Acidity Neutralization Cell (ANC) Pretreatment for BCR Influent

Crystal and Bullion Mines, Basin Mining Area Superfund Site, Montana

Field Pilot and Laboratory Column Treatability Studies

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Passive Treatment Overview

- Most PTS targeting trace metal removal are multi-component (staged) systems built around one or more main biochemical reactor (BCR) unit.
- The BCR media is designed to support high levels of anaerobic microbial activity over an extended timeframe (>10 years)
- Metal removal is through both biological and abiotic removal mechanisms; however, the media is prone to plugging by oxyhydroxides due to removal of hydrolysable metals (e.g., ferric iron and aluminum)
- Where mine drainage is highly acidic with a significant amount of hydrolyzable metals, an acid neutralization cell (ANC) containing media with high neutralization capacity may be used as pre-treatment in front of a main BCR unit.

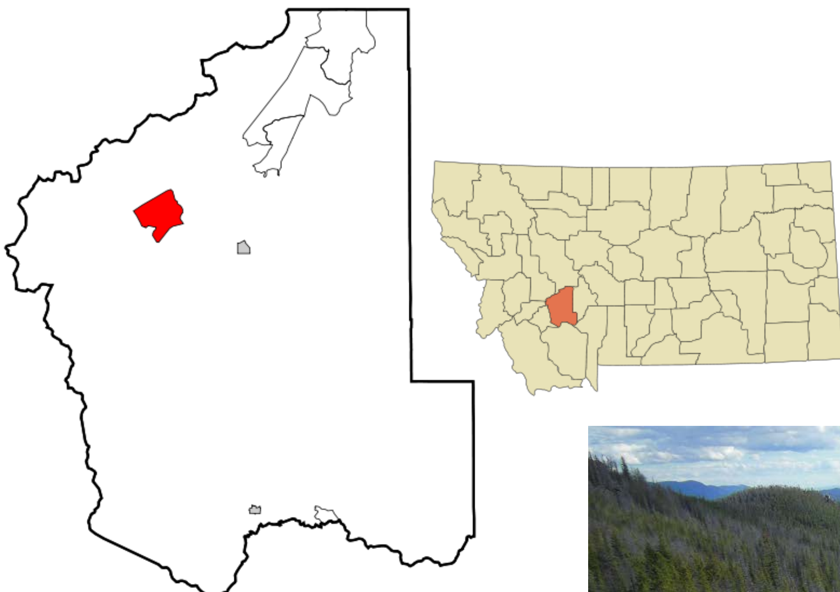
Passive Treatment Overview

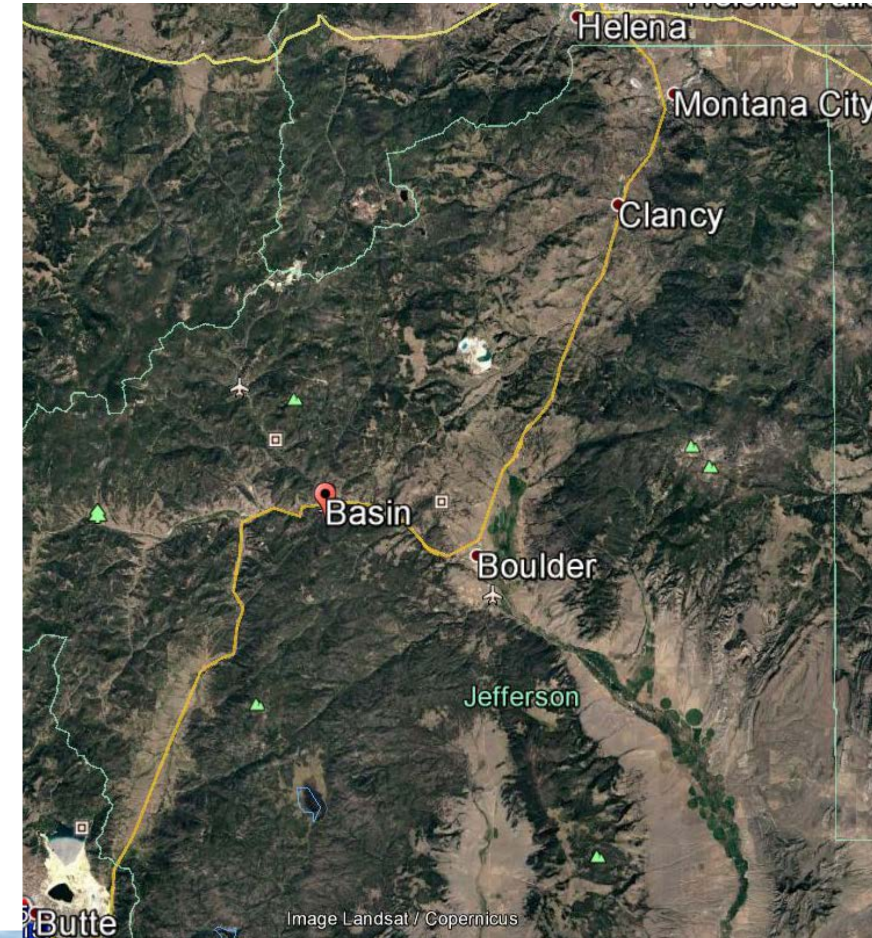
- ANC is used as a pre-treatment step in passive treatment systems to lower the overall influent acidity, remove hydrolyzable metals, and raise the pH.
- Generally small vertical- or horizontal-flow basins filled with organic materials and a relatively high proportion of limestone.
- The organic substrate in this media mix is used primarily as a matrix support for even distribution of sand-sized limestone, rather than to create high reducing conditions.
- The main function of an ANC is abiotic limestone dissolution and acid neutralization.
- ANCs are not designed for an extended life cycle (for example, decades), and require periodic media replacement (for example, 2-5 years, depending on size and load).
- Consequently, they are best configured to allow easy media change-out.

Demonstration Site

Location

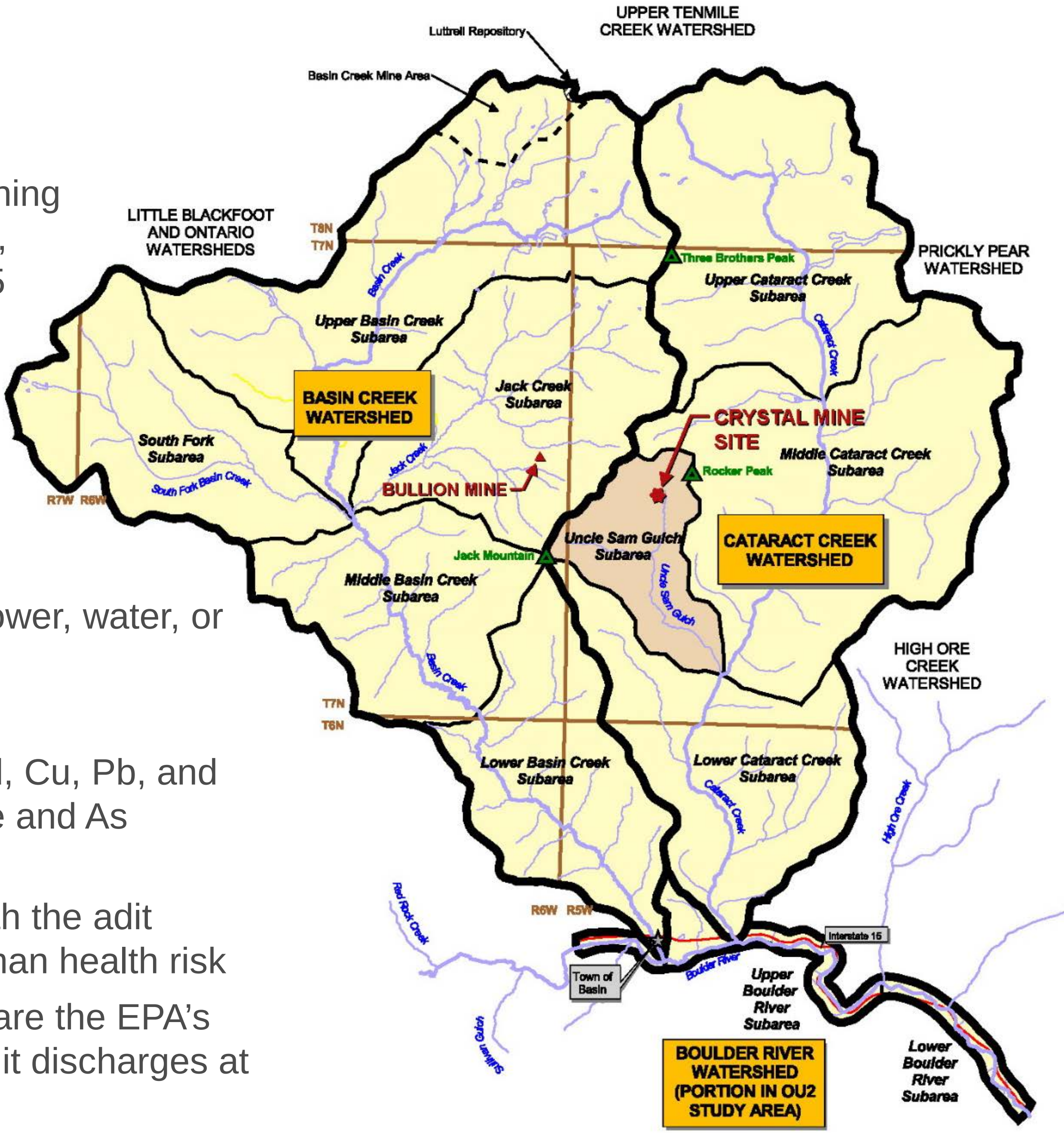
- The Crystal & Bullion Mine sites are abandoned mines located in Jefferson County, Montana near the town of Basin, between Helena and Butte.





Key Features

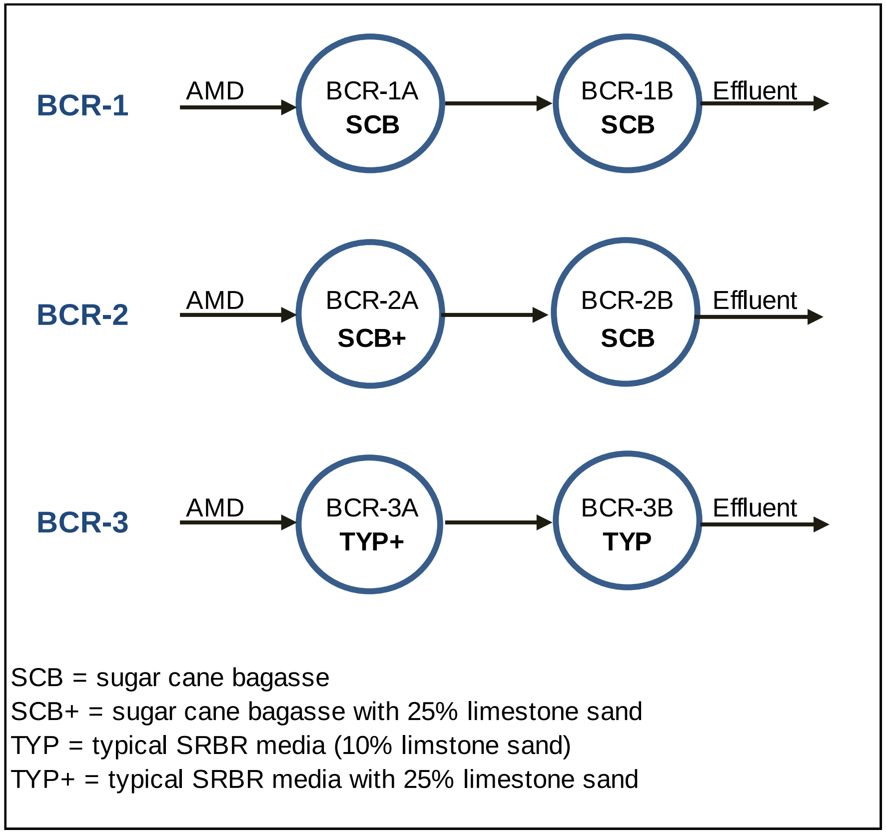
- Surface and underground mining (including gold, silver, copper, lead, and zinc) between 1885 and 1983.
- remote location, at high elevation (7,500 to 8,000 ft amsl); very difficult to access in winter (only by snow machine).
- not supplied with electrical power, water, or other utilities.
- The adit discharge is acidic
- COCs are Al, As (Bullion), Cd, Cu, Pb, and Zn; also contains elevated Fe and As (Crystal)
- Ecological risk associated with the adit discharge, but little or no human health risk
- Passive Treatment Systems are the EPA's preferred remedies for the adit discharges at the Crystal and Bullion Sites



Proof of Concept

Field Pilot “Barrel” and Laboratory Column Studies

Experimental Design – Field Pilot Barrel Study



- Started June 26, 2014 and ran continuously for nearly 15 weeks; shut down and dismantled on October 7, 2014

- Conducted as “Proof of Concept” to demonstrate ANC – BCR design
- Three, two-stage, pilot-scale, treatment systems operated in parallel
- Gravity flow from mine portal to collection sump
- Peristaltic pump to deliver controlled-flow AMD to each array
- Flow by gravity once delivered to system
- Gravity discharge back to Uncle Sam Gulch Creek

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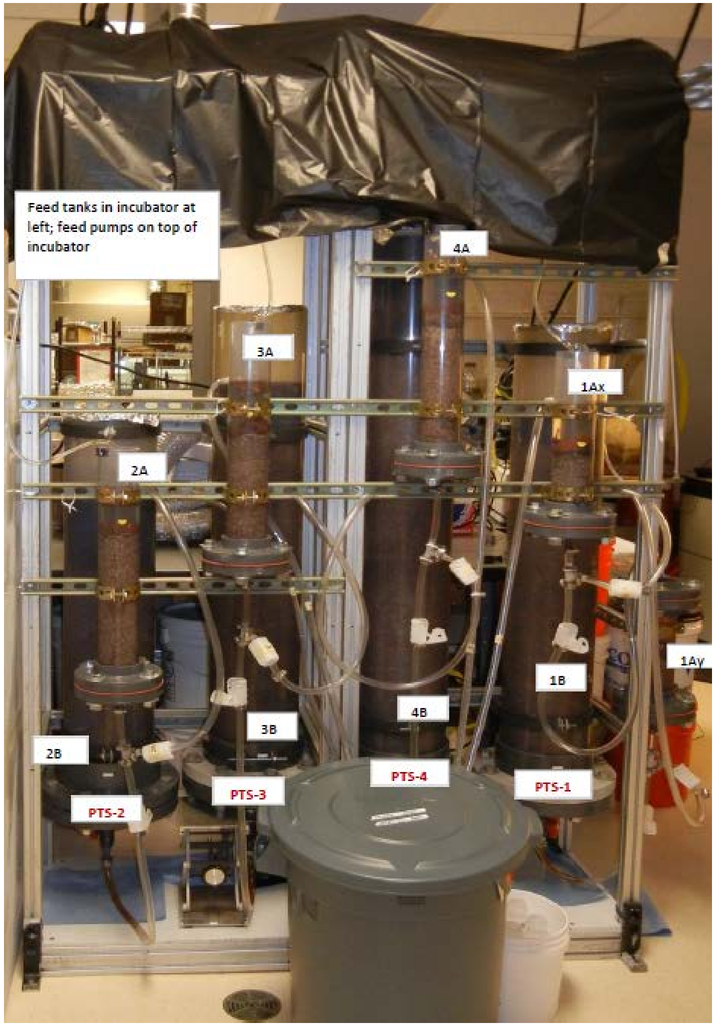
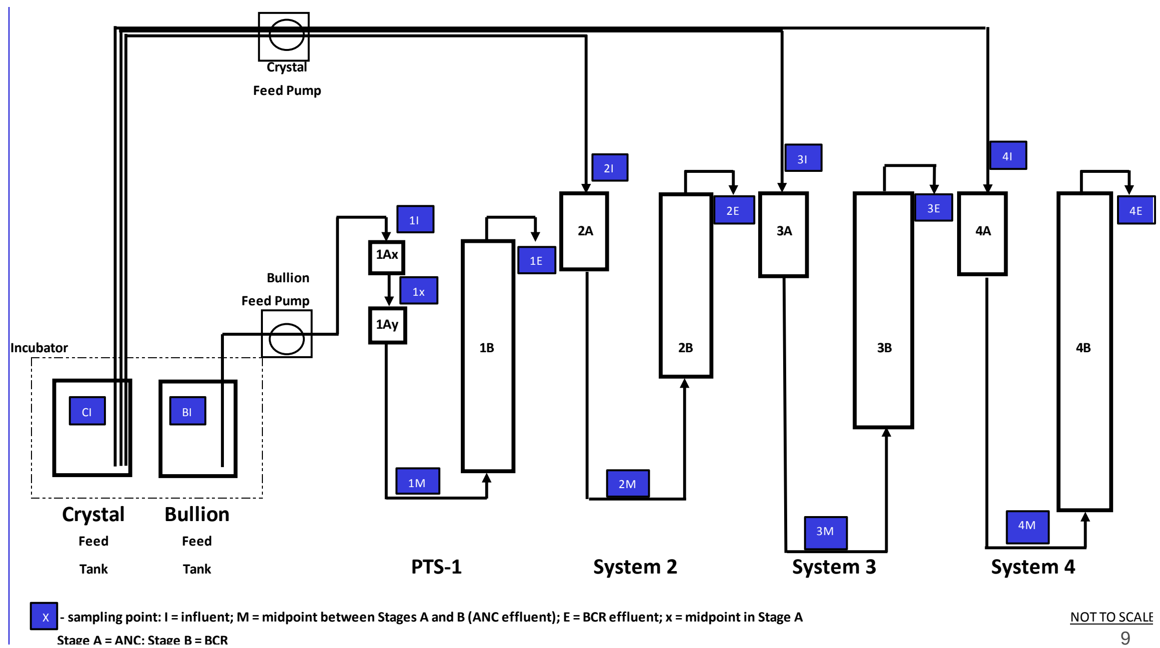
Experimental Design – Lab Column Study



- Conducted to refine from "proof of concept" to develop design parameters (i.e., optimize HRT)
- Two-stage column systems representing the first two stages of a PTS (i.e., ANC & BCR)
- Four continuous-flow column systems operated in parallel using synthetic Bullion and Crystal Mine water as influent.
- Operated over a range of HRTs.



Experimental Design – Lab Column Study

Column Testing Conditions

		Influent	Trial A HRT				Trial B HRT			
System ID	Influent Water	Flow [mL/min]	ANC1 [hours]	ANC2 [hours]	ANC total [hours]	BCR [days]	ANC1 [hours]	ANC2 [hours]	ANC total [hours]	BCR [days]
PTS-1	Bullion	3	3	3	6	5	1.5	1.5	3	2.5
PTS-2	Crystal	6	6	N/A	6	3	3	N/A	3	1.5
PTS-3	Crystal	6	6	N/A	6	5	3	N/A	3	2.5
PTS-4	Crystal	6	6	N/A	6	7	Discontinued			

Notes:
Trial A: March 9 - April 27; Trial B: May 1 - June 18 (approximately 7 weeks each)

- PTS-1 ANC divided in half to allow evaluation of two different ANC HRTs simultaneously
- PTS-2 through -4 treated synthetic Crystal Mine water at different BCR HRTs.
- Trial A was conducted during the first half of the approximately 14-week study
- During Trial B, the influent flow rates were doubled, effectively halving the treatment unit HRTs
- PTS-4 system was not operated in Trial B.

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Results

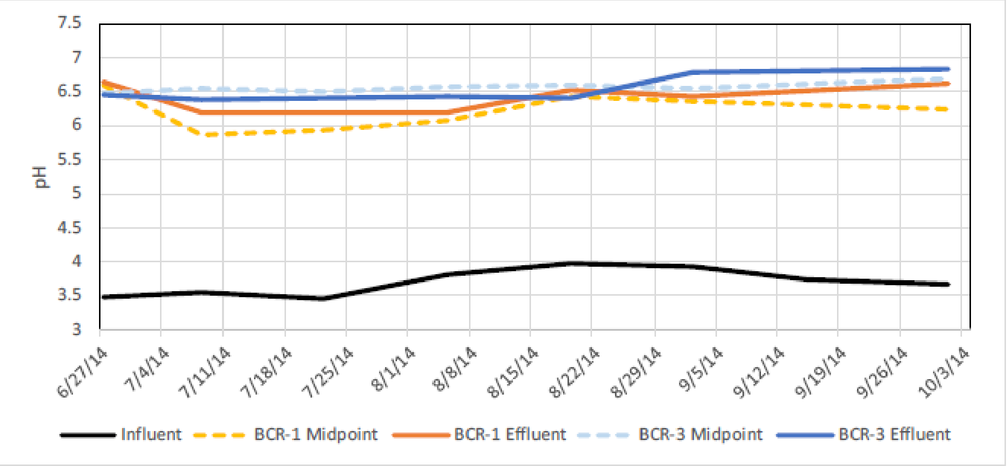
Adit Discharge Characteristics and Treatment Targets

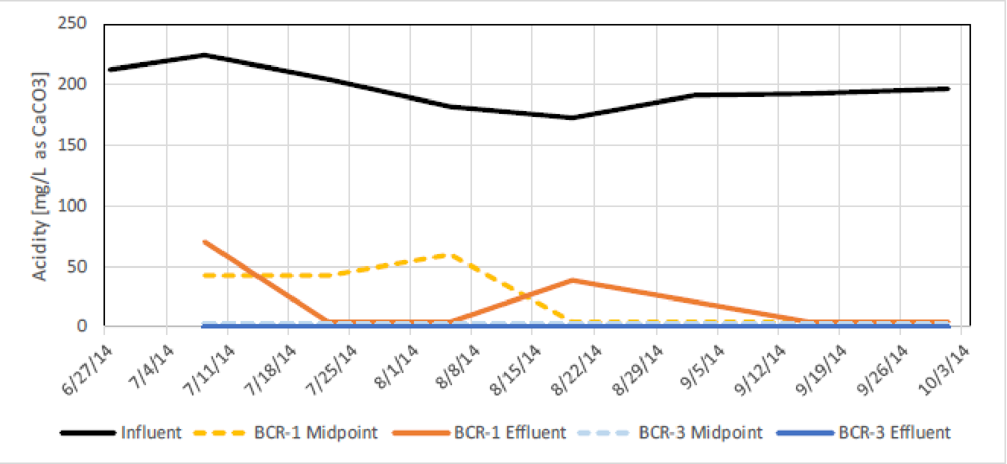
		Bullion Mine		Crystal Mine		Treatment Target	
Parameter	Units	Average	Range	Average	Range	Acute	Chronic
Flow	gpm	4.9	1.80 – 14.4	25.1	4.49 – 49.4		
Temperature	°C	5.2	0 – 9.7	5	2.5 – 7.0		
pH (field)	su	2.9	2.5 – 3.7	4.1	3.5 – 5.8		
Conductivity	µS/cm	1,840	1,130 – 3,100	747	478 – 1,270		
Sulfate (SO_4)	mg/L	995	718 – 1,302	406	240 – 528		
Dissolved Metals/Elements							
Aluminum (Al)	µg/L	14,850	8,900 – 21,120	3,170	564 – 7,310	750	87
Arsenic (As)	µg/L	2,480	160 – 10,100	122	37.0 – 315	340	150
Cadmium (Cd)	µg/L	435	251 – 1,070	559	331 – 737	8.73	0.76
Copper (Cu)	µg/L	8,120	2,060 – 23,600	5,770	2,610 – 9,330	51.7	30.5
Iron (Fe)	µg/L	160,000	127,000 – 206,000	39,300	19,500 – 55,100		1,000
Lead (Pb)	µg/L	402	196 – 801	37.3	7.00 – 73.7	477	18.6
Manganese (Mn)	µg/L	21,700	16,200 – 29,700	11,100	6,390 – 15,100		
Nickel (Ni)	µg/L	83.9	59.7 – 109	34.8	24.2 – 41.9	1,516	169
Silver (Ag)	µg/L	<1		<0.5		44	
Zinc (Zn)	µg/L	47,800	23,400 – 141,000	43,300	24,500 – 55,900	388	388

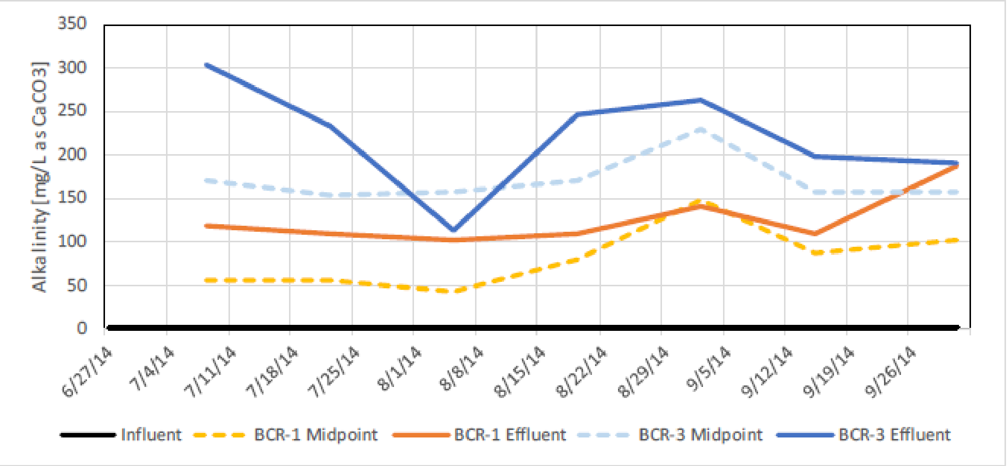
Field Pilot – Results

- ANC in all three arrays raised pH, lower acidity, and increased alkalinity
- BCR-3 best performance – complete acidity removal, higher pH

Parameter	Units	Influent Average		Midpoint Average		Effluent Average	
BCR-1							
pH	s.u.	3.67		6.15		6.36	
Acidity	mg/L as $CaCO_3$	197		26.5	<	24.8	<,a
Alkalinity	mg/L as $CaCO_3$	5.00	U	81.8		125	
BCR-2							
pH	s.u.	3.67		6.35		6.15	
Acidity	mg/L as $CaCO_3$	197		10.7	<,a	14.0	<,a
Alkalinity	mg/L as $CaCO_3$	5.00	U	167		214	
BCR-3							
pH	s.u.	3.67		6.56		6.50	
Acidity	mg/L as $CaCO_3$	197		10.0	U	10.0	U
Alkalinity	mg/L as $CaCO_3$	5.00	U	171		221	







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Field Pilot – Results (ORP)

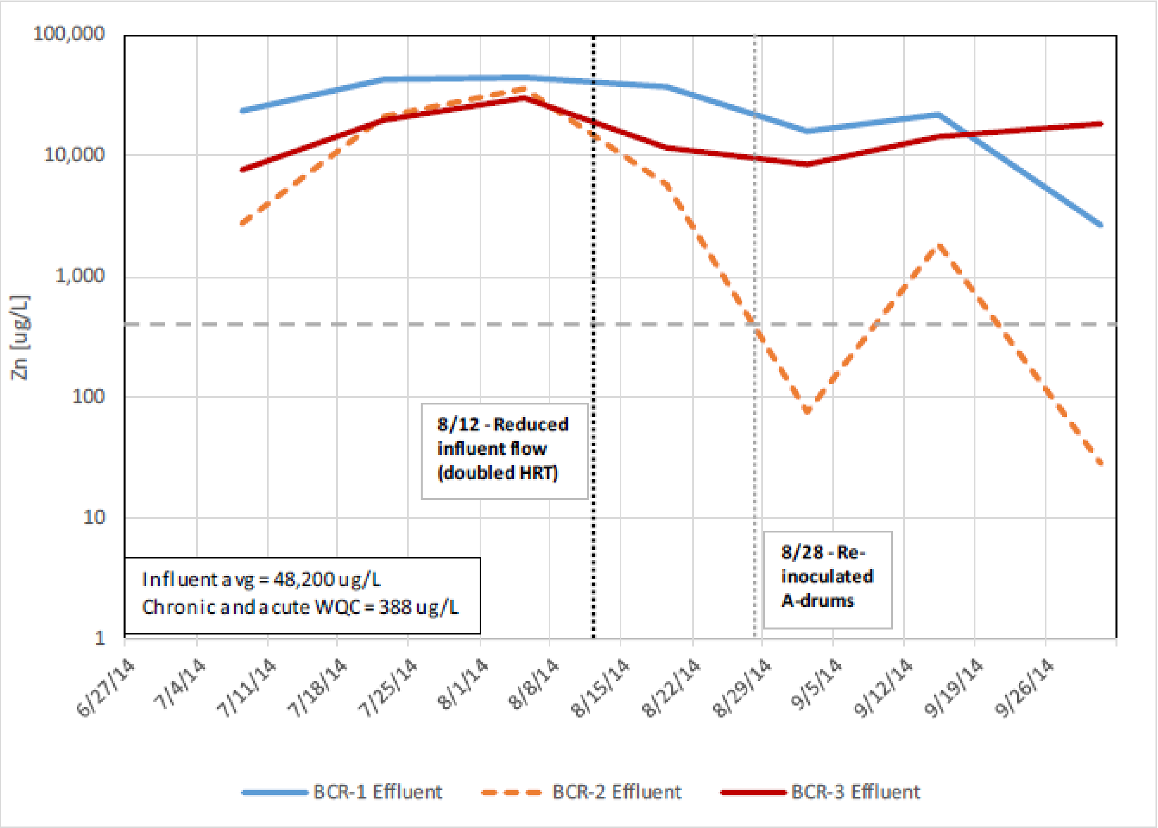
- While the ANC performed well, the BCR never obtained highly reducing conditions expected
- BCR-2 and -3 achieved negative ORP in final effluent
- BCR-1 had positive effluent ORP, but still achieved sulfate reduction
- BCR-3 reached negative ORP after ANC, but the BCR did not become highly reducing and the rate of sulfate reduction was well below normal
- BCR-2 had the highest rate of sulfate reduction

Redox Conditions Indicator Data

Parameter	Units	Influent Average	Midpoint Average		Effluent Average	
BCR-1						
ORP	mV	298	60.6		28.5	
Sulfate	mg/L	380	368		336	
Sulfate reduction[a]	mg/L		12		44	
Sulfide	mg/L		0.13		0.14	
COD	mg/L				134	
BCR-2						
ORP	mV	298	42.2		-25.5	
Sulfate	mg/L	380	361		259	b
Sulfate reduction[a]	mg/L		19		121	
Sulfide	mg/L		0.12		3.3	
COD	mg/L				287	
BCR-3						
ORP	mV	298	-15.6		-31.5	
Sulfate	mg/L	380	377	b	331	b
Sulfate reduction[a]	mg/L		3		49	
Sulfide	mg/L		0.89		1.5	
COD	mg/L				218	

Field Pilot – Trace Metal Results (Zn)

- All three systems achieved effluent dissolved concentrations of Al, As, Cu, and Pb that were lower than the respective treatment targets (Montana WQS)
- Cd & Zn were the most challenging metals for effective treatment
- In general, BCR-2 exhibited the best removal rates for Cd & Zn
- After re-inoculation, BCR-2 trended towards water quality standard
- BCR-1 and -3 removed zinc, but not below the target water quality standard



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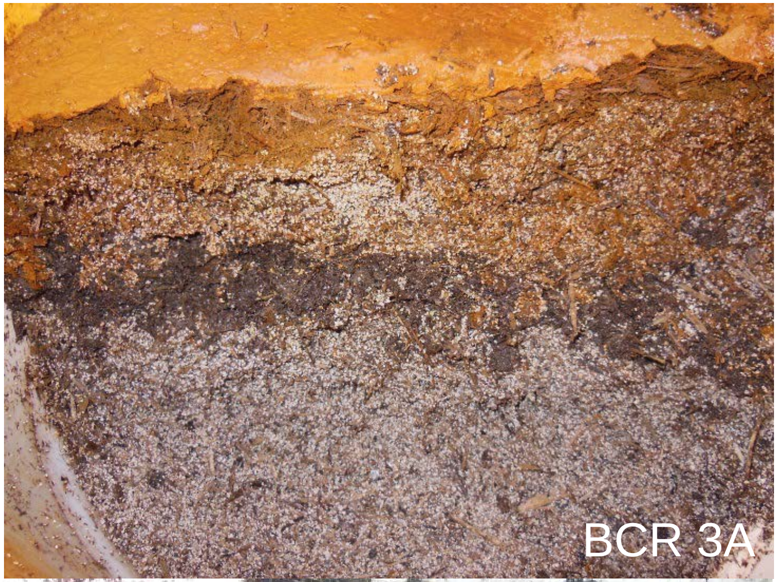
Field Pilot – Autopsy

- After decommissioning the pilot, the barrels were drained and substrate investigated
- The limestone-amended ANC's exhibited a sharp boundary of ferric and aluminum oxyhydroxides overlying relatively "fresh" substrate
- Purple S-bacteria were observed colonizing the substrate between the barrel wall and the substrate; may have impacted ORP values
- Elemental S at top of BCR indicate sulfate reduction and sulfide generation



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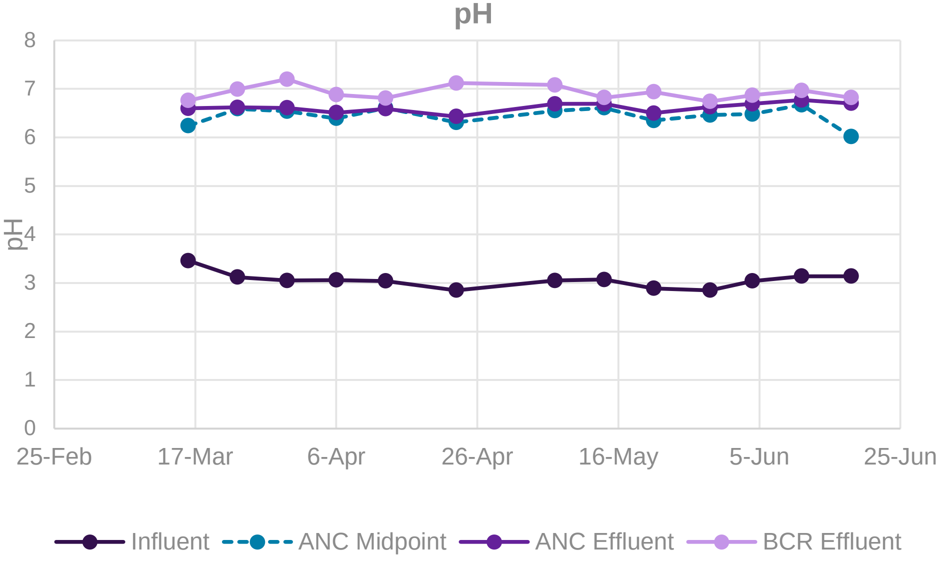
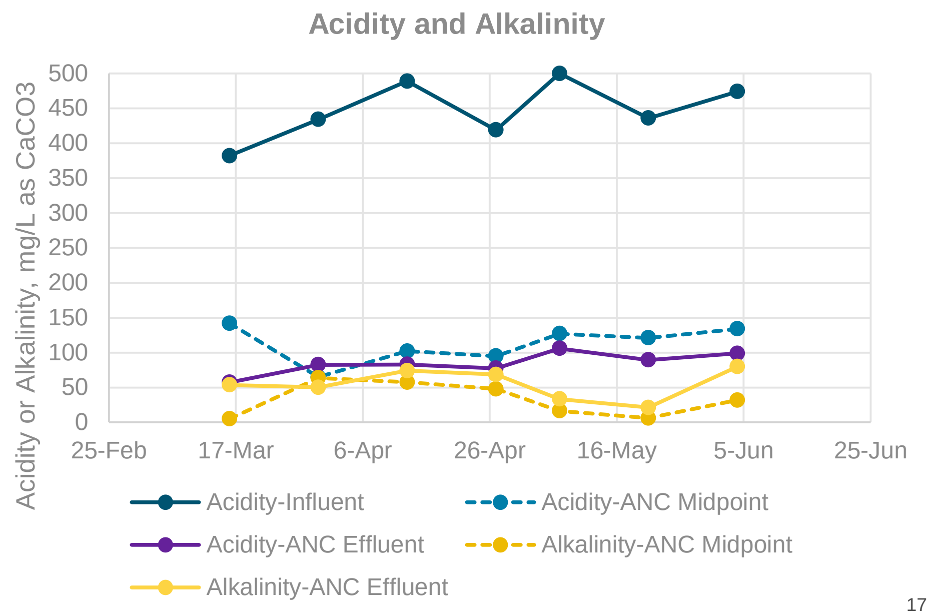
Lab Column – Results

- The column testing exhibited similar results for pH, acidity, and alkalinity compared with the field study.
- pH was effectively neutralized in the ANC for both waters and at HRTs of 3 and 6 hours, and pH was neutralized nearly as well even at an ANC HRT of 1.5 hours
- Influent acidity was reasonably well neutralized (e.g., alkalinity ≥ acidity in ANC effluent) for both waters at HRTs of 3 and 6 hours, although there was some evidence of slightly incomplete acidity neutralization for Bullion Water in Trial B (total HRT = 3 h)





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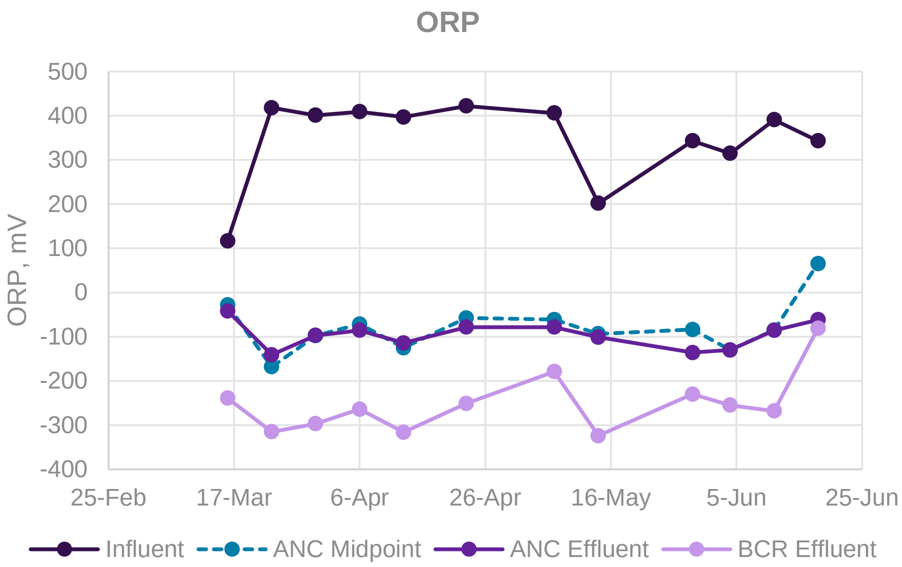
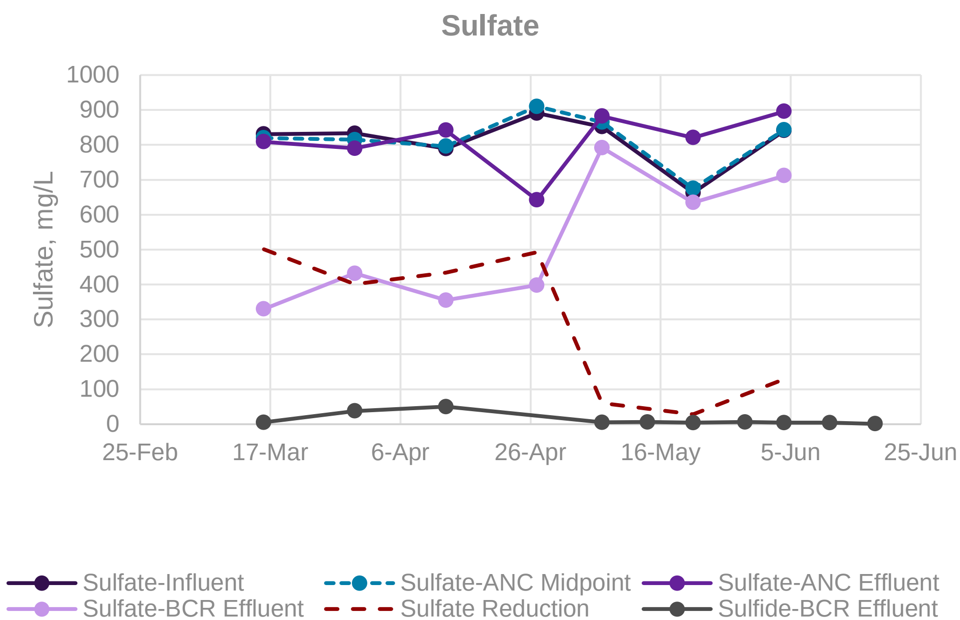
Lab Column – Results

- ORP was sufficiently low (-200 to -300 mV) in BCR Effluent, for both the Bullion and Crystal systems, to indicate strongly reducing redox conditions conducive to sulfate reduction
- A considerable excess of sulfate reduction (compared to the amount needed for sulfide precipitation of metals) occurred in all systems during Trial A
- In Trial B, the amounts of sulfate reduction exhibited were similar to the theoretical stoichiometric requirements for metals removal. No adverse effect on removal of Cd, Zn, or Fe was observed.





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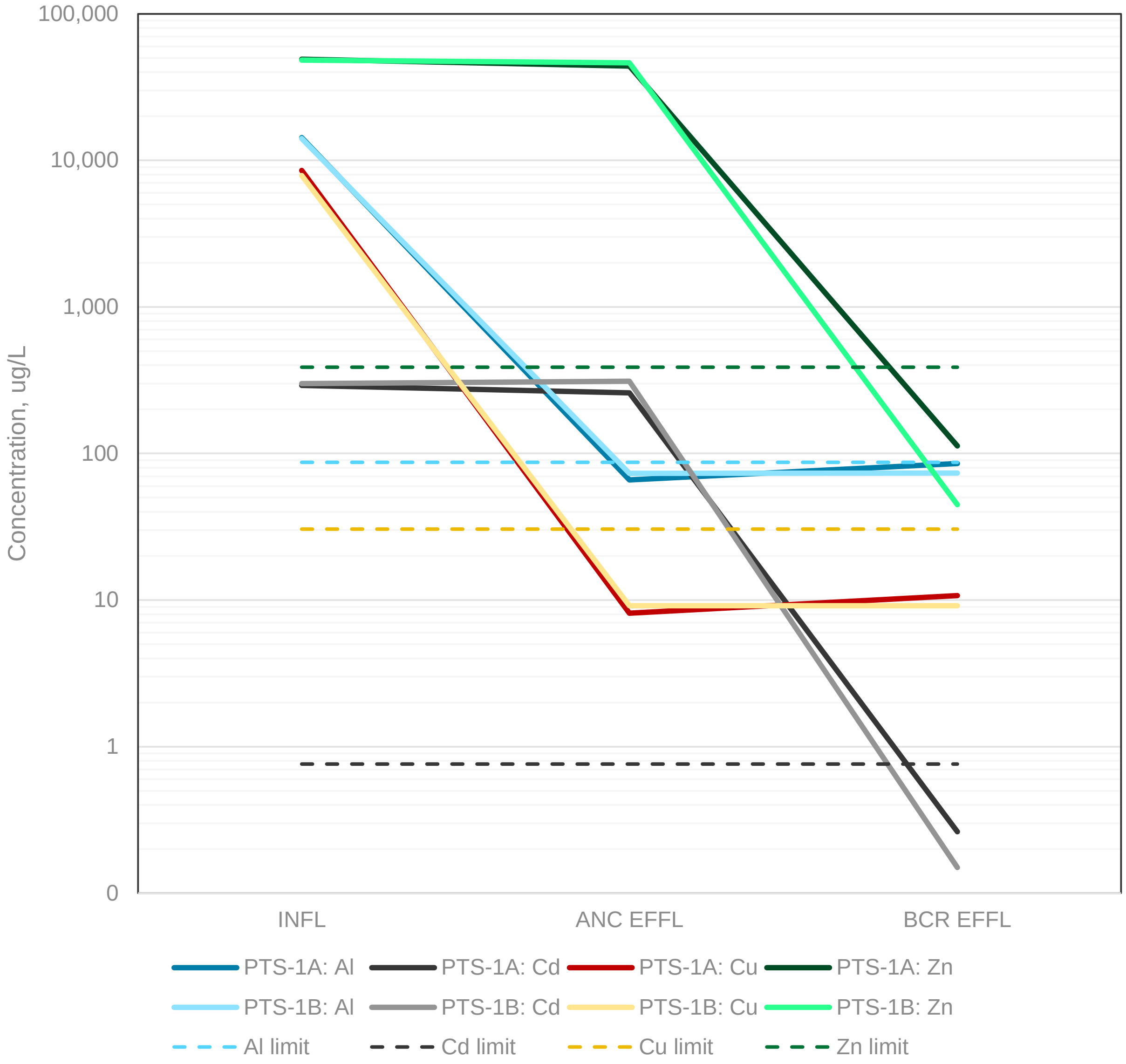
Lab Column – Results

- Typically 97 – 99+% removal efficiencies for all dissolved metals/elements of concern (Al, As, Cd, Cu, Fe, Pb, Zn) – both ARD sources
- Dissolved metals concentrations in virtually all BCR effluent samples met compliance with their respective treatment targets
- Similar removal for all HRTs tested, including the shortest HRTs evaluated for each treatment unit type: ANC – 3 hours; BCR – 1.5 days for Crystal (PTS-2B) and 2.5 days for Bullion (PTS-1B



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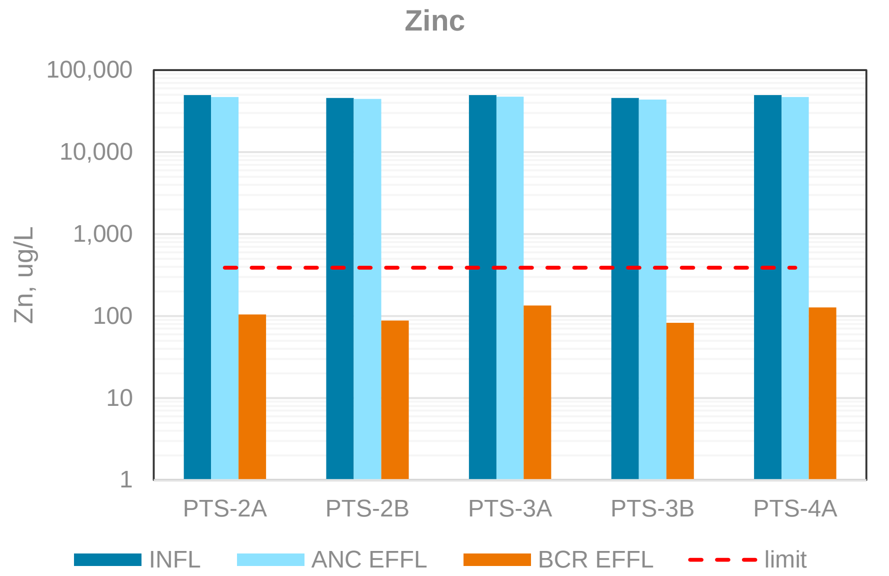
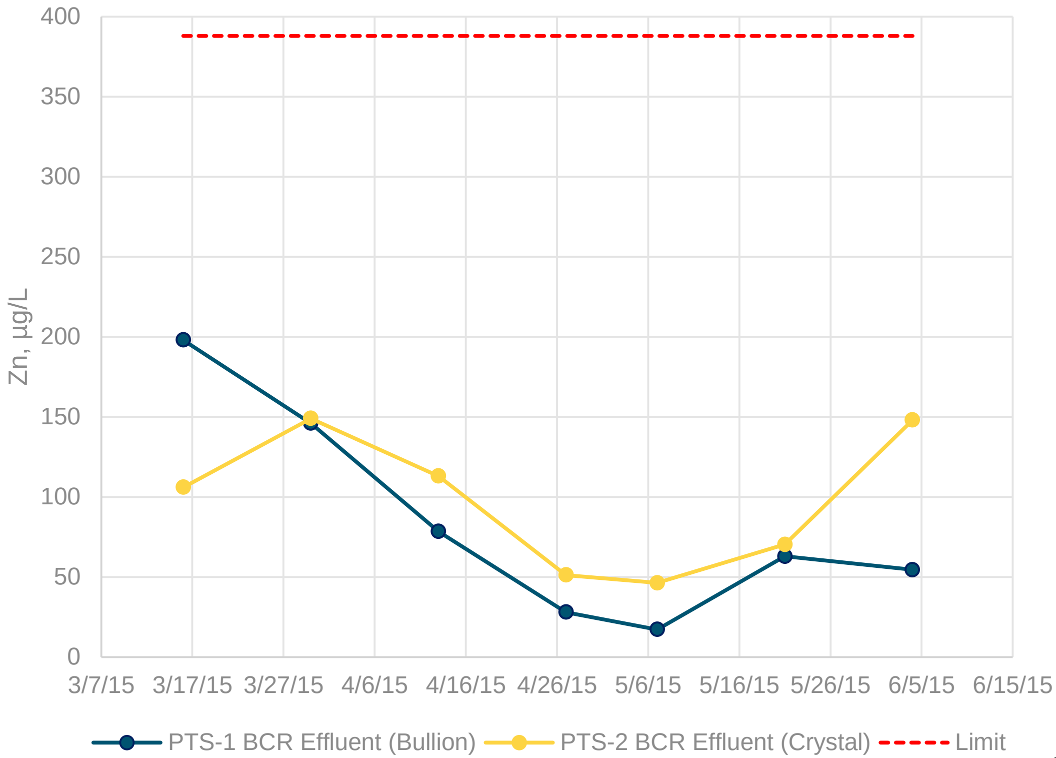
Lab Column – Results

- Elements largely removed in the ANC: Al, As, Cu, and Pb – plus Fe in Crystal systems but only roughly one-half of the Fe in Bullion systems (due to the markedly higher influent concentration).
- Elements largely removed in the BCR: Cd and Zn, plus approximately one-half of Fe in the Bullion system.



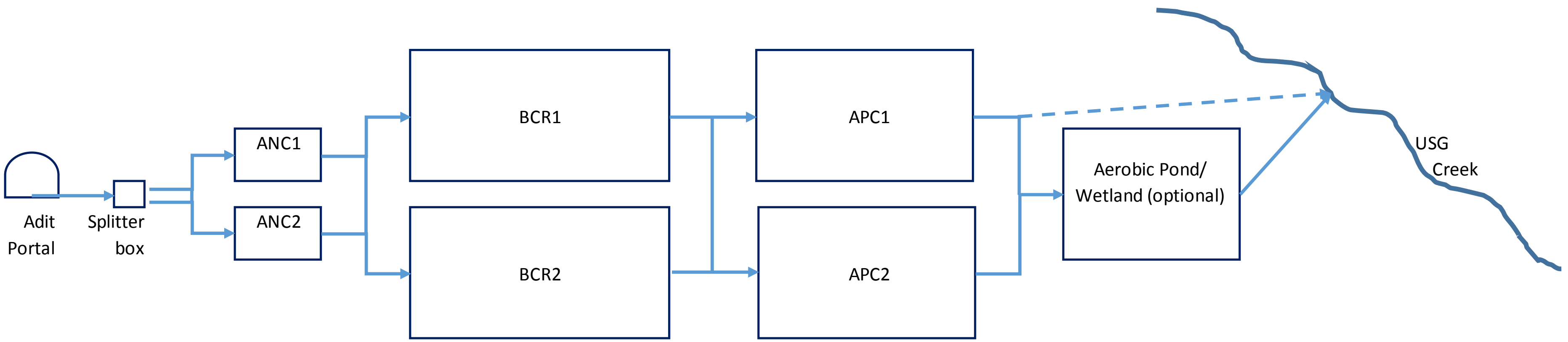


Considerations for Design and Construction

Residence Time and Unit Sizing

- HRT for sizing of ANC and BCR units in full-scale design of mine water passive treatment systems for the Bullion and Crystal Mine sites:
  - Bullion and Crystal ANC: 6 hours
  - Bullion BCR: 4 to 4.5 days (suggest 4 days at the design maximum flow)
  - Crystal BCR: at least 3 days (suggest 4 days at the design average flow)

Conceptual Design for Crystal Mine Adit



Preliminary PFD
Crystal Mine PTS

Thank You