THE RESEARCH INITIATIVE

2020

REPORT 1

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BIGHORN RIVER SIDE CHANNEL RESTORATION POTENTIAL

PREPARED FOR:

BIGHORN RIVER ALLIANCE

THE RESEARCH INITIATIVE

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Cover Photo: Entrance to Juniper Channel on September 5, 2019 (~3,200 cfs)

Table of Contents

List of Figures

List of Tables

Summary of Findings

This report summarizes an evaluation of side channel restoration potential on the Bighorn River below Yellowtail Dam. The need for restoration of side channels stems from a progressive loss of connectivity between the main channel and historically active side channels in recent decades. The loss of connectivity generally occurs due to sediment infilling and vegetation encroachment at the side channel entrances, although some channels are perched above the main river along their entire lengths.

The evaluation covers 83.5 river miles from Afterbay Dam to the confluence with the Yellowstone River. Air photos were used to identify channels that were historically connected but are currently dry under commonly occurring flows. High resolution topographic data (LiDAR) was then used to collect topographic profiles down the channels to determine their degree and nature of disconnection. Initially, dozens of channels were tagged, but many were immediately discarded due to poor feasibility caused by excessive perching, infrastructure complications, land use complications etc. Ultimately, a total of 13 channels were evaluated between Afterbay Dam and St Xavier, 7 between St Xavier and Hardin, and 10 below Hardin. Of these 29 channels evaluated, 13 were considered "top tier". These highest priority opportunities were identified as such because substantial reconnection can be achieved with minimal to moderate excavation. Each top tier channel is described in terms of the approximate amount of excavation necessary, the flows at which activation will occur, and the length of channel restored.

When considering implementation strategies, one important thing to consider is the accuracy of currently documented land ownership associated with the land forming and surrounding the channels. Property boundaries will change as the river shifts laterally and creates new landforms. This issue should be considered in any project.

The objective of this effort is to provide the Bighorn River Alliance with a prioritization scheme that was developed using a consistent methodology that will help their efforts in improving aquatic habitat on the river as opportunities arise.

1 Introduction

The flow regime of the Bighorn River has been dramatically altered by the construction of multiple dams in the watershed in the 20th Century (Boyd, 2019). These changes in flow patterns resulted in a major shift in the geomorphology and ecology of the river, especially below Yellowtail Dam, which is the largest and lowest major impoundment in the system. Cold water and dampened hydrographs released from Yellowtail Dam have produced a thriving trout fishery that many consider unparalleled in Montana. However, in recent years there has been growing concern over the loss of side channel habitats below Yellowtail Dam. The progressive abandonment of side channels has been observed in recent decades by scientists and anglers alike, with that abandonment characterized by progressively shallowing connections between the side channels and main river due to sediment deposition and vegetation encroachment (Godaire, 2010).

Figure 1. General project location map.

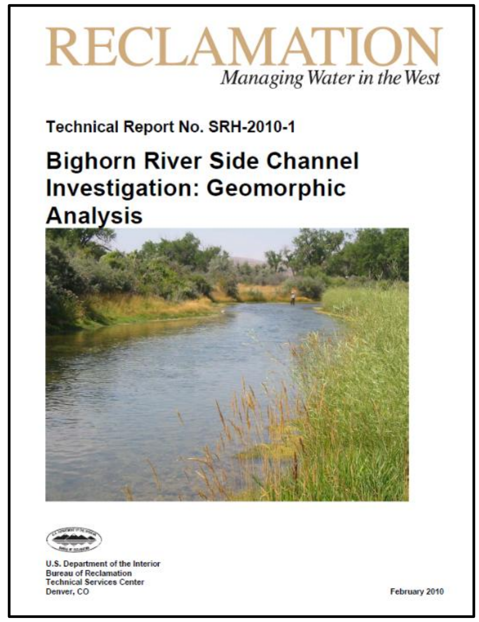
This report reflects the results of Task 3 of Contract Agreement #003-2020 between Applied Geomorphology Inc. and the Bighorn River Alliance. The intent of this effort is to identify and characterize side channel restoration opportunities based on high resolution topographic data (LiDAR) and stage/discharge relationships below Yellowtail Dam. The main restoration objectives are to expand and improve side channel habitat, remove invasive shrubs from side channels, and reduce mainstem bank erosion. The project covers 83.5 miles of river, extending northward from Afterbay Dam to the confluence of the Bighorn with the Yellowstone River (Figure 1).

Potential channels were initially mapped using 1950s imagery, which shows an extensive multi-thread channel network that has been simplified, and Relative Elevation Modeling results that show blocked or abandoned channels in terms of their height above the river. Where a high level of connectivity can be improved with a modest amount of excavation, channels were placed in a top tier, with lesser opportunities falling into lower tier levels. Top tier channels are explored in more detail, with some discussion on design considerations and permitting requirements for several sites above Mallards Fishing Access Site (RM 62.9).

2 Previous Efforts Related to Bighorn River Side Channel Assessment

The following is a brief summary of previous work that has been used to support this effort.

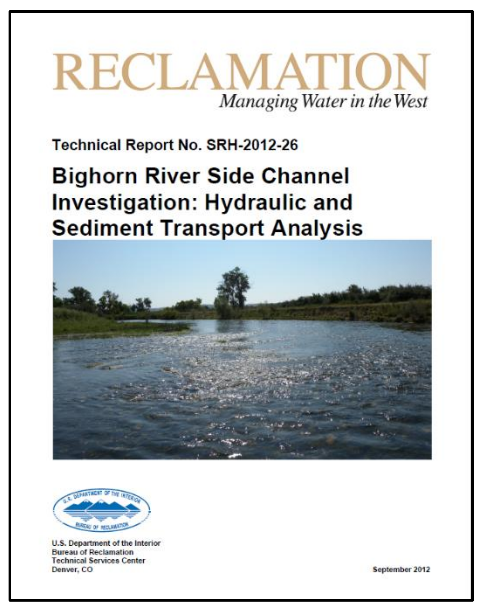
2.1.1 USBR Side Channel Investigation: Geomorphology (2010)



The primary body of work that evaluates side channel condition and restoration potential on the Bighorn River was completed by the Bureau of Reclamation in 2010 (Godaire, 2010). The study covered about 16 river miles from Yellowtail Dam to St. Xavier Bridge (RM 84 to RM 68). The main objective of the study was to investigate the loss of side channels in recent decades. Major findings of that effort include the following:

- As of 2010, bed elevations in the main channel had remained relatively stable throughout the post-dam period and channel incision had not been significant.
- The channel positions of the main stem and side channels have been largely maintained since 1980.
- Geomorphic complexity, quantified as active channel area, has been decreasing since 1961 as side channels have become abandoned and vegetation has encroached into their courses.
- Observations made in 2009 indicate that several critical side channels were becoming disconnected from the main channel due to fine sediment accumulations at side channel entrances.

2.1.2 USBR Side Channel Investigation: Hydraulics and Sediment Transport (2012)



Shortly after the 2010 geomorphic investigation report was completed, the Bureau of Reclamation released a second study, which focused on hydraulic and sediment transport characteristics of Bighorn River side channels (Hilldale, 2012). The primary focus of the study was to evaluate the loss of side channel connectivity at frequent discharges. The primary mechanism for loss of connectivity was deposition and vegetation encroachment into the side channel entrances. Tracer particles with RFID tags were placed in four side channels to track sediment movement and help quantify incipient motion. Results indicated that Yellowtail Dam releases were not likely to reverse the trend on their own, and that mechanical opening of the channels may be the best option to restore connectivity. Planned high flows could then minimize maintenance requirements and reduce the rate of vegetation encroachment. In some locations, the main channel was shown to be aggrading near the side channel entrance, making it more difficult to mechanically open them up. The study indicated that a flow in the range of 10,000-15,000 cfs would initiate sediment motion in the side channels without significantly disturbing sediment in the main channel. If a high flow release is adopted, a maximum flow of 12,000 cfs was recommended for the first event. Although a lower flow of 6,000-10,000 cfs was predicted to inundate significant areas and preclude vegetation encroachment, these flows could also cause side channel infilling if not coupled with occasional flows exceeding 10,000 cfs. The report also includes recommendations for the duration and frequency of high flows, with some sample hydrographs provided.

Table 1 shows the estimated minimum discharges required for connection of several side channels on the Bighorn River (Hilldale, 2012). Several of these channels are discussed further in this document.

Table 1. Table of approximate discharge at which specific side channels become connected at the upstream and downstream end. Discharges below 2,500 cfs were not evaluated (Hilldale, 2012).

USBR Channel ID	RM	Approximate minimum discharge required for connection (cfs)	Evaluated in this document?
Complex #4, river right, upstream channel	81.7 across from Red Cliffs	2,500	No—short and currently accessible
Complex #8, center island channel	78.8 Island near Drive In	3,475	Yes
Complex #8, far left channel	78.5 Pelican Island	8,000	Yes
Complex #10, far right channel	77.2	8,000	No—highly perched throughout
Complex #11 (Pipeline Channel)	76.4 Juniper Channel	3,475	Yes
Complex #12, island channel at upstream end	75.3 Bighorn Rapids	5,500	No—Existing strong split flow adjacent
Complex #13 (Clines channel prior to excavation)	74.6 Clines Channel	5,500 pre-excavation	No—project completed
Overflow channel, river left, upstream of Complex #15	73.9 above Little Bighorn Rapids	8.000 – 10,000	No—short channel
Complex #15, center island channel	73.3 below Little Bighorn Rapids	10,000	No—short and highly perched

2.1.3 Clines Channel Reactivation

Clines channel was reactivated during between October 2011 and February 2012. Hilldale (2012) reported that Clines channel had become reconnected at about 2,000 cfs, as opposed to 5,500 cfs prior. Figure 2 shows the channel entrance pre- and post- restoration and Figure 3 and Figure 4 show that the connectivity has been maintained.

Figure 2. Clines channel before (top) and after (bottom) excavation of the entrance at a Bighorn River discharge of~3,100 cfs (Hilldale, 2012).

Figure 3. Clines channel entrance at 3,200 cfs, September 5, 2019.

Figure 4. Clines channel entrance at 2,500 cfs, May 19, 2020 (Steve Hilbers photo).

Figure 5. Clines channel entrance at 2,000 cfs, May 29, 2020 (Jim Chalmers photo).

2.1.4 Bighorn River Alliance Spatial Imagery Consolidation and Channel Feature Delineation

In September of 2019, Tony Thatcher of DTM Consulting completed a spatial data compilation effort for the Bighorn River from Yellowtail Dam to the Yellowstone River (Thatcher, 2019). Deliverables for this effort included georeferenced imagery from the 1950s, late 1970s, 1996, 2005, and 2017, along with digitized banklines for those air photo suites. Additional Corps of Engineers Imagery for the upper river were also compiled (1939, 1961, 1970, and 1990). Scanned and georeferenced General Land Office Survey maps were included, these range in date from the 1880s through the 1920s. Another important dataset compiled is the Fall 2018 high-resolution LiDAR elevation data, as well as a Relative Elevation Model (REM; Figure 6). Several of these datasets were used extensively in this effort, including the imagery and REM.

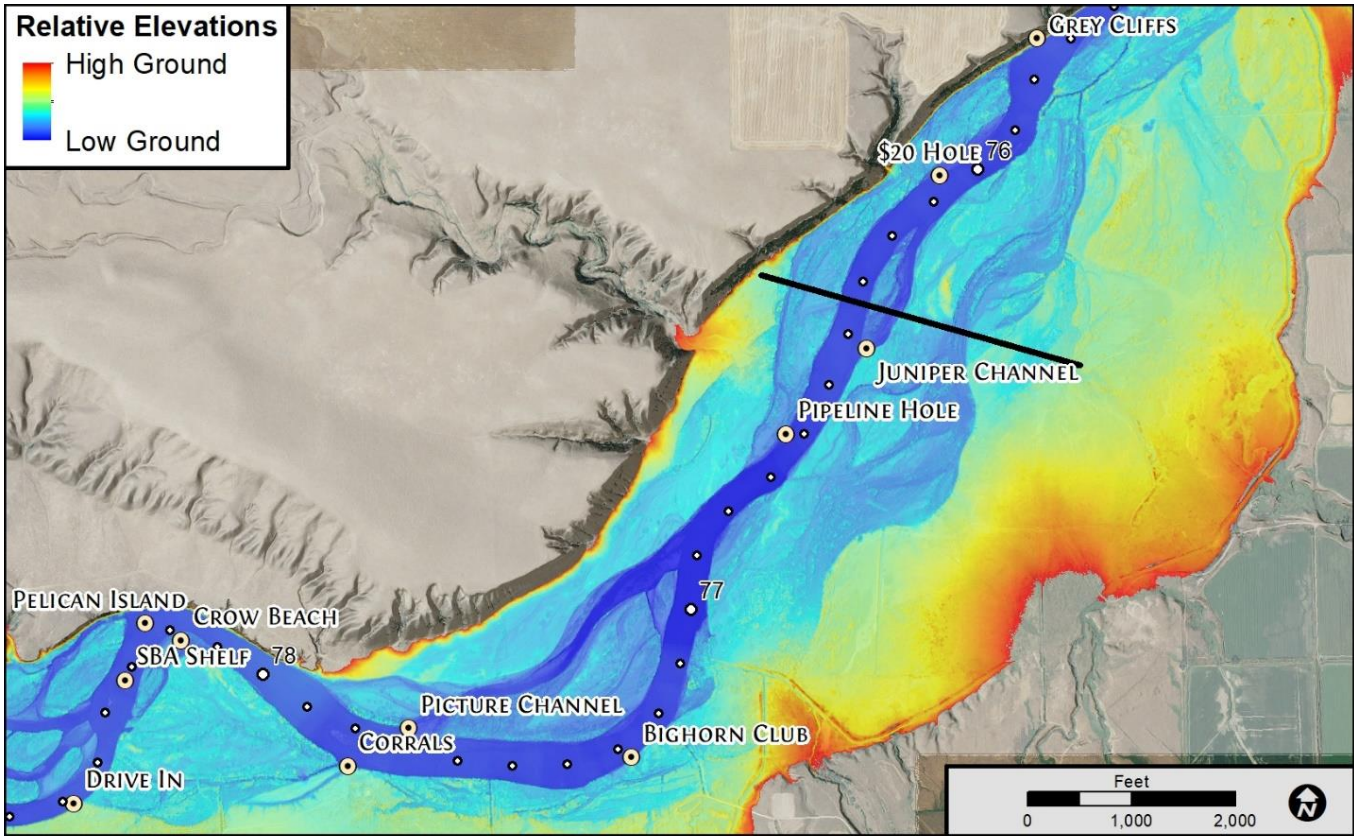


Figure 6. Relative Elevation Modeling (REM) using LiDAR elevation data (Thatcher, 2019).

2.1.5 Characterization of Bighorn River Hydrologic Alterations Below Yellowtail Dam (2019)

This document summarizes the hydrologic changes on the Bighorn River below Yellowtail dam, showing that dam construction has reduced spring flooding while increasing flows in fall and winter (Boyd, 2019). Flow patterns have been affected by both climate variability and dam operating criteria. The project also summarized data relative to optimal flow regimes relative to a range of functional attributes on the river. This includes a flow range of 2,000 to 6,000 cfs for side channel inundation that correlates to salmonid recruitment success, recommended releases of 6,000 – 10,000 cfs every 2-3 years to preclude vegetation encroachment, and recommended larger releases of 10,000 – 15,000 cfs every five years to geomorphically rejuvenate the side channels (Figure 7).

Figure 7 shows the frequency of flow pulses that should be considered to improve side channel conditions, but not the duration of those flows. If the goal is to drown out the vegetation, the flows should be kept at their target for two weeks, but if it is possible to scour out the vegetation, it might only take a day or two (Hilldale, 2012). Hilldale recommends that managers identify the best method based on observations of processes at work. With regard to side channel rejuvenation via sediment transport, Hilldale (2012) reports that since much of the sediment transport occurs during the rising limb of a hydrograph, "it makes little sense to sustain a prolonged peak discharge". To that end, they conclude that there is little to no benefit to maintaining a hydrograph peak for a duration greater than 24 hours.

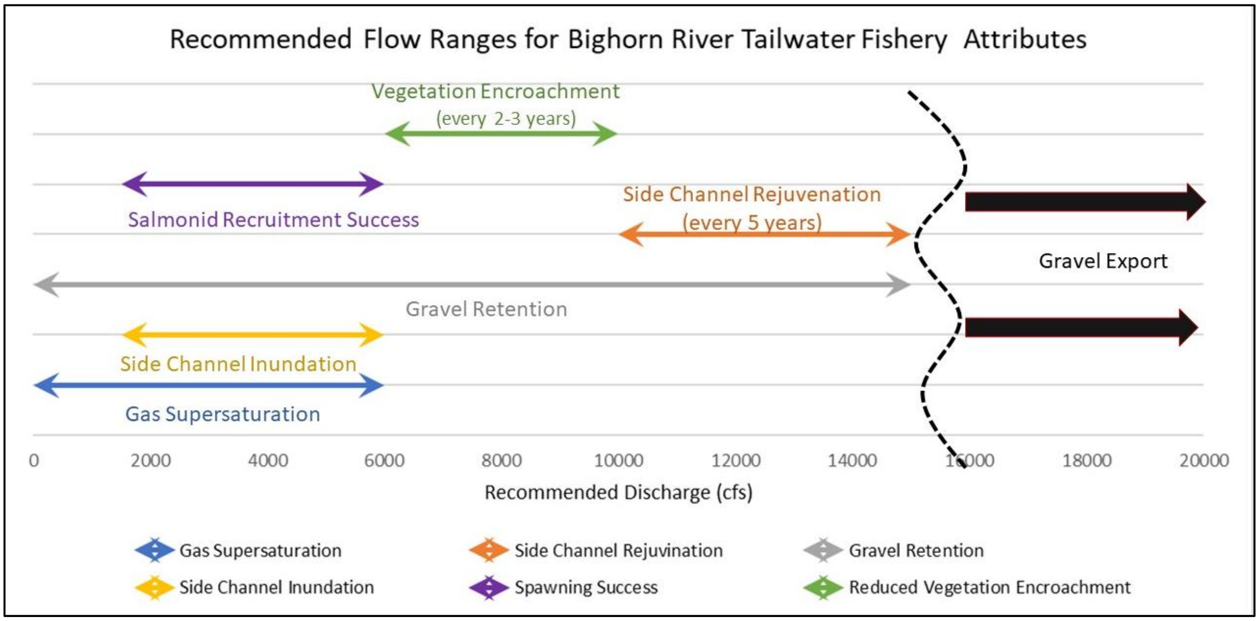


Figure 7. Recommended flow ranges for a series of tailwater fishery attributes generated from various sources (Boyd, 2019).

2.1.6 Bureau of Reclamation Side Channel Re-Investigation (2019-Current)

Engineers and scientists from the Bureau of Reclamation (USBR) are continuing to work on the river, performing a follow-up field investigation in September 2019. Some preliminary findings of their ongoing efforts include the following (Melissa Foster, Nate Bradley, Rob Hilldale, pers. comm):

- New survey data from the side channels is indicating that some of the side channels have incised since the previous survey. Picture channel shows about a foot of downcutting along its entire length. The tracer gravel recovery in Picture channel was 20%, suggesting that they have been flushed out.
- Although Picture channel appears to have dropped by a foot, the incision on other side channels is typically on the order of 0.5 feet.
- Since side channel connectivity does not appear to have increased (in fact some channels have lost connectivity), there is interest in seeing if the main channel downcut as well.
- As there is no new bathymetry from the main channel, it is unclear what changes occurred there during recent high flow years. The investigators would like to submit a proposal for

new bathymetry on the river to see how it has changed and potentially update the hydraulic model.

- In comparing their survey data to the LiDAR elevations, they found that the LiDAR is capturing the top of grass (not bare earth) in areas, indicating that the LiDAR might show ground higher than it is in places.

3 Methods

This effort reflects a reconnaissance evaluation of side channel topography and potential reactivation potential. With the availability of historic imagery and LiDAR, it is currently possible to identify channels that were active prior to dam construction that are now less connected to the river (Figure 8). This allowed channels to be initially identified for potential reactivation. The LiDAR dataset was then used to draw topographic profiles down the channels, to get a sense of just how perched they are above the main river. The goal was to identify channels that could be reactivated with minimal work, preferably at their entrances. Other factors regarding potential habitat generation were considered as well in channel prioritization. Using the LiDAR data, it was also possible to roughly calculate the amount of material that would need to be excavated to provide good connections.

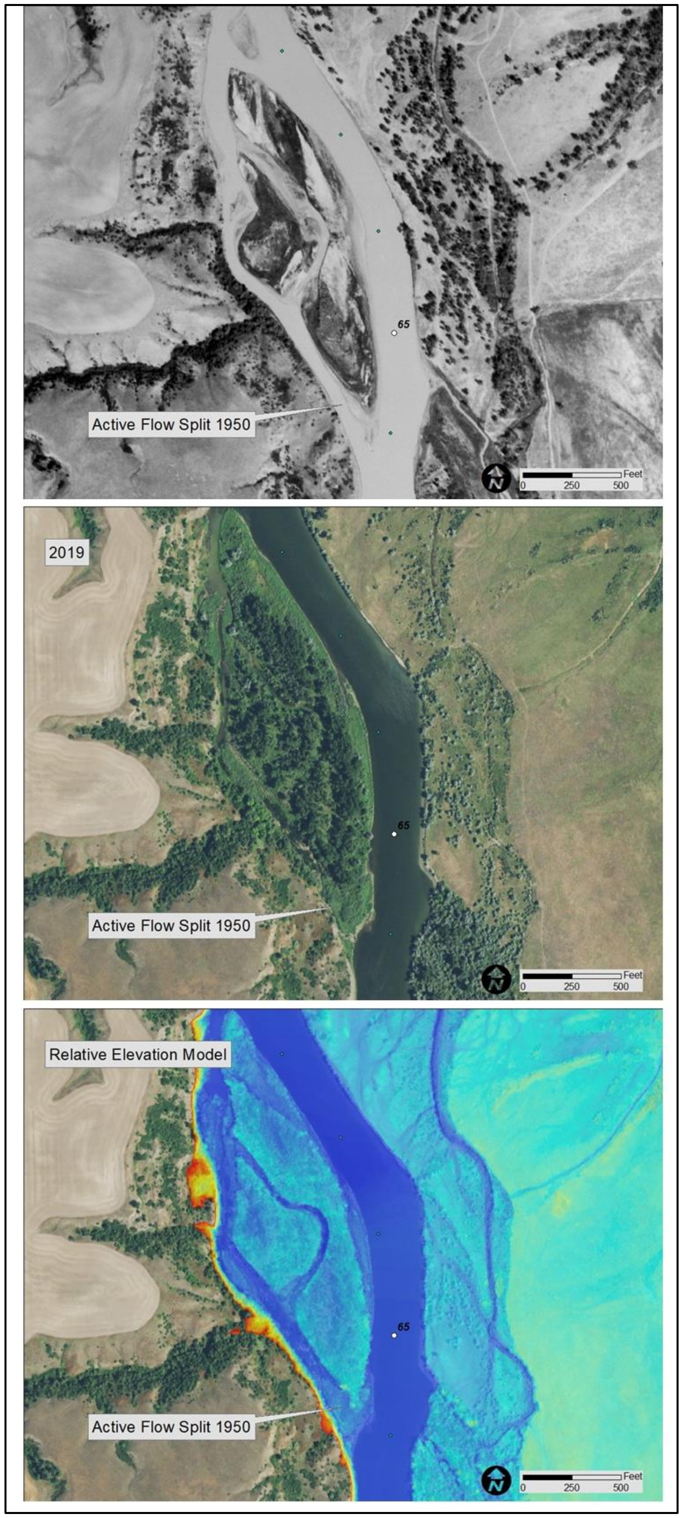


Figure 8. Example data used to identify potential channels, including 1950s imagery, 2019 imagery, and Relative Elevation Model (REM).

One major limitation of this effort is the lack of a complete, modern hydraulic model of the river. Without a model in hand, it is impossible to accurately identify the discharge that results in channel activation. Rather, the LiDAR data provides a base stage that can be compared to the entrance elevation. From that, a rating curve from gaging stations can provide some insight as to the level of connectivity achieved at a given discharge. This approach would have been best achieved if the LiDAR data had been collected at very low flows. Unfortunately, however, the LiDAR was flown in early July 2018, when the river was flowing at 6,800 cfs (Table 2). As a result, several of the most accessible channels were flowing at the time of the LiDAR. Fortunately, however, 2006 imagery was flown at around 1,500 cfs, allowing some empirical comparison of current side channel access.

The evaluation consists of the following steps:

1. Identify the specific dates that the imagery and LiDAR information was collected and assign river flows to each dataset (Table 2).
2. Download stage/discharge data from USGS web sites and plot values as rating curves. This shows how water depth changes with discharge. Identify the stage on each rating curve for the LiDAR water surface elevation data (Figure 9). This is because the LiDAR elevations capture the water surface rather than the bed of the river.
3. For each gage, determine stages and discharges above and below LiDAR water surface elevation data at half foot increments (Table 3). Define flows associated with each stage increment.
4. Construct flow duration curves for the post-dam period using the USGS Streamstats tool (Figure 10). A flow duration curve shows how frequently a given flow is equaled or exceeded. This can be used to estimate the number of days a given flow will likely occur in any given year and helps provide some context as to how frequently an excavated channel would be expected to flow.
5. Identify potential channels.
    a. Map 1950s channels that are now fully/partially abandoned.
    b. Map channels that look geomorphically active (bare gravels) but were dry during low flows of 2006.
    c. Evaluate connectivity using Relative Elevation Model and more recent imagery.
6. Extract a topographic profile of each channel of interest using LiDAR data, connecting both ends to the river (using ArcGIS 3D Analyst). This was only possible for channels that were dry during the LiDAR flight.
7. Determine the height of the channel entrance above the LiDAR water surface. This reflects the stage above LiDAR that currently activates the channel.
8. Create a "design grade" to lower the channel profile. Re-assess the height of the excavated channel entrance relative to the LiDAR water surface. Determine what flow that correlates to. This provides an estimate of the flows that will activate the channel if the design grade is constructed.
9. Use the flow duration curve to estimate the anticipated increase in number of days per year the channel will flow.
10. Estimate excavation volume using length and depth as defined by design grade line, and assuming a 20-foot excavated channel width.
11. Assign each channel a ranking (top, middle, bottom tier) based on activation potential and excavation volume.

This approach approximates the increased side channel connectivity that can be achieved through excavation, and the amount of work required to do so. The accuracy is limited because stage/discharge curves are developed for gaging station locations and these relationships, which are a function of both channel size and flow velocity, can vary substantially down the river. As a result, the change in stage/discharge relationships shown in Table 3 is an estimate when applied in areas away from the gaging station. A more accurate value can be pulled from a hydraulic model, and ongoing work by the

Bureau of Reclamation may include an updated model for at least a portion of the study area. As that information becomes available, the results provided here can be refined.

Additional work will be necessary to carry any of these potential sites to a full project. Concurrent work by the USBR in their re-assessment of activations should complement this effort.

Table 2. Dates and river discharges associated with major data sources used in this assessment.

Imagery (National Agricultural Inventory Program—NAIP)	Date	Afterbay USGS Gage #06287000* (cfs)	St X Bridge USGS Gage #06287800 (cfs)	Tullock Creek USGS Gage #06294500 (cfs)
2019 above RM 60	8/12/2019	3400	3280	3770
2019 RM 60 to RM 18	8/31/2019	3150	3120	3420
2019 below RM 18	7/22/2019	8730	8680	8770
2017 above RM 69	8/18/2017	3140	3120	3250
2017 below RM 69	8/10/2017	3990	4060	4030
2013	6/15-6/16 2013	N/A	2100	2800
2011 above RM 14	7/16/2011	11200	N/A	12100
2011 below RM 14	7/20/2011	11800	N/A	12000
2009	6/28-6/29/2009	N/A	N/A	12800
2006	7/27-7/28/2006	N/A	N/A	1475
LiDAR	**Date**	**Flow at Afterbay USGS Gage #06287000* (cfs)**	**Flow at St X Bridge USGS Gage #06287800 (cfs)**	**Flow Above Tullock Creek USGS Gage #06294500 (cfs)**
2018	7/12-7/13, 2018	6400	6400	6800

The USGS name for this gage is "Bighorn River near St Xavier"

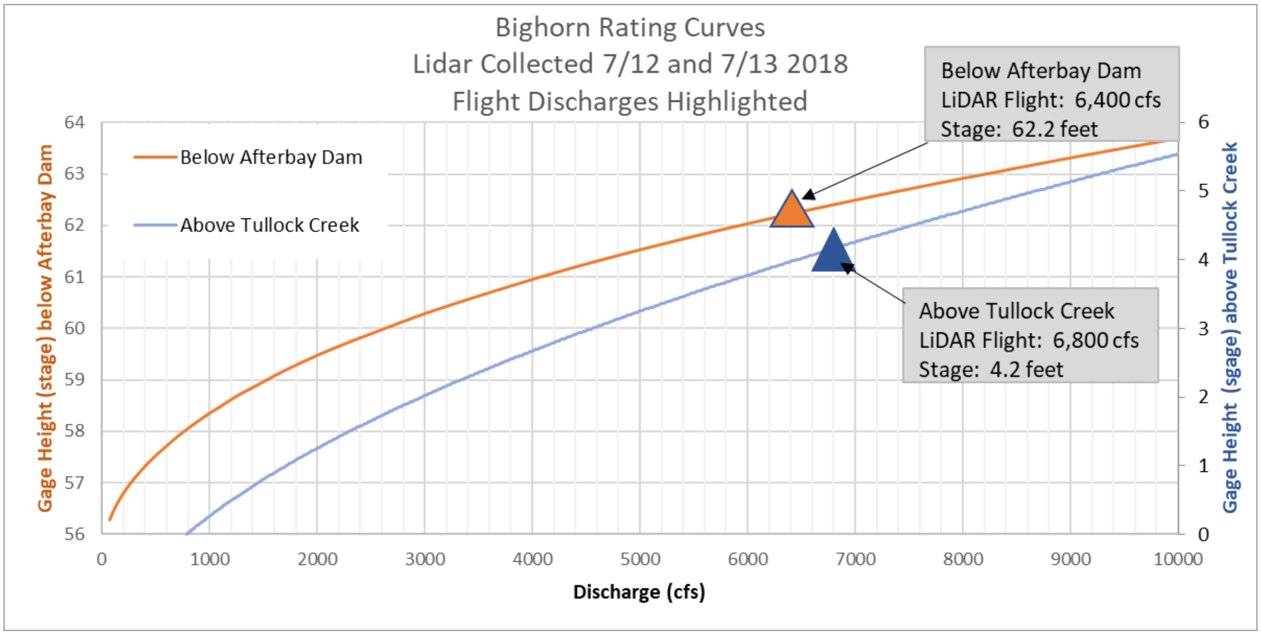


Figure 9. Rating curves for gaging stations below Afterbay Dam (USGS 06287000) and above Tullock Creek (USGS 06294500) showing relationship between river stage and discharge; triangles mark stage at time of LiDAR flight.

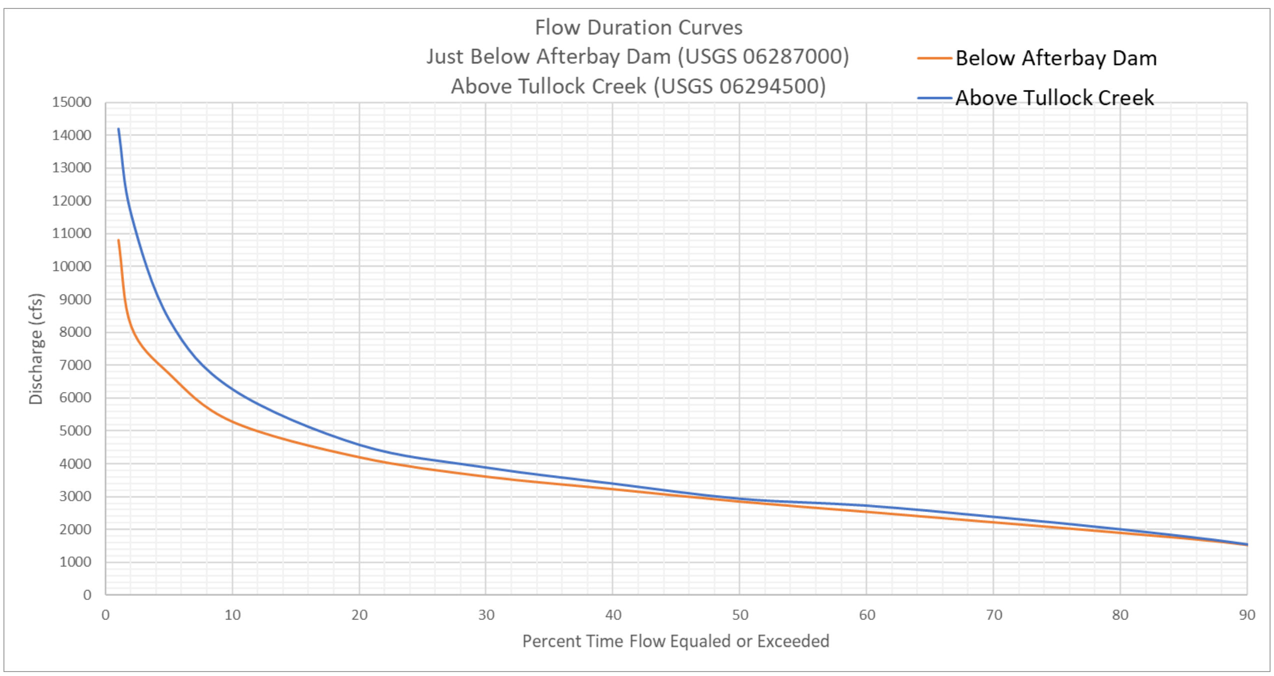


Figure 10. Flow duration curves (percent time a given flow is equaled or exceeded) for Bighorn River just below Afterbay Dam and near mouth above Tullock Creek.

Table 3. Discharge relative to LiDAR-based stage for each Bighorn River gaging station.

Afterbay (USGS 06287000)								
Stage Relative to LiDAR (ft)	**-2**	**-1.5**	**-1**	**-0.5**	**LiDAR (0)**	**0.5**	**1**	**1.5**
Stage on Rating Curve (ft)	60.2	60.7	61.2	61.7	62.2	62.7	63.2	63.7
Discharge (cfs)	2890	3630	4417	5354	6400	7515	8724	10040
Duration	51%	27%	16%	9%	6%	3%	2%	1%
Days Per Year	186	99	58	33	22	11	5	4
St X Bridge (USGS 06287800)								
Stage Relative to LiDAR (ft)	**-2**	**-1.5**	**-1**	**-0.5**	**LiDAR (0)**	**0.5**	**1**	**1.5**
Stage on Rating Curve (ft)	6.6	7.1	7.6	8.1	8.6	9.1	9.6	10.1
Discharge (cfs)	2750	3341	4343	5384	6400	7712	9100	10560
Duration	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Days Per Year	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Tullock Creek (USGS 06294500)								
Stage Relative to LiDAR (ft)	**-2**	**-1.5**	**-1**	**-0.5**	**LiDAR (0)**	**0.5**	**1**	**1.5**
Stage on Rating Curve (ft)	2.2	2.7	3.2	3.7	4.2	4.7	5.2	5.7
Discharge (cfs)	3300	4060	4926	5851	6800	7974	9200	10450
Duration	42%	27%	17%	12%	8%	6%	4%	3%
Days Per Year	153	99	62	42	29	22	15	11

4 Results

The following section describes the results of the side channel assessment, focusing on the highest tier opportunities.

Initially, dozens of channels were considered for detailed assessment, but many were immediately discarded due to poor feasibility caused by excessive perching, infrastructure complications, land use complications etc. Ultimately, a total of 29 channels were evaluated between Afterbay Dam and St Xavier, 7 between St Xavier and Hardin, and 10 below Hardin. Of these 29 channels, 13 were considered "top tier" and are described individually below. Appendix A contains profiles of all channels evaluated that were dry during the LiDAR flight.

Another important thing to consider is the accuracy of land ownership associated with the channels. In this report, adjacent land ownership has been assigned based on the most recent cadastral layer available. Although it is established that the State of Montana owns the bed and banks of channels of the Bighorn River that are active at low flow, adjacent property boundaries can shift due to river movement or side channel abandonment so ownership should be reviewed as part of project development.

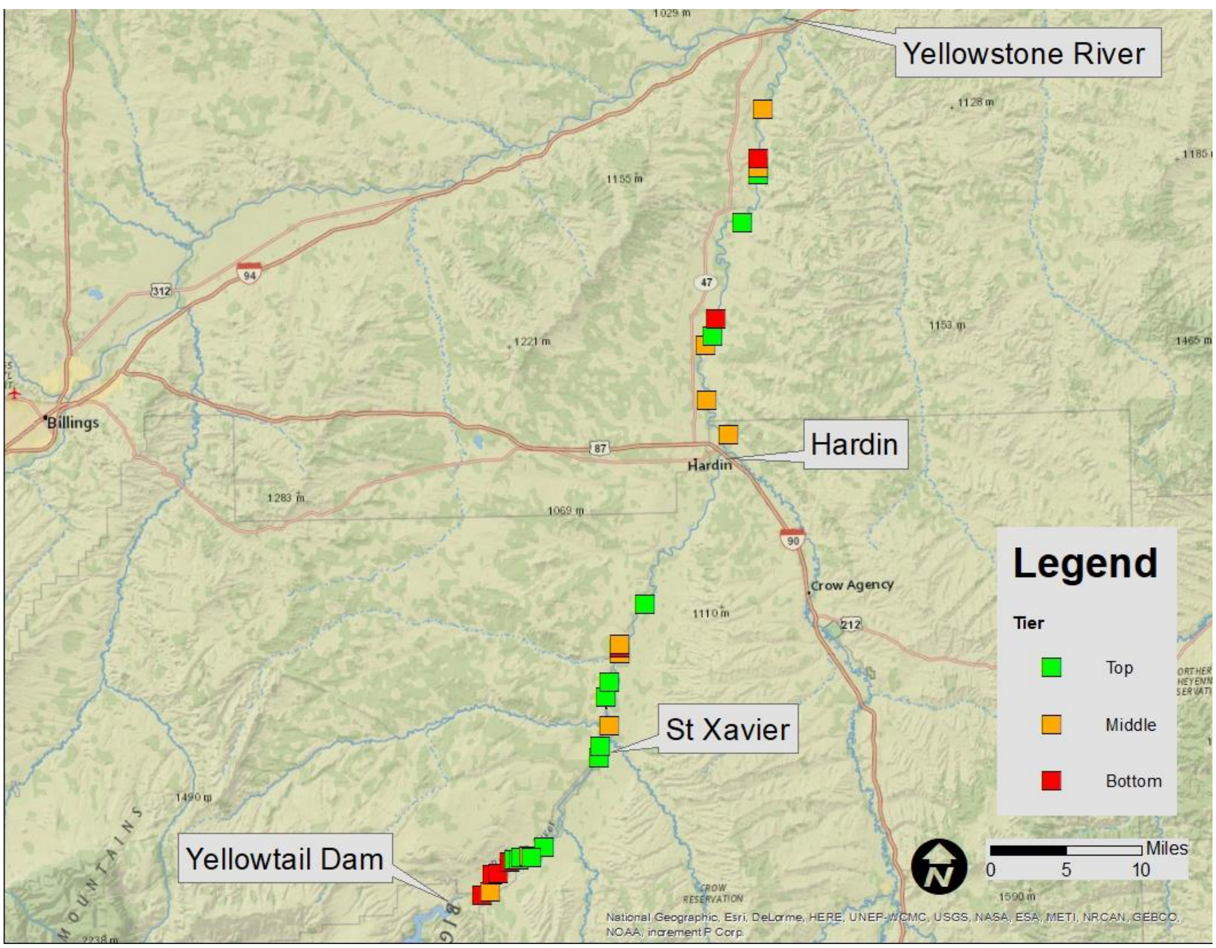


Figure 11. Map showing channels evaluated in this assessment.

4.1 Segment 1: Afterbay Dam to St Xavier

A total of 13 channels were evaluated between Afterbay Dam and St Xavier (Table 4). Several others were dismissed due to a high degree of perching. Those channels listed as Top Tier in Table 4 are described in more detail below, and Table 5 summarizes some key parameters for those top-tier channels.

Table 4. Side channels evaluated between Afterbay Dam and St. Xavier.

Entrance RM	***General Location***	***Length (ft)***	***Comments***	***Adjacent Landowner****	***Tier***
83.3	Just below Afterbay	2000	Would require extensive excavation; channel is perched throughout	Null	Bottom
82.7	Entrance at Breakfast Hole	3500	Could activate at LiDAR flow stage with flat entrance; would have to excavate about 2 feet over 700 feet of length	Grapevine Ranch	Middle
81.2	Dag's Run	4080	Emergent Wetland in lower end but perched; would require ~2,000 ft of excavation	Crow Tribe	Bottom
80.8	Landing Strip	2350	Feeds channel 81.2; ~2,400 ft of excavation required	Null	Bottom
79.5	Snag Hole	1600	Well-perched ~1,500 ft of excavation required	Null	Bottom
79.1	Rattlesnake Island	980	Flowing during LiDAR but lowering entrance 0.3ft would increase access from an estimated 146 to 182 days per year	Null	Top
78.8	Drive in	1500	Just dry during LiDAR -- lowering entrance 0.4 feet would increase access from an estimated 88 to 146 days per year	Null	Top
78.5	Pelican Island	1450	Great opportunity blockage on top could get great access, drop more could be even more frequent	Duck Blind LLC	Top
77.9	Above Picture Channel	1300	Would require extensive excavation to get activation below 6,000 cfs; would feed Picture Channel	Grapevine Ranch	Middle
77.7	Picture Channel	3380	Already designed for ~0.5 foot of excavation and 80 cy of removal	Grapevine Ranch	Top
76.4	Juniper Channel	1400	Flows at ~2,900 cfs but could substantially increase access substantially. ~0.4 ft lowering could increase to 240 days per year	Crow Tribe	Top
68.8	Turtle Rock	5100	Good access currently-- widen entrance and remove Russian olive? Road crossing has been removed.	Null/ Crow Tribe /Nevels	Top
67.9	St X Bridge	2250	Great opportunity at bridge-- Dennis Fischer explored this area with Melissa Foster from USBR	Crow Tribe/ Schwend	Top

***Based on available cadastral data (1/31/2019); "Null" values are presumed State of Montana lands. Land ownership should be verified based on Montana State Statute.**

Table 5. Estimated excavation volumes, activation discharges, and excavation required per activated channel length for top-tier channels between Afterbay Dam and St Xavier.

RM at Entrance	*General Location*	*Length (ft)*	*Estimated Excavation Volume (cy)*	*Estimated Activation Discharge with Excavation (cfs)**	*Excavation per foot of channel activated (cy/100 ft)*
79.1	Rattlesnake Island	980	44	2400	4.5
78.8	Drive in	1500	45	2000	3.0
78.5	Pelican Island	1450	389	5300	26.8
77.7	Picture Channel	3380	80	2200	2.4
46.4	Juniper Channel	1400	36	2300	2.5
68.8	Turtle Rock	5100	N/A	N/A	N/A
67.9	St X Bridge	2250	167	4200	7.4

This is an estimate based on rating curves at gaging stations and has been used for relative comparisons.

4.1.1 RM 79.1: Rattlesnake Island

Length: 980 feet
Estimated Excavation Volume: 44 cy

At RM 79.1, a well-formed side channel flows for almost 1,000 feet on the right (east) side of the main river (Figure 12). This channel just upstream of Rattlesnake Island was flowing during our field work of September 5th, when the river was flowing at about 3,200 cfs (Figure 13). This is about a 40% flow duration, so on average this channel flows about 150 days per year. Figure 14 shows a May 19, 2020 photo of the entrance at 2,500 cfs; the high ridge at the entrance supports excavation depths that can improve connectivity to below that 2,500 cfs. The disconnection is especially distinct at 2,000 cfs (Figure 15). Using the rating curve at Afterbay, lowering the entrance to this channel by 0.8 feet would increase access to about 2,200 cfs, and keep it wetted another ~110 days per year on average. As this channel was flowing during the LiDAR flight, no topographic profile was available for its course, however recent BOR survey data indicates that an excavation depth of 0.8 feet is feasible through the entrance.

This channel is referred to in the BOR study (Godaire, 2010) as “Channel 8a”.

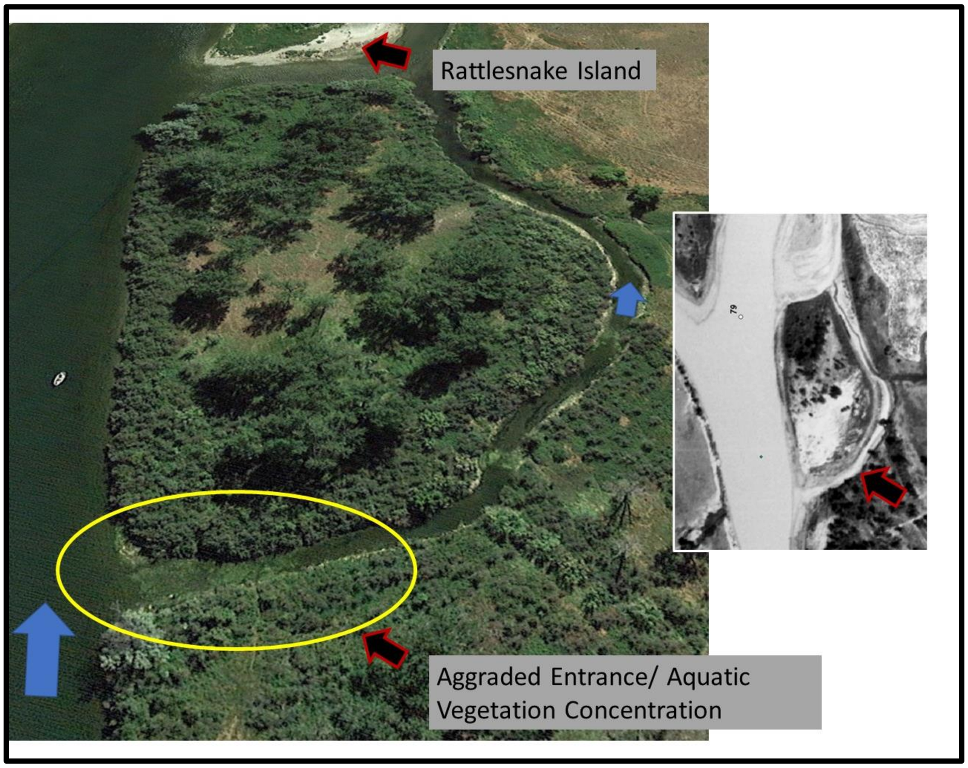


Figure 12. Google Earth Image (2014) showing impaired connectivity at head of channel just upstream of Rattlesnake Island; inset shows channel in 1954.

Figure 13. Shallow flow entering Rattlesnake Island channel at 3,200 cfs in September 2019.

Figure 14. Entrance to Rattlesnake Island Channel at 2,500 cfs on May 18, 2020 (Steve Hilbers photo).

Figure 15. Entrance to Rattlesnake Island Channel at 2,000 cfs on May 29, 2020 (Jim Chalmers photo).

4.1.2 RM 78.8 Near Drive In

Length: 1,500 feet
Estimated Excavation Volume: 44 cy

This channel flows through an island across from the car body riprap known as “Drive In” (Figure 16). The USGS estimated this channel to activate at 3,475 cfs (Table 1). During our field investigation in September, it was dry by about 0.3 feet, when flows were at 3,200 cfs. It was also dry in May 2020 at 2,500 cfs (Figure 17). If the entrance were lowered by 0.4 feet, the activation of this channel should occur at about 2,000 cfs. This channel has a robust willowed bankline, an emergent wetland on its lower end, and gravelly substrate in its bed (Figure 18 and Figure 19). This would increase that average duration of flows to this ~1,500 ft long channel from approximately 117 days per year to 250 days per year. As the channel is on an island, access may be a challenge; potential approaches to work from the river are described in Chapter 5.

This channel was also flowing during the LiDAR flight, so no topographic profile was available. It will be important to determine if a 0.4’ deep cut can tie in to the main channel topography without making the entrance too flat and prone to infilling.

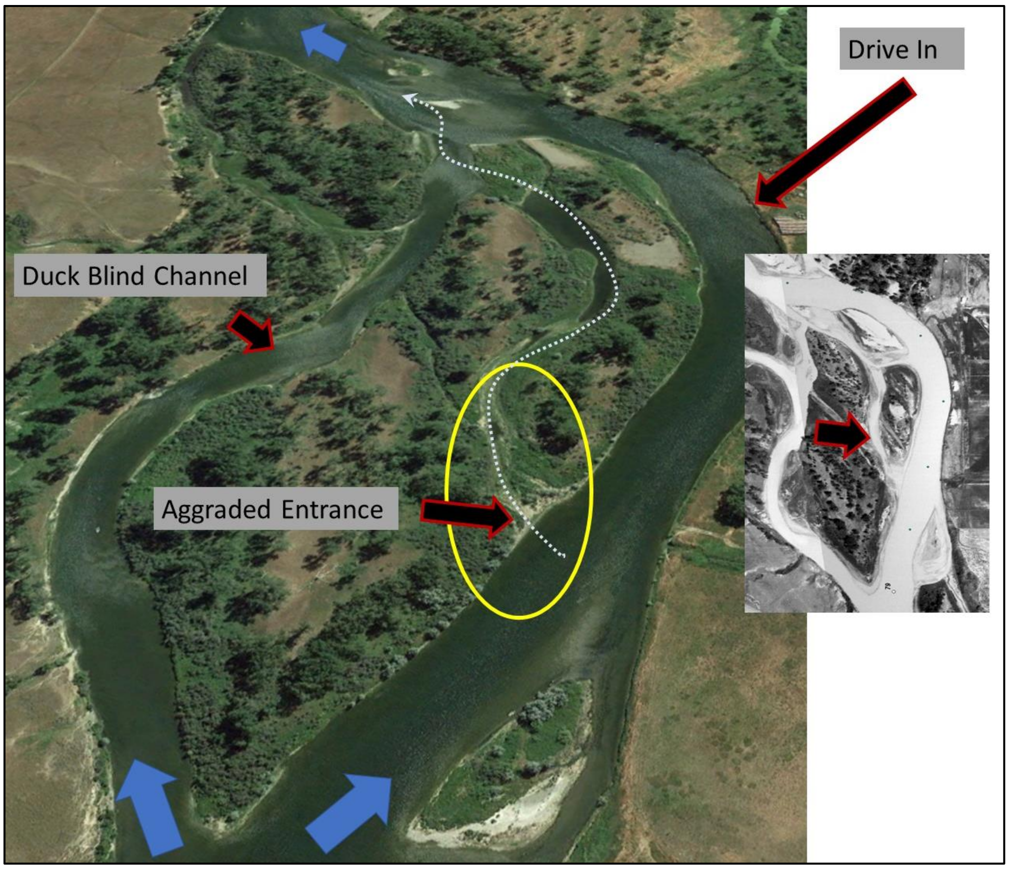


Figure 16. Google Earth Image (2014) lost connectivity at head of channel just across from Drive In; inset shows channel in 1954.

Figure 17. View into RM 78.8 side channel at 2,500 cfs on May 19, 2020 (Steve Hilbers photo).

Figure 18. View downstream of side channel at RM 78.8 showing robust bankline vegetation and coarse substrate.

Figure 19. Gravel substrate in lower end of disconnected channel at RM 78.8.

4.1.3 RM 78.5 near Pelican Island

Length: 1,450 feet
Estimated Excavation Volume: 335 cy

This channel is on the left floodplain and comes off of the Duck Blind Channel at RM 78.5 (Figure 20). According to the USGS, this channel activates at about 8,000 cfs (listed as "complex 8- far left channel in Table 1). This lack of activation is due to relatively high ground that extends about 200 feet down from the channel entrance (Figure 21). The lower end of the channel is a large backwater (Figure 22).

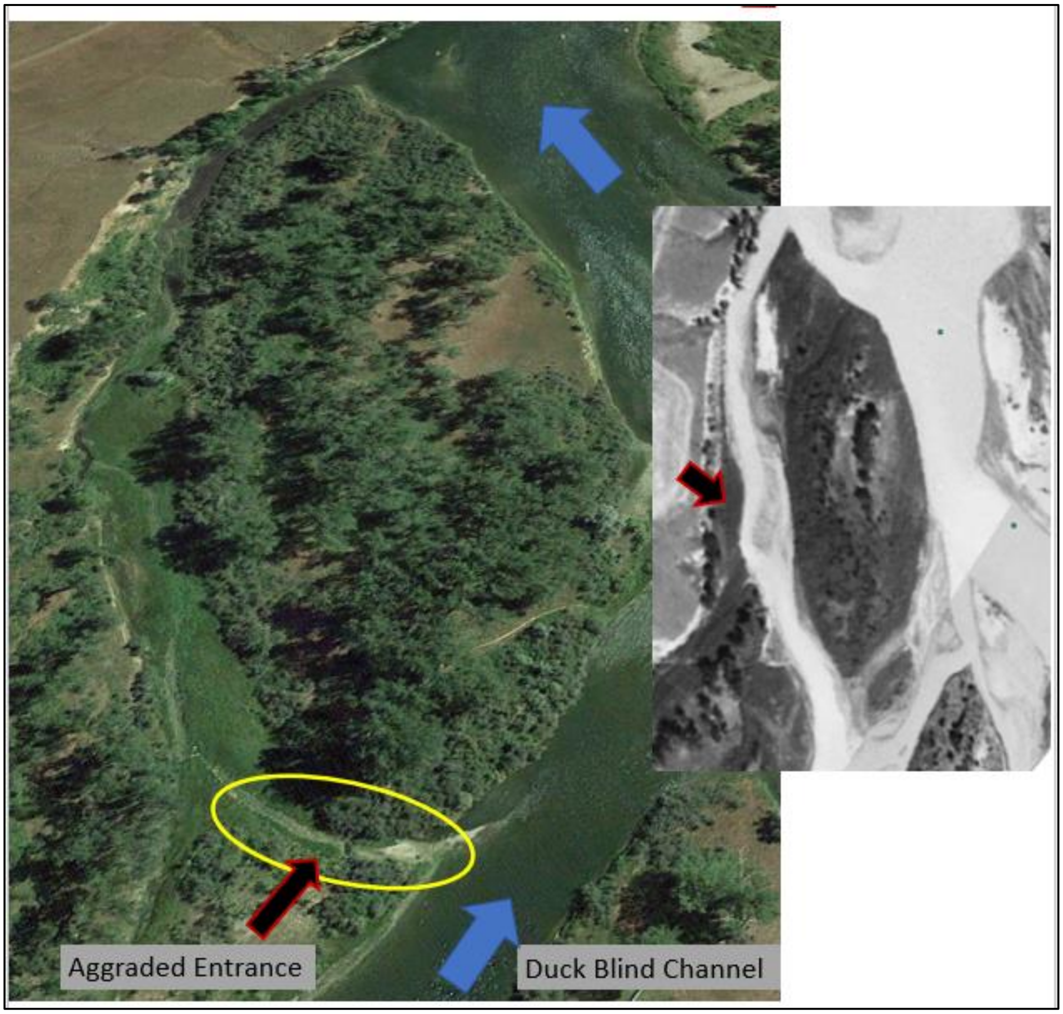


Figure 20. Google Earth Image (2014) lost connectivity at head of channel at RM 78.5; inset shows channel in 1954.

Based on the profile, it appears viable to lower the elevation of the entrance to about 0.5 feet below the water surface at the time of the LiDAR (6,400 cfs). This would require the removal of about 400 cubic yards of material. In doing so, the estimated activation would be somewhere around 5,300 cfs, which would still render it a largely seasonal channel, flowing about 11 days per year on average. Another potential limitation of this channel is its angle of entry, it is likely prone to infilling without more aggressive realignment to the river.

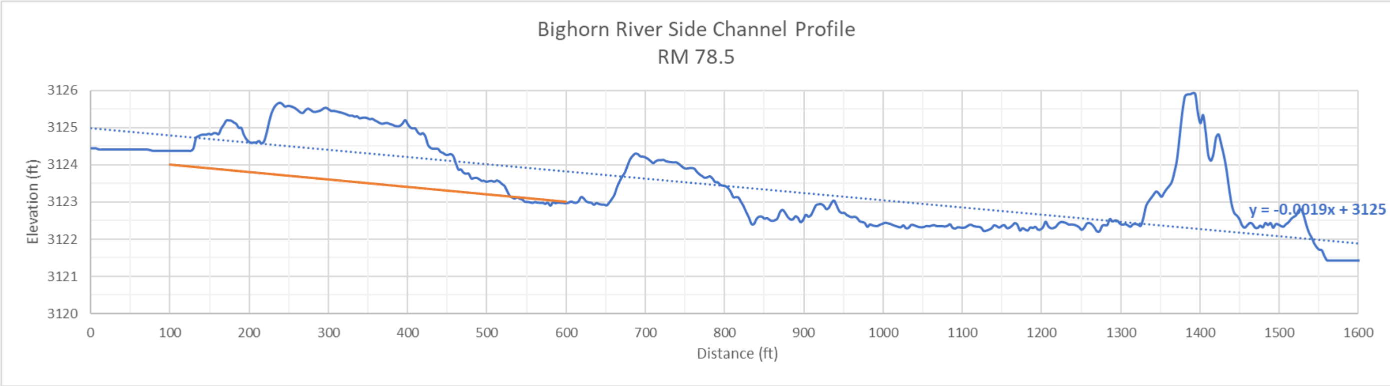


Figure 21. LiDAR profile of side channel at RM 78.5 showing high ground at entrance; proposed excavation profile is shown in orange.

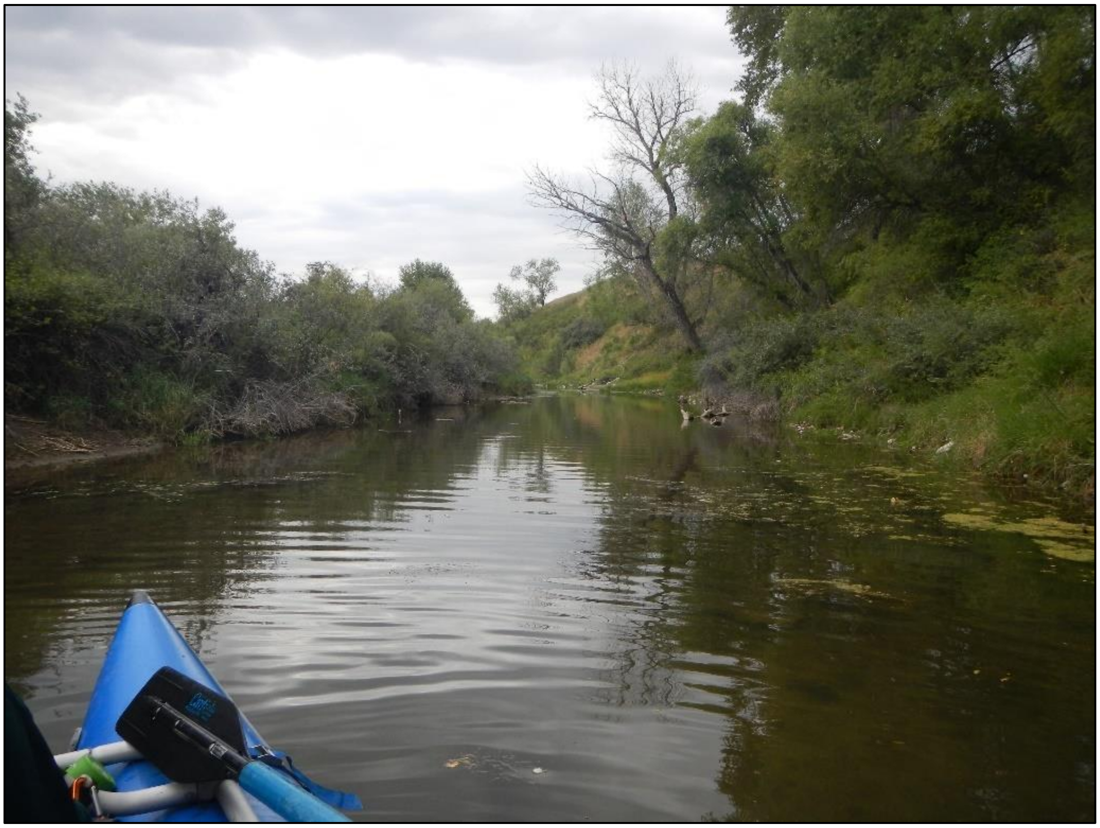


Figure 22. View upstream into lower end of disconnected side channel at RM 78.5 (~3,200 cfs).

4.1.4 RM 77.7 Picture Channel

Length: 3,380 feet
Estimated Excavation Volume: 80cy

This is a top-tier channel that has already been designed for 0.5 feet of excavation and 80 cubic yards of removal. The channel was flowing during the field work at 3,200 cfs (Figure 23) but was almost dry at 2,500 cfs in May of 2020 (Figure 22) and completely dry at 2,000 cfs ten days later (Figure 25). Although the channel seasonally dries, the 2006 imagery which shot when flows were about 1,500 cfs, shows that the channel has not decayed but continues to support open gravels along its length (Figure 26). This is a top-tier channel that will hopefully be able to get done in coming years as it provides excellent habitat area in return for minor excavation. According to available files, the proposed design is to drop the entrance elevation by about 0.5 ft. This should reduce the flows required to wet the channel from about 3,000 cfs currently to approximately 2,200 cfs. Currently, Picture Channel has a debris jam formed at the flow split- these features, which are commonly called "apex jams" or "bifurcation jams", can be used in project designs to promote stable flow splits (Figure 27 and Figure 28).

Figure 23. View downstream of Picture Channel at Bighorn River flow of 3,200 cfs (Sept 2019); note high water marks on bankline vegetation.

Figure 24. Entrance to Picture Channel at 2,500 cfs showing minimal connectivity and debris jam at head of flow split on May 19, 2020 (Steve Hilbers photo).

Figure 25. Entrance to Picture Channel at 2,000 cfs showing dry channel on May 29, 2020 (Jim Chalmers photo).

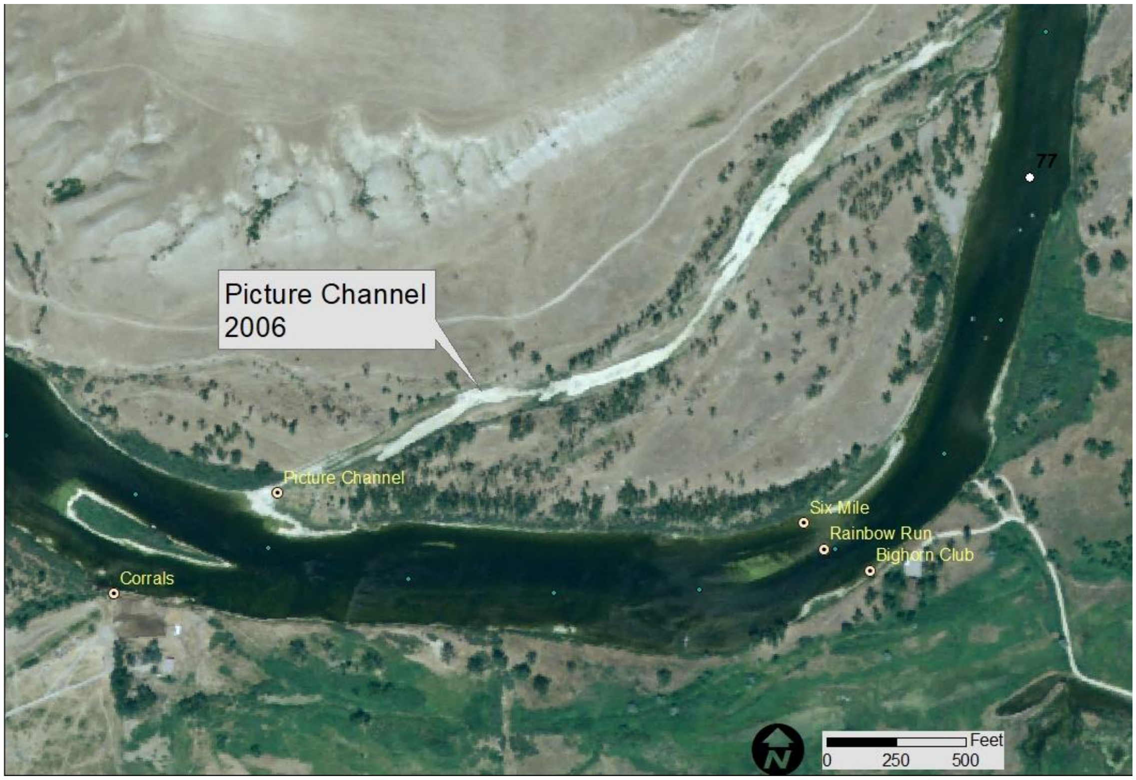


Figure 26. Picture channel completely dry in 2006 imagery (~1,475 cfs).

Figure 27. Debris jam at Picture Channel flow split showing how feature facilitates side channel flow.

Figure 28. View downstream of log jam at head of Picture Channel; main Bighorn River channel is to right (~3,200 cfs).

4.1.5 RM 76.4 Juniper Channel

Length: 1,400 feet
Estimated Excavation Volume: 100 cy

At RM 76.4, the Juniper Channel existed in the 1950s as a secondary channel behind a mid-channel bar. This bar has progressively established as a vegetated island, but the secondary channel has persisted since the dam was built. (Figure 29). The channel was flowing during our field work, when the river discharge was about 3,200 cfs (Figure 30), and in May of 2020 it was dry at 2,500 cfs (Figure 31). Figure 32 shows the entrance at 2,000 cfs. Based on stage comparisons, the estimated activation flow is about 2,900 cfs. If the entrance were dropped about 0.4 feet, the estimated activation could be dropped to about 2,300 cfs, which would wet the channel an additional 50 days per year. The material at the head of the channel is quite coarse, and it appears unlikely that it will naturally scour at high water, so mechanical excavation is likely necessary to maintain connectivity and prevent additional decay through vegetation encroachment onto the cobbles. The shallow water in the foreground of Figure 32 suggests that deep excavation through the head of Juniper Channel may be difficult.

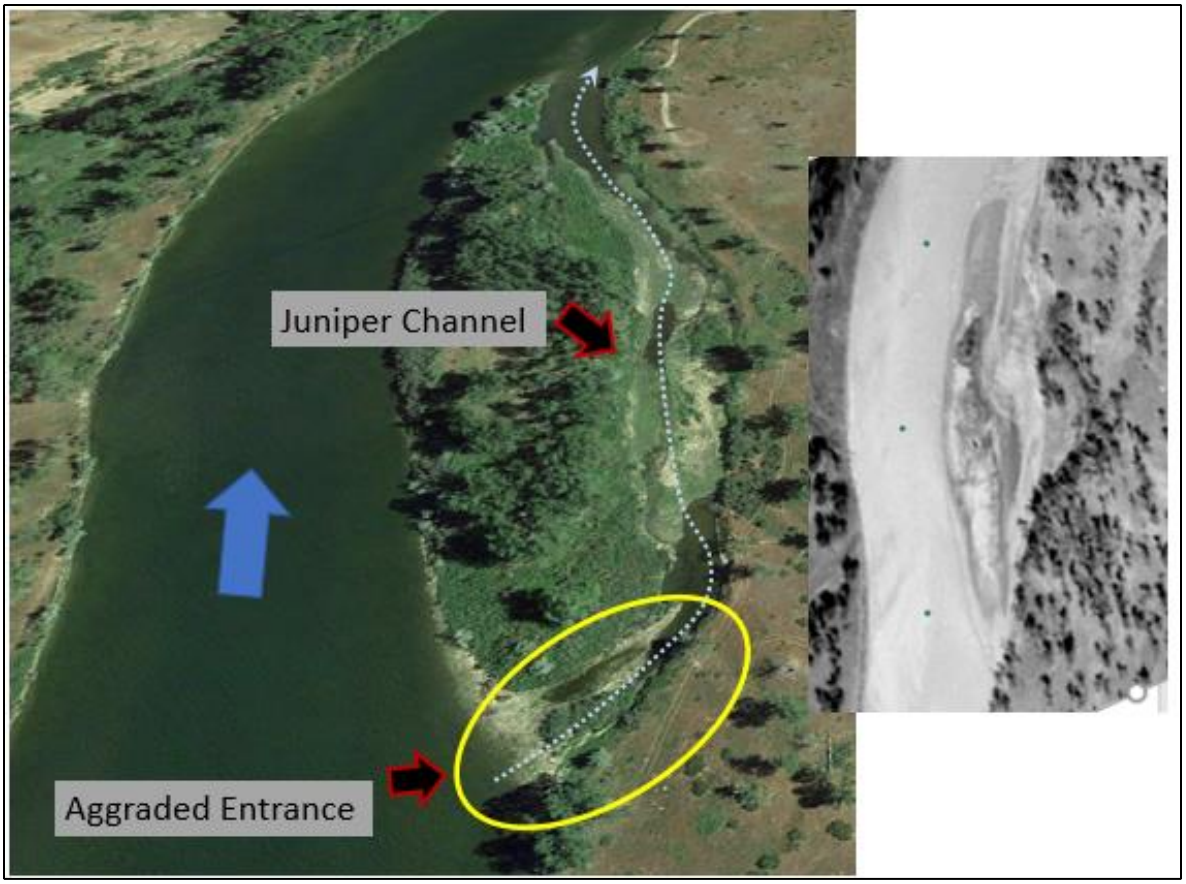


Figure 29. Google Earth Image (2014) lost connectivity at head of channel at RM 76.5; inset shows channel in 1954.

Figure 30. View downstream into Juniper Channel (3,200 cfs).

Figure 31. Entrance to Juniper Channel at 2,500 cfs on May 19, 2020 (Steve Hilbers photo).

Figure 32. Entrance to Juniper Channel at 2,000 cfs on May 29, 2020; note shallow water in foreground (Jim Chalmers photo).

4.1.6 RM 68.8 Turtle Rock

Length: 5,100 feet
Estimated Excavation Volume: Uncertain--just Russian olive?

This is a long side channel located on the right floodplain between Turtle Rock and the St Xavier bridge (Figure 33). Based on the LiDAR it appears that the channel has good topographic connectivity, however the entrance is densely choked with Russian olive. There is a primary road crossing about ¾ of the way down the channel that looks to have been improved in recent years through the addition of a culvert. Opportunities for this channel would be somewhat different than the others, in that Russian olive removal and culvert enlargement could potentially increase side channel function. That said, a more detailed evaluation is necessary; imagery shows the channel flowing during the high water of 2011 (~12,000 cfs) but it is difficult to see much activity in any other imagery.

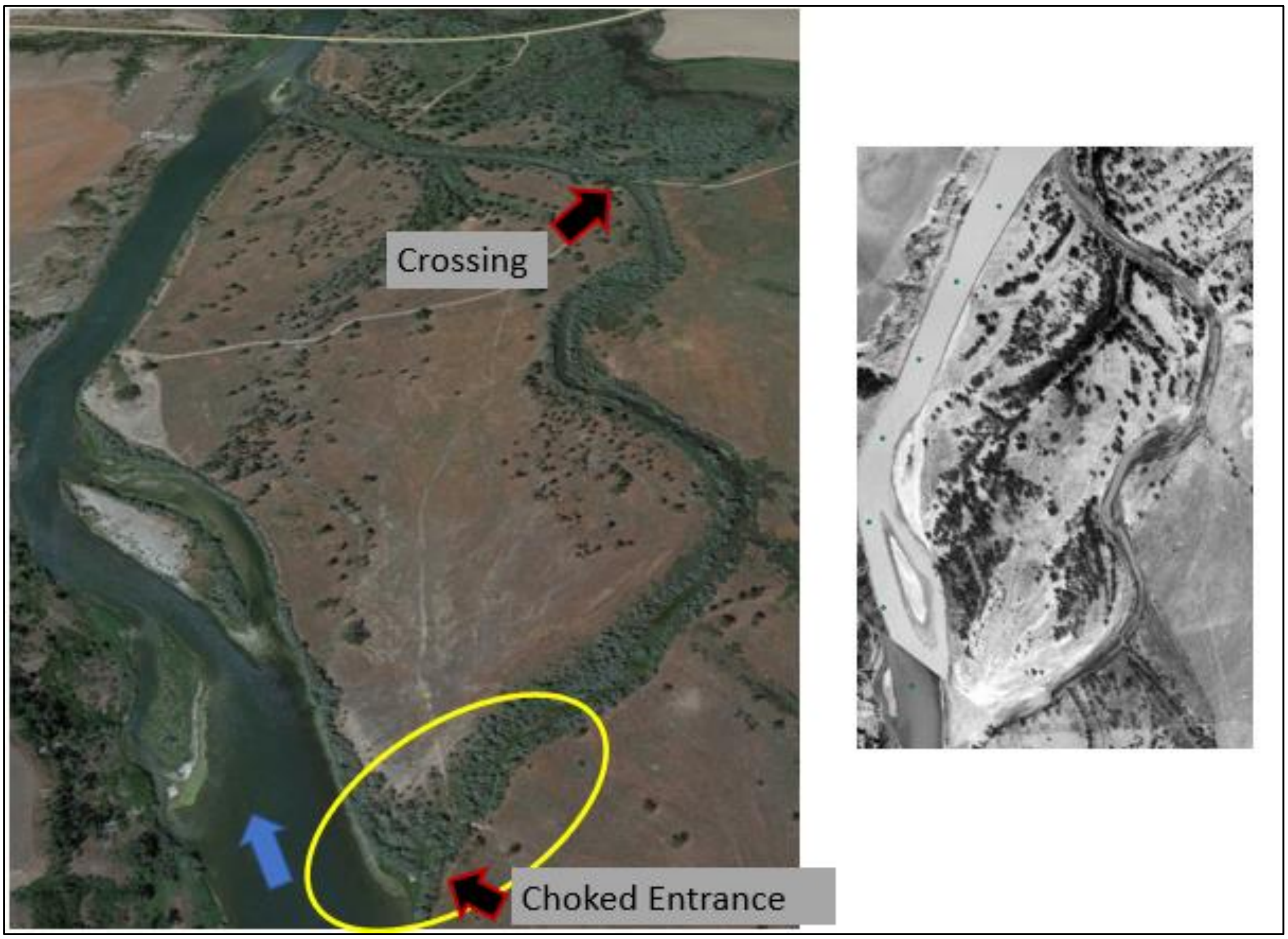


Figure 33. Google Earth Image (2013) showing dense vegetation at head of channel at RM 68.8; inset shows channel in 1954.

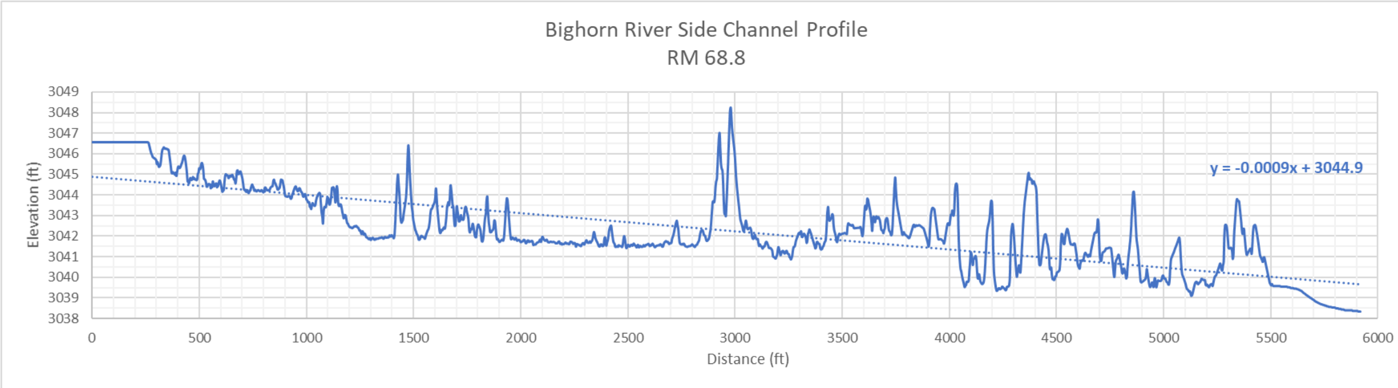


Figure 34. LiDAR profile of side channel at RM 68.8. profile connects with main river at upstream and downstream ends.

4.1.7 RM 67.9 St Xavier Bridge

Length: 2,250 feet
Estimated Excavation Volume: 170 cy

This channel is similar to the Juniper Channel, in that it was within the bankfull boundaries of the main river channel in the 1950s. It flows beneath the St Xavier bridge on the left floodplain (Figure 35). Currently, the channel entrance has several high points that reach up to about 2 feet above the river stage at 6,400 cfs. The profile of the channel shows that excavation could likely extend to about 1.0 feet below the 6,400 cfs line, which would make the channel accessible at about 4,200 cfs. The project imagery shows the channel flowing only in the high water of 2011.

Figure 35. Google Earth Image (2016) disconnected side channel at RM 67.9; inset shows channel in 1954.

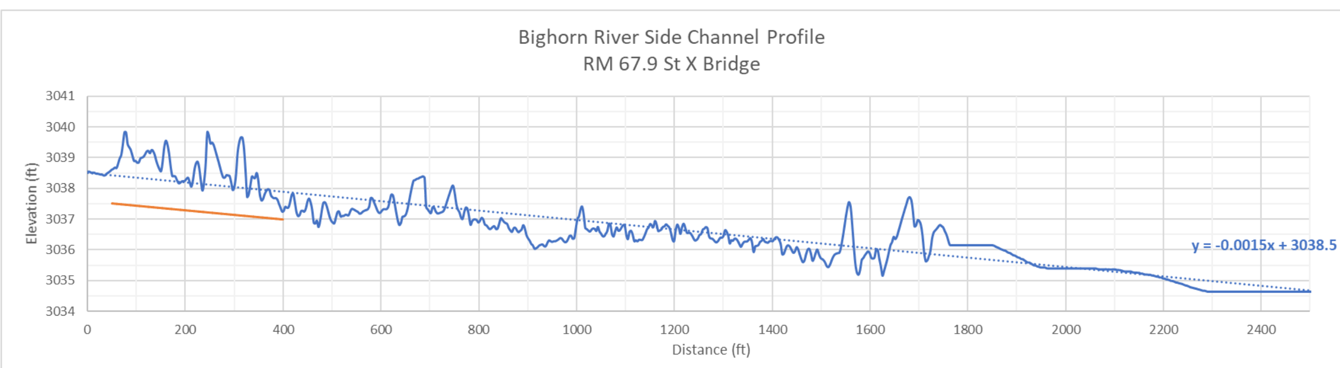


Figure 36. LiDAR profile of side channel at RM 67.9 showing high ground at entrance; proposed excavation profile is shown in orange.

4.2 Segment 2: St Xavier to Hardin

Between St Xavier and Hardin, a total of 17 channels were evaluated for potential reactivation. Of those 10 were dismissed due to low feasibility. The likeliest candidates are listed below in Table 6. Only the three top tier opportunities are described in more detail below, however Appendix A contains profiles for each of the channels listed.

Table 6. Side channels evaluated between St. Xavier and Hardin.

Entrance RM	*General Location*	*Length*	*Comments*	*Adjacent Owner**	*Tier*
66.5	Royal Bighorn	1650	Chute channel across from Royal Bighorn-- could activate small channel easily for habitat, could increase risk of cutoff	Crow Tribe	Middle
65.1	Below 511	1900	Would require extensive excavation at head to get activation at ~5,000 cfs	Crow Tribe	Middle
64.4	Stock Tank Hole	1550	Pretty good access now and chance for scour is good but recent decay indicates connectivity could be progressively lost; monitor.	Null	Top
63.3	Mallards	4700	Wet in most imagery but completely dry in low flows of 2006. Poor entrance alignment—could adjust	Harnish Group/Crow Tribe/ Schaak	Top
60.8	Woody Creek	5600	Substantial deposition at entrance-- good work from river, long channel. Good access now but poor entrance angle.	Null/Schaak Partnership	Middle
60.3	Below Woody Cr	2000	Feeds another side channel-- lots of work required	Null/Schaak Partnership	Bottom
60.1	Wild Horse Coulee	4900	Could potential feed other small channels but requires > 3 ft of excavation over hundreds of feet	Null/Schaak Partnership	Middle
56.7	Landslide	4500	Reroute channel around toe of landslide; Slide not there in 2011	Null	Top

Based on available cadastral data (1/31/2019); "Null" values are presumed State of Montana lands. Land ownership should be verified based on Montana State Statute.

Table 7. Key parameters for top tier sites between St Xavier and Hardin.

RM at Entrance	*General Location*	*Length (ft)*	*Estimated Excavation Volume (cy)*	*Estimated Activation Discharge with Excavation (cfs)**	*Excavation per foot of channel activated (cy/100 ft)*
64.4	Stock Tank Hole	1550	167	5300	10.8
63.3	Mallards	4700	Uncertain	<2,000?	N/A
56.7	Landslide	4500	Uncertain	<2,000?	N/A

This is an estimate based on rating curves at gaging stations and has been used for relative comparisons.

4.2.1 RM 64.4 Stock Tank Hole

Length: 1,550 feet
Estimated Excavation Volume: 170 cy

This channel is about 1,500 feet long and it appears that the entrance is progressively decaying, making a project potentially worthwhile (Figure 37). The LiDAR profile shows a distinct blockage on the upstream end of the channel; re-opening that channel would require an estimated 167 cy of excavation (Figure 38).

Figure 37. Google Earth Image (2016) showing decaying side channel entrance at RM 64.4; inset shows channel in 1954.

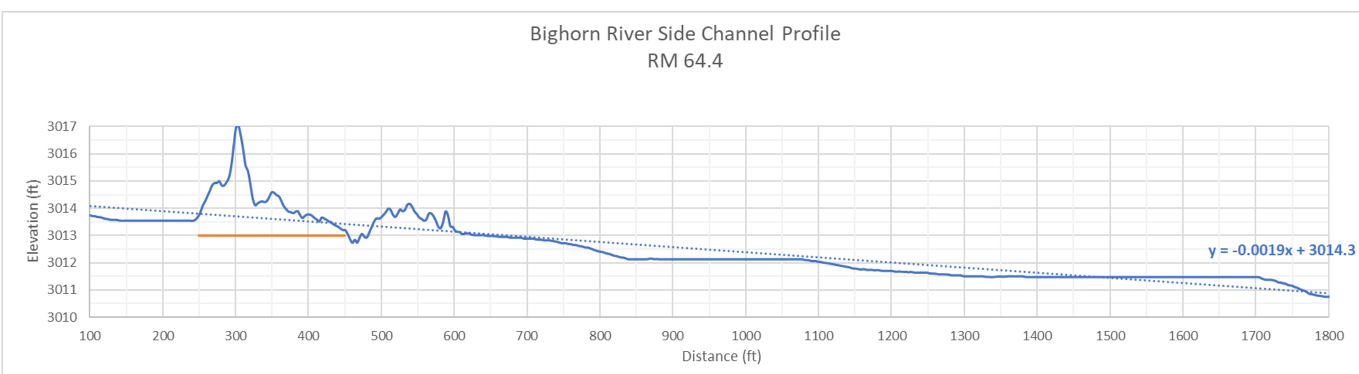


Figure 38. LiDAR profile of side channel at RM 67.9 showing high ground at entrance; proposed excavation profile is shown in orange.

4.2.2 RM 63.3 Mallards

Length: 4,700 feet
Estimated Excavation Volume: Uncertain

This is a long side channel across the river from Mallards Fishing Access Site. It made the top tier list because it shows good connectivity in most of the imagery with the exception of 2006 and 2013, when it was completely dry at flows of 1500 cfs and 2200 cfs, respectively. Figure 39 shows conditions in 2006. Other imagery shows that there is generally good connectivity above flows of around 3,000 cfs. As the channel was flowing when the LiDAR was collected at 6,400 cfs, there was not topographic profile available for the bed. However, imagery shows that there are some interesting geomorphic features at the site. The Google Earth image from 2013 (2,200 cfs) shows a bar forming at the mouth of the channel. This effectively splits flows right at the channel entrance, but it appears the entrance alignment/elevation doesn't capture those flows below 2,200 cfs.

Figure 39. Channel at RM 63.3 showing dry conditions at low flows in 2006; channel was also not flowing in Google Earth Imagery from summer 2013.

Figure 40. Entrance to channel at RM 63.3 showing bar formation at entrance—channel was not flowing when this image was taken in July 2013.

4.2.3 RM 56.7 Landslide

Length: 4,500 feet
Estimated Excavation Volume: Uncertain

This site provides a really interesting opportunity for side channel reactivation. At this location a major side channel has been blocked by a landslide (Figure 41). The imagery suites indicate that the landslide happened sometime between 2013 and 2015. Figure 41 shows that by 2019, water may be flowing around the toe of the slide. A profile along the side channel shows the deposit to be about 10 feet thick along the side channel route. It would be appropriate to further explore this site to see if a channel is naturally forming around the slide, or if the blockage appears to be long-term without intervention. If that is the case, a pilot channel could be cut around the toe of the slide to greatly improve access into the 4,500 ft long side channel.

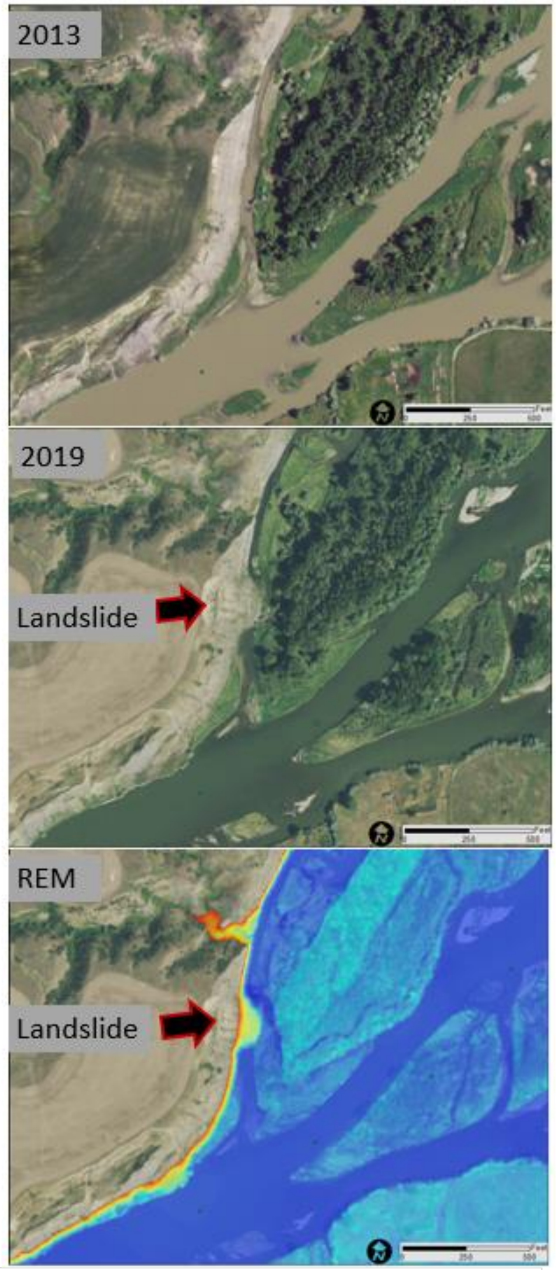


Figure 41. Google Earth (2016) image showing side channel blocked by landslide (top). Series to right shows Landslide forming channel blockage between 2013 (top) and 2019 (middle). Lower image shows feature on REM.

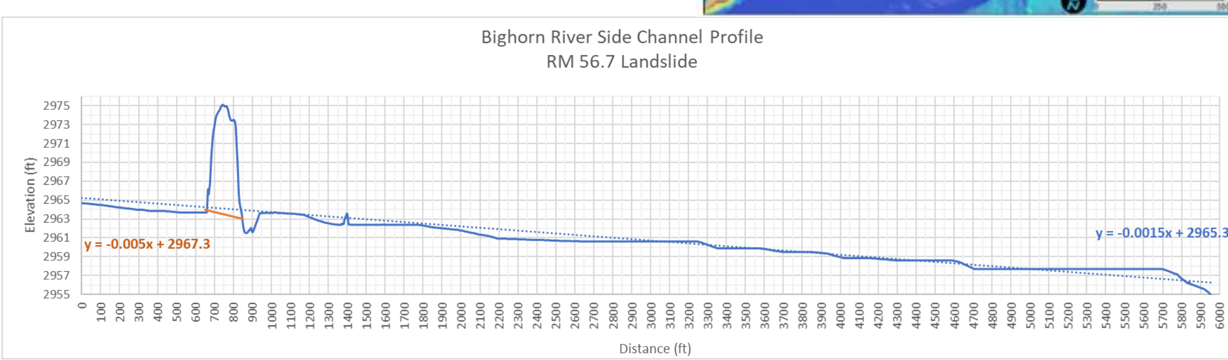


Figure 42. Side channel profile through landslide, RM 56.7.

4.3 Segment 3: Hardin to Yellowstone River

A total of 26 channels were evaluated for potential reactivation below Hardin. Of those, 16 were quickly assessed as having poor feasibility. The remaining 10 are listed below; only those identified as top tier are described in more detail below (Table 8 and

Table 9).

Table 8. Summary of channels evaluated below Hardin.

RM	***Location***	***Length (ft)***	***Comments***	***Adjacent Owner****	***Tier***
40.6	FWP	3950	Channel at FWP FAS Arapooish. May already have culvert on upper end? Could include a controlled entrance as unrestricted flow may threaten house downstream	MT Fish Wildlife and Parks (FWP)	Middle
36.7	Mouth of Dry Creek	3000	Could be good, with some excavation at head. Small channel though ~35 feet wide. Nice riparian bankline. Entrance is passive which might make it difficult to keep open	Ng Lit Family Trust, Yerger	Middle
32	Grant Marsh FAS	4700	Stepped profile due to crossing. Would be much more active with a bridge. May enlarge and impact FAS access.	FWP, Noel	Middle
30.8	Just below Grant Marsh	4800	Dennis Fischer visited-- long channel with blocked entrance, evidently car bodies. LiDAR appears unreliable here—it would require a survey but looks like a good opportunity with landowner interest.	Svaren	Top
29.5	End of Schultz Road	9800	Currently long abandoned channel with armored bank at entrance; would potentially benefit from culverts; upper end has blockage/road crossing to field. Would have to route water through currently armored bank. Low tier.	Hehling, Weinberg, Wacker, JC River	Bottom
19.9	Pocket Creek Ranch	6900	Looks like a terrific opportunity against the right valley wall in riparian bottoms just upstream of Pocket Creek. It would also pull water away from the power line tower that is seriously threatened	Pocket Creek Ranch	Top
16	Fountain of Youth Coulee	6650	Good opportunity for excavation on upper end; channel is long through riparian bottoms.	Pocket Creek Ranch/ State of Montana	Top
15.6	West of Fountain of Youth Coulee	3400	Blockage at top built ~2005-2011. Abuts agricultural fields.	Mission Creek Land and Cattle	Middle
14.4	Mission Creek	3100	Located just upstream of bridge at Mission Creek, above diversion dam. About 300 feet of so of excavation would be required at the entrance, but even then it will be difficult to frequently activate. The channel flows against a sandstone bluff line which could provide good habitat	Pocket Creek Ranch	Bottom
10.1	Greene Coulee	4100	Big project but would activate large swale in riparian bottoms; good habitat potential.	Pocket Creek Treasure	Middle

Based on available cadastral data (1/31/2019); "Null" values are presumed State of Montana lands. Land ownership should be verified based on Montana State Statute.

Table 9. Key parameters for top tier channels between Hardin and Yellowstone River.

RM at Entrance	*General Location*	*Length (ft)*	*Estimated Excavation Volume (cy)*	*Estimated Activation Discharge with Excavation (cfs)**	*Excavation per foot of channel activated (cy/100 ft)*
30.8	Just below Grant Marsh	2400	1481	3500	61.7
19.9	Pocket Creek Ranch	6900	1481	4900	21.5
16.0	Fountain of Youth Coulee	6650	296	4093	4.5

****This is an estimate based on rating curves at gaging stations and has been used for relative comparisons.***

4.3.1 RM 30.8 Just Below Grant Marsh FAS

Length: 2,400 feet

Estimated Excavation Volume: Minimal—debris and likely some sediment

This channel is located about a half mile downstream from Grant Marsh Fishing Access Site. It is a large remnant channel that was the main thread of the river in the 1950s (Figure 43). The channel was flowing during the LiDAR flight so the blockage on the upstream end is not captured in the topography. Figure 44 shows the blockage; this photo was taken on January 23, 2020 when the river was flowing at about 3,500 cfs (courtesy of Dennis Fischer). Connectivity is generally well-established here, however fairly minor work at the head of the channel appears likely to increase flow volumes and frequencies, while intercepting the degradation trend. This channel has a well-developed morphology with strong banklines and some minor islands. The old channel shown in the upper left corner of the 1950s imagery (Figure 43) forms a high flow swale that could be potentially be integrated into a larger project although it is perched a few feet above the side channel, indicating substantial post-1950s deposition in the oxbow feature. Currently the swale supports wetland habitats (Figure 46); the most cost-effective means of reconnecting this feature is likely via excavation on its lower end, to create a connected backwater.

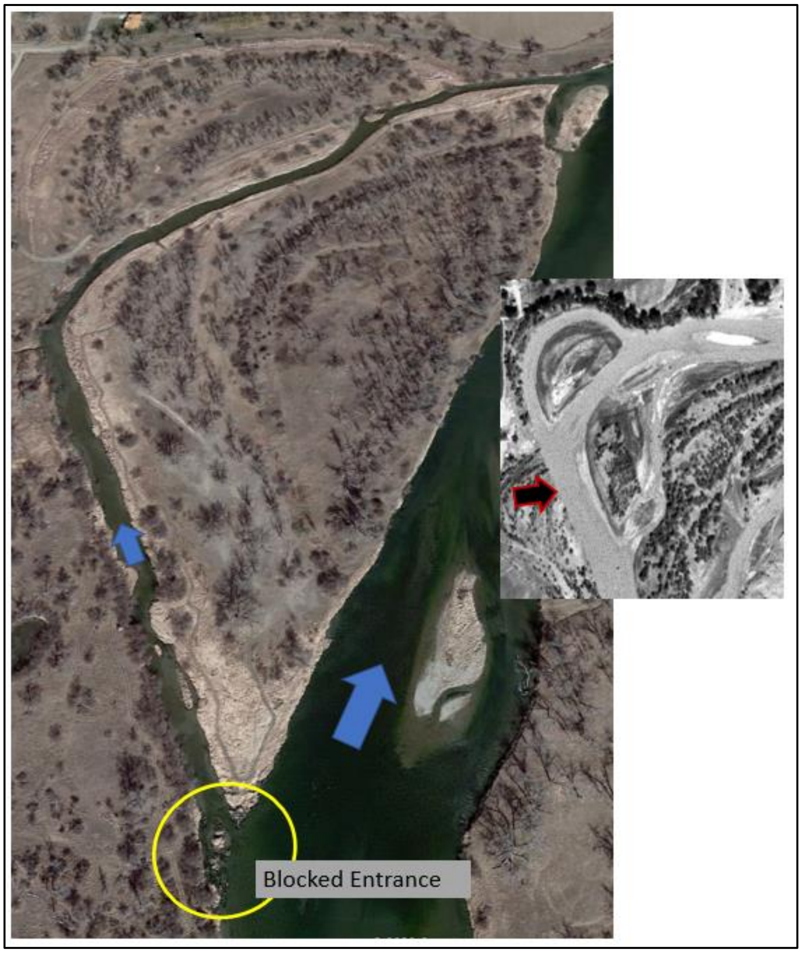


Figure 43. Google Earth Image (2016) showing partially disconnected side channel at RM 30.8; inset shows channel in 1954.

Figure 44. View upstream of channel entrance at RM 30.8 (Dennis Fischer photo).

Figure 45. View downstream of side channel at RM 30.3 (Dennis Fischer photo).

Figure 46. Overflow swale that connects to side channel at RM 30.3 (Dennis Fischer photo).

4.3.2 RM 19.9 Pocket Creek Ranch

Length: 6,900 feet
Estimated Excavation Volume: 1480 cy

This side channel is over a mile long, and it was a prominent secondary channel in the 1950s (Figure 47). The LiDAR profile shown in Figure 48 suggests that dropping the elevation at the head of this channel to about one foot below the LiDAR river stage may be feasible. Currently the channel does not appear to activate at flows less than 10,000 cfs; excavation could potentially drop the activation discharge to below 5,000 cfs, which would equate to about two months a year of active flow, on average. Working on this channel would also require intensive Russian olive removal.

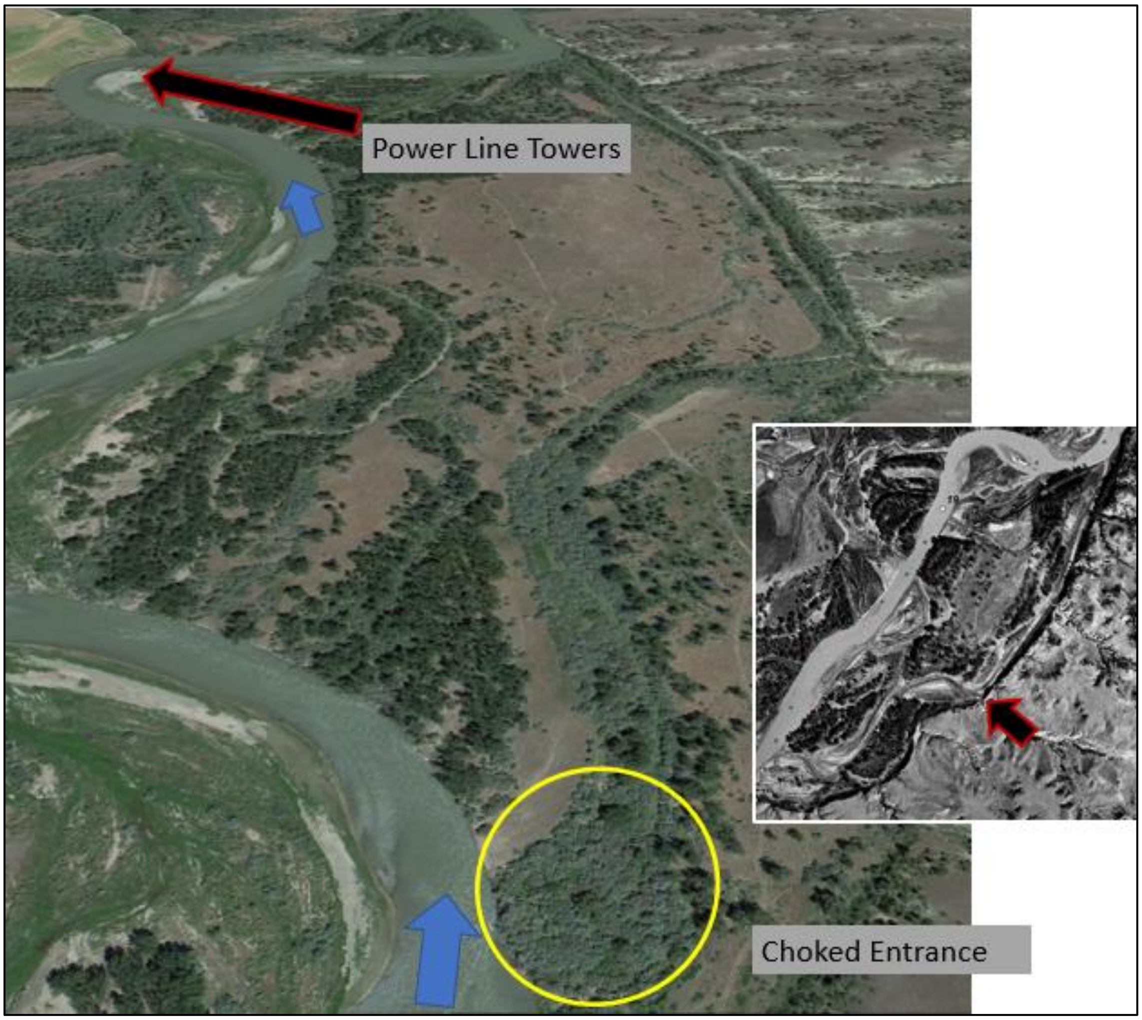


Figure 47. Google Earth Image (2013) disconnected side channel at RM 19.9; inset shows channel in 1954.

An interesting aspect of this site is that channel reactivation would reduce flows in the main channel where there are major erosion concerns at a powerline (Figure 47). Reactivation could potentially reduce erosive stress at the power line, however this channel is relatively small (~25 feet wide), so without major channel enlargement, its impact on reducing mainstem erosion rates will be relatively minor.

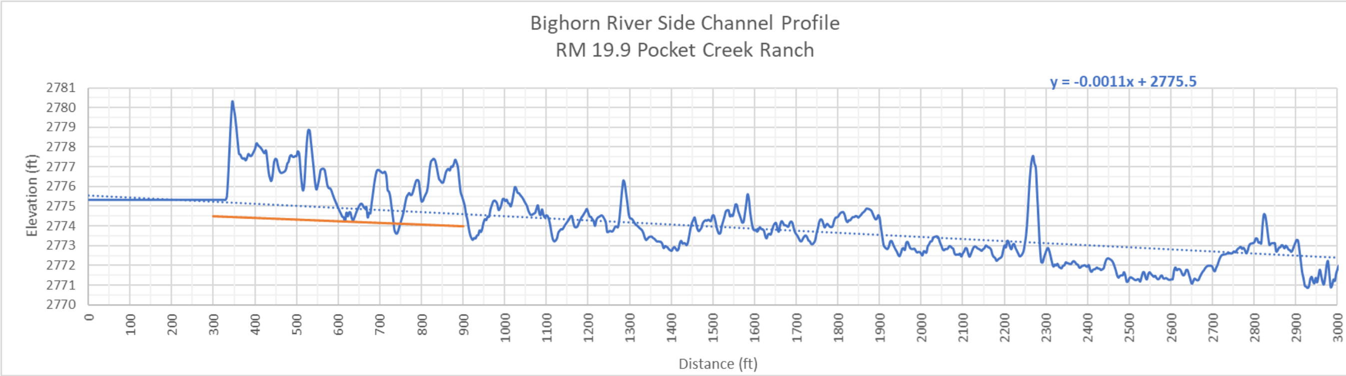


Figure 48. LiDAR profile of upper portion of side channel at RM 19.9; orange line shows rough design grade.

4.3.3 RM 16.0 Fountain of Youth Coulee

Length: 6,650 feet
Estimated Excavation Volume: 300 cy

At RM 16, an old major side channel has become disconnected at its entrance due to deposition (Figure 49). A LiDAR profile shows substantial aggradation over the uppermost ~200 feet of the channel. Based on the LiDAR, excavation could increase the connectivity to about one foot below LiDAR stage, or about 5,000 cfs. On the lower river, this flow is equaled or exceeded about 17% of the time, or 62 days per year.

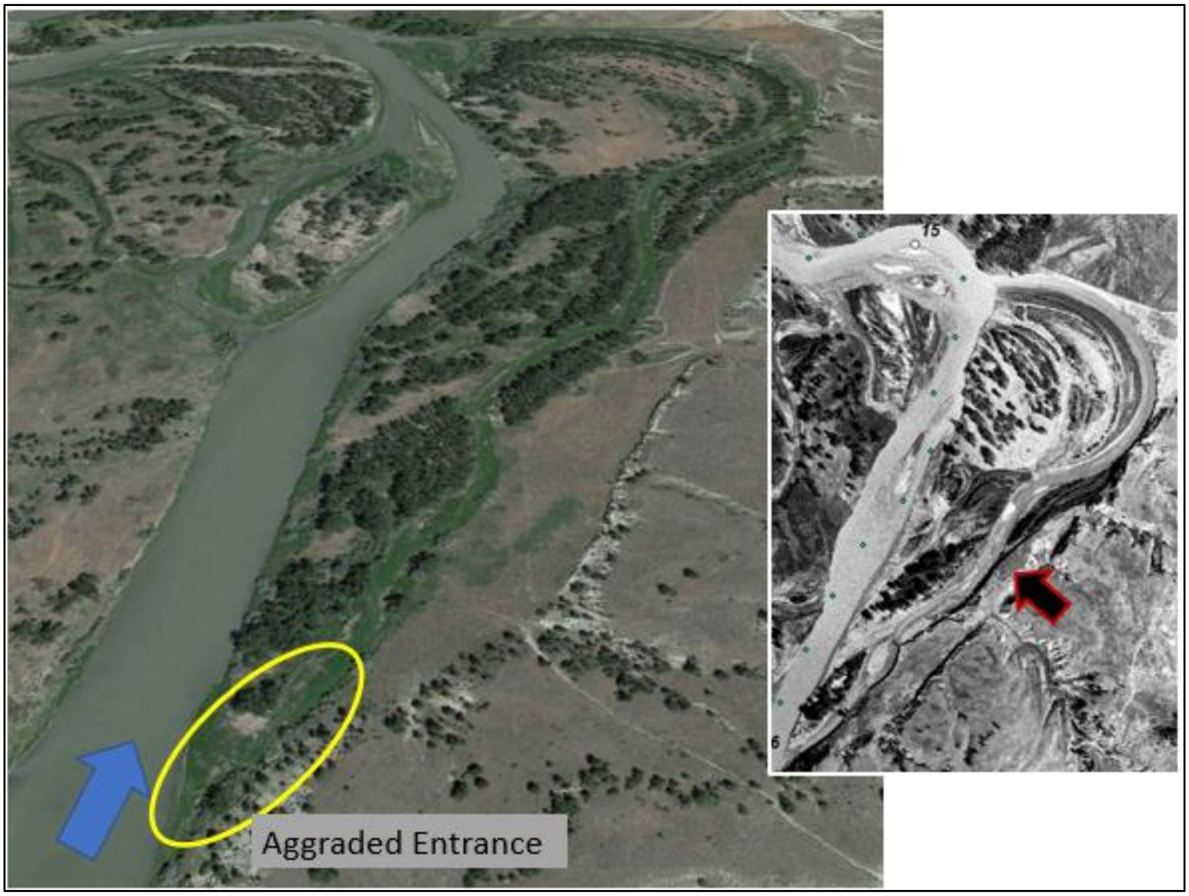


Figure 49. Google Earth Image (2013) disconnected side channel at RM 16.0; inset shows channel in 1954.

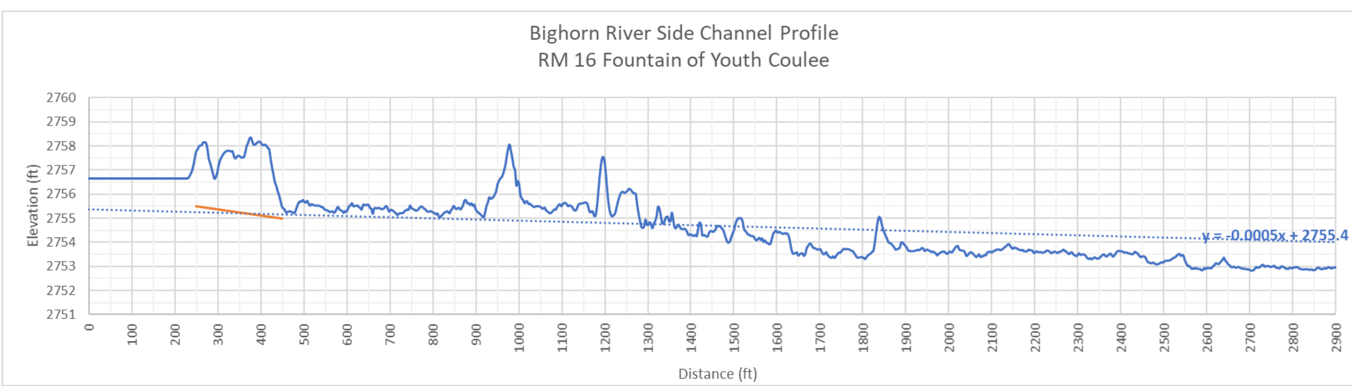


Figure 50. LiDAR profile of upper portion of side channel at RM 16; orange line shows rough design grade.

5 Next Steps for Project Development

The following section describes some considerations for continued project development, including site assessment, design, and permitting. Specific design considerations for several channels are provided as well.

5.1 Site Assessment and Design

Some main considerations for further project development include the following:

1. ***Landowner outreach:*** Landowners listed in this document should be verified with the most recent cadastral data prior to outreach.
2. ***Perform field review:*** A field review should happen early, to evaluate the possibility of additional habitat improvements on the side channels. With gravel excavation at the side channel entrance, it may be beneficial to use that material downstream in the side channel to enhance habitat, even though that requires more complicated permitting. Spawning gravels will only become more precious in this system with time, and if the river has indeed downcut (Section 2.1.6), that means it has flushed appreciable gravel in recent years. Site access should also be explored during the field review.
3. ***Collect survey data:*** Although the LiDAR data is immensely helpful, it does not capture bathymetry, and there might be some complications with vegetation in the data. As a result, it will be important to collect that information, especially on main channel at the side channel entrance and through the upper portion of the side channel, to see how much the entrance could be lowered.
4. ***Integrate with USBR model to define connectivity:*** If an updated model becomes available, the level of connectivity upon excavation could be more accurately estimated using that model.
5. ***Identify best construction strategy:*** Should the project site be accessed by land or by water?
6. ***Design, Permitting, and Construction***: There are numerous competent restoration practitioners who could take on all aspects of design, permitting, and contractor management.

5.2 Previous Design Efforts

Figure 51 shows the proposed cut profile for Picture channel, to show that the approach is similar to the one taken with other side channels evaluated in this report (placing a design cut grade on the existing profile to determine the proposed entrance elevation). As for channel cross section, the proposed dimensions for the Cline's Channel and Picture Channel are listed in Table 10. Picture channel was unfortunately never excavated due to landowner issues, but Clines channel has remained open and functional. The 30-ft channel topwidth prescribed for both channels was increased from an original topwidth design of 15 feet. In this assessment, a topwidth of 20 feet has been used to reduce excavation volumes and cost.

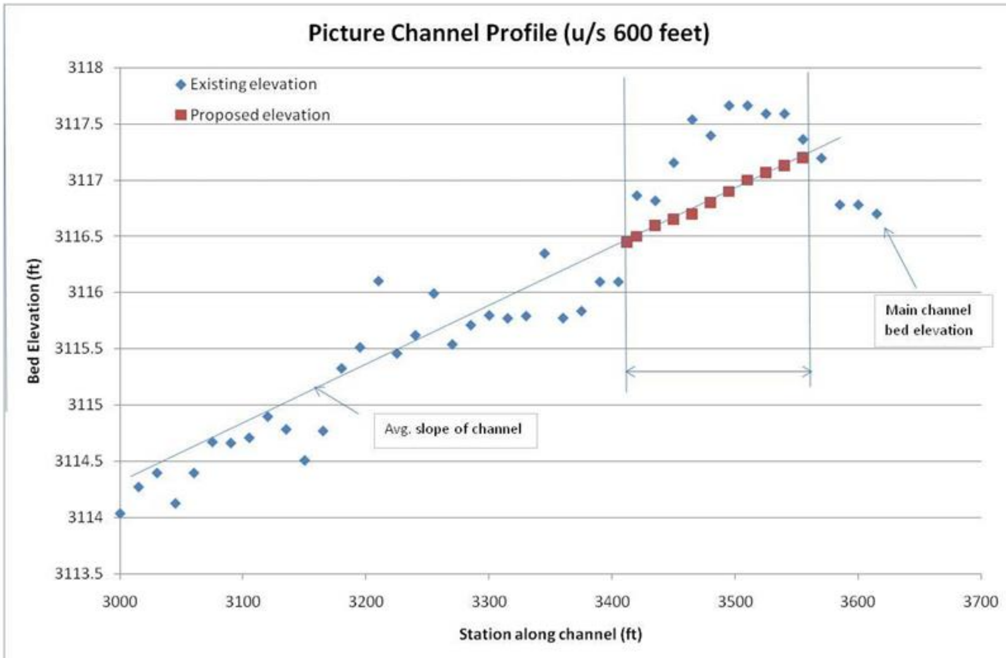


Figure 51. Picture channel profile showing proposed cut in red.

Table 10. Cut specification for Cline's Channel and Picture Channel*

Parameter	Clines Channel	Picture Channel
Top width (ft)	30	30
Bottom width (ft)	26	26
Side slope	2:1	2:1
Assumed average depth (ft)	1	1
Resulting volume (cy)	140	80
Slope	0.5% (Upper 250')	0.57% (Upper 600 ')

**source: pdf document titled "cline's and picture channel cut specs.pdf".*

5.3 Permitting

Permitting is an important consideration in all projects. It is always good practice to contact regulatory staff early in a project to clarify permitting needs.

5.3.1 Conservation District 310 Permit

The Cline's channel 310 permit was received in February of 2011, after it was approved by the Bighorn Conservation District Board of Supervisors. The permit includes conditions that are similar to those of the 318 permit, including removal of all excess material above the ordinary high water mark. The Cline's Channel 310 permit application included removal of 2.1 acres of salt cedar and Russian olive.

5.3.2 Corps of Engineers 404 permit (Nationwide 27)

The Corps of Engineers may or may not regulate sediment excavation in an active stream channel. In some cases, "dredging" is regulated under the 404 program, but in others, as long as the excavated material is disposed of above the high water mark and not in wetlands, there is no 404 permit required. If the project design includes excavation and removal of the excavated material to a nearby upland location, the COE should be contacted to make sure permitting requirements are met.

Since gravel is a precious commodity below Yellowtail Dam, it may be appropriate to use the excavated material to do restoration work on the channel below. This will require a COE Nationwide 27 permit. This is a more intensive process, as the process permits aquatic habitat restoration, enhancement, and establishment activities. The permit application generally calls for an "ecological reference", which should not be onerous on the Bighorn (eg Cline's channel). Again, the COE should be contacted early in any project development effort to determine the best way to approach permitting.

5.3.3 MT Department of Environmental Quality 318 Permit

The 318 permit provides a short-term water quality standard for turbidity related to construction. The Cline's channel 318 permit lays out construction requirements pursuant to the permit, including minimization of construction activities in the watercourse, spill precautions, erosion control, and disposal of materials. The materials disposal requirement is an important aspect of these projects; the 318 permit stated that "Any excess material generated from this project must be disposed of above the ordinary high water mark, not classified as a wetland, and in a position not to cause pollution to state waters".

5.4 Site Access Considerations

There has been some discussion regarding the use of amphibious equipment to perform side channel excavations, and this equipment is available for rent (Figure 52). This could be very appropriate for many of the sites however the issue remains as to dealing with the spoils generated.

Figure 52. Example amphibious excavator (Dennis Fischer).

5.5 Design Considerations for Specific Channels

It is important to recognize that each side channel described in this report will have unique site conditions that may improve or reduce the value of the ultimate outcome. Each site will need specific evaluation of those conditions. That said, a few ideas regarding some of the top tier sites above Mallards are briefly described below.

5.5.1 RM 79.1 Rattlesnake Island and RM 76.4 Juniper Channel

These two channels are similar in that they require minor excavation at their entrances to substantially improve connectivity. The recommended design approach for these channels is to work in a similar fashion to Cline's channel. The excavation should be 15-30 feet wide with 2:1 side slopes. The bed profile should be smooth in the excavated area to maximize velocities heading into the channel. For these channels it may be easiest to remove the material to an upland site to minimize permitting/design efforts. At Juniper Channel, the large wood that is lodged at the entrance could be used to build an apex bar jam at the head of the island (Figure 53).

Figure 53. Schematic example of a bar apex jam designed to maintain split flow conditions (Alcott, 2016).

5.5.2 RM 78.5 Pelican Island

The Pelican Island channel may be difficult to keep open because its entrance is on a passive edge of the river. Careful site review should be undertaken to see if there is an optimal flow path into the channel that can maintain higher velocities. As this channel requires more excavation than any other top-tier channel above St Xavier, I would recommend a restoration design that uses that material for habitat improvements along the side channel route, requiring a Nationwide27 COE permit.

5.5.3 RM 77.7 Picture Channel

Picture Channel work has been designed by the Bureau of Reclamation, and more recent survey data should be sufficient to revise that design as necessary. There currently a large woody debris jam at the head of the flow split, these features are effective at diverting flow into side channels hence I would recommend that it remain in place. If an agreement can be made with the landowner, this would be an appropriate channel to approach by removing the material at the head of the channel and relocating it to upland areas to the north. This may preclude the need for a 404 permit from the Corps of Engineers, but they should be contacted to make sure that is correct.

5.5.4 RM 68.8 Turtle Rock

The Turtle Rock channel could potentially be quite straightforward with Russian olive removal as the main project component, but the site will need to be more carefully evaluated to see if the LiDAR profile collected is accurate.

5.5.5 RM 67.9 St X Bridge

The St Xavier Bridge channel has a long swale remnant that is about 30 feet wide. The estimated excavation volume for this channel was based on a ~20 ft wide channel so that should be evaluated on site in terms of appropriateness. This may be an exceedingly difficult site to access from the road, even though the channel flows under the bridge. The feature is at the base of a tall bluff with no obvious access route.

The orientation of this channel to the river (essentially parallel) would make it a prime candidate for the inclusion of an apex bar jam at the head of the flow split (Figure 53).

5.5.6 RM 63.3 Mallards

This channel appears to be activated sometime between about 2,200 and 3,000 cfs. A depositional bar has developed at the mouth of the channel, which has created a small channel along the bank that is about 50 feet wide. This site could be evaluated to see if reshaping that bar and the channel entrance could effectively route water into the channel under most flows (Figure 54). This channel also provides an excellent opportunity for habitat restoration along its course, including riparian restoration and instream morphologic enhancement of habitat elements (pools/riffles/large wood).

Figure 54. View downs side channel at RM 63.3 showing potential to route additional flows with excavation and/or bar reshaping.

6 References

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Bureau of Reclamation

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Hilldale, R, 2012. Bighorn River Side Channel Investigation-- Hydraulic and Sediment Transport Analysis: U.S. Department of Interior, Bureau of Reclamation Technical Report No. SRH-2012-26.

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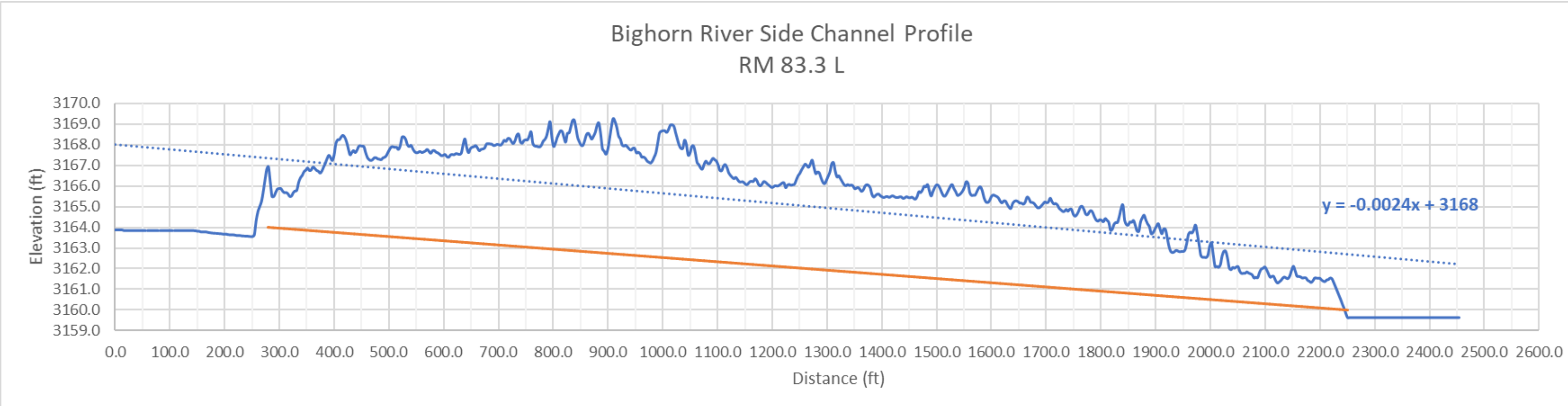
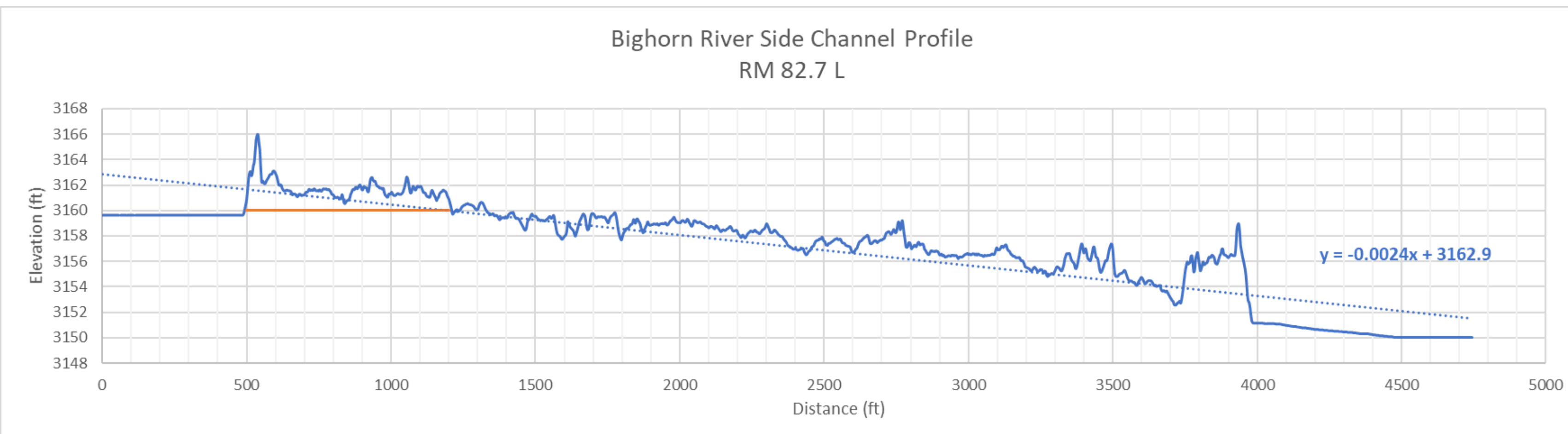
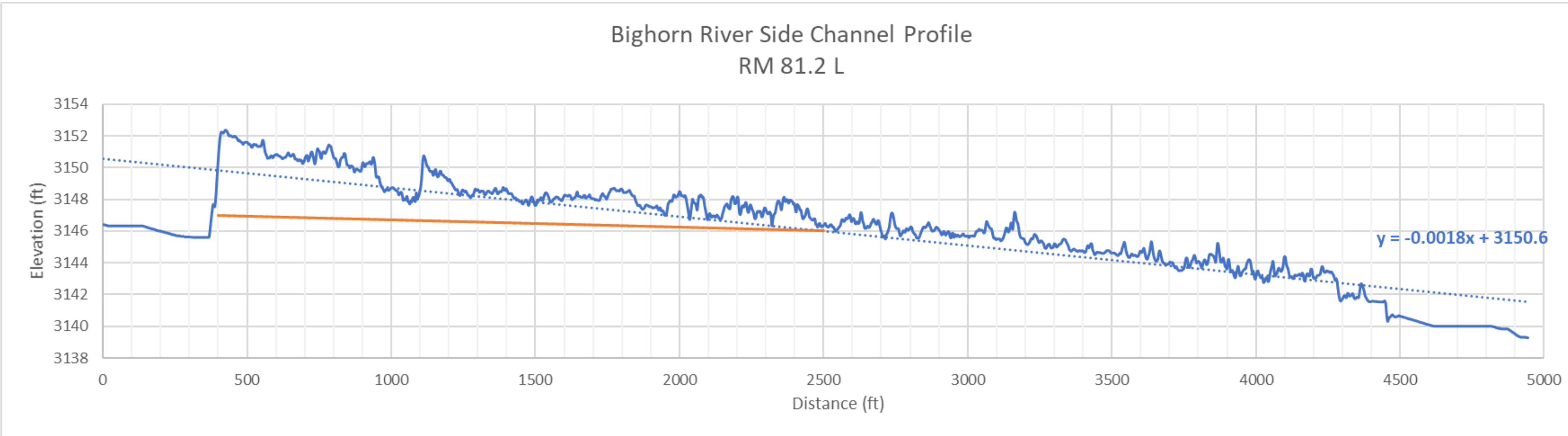
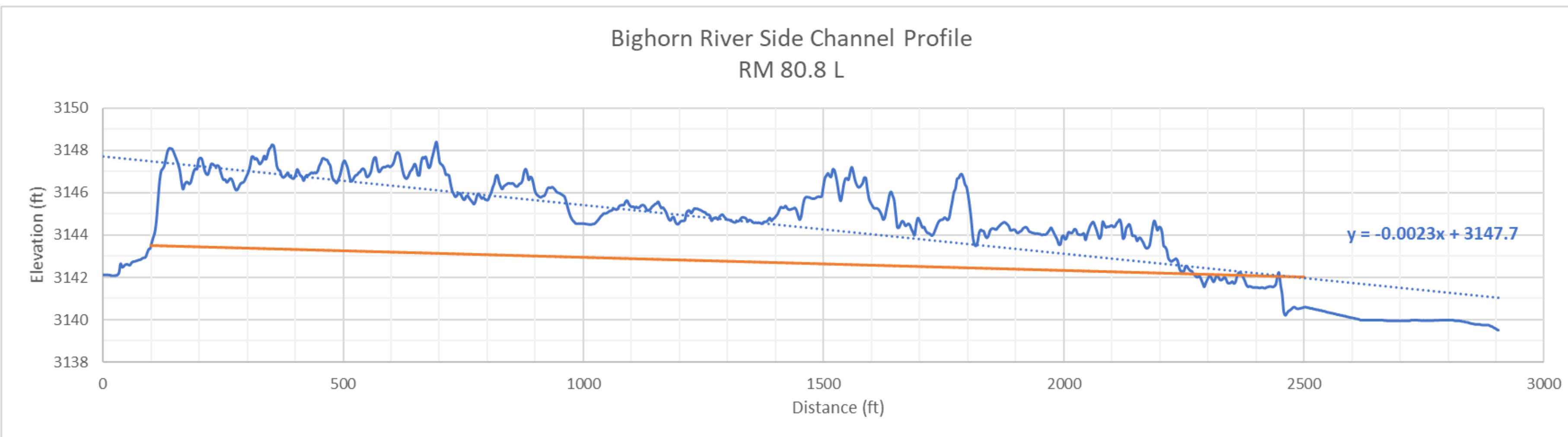
7 Appendix A: Profiles for High, Medium and Low Tier Channels

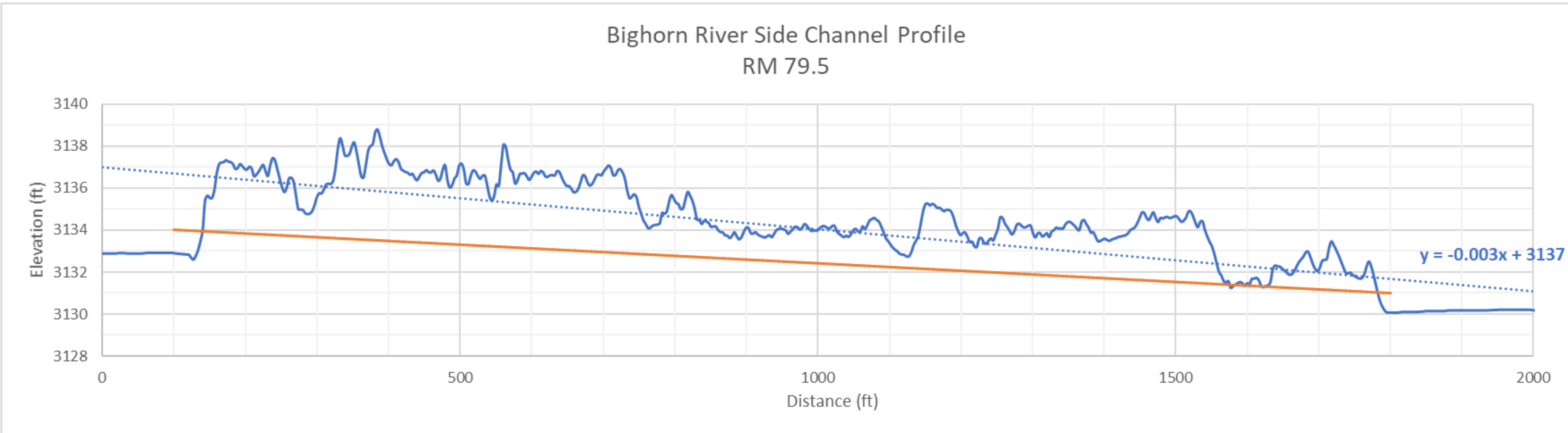
The following section contains topographic profiles of the side channels evaluated. The blue line is the existing topography, starting and ending in the main channel, and the orange line is a potential design grade for reactivation, to show the extent of excavation that would be necessary. No ground profiles were available for channels flowing at the time of the LiDAR survey.

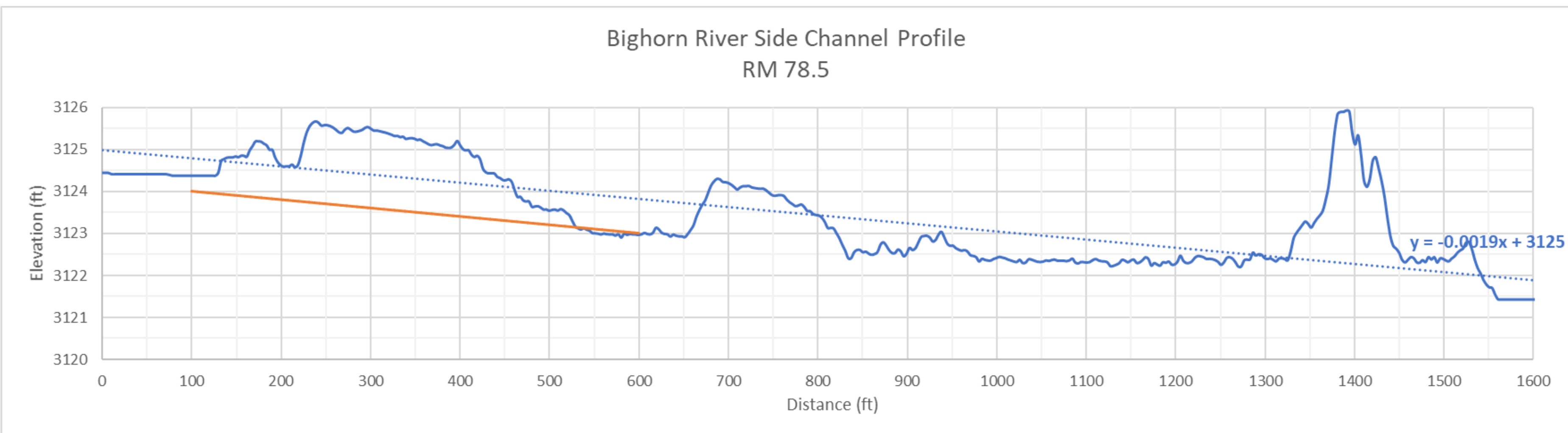


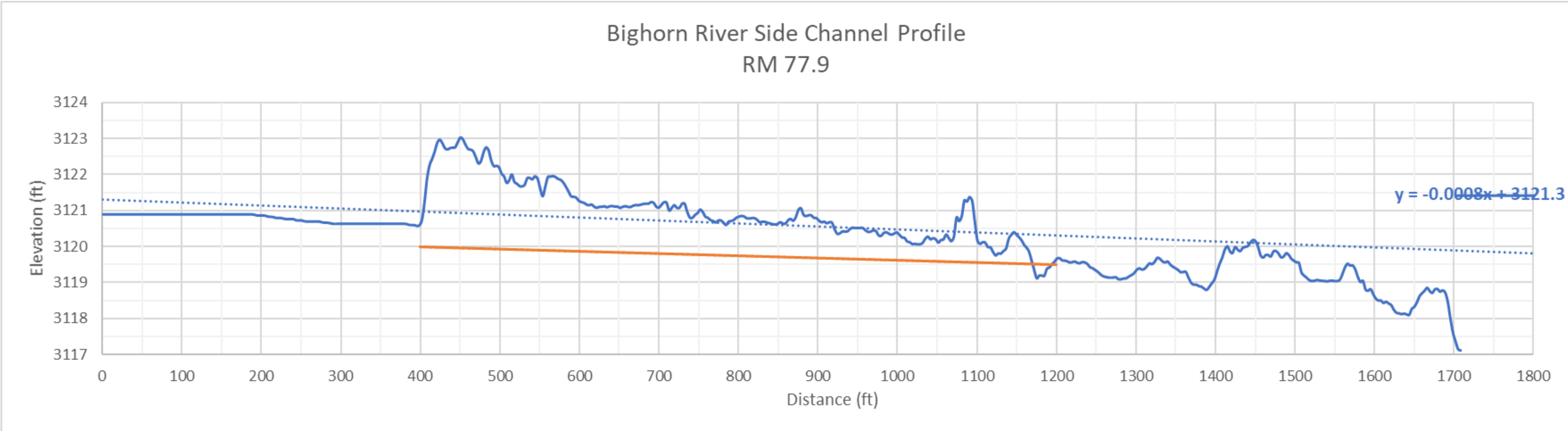


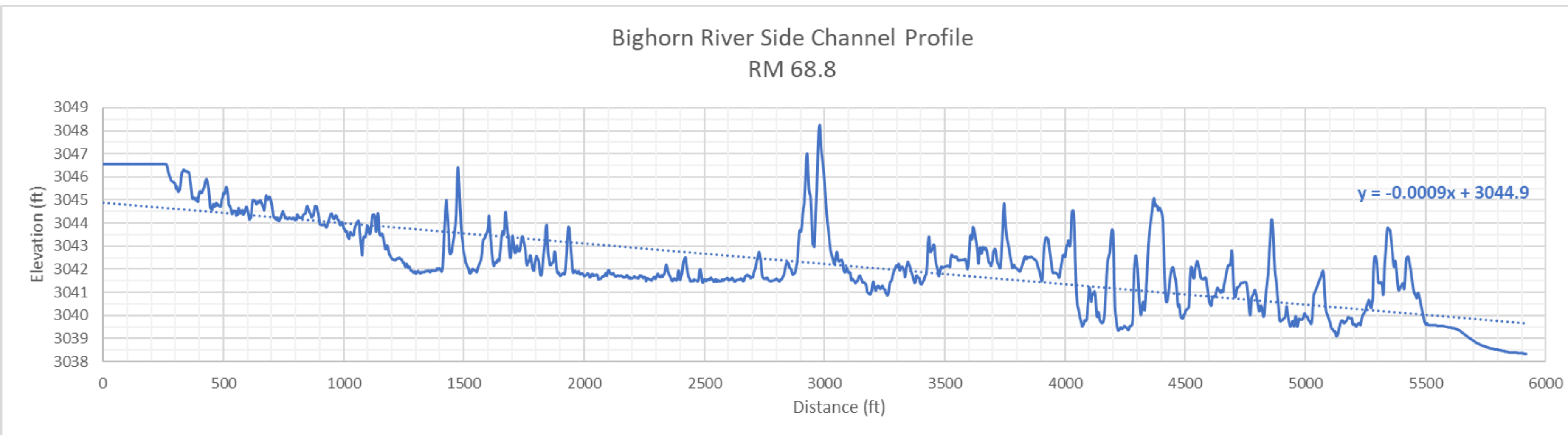

Bighorn River Side Channel Profile
RM 81.2 L
3154
3152
3150
3148
3146
3144
3142
3140
3138
Elevation (ft)
0
500
1000
1500
2000
2500
3000
3500
4000
4500
5000
Distance (ft)
y = -0.0018x + 3150.6

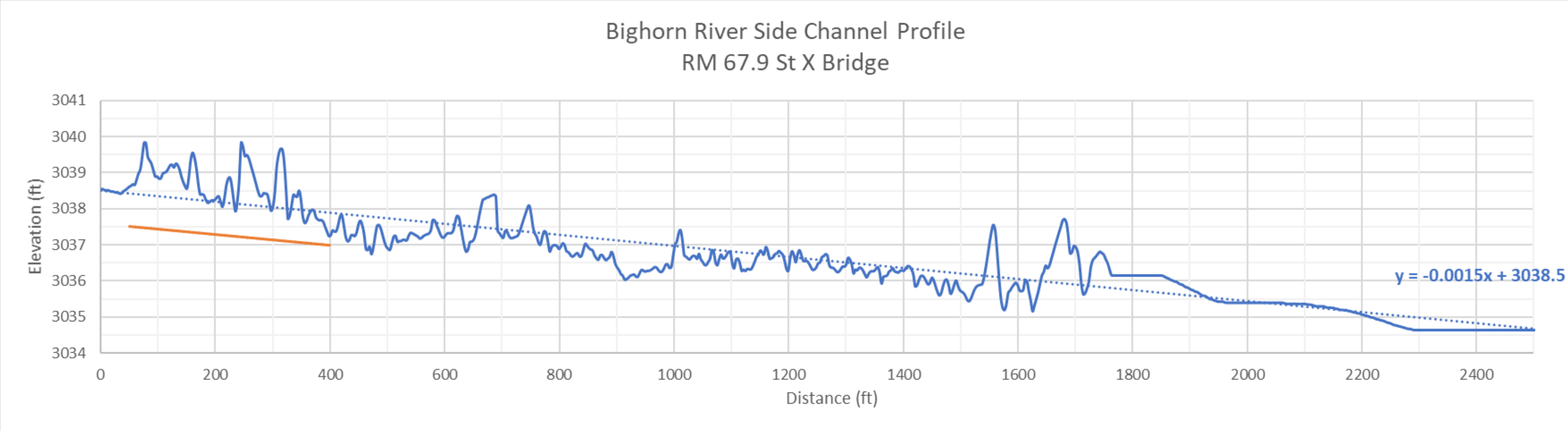

Bighorn River Side Channel Profile
RM 80.8 L
3150
3148
3146
3144
3142
3140
3138
Elevation (ft)
0
500
1000
1500
2000
2500
3000
Distance (ft)
y = -0.0023x + 3147.7

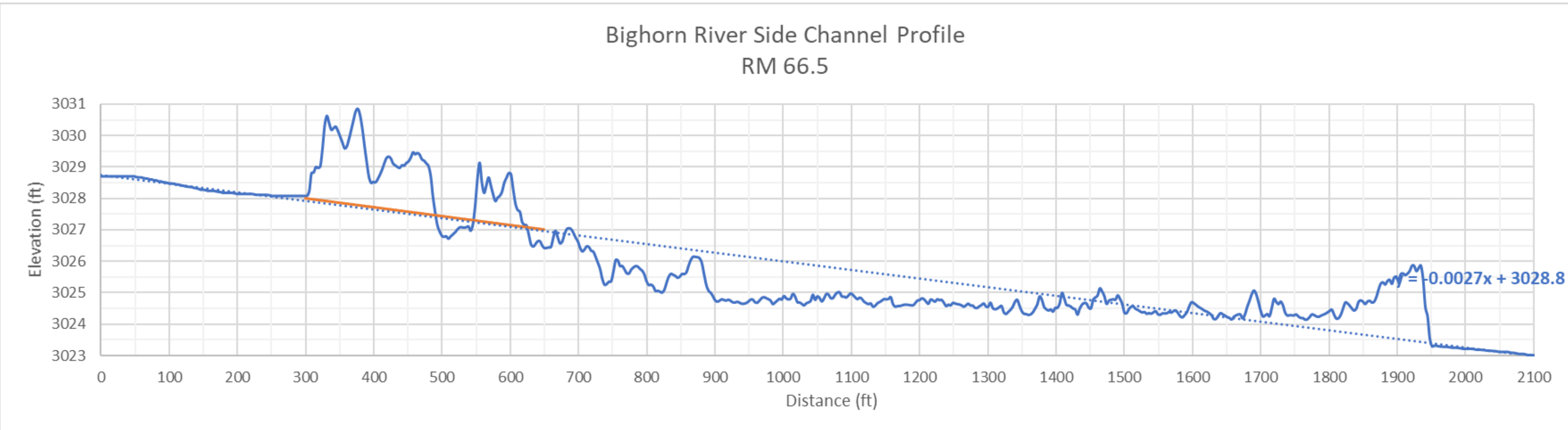

Bighorn River Side Channel Profile
RM 79.5
Elevation (ft)
3140
3138
3136
3134
3132
3130
3128
0
500
1000
1500
2000
Distance (ft)
y = -0.003x + 3137

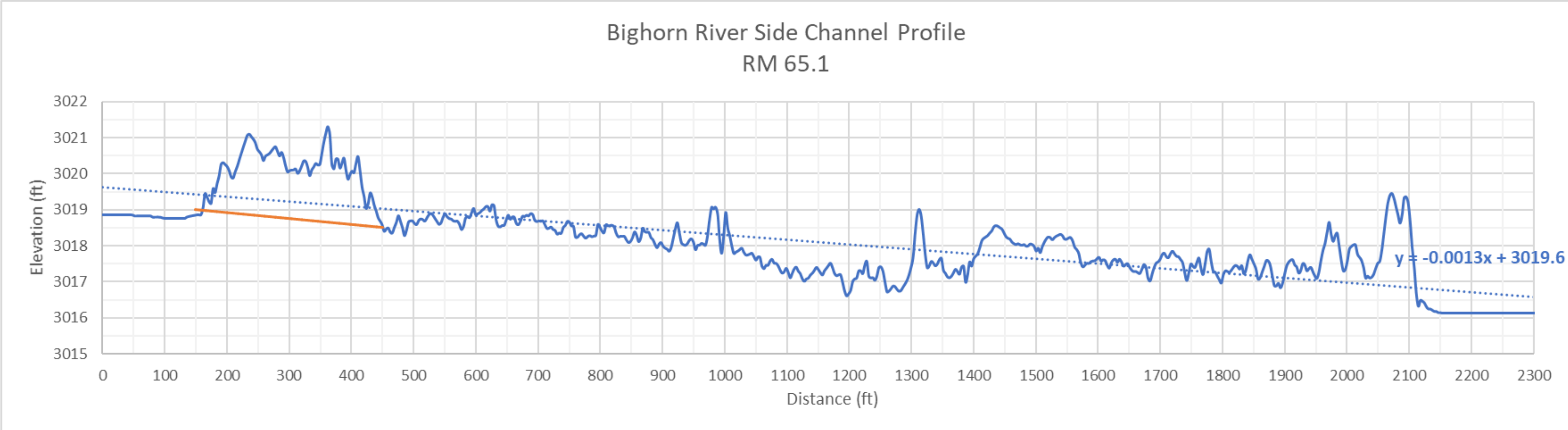

Bighorn River Side Channel Profile
RM 78.5
Elevation (ft)
3126
3125
3124
3123
3122
3121
3120
0
100
200
300
400
500
600
700
800
900
1000
1100
1200
1300
1400
1500
1600
Distance (ft)
y = -0.0019x + 3125

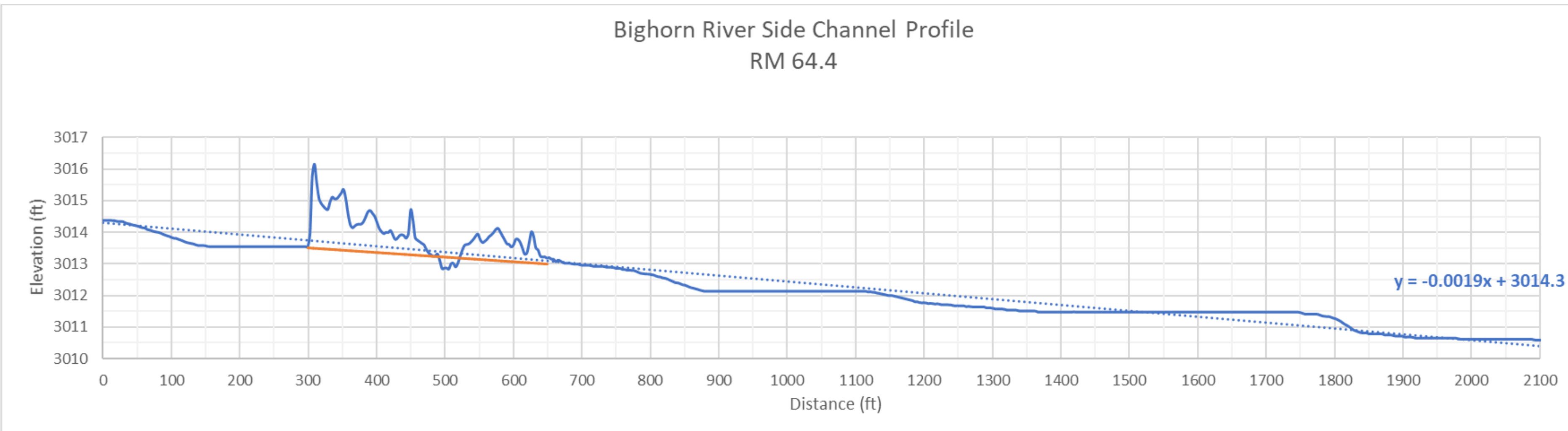

Bighorn River Side Channel Profile
RM 77.9
Elevation (ft)
3124
3123
3122
3121
3120
3119
3118
3117
0
100
200
300
400
500
600
700
800
900
1000
1100
1200
1300
1400
1500
1600
1700
1800
Distance (ft)
y = -0.0008x + 3121.3

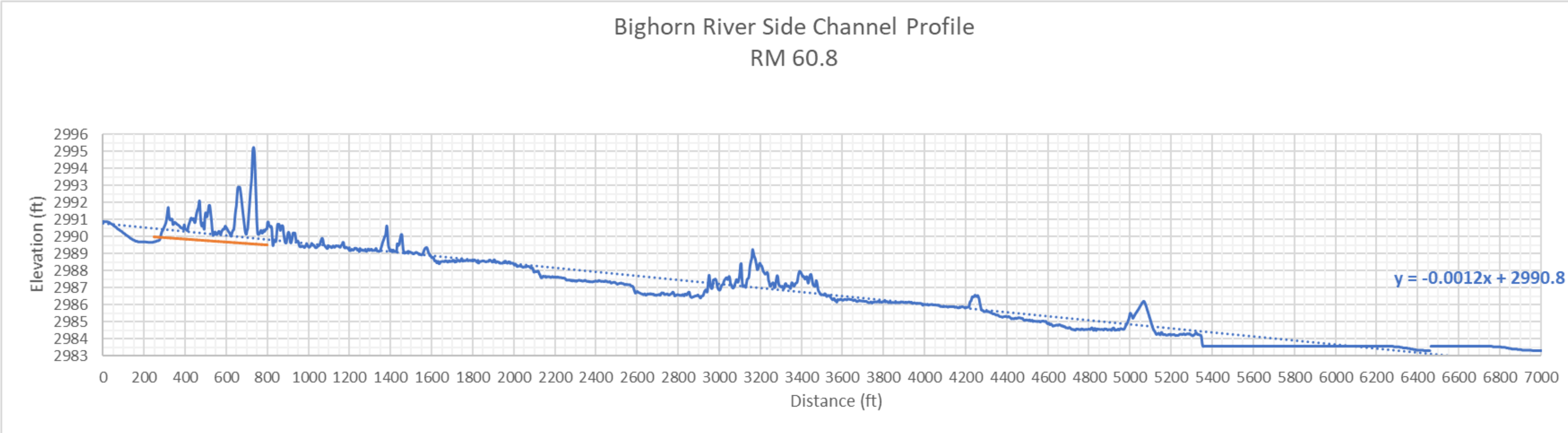

Bighorn River Side Channel Profile
RM 68.8
Elevation (ft)
3049
3048
3047
3046
3045
3044
3043
3042
3041
3040
3039
3038
0
500
1000
1500
2000
2500
3000
3500
4000
4500
5000
5500
6000
Distance (ft)
y = -0.0009x + 3044.9

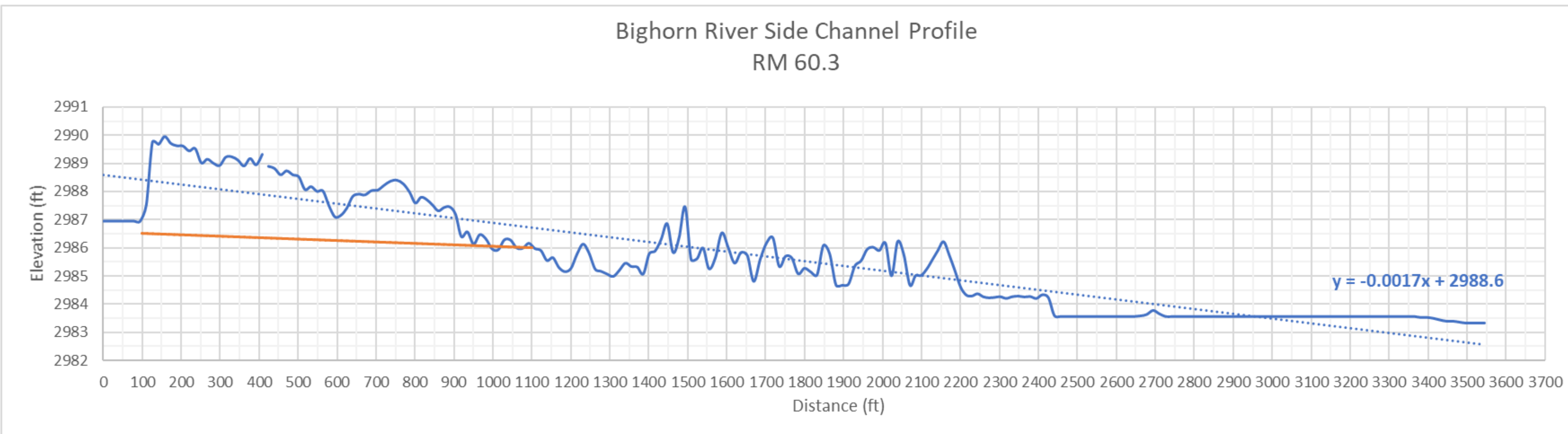

Bighorn River Side Channel Profile
RM 67.9 St X Bridge
Elevation (ft)
3041
3040
3039
3038
3037
3036
3035
3034
0
200
400
600
800
1000
1200
1400
1600
1800
2000
2200
2400
Distance (ft)
y = -0.0015x + 3038.5

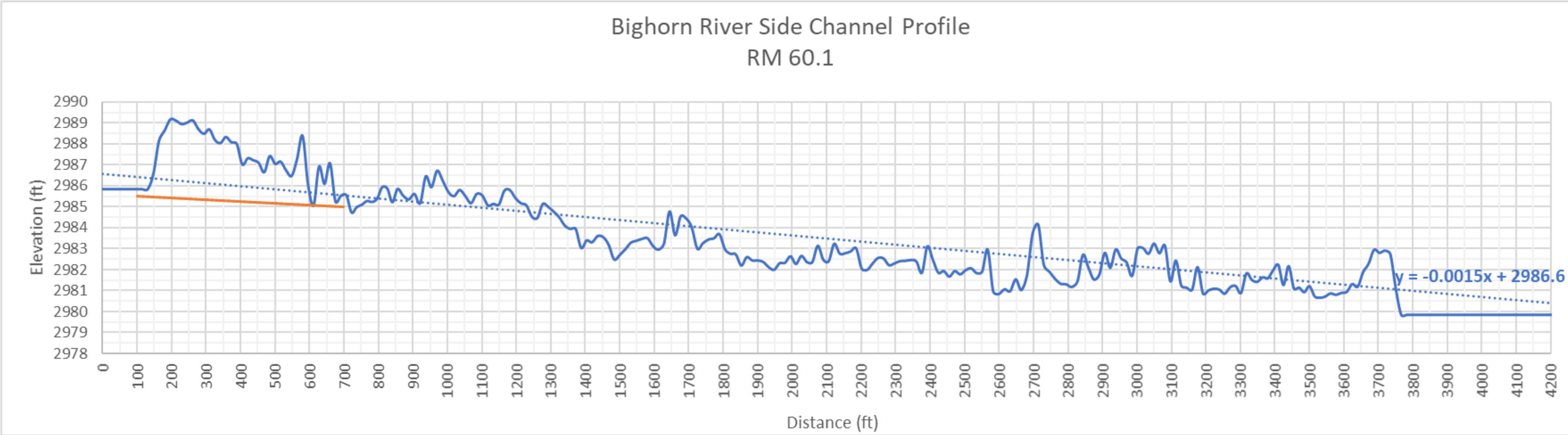

Bighorn River Side Channel Profile
RM 66.5
Elevation (ft)
3031
3030
3029
3028
3027
3026
3025
3024
3023
0
100
200
300
400
500
600
700
800
900
1000
1100
1200
1300
1400
1500
1600
1700
1800
1900
2000
2100
Distance (ft)
-0.0027x + 3028.8

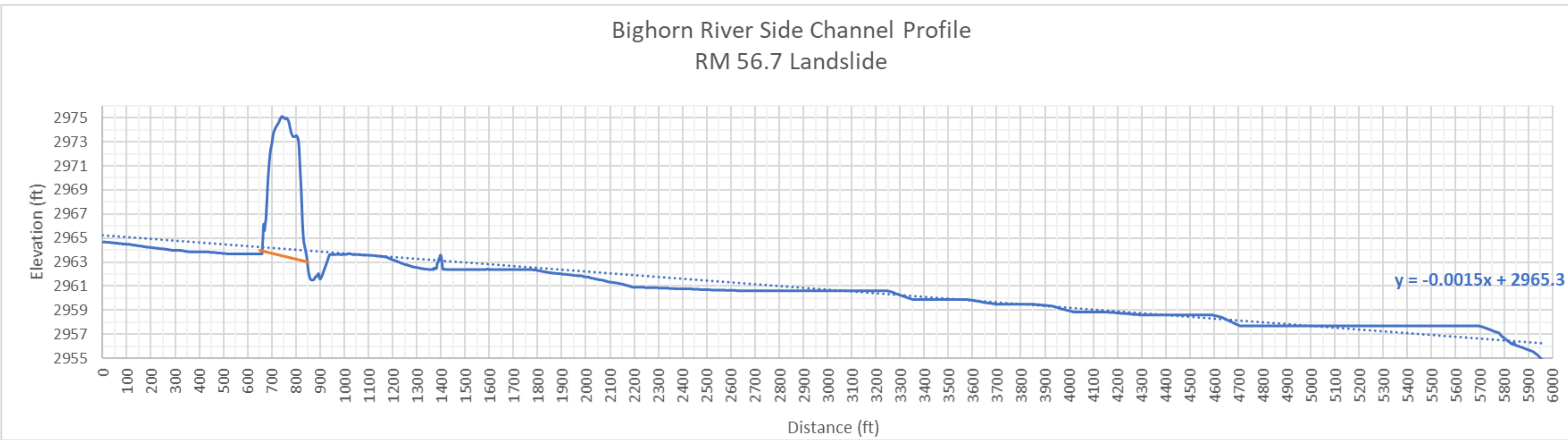

Bighorn River Side Channel Profile
RM 65.1
Elevation (ft)
3022
3021
3020
3019
3018
3017
3016
3015
0
100
200
300
400
500
600
700
800
900
1000
1100
1200
1300
1400
1500
1600
1700
1800
1900
2000
2100
2200
2300
Distance (ft)
y = -0.0013x + 3019.6

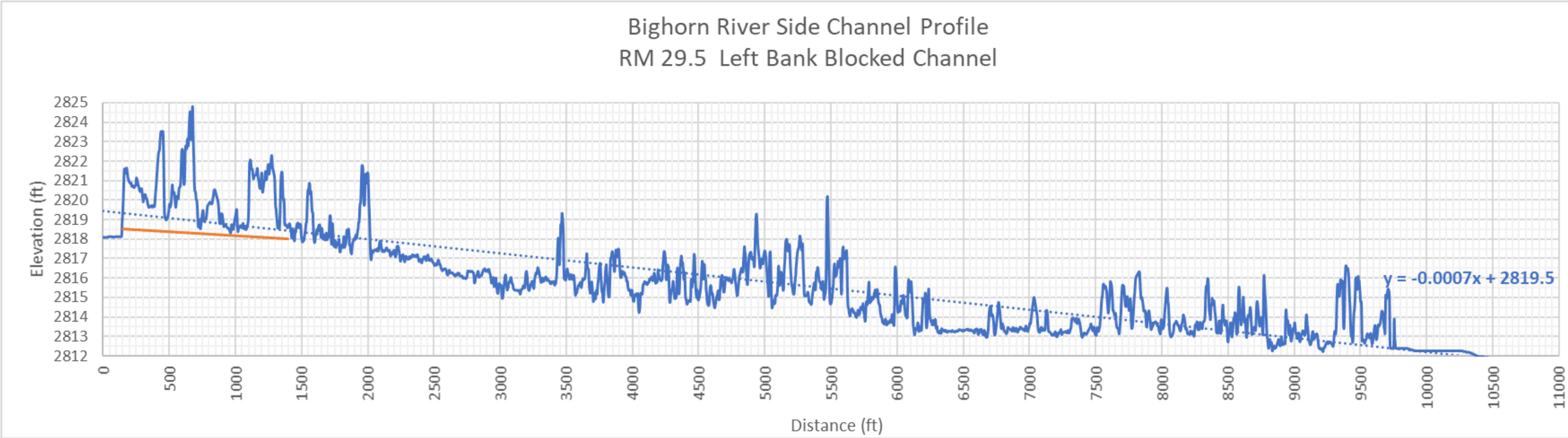

Bighorn River Side Channel Profile
RM 64.4
Elevation (ft)
3017
3016
3015
3014
3013
3012
3011
3010
0
100
200
300
400
500
600
700
800
900
1000
1100
1200
1300
1400
1500
1600
1700
1800
1900
2000
2100
Distance (ft)
y = -0.0019x + 3014.3

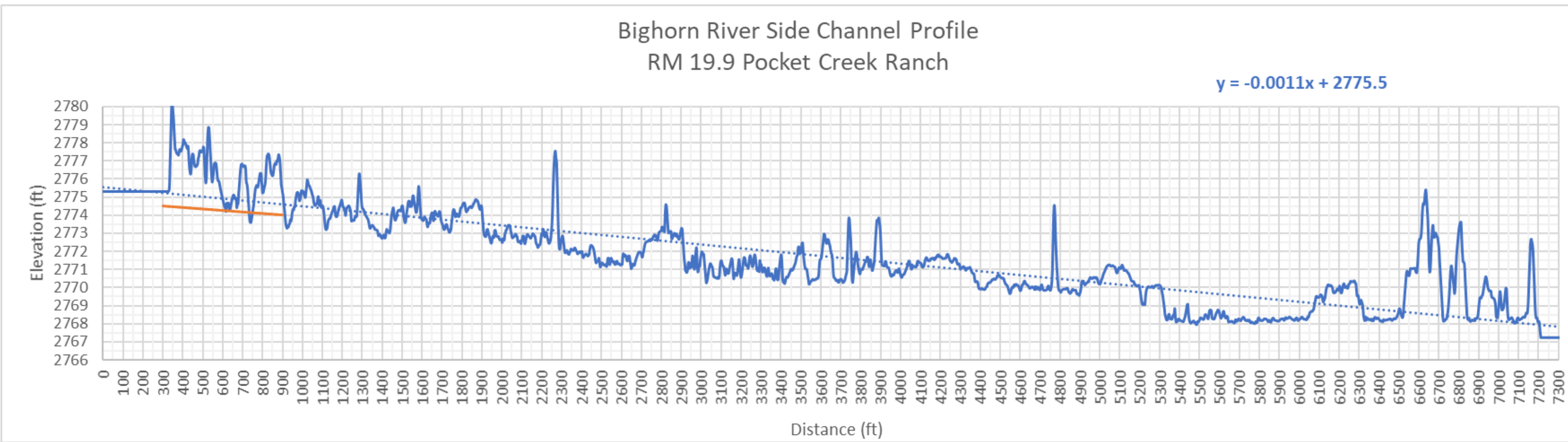

Bighorn River Side Channel Profile
RM 60.8
Elevation (ft)
2996
2995
2994
2993
2992
2991
2990
2989
2988
2987
2986
2985
2984
2983
0 200 400 600 800 1000 1200 1400 1600 1800 2000 2200 2400 2600 2800 3000 3200 3400 3600 3800 4000 4200 4400 4600 4800 5000 5200 5400 5600 5800 6000 6200 6400 6600 6800 7000
Distance (ft)
y = -0.0012x + 2990.8

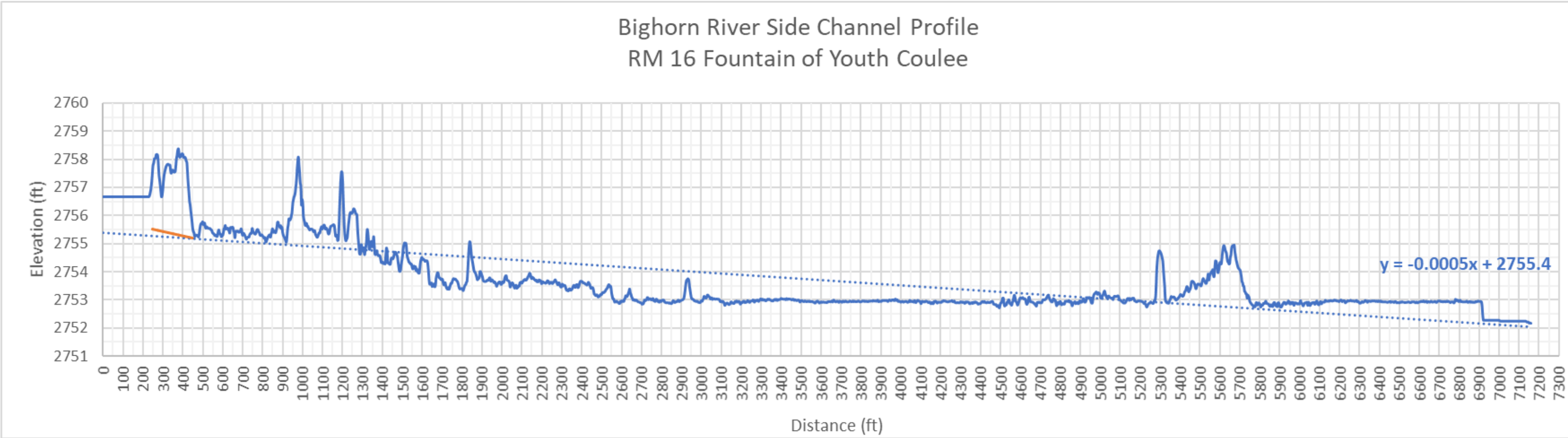

Bighorn River Side Channel Profile
RM 60.3
Elevation (ft)
2991
2990
2989
2988
2987
2986
2985
2984
2983
2982
0 100 200 300 400 500 600 700 800 900 1000 1100 1200 1300 1400 1500 1600 1700 1800 1900 2000 2100 2200 2300 2400 2500 2600 2700 2800 2900 3000 3100 3200 3300 3400 3500 3600 3700
Distance (ft)
y = -0.0017x + 2988.6

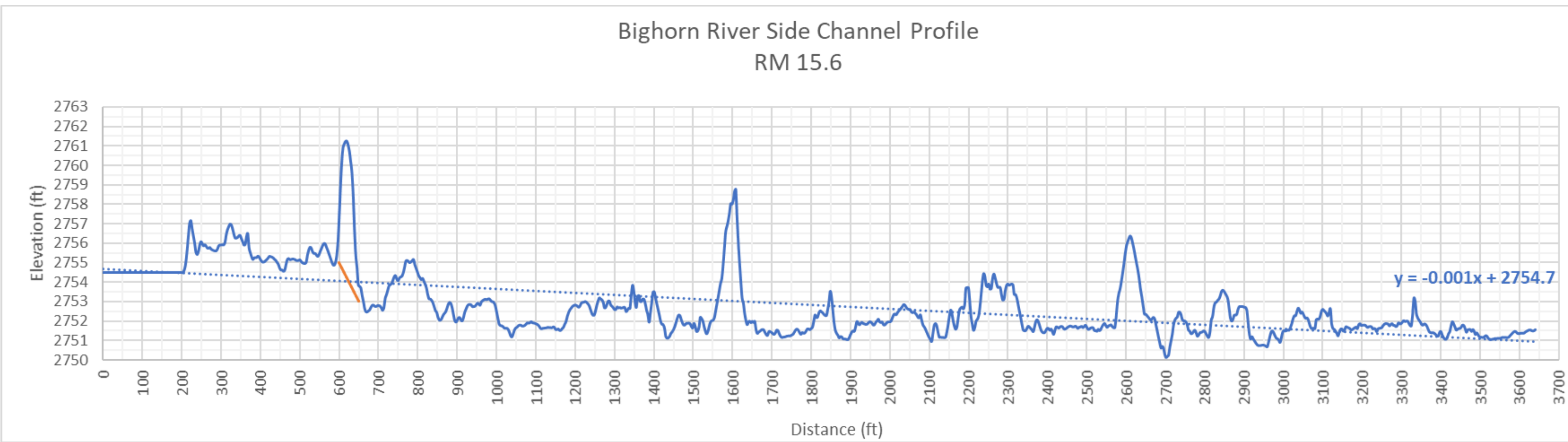

Bighorn River Side Channel Profile
RM 60.1
Elevation (ft)
Distance (ft)
y = -0.0015x + 2986.6

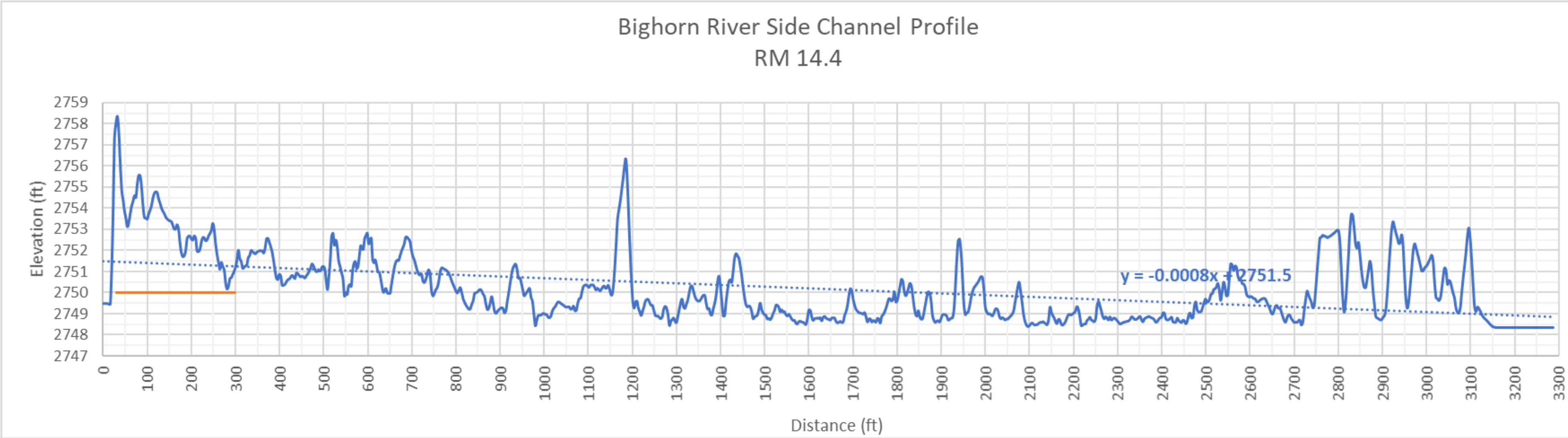

Bighorn River Side Channel Profile
RM 56.7 Landslide
Elevation (ft)
Distance (ft)
y = -0.0015x + 2965.3


Bighorn River Side Channel Profile
RM 29.5 Left Bank Blocked Channel
Elevation (ft)
Distance (ft)
y = -0.0007x + 2819.5


Bighorn River Side Channel Profile
RM 19.9 Pocket Creek Ranch
y = -0.0011x + 2775.5
Elevation (ft)
Distance (ft)


Bighorn River Side Channel Profile
RM 16 Fountain of Youth Coulee
Elevation (ft)
Distance (ft)
y = -0.0005x + 2755.4


Bighorn River Side Channel Profile
RM 15.6
Elevation (ft)
Distance (ft)
y = -0.001x + 2754.7


Bighorn River Side Channel Profile
RM 14.4
Elevation (ft)
Distance (ft)
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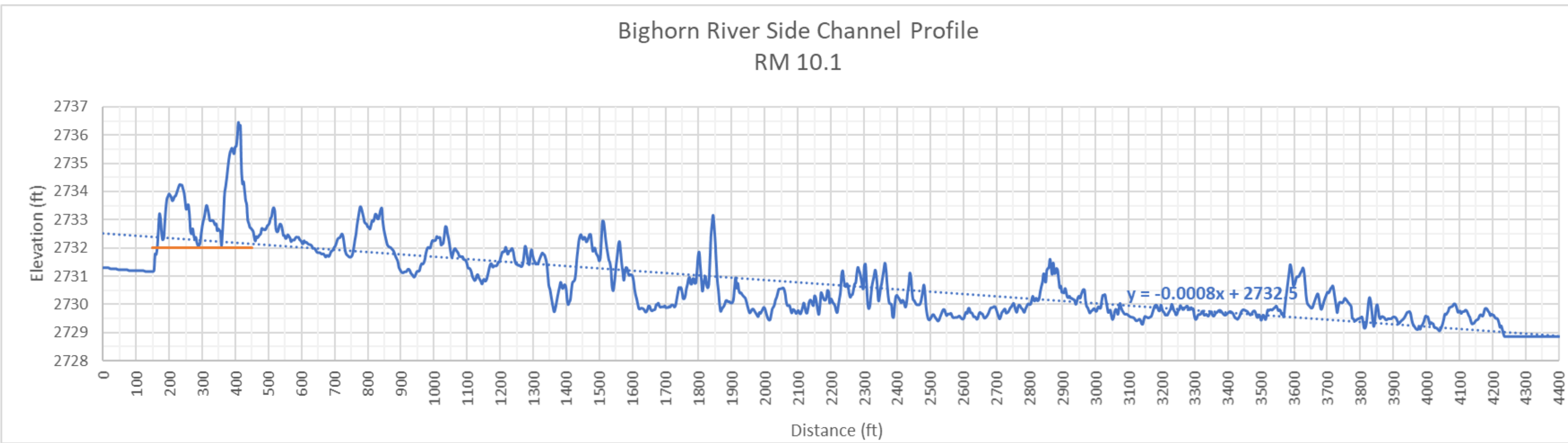
Bighorn River Side Channel Profile
RM 10.1
Elevation (ft)
Distance (ft)
y = -0.0008x + 2732.5