the most concentrated loss of channel area in Reach BH4 below Mallard's Landing (Figure 14). More recent expansion has been less dramatic, with a total post-drought channel enlargement of 15%. The greatest amount of channel enlargement occurred in Reach BH6 below the Little Bighorn River confluence.

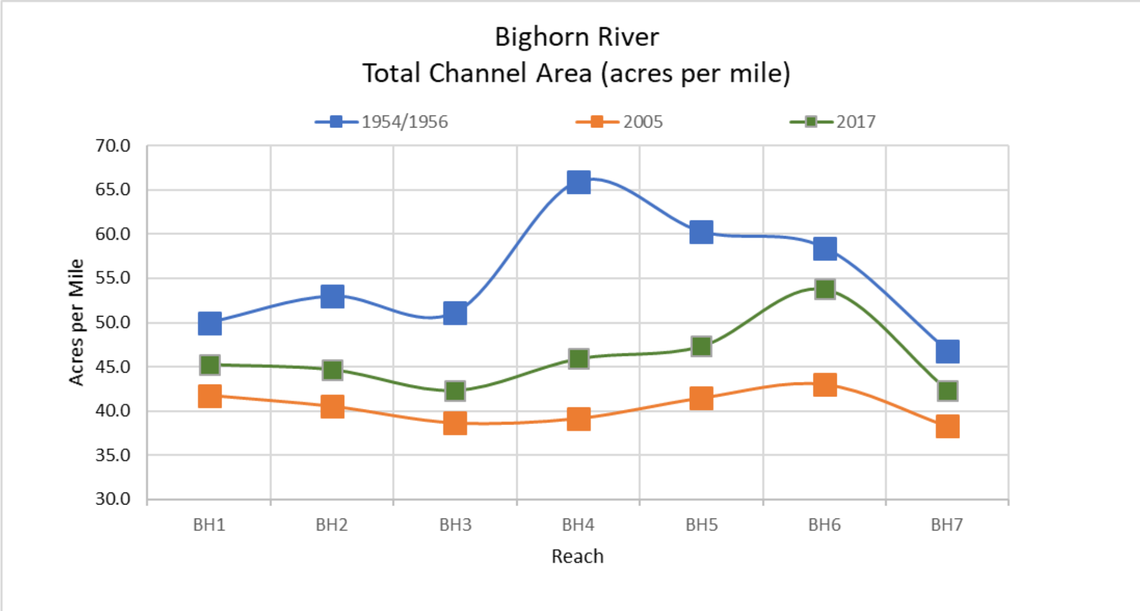

Figure 13. Total channel area (acres per mile) for pre-Yellowtail (1950s), drought (2005) and modern (2017) conditions by reach.

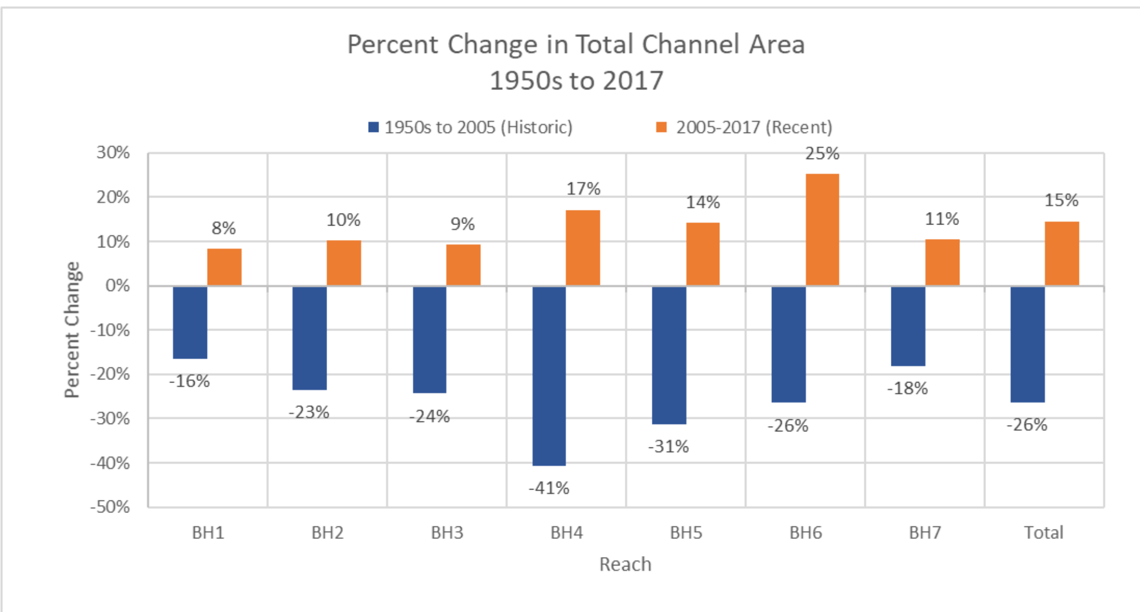

Figure 14. Percent change in channel area from 1950s to 2005 and 2005 to 2017 showing contracting channel area between Yellowtail Dam construction and early 2000s drought, and more recent channel expansion during years of high water.

4.1 Reach BH1: Afterbay Dam to Three Mile

Reach BH1 extends 3.7 miles from the Afterbay Dam to Three Mile Fishing Access (Figure 15). This section of river immediately below the Afterbay is geomorphically simple, with little in the way of geomorphic change in recent decades. Concerns over gas supersaturation have been expressed in this reach due to its proximity to the Afterbay Dam, which delivers water via a series of radial gates and a sluiceway (Figure 16; Boyd, 2019).

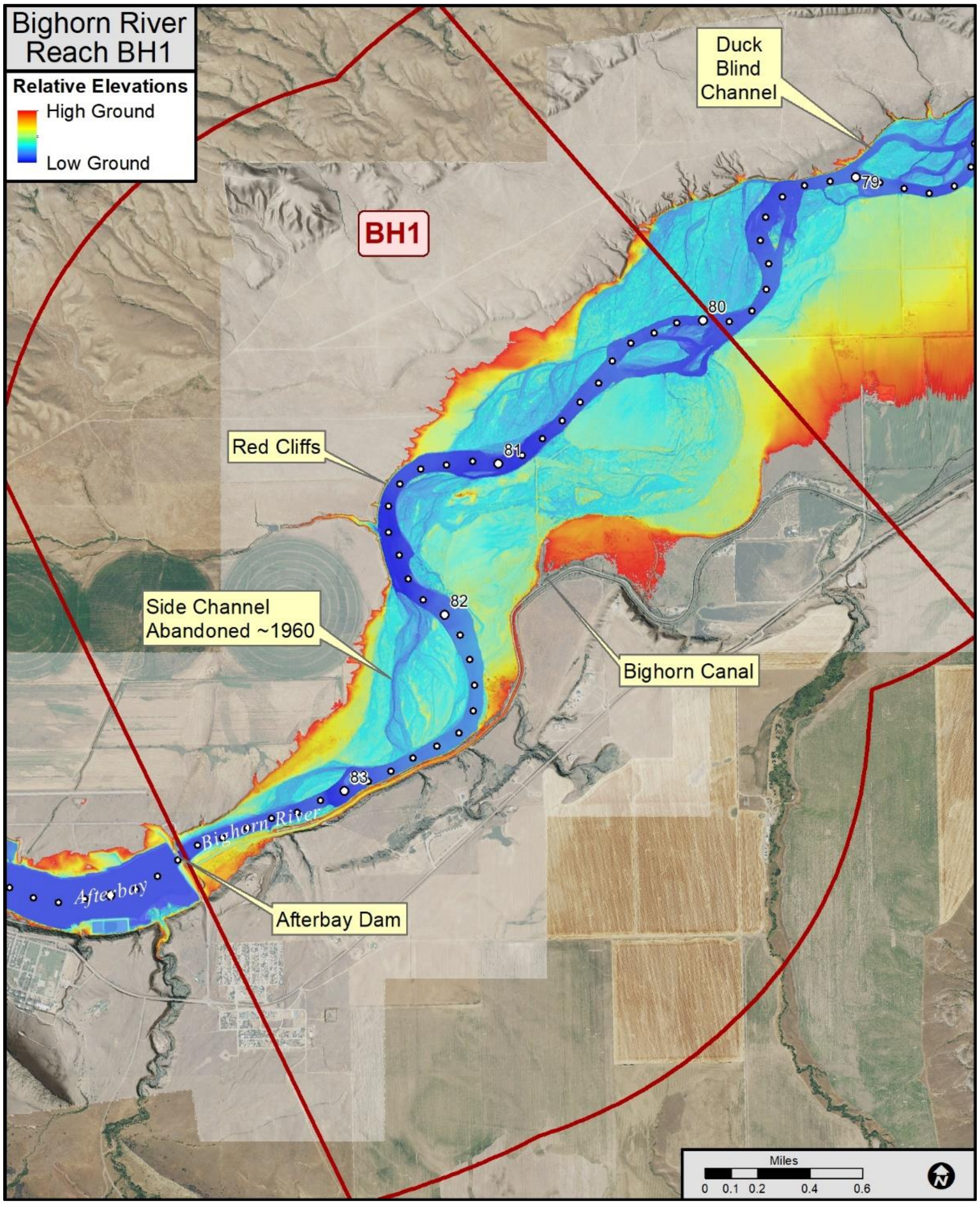

Figure 15. Relative Elevation Model (REM) map showing major features in Reach BH1.

Reach BH1 supports broad open meanders with a sparse woody riparian corridor. The high left bank at RM 81.5 known as the "Red Cliffs" consists of a high terrace that is mainly fine-grained, but also contains substantial amounts of gravel that is being actively eroded into the river, contributing to mobile substrate that will support spawning (Figure 17).

Reach BH1 does not have any active side channels, although remnants are visible on the floodplain. One channel at RM 82.5L was clearly active in the late 1930s but had largely closed off by 1960 (Figure 18). This channel abandonment between First Island and Red Cliffs may reflect the very early hydrologic alterations on the river caused by Boysen Dam which was completed in 1952.

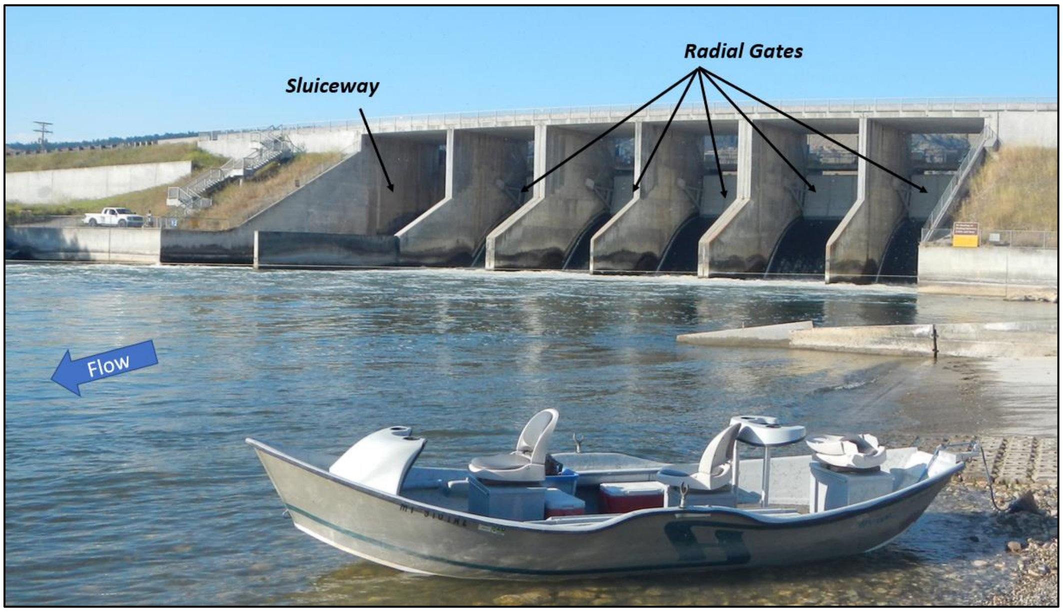

Figure 16. View upstream of Afterbay Dam showing five radial gates and sluiceway (09/05/2019, ~3,200cfs).

Figure 17. View downstream of alluvial terrace known as "Red Cliffs"; note coarse gravel toe.

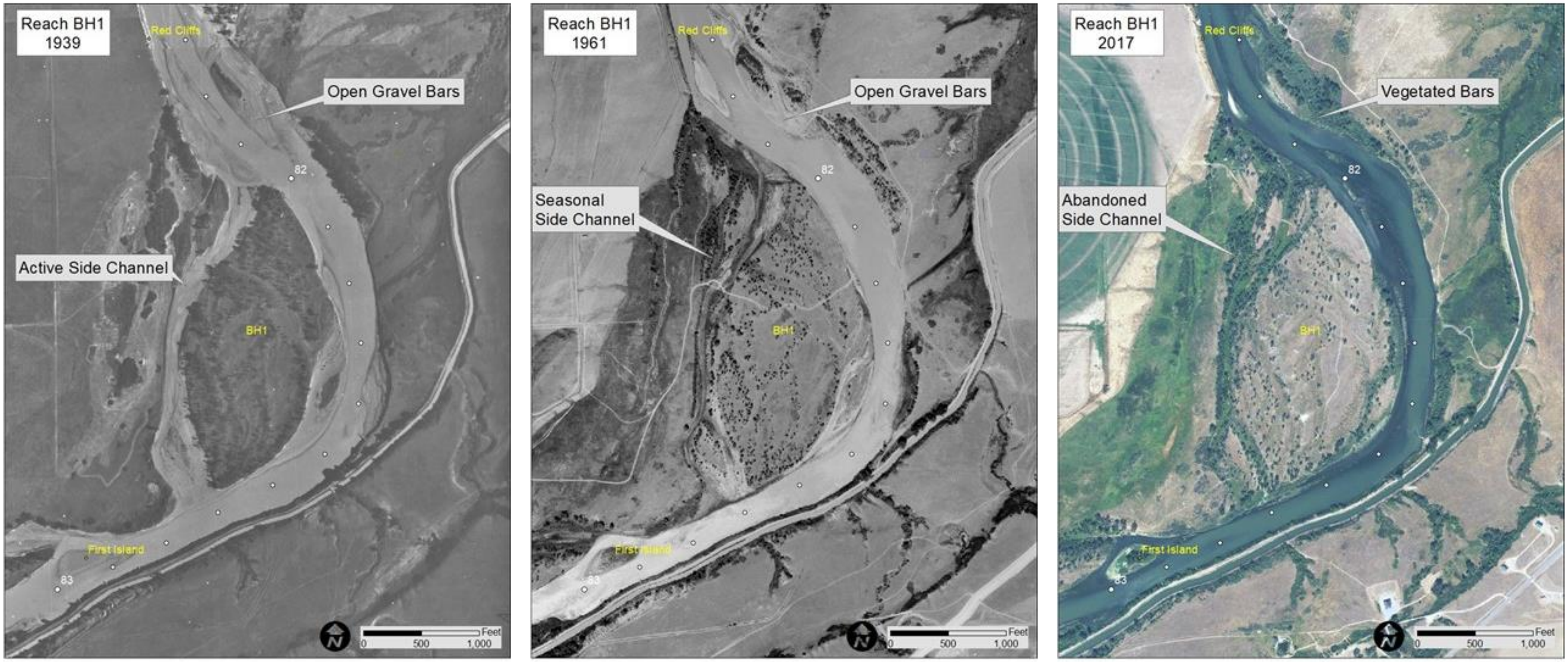

Figure 18. Comparison of section of BH1 upstream of Red Cliffs showing side channel loss and vegetation encroachment since 1939—flow direction is to north.

The Bighorn Canal closely follows the River on the right bank for about a mile below Afterbay Dam. There are several large concrete flow deflectors on the streambank in this area, and there has been some substantial scour upstream of one deflector, an area known as “The Whirlpool” (Figure 19). This flow deflector was built sometime prior to 1970, and the bank is currently about 85 feet from the canal margin (Figure 20).

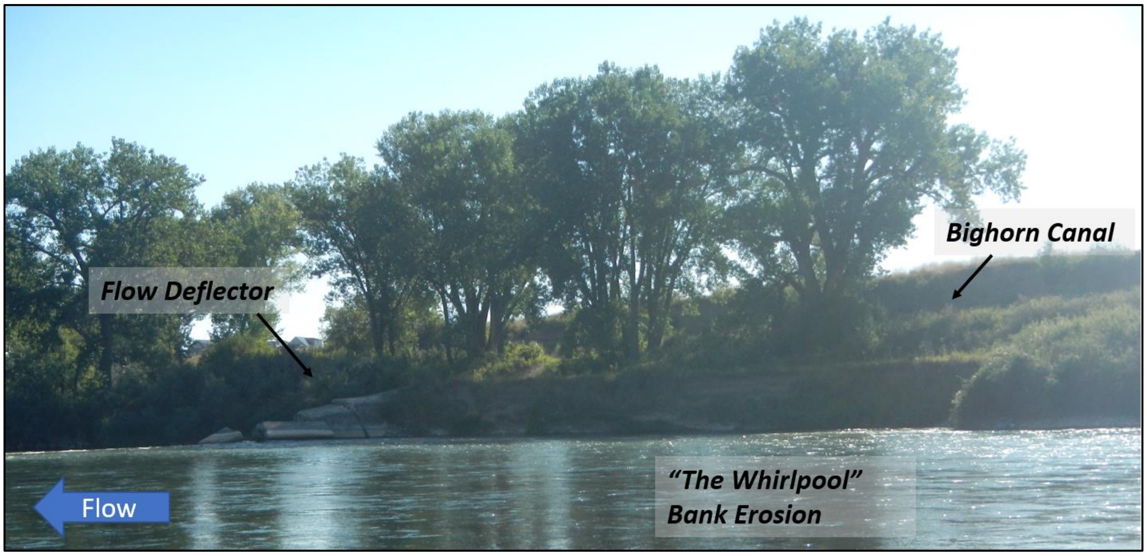

Figure 19. View across river showing severe bank erosion upstream of a large concrete flow deflector.

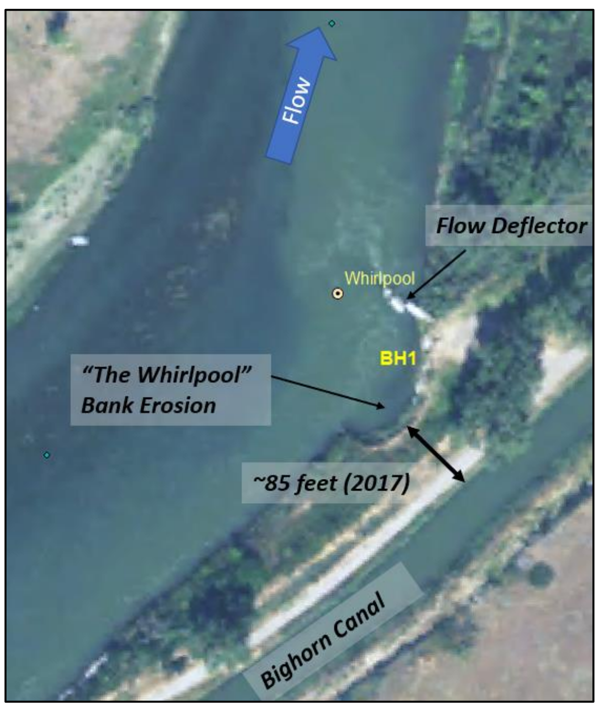

Figure 20. 2017 air photo showing scour upstream of flow deflector; back eddy has eroded the bank towards Bighorn Canal.

Channel migration has been minimal in this section of river since at least 1954. The only area showing notable change is the island complex on the lower end of the reach (Bureau of Reclamation "Channel Complex #6 just upstream of the 3-mile boat ramp), where recent changes have included island dissection, trimming, and new gravel bar formation. Figure 21 shows how the islands have changed since 1939, with some stabilization via vegetation and loss of open bar area. With recent high flows, however, there has been substantial bedload movement in the reach and some new open gravel bars have formed (Figure 22).

One concern with the lack of geomorphic disturbance in Reach BH1 is the total lack of riparian recruitment on the floodplain; all cottonwoods are mature and in some locations becoming decadent, with few young trees to take their place (Figure 23). Russian olive is common and commonly forms thick stands on the streambanks. One positive observation in the reach is the exposure of extensive gravels in low terraces and older floodplain features; erosion of these areas will contribute spawning gravels to the reach, helping to mitigate future inevitable gravel depletions due to the upstream trapping of sediment in Bighorn Lake.

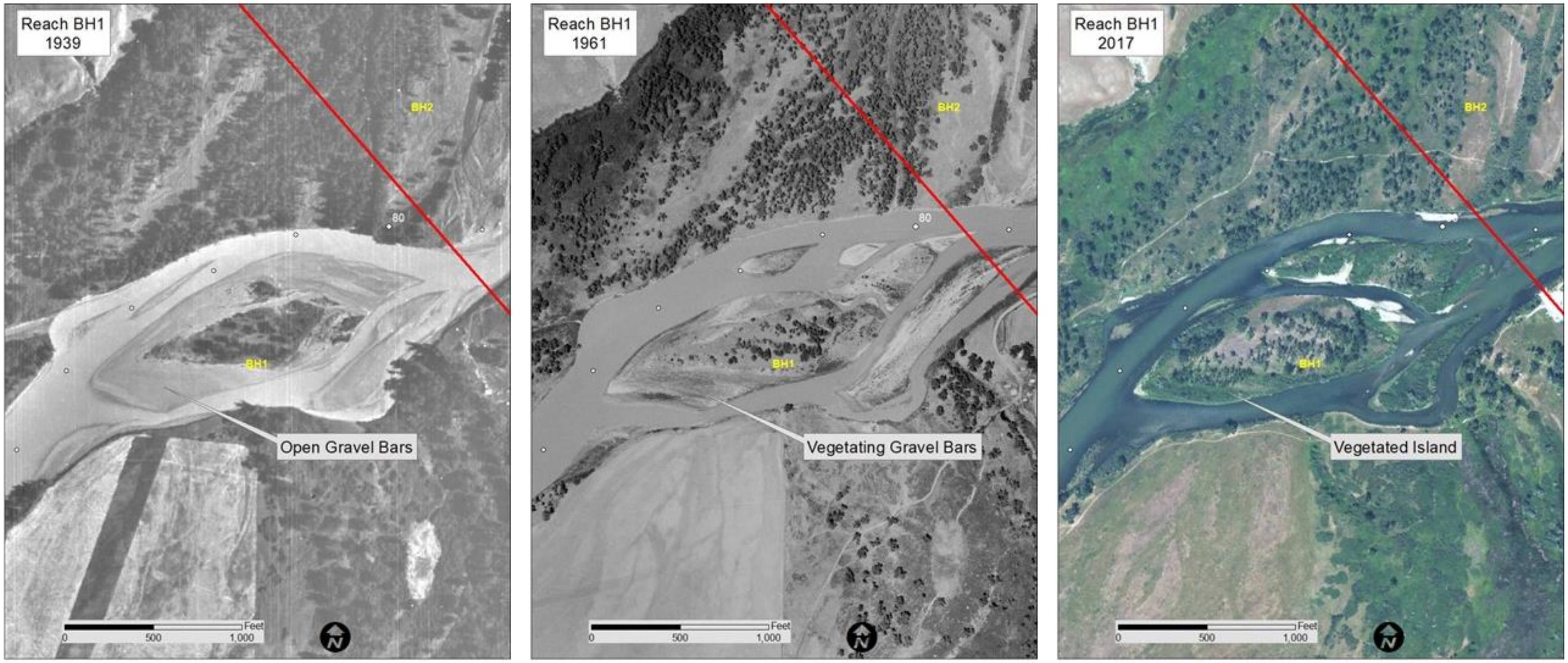

Figure 21. Comparison of section of BH1 just upstream of Three Mile showing side channel loss and vegetation encroachment since 1939—flow direction is left to right

Figure 22. Recent gravel bar formation on island complex just upstream of 3 Mile Fishing Access.

Figure 23. Moderately decadent cottonwood forest, Reach BH1.

Figure 24. Gravel/cobble alluvium in historic floodplain that provides good spawning substrate to river.

4.2 Reach BH2: Three Mile to Bighorn FAS

Reach BH2 extends from the 3-Mile to Bighorn Fishing Access sites, a channel distance of 8.3 miles (Figure 25). This reach is substantially more complex than Reach BH1 upstream, especially with respect to side channel density. The river tends to follow the west margin of the floodplain which is comprised of Cretaceous-aged Mowry shale in the upper portion of the reach and Belle Fouche Shale below RM 74 (Vuke et. al, 2007). This bluffline shows evidence of seepage and slumping, and woody vegetation has established on the wet slump benches (Figure 26).

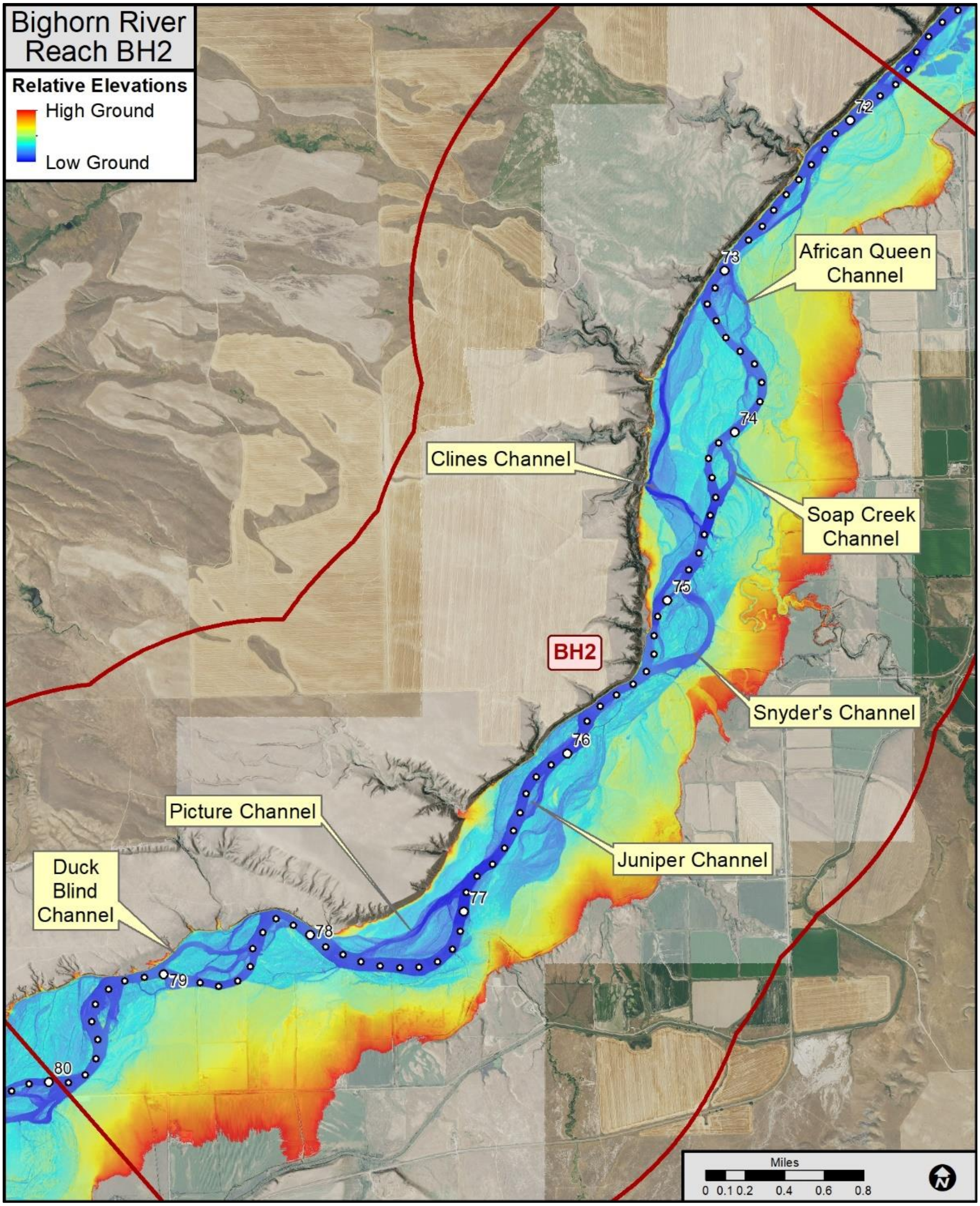

Figure 25. Relative Elevation Model (REM) map showing major side channels in Reach BH2.

Figure 26. View downstream in Reach BH2 showing Mowry Shale bluffline.

Reach BH2 shows evidence of more disturbance relative to the channel upstream. Although large wood is still relatively rare in the channel, it does locally affect geomorphology by promoting flow splits at the heads of islands (Figure 27). There is some evidence of beaver activity, primarily on islands, with willows foraged and some lodges present in the side channels (Figure 28). One positive aspect of the bedload movement and associated geomorphic disturbance in this reach is the presence of a few cottonwood seedlings (Figure 29). Although these cottonwoods will be prone to scour by high flows or ice, the survival of any seedlings will help sustain the Bighorn River cottonwood forest. Both Russian olive and Tamarisk (salt cedar) are common in the reach and may eventually replace cottonwoods without successful cottonwood recruitment.

During our field investigation on September 5-6, 2019, water temperatures were around 62 degrees F. Aquatic vegetation was pervasive, commonly accumulating at the head of side channels. The vegetation appears to be quite palatable to cattle (Figure 30).

Figure 27. Large wood accumulation at head of Picture Side Channel, Reach BH2.

Figure 28. Recent beaver foraging on banks of Picture Channel.

Figure 29. Cottonwood seedling, Reach BH2.

Figure 30. Cow grazing on aquatic vegetation.

The geomorphic features in Reach BH2 includes a primary thread, wetlands, sloughs, and side channels of varying connectivity (Figure 31 and Figure 32). In several locations, high lobate gravel bars record older flood events. Figure 33 shows one of these gravel bars located near the lower end of Duck Blind Channel at RM 78.5. The crest of this flood deposit is currently well above the active floodplain of the Bighorn River, and as such must capture some historic event. A comparison of air photos shows that this bar formed sometime between 1961 and 1970, which was a period of both dam building and repetitive flooding (Figure 34). During that decade, three major floods occurred: 1963 (25,000 cfs), 1965 (26,400 cfs), and 1967 (25,300 cfs). These flood deposits were seen in other areas as well and will continue to provide important spawning substrate to the river as they erode. Vegetation encroachment since 1939 has been pervasive (Figure 35).

Bank erosion has been a concern in this reach for decades (Figure 36), however it is important to acknowledge that the erosion will be necessary to mitigate eventual gravel depletions below the dam. Guides noted that more bedrock has become exposed in the streambed in recent years, indicating that bedrock sills will help prevent downcutting, but also that bedload has been exported from certain areas. A Google Earth image of Cabin Run shows a large sediment wave migrating down river, exemplifying patterns of sediment movement during high flows (Figure 37).

Figure 31. View downstream of marginally connected side channel with cobble deposits and aquatic vegetation accumulated at entrance, Reach BH2.

Figure 32. View downstream of Picture Side channel; note high water indicators on decadent shrubs.

Figure 33. High perched gravel deposit likely deposited by floods of the 1960s.

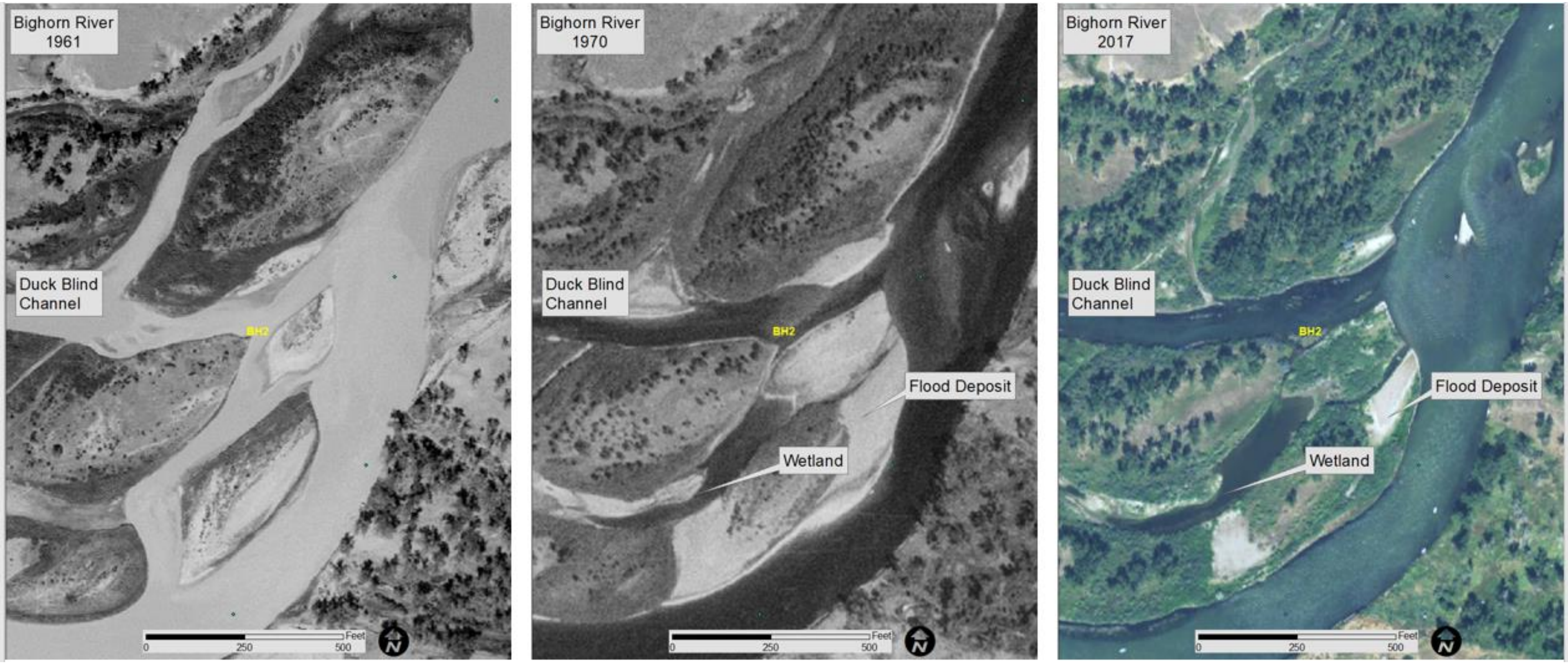

Figure 34. Comparison of section of BH2 at Duck Blind Channel showing flood deposits established between 1961 and 1970—flow direction is to northeast.

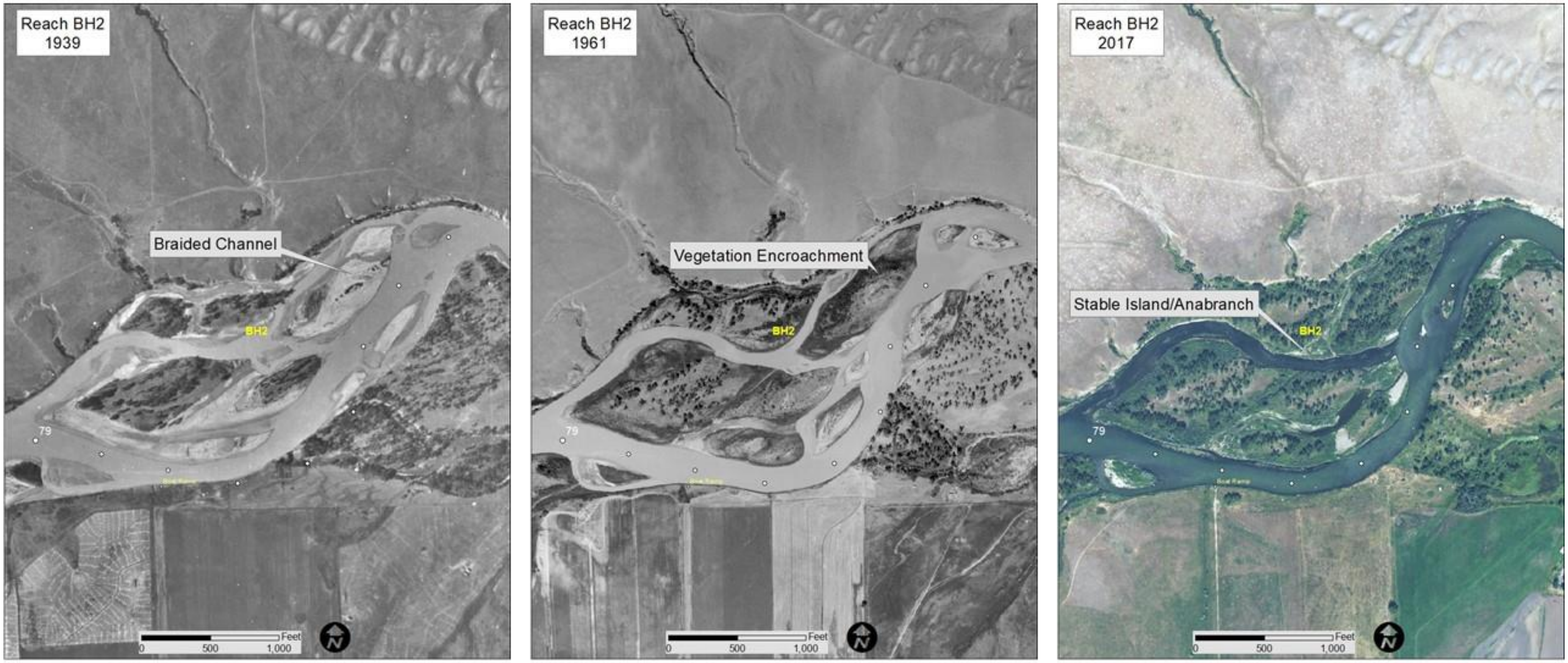

Figure 35. Comparison of section of BH2 at Duck Blind Channel showing channel simplification since 1939—flow direction is left to right.

Figure 36. "Detroit Riprap", also known as the "Drive-In" RM 78.5R.

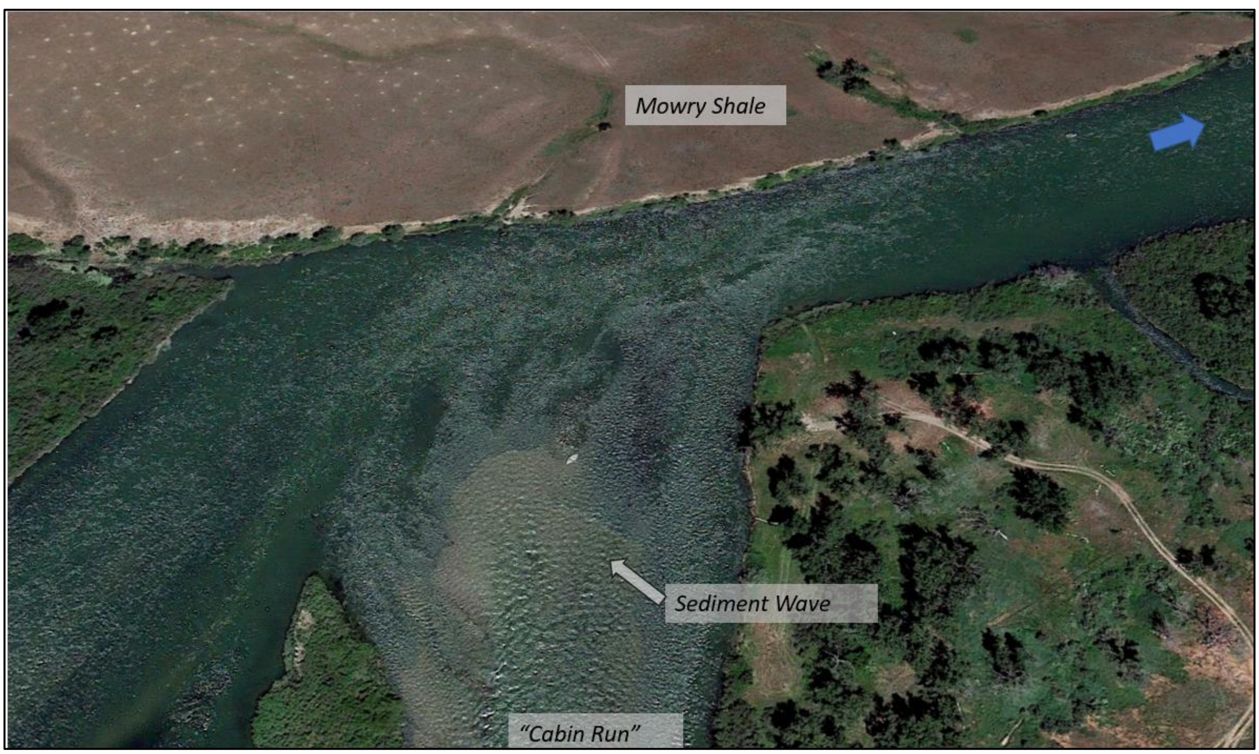

Figure 37. Google Earth image showing river hitting erosion resistant Mowry Shale unit; note sediment wave pattern on lower end of Cabin Run; the light spot at end of wave is a drift boat.

Table 4 provides a summary description of major Reach BH2 side channels as observed in the field and on imagery.

Table 4. Summary of observations regarding major side channels in Reach BH2.

Channel	River Mile (Left or Right)	Comments
Duck Blind	RM 78.7 L	Perennial, approximately 0.5 miles long and 130 feet wide, separated from river from ~900-ft wide forested island. Persistent since 1939. Some bank erosion recruiting gravels. Seasonal channel through island has created a broad 1.3-acre emergent wetland/slough complex.
Picture	RM 77.3 L	With river at 3,200 cfs, about 0.5 feet of water depth at entrance. Channel is 0.6 miles long and 50 feet wide. The entrance has been opened up since 2005. Seasonal channel in 1939.
Juniper	RM 76.3 R	Seasonal channel, 0.3 miles long and 85 feet wide. Entrance blocked by cobbles at 3,200 cfs; but standing water indicates good potential connectivity below. Some disturbance evident in recent years via open gravel bar formation. Persistent as seasonal channel since 1939.
Snyder's	RM 75.1 R	Meander bend that cut off sometime prior to 1939. Main channel is substantially steeper, and crosses Bighorn Rapids.
Cline's	RM 74 L	Left bank anabranch opened up in 2012, excavated about 1.5 feet down over 80 feet of length. Just over a mile long. Carrying about 30 cfs when Bighorn River flows at 3,200 cfs.
Soap Creek	RM 74 R	Across from Cline's channel, wide split flow segment that was established by 1961. Some open bar formation over last decade on margin.
African Queen	RM 73.2 R	Head of channel is at "little Bighorn Rapids", indicating potential bedrock control on flow split. Some recent bar formation in channel. Floatable when Bighorn is at 3,200 cfs.

4.3 Reach BH3: Bighorn FAS to Mallard's Landing FAS

Between Bighorn and Mallard's Landing Fishing Access Sites, the Bighorn River continues to follow the western bluff line, which consists of Upper Cretaceous Belle Fourche Shale overlain by young alluvial terrace deposits (Figure 38). The shale is described as dark grey with numerous bentonite beds (Vuke, et. al, 2007). Prior to the completion of Yellowtail Dam in 1967, the river was highly dynamic with extensive side channels and active lateral migration. Channel migration has been minimal since then. In recent decades islands have become stabilized by woody vegetation, and in some cases slightly expanding in the downstream direction.

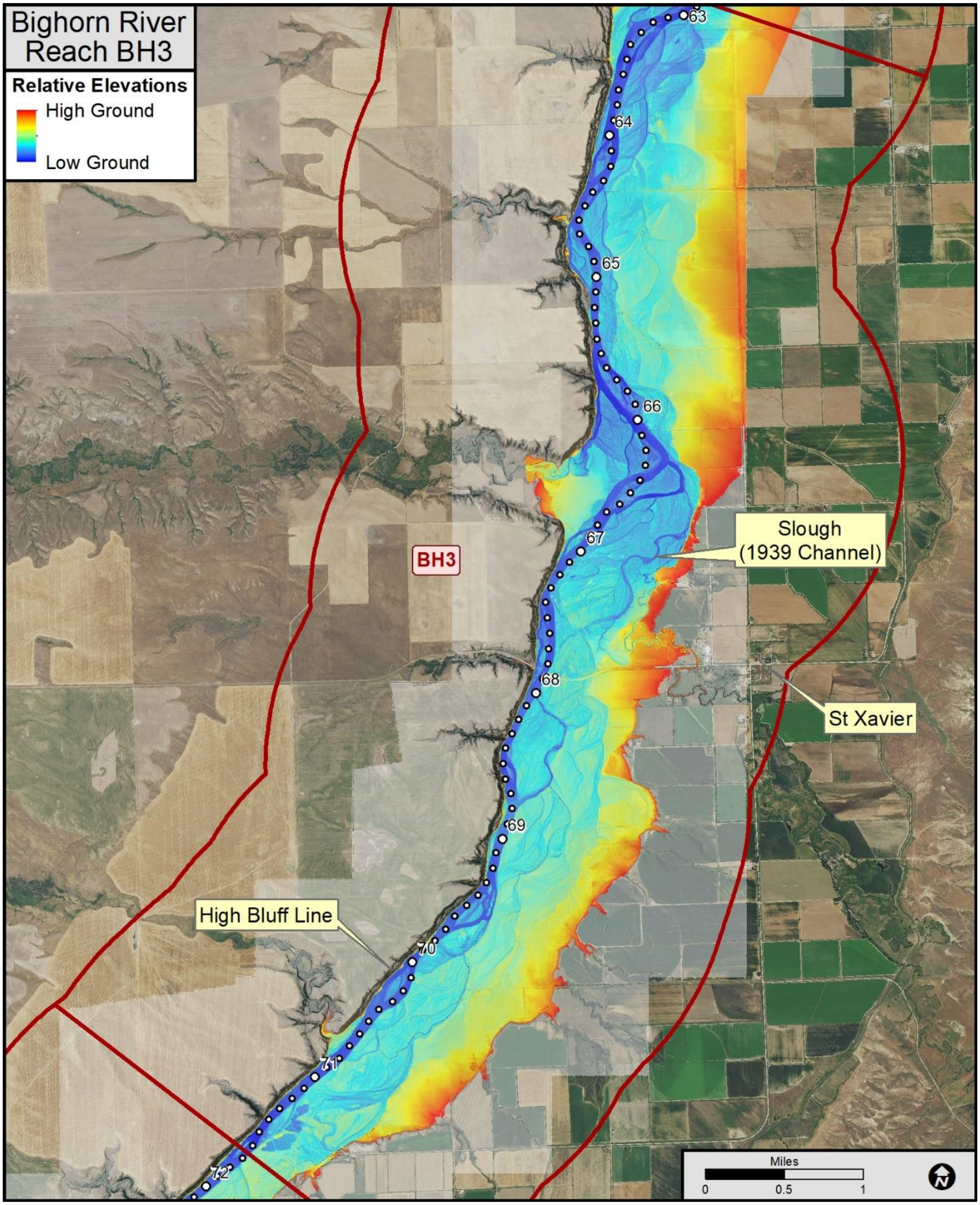

Figure 38. Reach BH3 showing relative elevations and major features.

Although rates of channel movement have been lower since the completion of Yellowtail Dam, there is sufficient sinuosity to impart some channel movement. Right below the St Xavier Bridge, for example, the construction of a series of homes exceedingly close to the river (one within about 50 feet) has resulted in the construction of a series of barbs along that bankline (Figure 39).

Figure 39. View downstream of barbs protecting homes just below St. Xavier Bridge.

The most striking geomorphic change evident on the historic imagery is the loss of several miles of side channel since 1939 right at St. Xavier. These long anabranches were fully active in 1939, and then progressively decayed since then (Figure 40). The lowermost side channel remnant is occupied by Rotten Grass Creek. This shows a major shift in overall channel type with time, from a complex anabranching (multiple channels with forested islands) river before Boysen/Yellowtail Dam construction, to a predominantly single thread channel with minor island complexes. One long slough that has formed in the old channel remnant is currently blocked by roads that access the homes at St Xavier described above.

Other observations from the recent imagery include the presence of dense Russian olive on the bankline, and low densities of floodplain cottonwoods.

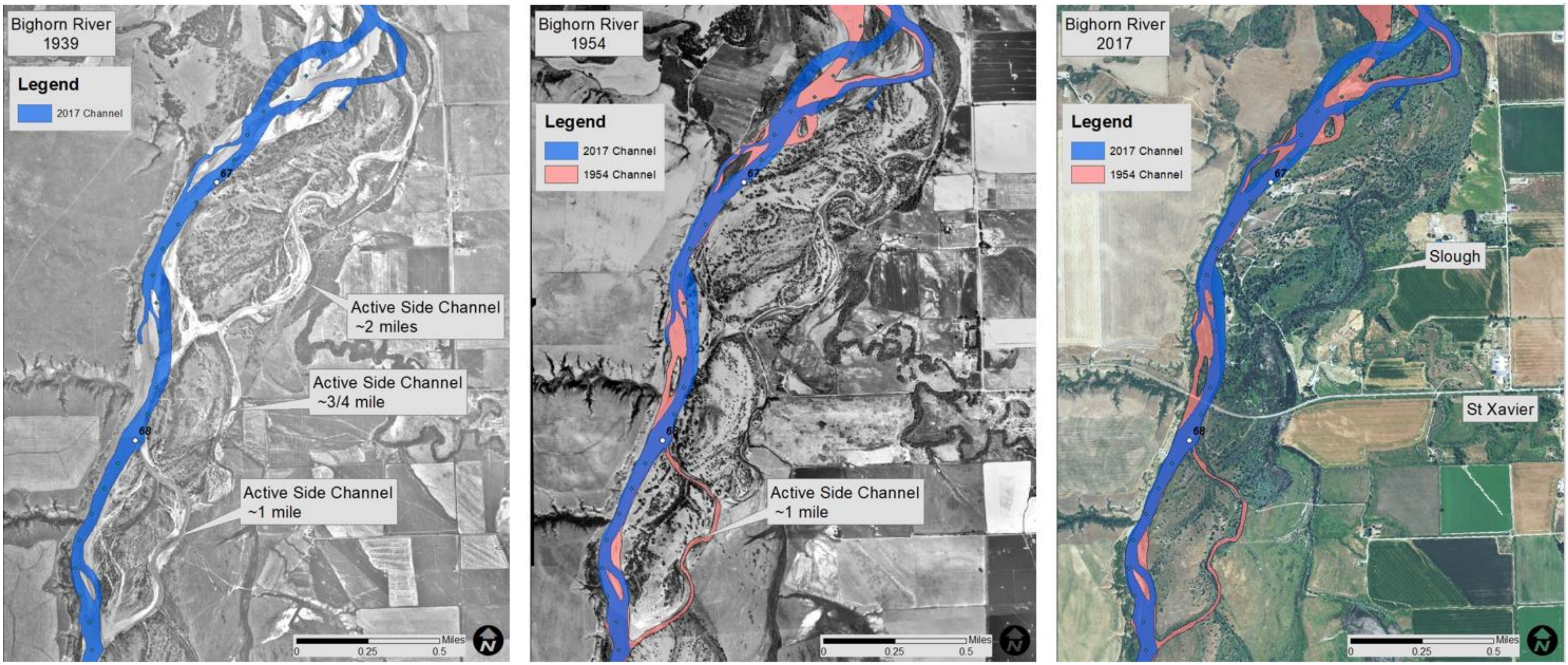

Figure 40. Progressive loss of several miles of side channels near St Xavier between 1939 (left) and 2017 (right)—flow direction is to north.

4.4 Reach BH4: Mallard's Landing FAS to Two Leggins FAS

Reach BH4 extends from Mallard's Landing to Two Leggins Fishing Access and is 10 miles long, flowing primarily against the western bluff line (Figure 41). The bluff consists of Carlisle shale, described as a very dark shale with bentonite beds (Vuke, et. al, 2007). It is capped by younger alluvium.

This reach has several complex island segments, which formed primarily with vegetation expansion since 1950. One example of a side channel blockage is evident in the middle portion of the reach, where a road has blocked a channel (Figure 42). This channel has been slated for potential reactivation.

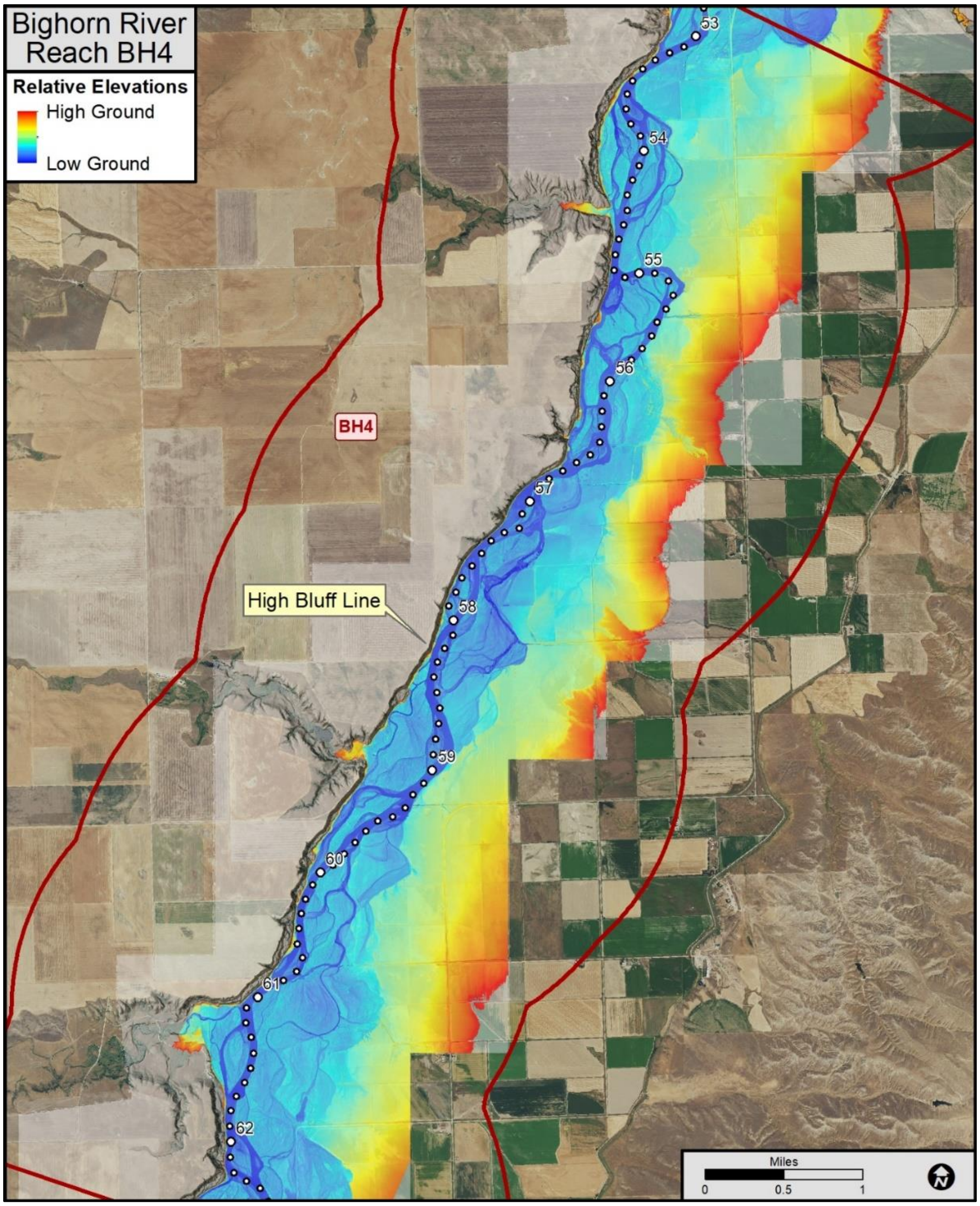

Figure 41. Relative elevations and major features, Reach BH4.

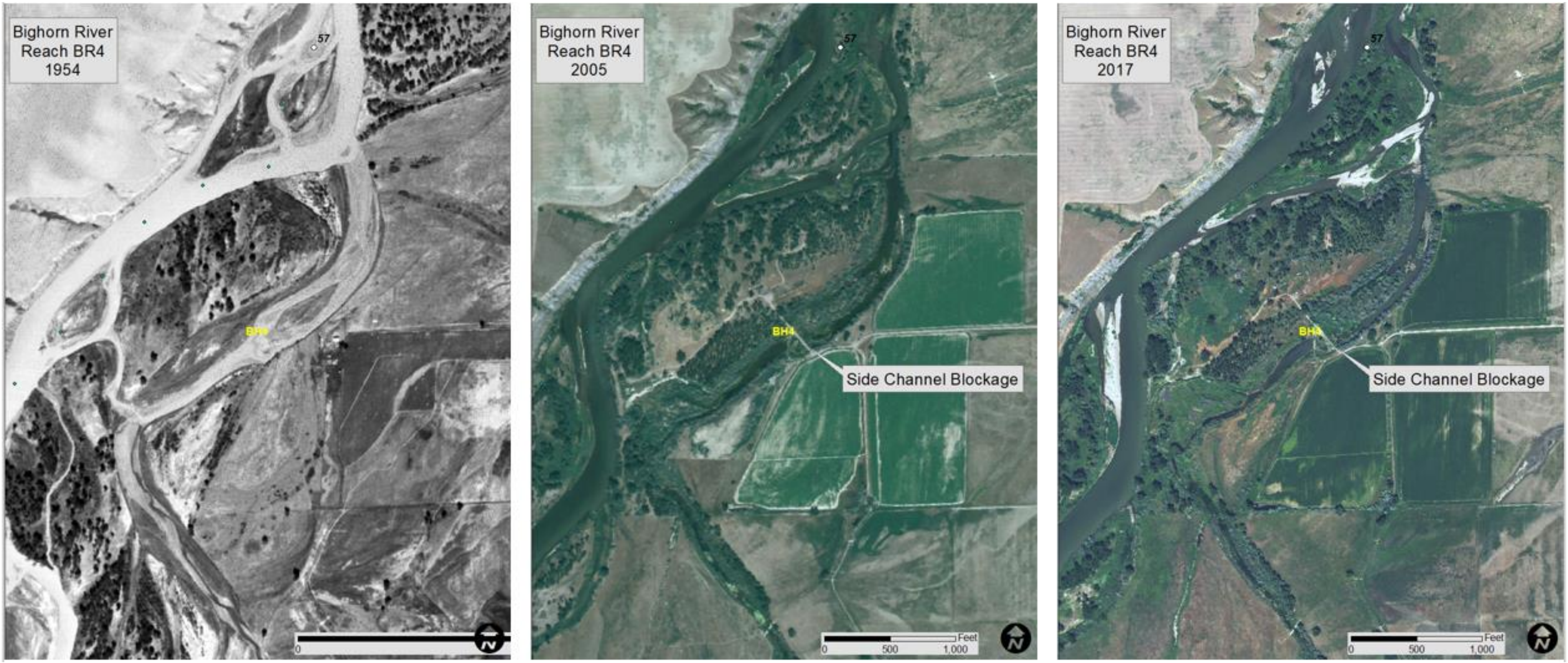

Figure 42. Side channel blockage at RM 57.3 sometime between 1954 (left) and 2005 (center)—flow direction is to northeast.

4.5 Reach BH5: Two Leggins FAS to Little Bighorn River near Hardin

At the Reach BH4/BH5 boundary, the Bighorn River crosses the valley to follow the eastern bluff line, which consists of Cretaceous-age Niobrara Shale (Figure 43). This unit is a dark brown shale with numerous bentonite beds (Vuke, et. al, 2007). Although the primary thread tends to hug the valley wall, in several locations, islands have formed that support persistent split flow. In the northernmost portion of the reach near Hardin, a 1956 side channel that was about a mile long has progressively decayed and lost its definition with floodplain development (Figure 44).

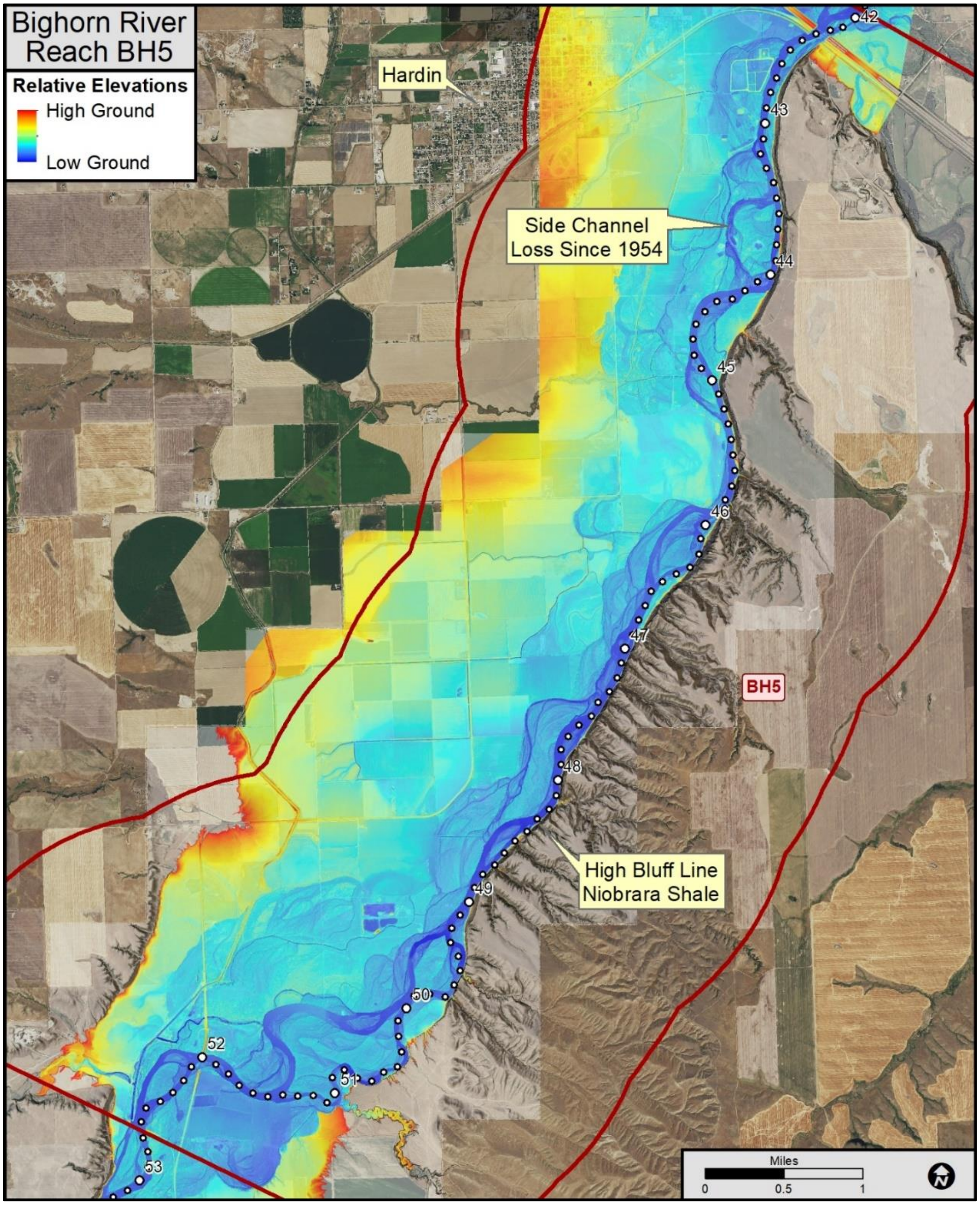

Figure 43. Relative elevations and major features, Reach BH5.

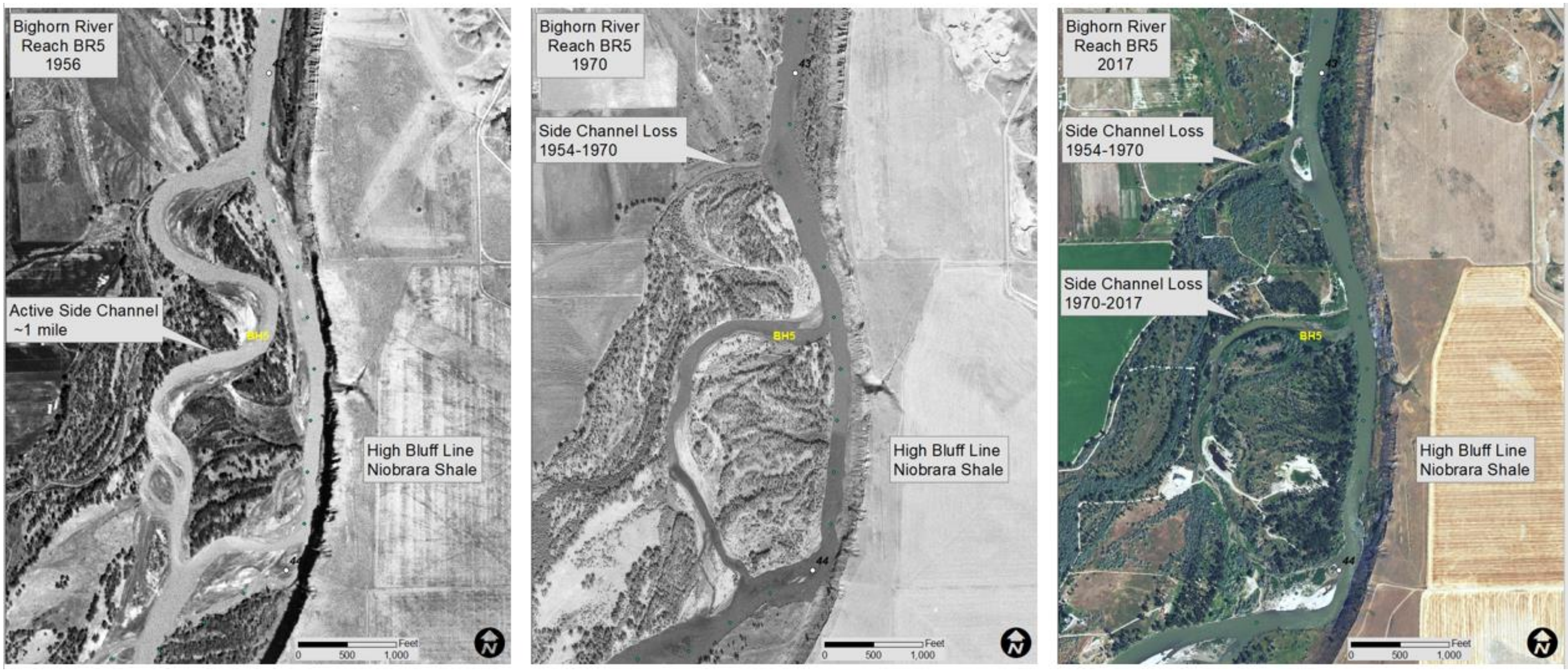

Figure 44. Progressive loss of a ~1 mile long side channel in northern portion of Reach BR5—flow direction is to north.

4.6 Reach BH6: Little Bighorn River near Hardin to General Custer FAS

Reach BH6 (Figure 45) is the first channel segment below the mouth of the Little Bighorn River. It is 17 miles long. Similar to most other reaches, long segments of the river closely follow the valley wall, which in this area consists of Cretaceous-age Bearpaw Shale (Vuke, et. al, 2007). This unit consists of dark interbedded siltstone and fine sandstone, reaching thicknesses of 860 feet. This is the first reach below Yellowtail Dam that shows meander development and associated channel migration, which likely reflects the sediment and flow inputs from the Little Bighorn River. Figure 46 shows a series of three meanders progressively developing since 1950, with several hundred feet of migration occurring on each.

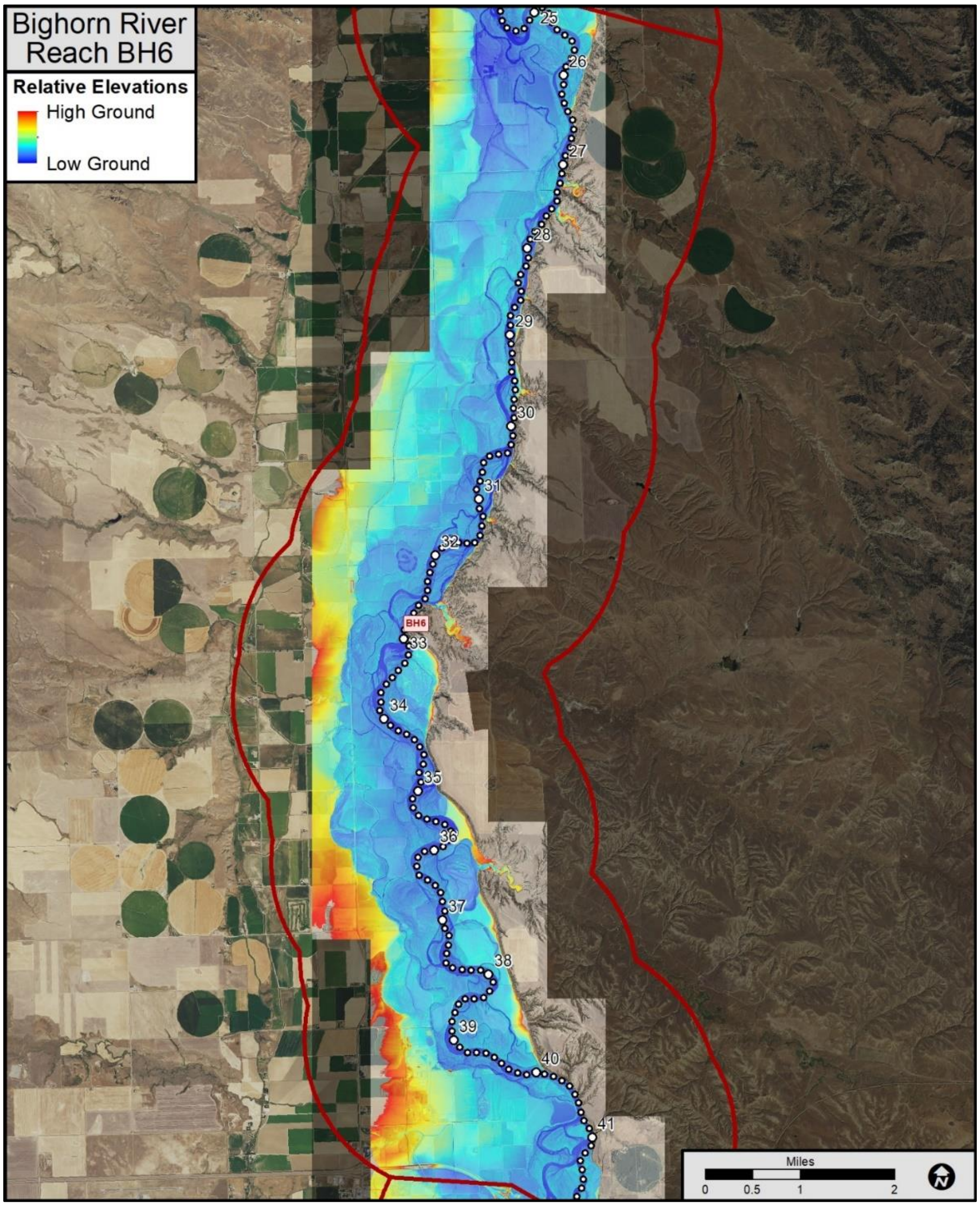

Figure 45. Relative elevations and major features, Reach BH6.

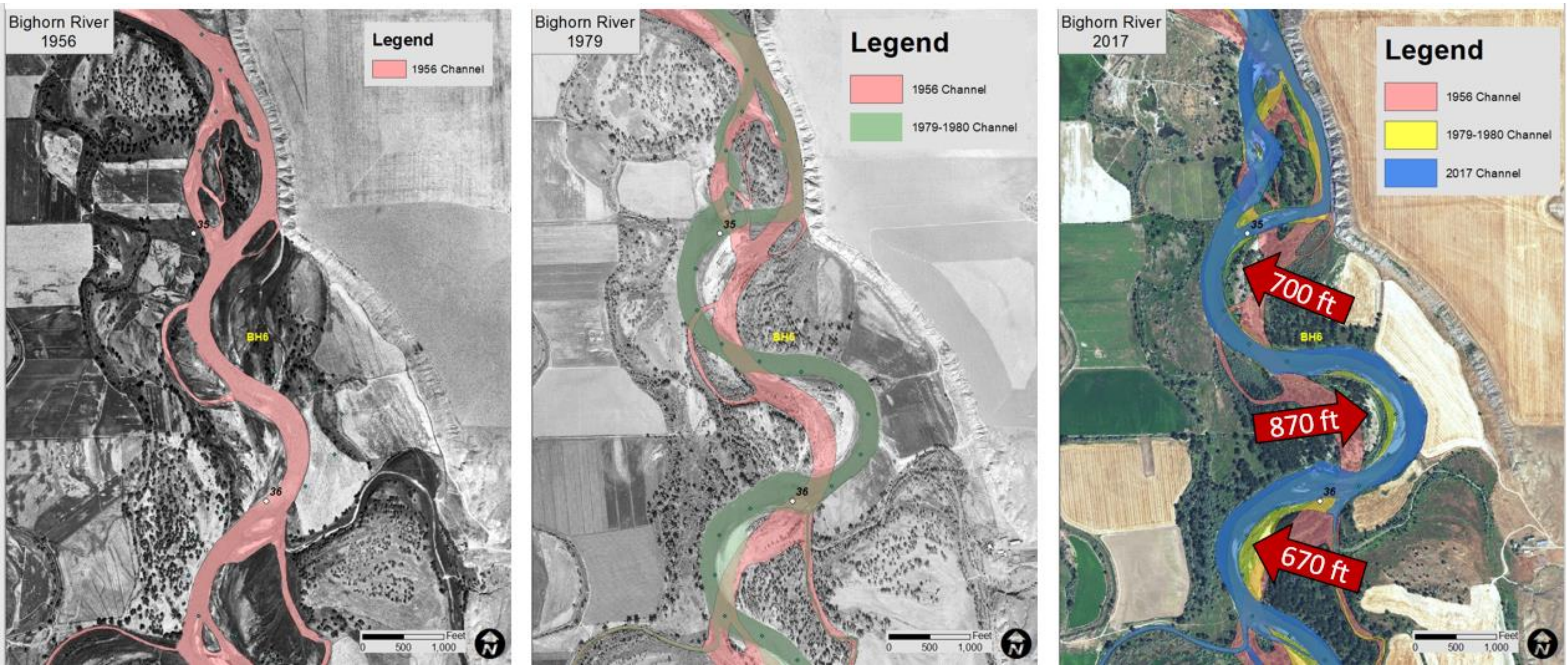

Figure 46. Channel migration and meander development in Reach BH6 since 1956—flow is to north

4.7 Reach BH7: General Custer FAS to Yellowstone River Confluence

Reach BH7 is about 24 miles long and extends to the mouth of the Bighorn River (Figure 47). Within this reach the river intermittently flows against sandstone rather than shale with the Lance Formation forming the valley wall for much of the reach. This unit also contains some conglomerate (Vuke, et al, 2008).

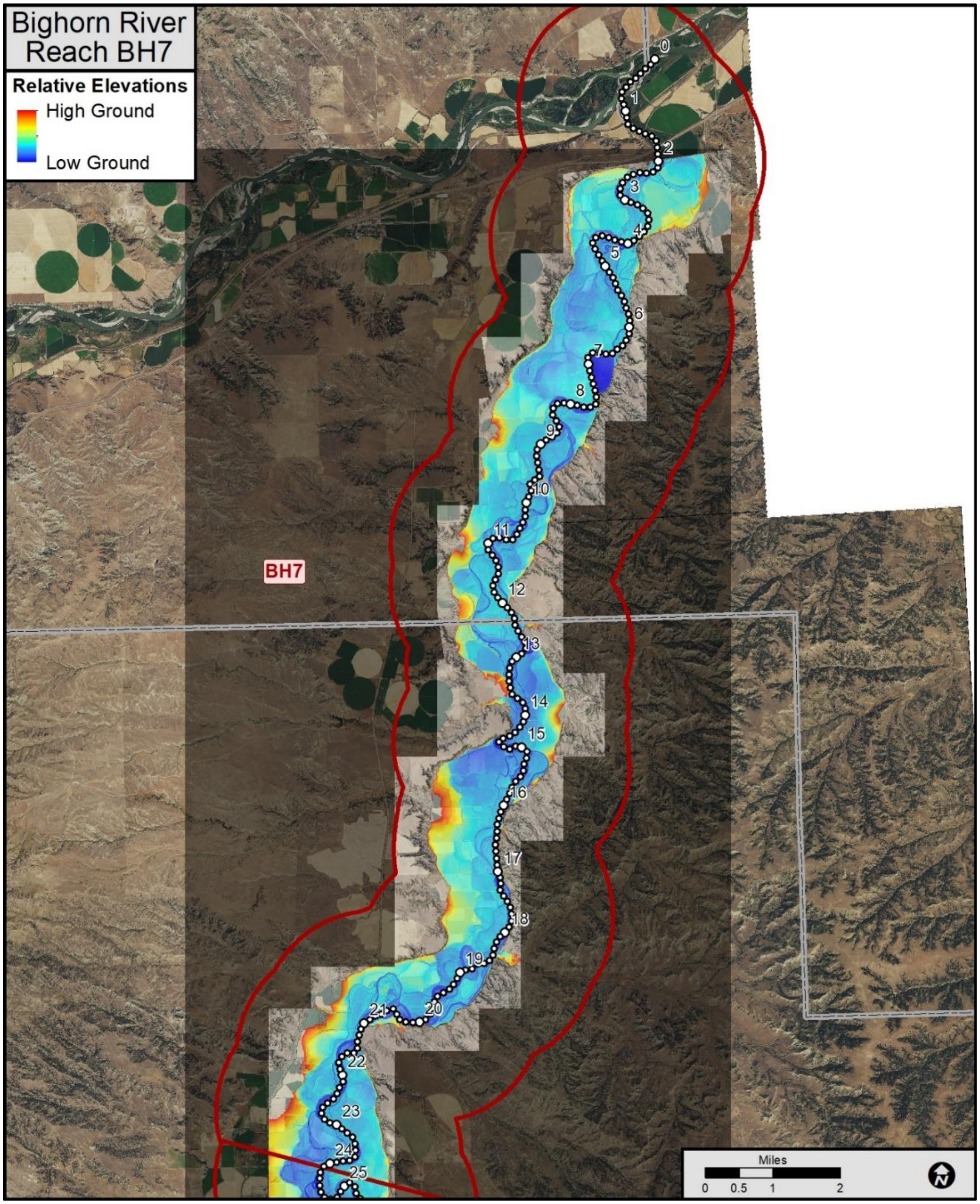

Figure 47. Relative elevations, Reach BH7.

Where the river follows the valley wall, migration rates tend to be low, however there are several areas where large, rapidly migrating bendways have formed away from the valley margin. One area of special concern is at RM 19, where a northward-migrating bendway has encroached into an irrigated field that has a massive power line tower currently sitting on the edge of the stream bank (Figure 48 and Figure 49). This bend has migrated over a thousand feet in the last 70 years, averaging over 14 feet of movement per year for 7 decades. Although several bendways are armored in Reach BH7, bankline erosion control is still relatively rare. As a result, the cottonwood forest appears much more robust and inherently sustainable relative to upstream reaches.

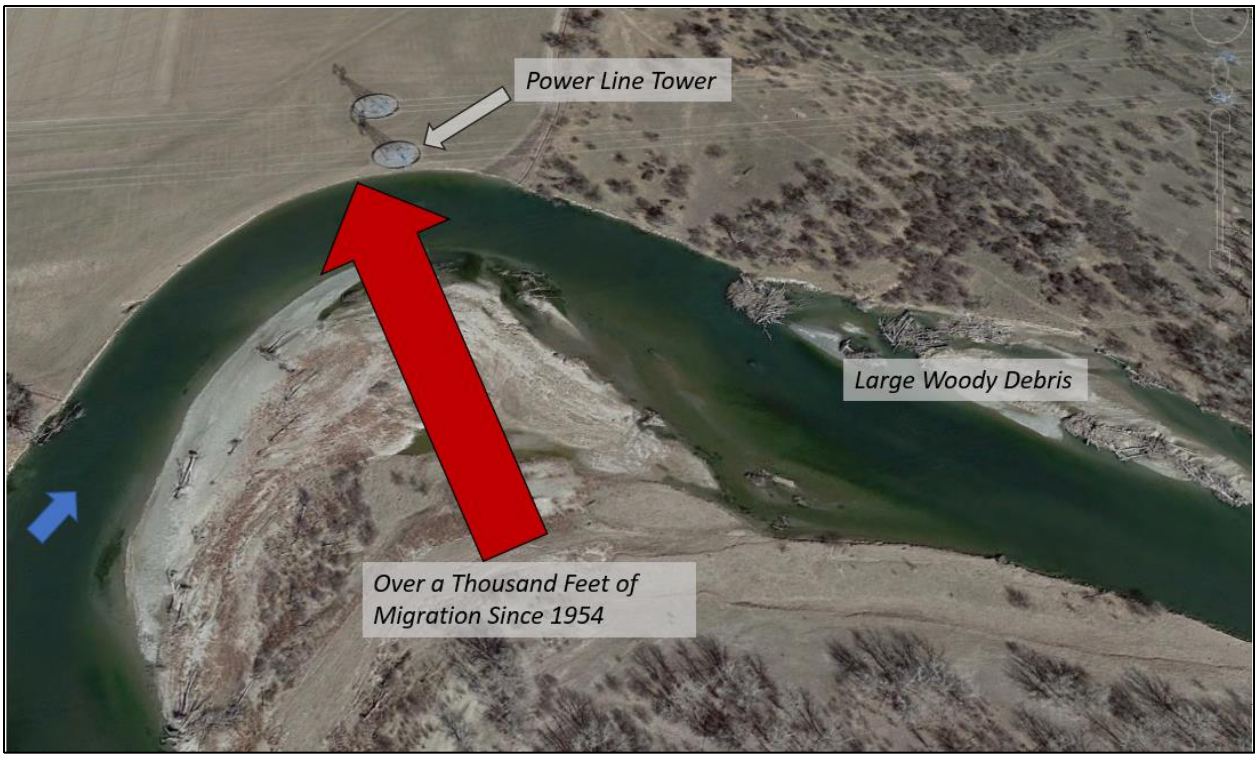

Figure 48. Google earth oblique view of rapidly migrating bendway and treat to power line tower, RM 18.8.

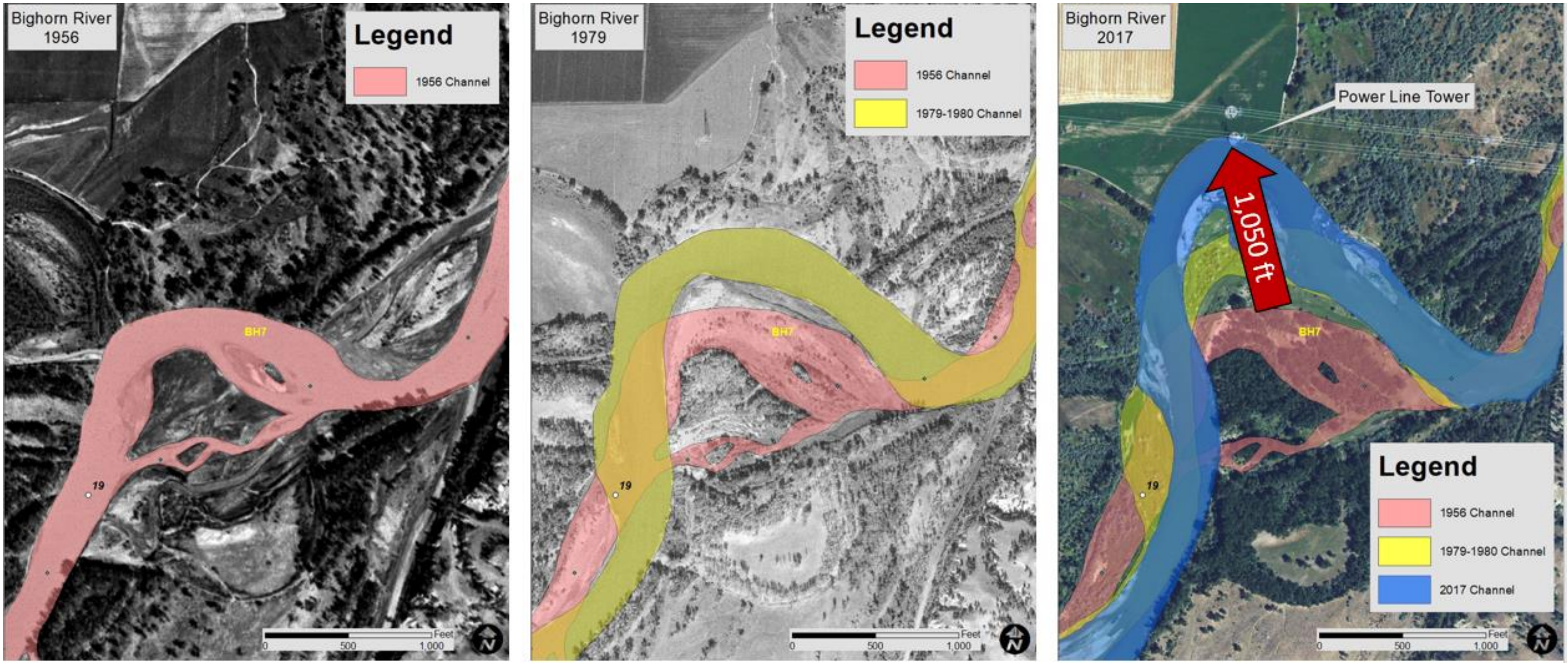

Figure 49. Northward migration of a large meander into a power line tower from 1956 to 2017; bank has moved over a thousand feet into infrastructure/irrigated field. Flow is to northeast.

5 References

Boyd, 2019. Bighorn River Alliance Research Initiative—Characterization of Bighorn River Hydrologic Alterations below Yellowtail Dam: Report prepared for Bighorn River Alliance, Sept 2019, 44p.

Vuke, S.M., E. M. Wilde, D. A. Lopez, and R. N. Bergantino, 2007. Geologic Map of the Lodge Grass 30'X60' Quadrangle, Montana: Montana Bureau of Mines and Geology Geologic Map Series No. 56.

Vuke, S.M., E. M. Wilde, Dand R. N. Bergantino, 2007. Geologic Map of the Hardin 30'X60' Quadrangle, Montana: Montana Bureau of Mines and Geology Geologic Map Series No. 57.

Vuke, S. M., E. M. Wilde, and R. N. Bergantino, 2008. Geologic Map of the Hysham 30' X 60' Quadrangle, Eastern Montana: Montana Bureau of Mines and Geology Open File Report 486.