Upper Clark Fork Slicken Assessment Report

March 2022

Nathan Cook (FWP)

Alex Leone (CFC)

Slicken Assessment Report

Purpose & Background

In 2018 the Clark Fork Coalition (CFC) completed a field survey and report of slickens[1] in the Upper Clark Fork River floodplain. CFC conducted a follow-up slickens assessment in 2019 to document evolving conditions, and completed an additional and expanded assessment and report in 2020 in partnership with Montana Fish Wildlife & Parks (FWP). This slickens assessment builds on those previous reports and provides data and observations from CFC and FWP's fieldwork conducted in 2020 and 2021.

Following several years of above-average streamflow in the upper Clark Fork River (UCFR), the Clark Fork Coalition (CFC) and local recreationists reported and documented numerous events that activated previously-contained floodplain slickens. These barren patches of ground were first contaminated by heavy metals-laced sediment from upstream mining operations as far back as the early 20th century (Figure 1). Mine owner Atlantic Richfield Company (ARCO) constructed berms around some slickens in the 1980s to keep the contaminated material from interacting with the river. But high, sustained stream flows have eroded many of these berms in recent years.

The CFC first documented major berm failures in 2017, and in September 2019, documented a significant fish kill that was caused in part by a rainfall-induced berm failure. It is important to note the sustained nature of the anomalously-high flows on the upper Clark Fork that occurred between 2017 and 2020 (Figure 2). For example, in 2020 the Clark Fork River USGS stream gauge at Galen recorded 50 days of flow in excess of 460 cfs, the long-term average peak streamflow value at the site. While recent high flows are considered to be a major causal factor, the deterioration of the berms themselves has also contributed to an increase in erosion hazards.

Following four years with sustained high streamflow (2017-2020), the UCF experienced extreme drought conditions in 2021, with flows dropping to levels not seen in close to 20 years at some locations. Although low stream flows stress aquatic ecosystems, conditions during 2021 also resulted in significantly less bank and floodplain erosion than previous years (and likely less entrainment of contaminated sediments into the active channel). As part of the 2021 slicken assessment, CFC and FWP staff revisited slickens evaluated in 2020 and found that conditions had not changed significantly between 2020 and 2021 (likely related to streamflow conditions).

[1] Slickens are contaminated patches of bare ground devoid of vegetation due to heavy metal contamination.

Figure 1. Example of a high-hazard floodplain “slicken” contaminated with high levels of metals including copper and arsenic. The person in the foreground is standing on a crumbling berm that is at risk of complete failure.

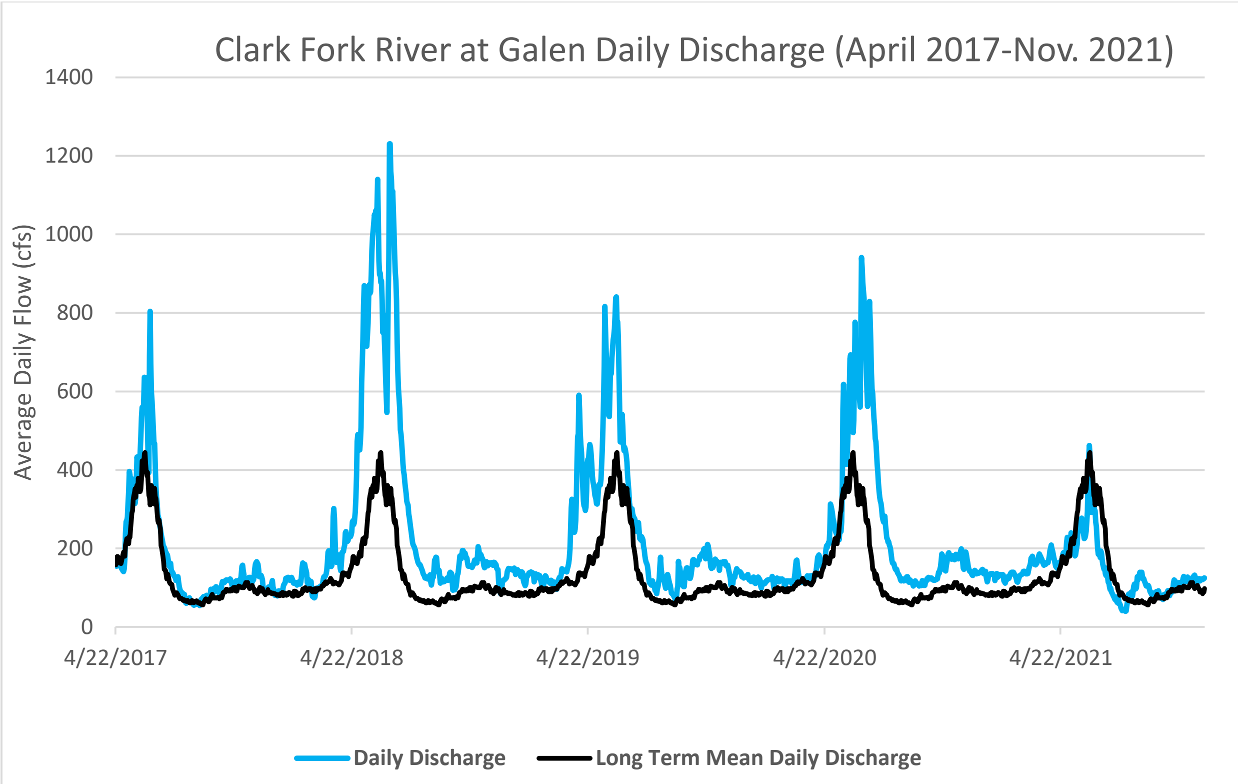

Figure 2. Median daily streamflow values for the USGS stream gage station Clark Fork River at Galen (2017-present). Note the large number of days flows exceeded the long term median daily value between 2017 and 2020 (i.e. the blue line is higher than the black line). After 4 years of above average flow conditions, 2021 saw below average flows (some of the lowest flows experienced in 20 years).

After several years of photo documenting avulsion events on a limited scale, Montana, Fish, Wildlife, and Parks and the CFC partnered to complete a comprehensive slicken risk assessment in the summer of 2020 along the un-remediated phases of the upper Clark Fork River above Deer Lodge. This slicken risk assessment was extended to the unremediated phases of the Clark Fork River between Grant-Kohrs Ranch and the Little Blackfoot River in 2021. The slicken assessment involved documenting the location and relative risk of all the major slickens proximate to the Clark Fork River and was conducted in the months of May and June (see Appendix A for additional methodologies). The report below presents the findings of both the 2020 and 2021 assessment.

Survey summary

In 2020, we surveyed at total of 109 slickens over 19.3 river miles between Perkins Lane and Arrowstone Park (see map, Figure 3). We surveyed an additional 48 slickens between Grant-Kohrs Ranch and the Little Blackfoot River in 2021. Using a scale of 1 to 4 to signify lowest to highest risk, we ranked 60 slickens as 3 or 4 for surface erosion risk and an additional 30 slickens as 3 or 4 for avulsion risk (Table 2). We determined 38 slickens to pose high risk to aquatic life (measured by a Hazard Index that combines surface erosion risk, avulsion risk, slicken size, and presence of bank calving into one metric).

Most of these high high-hazard slickens are located in phases 3A, 3B, 9-12 and 22 (Table 2; see Figure 3 for phase locations).

A subset of slickens identified as high-hazard in 2020 were revisited in summer 2021 to look for potential changes (see slicken database for details). No appreciable changes in risk were observed at these high-risk slickens, with slicken conditions in 2021 generally looking very similar to conditions in 2020. With the low stream flows of 2021, avulsion activity was likely reduced compared to previous high flow years. However, slickens with the highest avulsion risk are still inundated by the river even at base flows and continue to erode every year. In 2020, to help mitigate berm failure before remediation occurs, the Montana Natural Resource Damage Program installed hay bales and straw waddles around a number of high-risk slickens in Phase 3. While the large bales were intact and continued to provide protection against surface runoff, the small straw waddles had been eaten by cattle. Overall, however, it appears this mitigation measure was successful as short-term approach to addressing berm failure risk, and could be adapted and applied elsewhere if needed.

Table 2. Number of slickens and slicken risk scores by phase. A total of 157 Slickens were assessed. Risk level codes (L=Low, M=Medium, H=High, E=Extreme).

	Total Number of	**Surface erosion risk**				**Avulsion risk**				**Slickens with hazard index**
Phase	**slickens**	**L**	**M**	**H**	**E**	**L**	**M**	**H**	**E**	**≥ 10**
3a	7		2	2	3	1	2	3	1	4
3b	17	2	7	2	6	1	11	2	3	7
4	9	1	6	2		2	6	1		1
7	12	2	6	3	1	1	9	1	1	1
8	6	2	2	1	1	1	5			1
9	16	4	3	6	3	4	7	5		6
10	10	1	3	4	2		6	4		3
11	14	2	4	4	4	3	9	1	1	5
12	18	2	10	4	2	4	11	2	1	4
17	11	5	3	2	1	4	5	2		3
18	7	6		1		4	3			0
19	3	3				2	1			0
20	5	4	1			3	2			0
21	9	7	2			8	1			0
22	13	5	2	3	3	6	5	1	1	3
Total	157	46	51	34	26	44	83	21	9	38

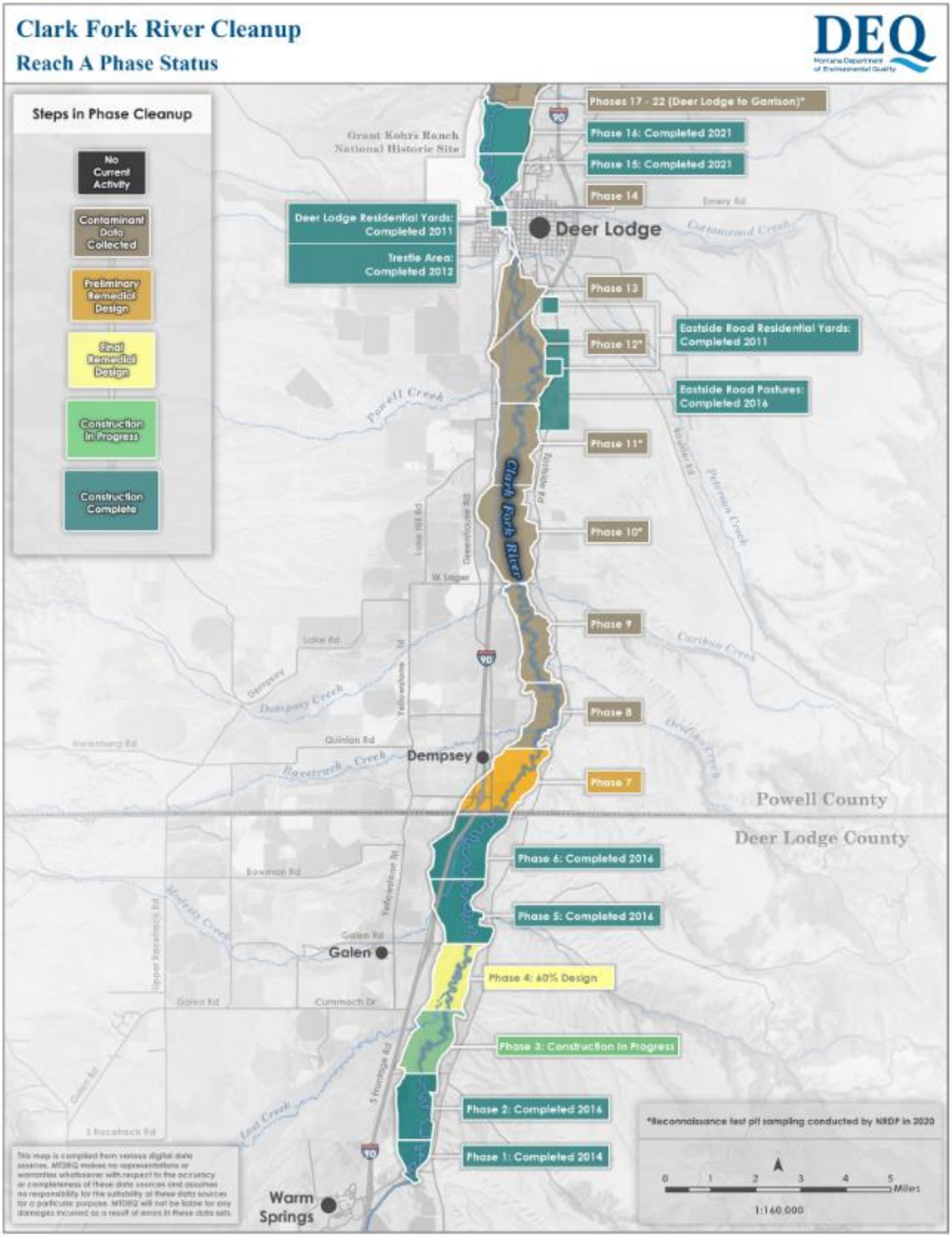

Figure 3. Status and location of cleanup phases on the Upper Clark Fork River south of Deer Lodge. Map credit: MT DEQ.

General Observations

Meander tabs

Although the condition of the slickens varied considerably, we noted some consistent trends, especially in the higher-hazard slickens. Many of the most visibly-contaminated slickens are located on meander tabs that have relatively low elevations (compared to surface water and adjacent floodplain elevation). These meander tab slickens tend to see berm failures at both the top and bottom of the tabs (related to distinct geomorphological forces). In some of the extremely high avulsion hazard slickens we noted head-cutting at the upstream end of the tab and significant down-cutting at the lower end. In some instances, these avulsions have matured to the point where much of the exposed contaminated material has been washed downstream (Figure 4).

Furthermore, we noted contaminated shallow surface water ponding at the downstream end of several of the severely-contaminated slickens. In some instances, this ponded water was just inches from the lip of a berm on the downstream end of a meander tab. These particular slickens pose an extremely high risk to the river during rainfall events. When the lower berm on these tabs is overtopped due to excessive surface runoff, contaminated water interacts directly with the river (Figure 5). This is the same mechanism that was documented on Slicken #6 after the September 2019 fish kill and is suspected to be a primary pathway transporting heavy metals in-channel during rainfall events (via aqueous and suspended sediment form).

In addition to direct surface connection, we also found clear evidence of contaminated groundwater interaction. At several of the severely contaminated slickens, we noted teal-stained water lingering in slack water areas on the downstream end of the meander tabs (Figure 6). This contaminated water is interacting directly with the Clark Fork River and potentially impacting aquatic resources downstream.

Figure 4. Newly-formed side channel through a slicken on a meander tab.

Figure 5. Partially-functioning berm on slicken #4 in Phase 3A. The berm contains some contaminated water, but is in danger of being overtopped during high river flows.

Figure 6. Teal-colored water entering the Clark Fork River at the downstream end of a contaminated meander tab on slicken # 4 in Phase 3A.

Berms

ARCO constructed berms in the 1980s along several reaches of the upper Clark Fork River to help prevent surface runoff events on slickens[2]. The berms were initially constructed as a stop-gap measure to prevent acute events. These berms were built with local earthen material (often contaminated) and typically positioned at the margins of severely-contaminated meander tabs. The berms have played a significant role in both preventing rainfall-related fish kill events, and hindering channel migration in the UCFR. After 30+ years with minimal maintenance (and several recent years of anomalously-high streamflow), the berms continue to erode and fail, exposing the river to once-contained contamination.

There are still several lateral miles of berm complexes that persist in the UCFR (in varying conditions). Most of the remaining berms are approximately 2-3 feet in height above the existing bankfull floodplain elevation. Although some berm complexes remain intact and functioning, many of the berms are experiencing significant sloughing and continue to erode and fail (Figure 1).

A prime example is slicken #10 in Phase 3B. CFC first documented major berm failure at this slicken in 2017. Since that initial failure (which started as a 1-2 foot breach), a mature side channel has formed through the slicken that, as of summer 2021, is more than 30 feet wide (Figure 4).

Berm failure not only increases avulsion hazard, it also may increase the likelihood of surface runoff events, as has occurred at slicken #6 in Phase 3A. This slicken was contained and somewhat stable until at least 2018, when significant berm sloughing was noted. In September 2019 a large rainfall event resulted in a complete failure at the downstream end of the meander tab, releasing contaminated water directly into the Clark Fork.

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[2] Former FWP fisheries biologist Wayne Hadley helped spur the establishment of the berms after documenting numerous rainfall-on-slicken fish kill events in the 1980s.

Figure 7. An intact berm on slicken #94 in Phase 12. Note that the berm is vegetated and keeps slicken material out of the river (on the left).

Surface erosion risks

The phytotoxic[3] properties of slicken deposits has led to many areas of bare ground in the UCFR floodplain (combined, these deposits equate to several acres of exposed ground). The lack of vegetation, combined with the fine-grained qualities of the soil itself, make these areas highly erodible. These areas are also relatively impermeable to water, so rain tends to either pond up (i.e., if the slicken is contained by a berm or other high spots) or runoff into the river (Figure 8). We found clear flow paths leading from slickens to the river in 50 of the slickens we surveyed (Figure 9). We also observed mineral salts forming on the surface of slickens. These salts wick to the surface as slickens dry out, and can be colored blue, green, white, or grey depending on their chemical composition (see cover photo). These salts are easily dissolved in water and are an acute risk to aquatic life during rain events.

[3] Phytotoxicity is a toxic effect by a compound on plant growth. Such damage in the upper Clark Fork is caused by elevated concentrations of trace metals and salts including copper, zinc, lead, arsenic, and cadmium.

Figure 8. Ponded water likely contaminated with high levels of copper and other heavy metals on slicken #6 (Phase3A).

Figure 9. Clear flow path leading from slicken #83 (a small but severe slicken located in Phase 11 between Sager Lane and Deer Lodge) to the Clark Fork River.

Avulsion risks

Like any river, the UCFR continues to migrate laterally across its floodplain. During high spring flows, the UCFR often flows outside its banks and begins to form new channels (avulsions). While this process is a normal part of a functioning river, in the UCFR, where so much of the floodplain is contaminated, it also poses a distinct risk due to erosion and sediment transport associated with avulsions. We observed the river flowing through several slickens at the time of our survey, and noted evidence of recent flow through others. As the UCFR cuts through these areas, it takes the contaminated material with it. This material undoubtedly leads to temporary increases in surface water metals concentrations and likely ends up deposited as fine sediment downstream.

In some cases, slicken avulsions are caused by the direct erosive power of the river. These avulsions are often found on the downstream end of meander tabs where backwaters and eddies form. In other cases, avulsions may form from head-cutting caused by surface runoff over slickens. This surface runoff collects at the lowest point and can form a flow channel and head-cut (Figure 10 & 11).

Figure 10- Aerial imagery of a contaminated meander tab in in Phase 3A. Active avulsion pathways are clearly noted with deltaic slicken sediments clearly present at the outlet of the avulsion.

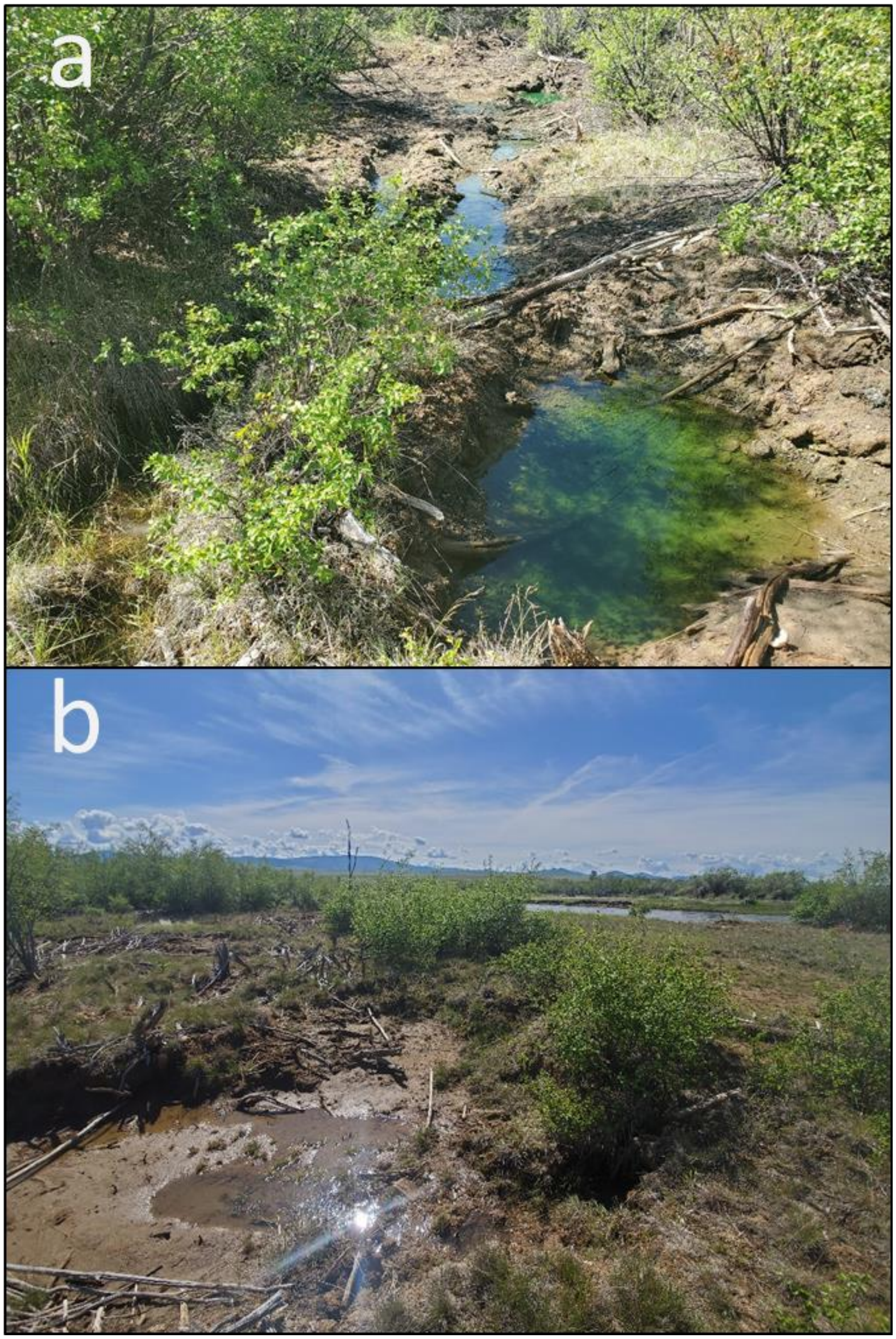


Figure 11. The photos above show an avulsion channel that has formed from surface runoff and erosion of slicken #95 (a large, high risk slicken in Phase 12 between Sager Lane and Deer Lodge). Photo “a” is on the lower, downstream portion of the meander tab, photo “b” was taken at the top of the tab. This channel is headcutting toward the upstream end of the meander tab and is within a few meters of causing the river to avulse into the slicken.

Garrison Area Slickens

The 2020 and 2021 slicken assessments show that the majority of high risk contamination in the floodplain of the Upper Clark Fork River are upstream of Deer Lodge. There is a sudden and significant decrease in the number of high risk slickens downstream from the I-90 bridge in Deer Lodge compared to upstream parts of the Clark Fork. This is consistent with previous evaluations of floodplain contamination. However, the 2021 survey documented four slickens downstream of Deer Lodge with hazard indices > 10. Three of the four high-risk slickens were in phase 22, immediately upstream of Garrison. Slickens #145 and #151 (Phase 22) are both large abandoned oxbow channels with severe contamination, that despite being disconnected from the active channel, could pose a risk to aquatic life during high flow events. Slicken #154 (also Phase 22) is located directly adjacent to the confluence of the Little Blackfoot and Clark Fork River and is clearly visible from I-90. This slicken exhibits evidence of active bank calving and is likely an acute threat to aquatic life.

ID #151 (Phase 22 near Garrison): This abandoned oxbow slicken is expansive, covering approximately 12 acres.

ID #154 (Phase 22 near Garrison): Located at the confluence of the Little Blackfoot, this slicken is a potential fish killer.

Conclusions

Surface runoff and avulsion events on slickens are not new phenomena in the upper Clark Fork, and entrainment and transport of contaminated material has been happening since the early 20th century. However, evidence from the recent slicken assessments does indicate that the upper Clark Fork has seen an increase in overall channel-forming processes over the past several years. These channel avulsions, along with berm failures and surface runoff, have caused large amounts of contaminated material to enter the Upper Clark Fork River channel. This contamination likely causes increased toxicity to aquatic life. Rainstorms that mobilize slicken materials over a short time period cause acute impacts, particularly when these events occur during periods of low river discharge. This was the scenario that occurred in September 2019 when severe thunderstorms washed contamination into the UCFR, an event that coincided with a significant fish kill.

Recent trout population estimates on the upper river (above Deer Lodge) are at their lowest point since the 1970s and several miles of river hold fewer than 100 trout per mile. Similar streams that are considered “reference reaches” hold in excess of 500 trout per mile. Fisheries biologists have also documented a near complete lack of recruitment of young fish to the population in the last 5 years. The lack of fish in the UCFR has not gone unnoticed by local anglers, who often report poor fishing results in the area. While fish numbers in the Upper Clark Fork throughout the last century have shown high fluctuation rates that fish biologists have struggled to explain, the current low trout numbers are likely exacerbated by acute fish kill episodes and recent large-scale contaminant transport in the upper Clark Fork. Although the 2019 fish kill was well documented, it is probable that other acute fish kill events have impacted populations in the UCF and gone unnoticed. The short duration and localized nature of the events makes them difficult to track and pin down.

Recommendations

Cleanup of the contaminated UCFR floodplain is underway in some areas. However, it could be many years, if not decades, before the cleanup reaches other parts of the river. In the meantime, mitigation strategies such as erosion control measures or berm rebuilding should be considered. For other slickens, such as those at the highest avulsion risk, removal may be the only option. High flows in 2017-2020 years have significantly altered the channel above Deer Lodge and future runoff events that activate the floodplain will continue to increase the risk of contaminant mobilization. High-risk slickens that pose the greatest threat to aquatic life need to be addressed as soon as possible to prevent further damage to the ecosystem.

As slickens continue to erode, we need to investigate the “ultimate fate” of the contaminated sediment that has become mobilized in-channel. This could at least be partially investigated through targeted sediment sampling and testing in areas that are suspected to be localized sources and sinks. The University of Montana Western (UMW) spearheaded a limited sediment contamination scoping assessment in 2019 and found dangerously elevated levels of instream sediment contamination at the downstream end of high risk slickens. Additional investigations into the biological ramifications resulting from the transport and deposition of contaminated sediment are needed.

Recent high flows have damaged the integrity of the berm structures put in place to contain contamination and ongoing study of slicken hazards is needed. The CFC and MT FWP plan to conduct annual slicken assessments for the next several years to continue to monitor and document conditions. An expedited slicken assessment of Reach B would also be valuable to determine if hazards exist downstream of Garrison.

The extent and severity of the floodplain contamination in Phase 22 (reach of River near Garrison) was somewhat unexpected. Slicken #154, located at confluence of the Little Blackfoot River, is exceptionally hazardous. This slicken should receive high priority for removal. If timely removal is not feasible, then erosion control measures should be implemented as soon as possible.

Appendix A (Methodology)

Date of Assessment	Average Daily Flow at Galen (cfs)	Phases Assessed
May 28, 2020	500	7, 8
June 2, 2020	618	8, 9
June 3, 2020	571	3a, 3b
June 18, 2020	942	3b, 4
June 23, 2020	760	10, 11
June 25, 2020	687	12
June 23, 2021	193	17-19
June 24, 2021	188	20-22

Table 1. Dates and phases floated during the slicken assessment and average daily flows at Galen. June 18th 2020 recorded the highest average daily flow at Galen between May 2020 and June 2021.

Methodology

The slicken assessments were completed by floating reaches of the river with staff from MT Fish Wildlife and Parks (FWP) and the Clark Fork Coalition (see slicken database for additional methodology). Slickens were located from aerial photos and from the boat. Each slicken was given a Slicken ID and GIS coordinates were recorded. Qualitative risk assessments were conducted from the boat and shoreline to categorize risks associated with avulsion and surface runoff events. Each slicken was given a surface erosion risk (SER) and avulsion risk (AR) score from 1-4, with 1 representing minimal risk and 4 signifying imminent risk (see Appendix A for examples). We considered slickens with SER or AR scores 3 or above to be the highest risks to aquatic life. Slickens were put into three general size categories of small (< ¼ acre), medium (¼ -1 acre), and large (> 1 acre). Evidence of bank calving was noted when present. Landowner permission was requested when it was necessary to survey slickens off-channel. Photos were taken at each slicken to document conditions. We also calculated an overall Hazard Index (HI) as a metric of the relative risk of each slicken. The HI score incorporates SER, AR, slicken size, and presence of bank calving into a single metric. We considered slickens with HI ≥ 10 to be the greatest risk to aquatic life.

Appendix A (Hazard Risk Examples-Class 4)

ID#22, **SER = 4** (AR=3): Built-up salts on this slicken will flow into the river during a rainfall event.

ID#74, **AR=4** (SER=3): Slicken is inundated and connected, and channel-forming processes are evident.

Appendix A (Hazard Risk Examples-Class 3)

ID#11, **SER=3** (AR=2): Large, severe slicken, but berm is partially intact, reducing SER.

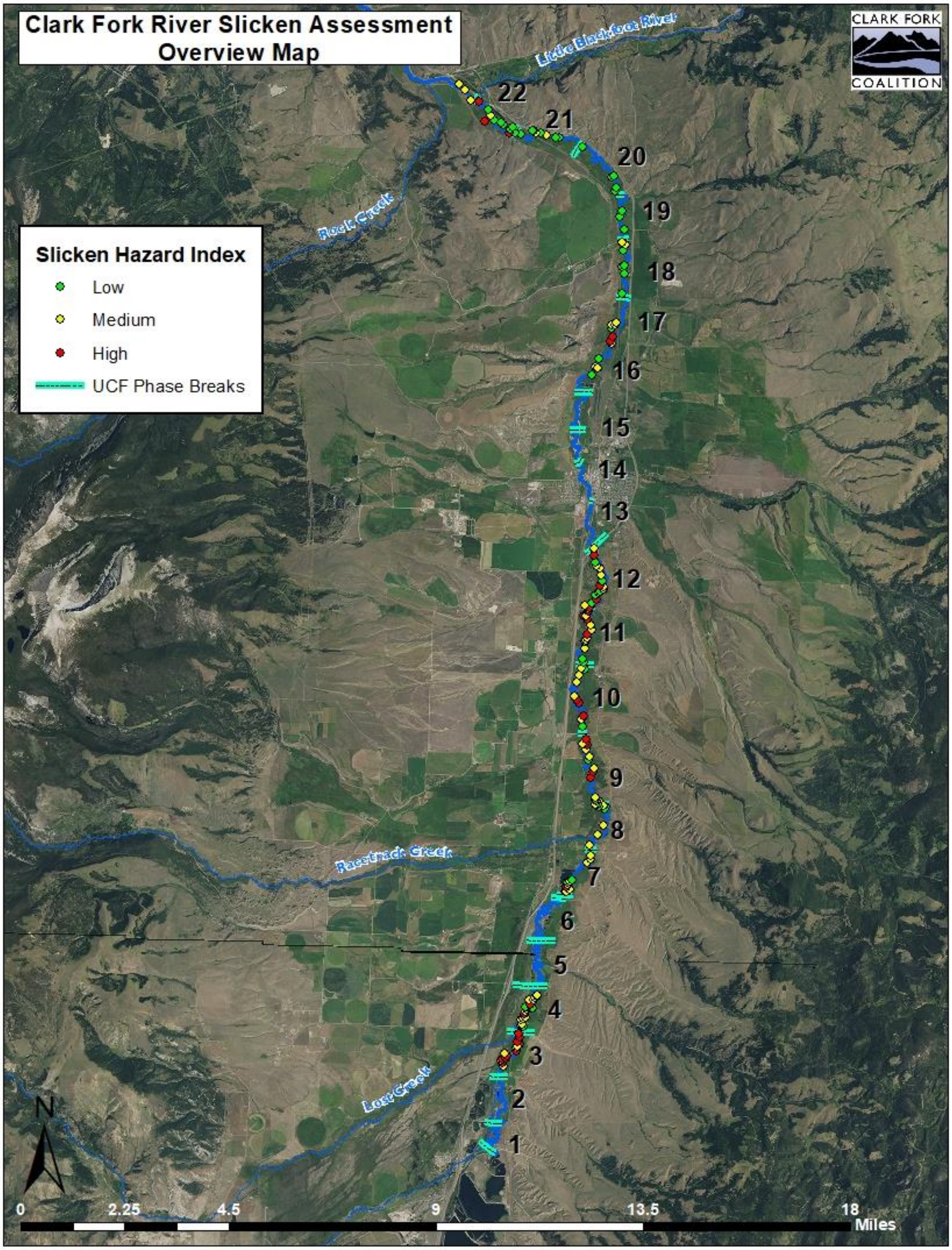
ID#71, **AR=3**, (SER=3): Evidence that river was flowing through slicken, but not at the time of the survey.

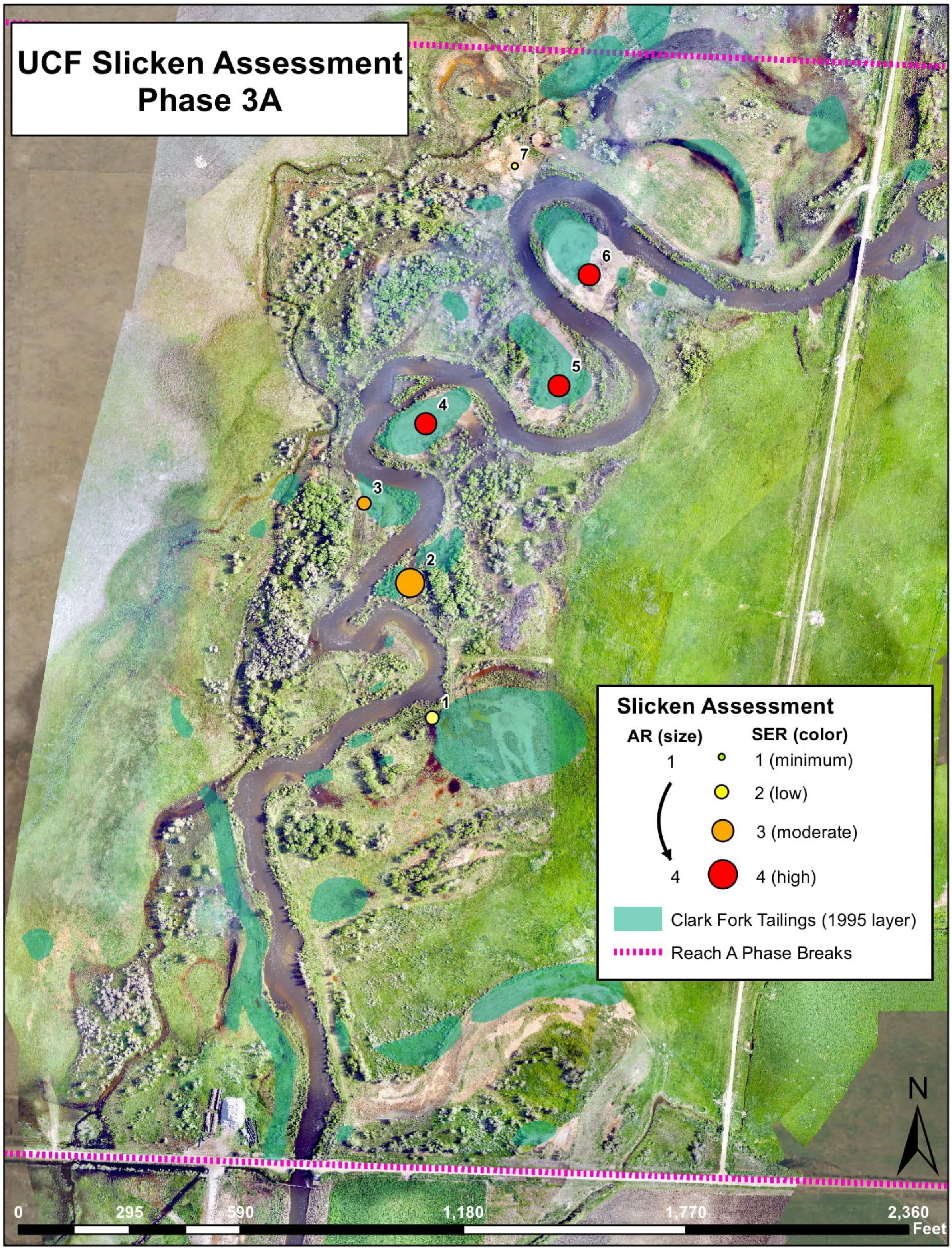
Appendix A (Hazard Risk Examples-Class 1 & 2)

ID#31, **SER=2, AR=2:** A good example of a berm keeping contamination from contacting the river.

ID#60, **SER=1, AR=1**: A spotty and mostly-vegetated slicken located away from the river.

Appendix B: River Phase Maps and Slicken Locations





UCF Slicken Assessment
Phase 3A
Slicken Assessment
AR (size)
SER (color)
1
1 (minimum)
2 (low)
3 (moderate)
4
4 (high)
Clark Fork Tailings (1995 layer)
Reach A Phase Breaks
1
2
3
4
5
6
7
N
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590
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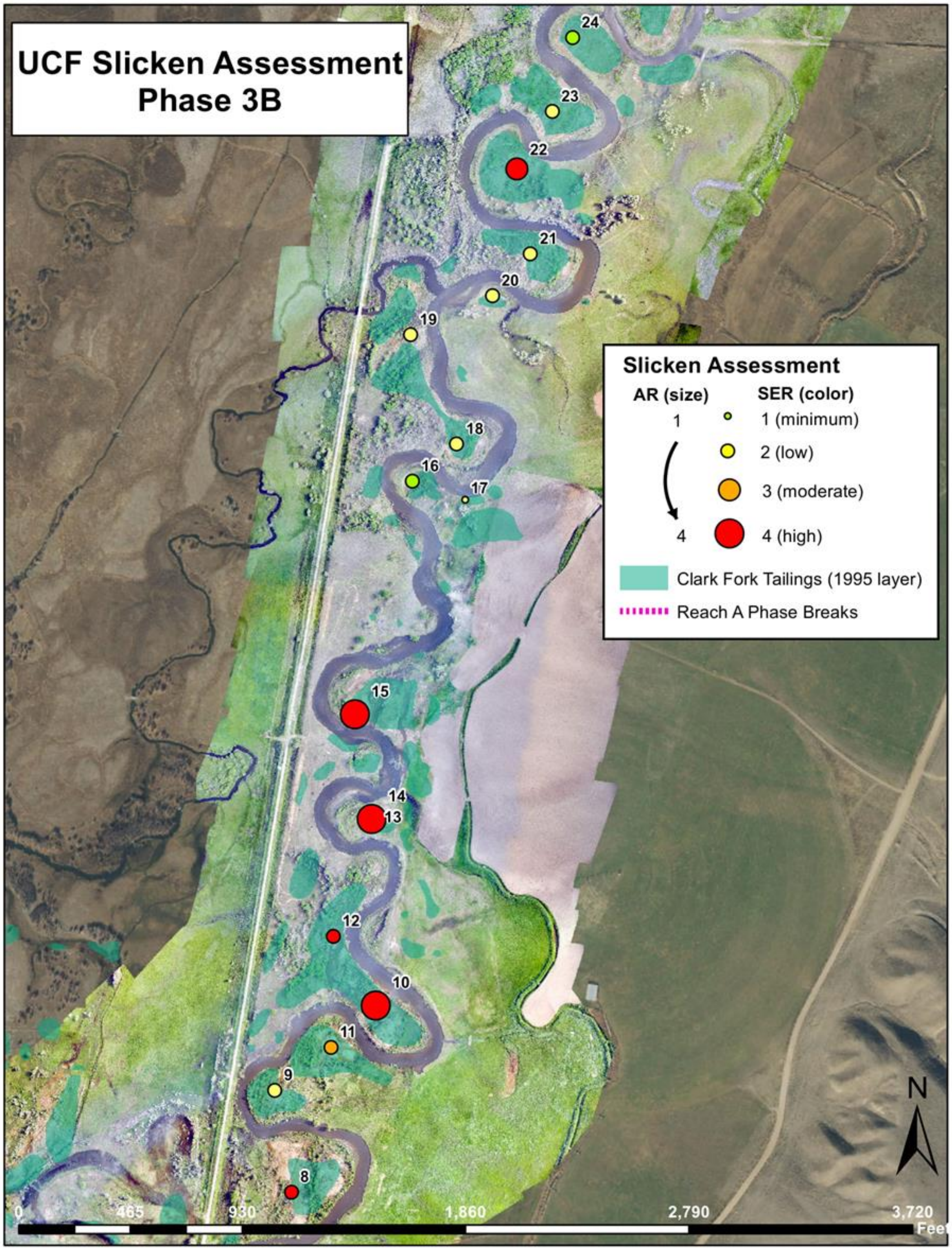
1,770
2,360
Feet


UCF Slicken Assessment
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Slicken Assessment
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SER (color)
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2 (low)
3 (moderate)
4
4 (high)
Clark Fork Tailings (1995 layer)
Reach A Phase Breaks
24
23
22
21
20
19
18
16
17
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9
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3,720
Feet
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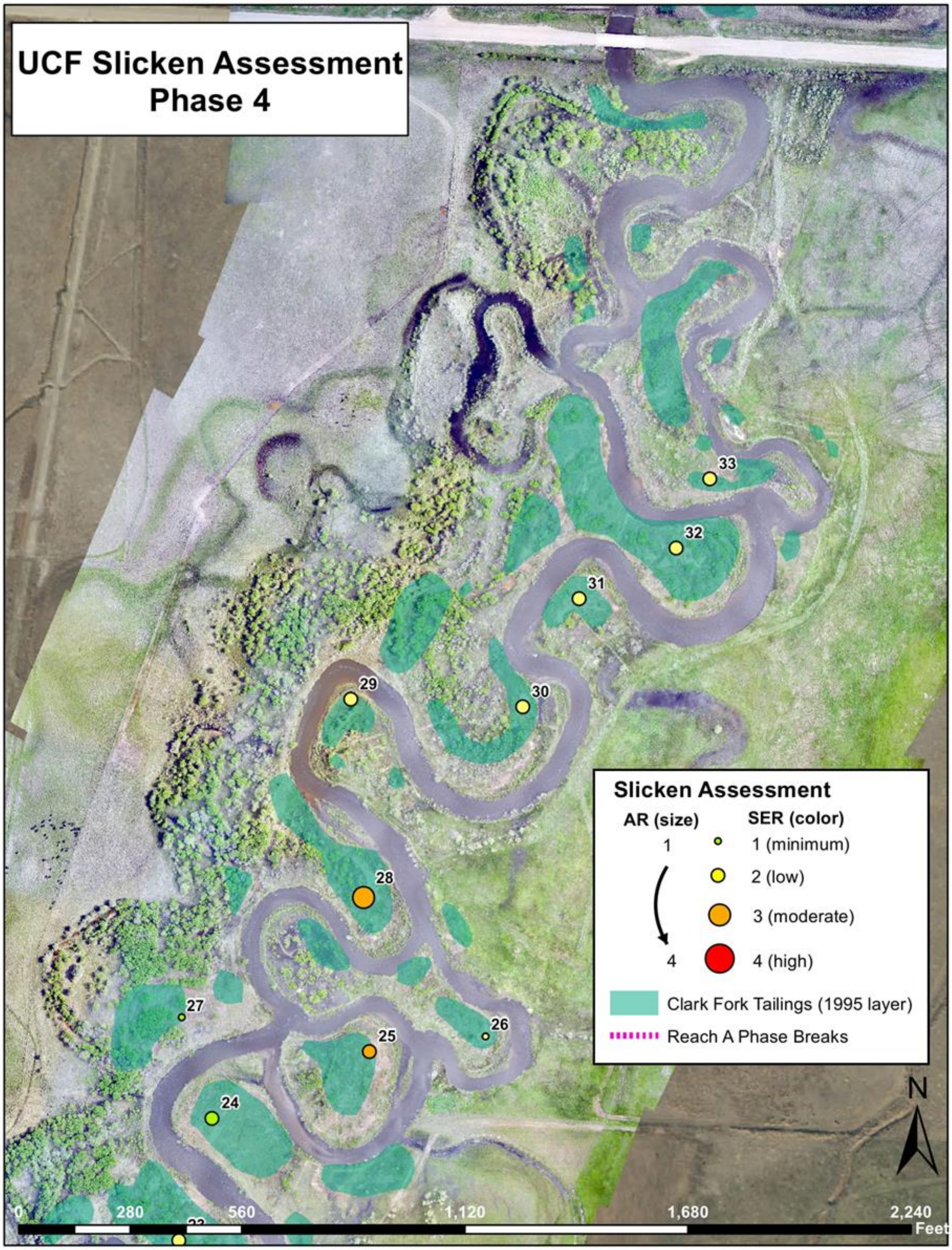

UCF Slicken Assessment
Phase 4
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30
28
27
26
25
24
Slicken Assessment
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SER (color)
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2 (low)
3 (moderate)
4
4 (high)
Clark Fork Tailings (1995 layer)
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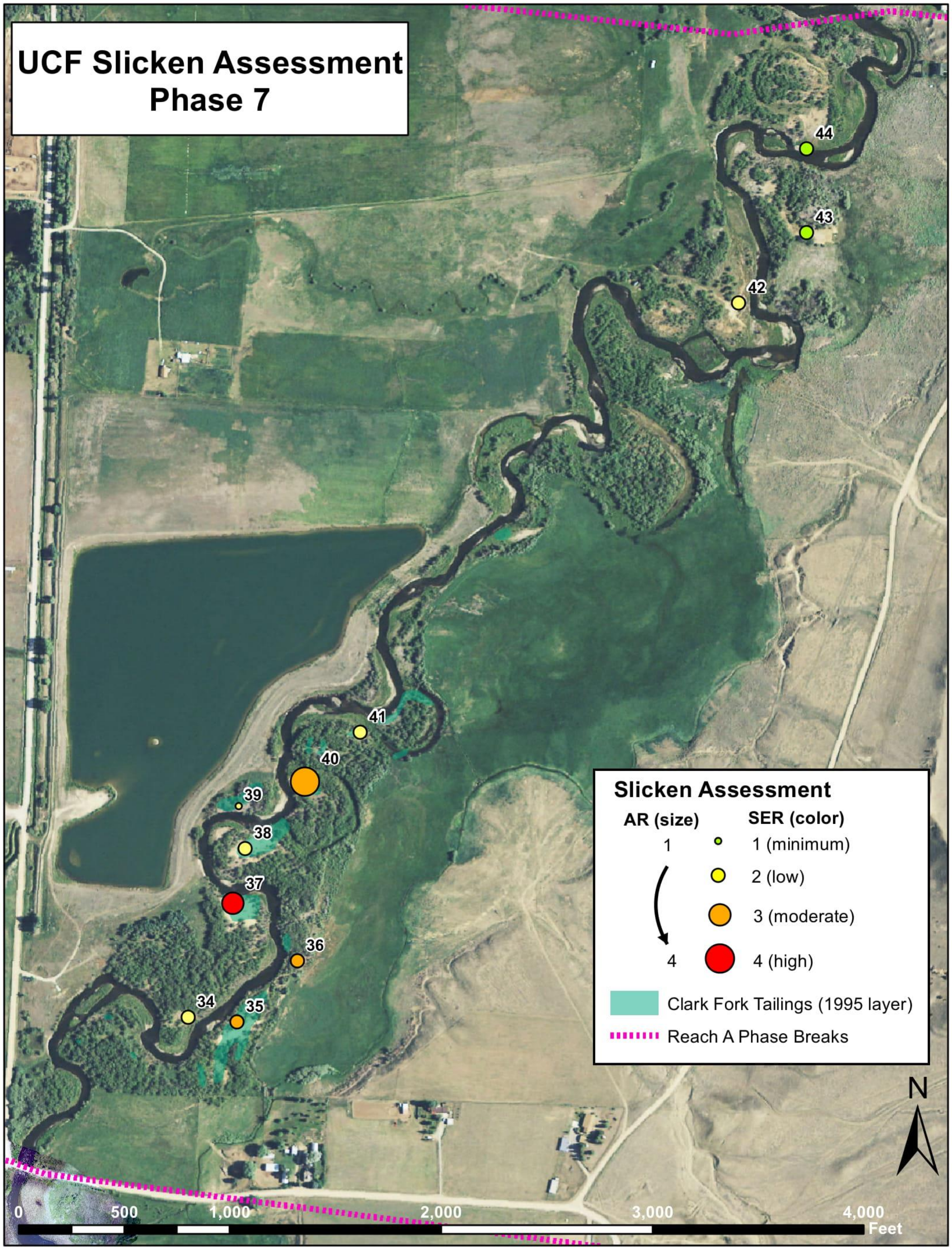
Feet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Phase 7
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43
42
41
40
39
38
37
36
35
34
Slicken Assessment
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SER (color)
1
1 (minimum)
2 (low)
3 (moderate)
4
4 (high)
Clark Fork Tailings (1995 layer)
Reach A Phase Breaks
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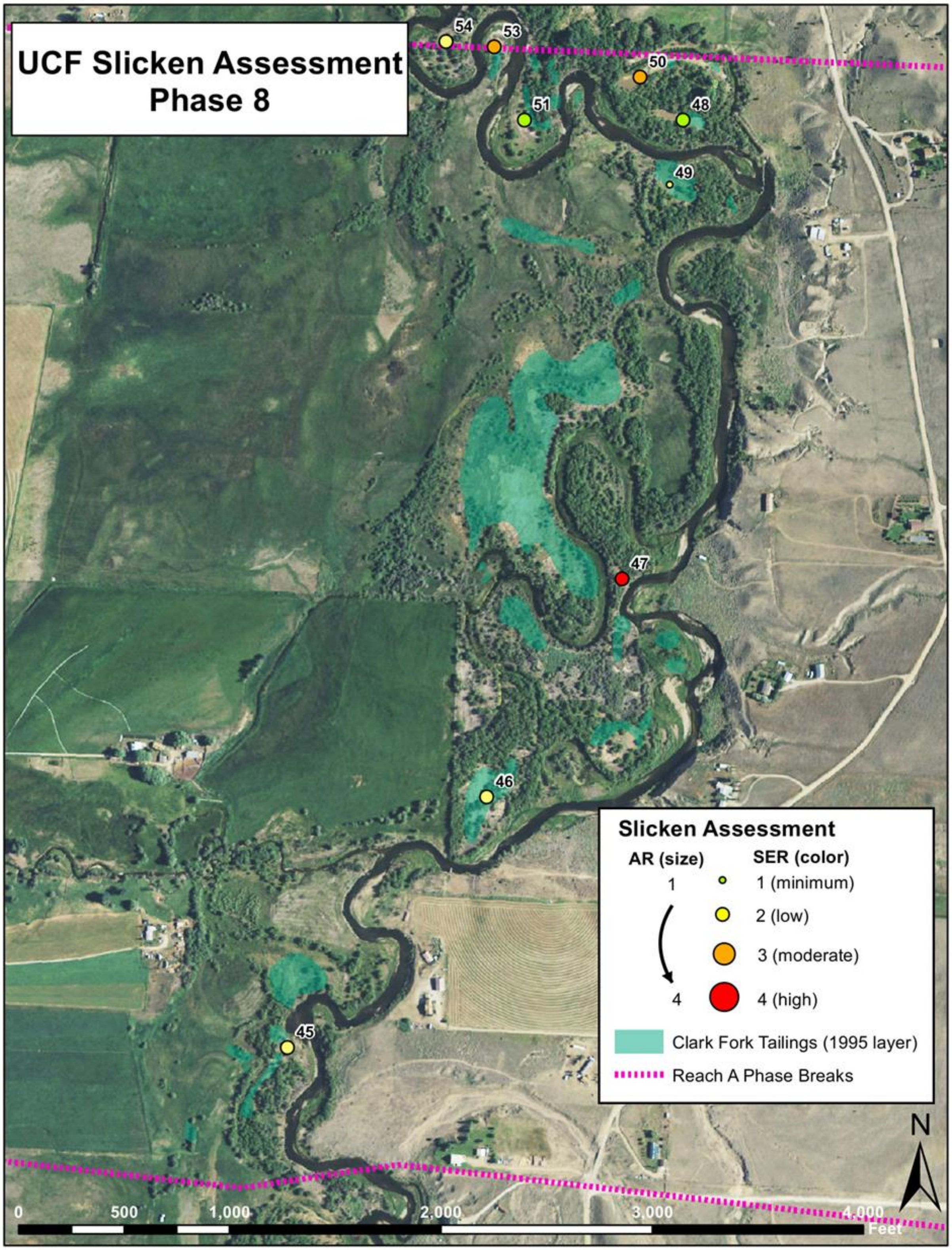
2,000
3,000
4,000
Feet


UCF Slicken Assessment
Phase 8
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47
46
45
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SER (color)
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2 (low)
3 (moderate)
4
4 (high)
Clark Fork Tailings (1995 layer)
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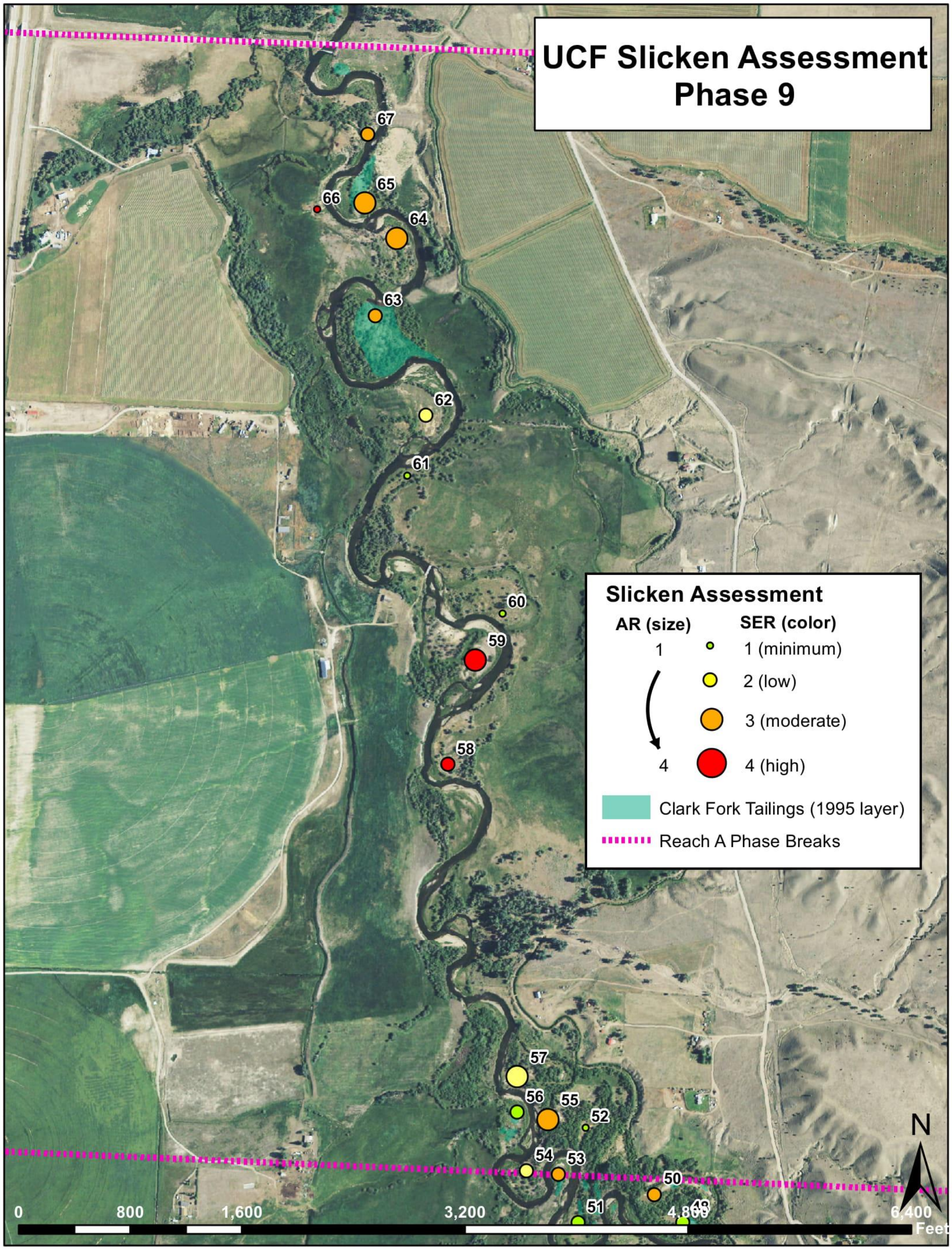
2,000
3,000
4,000
Feet



UCF Slicken Assessment
Phase 9
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52
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50
51
Slicken Assessment
AR (size)
SER (color)
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1 (minimum)
2 (low)
3 (moderate)
4
4 (high)
Clark Fork Tailings (1995 layer)
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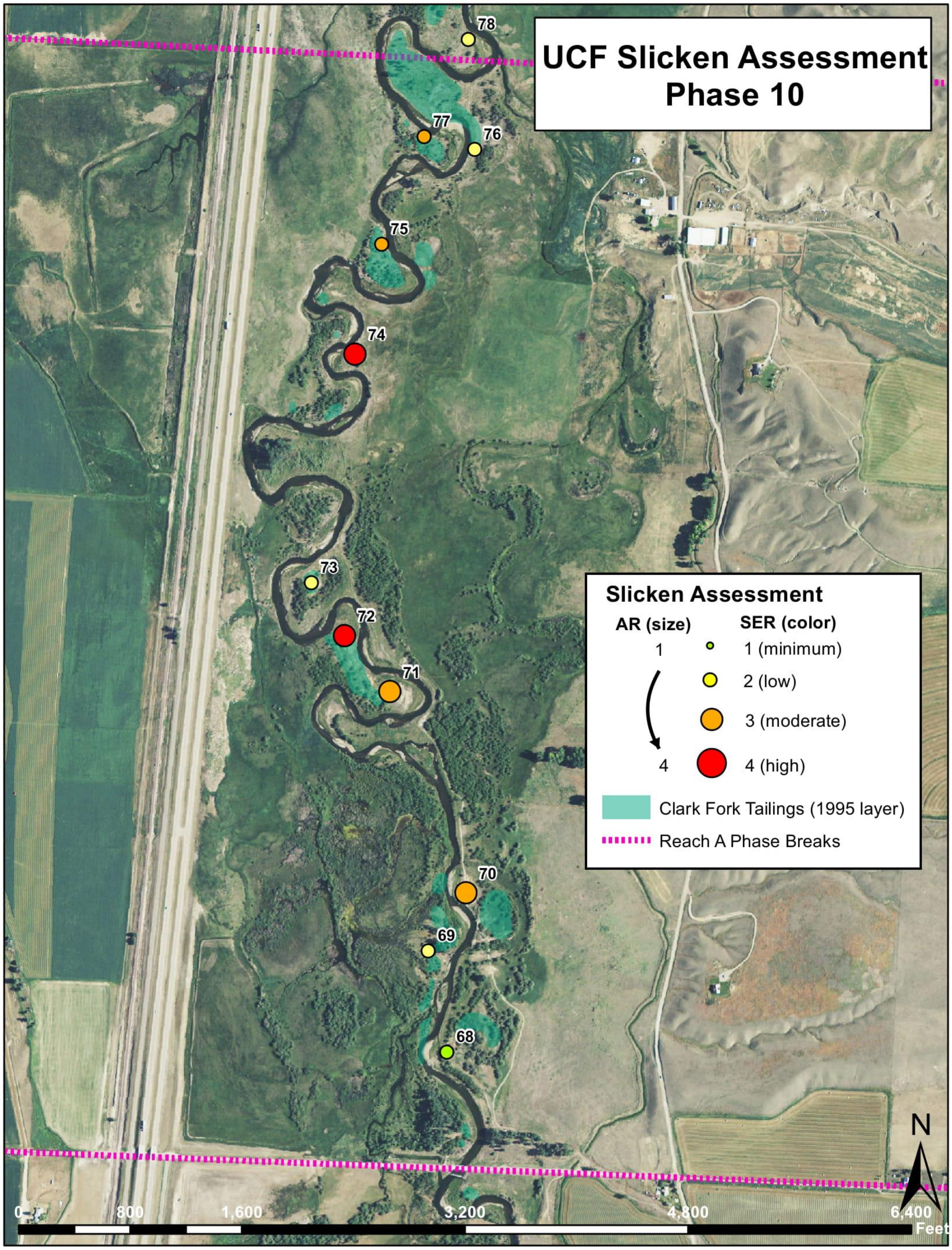
4,800
6,400
Feet


UCF Slicken Assessment
Phase 10
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77
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Slicken Assessment
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SER (color)
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1 (minimum)
2 (low)
3 (moderate)
4
4 (high)
Clark Fork Tailings (1995 layer)
Reach A Phase Breaks
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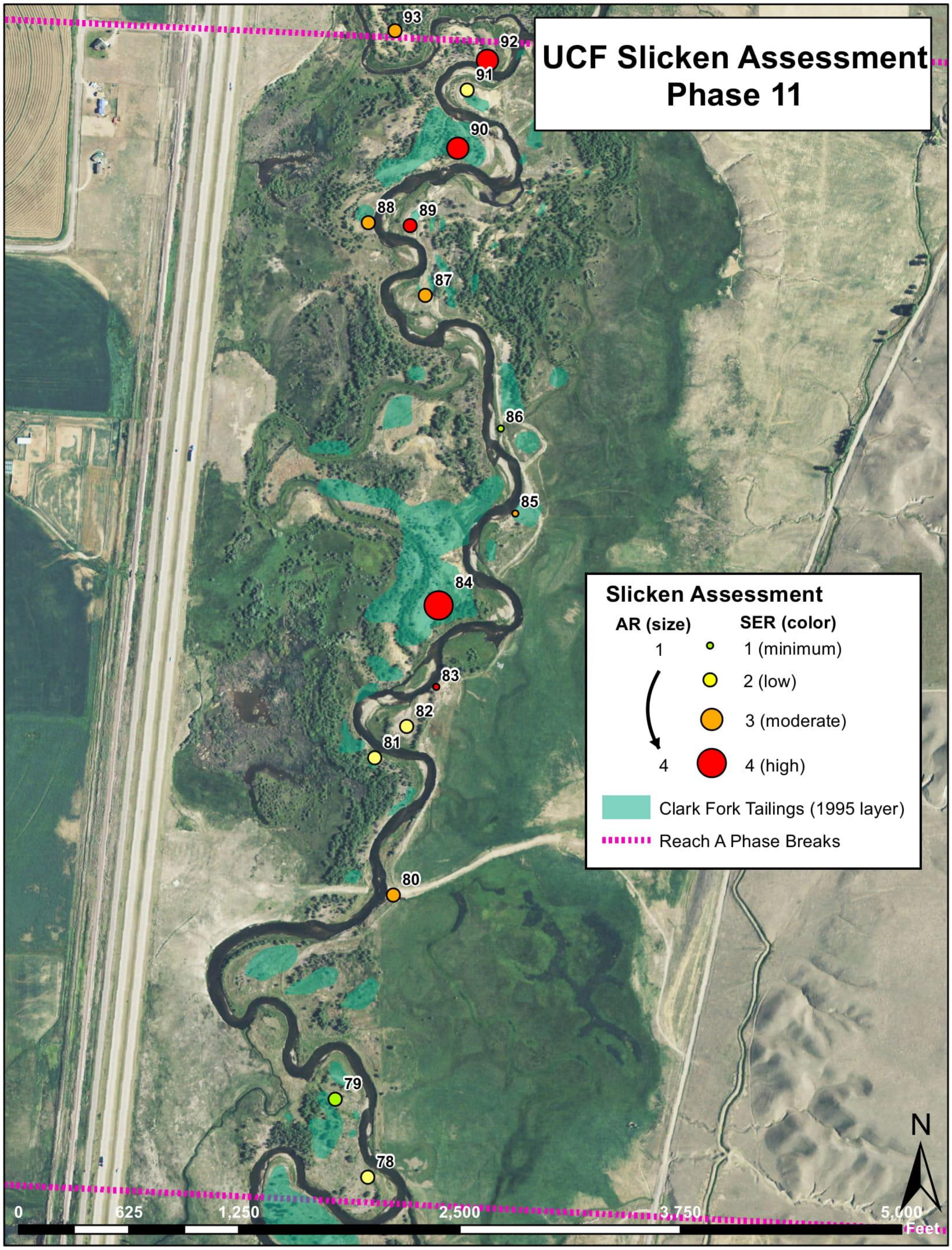
800
1,600
3,200
4,800
6,400
Feet



UCF Slicken Assessment
Phase 11
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90
88
89
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86
85
84
83
82
81
80
79
78
Slicken Assessment
AR (size)
SER (color)
1
1 (minimum)
2 (low)
3 (moderate)
4
4 (high)
Clark Fork Tailings (1995 layer)
Reach A Phase Breaks
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1,250
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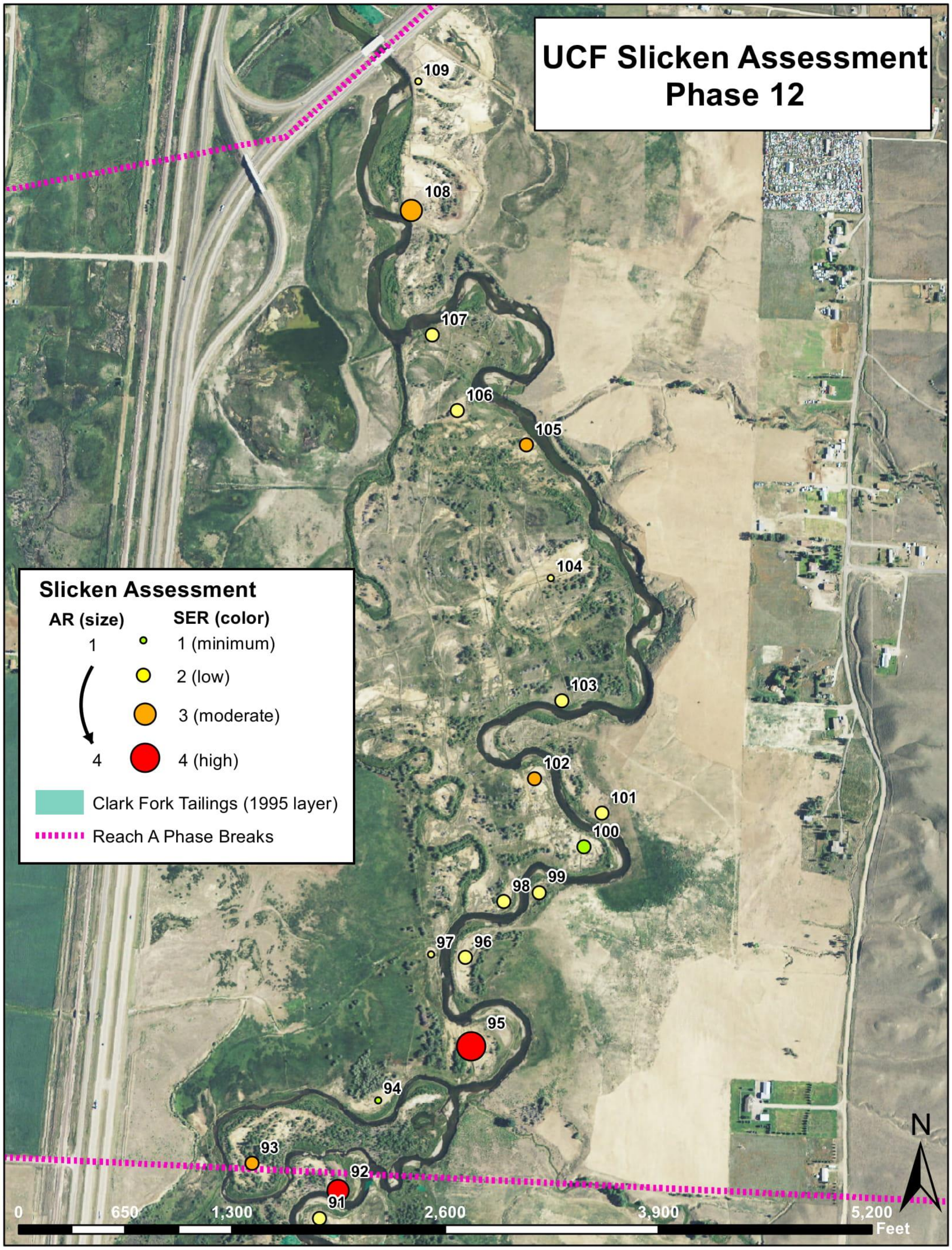
3,750
5,000
Feet


UCF Slicken Assessment
Phase 12
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108
107
106
105
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102
101
100
99
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97
96
95
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93
92
91
Slicken Assessment
AR (size)
SER (color)
1
1 (minimum)
2 (low)
3 (moderate)
4
4 (high)
Clark Fork Tailings (1995 layer)
Reach A Phase Breaks
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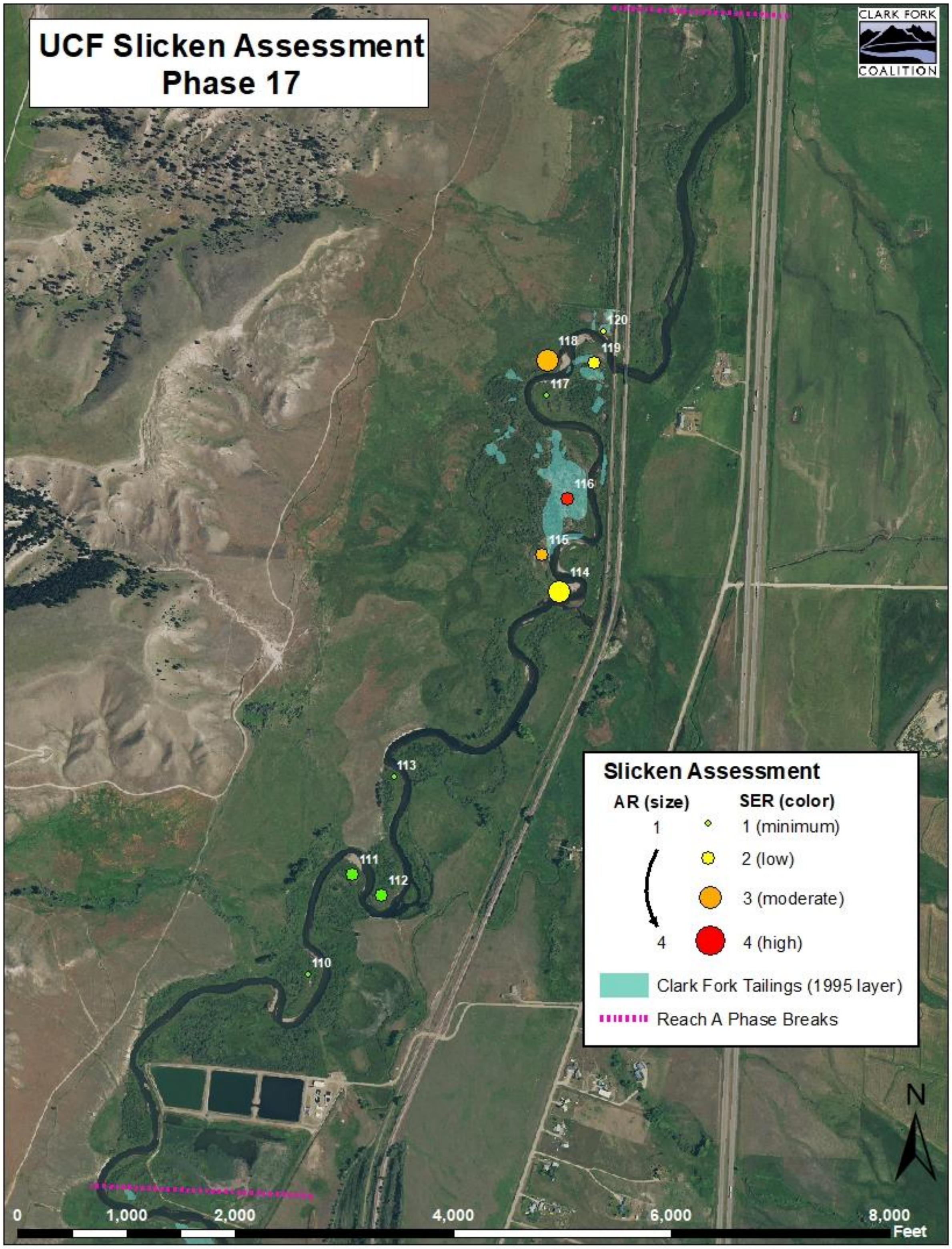
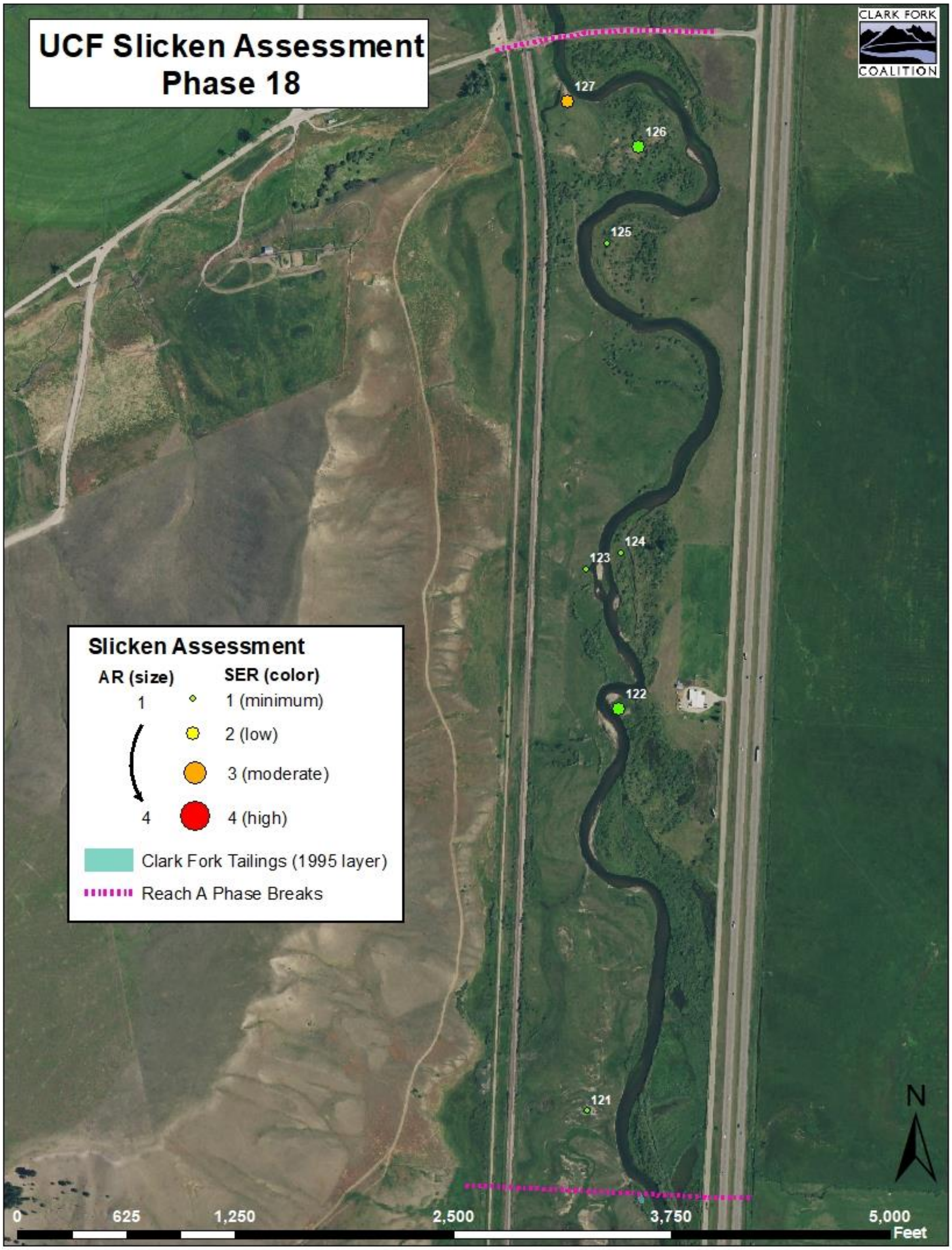
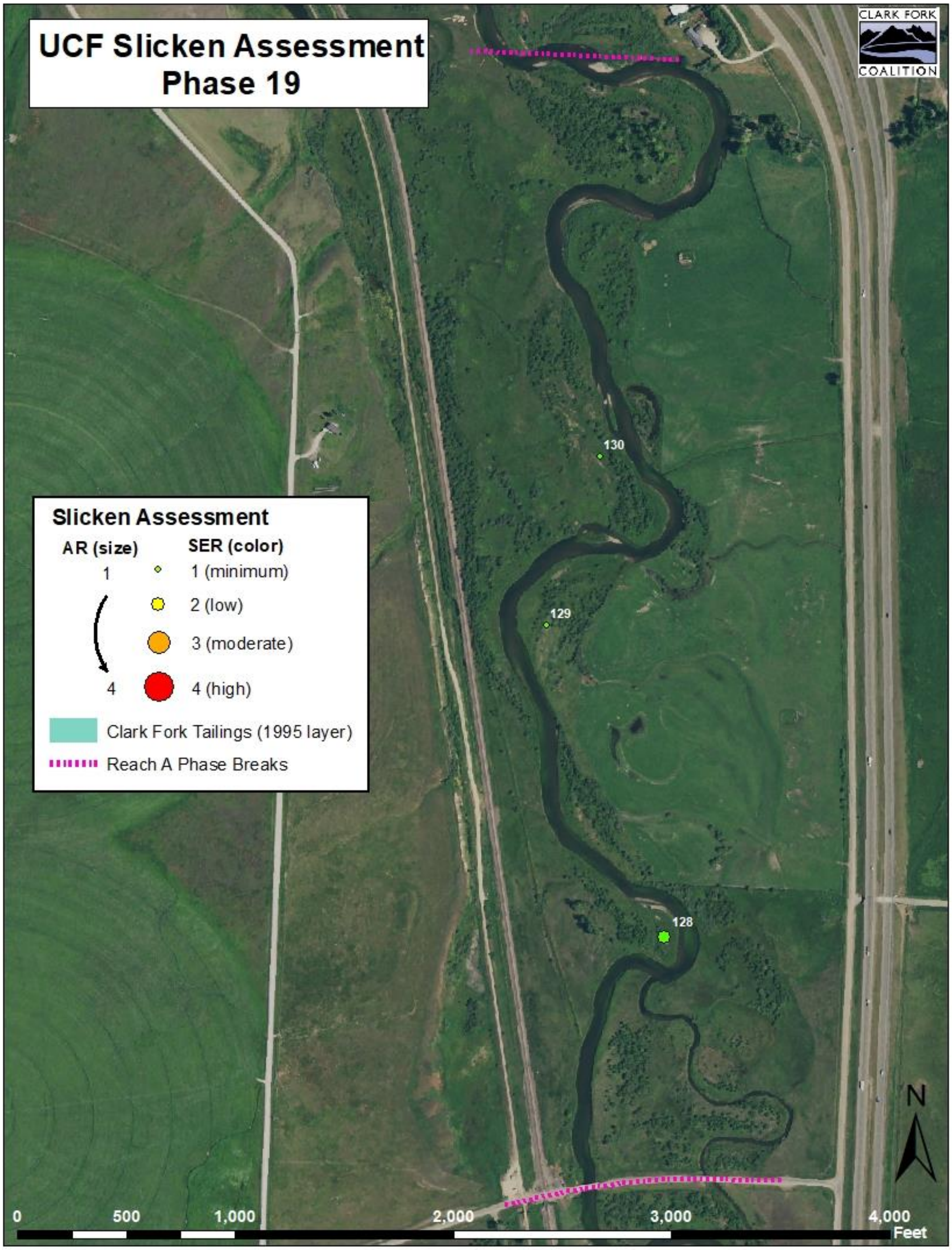
0
650
1,300
2,600
3,900
5,200
Feet

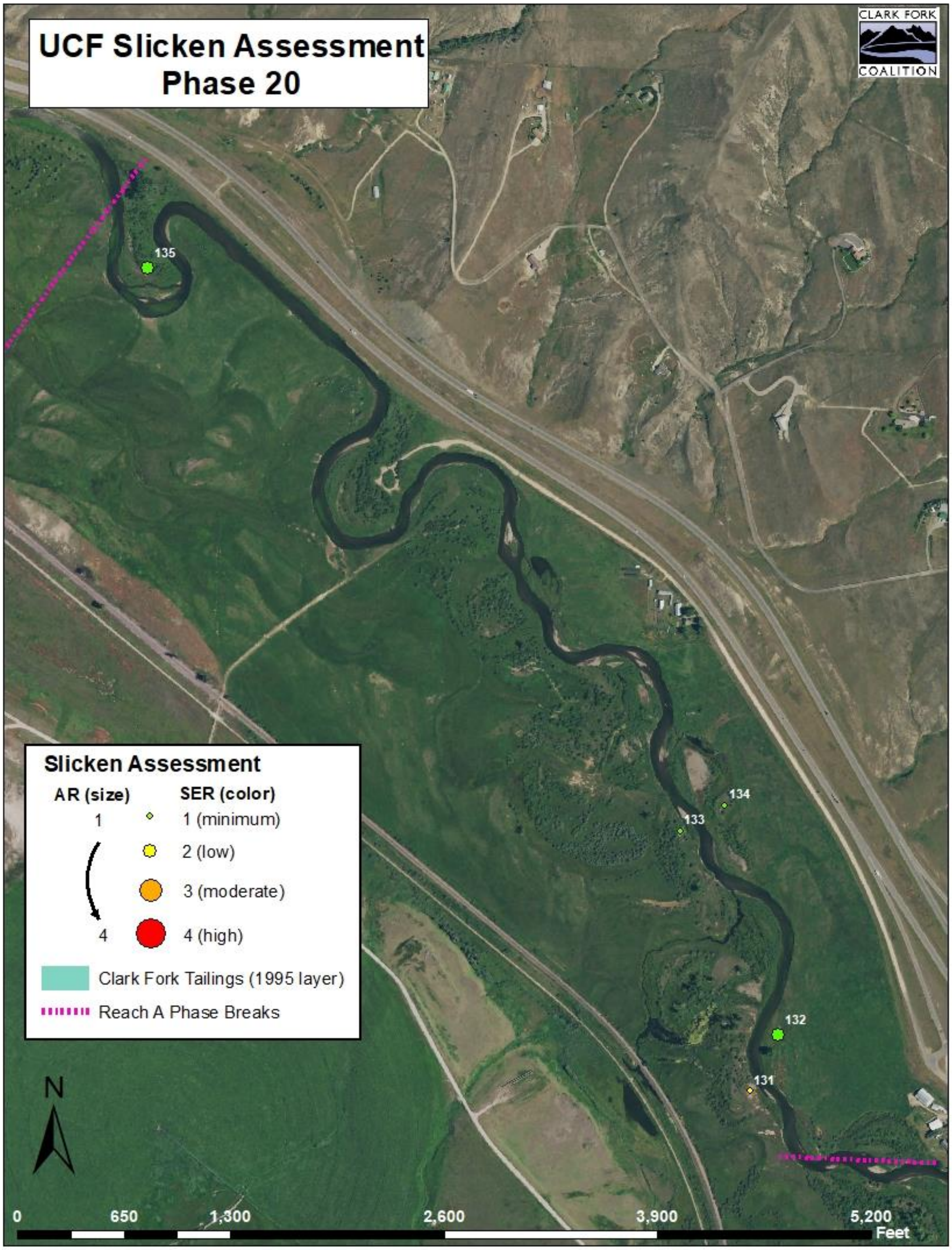
Appendix B (Slicken Maps by Phase from 2021 Assessment)

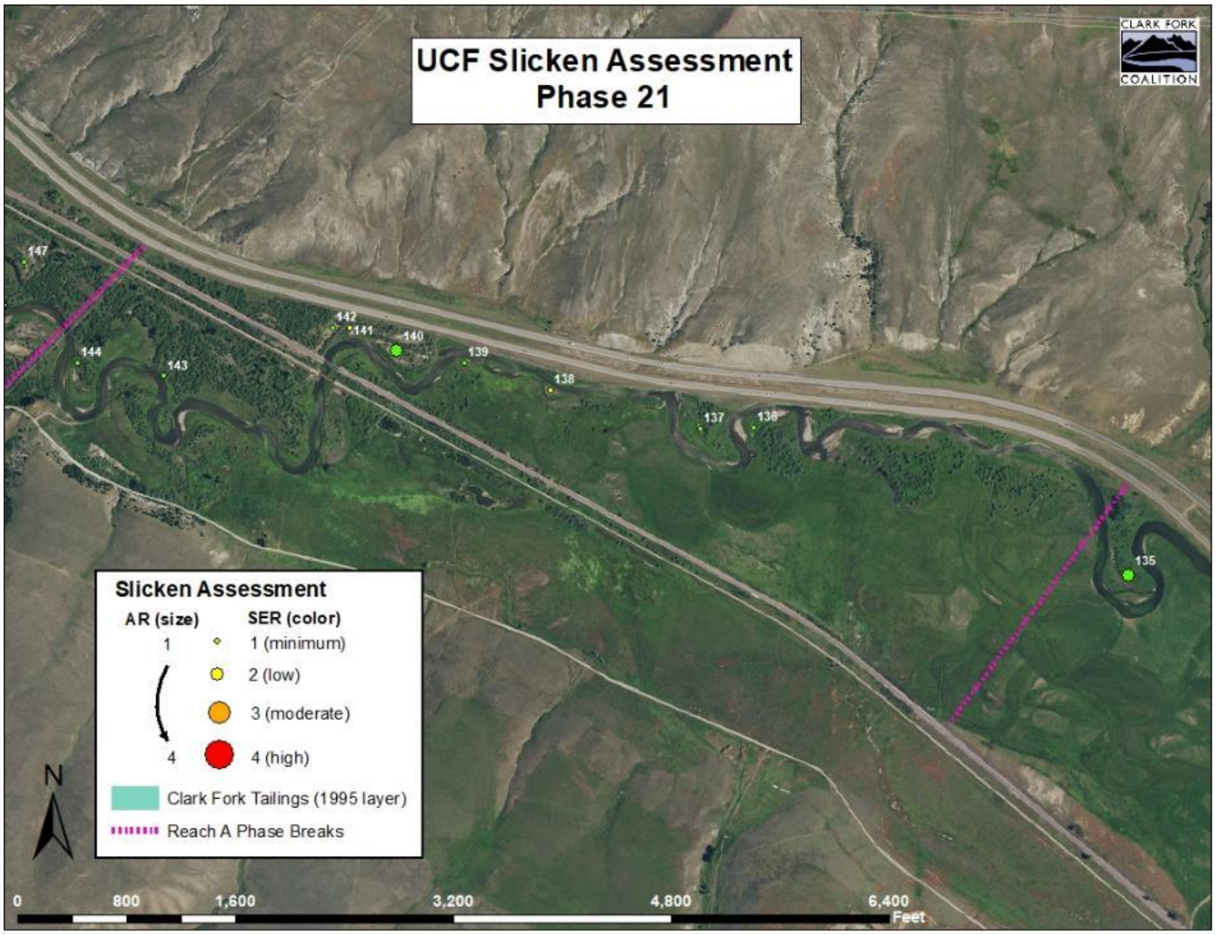


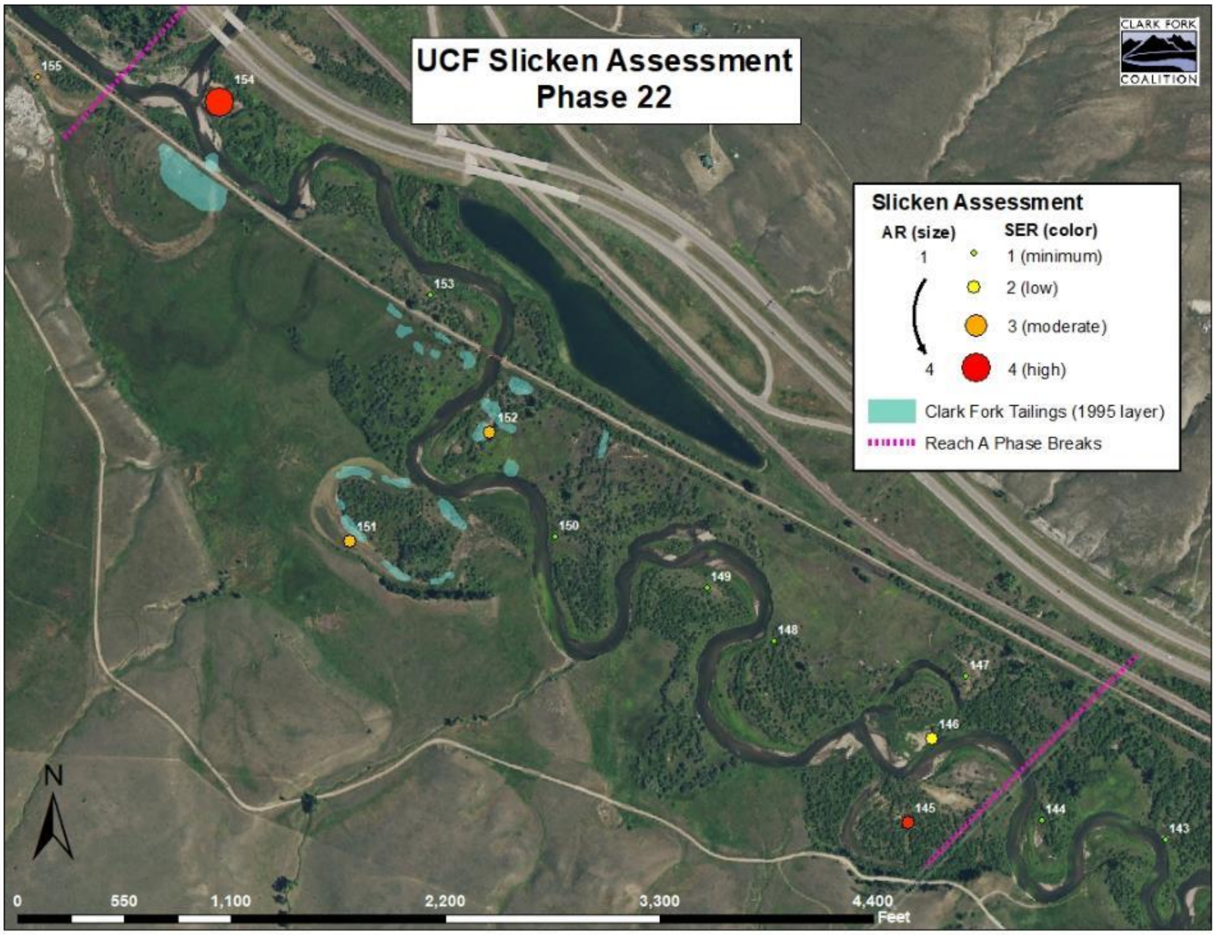

UCF Slicken Assessment
Phase 18
CLARK FORK
COALITION
127
126
125
124
123
122
121
Slicken Assessment
AR (size)
SER (color)
1
4
1 (minimum)
2 (low)
3 (moderate)
4 (high)
Clark Fork Tailings (1995 layer)
Reach A Phase Breaks
N
0
625
1,250
2,500
3,750
5,000
Feet

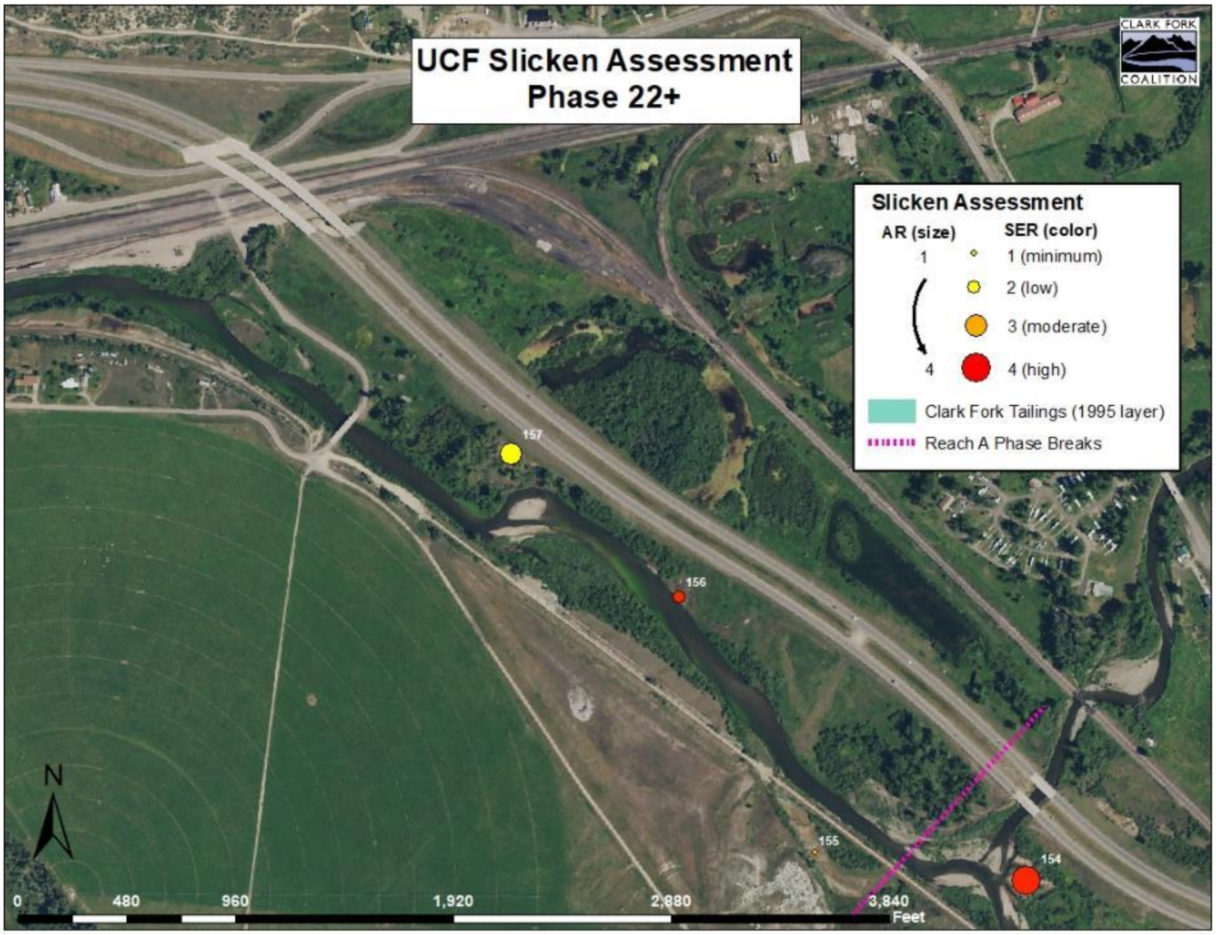


UCF Slicken Assessment
Phase 19
CLARK FORK
COALITION
130
129
128
Slicken Assessment
AR (size)
SER (color)
1
1 (minimum)
2 (low)
3 (moderate)
4
4 (high)
Clark Fork Tailings (1995 layer)
Reach A Phase Breaks
N
0
500
1,000
2,000
3,000
4,000
Feet


UCF Slicken Assessment
Phase 20
CLARK FORK
COALITION
135
134
133
132
131
Slicken Assessment
AR (size)
SER (color)
1
1 (minimum)
2 (low)
3 (moderate)
4
4 (high)
Clark Fork Tailings (1995 layer)
Reach A Phase Breaks
N
0
650
1,300
2,600
3,900
5,200
Feet


UCF Slicken Assessment
Phase 21
CLARK FORK
COALITION
147
144
143
142
141
140
139
138
137
136
135
Slicken Assessment
AR (size)
SER (color)
1
1 (minimum)
2 (low)
3 (moderate)
4
4 (high)
N
Clark Fork Tailings (1995 layer)
Reach A Phase Breaks
0
800
1,600
3,200
4,800
6,400
Feet


UCF Slicken Assessment
Phase 22
CLARK FORK
COALITION
Slicken Assessment
AR (size)
SER (color)
1
1 (minimum)
2 (low)
3 (moderate)
4
4 (high)
Clark Fork Tailings (1995 layer)
Reach A Phase Breaks
155
154
153
152
151
150
149
148
147
146
145
144
143
N
0
550
1,100
2,200
3,300
4,400
Feet


UCF Slicken Assessment
Phase 22+
CLARK FORK
COALITION
Slicken Assessment
AR (size)
SER (color)
1
1 (minimum)
2 (low)
3 (moderate)
4
4 (high)
Clark Fork Tailings (1995 layer)
Reach A Phase Breaks
157
156
155
154
N
0
480
960
1,920
2,880
3,840
Feet