Upper Clark Fork Slicken Assessment Report

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Slicken Assessment Report

Purpose & Background

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. Slickens are contaminated patches of bare ground devoid of vegetation due to heavy metal contamination dating back to the early 20th century (Figure 1). 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 over the past several years (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.

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.

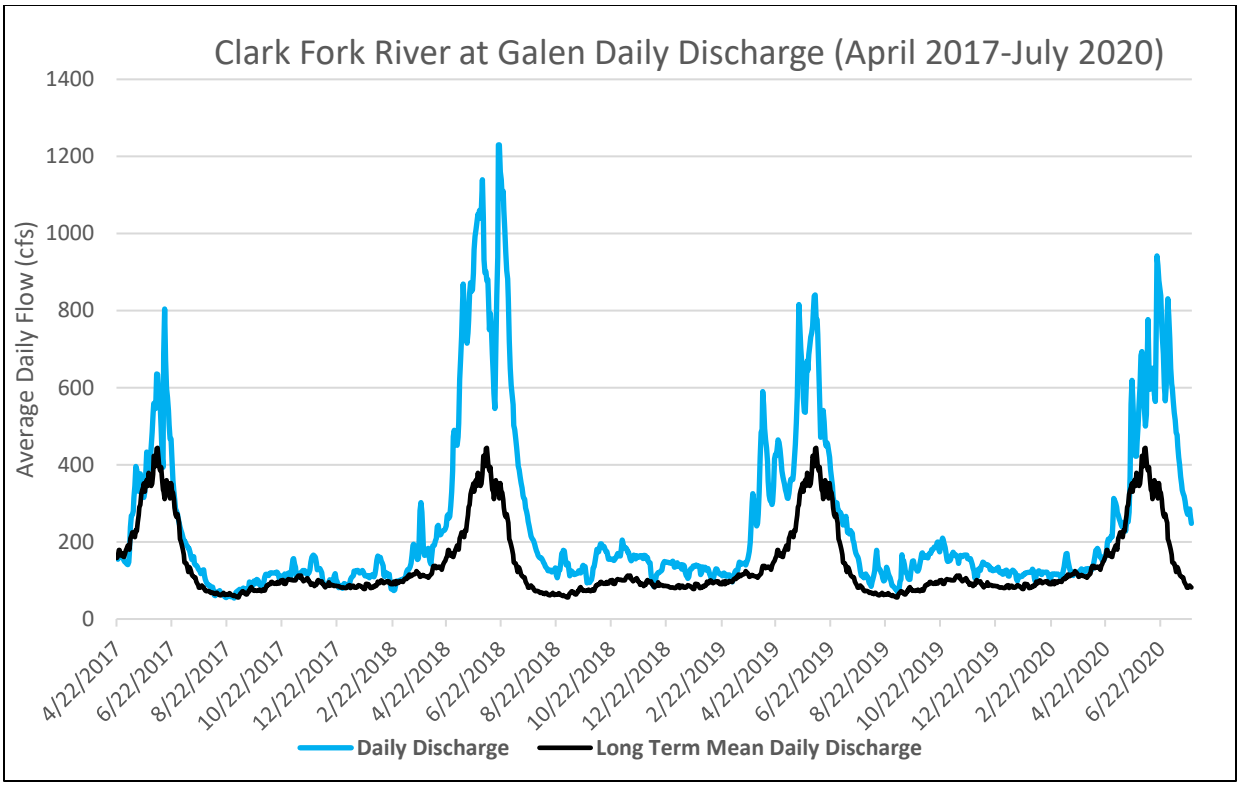


Figure 2. Median daily streamflow values for the USGS stream gage station Clark Fork River at Galen (2017-present). Note the large number of days flows exceeded the long term median daily value (i.e. the blue line is higher than the black line). Beginning in 2017, the Clark Fork River gage at Galen has seen annual peak flows well over the long term average of 460 cubic feet per second (cfs).

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. The slicken assessment involved documenting the location and relative risk of all the major slickens proximate to the Clark Fork River and was completed over a series of days in May and June 2020 (see Table 1). The report below presents the findings of this 2020 assessment.

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

Table 1. Dates and phases floated during the slicken assessment and average daily flows at Galen. June 18th recorded the highest average daily flow at Galen for 2020 (year-to-date).

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.

Survey summary

We surveyed at total of 109 slickens over 19.3 river miles between Perkins Lane and Arrowstone Park. A total of 50 slickens were ranked as 3 or 4 for surface erosion risk and 26 slickens were ranked as 3 or 4 for avulsion risk (Table 2). We found 32 slickens with hazard indexes ≥ 10. Most of these high HI slickens are located in phases 3A, 3B, and phases 9-12 (Table 2; see Figure 3 for phase locations).

Table 2. Number of slickens and slicken risk scores by phase. A total of 109 Slickens were assessed.

		Surface erosion risk				Avulsion risk				
Phase	**Total Number of slickens**	**1**	**2**	**3**	**4**	**1**	**2**	**3**	**4**	**Slickens with hazard index ≥ 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
Total	**109**	**16**	**43**	**28**	**22**	**17**	**66**	**19**	**7**	**32**

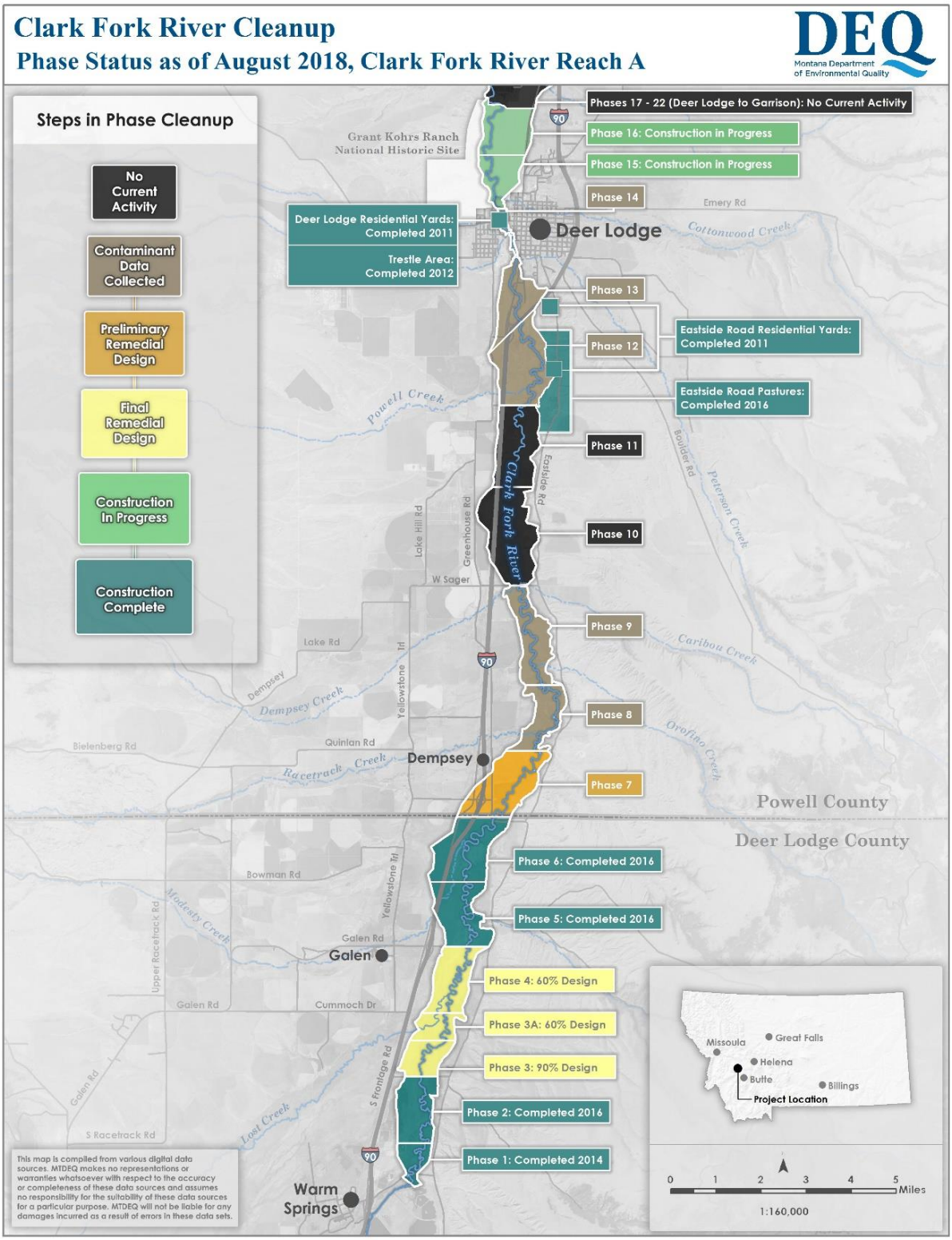


Figure 3. Status and location of cleanup phases on the Upper Clark Fork River south of Deer Lodge. Map credit: MT DEQ.

General Observations

Meander tabs

Although the condition of the slickens varied considerably, there were some consistent trends noted, 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 head-cutting was noted at the upstream end of the tab with significant down-cutting observed 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, contaminated shallow surface water was noted 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 5 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, there was also clear evidence of contaminated groundwater interaction. At several of the severely contaminated slickens, teal-stained water was noted 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. 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.

Berms

Berms were constructed by ARCO in the 1980s along several reaches of the upper Clark Fork River to help prevent surface runoff events on slickens[1]. 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 7). The CFC first documented major berm failure at slicken #10 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 June 2020 is over 30 feet wide. Berm failure not only increases avulsion hazard, it also may increase the likelihood of surface runoff events. Slicken #5 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 on slicken #5, releasing contaminated water directly into the Clark Fork.

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

[1] 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.

Surface erosion risks

The phytotoxic[2] 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 observed mineral salts forming on the surface of slickens. These salts wick to the surface as slickens dry out can be colored blue, green, white, or grey depending on the chemical composition. These salts are easily dissolved in water and are an acute risk to aquatic life during rain events.

Figure 8. Ponded water on slicken #6.

[2] 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 9. Clear flow path leading from slicken #83 (a small but severe slicken located 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. 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. 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 undoubtably 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).

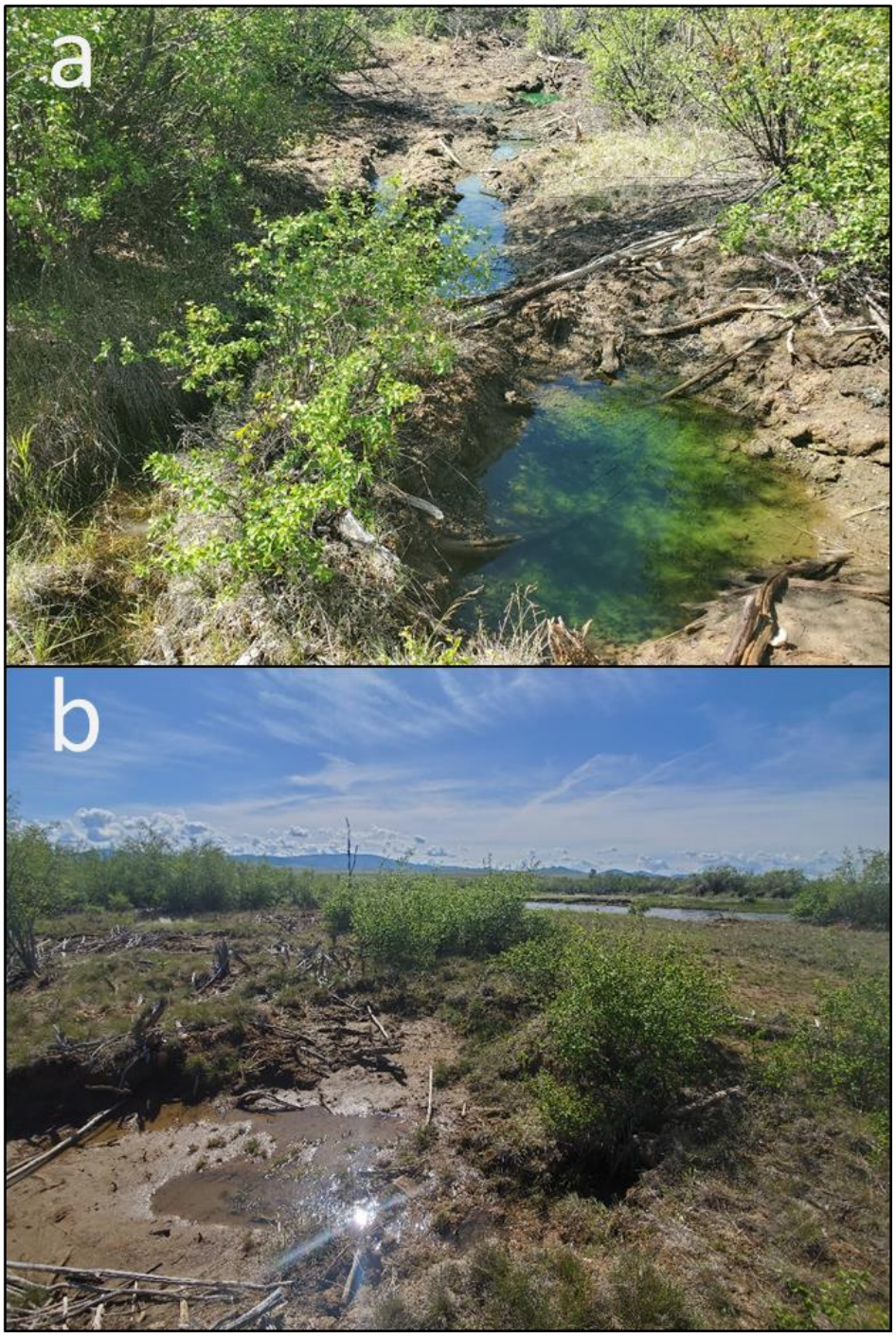


Figure 10. The photos above show an avulsion channel that has formed from surface runoff and erosion of slicken #95 (a large, high risk slicken between Sager Lane and Deer Lodge). Photo “a” is on the lower, downstream portion of the meander tab, photo “b” was taken at the top of the tab. This channel 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.

Synopsis and Next Steps

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 may cause increased toxicity to aquatic life. Rainstorms that mobilize slicken material have the potential to have 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.

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 less than 50 trout per mile. Similar streams that 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 4 years. The lack of fish in the UCFR has not gone unnoticed by local anglers, who often report poor fishing results in the area. The combination of low trout numbers, the 2019 fish kill, and recent evidence of large-scale contaminant transport in the upper Clark Fork are likely related.

Cleanup of the contaminated UCFR floodplain is underway in some areas. However, it could be many years 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 the past 3 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 be at least partially investigated through targeted sediment sampling and testing in areas that are suspected 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 contaminated 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.

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.

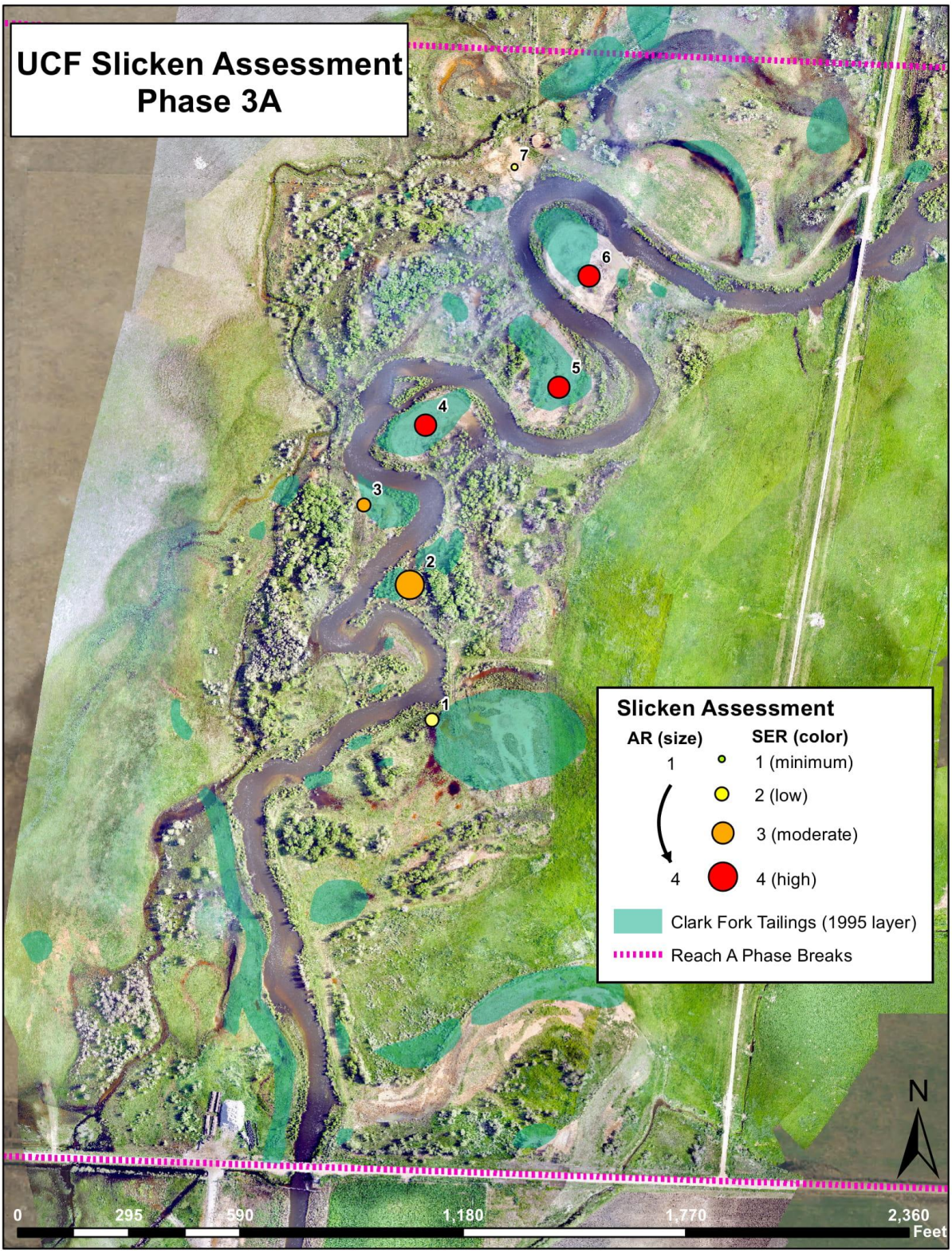
ID#71, **AR=3**, (SER=3): Evidence that river was flowing through slicken, but not at the time of the survey.

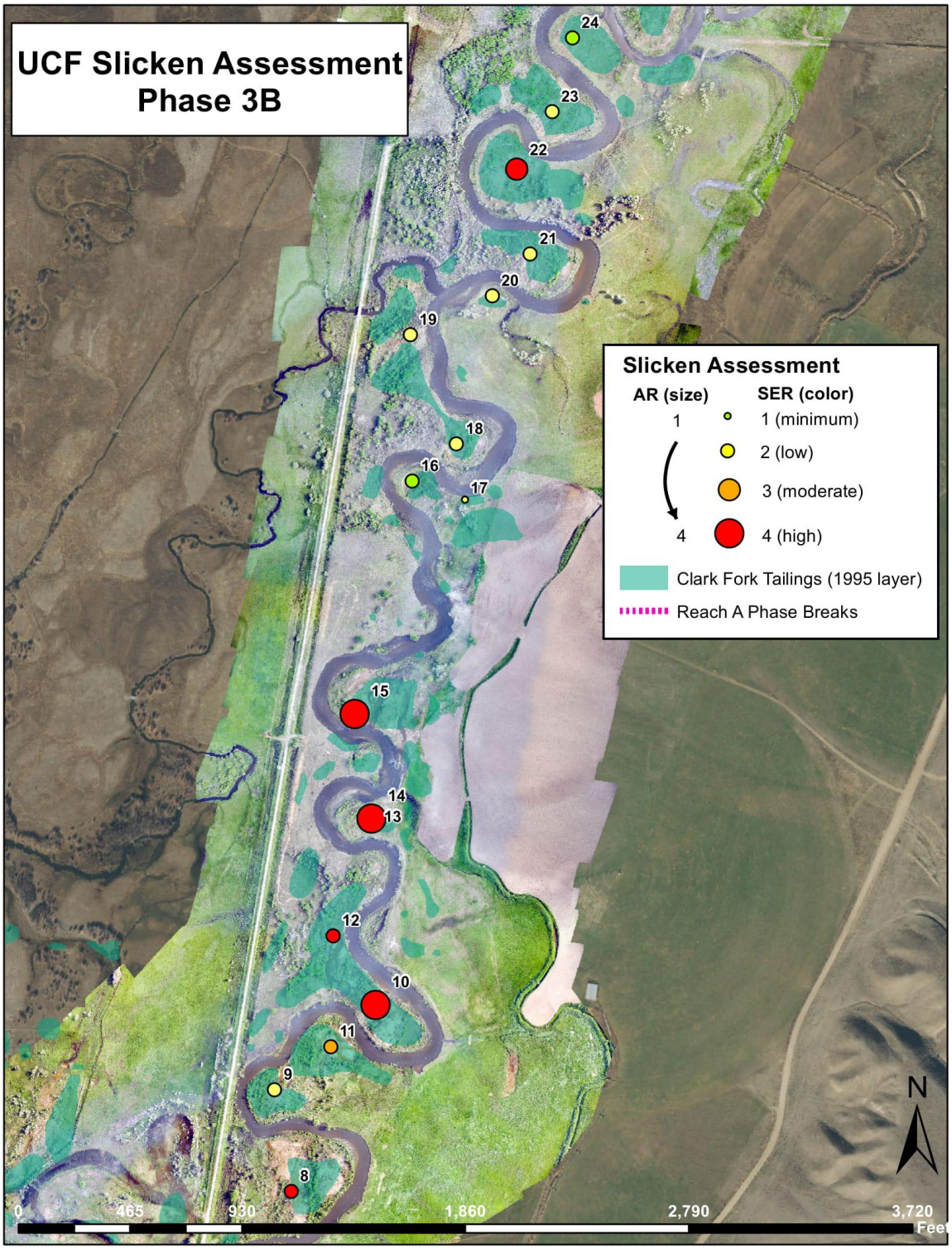
Appendix A (Hazard Risk Examples-Class 1 & 2)

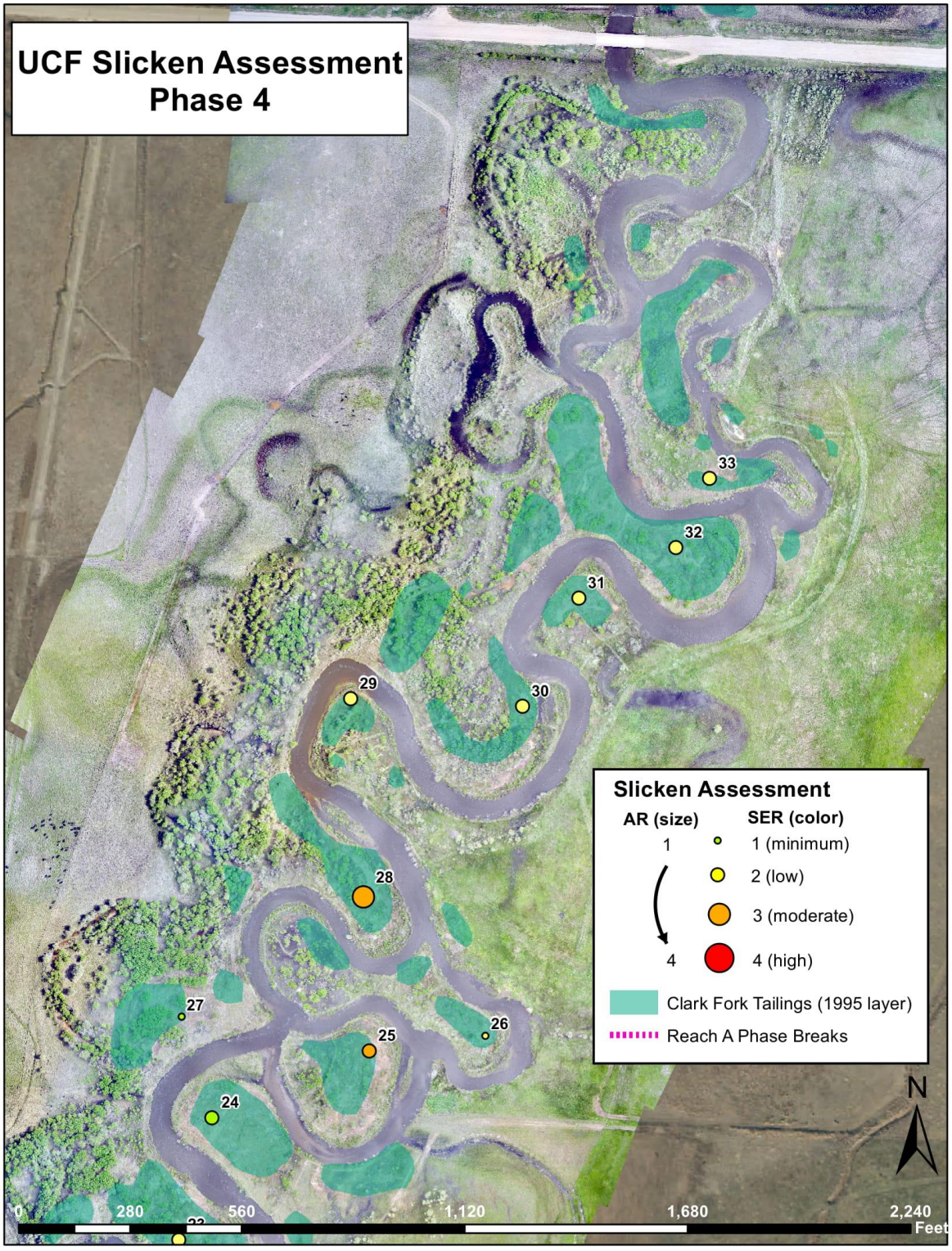
ID#31, **SER=2, AR=2:** A good example of a berm keeping contamination from contacting the river.

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

Appendix B (Slicken Maps by Phase)




UCF Slicken Assessment
Phase 3B
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
24
23
22
21
20
19
18
16
17
15
14
13
12
10
11
9
8
N
0
465
930
1,860
2,790
3,720
Feet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Phase 4
33
32
31
29
30
28
27
26
25
24
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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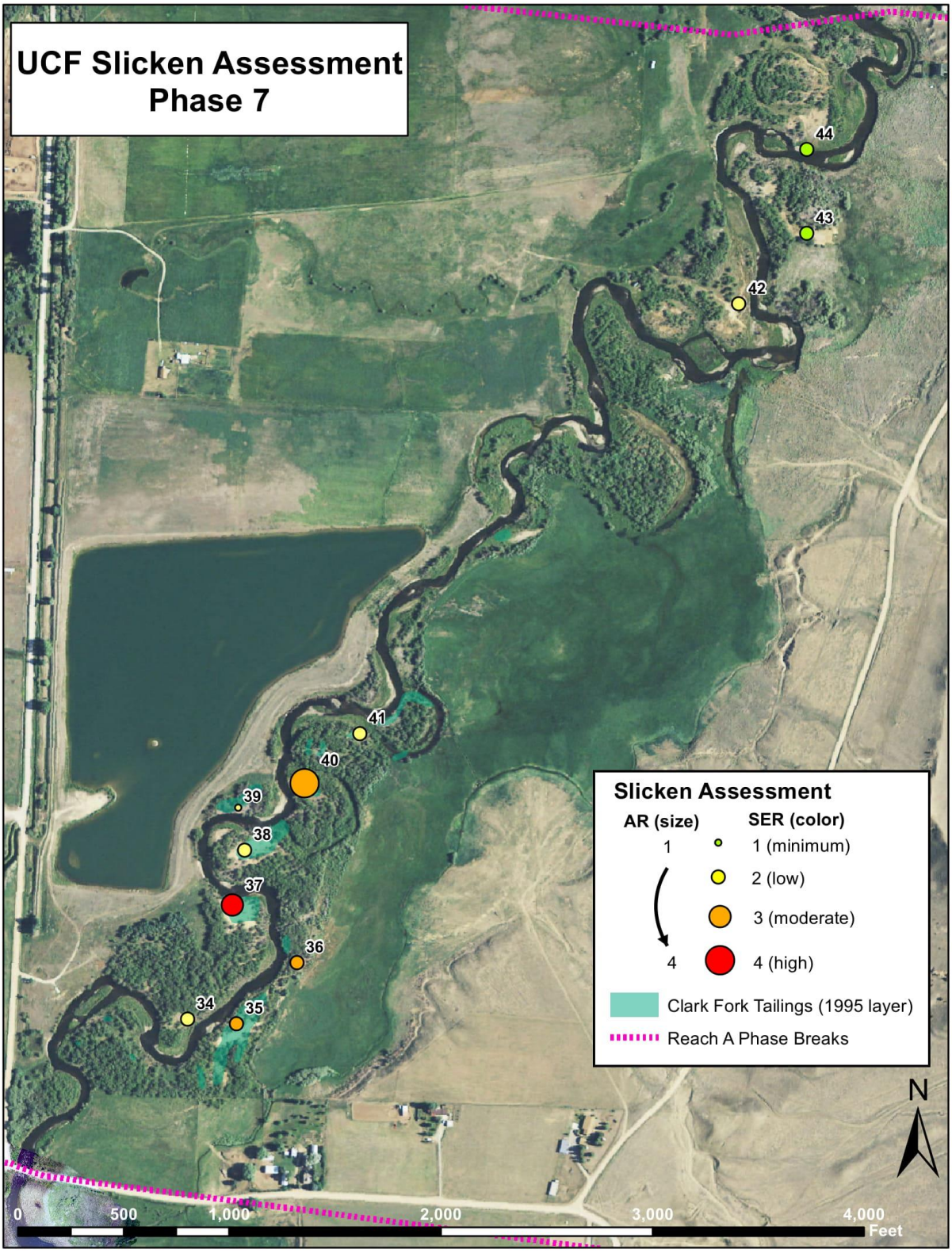
0
280
560
1,120
1,680
2,240
Feet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Phase 7
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43
42
41
40
39
38
37
36
35
34
Slicken Assessment
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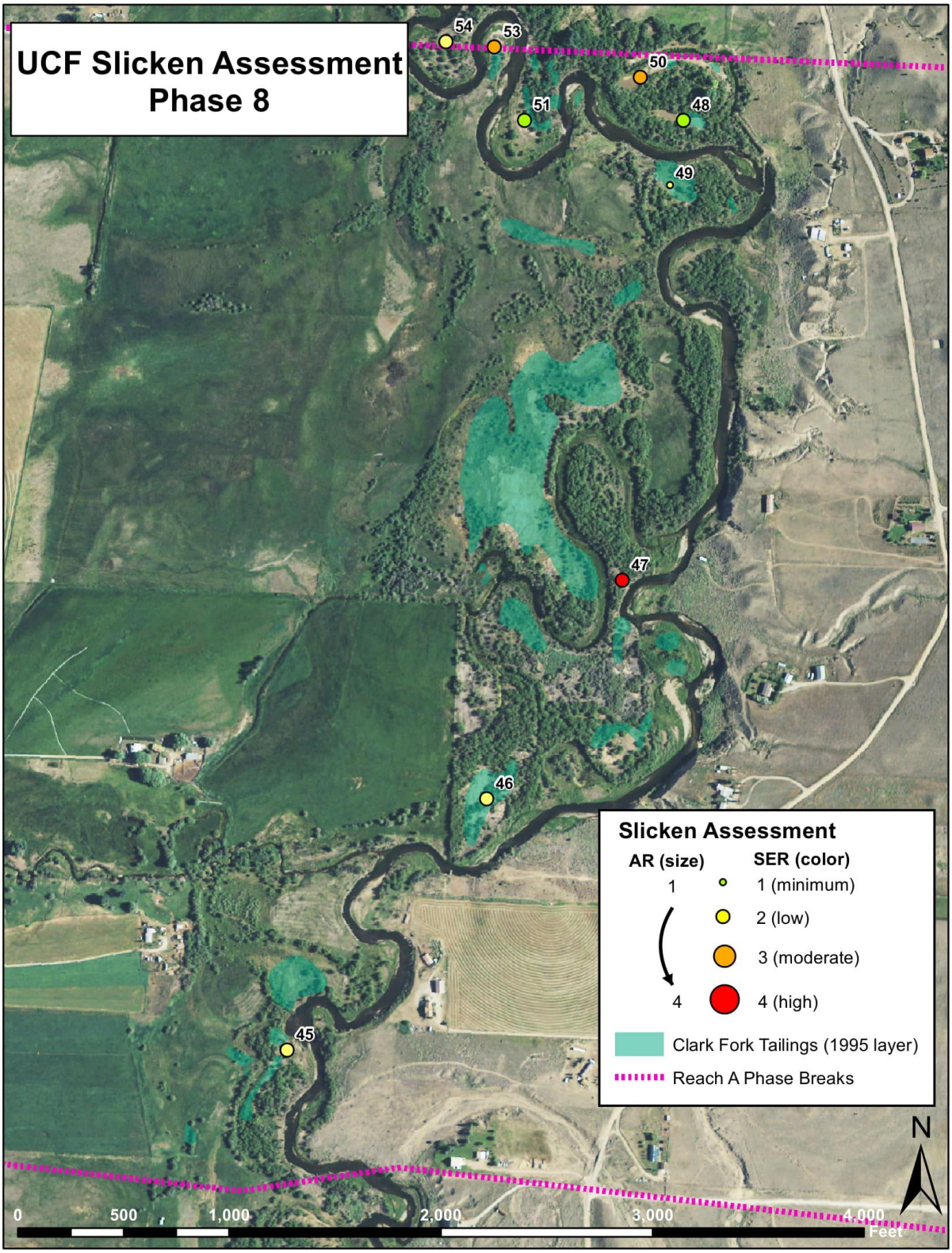
SER (color)
1
1 (minimum)
2 (low)
3 (moderate)
4
4 (high)
Clark Fork Tailings (1995 layer)
Reach A Phase Breaks
N
0
500
1,000
2,000
3,000
4,000
Feet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Phase 8
54
53
50
51
48
49
47
46
45
Slicken Assessment
AR (size)
SER (color)
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2 (low)
3 (moderate)
4
4 (high)
Clark Fork Tailings (1995 layer)
Reach A Phase Breaks
N
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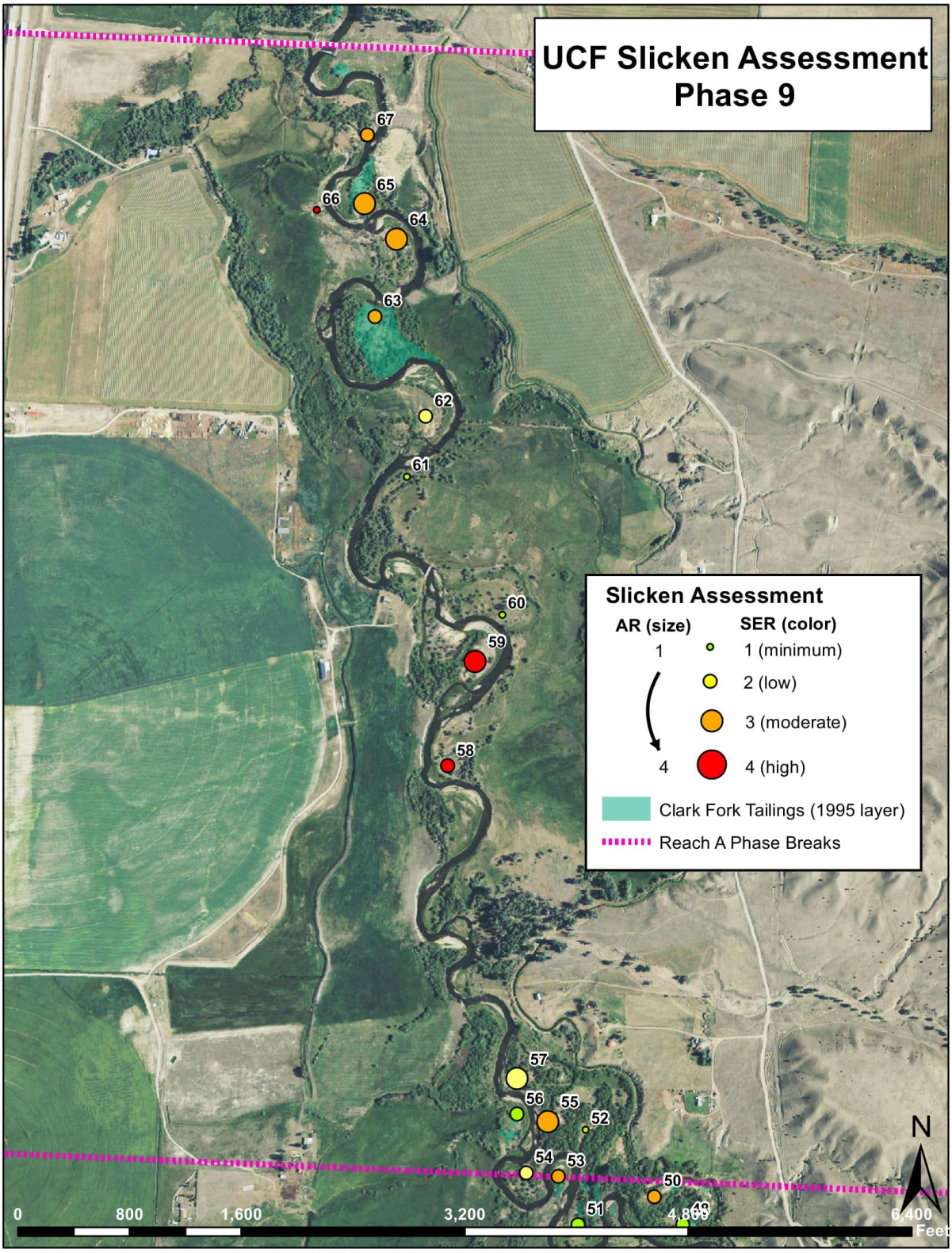
500
1,000
2,000
3,000
4,000
Feet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Phase 9
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66
64
63
62
61
60
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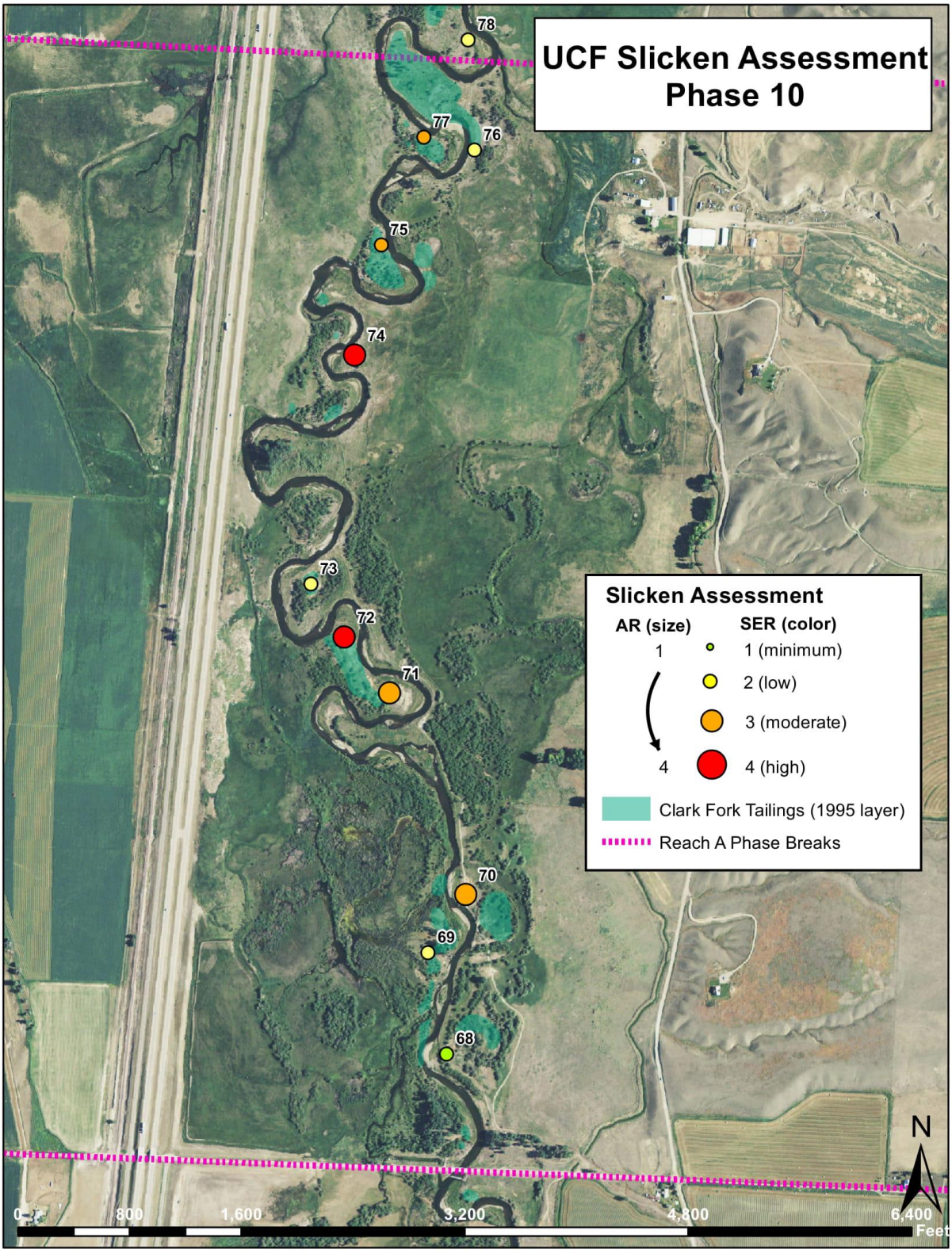
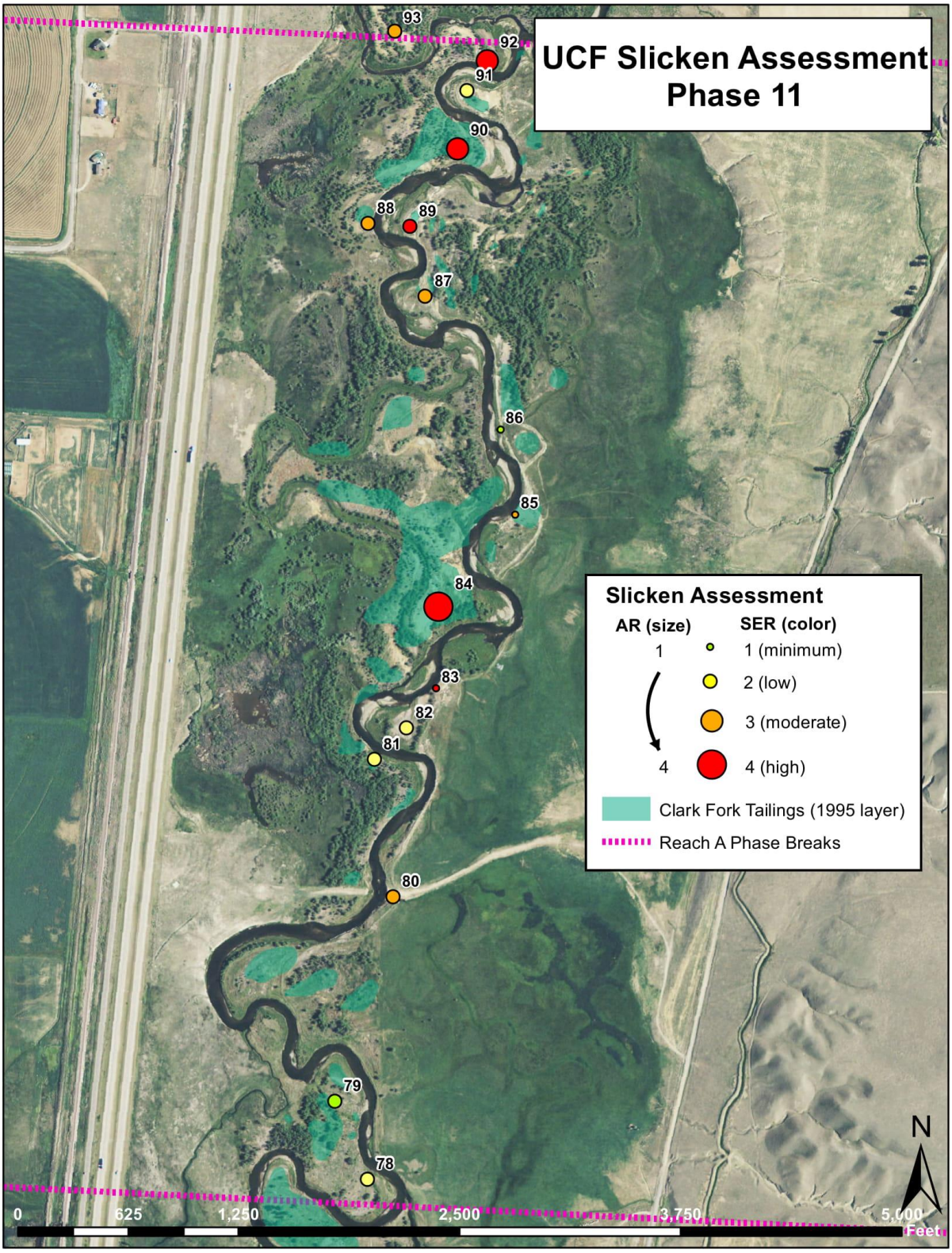
56
55
52
54
53
50
51
Slicken Assessment
AR (size)
SER (color)
1
1 (minimum)
2 (low)
3 (moderate)
4
4 (high)
Clark Fork Tailings (1995 layer)
Reach A Phase Breaks
N
0
800
1,600
3,200
6,400
Feet


UCF Slicken Assessment
Phase 10
78
77
76
75
74
73
72
71
70
69
68
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
800
1,600
3,200
4,800
6,400
Feet


UCF Slicken Assessment
Phase 11
93
92
91
90
88
89
87
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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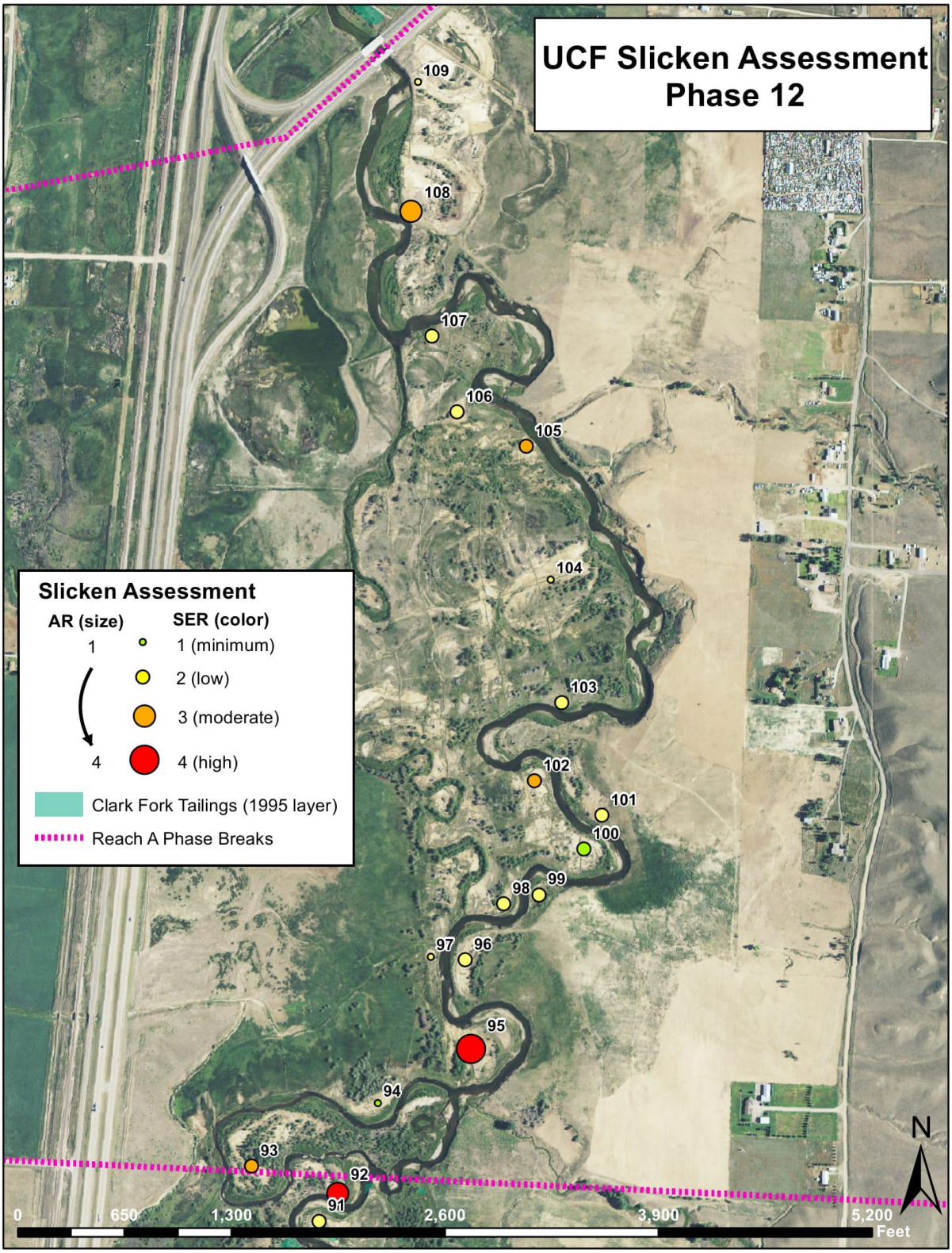
1,250
2,500
3,750
5,000
Feet


UCF Slicken Assessment
Phase 12
109
108
107
106
105
104
103
102
101
100
99
98
97
96
95
94
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
N
0
650
1,300
2,600
3,900
5,200
Feet