FREEPORT-MCMORAN

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Passive Bioremediation of Adit Discharge from a Legacy Mine in Central Montana

A Lab-Scale Treatability Study

May 9, 2019

Participants

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  - **Dan Ramey, Director, Tucson**
  - **Erick Weiland, Manager, Tucson**
- **U.S. EPA**
  - **Roger Hoogerheide, Remedial Project Manager, Helena**

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Outline

- History of the Barker Hughesville Mining District
- Collaboration between Mt. Emmons Mining Co. (MEMC) and U.S. EPA
- Passive Bioremediation Lab-Scale Treatability Study

Barker Hughesville Mining District

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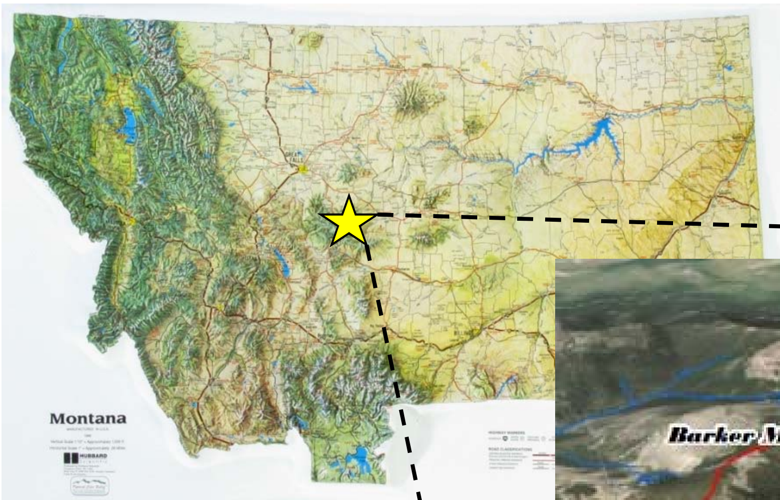
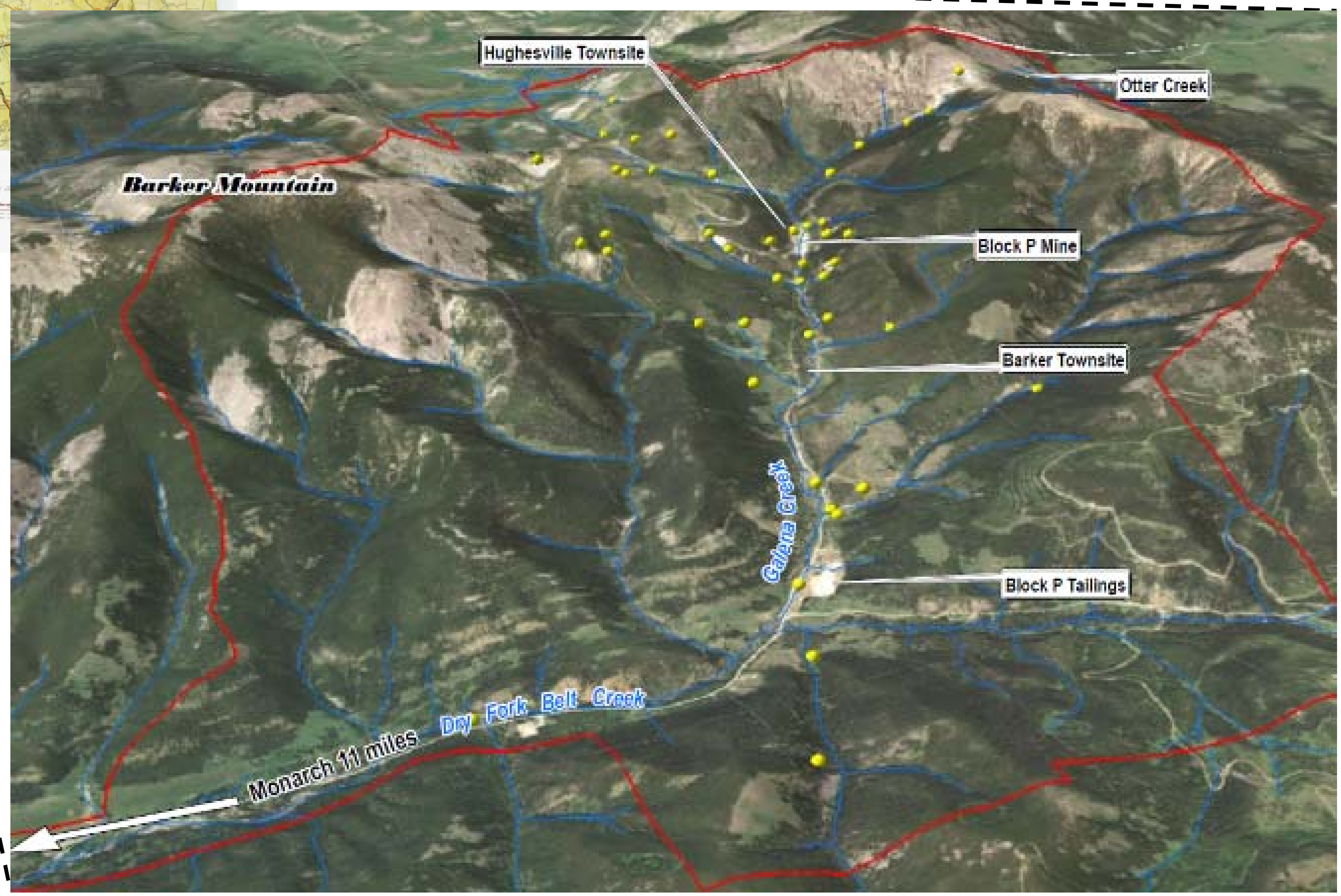
- Renowned for silver, zinc, and lead deposits
- First phase of mining (1879-1883) included silver ores at surface
  - Hampered by transport costs and fluctuating prices
- Second phase (1890s) began with the construction of a rail line from Great Falls to Neihart and the construction of smelters in Great Falls and Helena
- Final phase of mining (1920s) began with increasing metal prices and improvements in mining techniques
- Sporadic mining post-WWII

Barker Hughesville Mining District





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Regulatory History at the Site

Significant Regulatory History

Entity	Year	Purpose
State of Montana	1996	Owner/Operator Reports (RTI)
	1996	PRP Search (RTI)
	1993-1995	AMRB Hazardous Waste Inventory (Pioneer)
	1991	Galena Creek Drainage Preliminary Assessment (Chen-Northern)
	1989	Inventory of Features (DSL)
USFS	2001	EE/CA Removal/Relocate Block P Tailings (Barr)
	2000	Survey of Abandoned Mines on Lewis & Clark NF Property (MBMG)
	1998	Assessment of Doe Run Properties (Barr)
	1994	PRP Search (USFS)
Cascade County and DNRC	1972	Acid Mine Drainage Study

Danny T Treatability Study

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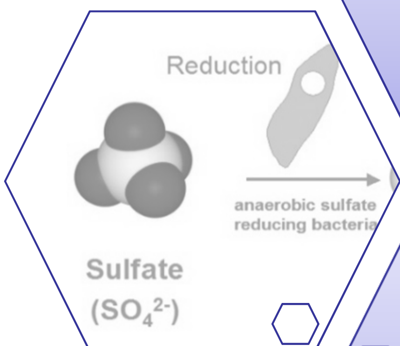
- **Conditions necessary to *realistically* implement "semi-passive" biochemical reactor treatment for acidic mine water exist at the Site (pH<3, high dissolved Fe, Al, and Zn ~ 100 mg/L).**

- **Collaboration between MEMC and U.S. EPA began in 2016.**
  - **MEMC and U.S. EPA entered into an agreement to perform a Treatability Study.**

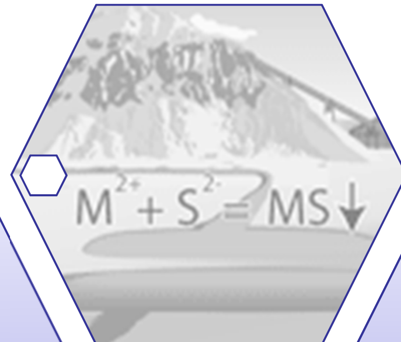
- **A Treatability Study Work Plan was approved by U.S. EPA in 2017 and included:**
  - **Field Sampling Plan (FSP)**
  - **Quality Assurance Project Plan (QAPP)**

Passive Bioremediation Overview



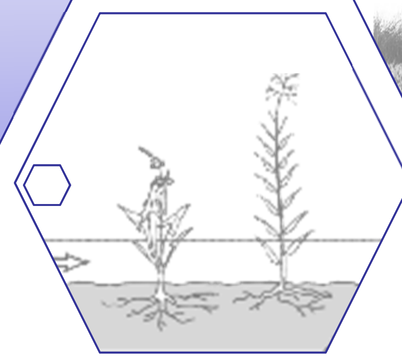
Biologically-based water treatment strategies

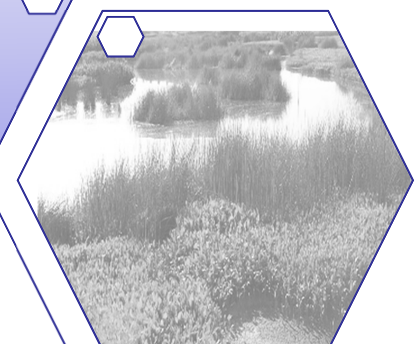
Natural physical, chemical, and biological processes



Cost-effective for remote locations

Sustainable green technology





Passive Bioremediation

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Benefits

- Natural organic substrate
- Low sludge production
- Low operating and maintenance costs
- Minimal energy consumption

Limitations

- Limited by microbe performance and toxicity and metal loading rates
- Seasonal variation in performance
- Space requirements

Treatability Study Goals & Objectives

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- **Goal: Evaluate the effectiveness of passive bioremediation to treat adit water and achieve identified benchmarks**

- **Objectives:**
  - **Assess the need for limestone pre-treatment**
  - **Evaluate performance of post-treatment wetlands**
  - **Provide insight into potential design of a full-scale system**

- **Technologies Evaluated:**
  - **Limestone pre-treatment**
  - **Sulfate-reducing biochemical reactors**
  - **Treatment wetlands**

Limestone Pre-Treatment

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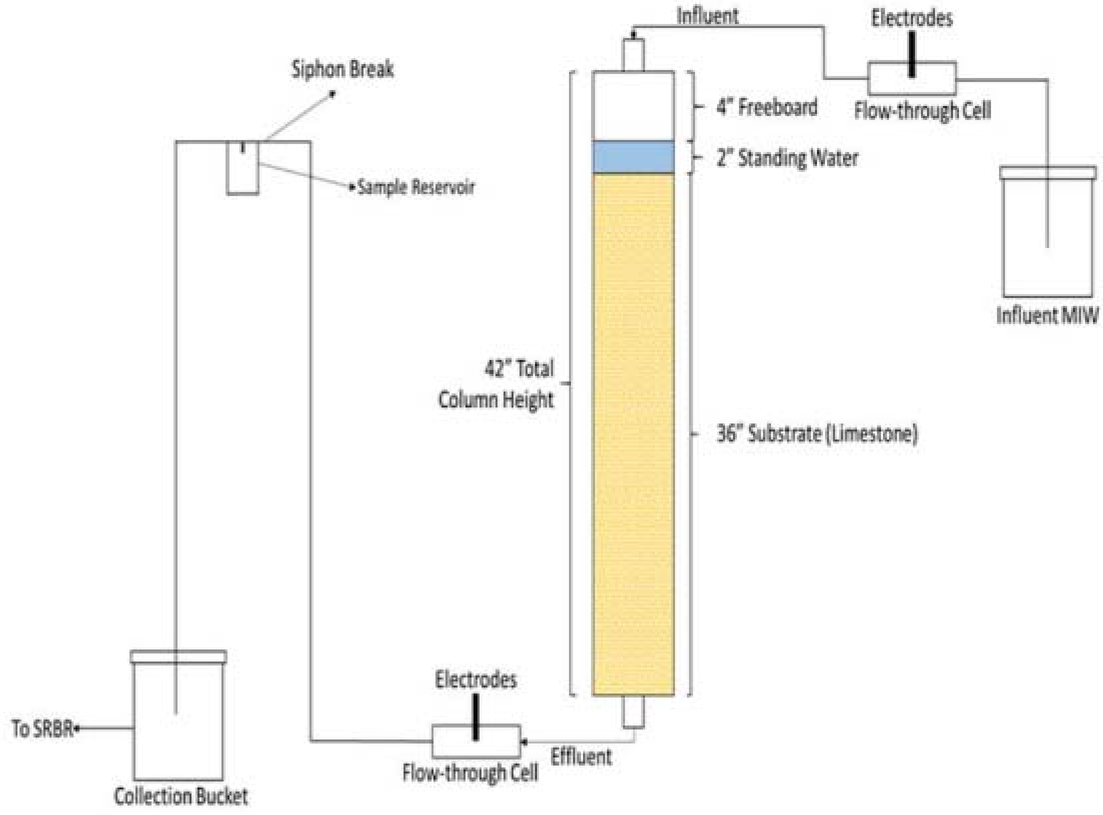
- **Increases pH**
  - **Aluminum and Iron precipitated as (oxy) hydroxides**
- **Generate aqueous alkalinity**
- **Reduce:**
  - **Aqueous Acidity**
  - **Dissolved Metals**
  - **Solids Loading**



Primary Treatment: Sulfate-Reducing Biochemical Reactor (SRBR)

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- **Background**
  - **Sulfate-reducing bacteria (SRB)**
    - Sulfate reduced and hydrogen sulfide (H_2S) released
    - Free sulfide combines with metals as metal sulfides
    - Increase pH of water via carbonate/bicarbonate alkalinity
  - **Requires a carbon source**
    - Organic matter provides carbon and a support matrix
- **Bioreactor sizing based on:**
  - **Metal, sulfate, and oxygen loading rates**
  - **Hydraulic retention time (HRT) target: 3-5 d**

Lab-Scale SRBRs

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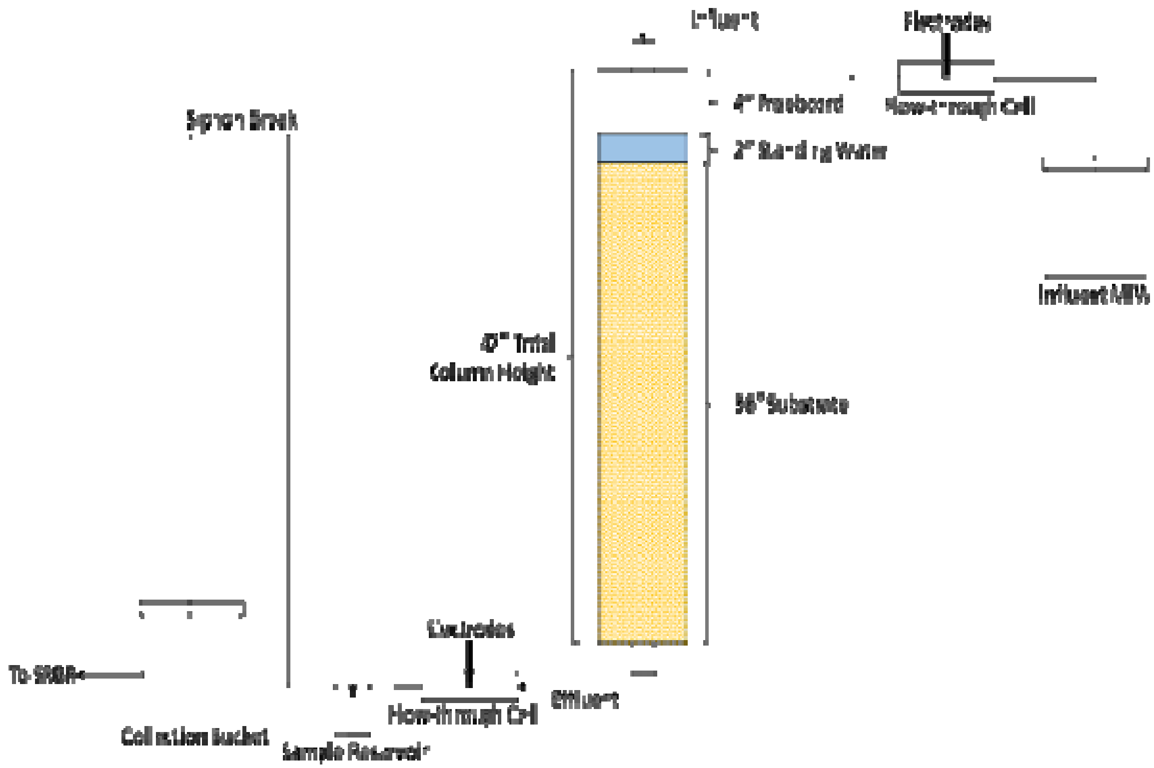
- **Eight 42-in. SRBRs**
  - **4-in diameter**
  - **8-in diameter**

- **Substrate:**
  - **Wood chips (10 or 30%)**
  - **Walnut shells (30 or 50%)**
  - **Alfalfa hay (10%)**
  - **Limestone (30%)**
  - **Manure (1%)**



Vertical Flow Wetlands (VFW)

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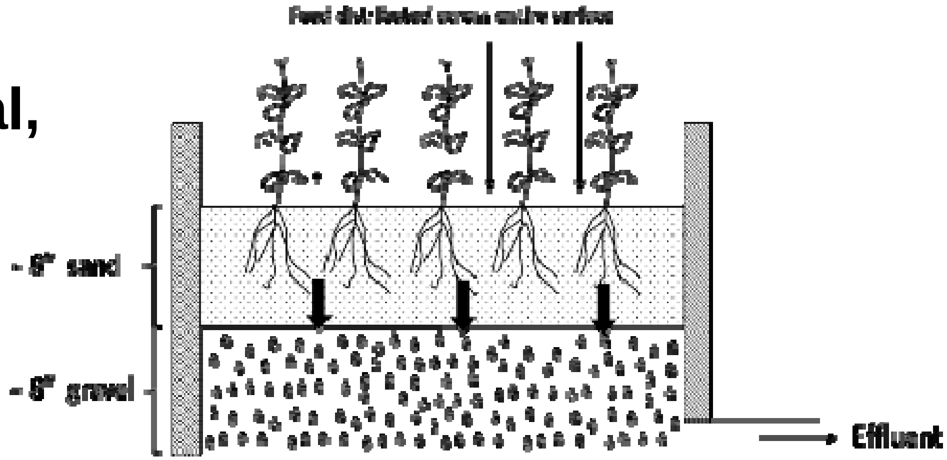
- **Background**
  - **Emphasize aeration**
  - **COCs removed via physical, biological, and chemical processes**



- **Sizing**
  - **Designed for BOD and Mn removal**
  - **Each VFW fed by 2 SRBRs**
- **Vegetation**
  - **Arctic rush (*Juncus arcticus*)**
  - **Water sedge (*Carex aquatilis*)**

Lab-Scale Set Up

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Methods

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- Adit water collected and shipped to Tucson in July 2017

- Start Up in August 2017
  - SRBRs filled with water and left idle for 3 wks
    - ORP used to monitor conditions

- Operational Monitoring
  - Weekly sampling of influent and effluent at each stage
    - Physico-chemical parameters (in-house)
    - Metals, metalloids, anions (ACZ Labs)
      - Total and dissolved fractions

Results: Influent Physico-Chemical Parameters

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- **Influent water chemistry largely similar to adit water**

Analyte	Mean	Range	Units
pH	2.46	2.16-2.58	s.u.
ORP	519	413-601	mV
Conductivity	2,690	2,540-2,780	µS/cm
DO	7.6	5.2-9.3	mg/L
Temp.	21.3	15.5-26.5	°C

- **Exceptions**
  - **pH decreased slightly relative to Adit water (2.88 s.u.)**
    - **Likely due to acidity stemming from Fe oxidation**

Results: Influent Aqueous Chemistry

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- **Influent water chemistry largely similar to adit water**
  - **The following (in µg/L) exceed identified benchmarks:**

	Adit	Benchmark			Adit	Benchmark
Aluminum (D)	11,900	87		Iron	46,600	1,000
Arsenic	101	10		Lead	132	3.2
Beryllium	6.2	4		Thallium	2.0	0.24
Cadmium	226	0.3		Zinc	48,200	120
Copper	1,020	9.3				

- **Fe decreased relative to Adit (111,000 µg/L)**
- **Anions and indicator parameters**
  - **Sulfate (867 mg/L) is the dominant anion**
  - **Acidity: 540 mg/L as $CaCO_3$**

Pre-Treatment Water Quality Improvements

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- **pH increased**
- **Al and Fe removed along with As, Be, Cu, and Pb**
- **Alkalinity generated**

Parameter	Influent	Effluent	Unit
pH	2.5	6.6	s.u.
Aluminum (D)	11,900	245	µg/L
Iron	46,600	197	µg/L
Arsenic	101	<2	µg/L
Beryllium	6.2	<3	µg/L
Copper	1,020	125	µg/L
Lead	132	<1	µg/L
Alkalinity	--	133	mg/L as $CaCO_3$

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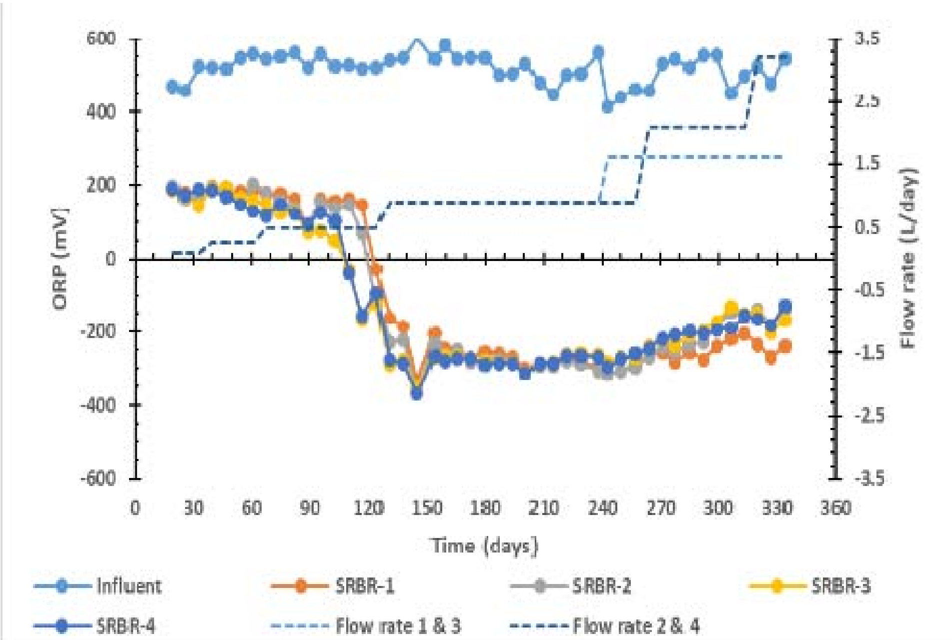
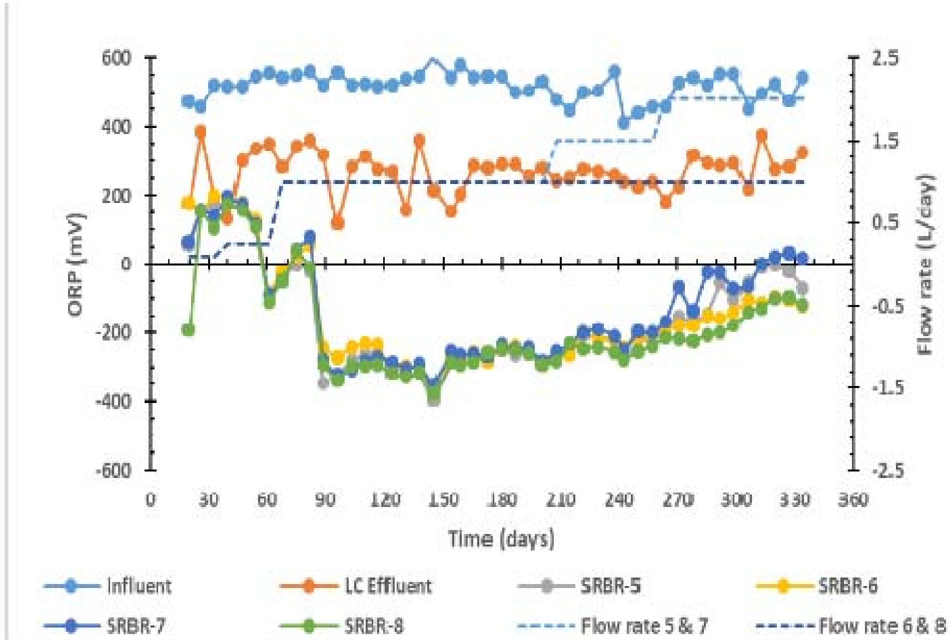
SRBRs Supporting Reducing Conditions

- **Anoxic and anaerobic conditions maintained**
  - **ORP: <-100 mV and DO: <2 mg/L**





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SRBRs Improved Aqueous Chemistry

- **All metals (µg/L) at or below benchmarks**

	w/o Pre-Treat.			**w/ Pre-Treat.**	
	Influent	Effluent		Influent	Effluent
Al (D)	11,900	<87		246	<10
As	101	<10		5.6	<10
Be	6.2	<0.25		1.4	<0.5
Cd	226	<1		190	<0.5
Cu	1,020	<10		256	<4
Fe	46,600	50		243	<1,000
Pb	132	<1		1.0	<1
Tl	2.0	<0.5		<1	<1
Zn	48,200	<100		43,700	2,150

Primary Treatment Summary

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- Effluent circumneutral and net alkaline
- Optimal conditions maintained in SRBRs at design flow rate
  - Oxygen may have hindered SRBRs at higher flow rates
- Minimal effect from different substrates evaluated

VFWs Improved Aqueous Chemistry

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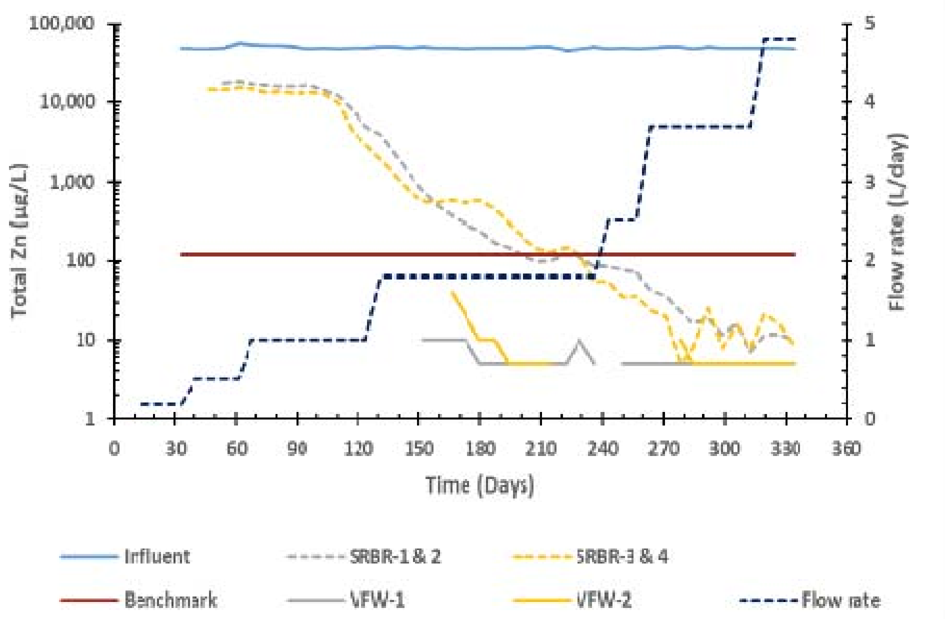
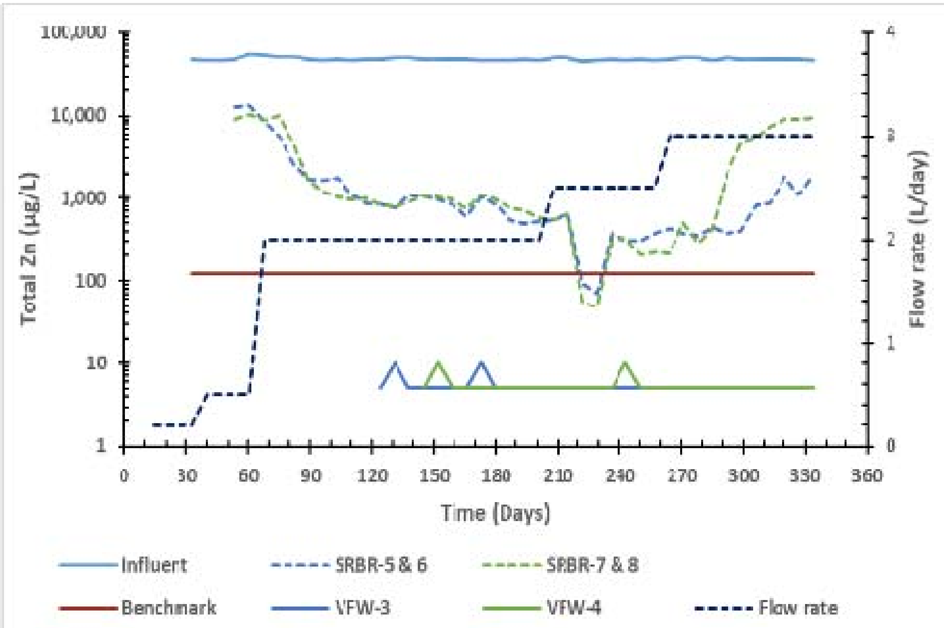
- **Oxic conditions restored**
  - **Increases in DO (7 mg/L) and ORP (+170 mV)**
- **VFW effluent exhibited nearly all metals below benchmarks**
  - **Some metals leached from substrates (e.g., Sr)**
  - **Mn removal 97%**
- **Water quality improved**
  - **BOD removed (<MDL)**
  - **Slight increase in pH (7.6 s.u.)**
  - **Effluent was net alkaline (110-200 mg/L as $CaCO_3$)**
- **Anions largely unchanged (Br, Cl, F, and Sulfate)**

VFWs Further Treated Water

- **VFWs polished SRBR effluent**





- **Zn particulates are small enough to escape SRBR but not VFWs.**

Conclusions

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- Both 2- and 3-stage systems improved water quality
  - Treatability Study benchmarks were attained
  - Design flow rates were appropriate starting point
  - Evidence of additional capacity for treating higher flows observed
    - Limited capacity for improved sulfate removal
    - Some metals removed as carbonates (e.g., Zn)
- Potential benefits to separate pre-treatment
  - Reduced metal, acidity, and solids loading to SRBRs
  - Reduced operation and maintenance

Conclusions (Continued)

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- **Multi-stage system was most effective**
  - **Targets specific COCs**
  - **Provides redundancy**
- **Substrates should be characterized prior to use**
- **Collaboration, cooperation, and communication with State and Federal Agencies was invaluable for project success**

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Thank you.