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BIGHORN RIVER SIDE CHANNEL RESTORATION PROJECT ANNUAL MONITORING REPORT

PREPARED FOR:

BIGHORN RIVER ALLIANCE

PREPARED BY:

Mike Sanctuary

Confluence Consulting
msanctuary@confluenceinc.com

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APPENDICES

Appendix A: Geomorphic Survey Results

1.0 INTRODUCTION

In 2020, the Bighorn River Alliance (Alliance) initiated an ambitious plan to improve the long-term health and productivity of the Bighorn River by improving connectivity between the mainstem river and several side channels. The need for side channel restoration stemmed from the progressive loss of connectivity between the main channel and historically active side channels in recent decades; generally due to gravel deposits and vegetation establishment at side channel entrances (AGI 2020). The Alliance's approach began with an evaluation of 29 side channels along 83.5 miles of the river, with prioritization of 13 side channels exhibiting the greatest opportunity to achieve substantial reconnection with minimal to moderate effort. The Rattlesnake 1 and Juniper side channels were selected to serve as pilot projects to assess the feasibility, costs, and effectiveness of improving connectivity. In August 2021, the Alliance completed construction on these two channels, which included excavating gravel and cobble deposits and reconfiguring the departure angle to improve sediment transport through their entrances.

The short-term success of these restoration efforts encouraged the Alliance to move forward with additional side channel reconnection work in 2023 and 2024. In the fall of 2023 the Rattlesnake 2, Clines, African Queen, Turtle Rock and St. Xavier Bridge side channels were reconnected, followed by Mallards and Mushroom side channels in the fall of 2024.

The Alliance strongly believes it is important to assess whether these initial efforts have been effective at increasing the duration of surface water connection to the targeted side channels, and whether the improved connectivity is sustainable over time. More clearly understanding these key factors will help the Alliance determine whether additional side channel reconnection projects are a cost effective and justifiable approach to improving the ecological function of the lower Bighorn River.

The following report provides an initial perspective on the effectiveness and sustainability of side channel reconnections at the Rattlesnake 2, Clines, African Queen, and Turtle Rock side channels one year following their completion, and the Rattlesnake 1 and Juniper side channels three years following their completion. Monitoring results for the St. Xavier Bridge, Mallards, and Mushroom side channels will be evaluated in future reports.

2.0 SIDE CHANNEL LOCATIONS

The entrance to the Rattlesnake 1 side channel lies 0.75 miles downriver from the 3-Mile Fishing Access site on the Bighorn River. The side channel extends approximately 1,100 feet where it joins the Rattlesnake 2 side channel and then returns to the Bighorn River mainstem after another 500 feet. The entrance to the Juniper side channel lies 3.5 miles downriver from the 3-Mile Fishing Access site and extends 1,500 feet before returning to the mainstem. The Clines side channel is located 5 miles downriver from the 3-Mile Fishing Access site and extends 7,700 feet before reconnecting with the mainstem. The African Queen side channel lies 1 mile downstream of the entrance to the Clines side channel and extends 2,600 feet before returning to the Bighorn mainstem. The Turtle

Rock Side Channel is positioned 0.75 miles upstream of the St. Xavier bridge and extends 1,100 feet before returning to the mainstem (Figure 1).

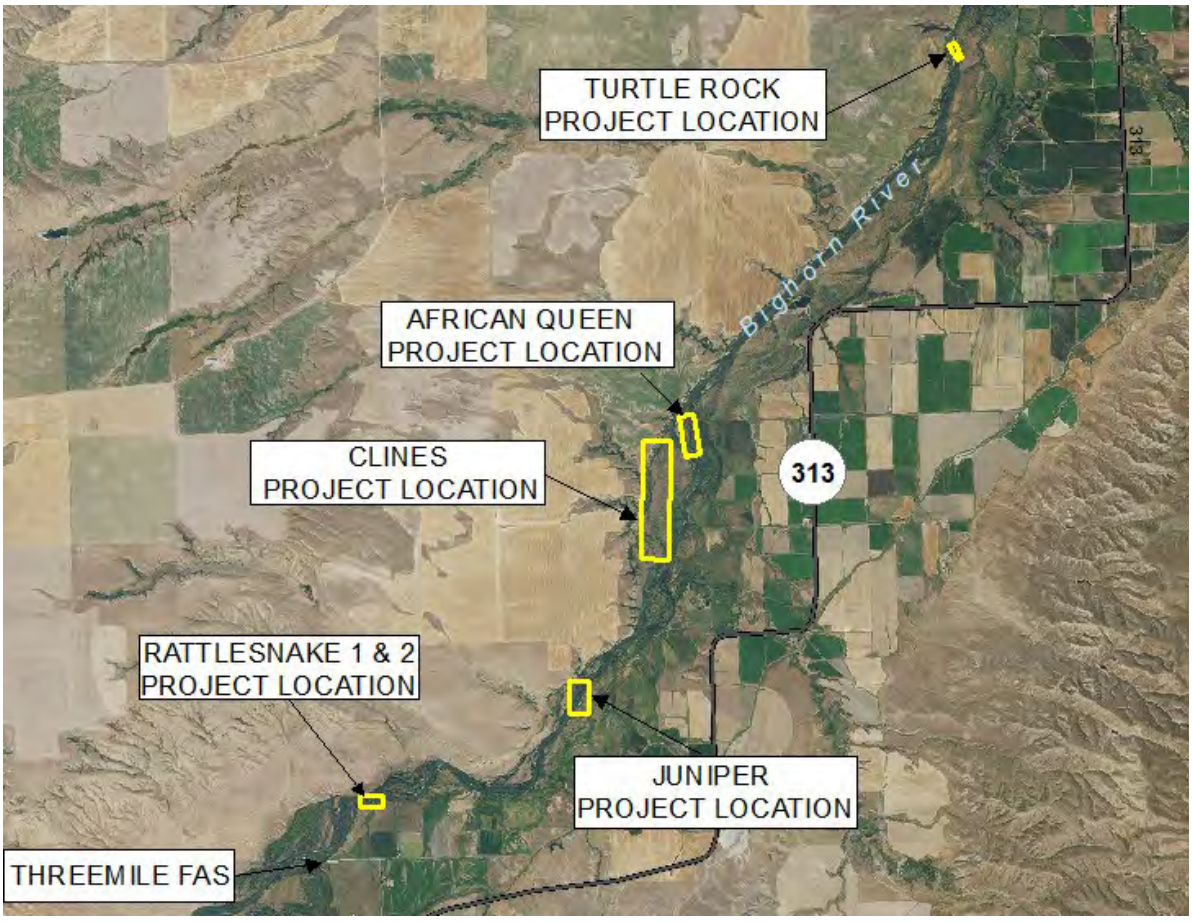


Figure 1. Location of Rattlesnake 1, Rattlesnake 2, Juniper, Clines, African Queen, and Turtle Rock Side Channel Reconnection Projects.

3.0 2023 FLOOD

Above average precipitation in southern Montana and northern Wyoming in June of 2023 prompted the Bureau of Reclamation to release excess water from the Bighorn Reservoir through Yellowtail Dam. Discharge records provided by the USGS indicate a peak flow of 16,200 cfs was released on June 25th, 2023, as compared to an annual peak flow of 6,110 cfs on April 25, 2024 and an average annual peak flow of around 7,200 cfs over the gage's 89-year period of record (Figure 2 and Figure 3). The release of well above-average flows resulted in widespread flooding, erosion, sediment deposition, and both habitat creation and destruction along the lower Bighorn River. The prolonged flood in 2023 provided an excellent opportunity to assess whether the approach of improving connectivity to the Rattlesnake 1 and Juniper side channels by excavating deposits and reconfiguring entrance angles is sustainable and resilient to very high flow events. Completion of the Rattlesnake 2, Clines, African Queen, and Turtle Rock side channels occurred after the 2023 flood, therefore the monitoring results presented in this report were not influenced by that extreme flow event.

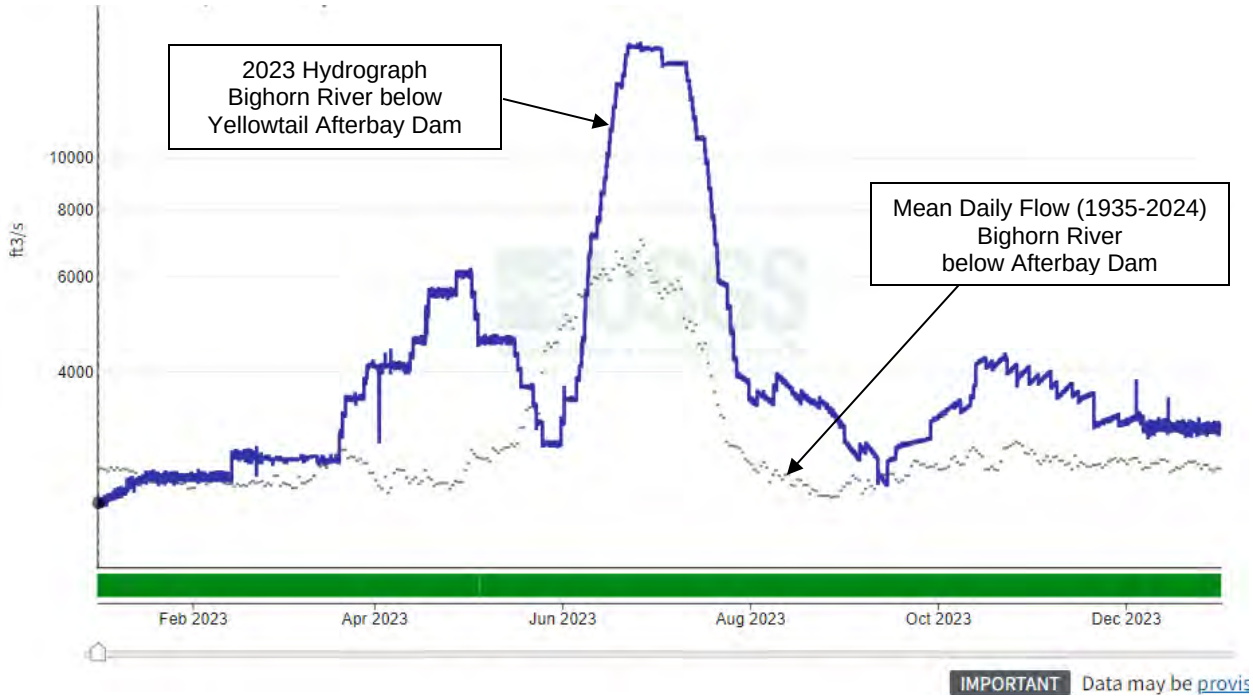


Figure 2. 2023 hydrograph and mean daily flow for Bighorn River below Afterbay Dam.

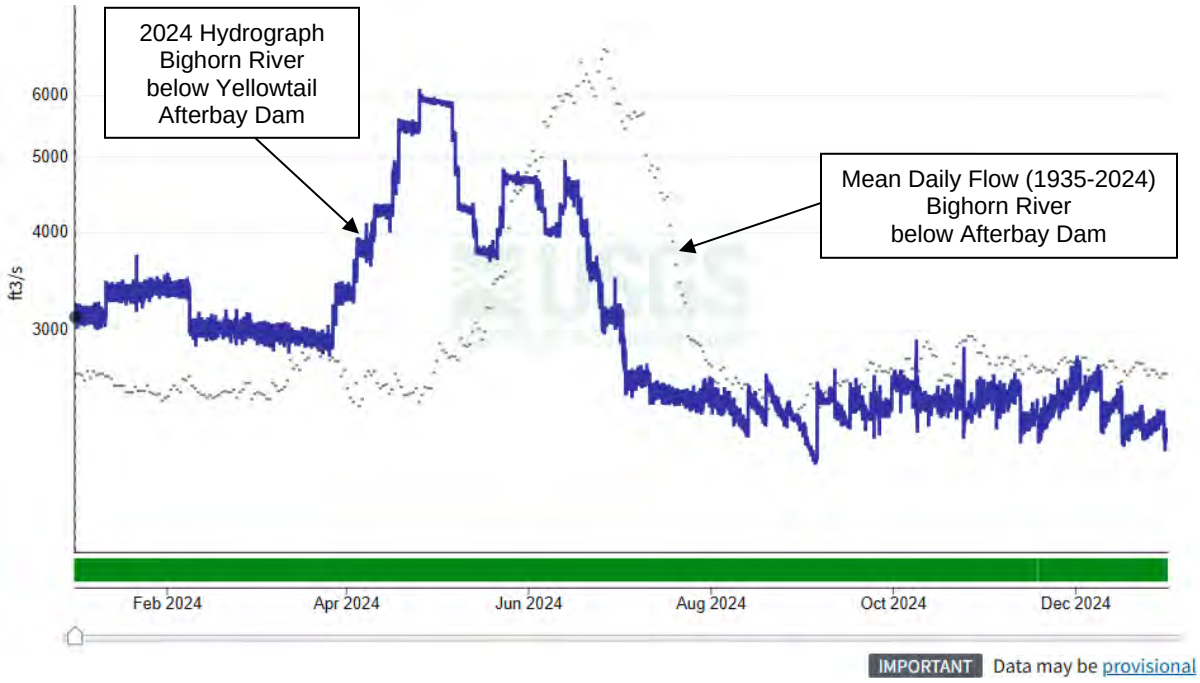


Figure 3. 2024 hydrograph and mean daily flow for Bighorn River below Afterbay Dam.

4.0 MONITORING METHODS

The following monitoring methods were employed to assess the effectiveness of restoration efforts at Rattlesnake 1, Rattlesnake 2, Juniper, Clines, African Queen, and Turtle Rock side channels:

4.1. Geomorphic Evaluation

A primary objective of the monitoring effort is to assess whether the improved connectivity of each side channel to the mainstem Bighorn River is sustainable over time. To address this objective, the following geomorphic data were collected for each of the six side channels:

A. Longitudinal profile survey of the thalweg along the length of the side channel to document locations of bed deposition and scour.

B. One channel-spanning cross section survey to assess capacity at the side channel's entrance.

C. Topographic survey of the upper 200-250' of the side channel entrances to assess and quantify bed material deposition and transport.

Geomorphic survey data for the Rattlesnake 1 and Juniper channels was collected in April 2023 (pre-flood), September 2023 (post-flood), and December 2024. Data for Rattlesnake 2, Clines and African Queen was collected in April 2024 and December 2024. Data for Turtle Rock was collected in April 2024 but could not be completed in December 2024 due to high water velocities at the channel entrance. All survey data was collected using an RTK survey-grade instrument with base station and rover units. Survey data from multiple years were correlated by tying into control points established during previous surveying events.

4.2. Discharge Monitoring

Measuring side channel discharges over a range of mainstem Bighorn River flows addresses several additional monitoring objectives, including:

- Documenting relationships between mainstem Bighorn River and side channel discharge,
- Assessing whether the mainstem to side channel discharge relationship is more stable in some side channels relative to others,
- Documenting whether the relationship adjusts due to geomorphic channel changes over time,
- Determining whether variables other than geomorphology contribute to the relationship between mainstem and side channel discharge.

Side channel discharges were measured using a SonTek FlowTracker 2 acoustic doppler velocimeter (Photo 1). In 2024, discharges were measured nine times at Rattlesnake 1, five times at Rattlesnake 2, eight times at Juniper, seven times at Clines and African Queen, and four times at Turtle Rock.

Photo 1. Discharge monitoring using SonTek Flow Tracker 2 on Turtle Rock side channel.

4.3. Orthophotography

Drone-based aerial photography was collected to generate detailed orthophotography mosaics for each of the reconfigured side channels during a variety of mainstem river discharges. These orthophotos are archived and available for visual comparisons of side channel conditions over time. Orthophoto mosaics documenting pre-construction, as-built, and annual post-construction conditions for the side channels mentioned in this report are available at the following link:

Monitoring_Orthophotography

5.0 MONITORING RESULTS

5.1. Rattlesnake 1 Side Channel

5.1.1. Geomorphology and Entrance Characteristics

Results of the channel's longitudinal profile and monitoring cross section surveys from spring 2023 (as-built, pre-flood), spring 2024 (1st annual, post-flood), and fall 2024 (2nd annual), as well as the design profile are illustrated on Sheet 1 in Appendix A. Sheet 2 provides an illustration of overall changes to the bed elevation at the entrance to the channel between spring 2023 and fall 2024. These results indicate:

- The elevation of the channel bed at the monitoring cross section rose by ~0.5 feet between spring 2023 and fall 2023 and then dropped by ~0.3 feet between fall 2023 and fall 2024, indicating gravels initially deposited in 2023, then scoured at this location in 2024.
- The longitudinal profile indicates gravel deposited at the side channel inlet between station 0+00 and 0+40 in 2023 and then eroded back to the originally excavated grade in 2024.
- Gravel has not deposited between Station 0+40 and 0+60, which was the original crest of the restored side channel entrance.
- Between stations 0+70 and 1+10, gravel deposition has adjusted the bed elevation ~0.3 feet higher than the design grade.
- The longitudinal profile indicates controlling elevations of the bed slope (riffle crests) closely match the design grade along the length of the side channel. All of the controlling elevations are within 0.3 feet of the design grade.
- The longitudinal profile from Station 8+30 to Station 9+80 dropped by ~0.75 to 1.0 feet between fall 2023 and fall 2024, indicating expansion of pool habitat in this location.
- A comparison of spring 2023 and fall 2024 elevations at the entrance indicates up to one foot of gravel has deposited on the inside of the entrance bend, while scour has resulted in deepening of the entrance by up to 0.6 feet on the outside of the entrance bend.
- The bed material volume comparison between spring 2023 (as-built) and fall 2023 (post-flood) revealed a net fill of 42 cubic yards. The comparison between spring 2023 and fall 2024 (2nd annual survey) also revealed a net fill of 42 cubic yards, indicating the channel's entrance did not continue to fill with gravel following the initial flood flows in 2023.

5.1.2. Discharge Monitoring

Results of discharge monitoring for the Rattlesnake 1 side channel are provided in Table 1, and are listed in order of magnitude. The table provides a corresponding Bighorn River discharge and river shift as reported by the USGS gage below Afterbay Dam on each discharge monitoring date. Measured side channel discharges ranged from a low of 16.3

cfs on 3/12/25 to a high of 150 cfs on 4/23/24. Measurements were taken while flow releases from Yellowtail Dam ranged from 2,270 to 5,450 cfs. A plot of Rattlesnake 1 side channel versus mainstem Bighorn River discharge is shown in Figure 4.

Table 1. Discharge monitoring results for Rattlesnake 1 side channel.

Date	Side Channel Discharge (cfs)	Staff Gage Reading (ft)	Bighorn River Discharge (cfs)	River Shift (ft)	% of BHR Discharge Captured by Side Channel
3/12/25	16.3	0.16	2270	-0.18	0.72
7/8/24	26.9	0.43	2600	-0.44	1.03
10/21/24	38.5	1.16	2430	-1.83	1.58
3/15/24	42	N/A	2930	-0.15	1.43
3/16/24	42	N/A	2930	-0.15	1.43
9/13/24	46.9	0.96	2350	-1.34	2.00
6/20/24	86	1.20	3950	-0.49	2.18
6/13/24	113	1.50	4490	-0.49	2.52
4/23/24	150	1.76	5450	-0.3	2.75

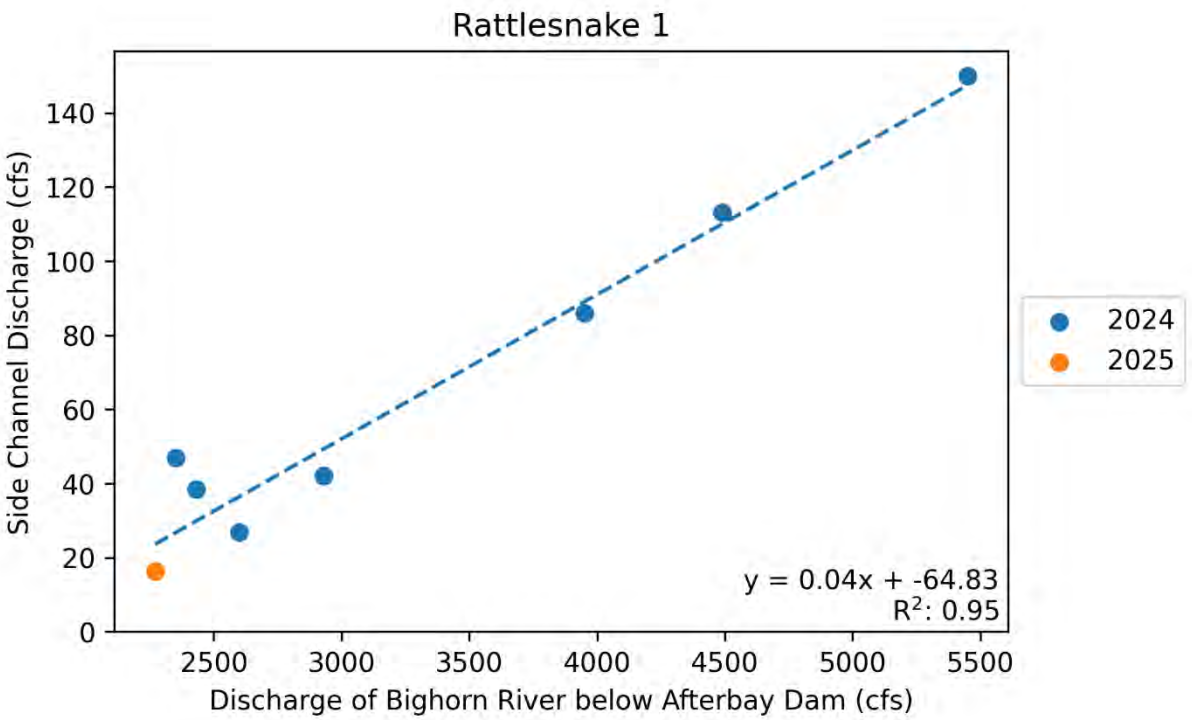


Figure 4. Relationship between mainstem Bighorn River and Rattlesnake 1 side channel discharge.

Discharge monitoring thus far at Rattlesnake 1 side channel suggests the following:

- Overall, the eight data records generate a tight-fitting relationship between mainstem river and side channel discharges (R^2 = 0.95).
- The relationship shows a particularly strong correlation during the higher end of the range of recorded flows (>80 cfs in the side channel and >4,000 cfs in the mainstem).
- The relationship indicates greater variability during the lower end of the range of recorded flows (<50 cfs in the side channel and <3,000 cfs in the mainstem).
- The slope of the regression equation produced by the discharge relationship (0.04) is flatter than all other side channels, indicating a lesser influence of mainstem river discharge on flows in the Rattlesnake 1 side channel (i.e. an increase by 1,000 cfs in the mainstem will have less of an effect on flows in Rattlesnake 1 as compared to other side channels that exhibit a steeper regression slope).

5.2. Rattlesnake 2 Side Channel

5.2.1. Geomorphology and Entrance Characteristics

Results of the channel's longitudinal profile and monitoring cross section surveys from spring 2024 (as-built) and fall 2024 (1st annual), as well as the design grade profile are illustrated on Sheet 3 in Appendix A. Sheet 4 provides an illustration of elevation changes between the spring 2024 and fall 2024 surveys at the entrance and along 300 feet of the channel. These results indicate:

- The elevation of the channel bed at the monitoring cross section remained consistent between spring and fall 2024.
- The longitudinal profile between stations 0+15 and 2+00 indicates gravel deposition ranging from 0.1 to 0.3 feet.
- A comparison of spring 2024 and fall 2024 elevations at the entrance indicate up to 0.5 feet of gravel deposited on the inside of the entrance bend and scoured up to 1.0 feet on the outside of the bend.
- A net overall volume difference of 53 CY of fill indicates material deposited into the side channel entrance between spring 2024 and fall 2024.

5.2.2. Discharge Monitoring

Results of discharge monitoring for the Rattlesnake 2 side channel are provided in Table 2, and are listed in order of magnitude. The table provides a corresponding Bighorn River discharge and river shift as reported by the USGS gage below Afterbay Dam on each discharge monitoring date. Measured side channel discharges ranged from a low of 12.0 cfs on 3/12/25 to a high of 26.2 cfs on 9/13/24. Measurements were taken while flow releases from Yellowtail Dam ranged from 2,270 to 2,600 cfs. A plot of Rattlesnake 2 side channel versus mainstem Bighorn River discharge is shown in Figure 5.

Table 2. Discharge monitoring results for Rattlesnake 2 side channel.

Date	Side Channel Discharge (cfs)	Staff Gage Reading (ft)	Bighorn River Discharge (cfs)	River Shift (ft)	% of BHR Discharge Captured by Side Channel
3/12/25	12	N/A	2270	-0.18	0.53
7/8/24	14.6	N/A	2600	-0.44	0.56
8/14/24	24.6	N/A	2450	-0.71	1.00
10/21/24	24.9	N/A	2430	-1.83	1.02
9/13/24	26.2	N/A	2350	-1.34	1.11

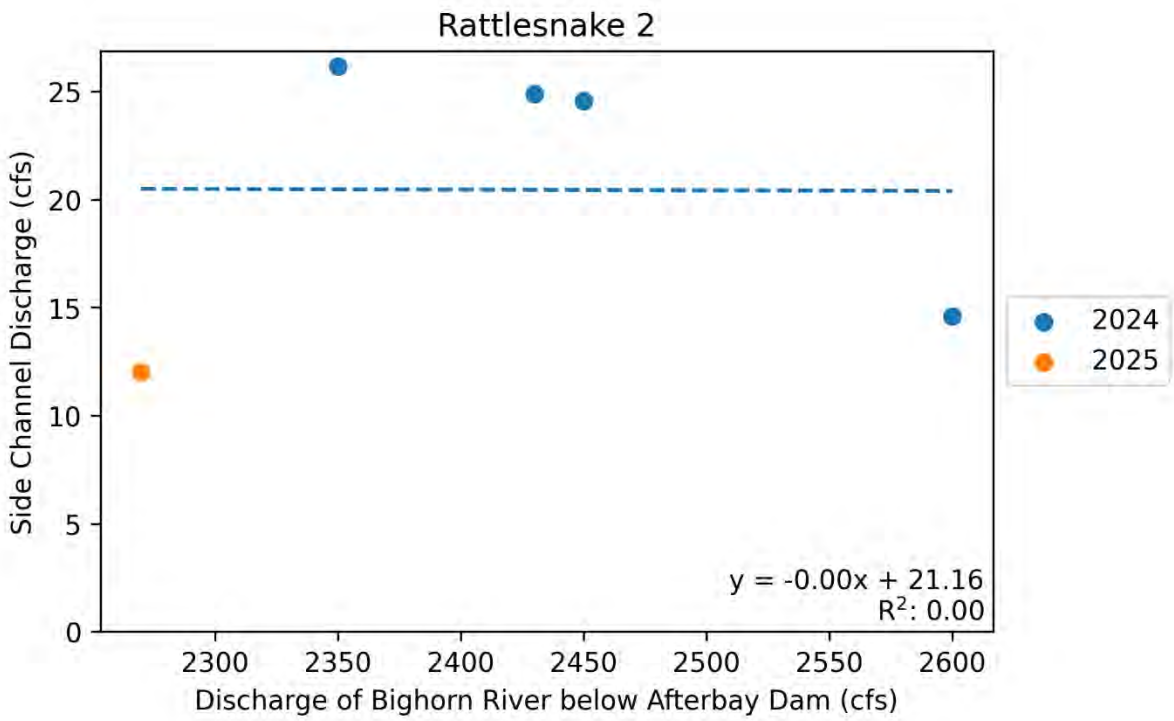


Figure 5. Relationship between mainstem Bighorn River and Rattlesnake 2 side channel discharge.

Discharge monitoring thus far at Rattlesnake 2 side channel suggests the following:

- The five data records collected do not generate a tight-fitting relationship between mainstem river and side channel discharges (R^2 = 0.00).
- The lowest recorded discharge in Rattlesnake 2 (12.0 cfs) occurred in March 2025 during a mainstem river discharge of 2,270 cfs and a shift of -0.18 feet.
- The highest recorded discharge in Rattlesnake 2 (26.2 cfs) occurred in September 2024, during a mainstem river discharge of 2,350 and a shift of -1.34 feet.

- The similarity in mainstem river discharges during the lowest and highest side channel discharges recorded in Rattlesnake 2 suggests shift may have an influence on the relationship between mainstem and side channel discharge.
- Additional side channel discharge data collection is needed to generate more conclusive results as to the relationship between mainstem river and side channel discharges at this location.

5.3. Juniper Side Channel

5.3.1. Geomorphology and Entrance Characteristics

Results of the Juniper channel's longitudinal profile and monitoring cross section surveys from spring 2023 (as-built, pre-flood), spring 2024 (1st annual, post-flood), and fall 2024 (2nd annual), as well as the design profile are illustrated on Sheet 5 in Appendix A. Sheet 6 provides an illustration of overall changes to the bed elevation at the entrance to the channel between spring 2023 and fall 2024. These results indicate:

- The monitoring cross section indicates scour on the left (outside of the bend) and deposition on the right (inside of the bend) at the entrance. The thalweg elevation at the cross section has remained consistent throughout the three monitoring surveys.
- The elevation of the riffle crest at station 2+60 increased by 0.35 feet between 2023 and 2024 and is now very close to the elevation at the side channel's entrance.
- The thalweg between station 7+50 and 9+00 has shifted several times, both laterally and longitudinally. In spring 2023 the riffle crest was located at station 8+30. Between spring 2023 and fall 2023 it shifted east and moved upriver to station 8+00. These results indicate a shifting channel bed and thalweg elevation at a location where the side channel widens and deposits gravel during high flows.
- A comparison of 2023 spring and 2024 fall elevations at the entrance of the channel indicates up to one foot of material deposited on the inside of the entrance bend and up to three feet of material scoured from the outside of the bend. The net material balance between spring of 2023 and fall of 2024 shows a loss of 63 CY of material at the channel entrance, indicating an overall increase in channel capacity since construction in 2021.

5.3.2. Discharge Monitoring

Results of discharge monitoring for the Juniper side channel are provided in Table 3, and are listed in order of magnitude. The table provides a corresponding Bighorn River discharge and river shift as reported by the USGS gage below Afterbay Dam on each discharge monitoring date. Measured side channel discharges ranged from a low of 72.5 cfs on 9/13/24 to a high of 349 cfs on 4/23/24. Measurements were taken while flow releases from Yellowtail Dam ranged from 2,270 to 5,450 cfs. A plot of Juniper side channel versus mainstem Bighorn River discharge is shown in Figure 6.

Table 3. Discharge monitoring results for Juniper side channel.

Date	Side Channel Discharge (cfs)	Staff Gage Reading (ft)	Bighorn River Discharge (cfs)	River Shift (ft)	% of BHR Discharge Captured by Side Channel
9/13/24	72.5	0.99	2350	-1.34	3.08
10/21/24	77.7	1.05	2430	-1.83	3.20
3/12/25	80.2	0.7	2270	-0.18	3.53
7/8/24	104	1.11	2600	-0.44	4.00
3/19/24	134	1.06	2910	-0.15	4.60
6/20/24	212	1.60	3950	-0.49	5.37
6/13/24	263	1.80	4490	-0.49	5.86
4/23/24	349	1.90	5450	-0.3	6.40

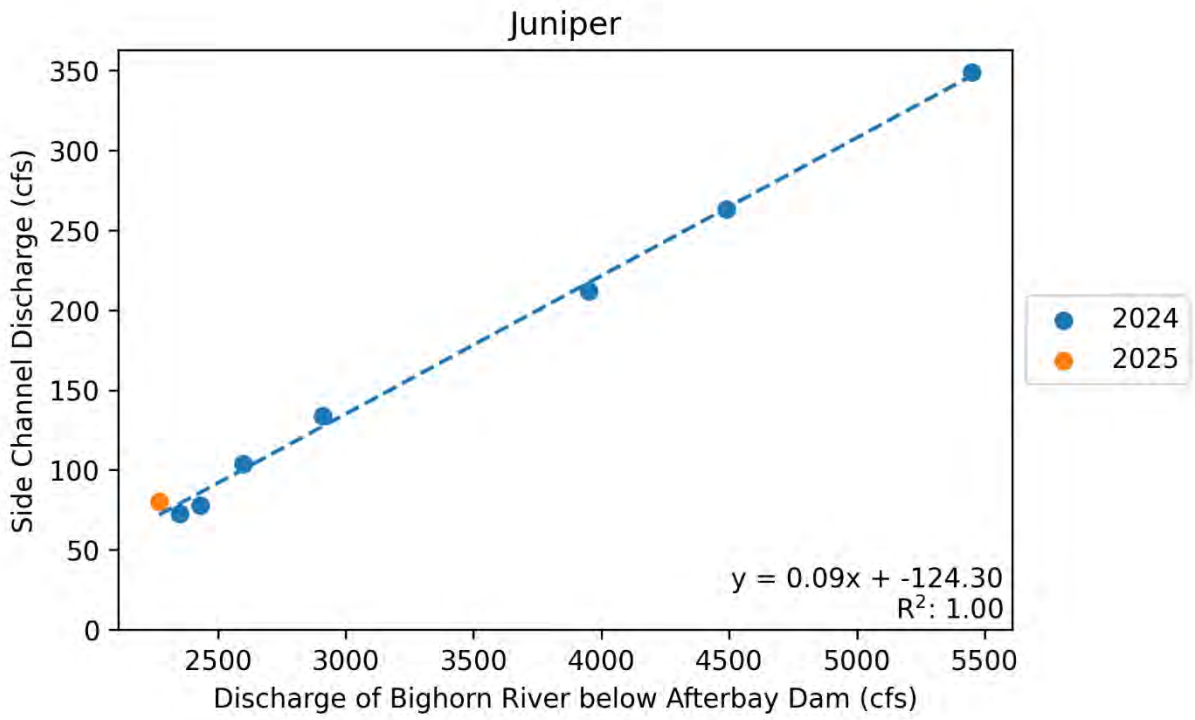


Figure 6. Relationship between mainstem Bighorn River and Juniper side channel discharge.

Thus far, discharge data collected at the Juniper side channel suggests the following:

- Overall, the eight data records generate a very tight-fitting relationship between mainstem river and side channel discharges (R^2 = 1.00).
- The relationship shows strong correlations during the entire range of recorded flows.
- The slope of the regression equation produced by the discharge relationship (0.09) is close to the average regression slope for the other side channels excluding Rattlesnake 2 (0.084). The discharge in side channels with flatter regression

slopes (Rattlesnake 1 and African Queen) will be less influenced by mainstem river discharges, while the discharge in side channels with steeper slopes (Clines, Turtle Rock) will be more influenced.

5.4. Clines Side Channel

5.4.1. Geomorphology and Entrance Characteristics

Results of the Cline channel's longitudinal profile and monitoring cross section surveys from spring 2024 (as-built) and fall 2024 (1st annual), as well as the design profile are illustrated on Sheet 7 in Appendix A. Sheet 8 illustrates the longitudinal profile of the entire length of Cline's channel. Sheet 9 illustrates bed elevation changes between the spring 2024 and fall 2024 surveys along 150 feet of the channel at its entrance. These results indicate:

- The thalweg at the monitoring cross section dropped 0.2 feet.
- The riffle crest located at station 2+50 increased by 0.4 feet
- Between stations 2+40 and 3+75 the bed elevation has increased 0.1 to 0.2 feet.
- Between stations 4+30 and 15+50, the bed elevation has increased ~0.2 to 1.0 feet, indicating deposition in this area.
- From station 15+50 to 23+40 the bed elevation has remained relatively consistent.
- A 2-foot deep pool has formed between stations 23+40 and 25+00.
- From station 25+00 to 58+50 the bed elevation has remained relatively consistent.
- Although the profile indicates development of a deeper pool between stations 58+50 to 60+40, the bed profile in this location was not surveyed in 2023 due to excessive channel depth.
- Material deposition has caused the bed elevation to increase by ~0.1 to 1.0 feet between stations 62+50 and 68+00 and stations 72+50 to 74+75.
- Bed elevations at the channel's entrance have generally increased by 0.1 to 0.3 feet. Since spring of 2024, a net of 52 CY of material deposited into the side channel's entrance, indicating a reduced capacity following the initial reconnection work.

5.4.2. Discharge Monitoring

Results of discharge monitoring for the Clines side channel are provided in Table 4 and are listed in order of magnitude. The table provides a corresponding Bighorn River discharge and river shift as reported by the USGS gage below Afterbay Dam on each discharge monitoring date. Measured side channel discharges ranged from a low of 15.1 cfs on 3/13/25 to a high of 232 cfs on 6/20/24. Measurements were taken while flow releases from Yellowtail Dam ranged from 2,270 to 4,250 cfs. A plot of Clines side channel versus mainstem Bighorn River discharge is shown in Figure 7.

Table 4. Discharge monitoring results for Clines side channel.

Date	Side Channel Discharge (cfs)	Staff Gage Reading (ft)	Bighorn River Discharge (cfs)	River Shift (ft)	% of BHR Discharge Captured by Side Channel
3/13/25	15.1	0.04	2270	-0.18	0.67
9/14/24	22.8	0.17	2310	-1.34	0.99
12/12/24	23	0.16	2370	-0.9	0.97
10/22/24	35	0.23	2430	-1.83	1.44
7/8/24	46.4	0.40	2600	-0.44	1.79
4/15/24	212	N/A	4250	-0.15	4.99
6/20/24	232	1.20	3950	-0.49	5.88

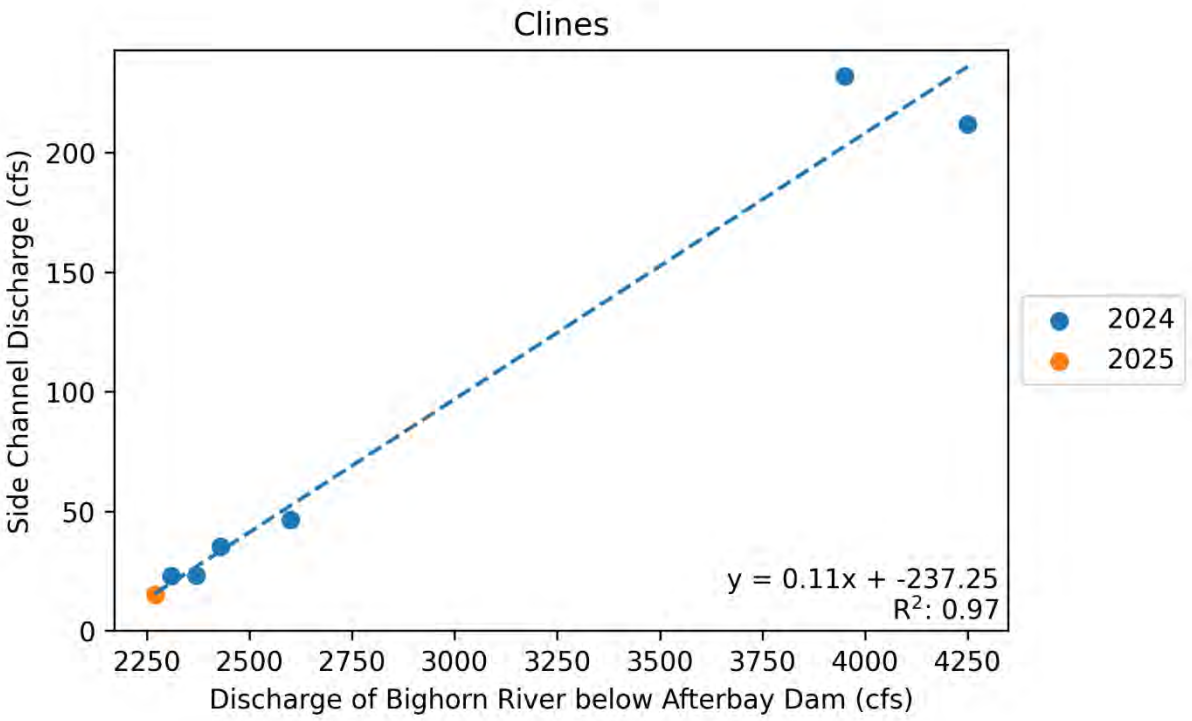


Figure 7. Relationship between mainstem Bighorn River and Clines side channel discharge.

Thus far, the discharges collected at the Clines side channel suggest the following:

- The data records to date generate a very tight-fitting relationship between mainstem river and side channel discharges (R^2 = 0.97).
- The relationship shows very strong correlations during the lower end of the range of recorded flows (<50 cfs in the side channel and <2,700 cfs in the mainstem).
- The relationship indicates greater variability during the higher end of the range of recorded flows (>200 cfs in the side channel and >3,900 cfs in the mainstem).

- The regression equation slope produced by the discharge relationship (0.11) is relatively steep compared to the other side channels, indicating a greater influence of mainstem river discharge on flows in Clines side channel (i.e. an increase mainstem discharge will have a greater effect on flows in Clines as compared to other side channels that exhibit a flatter regression slope).

5.5. African Queen Side Channel

5.5.1. Geomorphology and Entrance Characteristics

Results of the channel's longitudinal profile and monitoring cross section surveys from spring 2024 (as-built) and fall 2024 (1st annual), as well as the design profile are illustrated on Sheet 10 in Appendix A. Sheet 11 provides an illustration of elevation changes between the spring 2024 and fall 2024 surveys along 225 feet of the channel at its entrance. These results indicate:

- The thalweg of the monitoring cross section has dropped 0.25 feet, while the shape of the monitoring cross section has generally remained consistent.
- Bed elevations through the channel entrance between stations 0+00 and 1+50 indicate the crest elevation has remained consistent, while shallow sediment deposits are evident both upstream and downstream of the crest.
- Pool depth between stations 5+30 and 6+90, 10+20 and 12+20, 12+60 and 14+90, 18+80 and 20+50 have deepened by ~0.5 to 1.5 feet.
- The controlling riffle elevations of the channel bed have remained consistent between spring 2024 and fall 2024.
- A comparison of the spring 2024 and fall 2024 entrance topography indicates up to 1.2 feet of scour on the outside of the entrance bend and up to 0.8 feet of gravel has deposited on the inside of the entrance bend. The net volumetric difference between spring and fall of 2024 is 111 CY of fill, indicating a slightly reduced capacity as compared to the entrance immediately following the reconnection effort.

5.5.2. Discharge Monitoring

Results of discharge monitoring for the African Queen side channel are provided in Table 5 and are listed in order of magnitude. The table provides a corresponding Bighorn River discharge and river shift as reported by the USGS gage below Afterbay Dam on each discharge monitoring date. Measured side channel discharges ranged from a low of 48 cfs on 7/8/24 to a high of 175 cfs on 4/15/24. Measurements were taken while flow releases from Yellowtail Dam ranged from 2,270 to 4,250 cfs. A plot of African Queen side channel versus mainstem Bighorn River discharge is shown in Figure 8.

Table 5. Discharge monitoring results for African Queen side channel.

Date	Side Channel Discharge (cfs)	Staff Gage Reading (ft)	Bighorn River Discharge (cfs)	River Shift (ft)	% of BHR Discharge Captured by Side Channel
7/8/24	48	0.88	2600	-0.44	1.84
10/22/24	58.1	0.72	2430	-1.83	2.39
3/13/25	64.2	0.7	2270	-0.18	2.83
12/12/24	67	0.77	2370	-0.9	2.83
9/19/24	68.5	0.73	2440	-1.54	2.81
6/20/24	116	1.25	3950	-0.49	2.94
4/15/24	175	1.24	4250	-0.15	4.12

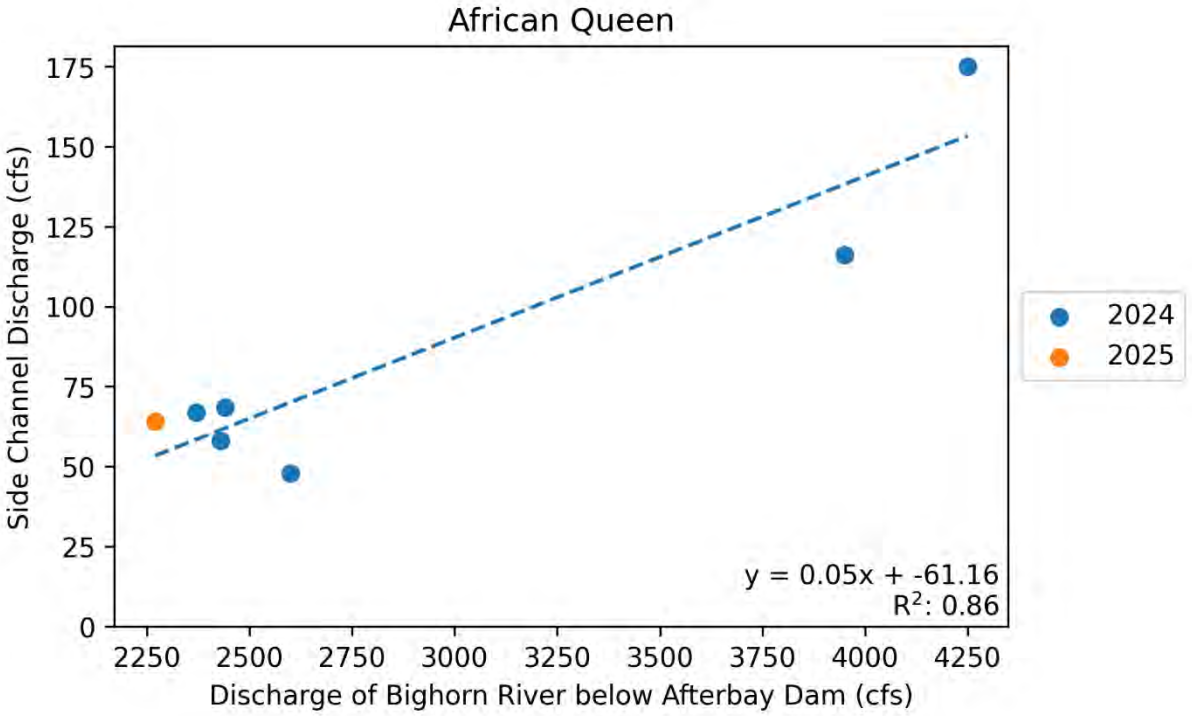


Figure 8. Relationship between mainstem Bighorn River and African Queen side channel discharge.

Discharges collected to date at African Queen side channel suggest the following:

- The data records generate a reasonably tight-fitting relationship between mainstem river and side channel discharges (R^2 = 0.86).
- The relationship shows some degree of variability across the lower end of the range of recorded flows (<75 cfs in the side channel and <2,500 cfs in the mainstem) as well as the higher end of this range (>100 cfs in the side channel and >3,900 cfs in the mainstem).

- The slope of the regression equation produced by the discharge relationship (0.05) is flatter than all but one other side channel (Rattlesnake 1), indicating a lesser influence of mainstem river discharge on flows in the African Queen side channel (i.e. an increase mainstem discharge will have less of an effect on flows in African Queen as compared to side channels that exhibit a steeper regression slope).

5.6. Turtle Rock Side Channel

5.6.1. Geomorphology and Entrance Characteristics

As-built geomorphic survey data was collected for Turtle Rock in April of 2024; however, no additional data has been collected due to excessive depth and high water velocities at the channel's entrance. For these reasons, a comparison of longitudinal profile, cross section, and entrance topography to current conditions is not currently available.

5.6.2. Discharge Monitoring

Results of discharge monitoring for the Turtle Rock side channel are provided in Table 6 and are listed in order of magnitude. The table provides a corresponding Bighorn River discharge and river shift as reported by the USGS gage below Afterbay Dam on each discharge monitoring date. Measured side channel discharges ranged from a low of 209 cfs on 8/3/24 to a high of 244 cfs on 9/19/24. Measurements were taken while flow releases from Yellowtail Dam ranged from 2,270 to 2,440 cfs. Discharge monitoring in the Turtle Rock side channel presents challenges due to deeper and swifter conditions compared to other side channels; therefore, data is available over a narrower range of mainstem river flows. A plot of Turtle Rock side channel versus mainstem Bighorn River discharge is shown in Figure 9.

Table 6. Discharge monitoring results for Turtle Rock side channel.

Date	Side Channel Discharge (cfs)	Staff Gage Reading (ft)	Bighorn River Discharge (cfs)	River Shift (ft)	% of BHR Discharge Captured by Side Channel
8/13/24	209	0.73	2330	-0.71	8.96
3/11/25	218	0.638	2270	-0.18	9.61
10/23/24	227	0.91	2440	-1.83	9.31
9/19/24	244	0.99	2440	-1.54	9.99

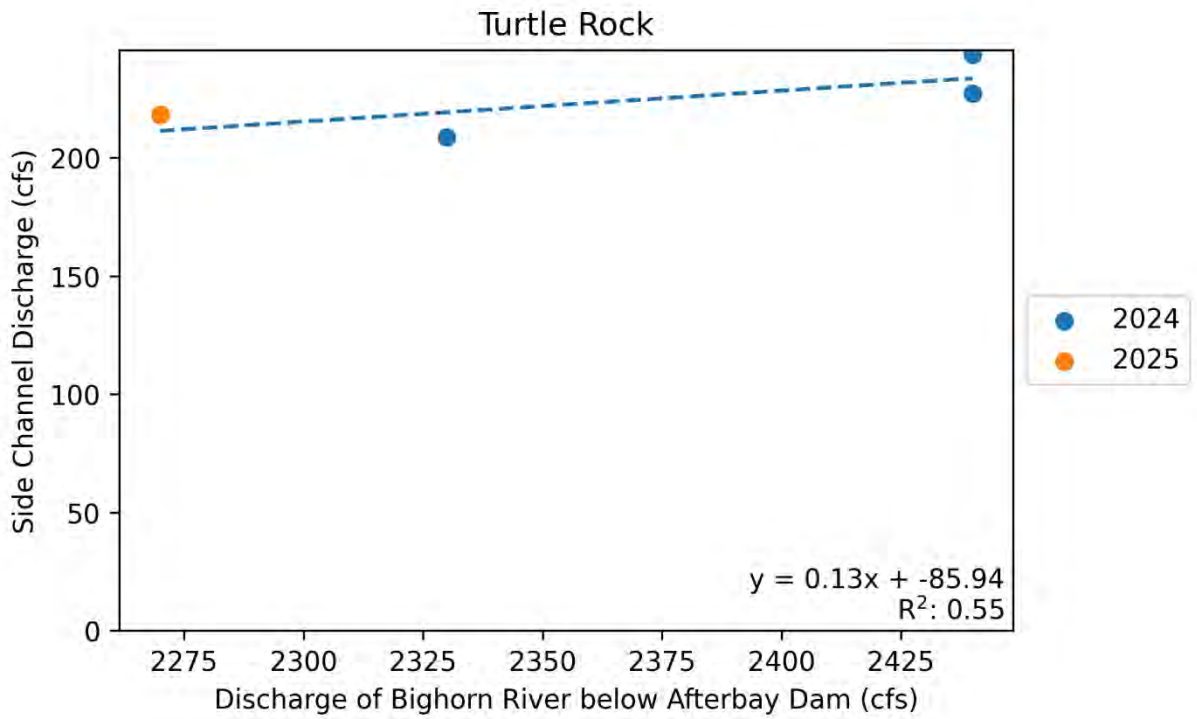


Figure 9. Relationship between mainstem Bighorn River and Turtle Rock side channel discharge.

While only four discharge records are available for the Turtle Rock channel, the data suggest the following:

- Thus far, the data records generate a poorly fitting relationship between mainstem river and side channel discharges (R^2 = 0.55).
- Additional side channel discharge data collection is needed to generate more conclusive results as to the relationship between mainstem river and side channel discharges at this location.
- The slope of the regression equation produced by the discharge relationship (0.13) is steeper than all other side channels, indicating the potential of a greater influence by mainstem river discharge on flows in the Turtle Rock side channel (i.e. an increase mainstem discharge will have a greater effect on flows in Turtle as compared to side channels that exhibit a flatter regression slope).

6.0 CONCLUSIONS

The monitoring results produced thus far on six of the Bighorn River Alliance's side channel reconnection projects provide an early understanding of the effectiveness of these projects to increase habitat availability and surface water connectivity over a wider range of flows in the Bighorn River. The pre- and post-construction geomorphic and discharge data collected to date offer the following initial conclusions:

- Survey data collected at the Rattlesnake 1 and Juniper side channels indicates both channels remain able to convey flows during a wider range of mainstem river discharges after the historic 2023 floods. Minor gravel deposition was evident at the entrance to Rattlesnake 1 in the year following the flood; however additional deposition was not observed following the second high flow event following construction. Capacity at the entrance of the Juniper side channel increased following the 2023 flood, indicating a greater ability to convey flows through this channel during a wide range of mainstem river discharges.

- Minor gravel deposition is evident at the entrances to Rattlesnake 2, Clines, and African Queen side channels following one spring runoff; however, all three channels remain capable of conveying flows over a wider range of mainstem discharges than before work was completed.

- Initial observations of the large wood features installed at the heads of African Queen and Turtle Rock side channels indicate early success of these features to remain stable and in place following one high water event.

- Side channel discharge relates closely to mainstem river discharge in some sites (Rattlesnake 1, Juniper, Clines, African Queen); however, this relationship is less apparent at Rattlesnake 2 and Tuttle Rock based on the data collected to date. Additional data collection at these two sites may generate tighter fitting relationships over time.

- The influence of mainstem river flows on side channel discharge also varies. Side channels exhibiting steeper regression slopes (Turtle Rock, Clines, and Juniper) are more influenced by mainstem discharge than those with flatter regression slopes (African Queen and Rattlesnake 1). No regression slope is available for Rattlesnake 2 at this time.

- Caution should be taken when making conclusions about the Turtle Rock side channel based on the lack of post-construction geomorphic data and a relatively few number of discharge records (4) over a narrow range of mainstem flows.

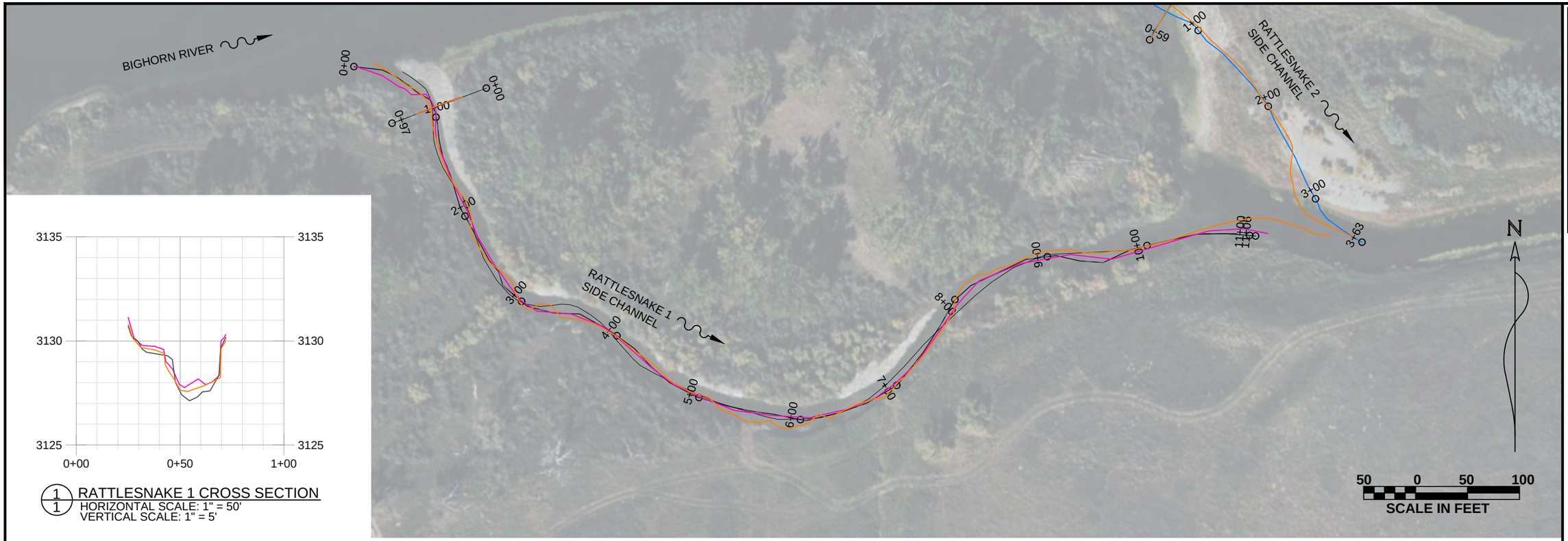
7.0 LITERATURE CITED

Boyd, K. 2021. Bighorn River Side Channel Restoration Potential. Report prepared for the Bighorn River Alliance.

Appendix A

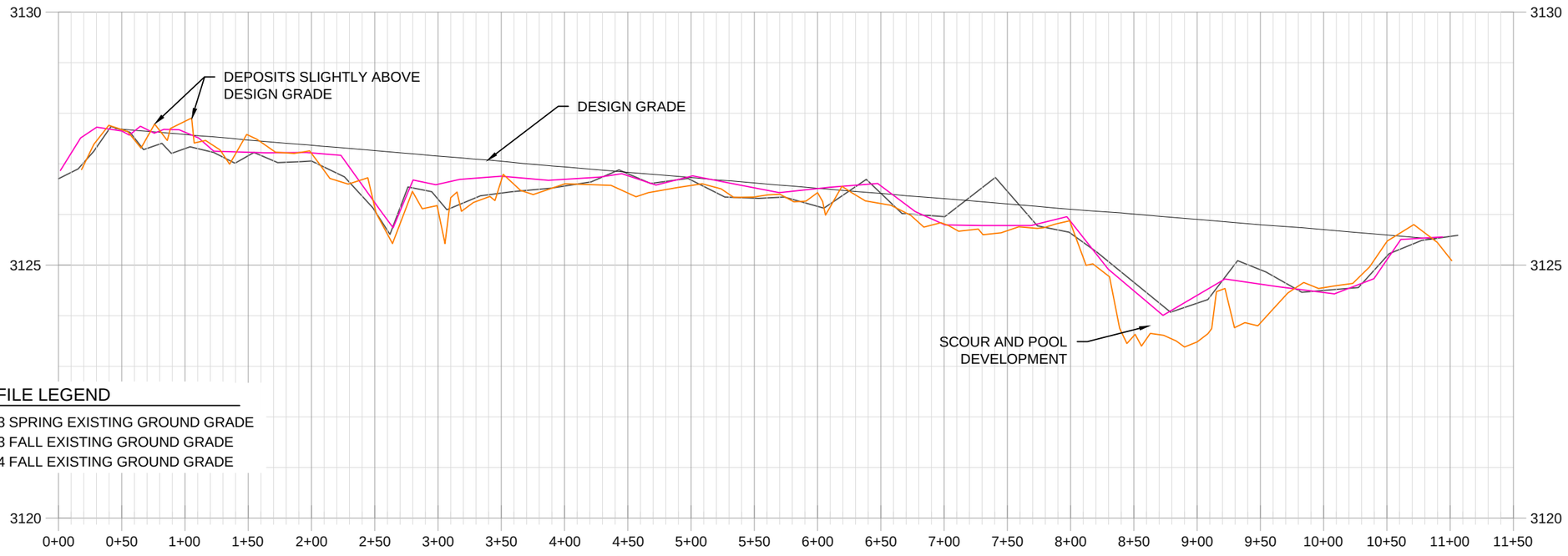
Geomorphic Survey Results

Bighorn River Side Channel Restoration Project
Annual Monitoring Report - 2024



1/1 RATTLESNAKE 1 CROSS SECTION
HORIZONTAL SCALE: 1" = 50'
VERTICAL SCALE: 1" = 5'

RATTLESNAKE 1 SIDE CHANNEL MONITORING



PLAN AND PROFILE LEGEND
- 2023 SPRING EXISTING GROUND GRADE
- 2023 FALL EXISTING GROUND GRADE
- 2024 FALL EXISTING GROUND GRADE

2/1 RATTLESNAKE 1 SIDE CHANNEL PROFILE
HORIZONTAL SCALE: 1" = 100'
VERTICAL SCALE: 1" = 2.5'

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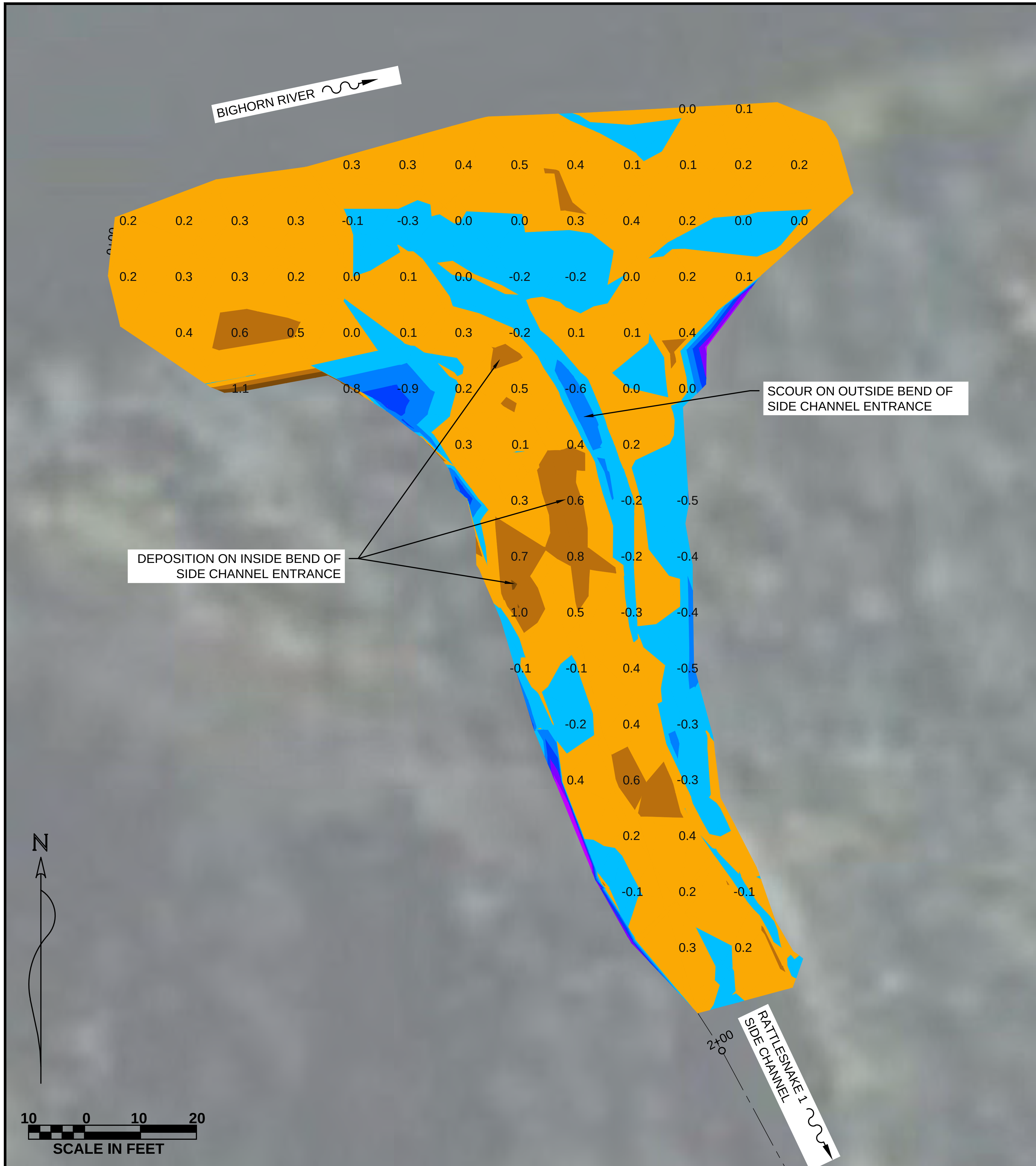
CONFLUENCE CONSULTING

BIGHORN SIDE CHANNEL REACTIVATION MONITORING
FORT SMITH, MT

RATTLESNAKE 1 SIDE CHANNEL MONITORING

SHEET: 1



LEGEND

(magenta)	CUT >2.0'
(purple)	CUT 2.0' - 1.5'
(blue)	CUT 1.5' - 1.0'
(medium blue)	CUT 1.0' - 0.5'
(light blue)	CUT 0.5' - 0.0'
(orange)	FILL 0.0 - 0.5'
(brown)	FILL 0.5' - 1.0'
(dark brown)	FILL 1.0' - 1.5'
- #.#	CUT VALUE
#.#	FILL VALUE

NOTES:

1. VOLUME COMPARISON IS BETWEEN SPRING 2023 SURVEY AND FALL 2024 SURVEY.
2. A FILL VALUE IS MATERIAL GAIN BETWEEN SPRING 2023 AND FALL 2024.
3. A CUT VALUE IS MATERIAL LOSS BETWEEN SPRING 2023 AND FALL 2024.
4. TOTAL FILL VOLUME = 63 CUBIC YARDS
5. TOTAL CUT VOLUME = 22 CUBIC YARDS
6. NET CUT/FILL = 42 CUBIC YARDS OF FILL

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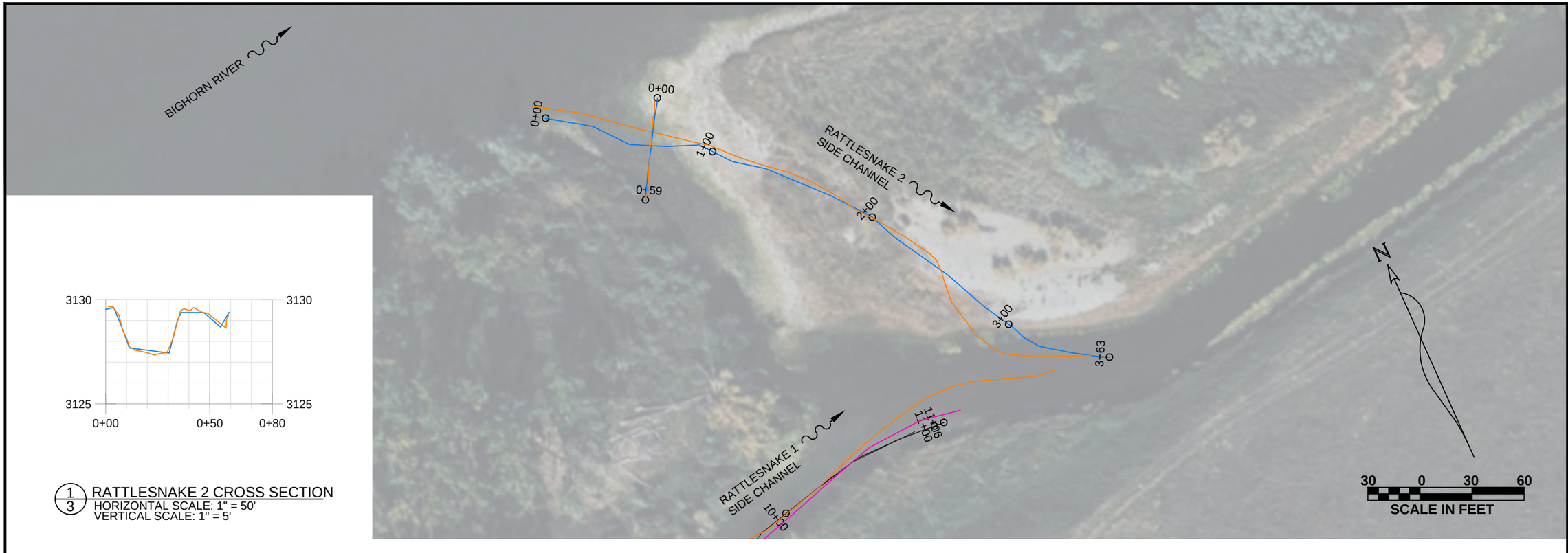
CONFLUENCE CONSULTING

BIGHORN SIDE CHANNEL REACTIVATION MONITORING
FORT SMITH, MT

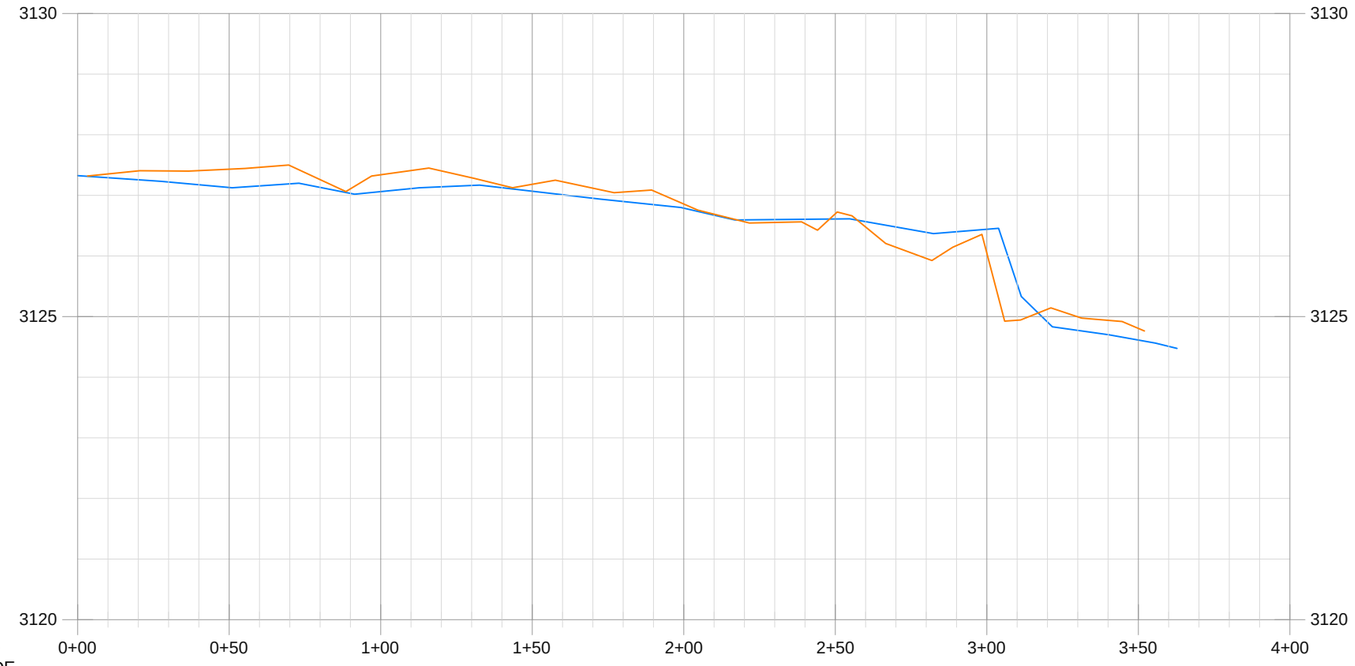
RATTLESNAKE1 2023/2024 VOLUME COMPARISON

SHEET: 2



1/3 RATTLESNAKE 2 CROSS SECTION
HORIZONTAL SCALE: 1" = 50'
VERTICAL SCALE: 1" = 5'

RATTLESNAKE 2 SIDE CHANNEL MONTORING



2/3 RATTLESNAKE 2 SIDE CHANNEL PROFILE
HORIZONTAL SCALE: 1" = 50'
VERTICAL SCALE: 1" = 2.5'

PLAN AND PROFILE LEGEND
2024 SPRING EXISTING GROUND GRADE
2024 FALL EXISTING GROUND GRADE

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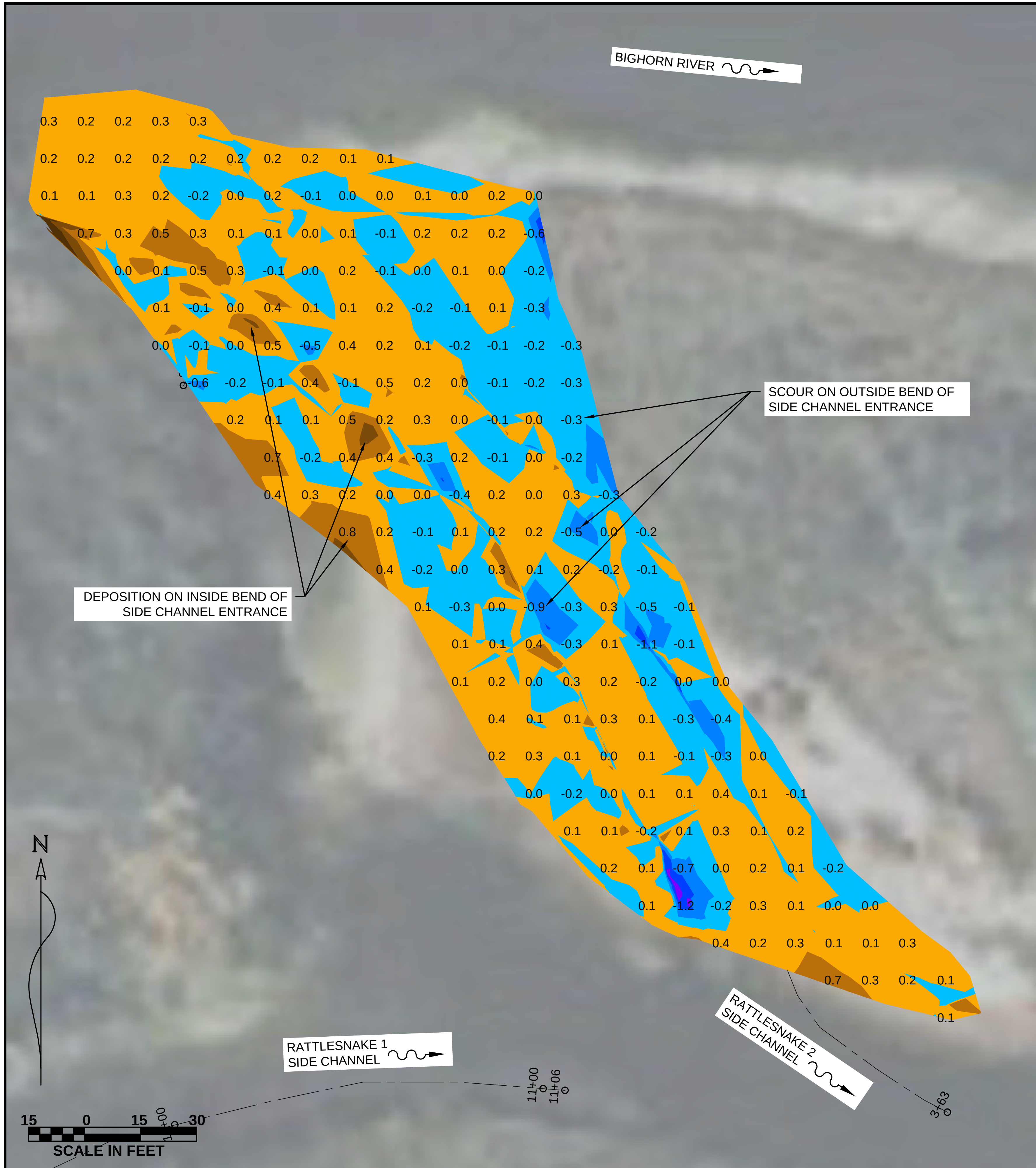
CONFLUENCE CONSULTING

BIGHORN SIDE CHANNEL REACTIVATION MONITORING
FORT SMITH, MT

RATTLESNAKE 2 SIDE CHANNEL MONITORING

SHEET: 3

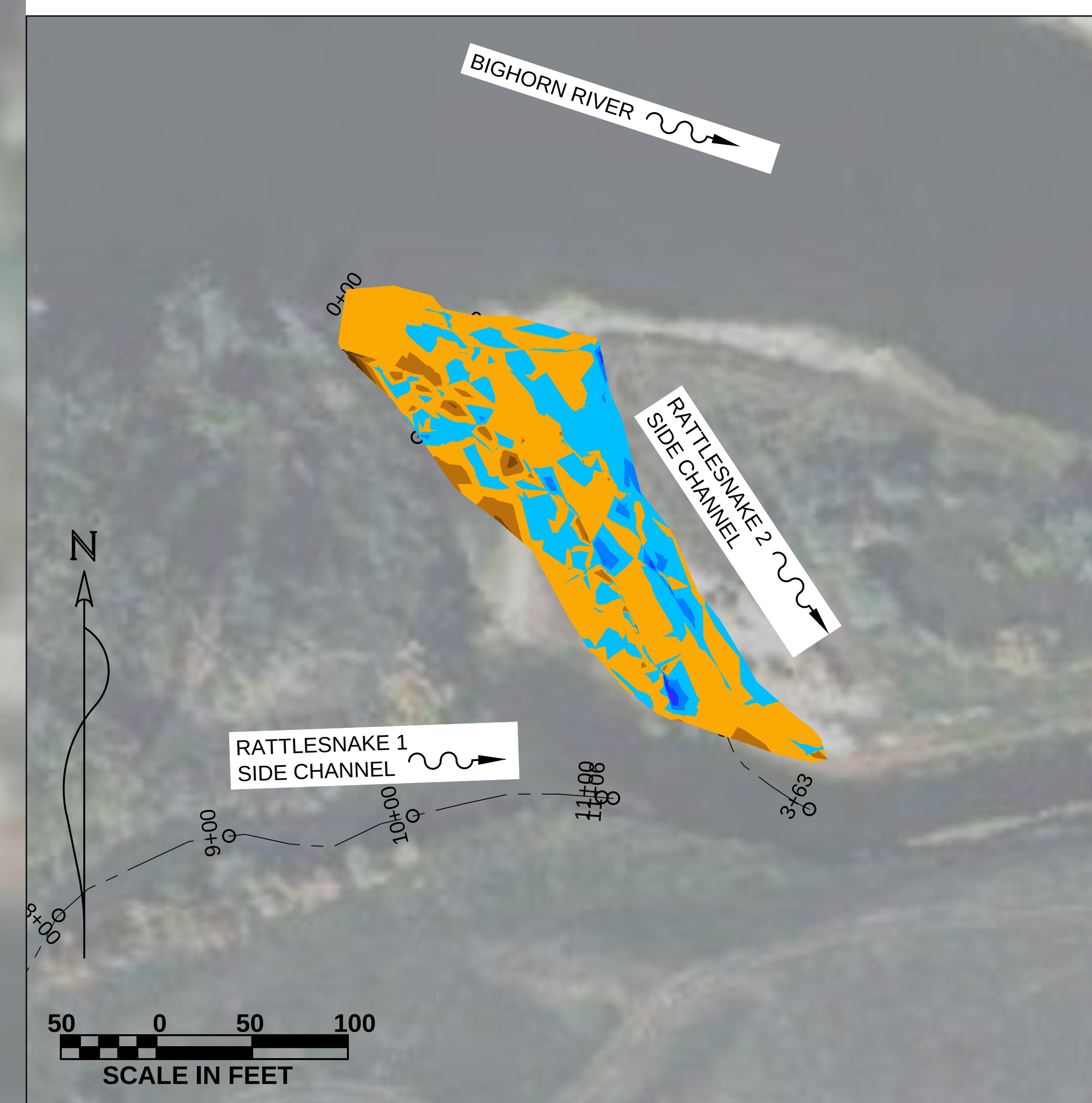


LEGEND

(purple)	CUT 2.0' - 1.5'
(blue)	CUT 1.5' - 1.0'
(medium blue)	CUT 1.0' - 0.5'
(light blue)	CUT 0.5' - 0.0'
(orange)	FILL 0.0 - 0.5'
(light brown)	FILL 0.5' - 1.0'
(brown)	FILL 1.0' - 1.5'
(dark brown)	FILL 1.5' - 2.0'
- #.#	CUT VALUE
#.#	FILL VALUE

NOTES:

1. VOLUME COMPARISON IS BETWEEN SPRING 2024 SURVEY AND FALL 2024 SURVEY.
2. A FILL VALUE IS MATERIAL GAIN BETWEEN SPRING 2024 AND FALL 2024.
3. A CUT VALUE IS MATERIAL LOSS BETWEEN SPRING 2024 AND FALL 2024.
4. TOTAL FILL VOLUME = 110 CUBIC YARDS
5. TOTAL CUT VOLUME = 56 CUBIC YARDS
6. NET CUT/FILL = 53 CUBIC YARDS OF FILL



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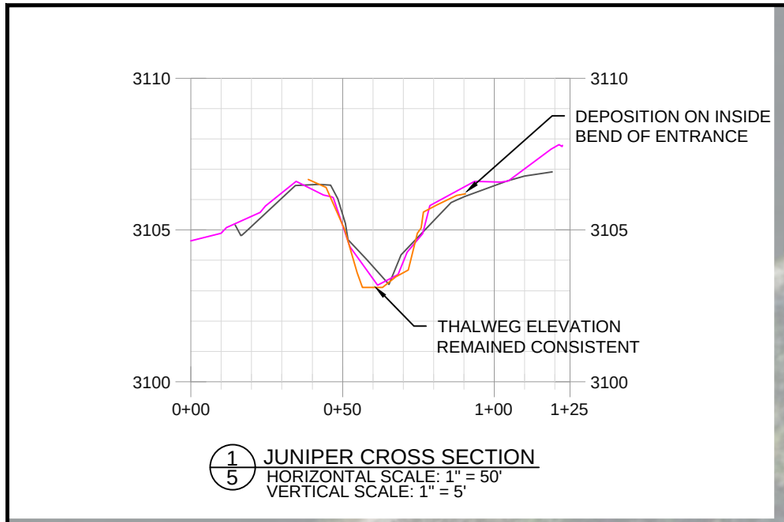
CONFLUENCE CONSULTING

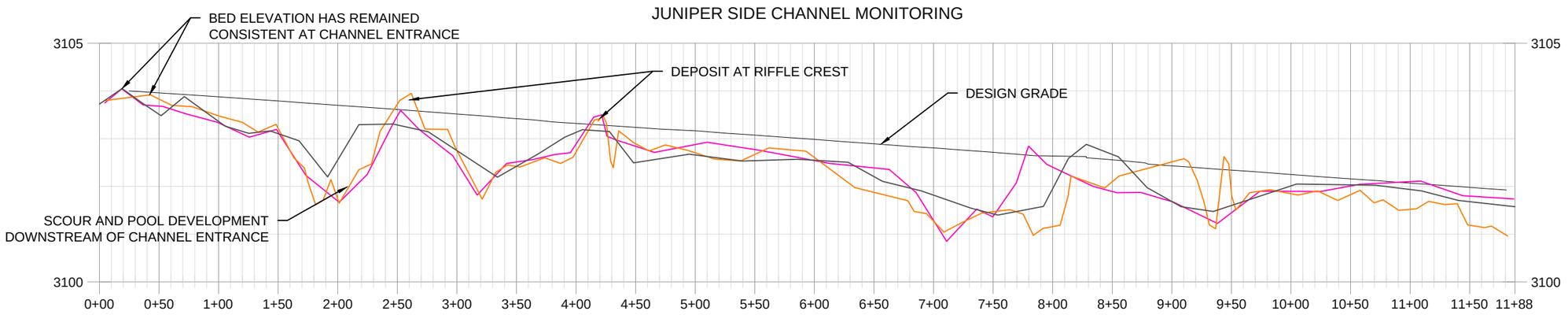
BIGHORN SIDE CHANNEL REACTIVATION MONITORING
FORT SMITH, MT

RATTLE SNAKE 2 2024 VOLUME COMPARISON

SHEET: **4**



1/5 JUNIPER CROSS SECTION
HORIZONTAL SCALE: 1" = 50'
VERTICAL SCALE: 1" = 5'



2/5 JUNIPER SIDE CHANNEL PROFILE
HORIZONTAL SCALE: 1" = 100'
VERTICAL SCALE: 1" = 2.5'

PLAN AND PROFILE LEGEND

- 2023 SPRING EXISTING GROUND GRADE
- 2023 FALL EXISTING GROUND GRADE
- 2024 FALL EXISTING GROUND GRADE

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CONFLUENCE CONSULTING

BIGHORN SIDE CHANNEL REACTIVATION MONITORING
FORT SMITH, MT

JUNIPER SIDE CHANNEL MONITORING

SHEET: 5

SCOUR ON OUTSIDE BEND OF SIDE CHANNEL ENTRANCE

DEPOSITION ON INSIDE BEND OF SIDE CHANNEL ENTRANCE

BIGHORN RIVER

JUNIPER SIDE CHANNEL

3+00

N

10 0 10 20
SCALE IN FEET

BIGHORN RIVER

JUNIPER SIDE CHANNEL

5+00

4+00

3+00

N

50 0 50 100
SCALE IN FEET

LEGEND

- CUT > 2.0'
- CUT 2.0' - 1.5'
- CUT 1.5' - 1.0'
- CUT 1.0' - 0.5'
- CUT 0.5 - 0.0'
- FILL 0.0' - 0.5'
- FILL 0.5' - 1.0'
- FILL 1.0' - 1.5'
- - #.# CUT VALUE
- #.# FILL VALUE

NOTES:

1. VOLUME COMPARISON IS BETWEEN SPRING 2023 SURVEY AND FALL 2024 SURVEY.
2. A FILL VALUE IS MATERIAL GAIN BETWEEN SPRING 2023 AND FALL 2024.
3. A CUT VALUE IS MATERIAL LOSS BETWEEN SPRING 2023 AND FALL 2024.
4. TOTAL FILL VOLUME = 96 CUBIC YARDS
5. TOTAL CUT VOLUME = 159 CUBIC YARDS
6. NET CUT/FILL = 63 CUBIC YARDS OF CUT

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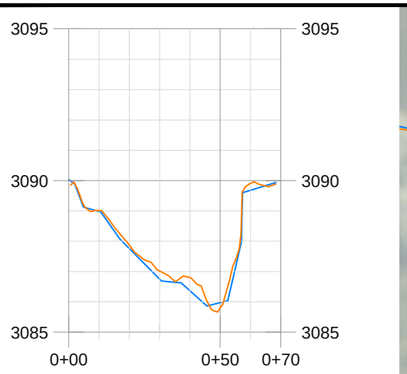
CONFLUENCE CONSULTING

BIGHORN SIDE CHANNEL REACTIVATION MONITORING
FORT SMITH, MT

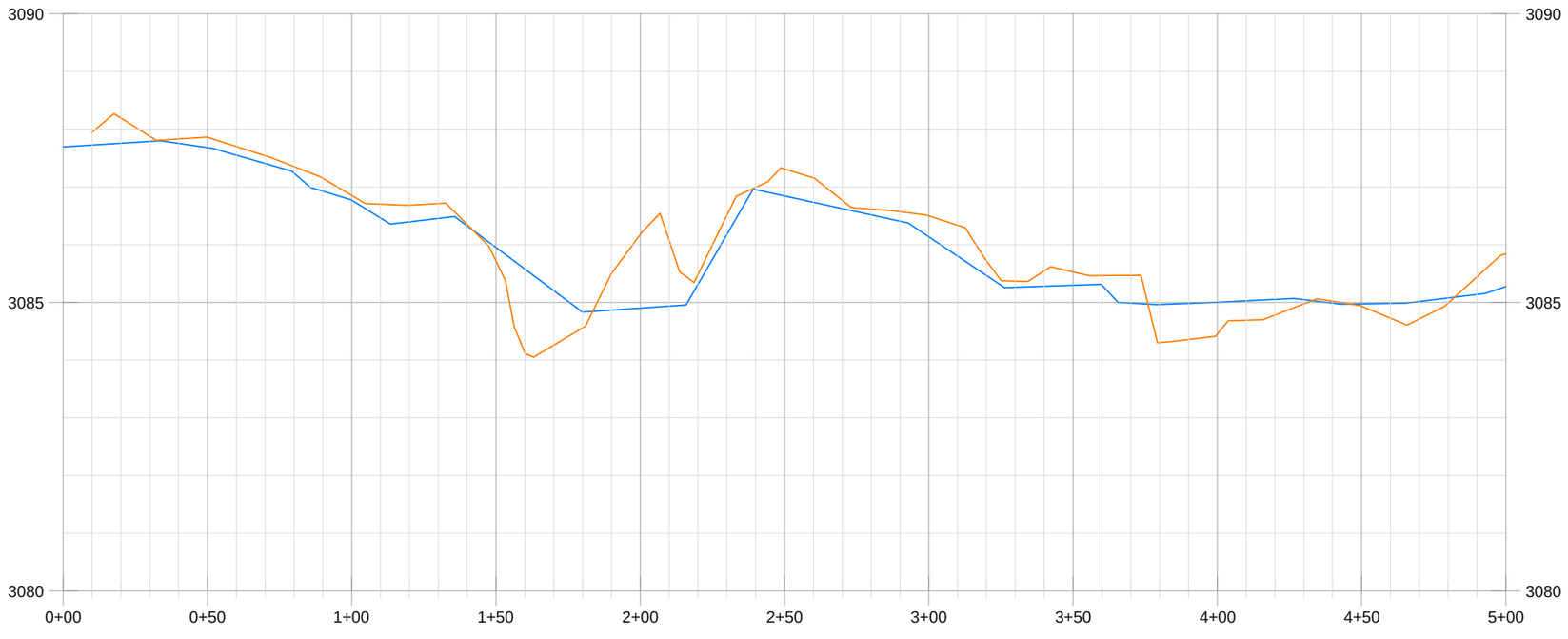
JUNIPER 2023/2024 VOLUME COMPARISON

SHEET: 6



1/7 CLINES CROSS SECTION
HORIZONTAL SCALE: 1" = 50'
VERTICAL SCALE: 1" = 5'

CLINES SIDE CHANNEL ENTANCE MONITORING



PLAN AND PROFILE LEGEND
- 2024 SPRING EXISTING GROUND GRADE
- 2024 FALL EXISTING GROUND GRADE

2/7 CLINES SIDE CHANNEL ENTRANCE PROFILE
HORIZONTAL SCALE: 1" = 50'
VERTICAL SCALE: 1" = 2.5'

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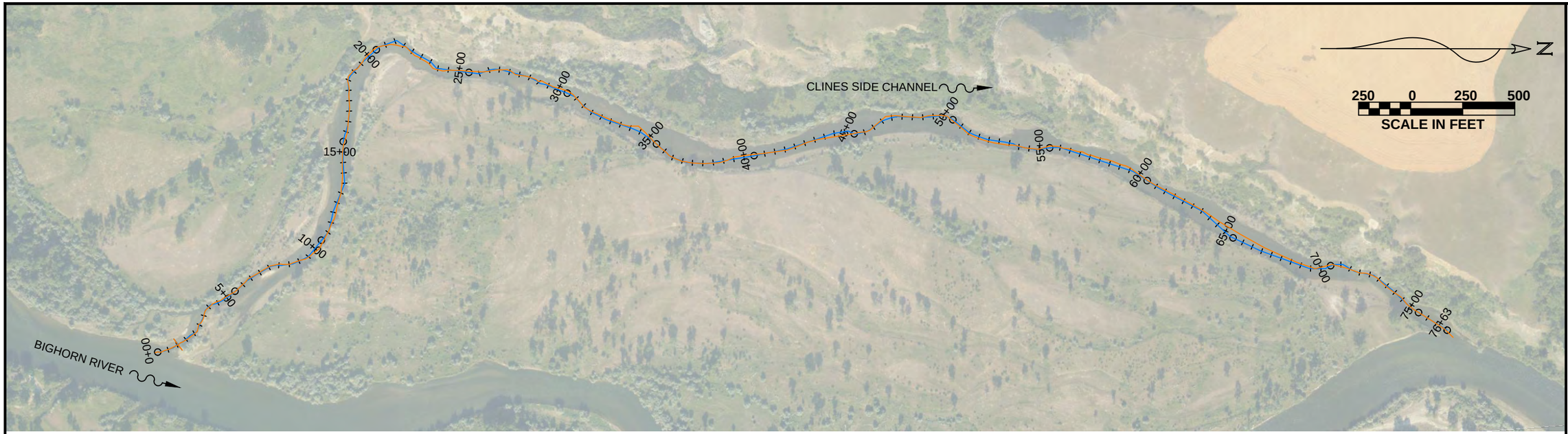
CONFLUENCE CONSULTING

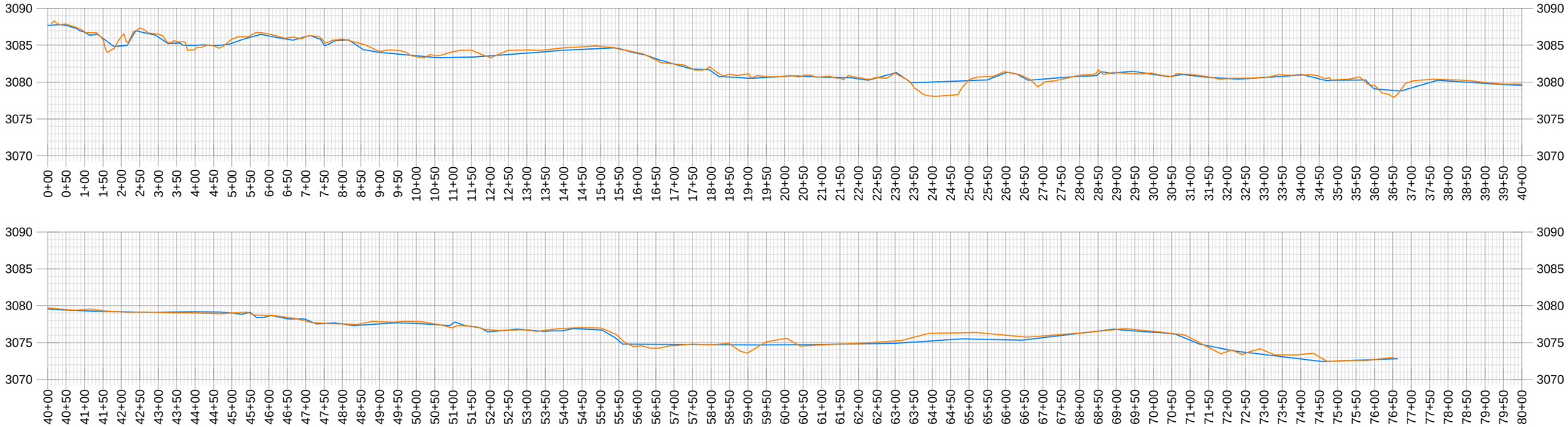
BIGHORN SIDE CHANNEL REACTIVATION MONITORING
FORT SMITH, MT

CLINES SIDE CHANNEL ENTRANCE MONITORING

SHEET: 7



CLINES SIDE CHANNEL MONITORING



1/8 CLINES SIDE CHANNEL PROFILE
HORIZONTAL SCALE: 1" = 300'
VERTICAL SCALE: 1" = 15'

PLAN AND PROFILE LEGEND

- 2024 SPRING EXISTING GROUND GRADE
- 2024 FALL EXISTING GROUND GRADE

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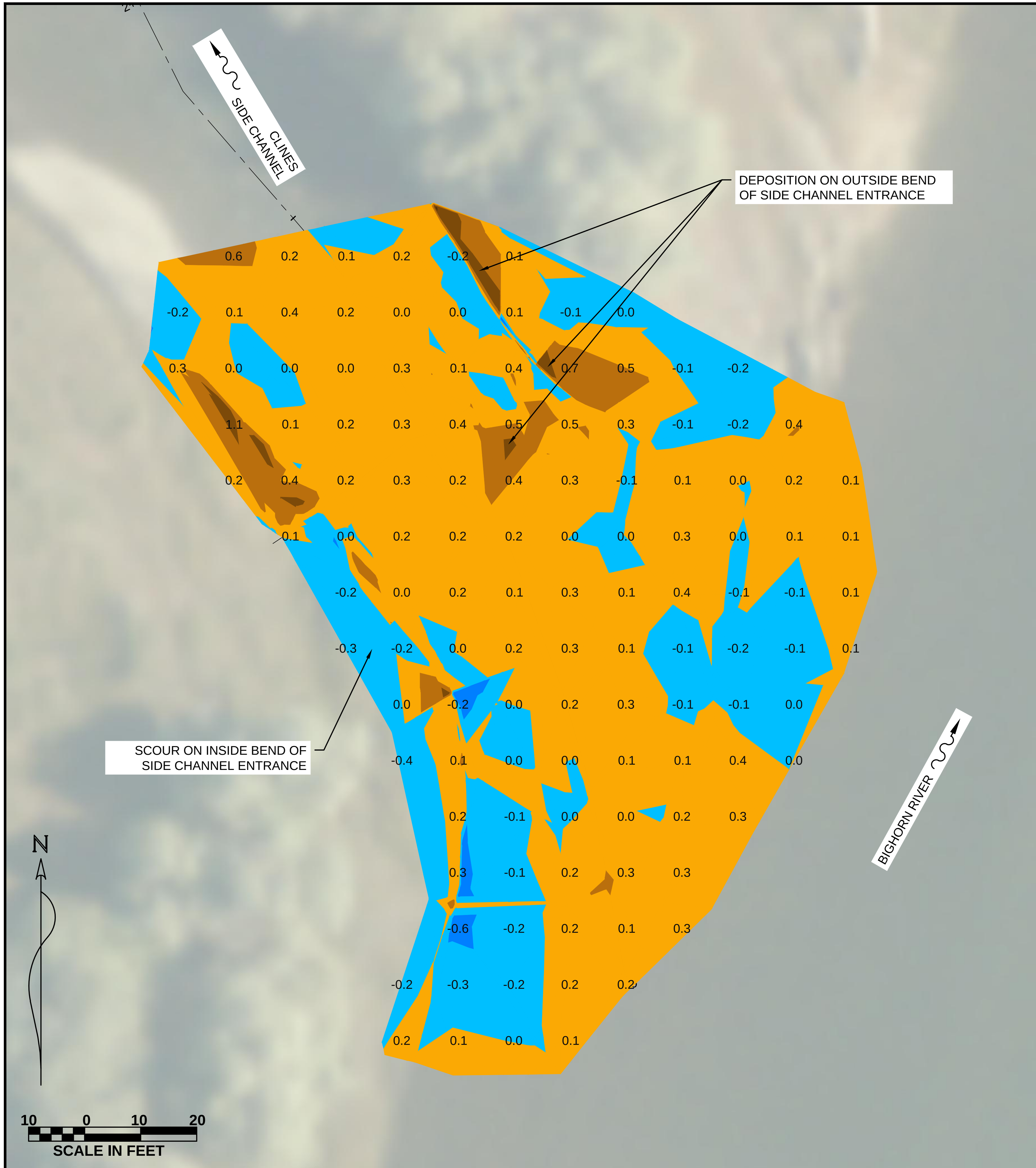
CONFLUENCE CONSULTING

BIGHORN SIDE CHANNEL REACTIVATION MONITORING
FORT SMITH, MT

CLINES SIDE CHANNEL MONITORING

SHEET: 8

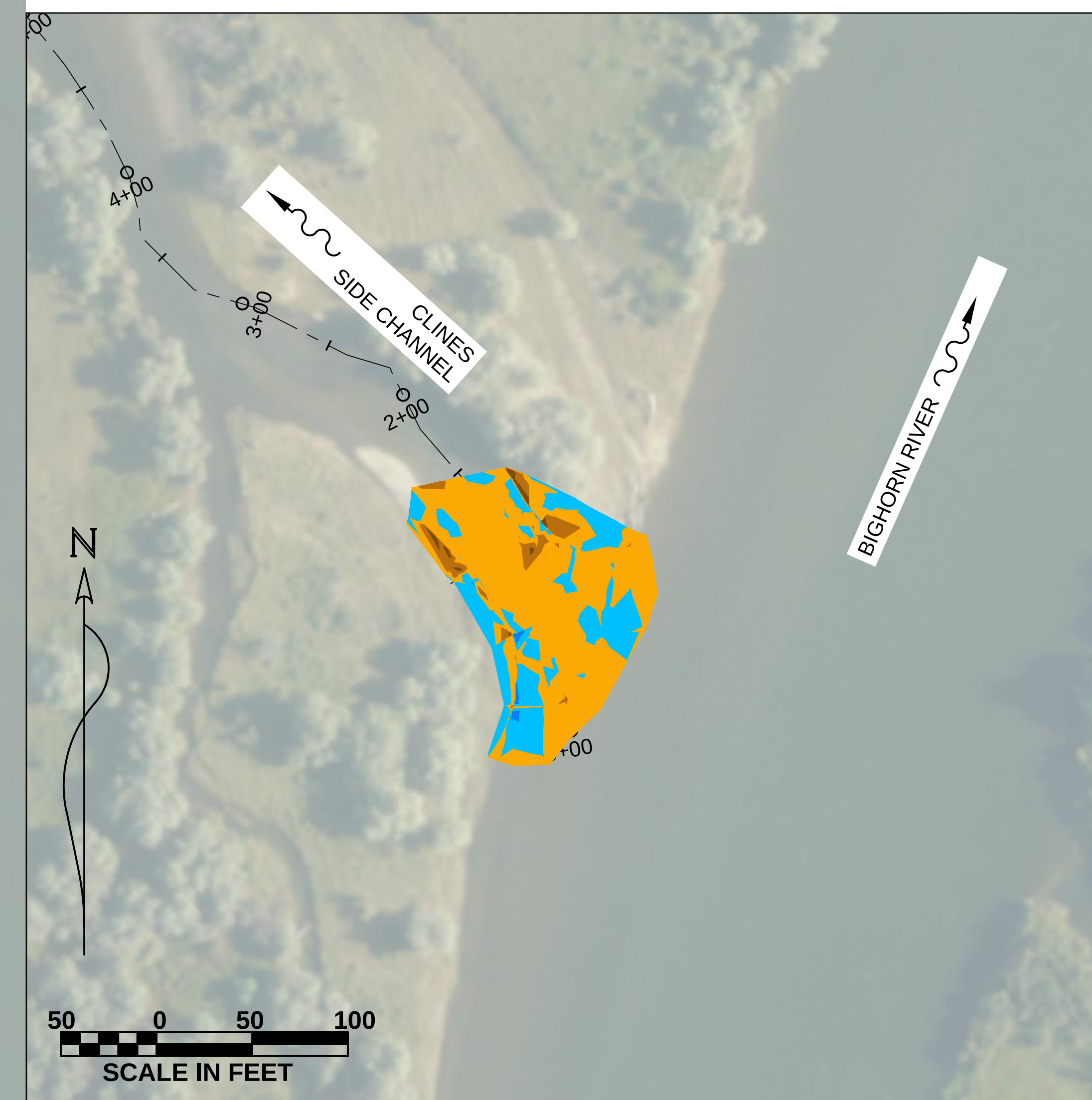


LEGEND

(dark blue)	CUT 1.5' - 1.0'
(blue)	CUT 1.0' - 0.5'
(light blue)	CUT 0.5' - 0.0'
(orange)	FILL 0.0 - 0.5'
(light brown)	FILL 0.5' - 1.0'
(brown)	FILL 1.0' - 1.5'
(dark brown)	FILL 1.5' - 2.0'
- #.#	CUT VALUE
#.#	FILL VALUE

NOTES:

1. VOLUME COMPARISON IS BETWEEN SPRING 2024 SURVEY AND FALL 2024 SURVEY.
2. A FILL VALUE IS MATERIAL GAIN BETWEEN SPRING 2024 AND FALL 2024.
3. A CUT VALUE IS MATERIAL LOSS BETWEEN SPRING 2024 AND FALL 2024.
4. TOTAL FILL VOLUME = 69 CUBIC YARDS
5. TOTAL CUT VOLUME = 18 CUBIC YARDS
6. NET CUT/FILL = 52 CUBIC YARDS OF FILL



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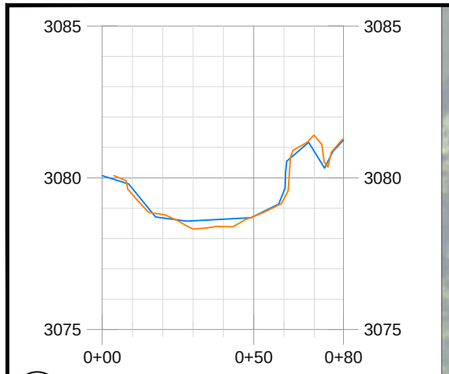
CONFLUENCE CONSULTING

BIGHORN SIDE CHANNEL REACTIVATION MONITORING
FORT SMITH, MT

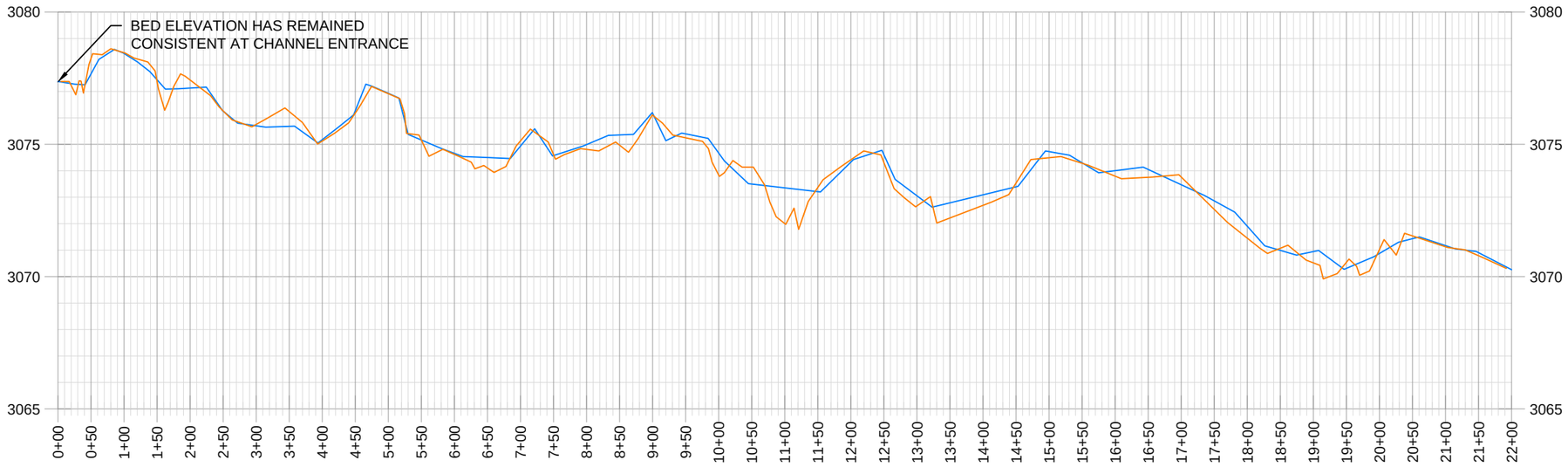
CLINES
2024 VOLUME
COMPARISON

SHEET: 9



1/10 AFRICAN QUEEN CROSS SECTION
HORIZONTAL SCALE: 1" = 50'
VERTICAL SCALE: 1" = 5'

AFRICAN QUEEN SIDE CHANNEL MONITORING



PLAN AND PROFILE LEGEND
- 2024 SPRING EXISTING GROUND GRADE
- 2024 FALL EXISTING GROUND GRADE

2/10 AFRICAN QUEEN SIDE CHANNEL PROFILE
HORIZONTAL SCALE: 1" = 200'
VERTICAL SCALE: 1" = 5'

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FILE NAME: BIGHORN SIDE CHANNEL REACTIVATION MONITORING 2024 FALL.dwg

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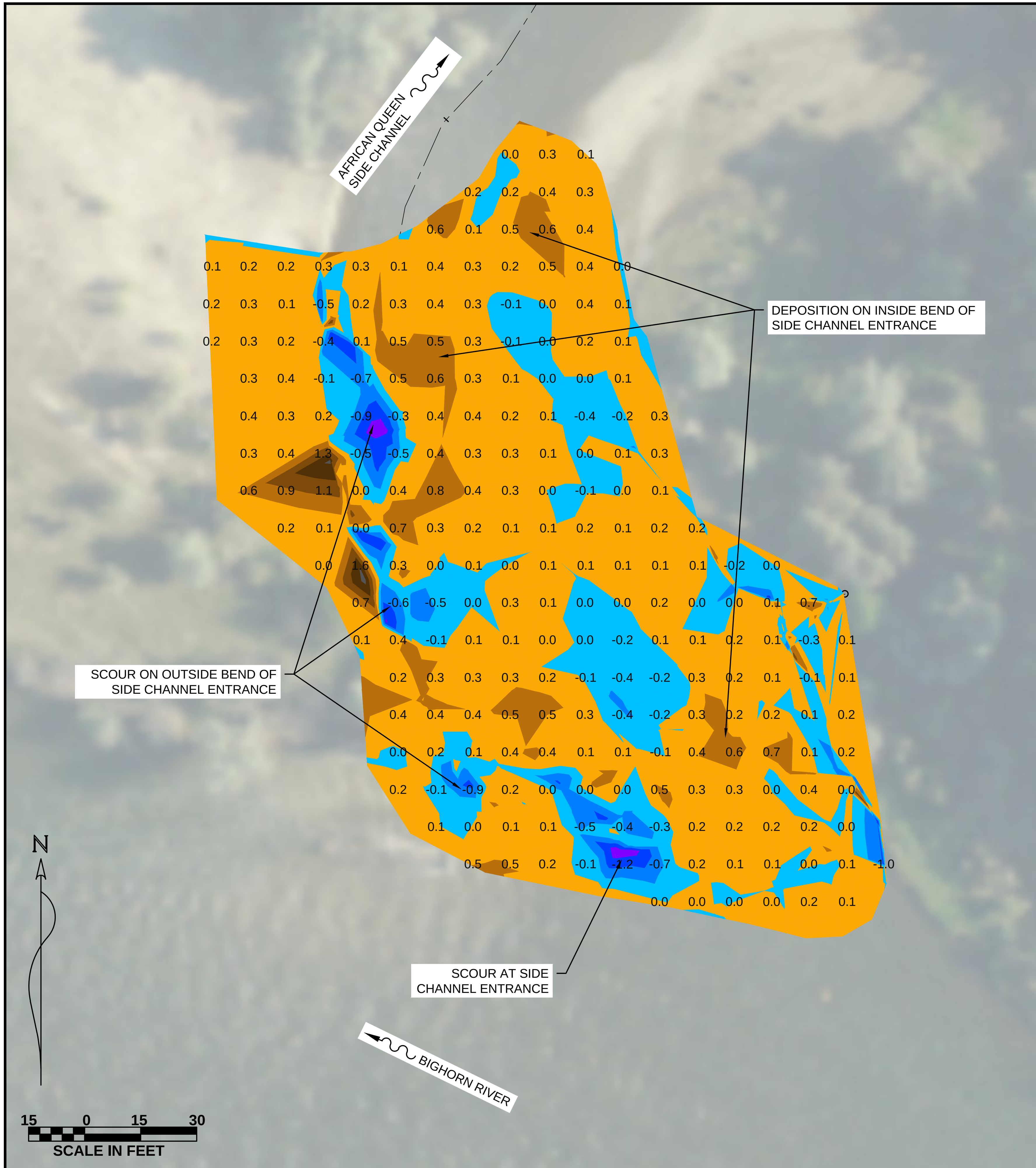
CONFLUENCE CONSULTING

BIGHORN SIDE CHANNEL REACTIVATION MONITORING
FORT SMITH, MT

AFRICAN QUEEN SIDE CHANNEL MONITORING

SHEET: 10

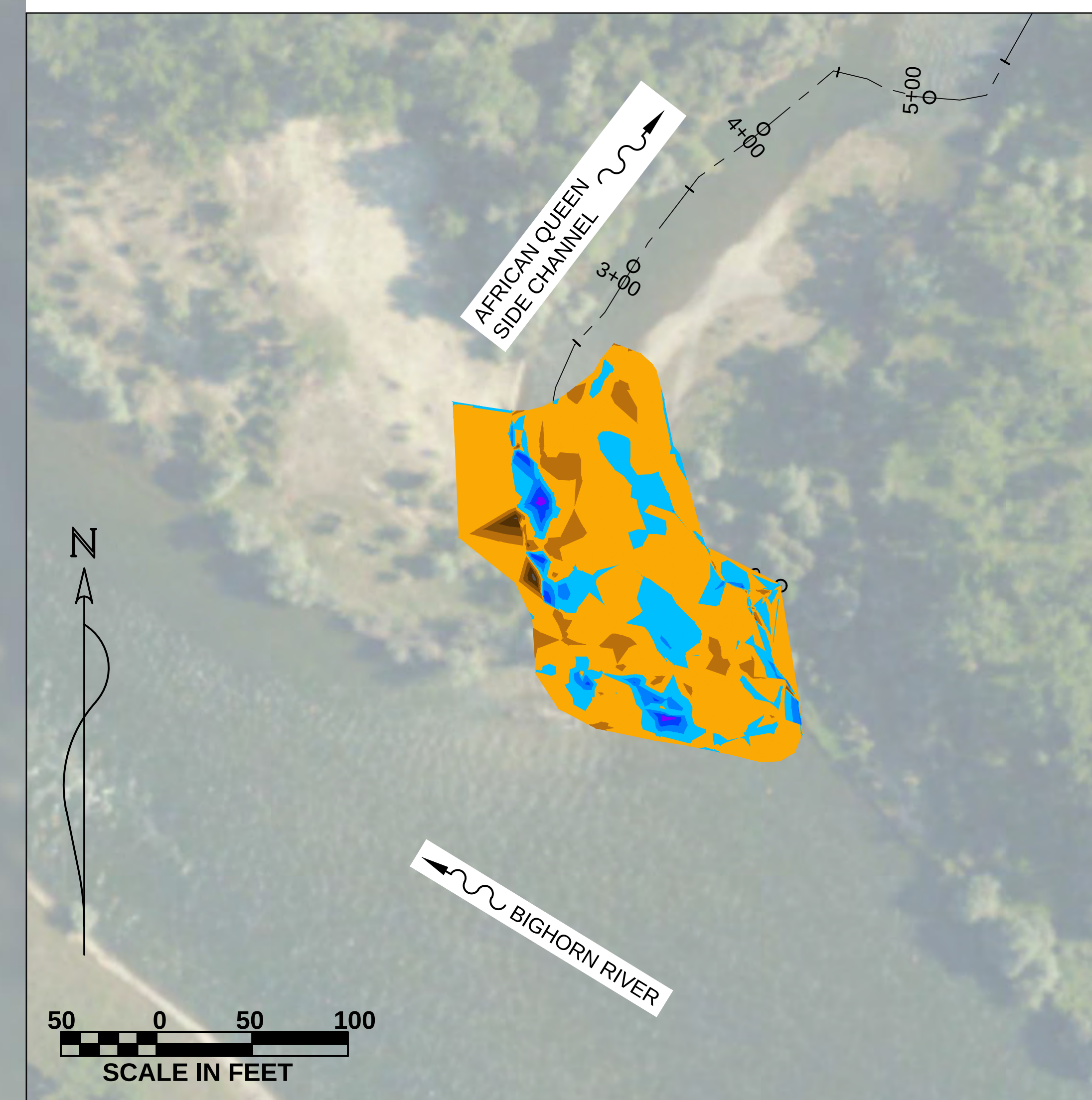


LEGEND

(purple)	CUT 2.0' - 1.5'
(dark blue)	CUT 1.5' - 1.0'
(blue)	CUT 1.0' - 0.5'
(light blue)	CUT 0.5' - 0.0'
(orange)	FILL 0.0 - 0.5'
(light brown)	FILL 0.5' - 1.0'
(brown)	FILL 1.0' - 1.5'
(dark brown)	FILL 1.5' - 2.0'
(grey)	FILL 2.0' - 2.5'
- #.#	CUT VALUE
#.#	FILL VALUE

NOTES:

1. VOLUME COMPARISON IS BETWEEN SPRING 2024 SURVEY AND FALL 2024 SURVEY.
2. A FILL VALUE IS MATERIAL GAIN BETWEEN SPRING 2024 AND FALL 2024.
3. A CUT VALUE IS MATERIAL LOSS BETWEEN SPRING 2024 AND FALL 2024.
4. TOTAL FILL VOLUME = 170 CUBIC YARDS
5. TOTAL CUT VOLUME = 59 CUBIC YARDS
6. NET CUT/FILL = 111 CUBIC YARDS OF FILL



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CONFLUENCE CONSULTING

BIGHORN SIDE CHANNEL REACTIVATION MONITORING
FORT SMITH, MT

AFRICAN QUEEN 2024 VOLUME COMPARISON

SHEET: 11