THE RESEARCH INITIATIVE

2020

REPORT 6

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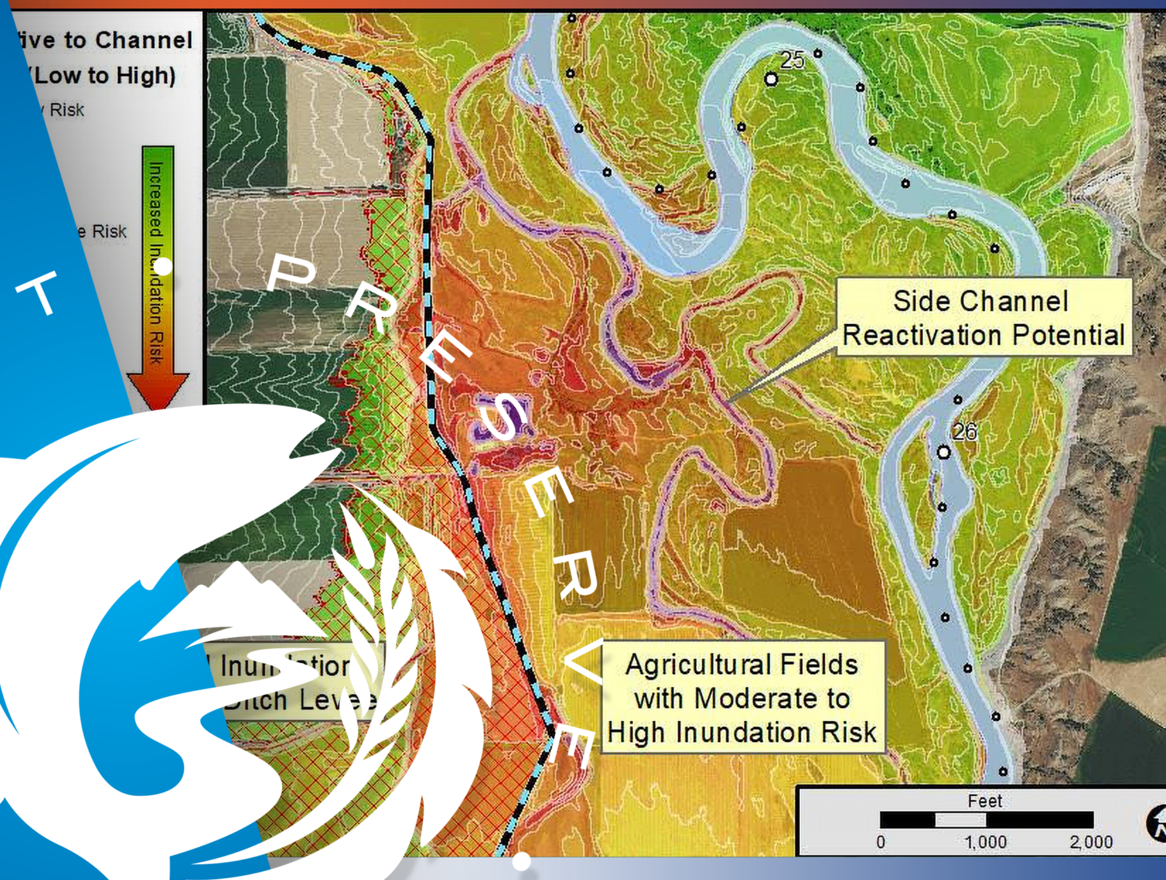

BIGHORN RIVER INUDATION RISK MAPPING

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1 Introduction

There has been a strong desire to assess flood risk along the Bighorn River corridor. Creating flood maps that are regulatory in nature is a costly process that relies on both elevation data and a calibrated hydraulic model. That said, the elevation data itself can be used to estimate extents of anticipated inundation based on river stage. The results help landowners understand the elevation of their properties relative to water surface elevations on the river and better understand risk.

To support the 2020 Bighorn River Alliance Research Initiative, a series of Inundation Risk Maps were generated for the river corridor from Yellowtail Dam to the Interstate 94 river crossing near the Yellowstone River confluence. This builds on work completed in 2019 to develop baseline data sets and assessments of conditions in the corridor. The primary goal is to develop a series of maps depicting relative levels of inundation risk posed by river flooding. These maps should not be confused with flood mapping that relies on calibrated hydraulic modeling. They are intended to act as a tool to help river and land use managers, both public and private, better understand potential risks from overbank flow. These maps can be used in conjunction with other resources such as the Channel Migration Zone Mapping (AGI/DTM, in progress) to make informed management decisions.

The mapping is based on Relative Elevation Modeling (REM) of the river corridor using 2018 LiDAR data collected by Woolpert for the Montana Natural Resource Conservation Service and the United States Geological Survey (USGS 2019).

1.1 Study Area

The study includes approximately 83 miles of river (Montana Fish Wildlife & Parks stream stationing) from the Afterbay Dam to the Interstate 94 bridge one mile upstream of the Yellowstone River confluence (Figure 1).

1.2 Deliverables

The primary deliverables associated with this work scope include:

- GIS Data – All compiled GIS spatial data sets will be delivered or made available in ESRI Geodatabase, Shape File, or image formats. The LiDAR data and associated REM are very large data sets and not easily transferable except on external hard drive.
- Summary Report – A short 2-page summary of objectives, findings and implications of this work scope.
- Full Report – This document represents a full documentation of this work scope.
- Bighorn River Inundation Atlas – A PDF version of the 24 page Inundation maps.

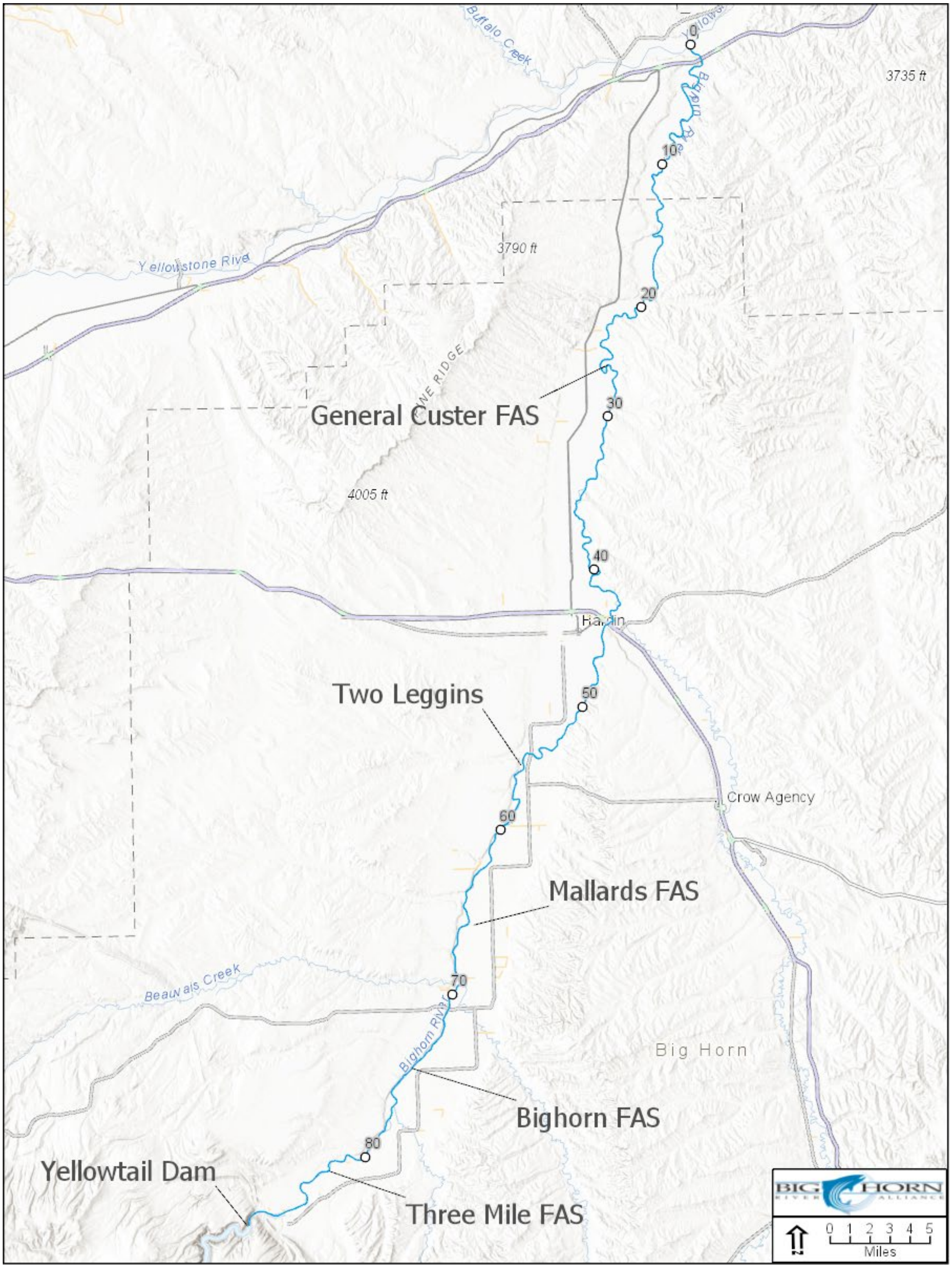

Figure 1. Study area.

2 Data

The Inundation Risk Maps relied on existing and new data sets created for this study.

2.1 LiDAR Elevation Data

LiDAR elevation data collected on July 12 and 13, 2018 (USGS, 2019) was the primary data set used for the inundation modeling. The LiDAR elevation data represents “bare earth” conditions at the time of imagery collection. As such, any vegetation or structures above the ground surface are digitally removed to produce a Digital Elevation Model (DEM) that captures true ground elevations. The LiDAR collection system relies on laser light that cannot penetrate water surfaces, so a secondary process is used to fill in the blank water areas of the bare earth DEM to create consistent elevations from bank to bank across water bodies. Thus, within the channel banks the DEM represents the water surface elevation at the time of data capture.

2.2 Relative Elevation Model (REM)

Relative Elevation Modeling is an analysis technique used to highlight the relative elevations of terrain adjacent to a river channel. This analysis and visualization technique is useful for a number of tasks such as identifying perched or inset channels, historic sloughs or meander bendways where the river might abandon the current channel in favor of a new flow pathway, and terrain visualization. A REM can also be used to approximate the potential inundated area at a given flood stage. While this is not equivalent to using a calibrated flood water model, it can be a useful tool for understanding where water may end up as water levels rise.

Relative Elevation Models (REM) are created by normalizing the elevation data set (LiDAR data) to the approximate the trend of a water surface in a stream. The resulting data displays areas above the river grade as positive values and areas below the river grade as negative values. There are several methods available for generating a REM. The cross section method is best suited to rivers with sinuous channels such as the Bighorn River.

The cross section method relies on defining cross sections that span the valley bottom at consistent spacings along the channel. These cross sections are augmented with additional cross sections at key locations such as tributary confluences, bridges, constrictions, or slope breaks. Each cross section is assigned the lowest elevation where the cross section intersects the stream channel (Figure 2). This elevation value is assumed to be the water surface elevation for that cross section. The cross sections are connected to create a TIN (Triangulated Irregular Network) surface that approximates the water surface between each cross section. The TIN is then subtracted from the original elevation data set. The resulting data set represents the difference in elevations between the actual elevation and the water surface elevation as it extends laterally away from the river.

A preliminary REM from Yellowtail Dam to the lower end of the LiDAR data at the Interstate 94 bridge was created as part of the 2019 Bighorn River Alliance Research Initiative Spatial Information work task (Thatcher, 2019) to aid in characterizing the conditions in the river corridor. This REM was updated with additional cross sections and a more detailed examination of water surface elevations to create a more detailed REM for the inundation risk maps.

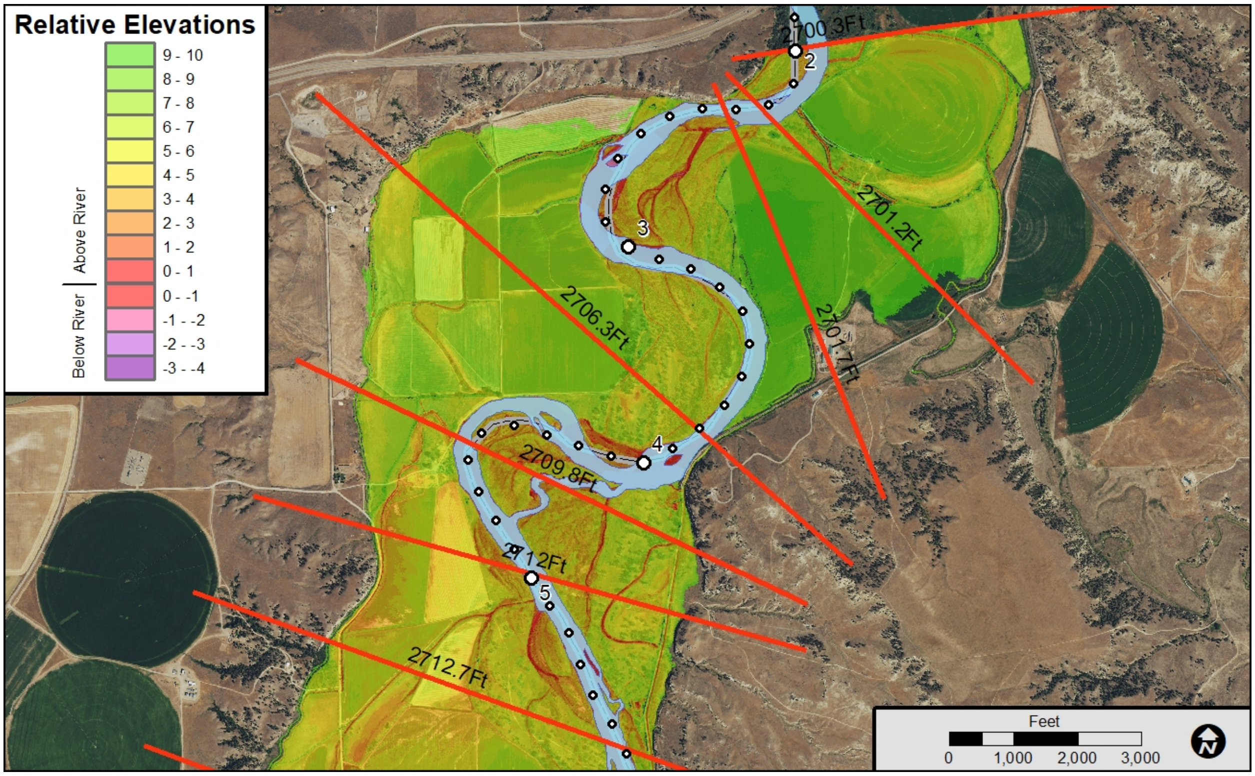

Figure 2. REM map showing cross sections and labeled with the elevation where it crosses the river.

2.3 Inundation Risk Maps

Inundation risk maps should not be confused with flood risk mapping such as FEMA Flood Risk maps. Traditionally, flood mapping is regulatory in nature and used to define flood risk at a specific discharge for insurance purposes or to restrict development in flood-prone areas. While inundation risk maps are similar in nature in that they attempt to define areas that may get wet as river flows increase, flood mapping is based on intensive hydraulic modeling efforts that take into account changes in discharge along the stream corridor, backwater effects caused by changes in slope or bridge constrictions, floodplain roughness created by vegetation and other variables. Inundation risk maps are based entirely on a location's elevation relative to the adjacent channel as defined by a Relative Elevation Model (REM). They are non-regulatory and are intended to help educate land managers about risk to land and/or infrastructure due to overbank flows. When used in conjunction with other information such as Channel Migration Zone (CMZ) mapping, land managers can make informed decisions about how best to live with the river.

The revised Relative Elevation Model (REM) (Section 2.2) was used to define inundation risk for the Bighorn River. A review of stage discharge relationships for the three USGS Bighorn River gages was used to define a range of elevations relative to the LiDAR river elevations that may be at risk of inundation (Table 1). The LiDAR data was collected in July of 2017 when the river was flowing between 6,400 cfs at the Afterbay and 6,800 cfs just above the Yellowstone confluence. As each of the three gages on the river have a published rating curve, the LiDAR flows could be assigned a stage from each curve. A rating curve depicts the relationship between flow and river stage, although the stage value itself should not be confused with flow depth, as the rating curve may have an arbitrary scale range. To compare stage values between the LiDAR and higher discharges, the LiDAR stage at each gage was set to zero, and the stages at higher flows were compared to identify "height above lidar" for a given flood event. This allows a direct comparison of the water surface profile in the LiDAR to higher stages/floods. It must be kept in mind that the rating curves at any given point on the river will change due to local conditions, however, given the data we have in hand at present, the information derived from gaging stations provides an estimate of the ranges one might expect to see on the river for a given flow. For example, the stage above the LiDAR for a 5-year flood ranges from 3.0 feet at the lowermost gage near Tullock Creek to 1.8 feet at the St Xavier Bridge. Similarly, the stage above the LiDAR for at 10-year event ranges from 4.7 to 2.7 feet. The value of this is that it helps show the general range in stage increases for more frequent flood events. It also shows that once the floodplain elevation is more than about 6 feet higher than the LiDAR water surface, flood inundation should be relatively rare.

From this assessment, the 5-year flood stage is typically 2-3 feet above this elevation, and 10-year stage is typically 3-5 feet above (Table 1). The flood stage increases downstream due to the flows being greater. Published flood frequency values for the 25, 50, and 100-year events were only available for the gage at the Afterbay with a stage of approximately 6 feet for the 100-year event. As the gages tend to be located at bridges or fairly confined river segments, the river stage probably rises faster with discharges at the gages relative to other locations, making this risk assessment somewhat conservative. That said, areas within 2-3 feet vertical feet of the LiDAR stage are likely at substantial risk of flooding, whereas area more than 6 feet above the LiDAR stage are probably not.

Table 1. Stage above LiDAR calculations for Bighorn River gages.

	Event					
Afterbay (USGS 06287000)	**LiDAR**	**Q5**	**Q10**	**Q25**	**Q50**	**Q100**
Discharge	6,400	11,600	14,500	18,400	21,400	24,500
Stage	62.2	64.3	65.25	66.3	67.2	68.1
Height above LiDAR		2.1	3.05	4.1	5	5.9
St Xavier Bridge (USGS 06287800)	**LiDAR**	**Q5**	**Q10**	**Q25**	**Q50**	**Q100**
Discharge	6,400	11,600	14,500	18,400	21,400	24,500
Stage	8.6	10.4	11.3	N/A	N/A	N/A
Height above LiDAR		1.8	2.7	N/A	N/A	N/A
Tullock (USGS 06294500)	**LiDAR**	**Q5**	**Q10**	**Q25**	**Q50**	**Q100**
Discharge	6,800	14,600	20,300	29,800	38,700	49,500
Stage	4.2	7.2	8.9	10.5	N/A	N/A
Height above LiDAR		3	4.7	6.3	N/A	N/A

Based on this assessment, elevations within two to three feet of the LiDAR river elevation are described as relatively high risk, three to six feet are considered moderate risk, and above 6 feet are considered low risk. Elevations below the LiDAR river elevation are assumed to be at very high risk of inundation, as the river typically flows at 6,400 cfs for about two weeks to a month each year on average. Areas greater than 10 feet above the LiDAR river elevation were determined to be above any likely inundation scenario and thus excluded from the maps. These risks are presented as a color gradient on the maps as shown in the map legend (Figure 3).

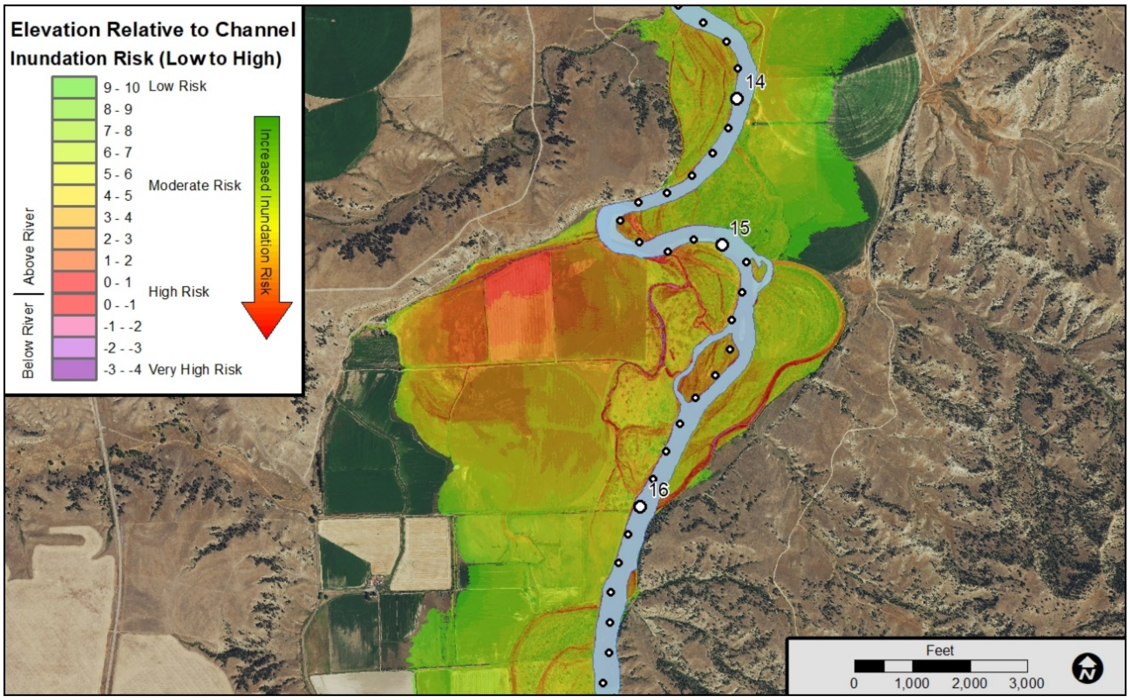

Figure 3. Inundation highlighting historic side channels on both sides of the river and low ground in agricultural field on the west side.

Additionally, one-foot contours were generated from the REM that represent equal elevations above the adjacent river elevation (Figure 4). These contours help to visualize the terrain variability and subtle differences in inundation risk.

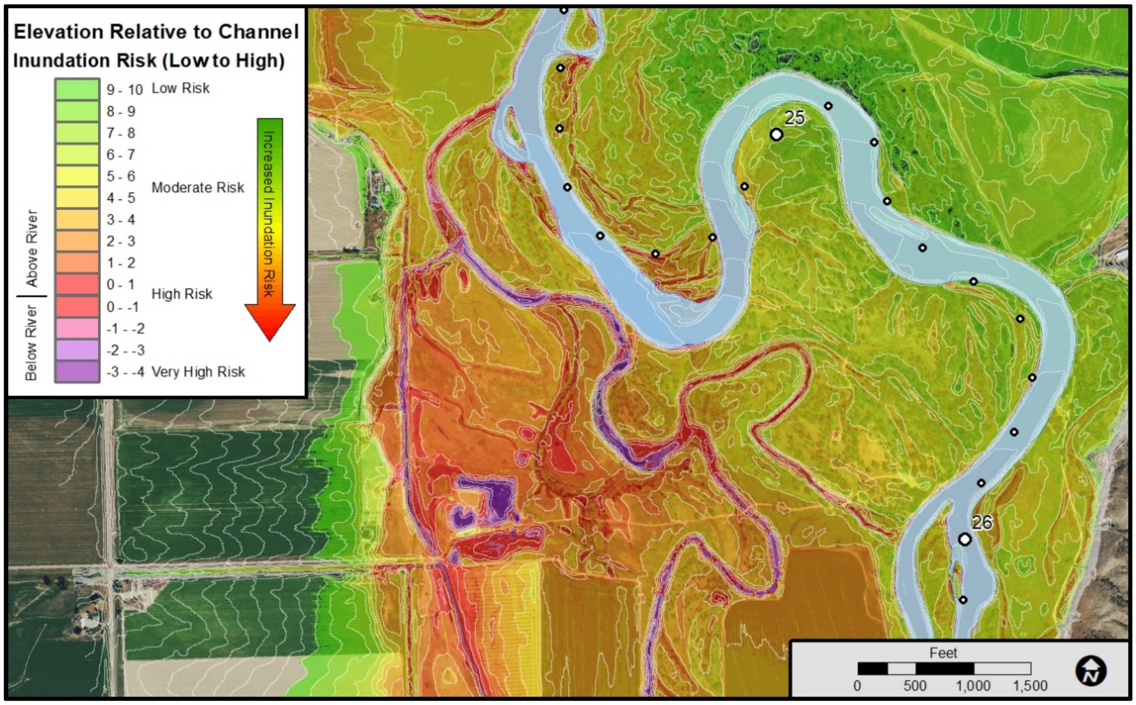

Figure 4. Part of an Inundation Risk Map for the lower river. White contour lines are 1 foot elevations relative to the river.

2.4 Floodplain Features and Restricted Inundation

Linear features on the floodplain such as road grades and ditch levees can have a large influence on inundation acting as barriers for overbank flows. Areas behind these features may have a lower risk of inundation depending on the height, construction methods, and breaks in the linear extent the feature. To address the influence of linear floodplain features on potential inundation, features running parallel or nearly parallel to the river corridor that were elevated above the surrounding land were mapped. These included road and railroad prisms, bridge approaches, canal levees or significant ditches that had associated berms. While no effort was made to assess the effectiveness of the floodplain features for restricting flows due to culverts or other breaks in the feature, areas behind mapped features were identified as potentially having "restricted inundation" (Figure 5).

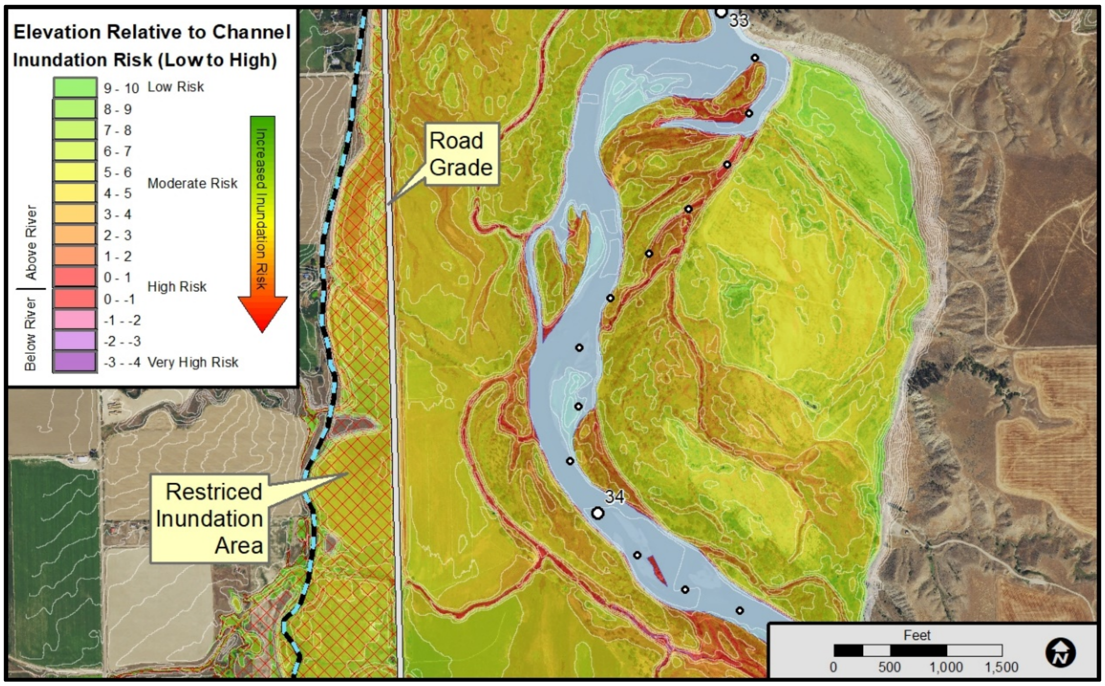

Figure 5. Part of an Inundation Risk Map showing an area of restricted inundation due to a road prism. A historic slough can be seen at the north end of the restricted inundation area.

3 Bighorn River Inundation Atlas

The resulting mapping was compiled in a series of 24 maps at approximately 1:18,000. An example map page is shown in Figure 6 below.

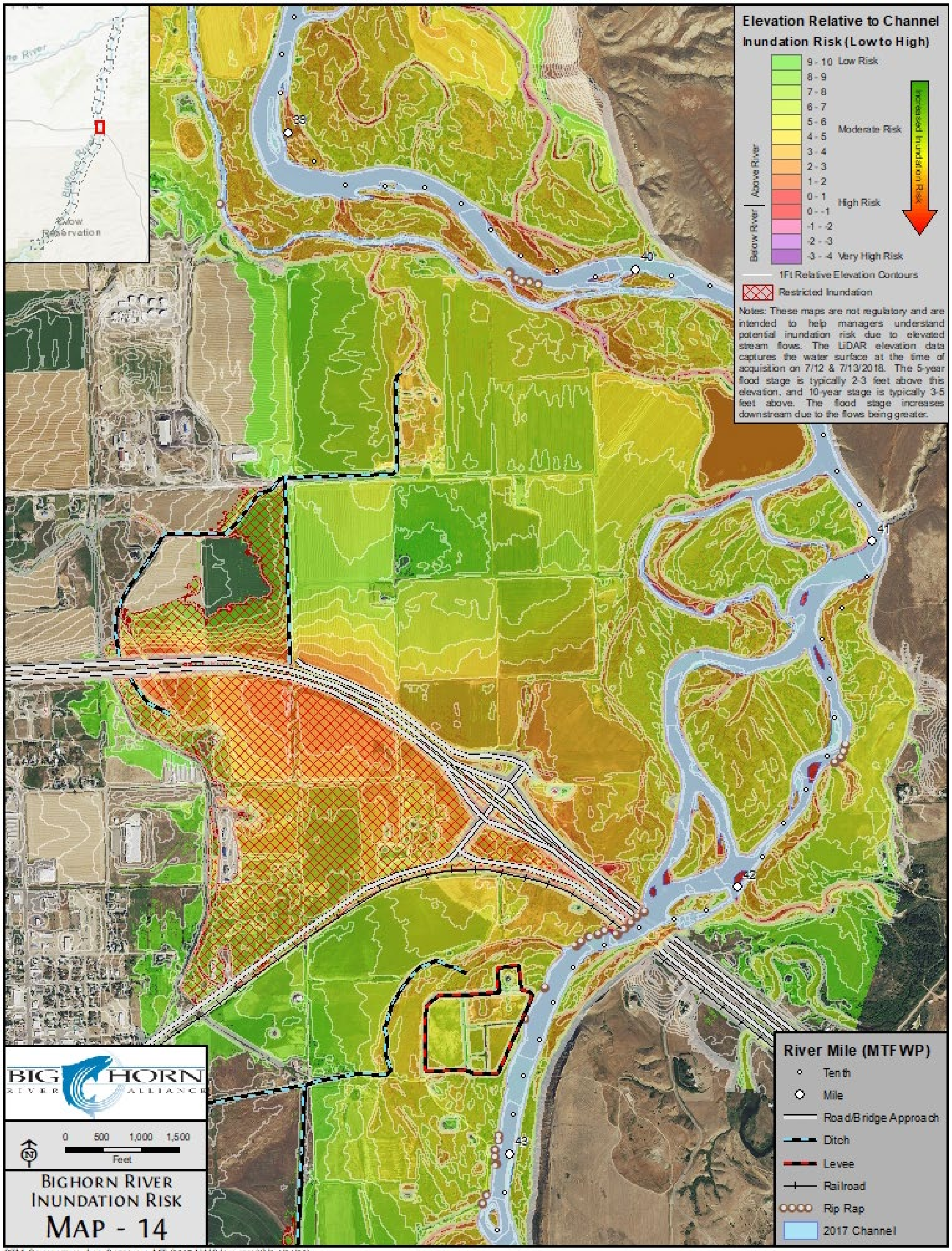

Figure 6. Example page from Bighorn River Inundation Atlas.

4 Understanding Inundation Risk Maps

Inundation risk maps are helpful for understanding how land adjacent to a river may be impacted by flooding. Generally speaking, the higher you are above the river, the less risk of that land being inundated by rising water. The risk maps are designed to highlight those areas at highest risk. These risks will change depending local geography, constrictions, and distance downstream from Yellowtail Dam. Areas with entrenched channels, high banks, or along terrace edges will be less likely to flood due to those channel controls, though these channelized flows will result in deeper and higher energy flows. Conversely, areas with broad open valleys and low banks are more likely to experience flood waters, though it will likely be more shallow and lower energy. Additionally, as flows increase downstream with tributary contributions, the depth of inundation will also generally increase due to the additional flow. So, for a given flood event (e.g., 20-year event), the stage will increase downstream, and thus the extent of inundation.

Aside from inundation risk, the low areas at high risk of inundation can help identify areas for side channel reactivation or riparian restoration. Everything that is purple/red should have good potential for riparian recovery. As additional data comes available, there is potential to better calibrate the inundation depths to actual flood events. This would require access to flood photos or hydraulic modeling.

The following annotated examples are intended to highlight different inundation scenarios. They are arranged from upstream to down.

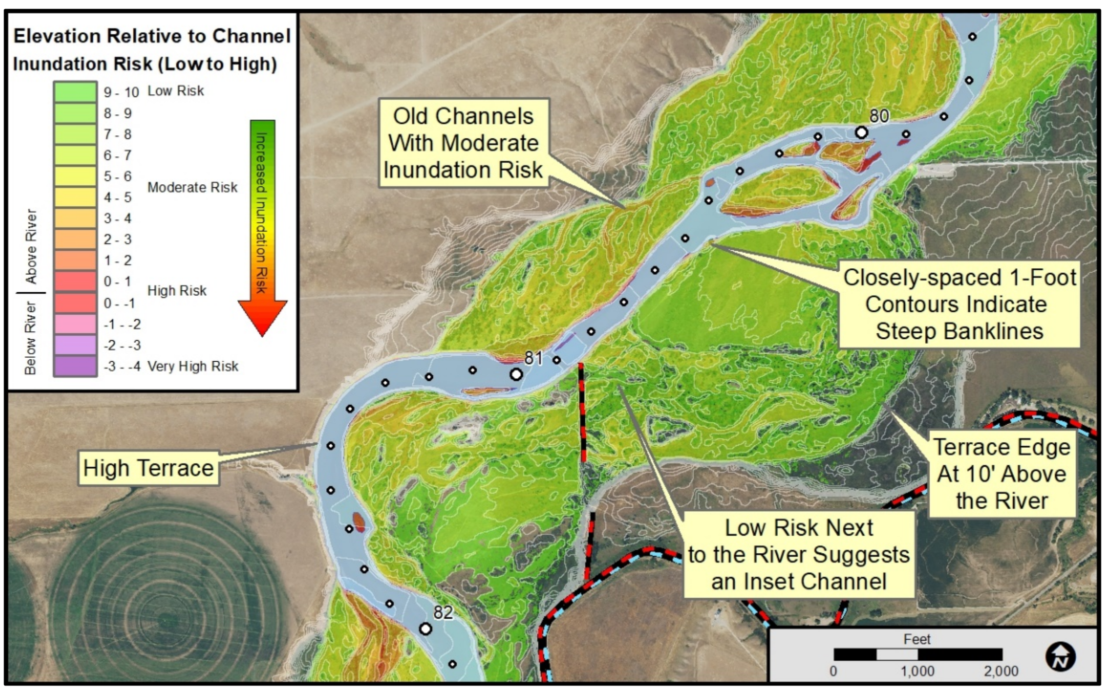

Figure 7. A variable width floodplain with elevated inundation risk limited to historic side channels.

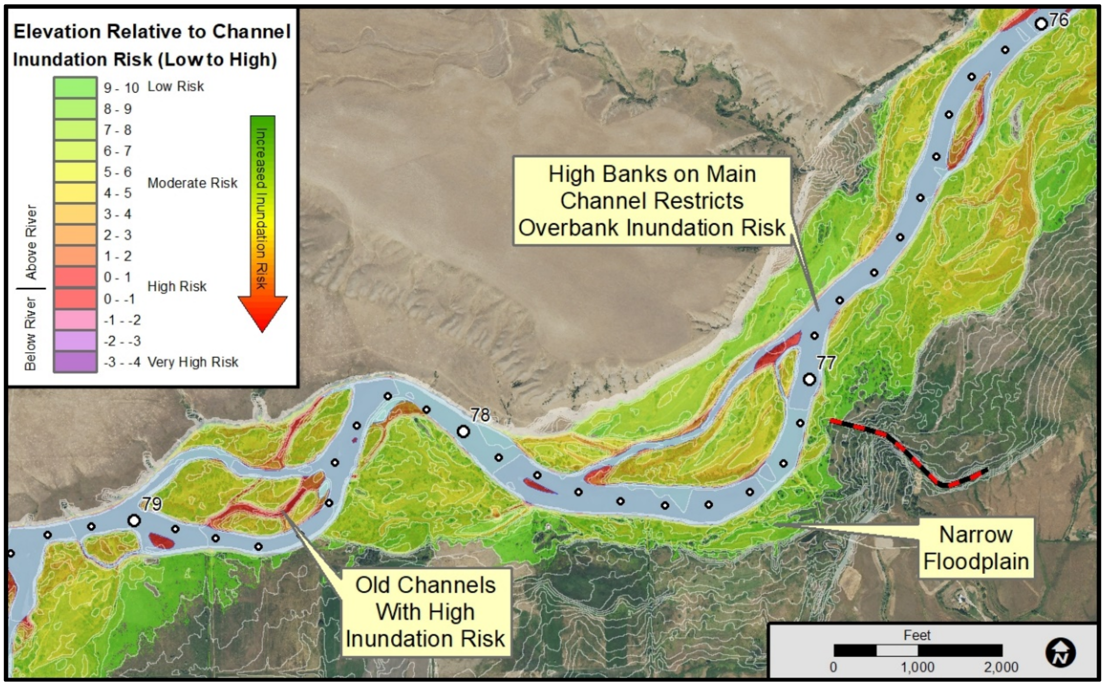

Figure 8. A narrow floodplain with only limited moderate risk away from the active channel.

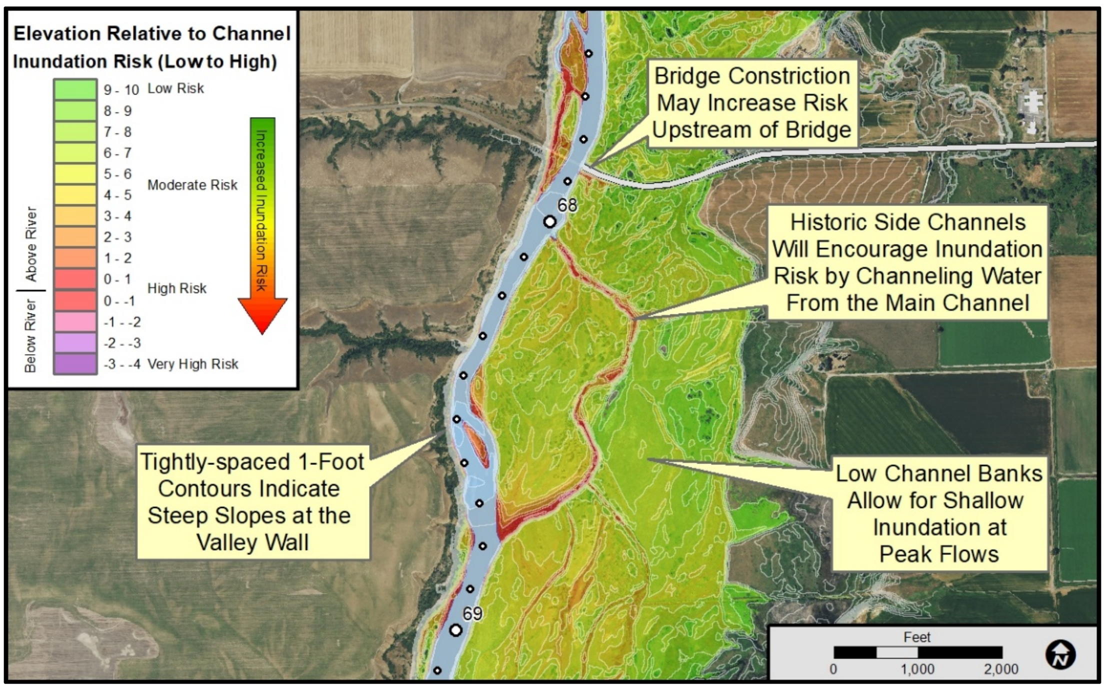

Figure 9. The eastern (right) bank shows areas of elevated inundation risk, mainly along historic channels. The bridge crossing and road grade may increase inundation risk upstream of the bridge due to backwatering.

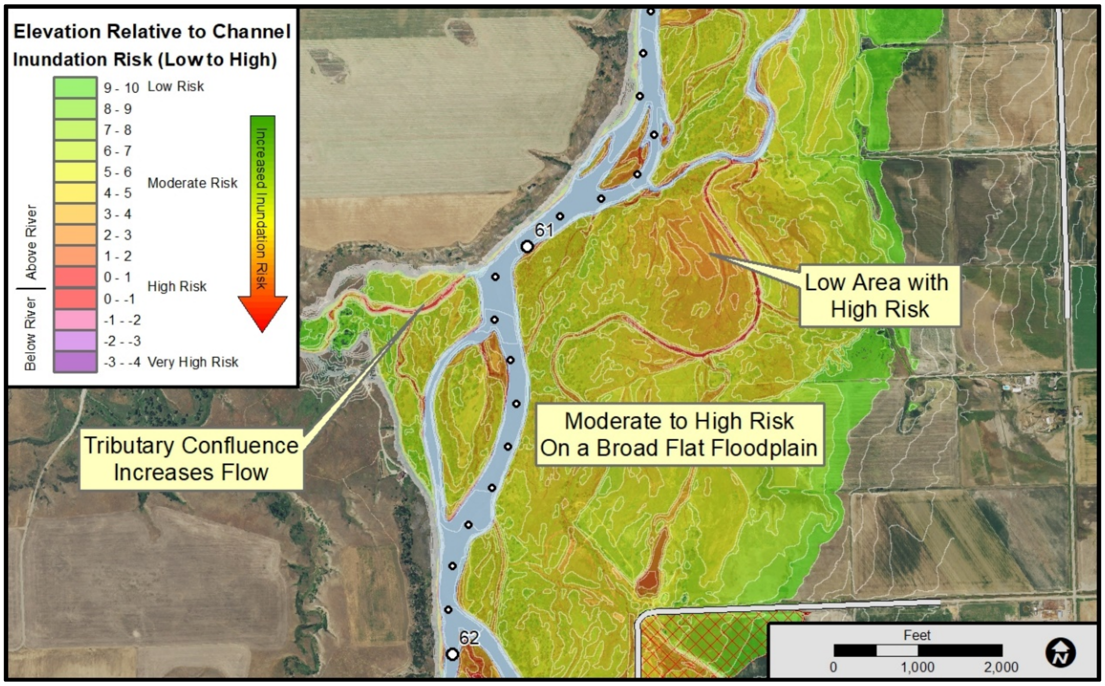

Figure 10. A low, flat floodplain on the east (right) side of the river with areas of high inundation risk. Tributaries add flow and will increase risk downstream of the confluence.

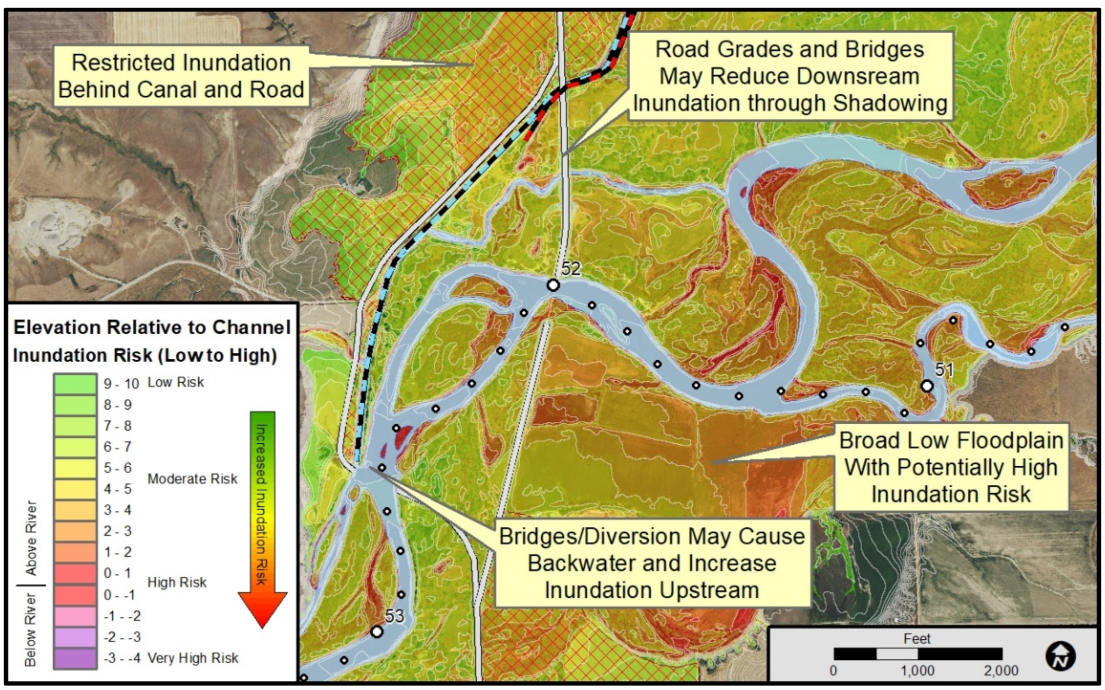

Figure 11. A broad, flat floodplain with extensive areas of high inundation risk. Road grades, canal levees and bridges will greatly impact inundation risk.

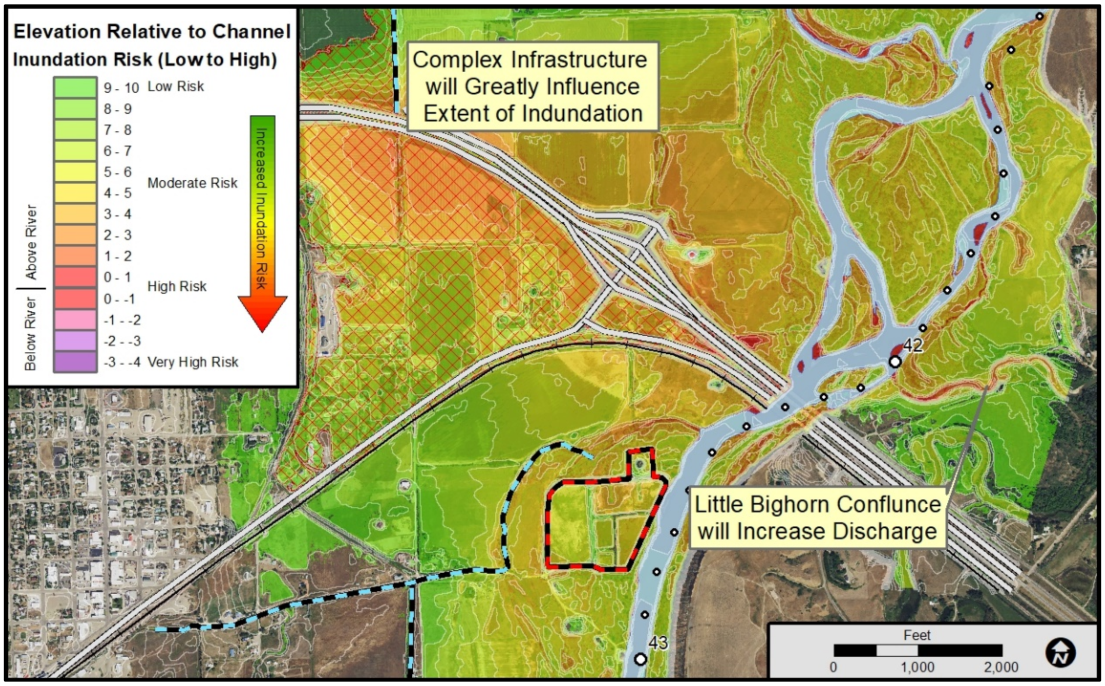

Figure 12. A complex network of transportation and agricultural infrastructure at Hardin will influence where floodwaters can reach. The Little Bighorn River adds a significant amount of water, potentially increasing extent of high risk inundation downstream.

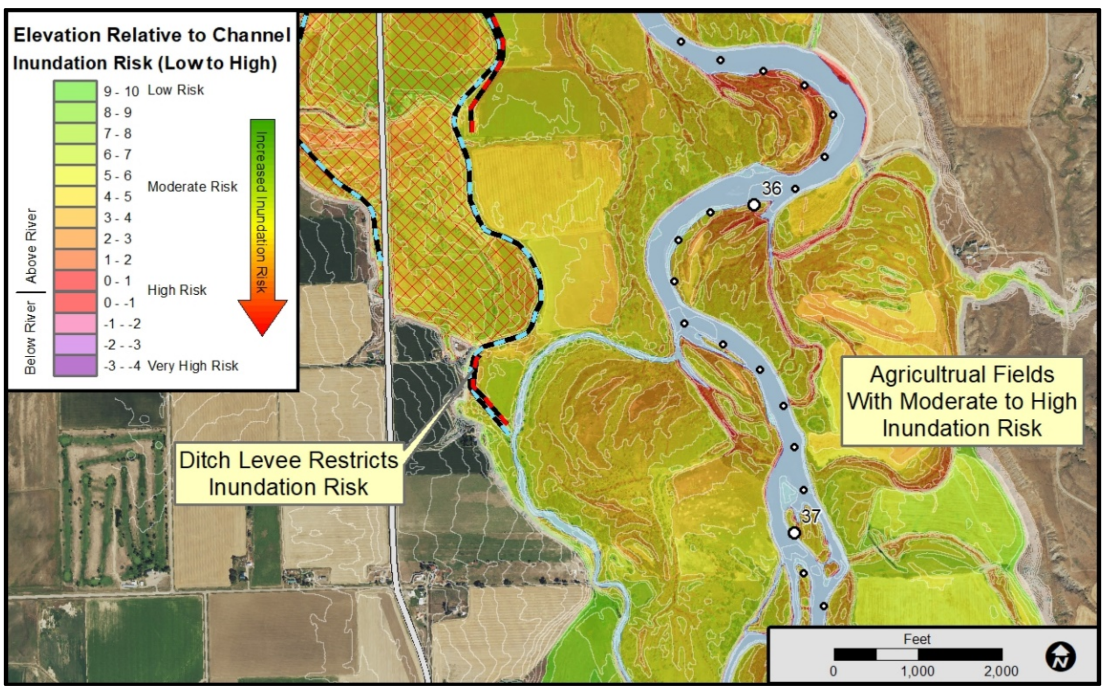

Figure 13. Below Hardin, agricultural fields adjacent to the river are often at moderate to high inundation risk. Floodplain features such as roads and levees may act as dams and restrict floodwater access to areas outside of the feature.

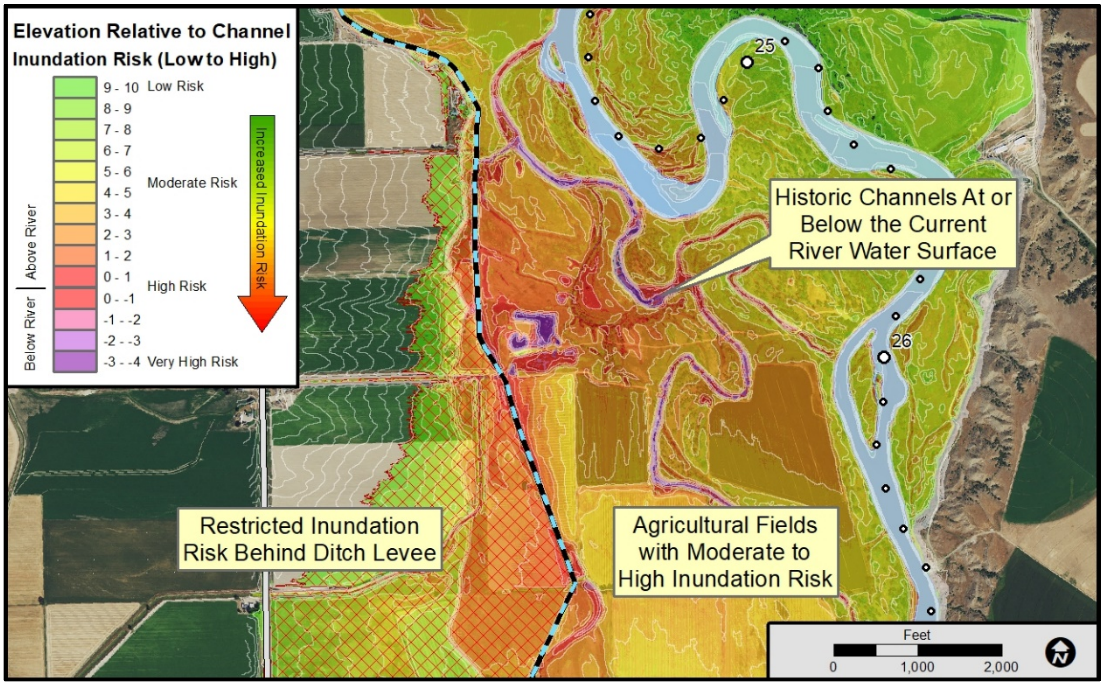

Figure 14. Some historic channels may be below the elevation of the current river. This creates areas of very high risk.

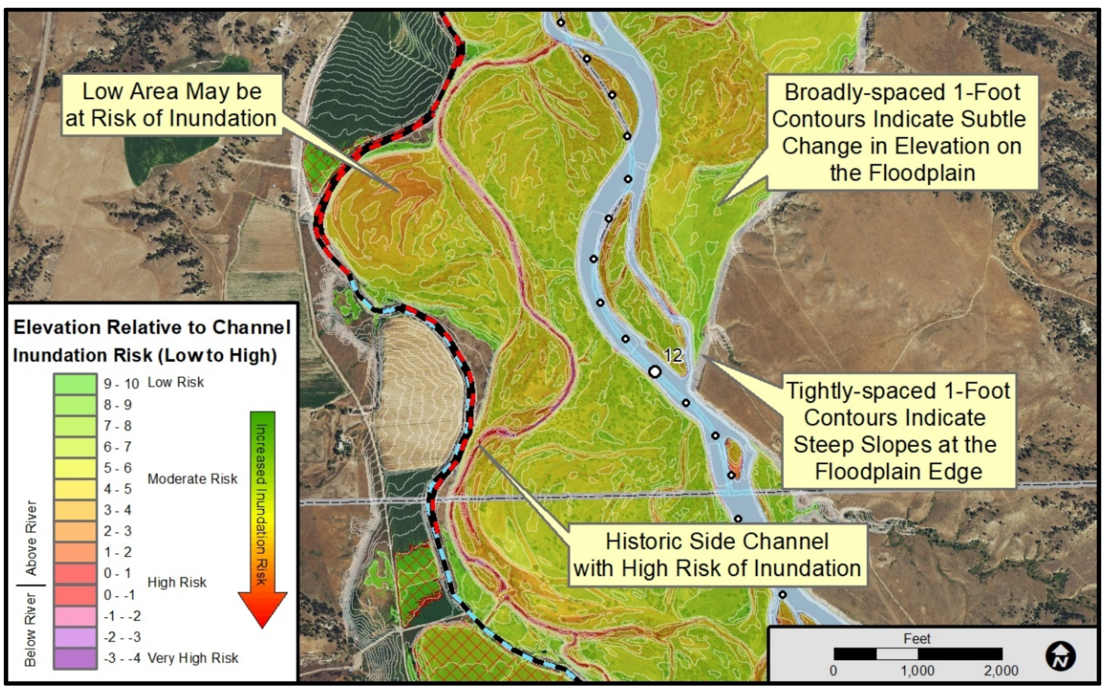

Figure 15. Historic channels with high risk may channel flood waters to low areas, far from the current river location.

5 References

Thatcher, T, 2019. Bighorn River Alliance Research Initiative Spatial Information, p55.

United States Geological Survey, 2019. MT NRCS MT 2018 D18 Airborne Lidar Report, 85p.