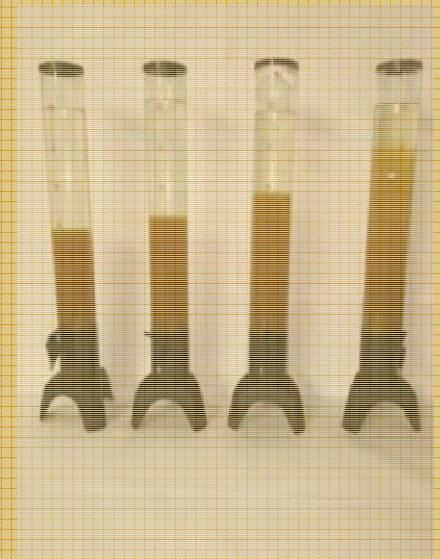


Advanced Neutralization and MBS® Technology Pairing for the Treatment of Acidity and Heavy Metals in Acid Mine Drainage and Resultant Residual Solids

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ABSTRACT

The paired use of Advanced Neutralization (AN) with the Molecular Bonding System[®] (MBS) holds promise for the treatment of acidity and heavy metals in Acid Mine Drainage (AMD); and to yield 1000-year stability of heavy metals in AN derived residual solids when exposed to landfill leachate, acid rain, or other potential acidic conditions such as AMD itself. AN utilizes electric power to neutralize acidity and concomitantly remove of heavy metals to non-detectable or low ppb concentrations without the use of additive chemical reagents. AN generated solids subsequently treated with the MBS technology contain heavy metals as stable sulfide, apatite, and other mixed mineral forms that may be managed onsite with appropriate engineering controls. Laboratory and field trial studies performed on AMD sourced from various legacy and active mines in the basins of the Animas River in Colorado and the Coeur d'Alene River in northern Idaho successfully processed AMD taking pH from 2.3 to over 8.0 S.U., removed heavy metals from the water, and stabilized metals in solids after application of both treatments. Data generated by independent analytical laboratories from bench, laboratory, and field engineering scale treatments will be presented along with technology limitations, and planned enhancements including in-mine solids dewatering, and hydropower coupling.

The Technologies – Advanced Neutralization

Advanced Neutralization:

- pH from <2 to 7.85 S.U. (AMD, Landfill Leachate, Acid Rain w/SO_x + NO_x)
- Electric Power, NO chemical reagent (e.g., alkaline, polymer, coagulants, etc.)
- Metallic oxides and potential carbonates and/or sulfides
- Innovative dimensionally stable and sacrificial electrode combinations
- Oxidation or Reduction reactions induced
- Disruption and Activation
- Reactive Surface Agglomeration
- Controlled Energy Fields
- Hydroxyl radicals and mixed oxidant formation
- Settling/Clarification
- No polishing filtration or adsorption media (used to date)
- Self-cleaning
- Patent Pending

Advanced Neutralization – Engineering Scale



The Technologies – MBS

Molecular Bonding System (MBS®)

- Sulfide-based reagent system w/phosphate and carbonate
- Forms stable insoluble mineral and mixed mineral forms (e.g., sulfides/apatites), and other complexes with heavy metals
- Solid, slurry, or liquid reagent options
- Applicable to water treatment system solids, soil, sediments, and other solid waste
- Renders RCRA heavy metals non-hazardous under waste characteristic toxicity rule (TCLP)
- Treats ALL base metals for 1000-yr stability allowing for onsite material management options. (USEPA's Method 1320 Multiple Extraction Procedure)
- USEPA SITE Program evaluated and approved
- Patented – East Morgan Holding, Inc., Lakewood, NJ

MBS Application Options

- Insitu
 - Injection Mixing (solids or slurries)
 - Surface Grid Vertical Profiling
 - Plow, Till, and Disc
- Exsitu
 - Small mobile
 - Large temporary
 - Central Processing Area



Studies and Field Trials

- Success Mine, Wallace ID
- Bunker Hill Mine, Kellogg ID
 - Russel Tunnel
 - Reid Tunnel
 - Kellogg Tunnel
- Idarado Mine, Red Mountain Creek, Ouray CO
- Animas River Basin, CO
 - Mogul Mine, Gladstone CO
 - Cement Creek, Gladstone CO
 - American Tunnel, Gladstone CO
 - Gold King Mine, Gladstone CO
 - Animas River, Aztec NM



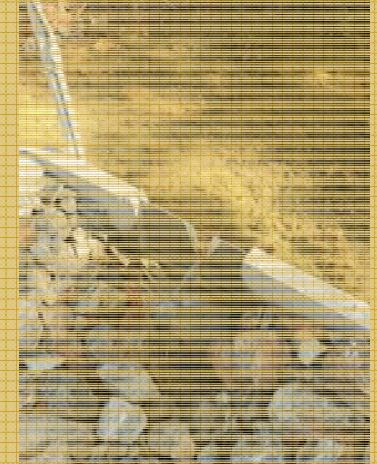
Success Mine, Wallace ID

Legacy Site – Mine Drainage

Issues: Heavy Metals

Technologies: AN

Unresolved: Mn, Zn, optimized refinement



<u>ANALYTE</u>	<u>UNITS</u>	Untreated	AN Treated		
		<u>RESULT</u>	<u>RESULT-3/1</u>	<u>Result-3/8</u>	<u>Result 8/1</u>
Aluminum	mg/L	3.5	0.279	0.104	0.18
Arsenic	mg/L	<0.0025	<0.0025	<0.0025	<0.0025
Cadmium	mg/L	0.0554	<0.005	<0.005	<0.005
Copper	mg/L	0.0187	0.026	0.179	<0.005
Iron	mg/L	25.5	1.86	0.797	25.8
Lead	mg/L	0.251	<0.0025	<0.0025	<0.0025
Manganese	mg/L	28.1	4.28	4.09	9.99
Zinc	mg/L	32.1	0.189	0.135	1.35
pH	S.U.	5.86	6.19	6.82	6.21



Success Mine, Wallace ID

AN Water Treatment Solid Residuals

Study Intent: Heavy Metals – Long Term Leaching

Technologies: MBS

Unresolved: Partial MEP, Aluminum optimization,
Viability established



USEPA SW-846, Method 1320 (Multiple Extraction Procedure)

ANALYTE	UNITS	1	2	Trending
		EPTOX-1310	SPLP-1312	Status
Run 1				
Aluminum	mg/L	0.216	0.461	↑
Arsenic	mg/L	ND	ND	viable
Cadmium	mg/L	ND	ND	viable
Copper	mg/L	ND	ND	viable
Iron	mg/L	0.564	0.771	↑
Lead	mg/L	ND	ND	viable
Manganese	mg/L	0.788	0.550	viable
Zinc	mg/L	ND	ND	viable
Run 2				
Aluminum	mg/L	ND	0.079	↑
Arsenic	mg/L	ND	ND	viable
Cadmium	mg/L	ND	ND	viable
Copper	mg/L	ND	ND	viable
Iron	mg/L	ND	ND	viable
Lead	mg/L	ND	ND	viable
Manganese	mg/L	0.951	0.820	viable
Zinc	mg/L	ND	ND	viable
Run 3				
Aluminum	mg/L	ND	0.662	↑
Arsenic	mg/L	ND	ND	viable
Cadmium	mg/L	ND	ND	viable
Copper	mg/L	ND	ND	viable
Iron	mg/L	ND	1.05	↑
Lead	mg/L	ND	ND	viable
Manganese	mg/L	0.753	0.246	viable
Zinc	mg/L	0.309	0.062	viable

Bunker Mine/Kellogg Tunnel, Kellogg ID

Active Mine – AMD



Bunker Mine/Kellogg Tunnel, Kellogg ID

Issues: pH, Heavy Metals

Technologies: AN

Unresolved: Sulfate removal, Mn, Zn



Parameter	Units	Untreated	AN - Treated	
			R-1	R-2
Aluminum, dissolved	mg/L	1.23	0.476	0.05
Aluminum, total	mg/L	1.27	0.893	0.19
Arsenic, dissolved	mg/L	<0.025	<0.0030	0.0004 J
Arsenic, total	mg/L	0.040	<0.0030	0.0004 J
Cadmium, dissolved	mg/L	0.0753	0.0500	0.020
Cadmium, total	mg/L	0.0750	0.0492	0.021
Calcium, total	mg/L	207	NT	197
Copper, dissolved	mg/L	0.059	0.00993	0.0018 J
Copper, total	mg/L	0.0600	0.0107	0.0014 J
Iron, dissolved	mg/L	18.8	36.8	1.98
Iron, total	mg/L	88.6	44.9	1.98
Lead Dissolved	mg/L	0.558	<0.00300	0.00027 J
Lead, total	mg/L	0.607	0.00539	0.00086
Magnesium, total	mg/L	113	NT	74.7
Manganese, dissolved	mg/L	68.2	61.0	46.66
Manganese, total	mg/L	68.8	60.5	48.04
Nickel, dissolved	mg/L	0.0615	0.162	0.024
Nickel, total	mg/L	0.059	0.165	0.025
Sulfate	mg/L	1430	NT	858
Zinc, dissolved	mg/L	40.3	14.5	2.197
Zinc, total	mg/L	50.2	15.1	2.296
pH	S.U.	2.34	6.74	7.54

Bunker Mine/Kellogg Tunnel, Kellogg ID

AN Solids

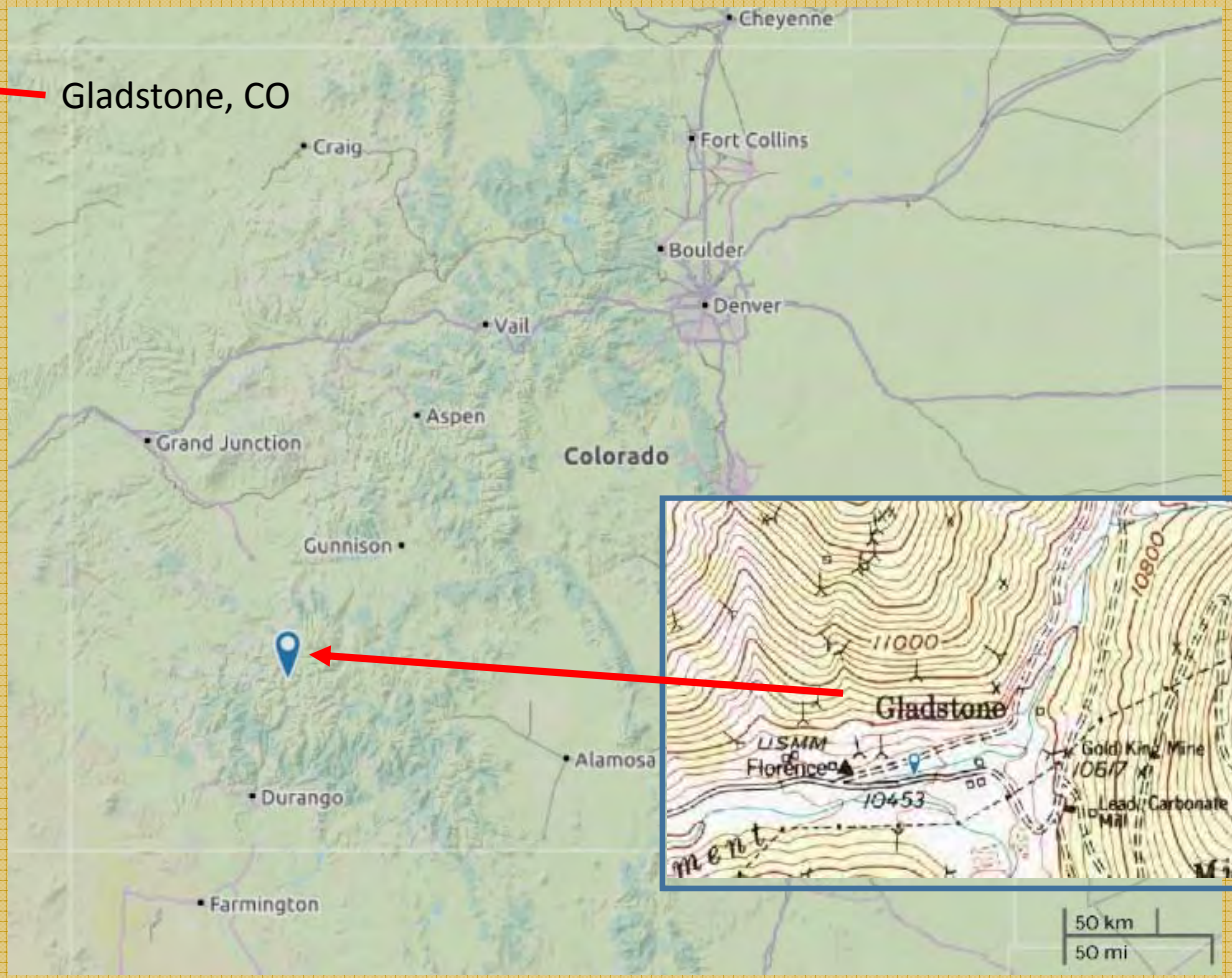
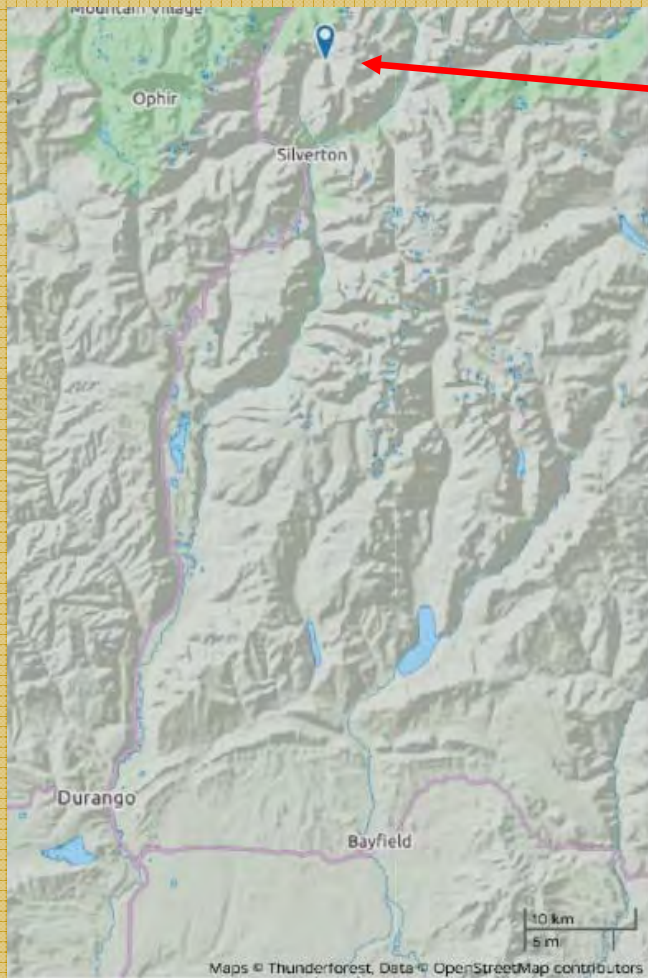
Unresolved: Sulfur, metal recovery



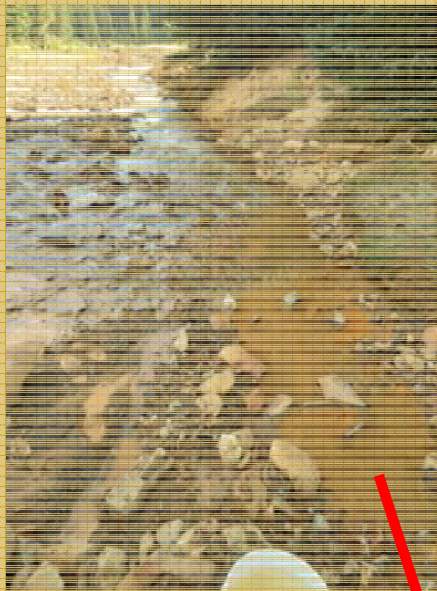
Gypsum
Needles

AN - Solids		R-1	R-2
<u>Parameter</u>	<u>Units</u>	<u>Result</u>	<u>Result</u>
Aluminum, total	mg/Kg	42,149	18,400
Arsenic, total	mg/Kg	7.66	54.8
Cadmium, total	mg/Kg	8.67	41.5
Calcium, total	mg/Kg	9,095	5190
Copper, total	mg/Kg	129	931
Iron, total	mg/Kg	36,996	414,000
Lead, total	mg/Kg	128	478
Magnesium, total	mg/Kg	7,250	5020
Manganese, total	mg/Kg	4,076	4940
Nickel	mg/Kg	40.2	455
Silver	mg/Kg	0.83	NT
Sulfur, total	mg/Kg	8,707	2.88
Zinc, total	mg/Kg	7,866	40,400
pH	S.U.	6.99	7.12

Cement Creek/Animas River Basin



Cement Creek: Mogul Mine to Gladstone, CO (August 14, 2015)



Sampling Location



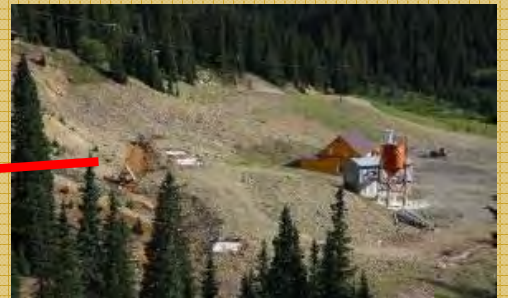
Mogul Mine



Gold King Mine
USEPA
Incident
Response



American
Tunnel

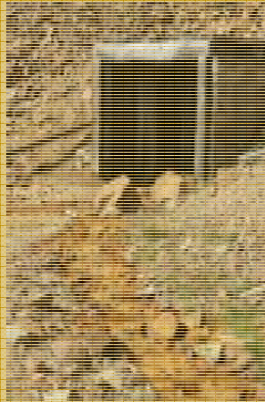
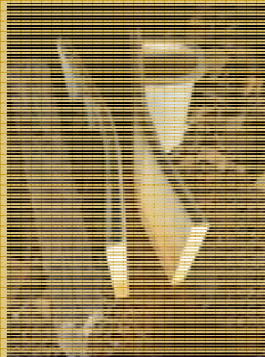


Mogul Mine, Gladstone CO

Legacy Site – Mine Drainage

Issues: pH, Heavy Metals

Technologies: AN



AN Treatability Results

Mogul Mine AMD Treatability Study Data

<u>ANALYTE</u>	<u>Untreated</u>	<u>AN Treated</u>	
	<u>Total</u>	<u>Total</u>	<u>Dissolved</u>
Aluminum	3.34	3.32	0.06
Arsenic	<0.0025	<0.0005	0.0002 J
Cadmium	0.0573	<0.0001	0.000125 J
Copper	0.0197	0.0087	0.0013 J
Iron	11.2	0.574	0.03 J
Lead	0.253	0.0007	0.00016 J
Manganese	26.2	0.27	0.30
Nickel	0.0216	0.0105	0.009
Silver	<0.0005	<0.0001	ND
Zinc	32.1	<0.050/0.0255	0.019
pH	3.46	N/A	6.48/7.52

Cement Creek, Gladstone CO

Site: Legacy AMD impacted creek

Issues: pH, Heavy Metals
(water & sediments)

Technologies: AN + MBS



<u>Water</u>		<u>Untreated</u>	<u>AN Treated</u>	
		<u>Cement Creek</u>	<u>Cement Creek</u>	<u>Cement Creek</u>
<u>Parameter</u>	<u>UNITS</u>	<u>Total</u>	<u>Total</u>	<u>Dissolved</u>
Aluminum	mg/L	12.7	1.29	0.04
Arsenic	mg/L	0.0027	0.0003 J	NT
Cadmium	mg/L	0.0397	0.0002 J	0.0002 J
Copper	mg/L	1.83	0.03	0.0013 J
Iron	mg/L	20.6	0.23	0.05
Lead	mg/L	0.0661	0.0002 J	<0.0005
Manganese	mg/L	19.5	1.422	1.446
Nickel	mg/L	0.0432	0.003	0.0037
Zinc	mg/L	8.86	0.009	0.0027 J
pH	S.U	3.19	N/A	7.83

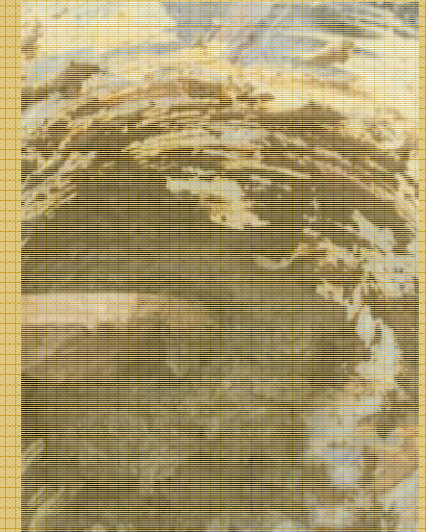
Cement Creek, Gladstone CO

AN Water Treatment Solid Residuals

Study Intent: Long Term Leaching

Technology: MBS

Unresolved: Iron, Mn



Multiple Extraction Results by Extraction No. and Type (USEPA SW-846 Method 1320, Extraction Method)

	AN Solids	1	2	3	4	5	6	7	8	9	10	1000 Yr
Metal	TOTAL (mg/Kg)	EP-1310	SPLP-1312	SPLP-1312	SPLP-1312	SPLP-1312	SPLP-1312	SPLP-1312	SPLP-1312	SPLP-1312	SPLP-1312	SUM
Aluminum	166,910	1.04	1.87	3.98	0.22	0.28	0.23	0.18	0.18	0.31	0.2	8.49
Cadmium	12.8	0.009	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.009
Copper	656	<0.02	0.021	0.028	0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	0.069
Iron	254,290	146.2	2.26	4.91	0.25	0.32	0.21	0.26	0.14	0.17	0.12	155
Lead	9.1	<0.05	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010
Manganese	8,525	17.26	1.625	0.365	0.059	0.039	0.14	0.21	0.042	0.047	0.028	19.8
Zinc	4,211	0.149	0.299	0.104	0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	0.57

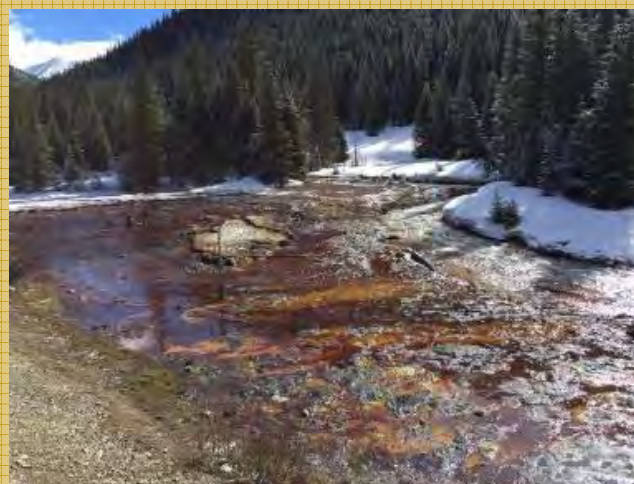
All units in mg/L unless noted

Cement Creek, Gladstone CO

Cement Creek Sediments

Study Intent: Long Term Leaching

Treatment Technology: MBS



Creek Sediments		Multiple Extraction Results by Extraction No. and Type (USEPA SW-846 Method 1320, Extraction Method)										1000-Yr
		1	2	3	4	5	6	7	8	9	10	SUM
Metal	Total (mg/Kg)	EP-1310	SPLP-1312	SPLP-1312	SPLP-1312	SPLP-1312	SPLP-1312	SPLP-1312	SPLP-1312	SPLP-1312	SPLP-1312	SUM
Aluminum	9130	0.279	0.216	0.461	0.164	0.062	0.174	0.406	0.556	0.562	1.65	4.53
Arsenic	43.7	<0.100	<0.100	<0.100	<0.100	<0.100	<0.100	<0.100	<0.100	<0.100	<0.100	<0.100
Cadmium	7.69	<0.050	<0.050	<0.050	<0.050	<0.050	<0.050	<0.050	<0.050	<0.050	<0.050	<0.100
Copper	274	0.026	<0.050	<0.020	0.021	0.025	<0.080	0.045	0.102	0.130	0.182	0.531
Iron	72300	1.86	0.564	0.771	0.397	0.337	0.505	1.40	1.48	1.51	3.58	12.4
Lead	1040	<0.100	<0.100	<0.100	<0.100	<0.100	<0.100	<0.100	<0.100	<0.100	<0.100	<0.100
Manganese	738	4.280	0.788	0.550	0.406	0.828	0.596	0.661	0.584	0.397	0.393	9.5
Zinc	897	0.189	<0.050	<0.050	<0.050	0.128	0.151	0.244	0.291	0.230	0.235	1.47

All units in mg/L

American Tunnel Mine

Gladstone, CO

Legacy Site – Mine Drainage

Issues: pH, Heavy Metals

Technologies: AN

Unresolved: pH vs. Al, Fe, Mn, Zn



AN Treatability Results

American Tunnel

April 12-15, 2016

<u>Parameter</u>	<u>Units</u>	<u>AN</u>	
		<u>Untreated</u>	<u>Treated</u>
Aluminum, total	mg/L	5.15	1.39
Aluminum, dissolved	mg/L	4.35	<0.500
Cadmium, total	mg/L	0.0019	0.0015
Cadmium, dissolved	mg/L	0.0022	0.0017
Calcium, total	mg/L	421	514
Calcium, dissolved	mg/L	424	391
Copper, total	mg/L	0.0160	<0.0100
Copper, dissolved	mg/L	0.0136	0.0018
Iron, total	mg/L	129	102
Iron, dissolved	mg/L	126	75.2
Magnesium, total	mg/L	30.1	29.6
Magnesium, dissolved	mg/L	29.9	23.1
Manganese, total	mg/L	44.2	33.5
Manganese, dissolved	mg/L	42.5	36.3
Lead, total	mg/L	<0.0050	<0.0050
Lead Dissolved	mg/L	<0.0050	<0.0050
Zinc, total	mg/L	14.1	4.10
Zinc, dissolved	mg/L	14.4	4.09
pH	S.U.	3.82	7.66

American Tunnel Mine, Gladstone CO

April 13, 2016



Gold King Mine

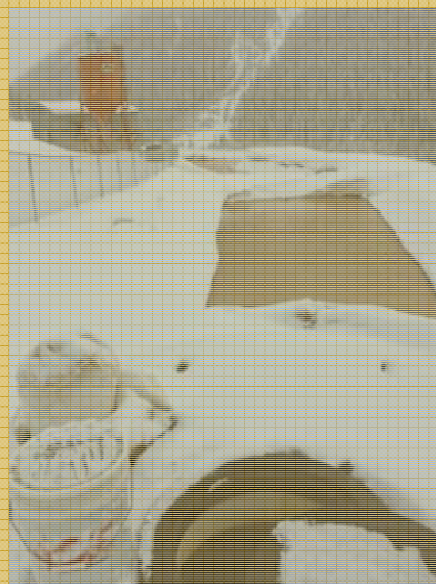
Gladstone, CO

Legacy Site – Mine Drainage

Issues: pH, Heavy Metals

Technologies: AN

Unresolved: Sulfate, Sulfide, Sulfur



AN Treatability Results

Gold King Mine AMD

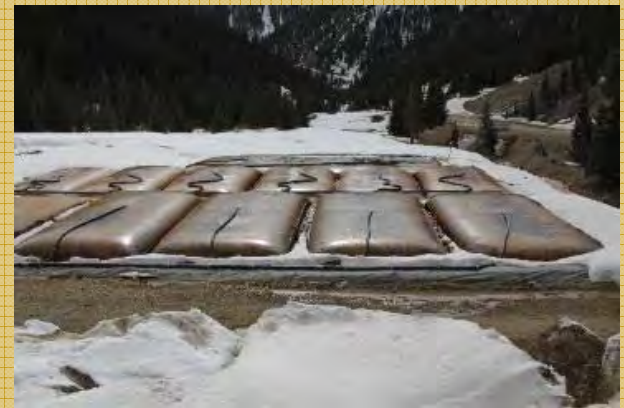
April 12-15, 2016

AMD Parameter	Units	Untreated	AN Treated			
			R-1	R-1A	R-2	R-3
Aluminum, total	mg/L	13.9	1.43	1.39	DGap	DGap
Aluminum, dissolved	mg/L	8.94	<0.500	<0.500	DGap	DGap
Arsenic, total	mg/L	53*	NT	NT	0.0004 J	0.00035 J
Arsenic, dissolved	mg/L	62*	NT	NT	0.0005	0.00036 J
Calcium, total	mg/L	367	342	340	143.8	102.2
Calcium, dissolved	mg/L	371	335	302	151.2	90.8
Cadmium, total	mg/L	0.0379	0.0285	0.0017	0.0012	<0.00025
Cadmium, dissolved	mg/L	0.0384	0.0302	0.0014	0.0009	<0.00025
Copper, total	mg/L	2.96	0.114	<0.0100	0.008	0.002
Copper, dissolved	mg/L	2.69	0.109	<0.0100	0.0016 J	0.0013 J
Iron, total	mg/L	58.5	5.58	<0.500	23.54	2.05
Iron, dissolved	mg/L	43.8	4.28	<0.500	0.03 J	0.007 J
Lead, total	mg/L	0.0193	<0.0050	<0.0050	0.00017 J	0.0017
Lead Dissolved	mg/L	0.0086	<0.0050	<0.0050	<0.0005	<0.0005
Magnesium, total	mg/L	17.7	16.4	13.4	7.4	2.8
Magnesium, dissolved	mg/L	17.4	16.3	12.1	7.7	2.5
Manganese, total	mg/L	21.5	18.2	5.53	7.762	0.303
Manganese, dissolved	mg/L	20.0	18.6	5.44	4.631	0.012
Sulfate	mg/L	1685*	983	811	NT	NT
Sulfide, total	mg/L	NT	NT	NT	<0.05	NT
Sulfur, total	mg/L	NT	NT	NT	157	153
Sulfur, dissolved	mg/L	NT	NT	NT	167	166
Zinc, total	mg/L	21.5	5.54	<0.100	0.038	0.019
Zinc, dissolved	mg/L	10.1	5.69	<0.100	0.0074	0.001 J
pH	S.U.	5.2	5.75	7.66	6.62	7.24
pH	S.U.	3.28*				

* Historic average

Gold King Mine, Gladstone CO

April 13, 2016 – USEPA Settling Pond/Lime/Polymer and Solids Dewatering System



Gold King Mine, Gladstone CO



GKM - AN Solids Maturation



GKM - AN Clarified Effluent

Miscellaneous AN Studies & Curiosities

- AN Solids Settling Times
- Lime (Ca hydroxide) vs. AN Treatment of Mogul AMD
- Sulfate, Sulfide, Sulfur (AMD > AN effluent > AN Solids)
- Total Metals in AN Solids (recoverable commodity metals)
- Oxidation/Reduction ($\text{Fe}^{+3} \leftrightarrow \text{Fe}^{+2}$ via AN) & ($\text{Mn}^{+2} \rightarrow \text{MnO}^{+4} \downarrow$)
- Metal mineral forms in AN solid residuals?
- Carbon dioxide > carbonates >> Metallic carbonates \downarrow ?
- MBS treated metals: long-term leachability resistance to AMD?
- Elimination of clarification?
- In-mine AN + MBS solids dewatering in final repository?

AN Solids Settling Times

Left to Right:

- 2 minutes
- 5 minutes
- 7 minutes
- 10 minutes



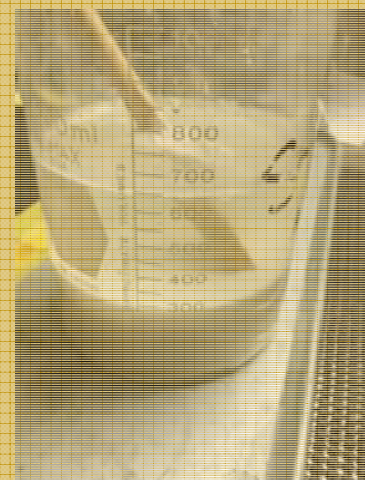
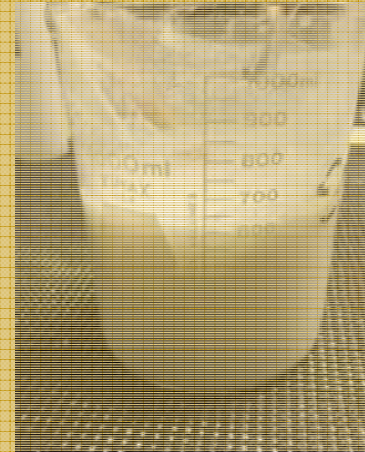
30 minutes

9.86 gallons of Mogul Mine AMD → 86.7 g of AN solids (air dried to damp paste)

AN vs. Lime Treatment – Mogul Mine AMD

Comparison of Lime vs. AN Treated AMD for Dissolved Metals and pH Mogul Mine, Cement Creek/Animas River Basin, Colorado

<u>Parameter</u>	<u>Units</u>	<u>Untreated</u>	<u>Lime Treated</u> <u>pH 7.86 S.U.</u>	<u>Lime Treated</u> <u>pH 10.34 S.U.</u>	<u>AN Treated</u> <u>pH 7.00 avg. S.U.</u>	<u>Potential</u> <u>Discharge</u> <u>Limits</u>
Aluminum	mg/L	3.5	0.05	0.17	0.06	N/A
Arsenic	mg/L	<0.0025	0.0004 J	0.0003 J	0.0002 J	N/A
Cadmium	mg/L	0.054	0.031	<0.00025	0.000125 J	0.050
Chromium	mg/L	N/A	<0.001	<0.001	N/A	N/A
Copper	mg/L	0.0187	0.002	0.0007 J	0.0013 J	0.015
Iron	mg/L	25.5	<0.050	<0.050	0.03 J	N/A
Lead	mg/L	0.251	0.00016 J	<0.0005	0.00016 J	0.010
Manganese	mg/L	28.1	22.10	0.068	0.30	TBD
Nickel	mg/L	0.016	0.017	0.007	0.009	N/A
Silver	mg/L	0.00006 J	<0.0002	<0.0002	<0.00001	N/A
Zinc	mg/L	32.1	8.740	0.022	0.019	0.75
pH	S.U.	3.46	7.86	10.34	6.48/7.52	6.5-9.0



AN Oxidation-Reduction



AN Settling Column



Decanted Solids



Decanted Solids + 30% H₂O₂

Summary of AN & MBS

- AN is electric power driven. Comparable/less cost than alkali.
- Elevates pH of AMD and other acidic fluids without reagent addition
- Removes heavy metals
- No filtration (used to date), but suitable for polishing component addition.
- Scalable. 10-50 gpm system in fabrication.
- No base, alkali, polymer, or other chemical reagents required.
- AN solids:
 - No mass increase from added calcium or other chemical reagents
 - Treatable for RCRA metals per TCLP with MBS
 - ALL metals in solids treatable with MBS to yield end-product solids with 1000 year stability against leaching
- AN effluent suitable for delivery to penstock and turbine for hydropower generation for AN system. Excess to grid??



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- Todd Hennis, Owner: Mogul, Gold King and American Tunnel Mines



QUESTIONS?

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