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Semi-Passive Bioreactors and Cost-Effective Lime Treatment at Remote Locations

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Bridging the Gap Between Passive and Active

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PASSIVE	→	ACTIVE
Limestone channels	SAPPS	HDS
Organic bioreactors	Semi-Passive bioreactors	RO
	RCTS Lime Treatment	

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Solubility Products for Metal Complexes

Complex	K_{sp}	Complex	K_{sp}
HgS	6.38×10^{-53}	$Zn(OH)_2$	7.68×10^{-17}
$Fe(OH)_3$	2.67×10^{-39}	$Ni(OH)_2$	5.54×10^{-16}
CuS	1.28×10^{-36}	$Cd(OH)_2$	5.33×10^{-15}
CdS	1.4×10^{-29}	MnS	4.55×10^{-14}
PbS	8.81×10^{-29}	$Mn(OH)_2$	2.04×10^{-13}
ZnS	2.91×10^{-25}	$PbCO_3$	1.48×10^{-13}
NiS	1.08×10^{-21}	$CdCO_3$	6.20×10^{-12}
$Pb(OH)_2$	1.4×10^{-20}	$FeCO_3$	3.13×10^{-11}
FeS	1.57×10^{-19}	$MnCO_3$	2.23×10^{-11}
$Fe(OH)_2$	4.79×10^{-17}	$NiCO_3$	1.45×10^{-7}

Treatment Process

Sulfate-reducing Bioreactors

Sulfate-reduction

$$4\,AH_2 + SO_4^{2-} + 2\,H^+ \longrightarrow 4\,A^{2-} + H_2S + 4\,H_2O$$

Ethanol + Sulfate + Acidity → Carbon Dioxide + Hydrogen sulfide + Water

Sulfide Precipitation of Metals

$$H_2S + M^{2+} \longrightarrow MS + 2\,H^+$$

Hydrogen sulfide + Metals → Metal sulfides

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Leviathan Bioreactors

Constructed fall 2002 – Spring 2003

Pretreat by raising pH over 4

2 rock SRB cells

1 pretreat and 2 post treat ponds

Design flow 20-30 gpm, Peak 40 gpm

Average flow Aspen Seep 12 gpm

Climate – cool (snow in April)

During UNR operation:

visits 1 to 2 times per month in winter

visits weekly in summer

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Comparison Gravity-Recirculation

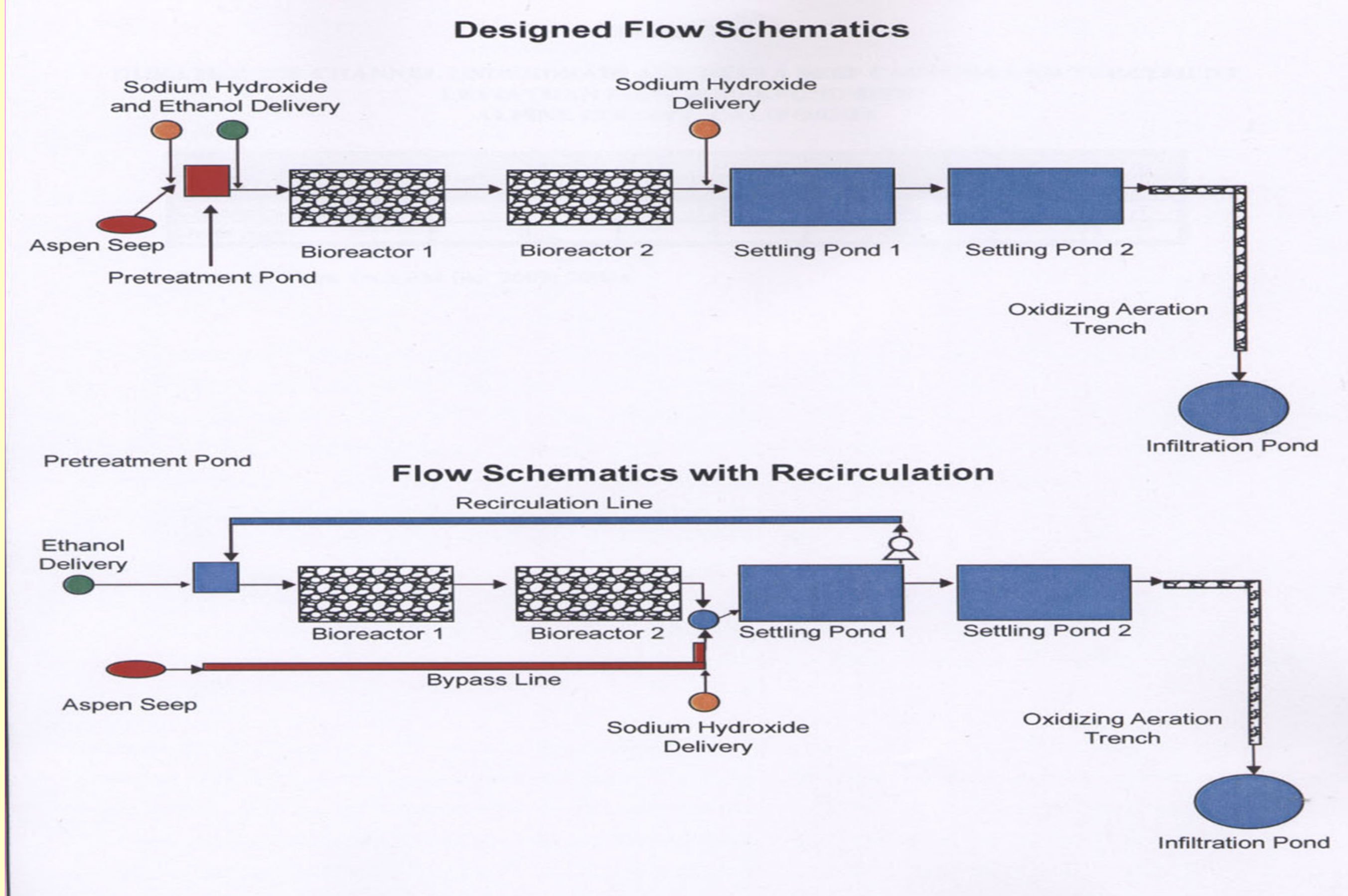

FIGURE 2-6

COMPARISON OF ASPEN SEEP BIOREACTOR OPERATION WITH AND WITHOUT RECIRCULATION LEVIATHAN MINE SUPERFUND SITE ALPINE COUNTY, CALIFORNIA

Modified from Tsukamoto 2004

Tetra Tech EM Inc.

Constituent	Aspen Seep	Bioreactor 1 effluent	Bioreactor 2 effluent	Discharge	Discharge objectives
pH	3.17	4.70	4.77	7.19	6-9
SO_4	1502	1307	1269	1222	NA
Al	35	21	18	<0.1	4.0
Fe	107	69	65	1.9	2.0
Ni	0.40	0.26	0.21	0.06	.84
Cu	0.55	0.01	<0.01	<0.01	.026
Zn	0.74	0.08	0.04	0.02	.21


United Rentals
45
DANGER
HIGH VOLTAGE

Constituent	Aspen Seep	Bioreactor 1 effluent	Bioreactor 2 effluent	Discharge	Discharge objectives
pH	2.93	6.79	6.86	7.66	6-9
SO_4	1530	1090	1080	1170	NA
Al	28	<0.5	<0.5	<0.5	4.0
Fe	99	0.16	0.13	0.04	2.0
Ni	0.50	0.15	0.05	0.1	0.84
Cu	0.62	0.02	0.01	0.01	0.026
Zn	0.73	0.02	0.02	0.06	0.21

Residence Time and Working Volume for Leviathan Bioreactor

System Component		Working Volume	Calculated Residence Time (38 Lpm)
Pretreatment Pond		100 ft^3	0.5 days
Pond 1		5,300 ft^3	3.5 days
Pond 2		3,000 ft^3	1.5 days
Settling Pond 1		16,500 ft^3	8.5 days
Settling Pond 2		18,000 ft^3	9.4 days
	Totals	**42,900** ft^3	**23 days**

Nacimiento Mine

US Forest Service, New Mexico

Up to 120 gpm, Rock Substrate, Recycle

Construction Completed 2009

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Nacimiento Mine

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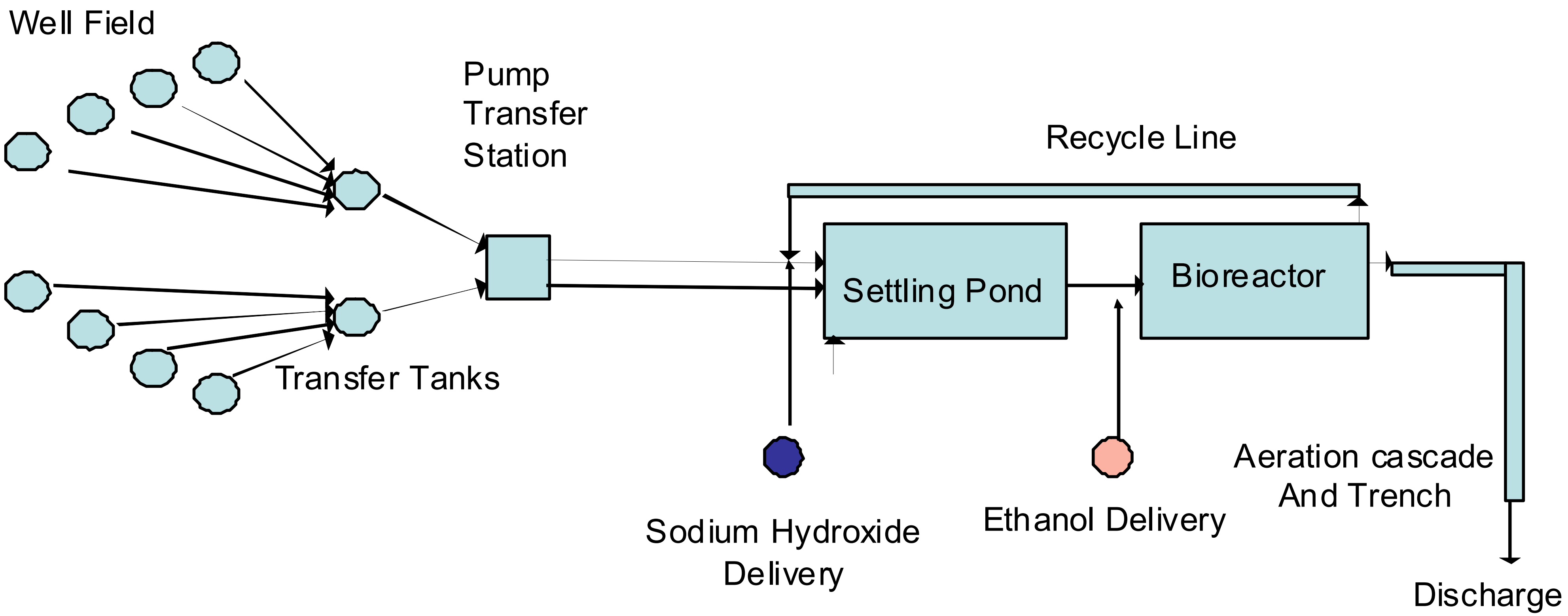
Nacimiento Mine



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Nacimiento Mine

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Nacimiento Mine

Residence Time and Working Volume for Nacimiento Bioreactor

System Component		Working Volume	Calculated Residence Time (240 Lpm)
Settling Pond		117,000 ft^3	7.5 days
Bioreactor		50,000 ft^3	3.2 days
	Totals	**167,000** ft^3	**10.7 days**

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Comparison Between Nacimiento and Leviathan

Average Influent and Effluent Concentrations of Constituents of Concern (Dissolved Metals mg/L)

Sample Location	**Number of sampling events**	**pH**	**Sulfate**	**Al**	**Cu**	**Fe**	**Ni**	**Zn**
Leviathan Mine Influent*	7			40.0 4.837**	0.795 0.187**	116 13**	0.529 0.034**	0.776 0.052**
Leviathan Mine Effluent*	7			0.0527 0.026**	0.0046 0.003**	2.704 3.0**	0.0697 0.044**	0.0089 0.007**
Leviathan Discharge Objective*				4.000	0.026	2.000	0.840	0.210
Nacimiento Mine Influent	9	4.91	884	2.35 1.83**	17.84 25.12**	61.6 0.041**	0.09 0.041**	4.44 2.239**
Nacimiento Mine Effluent	9	6.89	385	<0.05***	0.004 0.002**	0.07 0.039**	0.0032 0.001**	0.0083 0.004**
Nacimiento Discharge Objective		6.6-8.8	NA	0.087	0.0152	NA	0.088	0.198

*Data from EPA 2006

**Standard deviation

*** 4 values detected all at less than 0.056 mg/l and an average concentration of .036 mg/L

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Neutralization Options for Treating Acid Mine Drainage

	Advantages	Disadvantages
Limestone	Mostly Passive	Higher space requirement Limited lifetime Higher capital cost Limited to AMD with specific chemistry
Caustic	Semi-passive Easily implemented	Higher chemical cost Increased sludge volume Adds sodium to water
Lime precipitation	Removes sulfate Decreases TDS Can treat AMD with high loading	Higher capital cost Requires some O&M

Lime Precipitation

Add lime (CaO) or $Ca(OH)_2$ to raise the pH

Precipitate metals as hydroxides

Precipitate sulfate as gypsum

Requires oxygen addition if there is significant dissolved iron, manganese

Oxygen addition is typically accomplished with large compressors and air diffusers and tanks

Lime addition requires thorough mixing due to it's low solubility and slow dissolution rate.

Mixing is typically accomplished with large mixers inside reaction tanks

Labor and energy demanding

RCTS CONCEPT

Rotating perforated cylinders add oxygen from the atmosphere to the water

Energy efficient 10 hp system treats up to 500 gpm

Aggressive agitation near 100% reagent efficiency
Reduced lime costs and sludge handling costs

Low maintenance rotor maintenance on most sites
2 to 3 times per year (takes 3 to 4 hours)

Small footprint most units are mobile

Effective Aeration and Oxidation

Less Sludge produced

Faster sludge settling

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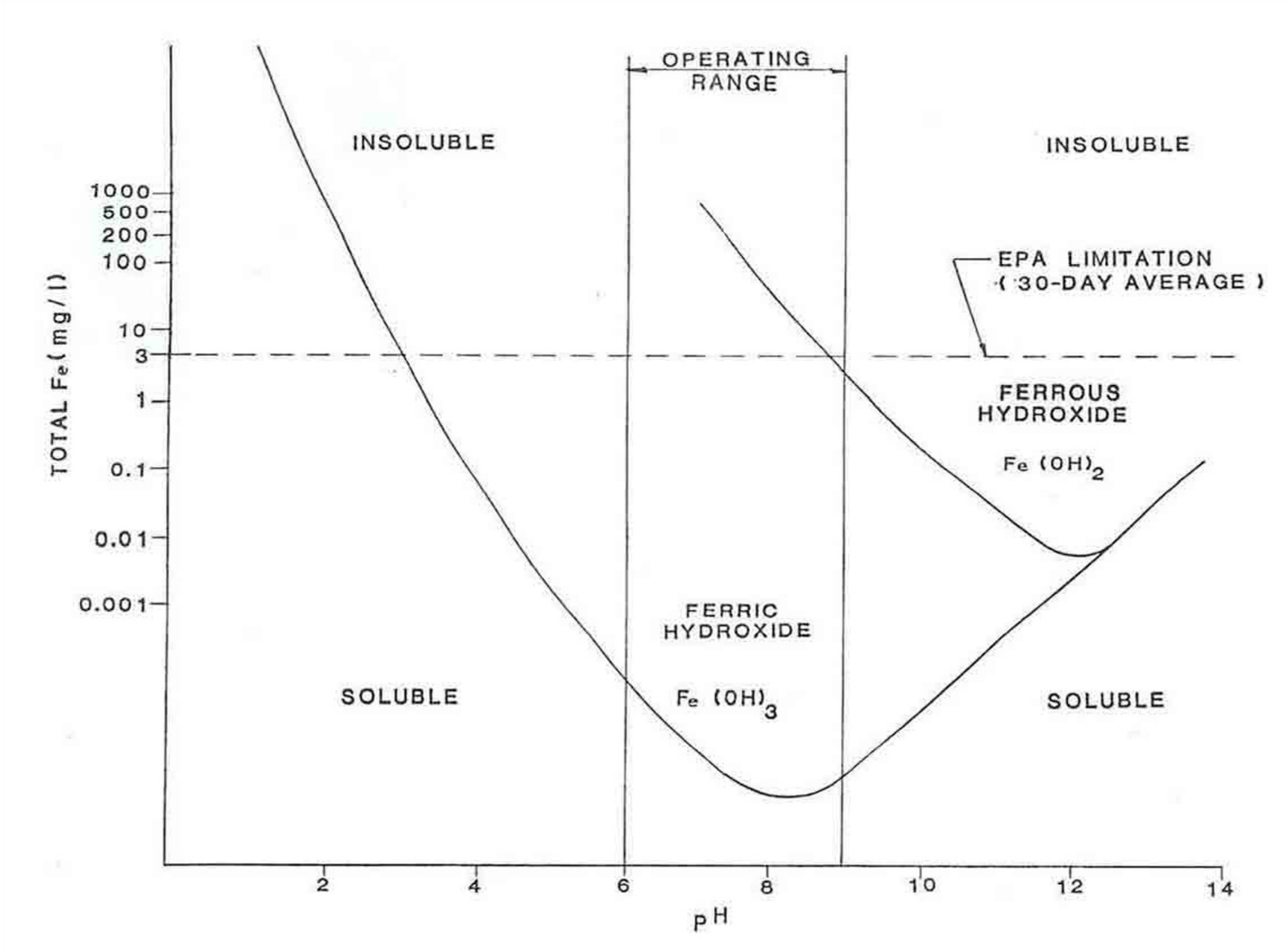
Iron Hydroxide Solubility with Respect to pH

pH vs Total Iron Solubility Diagram for Ferrous and Ferric Hydroxide Precipitation. Note the Minimum Solubility for Manganese Precipitation is Between pH 9 and 10. (Taken from USEPA 1983).



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Iron and Manganese Oxidation

Sludge Generation

RCTS: Most of the lime dissolves, sludge volume low

Conventional system: 40-70% lime utilization, sludge volume higher

Passive Systems: inefficient lime utilization, higher volume of waste

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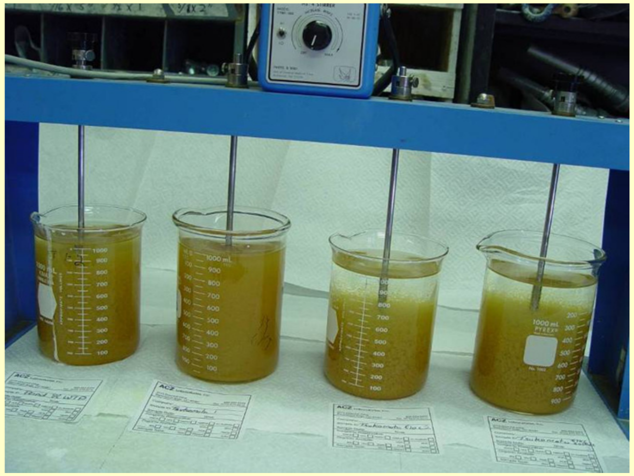
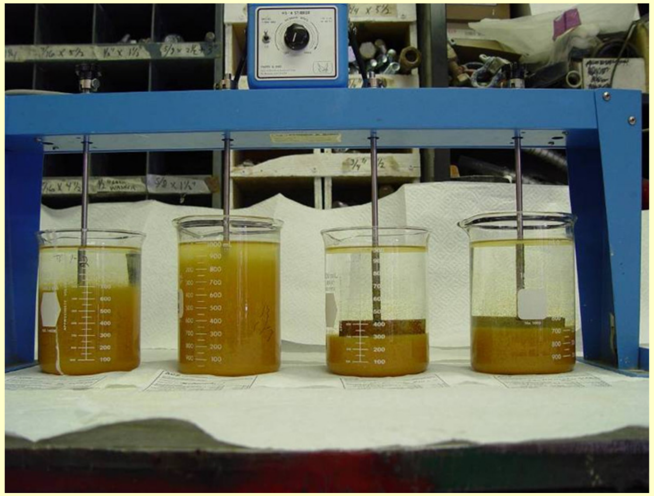
Sludge Settling Grouse Creek

Grouse Creek Mine RCTS Settling vs Conventional System



A B C D

1 Minute



A B C D

2 Minute

A= Conventional System with polymer and sulfide
B= RCTS no polymer no sulfide
C= RCTS with polymer no sulfide
D= RCTS with polymer and sulfide

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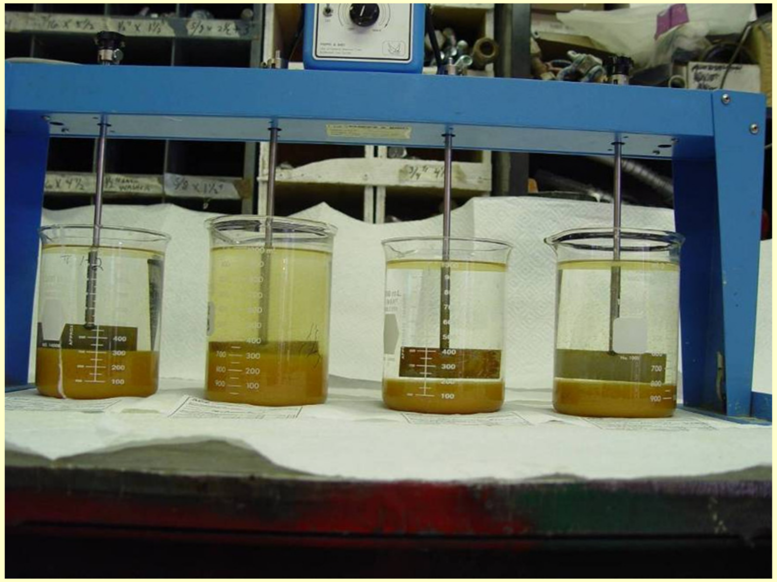
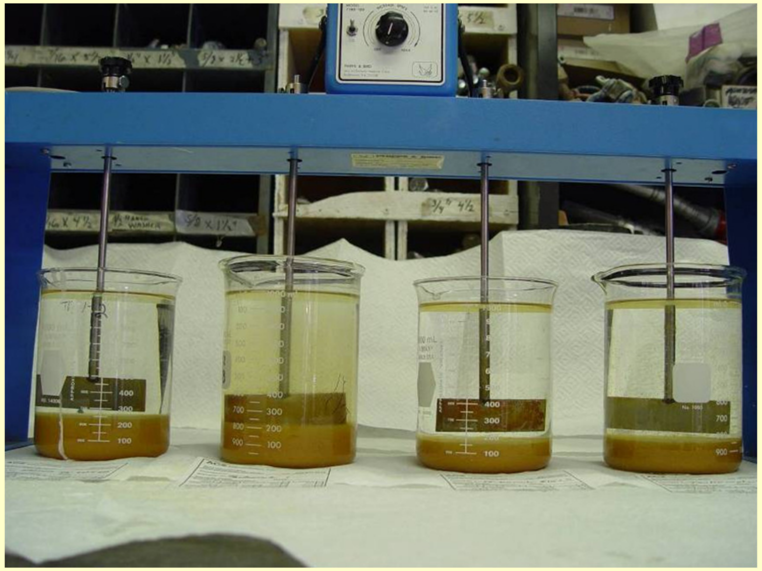
Sludge Settling Grouse Creek



A B C D

5 Minute Settling



A B C D

20 Minute Settling

A= Conventional System with polymer and sulfide
B= RCTS no polymer no sulfide
C= RCTS with polymer no sulfide
D= RCTS with polymer and sulfide

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Sludge Settling Cement Creek

10 minutes

20 minutes

75 minutes

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Sludge Settling American Tunnel

15 minutes

45 minutes

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Sludge Settling American Tunnel

120 minutes

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Comparison of RCTS with Conventional System Leviathan Mine

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Comparison of RCTS with Conventional System Leviathan Mine

- Plowed the road & mobilized the entire system including lime in approximately 1 week.
- Treated 24 hours/day with 2 man crew onsite an average of 4.6 hours/day
- Met USEPA directives
- Treated and actively discharged ~7.5 million gallons of water containing iron as high as 610 mg/L and aluminum as high as 490 mg/L.
- Removed ~ 1800 yd3 of sludge from the lined pond in 2 days

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RCTS vs Conventional System Leviathan Mine

	Hydraulic Capacity (gallons)	Maximum Flow Rate (gpm)	Average Flow Rate	System Residence Time Minutes Max Flow (Ave Flow)	Effluent pH Ave	Gallons water Treated per ton lime
Conventional System	40,000	300	200	133 (200)	7.8	73,700
Rotating Cylinder Treatment System	130	330	55	0.23 (2.36)	8.16	149,700

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Comparison of RCTS with Conventional System Leviathan Mine

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Comparison of RCTS with Conventional System Leviathan Mine

	Hydraulic Capacity (gallons)	Average Flow Rate (gpm)	System Residence Time (minutes)	Influent pH	Effluent pH	Filter Bag pH	Effluent DO mg/l	Average Lime per Day
Conventional Tank Reactor System	4000	30.38	131.67	4.73	7.88	8.12	4.22	398
Rotating Cylinder Treatment System	1600 * includes dosing tank	27.33	58.54	4.86	8.12	8.11	7.86	233

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Elizabeth Mine Dry Feed System

WESTON SOLUTIONS
an employee-owned company

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Elizabeth Mine Dry Feed System

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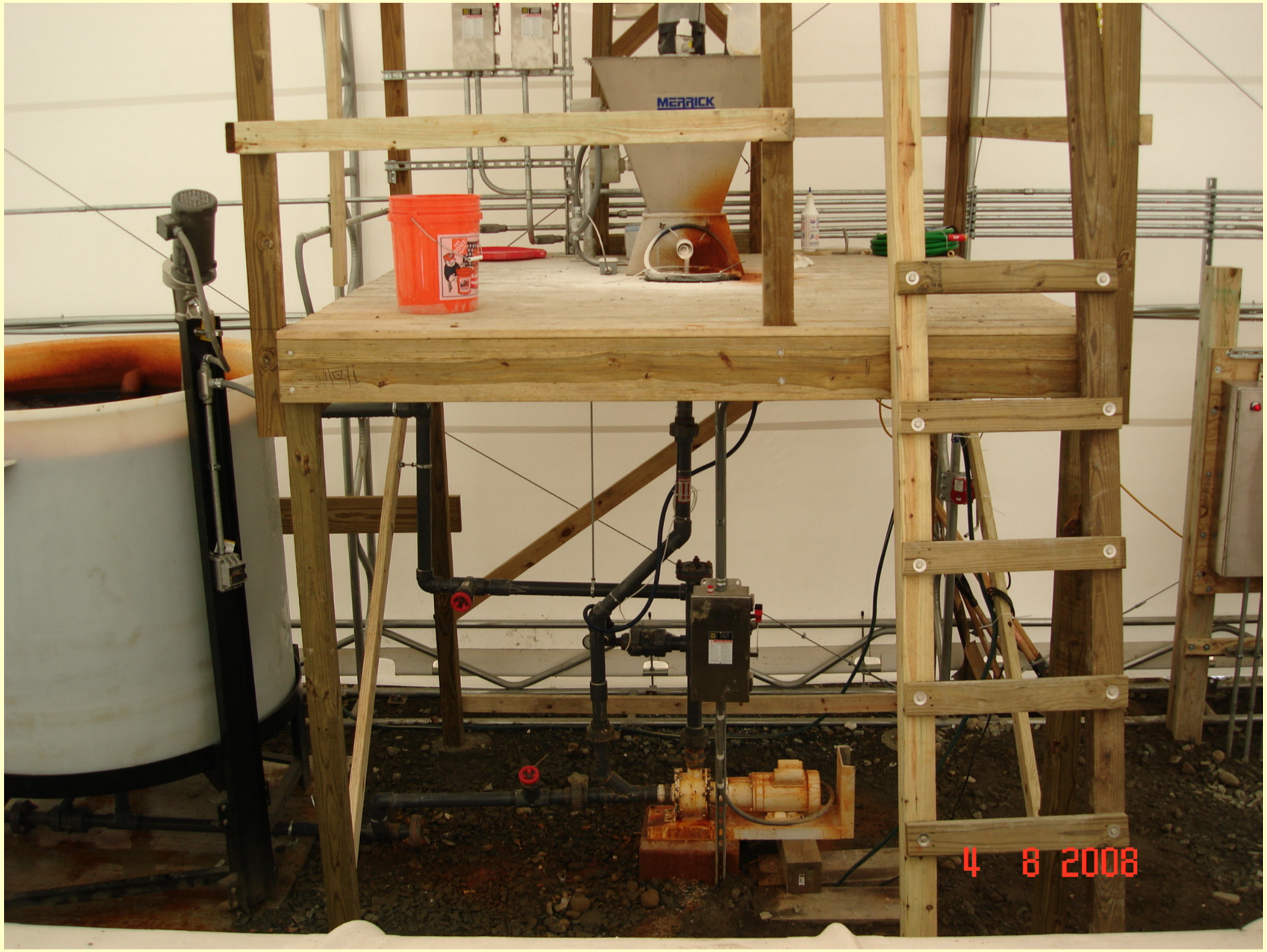

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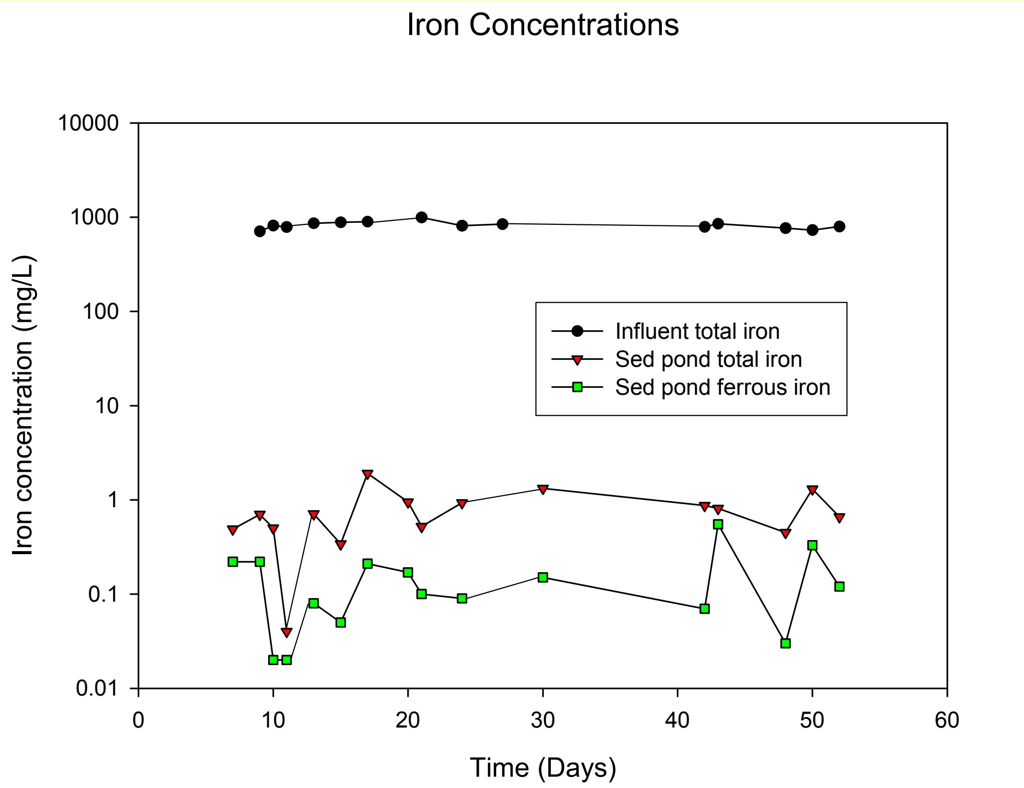
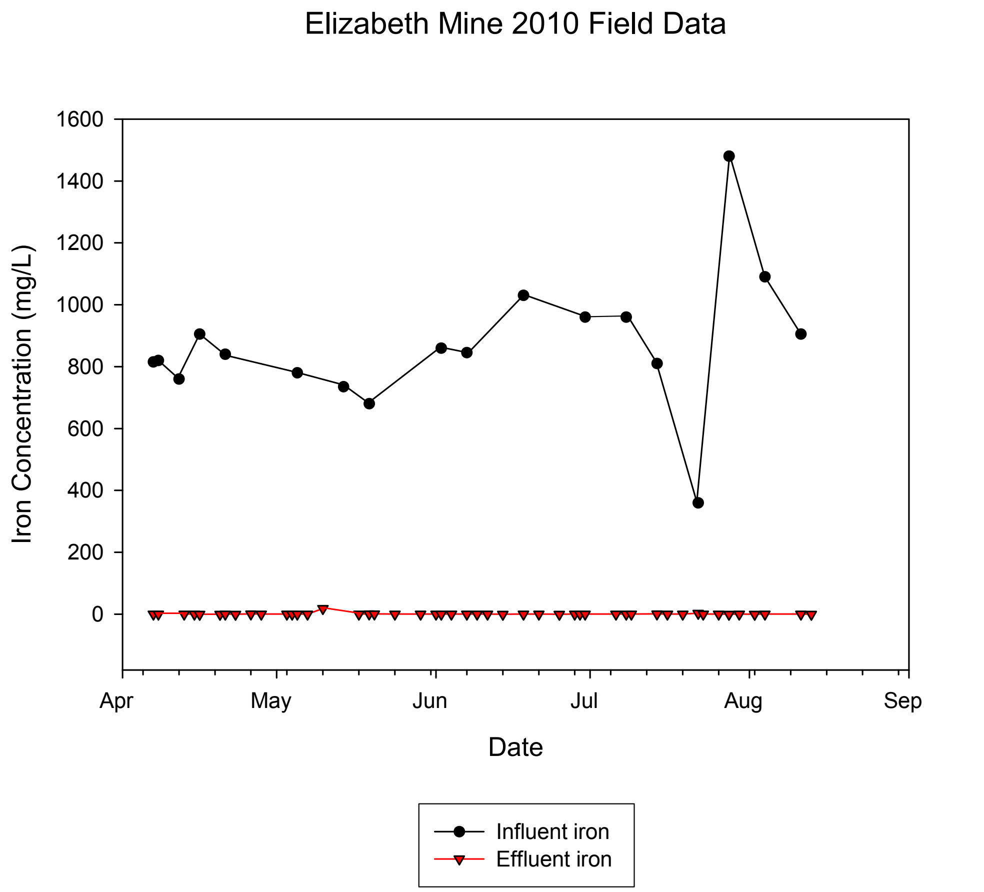
Results from Startup and 2010 Season Elizabeth Mine





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Swift Gulch System

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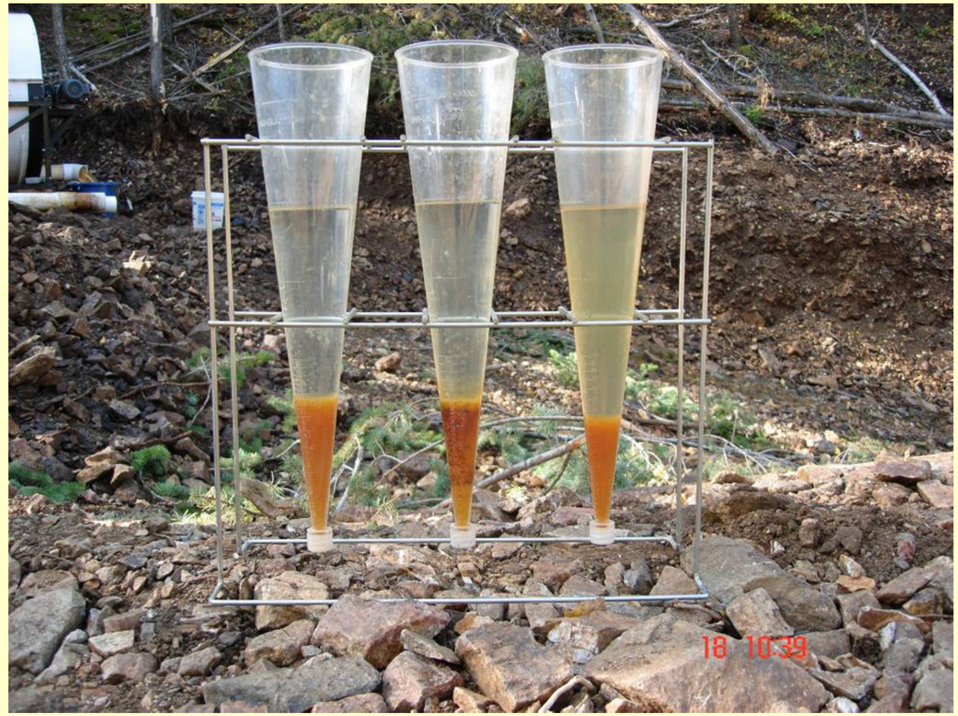
Swift Gulch System

1 hour



2 hours

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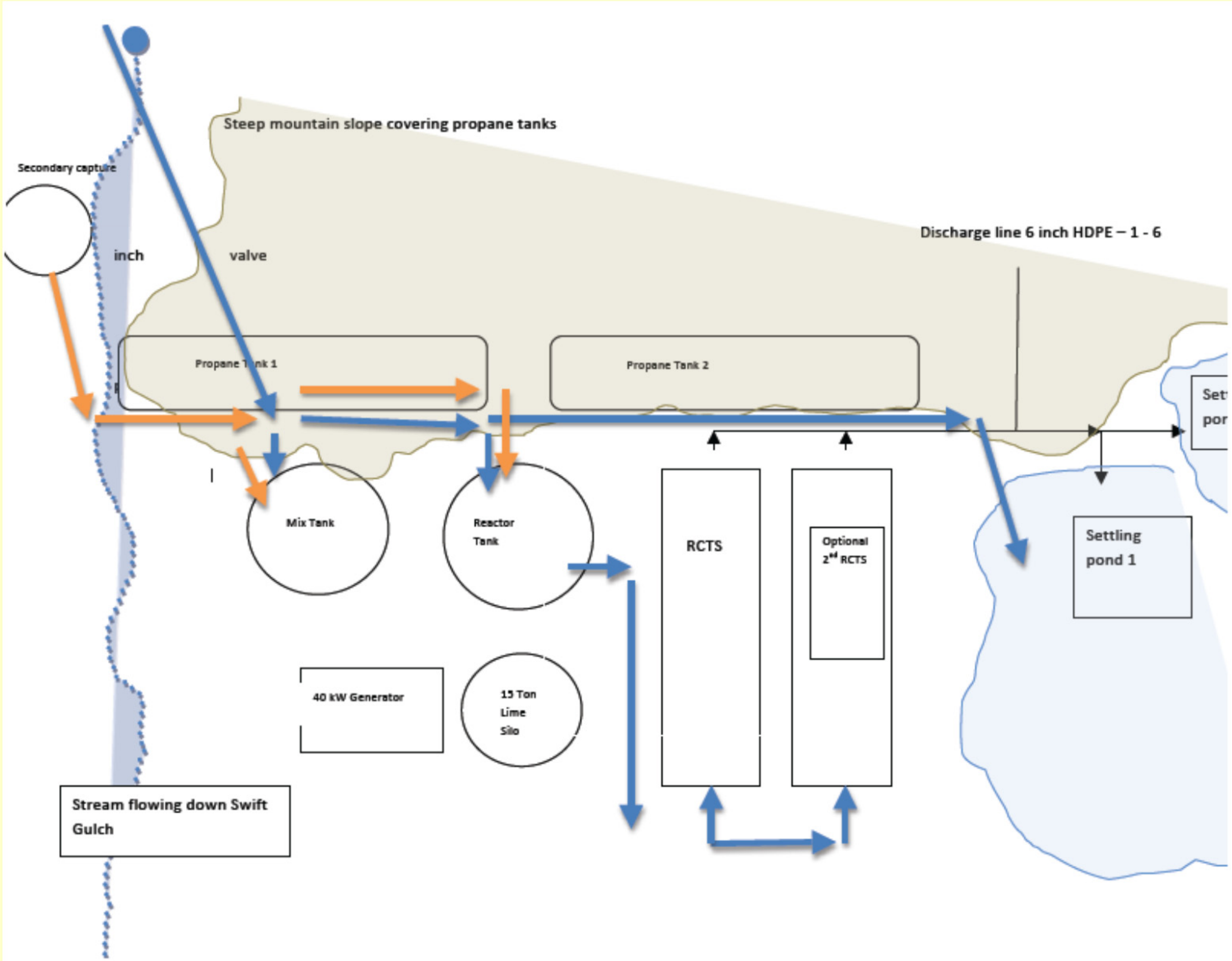
2010 Swift Gulch

Swift Gulch

- Utilize hydrated lime
- Treats for Al, As, Cd, Fe, Mn and Zn
- 50 to 500 gpm with iron up to 100 mg/L
- System checked daily (less than 1 hour)

2010 Swift Gulch System



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Alaska Connex System System

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Alaska Connex System

- Utilize bagged hydrated lime, hand mix
- Operated at 10 to 20 gpm intermittently

Alaska Project

Sample # Test pH	Date	Lime Dose (mg/L)	24 Hr pH	Fe mg/L	Mn ug/L	Ni ug/L	Zn ug/L	Al ug/l	Cd ug/l	Cu ug/L
nfluent 2.93	1/15/2009		2.80	32.70	5330	970	21500	10840		730
4.00	1/28/2009	63	4.20	1.06	5160	980	9010	7200		570
5.00	1/28/2009	115	5.37	0.07	4430	890	8350	700		120
6.00	1/28/2009	120	5.84	0.00	4170	790	6770	< 500		<50
7.00	1/28/2009	155	6.21	0.02	3510	310	1440	< 500		<50
7.50	1/27/2009	160	6.48	0.03	3460	300	1020	< 500		<50
8.00	1/27/2009	168	8.28	0.02	2770	170	300	**<4.5**	**40.00**	<50
8.50	1/27/2009	185	8.37	<0.01	2070	100	130	**<4.5**	**17.00**	<50
9.00	1/27/2009	203	8.54	<0.01	1000	80	<50	**21**	**6.90**	<50
9.50	1/27/2009	220	8.65	<0.01	340	<50	<50	**56**	**2.30**	<50
10.00	1/27/2009	328	8.80	<0.01	190	<50	<50	800	**1.20**	<50
10.50	1/27/2009	380	9.08	<0.01	< 50	<50	<50	1400	**<0.98**	<50
11.00	1/27/2009	400	10.81	<0.01	< 50	<50	<50	5800	**<0.98**	<50
11.50	1/27/2009	545	10.92	<0.01	< 50	<50	<50	1600	**3.30**	<50

	Fe	Mn	Ni	Zn	Al	Cd	Cu
pH Modification Pond	1.00	50	281	640	87	0.98	49.2
Outflow 1	1.00	50	42.28	96.02	87	0.21	7.27

Bold= certified samples run by ICP

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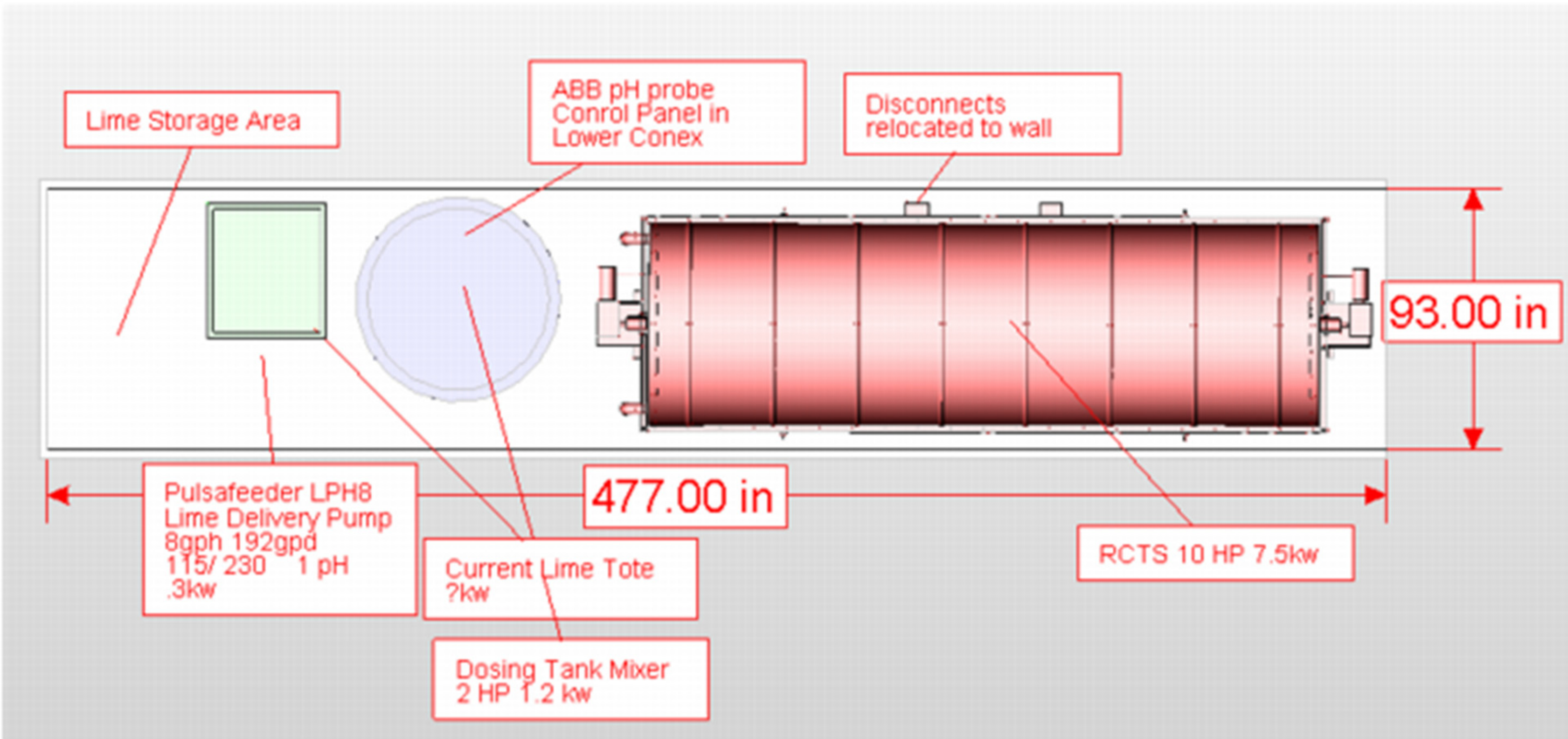
Alaska Connex System



Alaska Connex System

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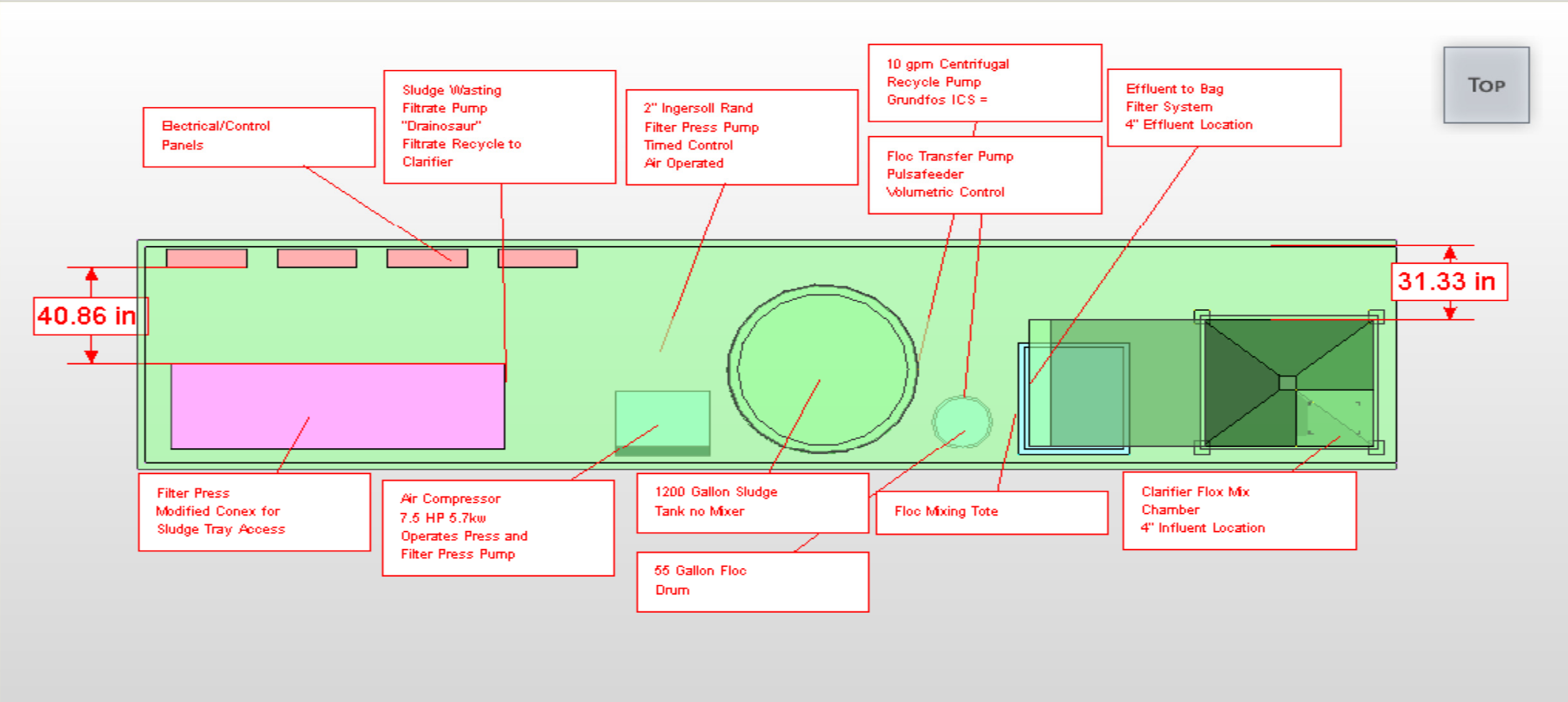

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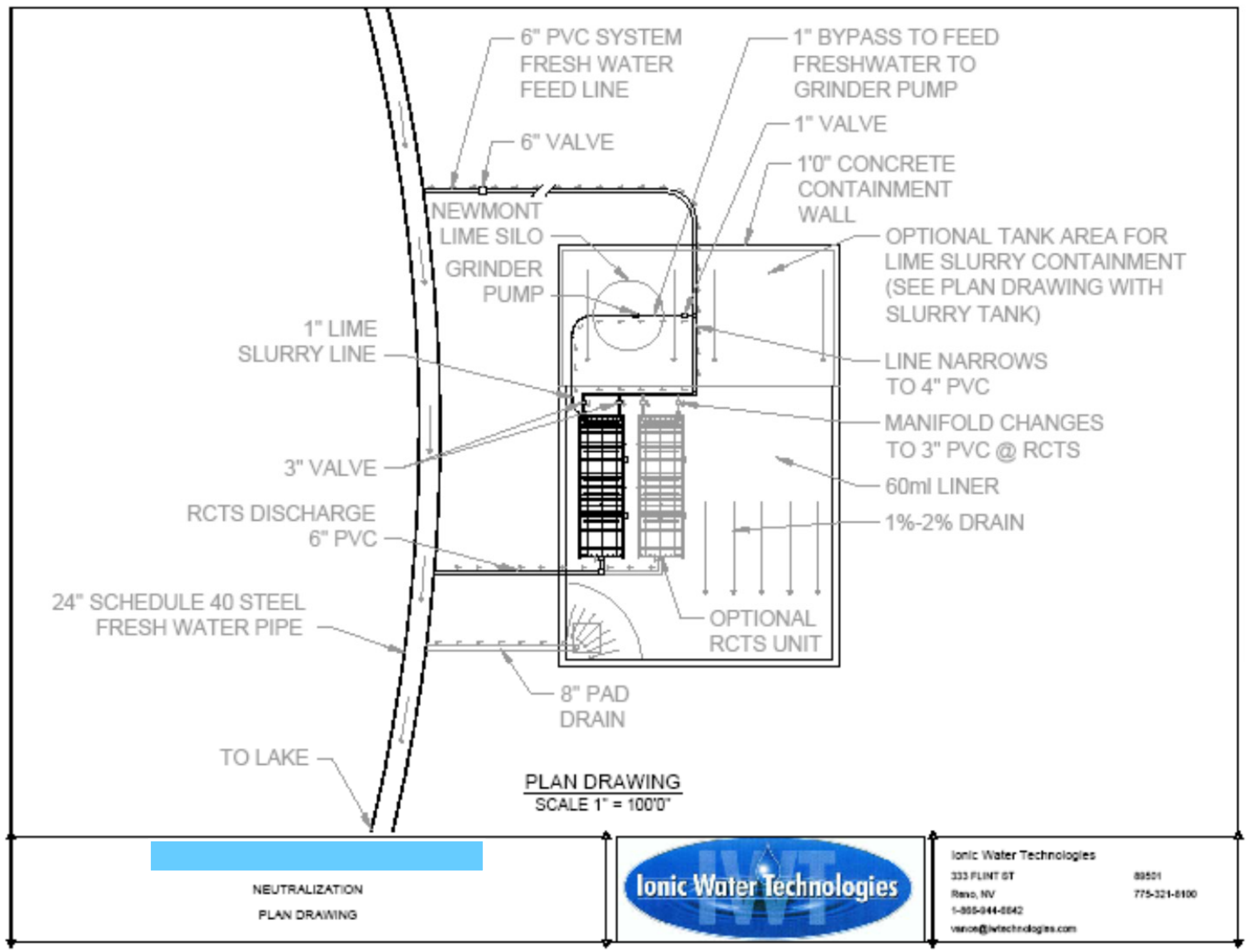
Nevada Pit Lake



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Nevada Pit Lake

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Nevada Pit Lake

- Utilize 1/8 minus CaO fed through a silo

- Typically a slaker is required to convert CaO to $Ca(OH)_2$

- Utilize the RCTS and IWT lime grinder to slake the lime and dissolve it

- Add CaO at 25 to 35 lbs/ min and slake with side stream of well water to obtain a slurry (~1 silo every 3 days)

- Re-mix with well water and introduce to pitlake

- System is maintained once per week

- New grinder every 8 to 12 weeks