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A Semi-Passive Bioreactor for Treatment of a Sulfate and Metals Contaminated Well Field Nacimiento Mine, New Mexico

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Why Semi-passive?

PASSIVE		ACTIVE
Limestone channels		HDS
Organic bioreactors	Semi-Passive bioreactors	RO
O&M		
Less	moderate	More
Effectiveness		
Good for low Concentrations of metals	Good for full concentration range Removes sulfate to low conc	Proven and Robust for full concentration range
Cost		
Low if metals concentrations are low High for medium to high conc.	Good for medium concentrations Higher for low and high conc.	High for low to medium metals loading low for high metals loading

Particularly good for sites with moderate loading and sites that require sulfate removal

Treatment Process
Sulfate-reducing Bioreactors

Sulfate-reduction

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

Ethanol + Sulfate + Acidity → **Bicarbonate + Hydrogen sulfide + Water**

Metal Sulfide Precipitation

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

Hydrogen sulfide + Metals → **Metal sulfides**

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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}

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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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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

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Nacimiento Mine

- Operations began December 2008
- Rock Substrate, Recycle system
- Climate - cool elevation 7500 ft
- Design flow up to 120 gpm
- Site visits 1 to 2 times per week

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Site Background

- 1880- late 1960s Copper was mined from shallow shafts and adits
- Late 1960s until 1975, copper was mined from open pit
- Beginning in 1984, in-situ leaching to recover copper was pilot tested. The 225,000 gallons of leaching solution (ferric chloride and sulfuric acid) was injected into the ground.
- Copper recovery was unsuccessfull, and the sulfuric acid and leachates remained in the groundwater.
- In 1987 the New Mexico Environment Department (NMED) began investigating the mine, concerned about migration of groundwater and runoff from the site.
- Five studies were conducted including: a Preliminary Assessment (NMED, 1987), Screening Site Assessment (NMED, 1989), an Expanded Site Inspection (NMED, 1994), and groundwater sampling for the Forest Service by Walsh Environmental Engineers and Scientists LLC (2001) and Maxim Technologies Inc. (2004).
- With advice from EPA, the Forest Service employed Weston Solutions and TKT to design a water extraction and treatment system and ERRG to construct the system.
- ERRG and IWT/TKT were selected to provide operations and maintenance for the system.

Nacimiento Mine

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Nacimiento Mine

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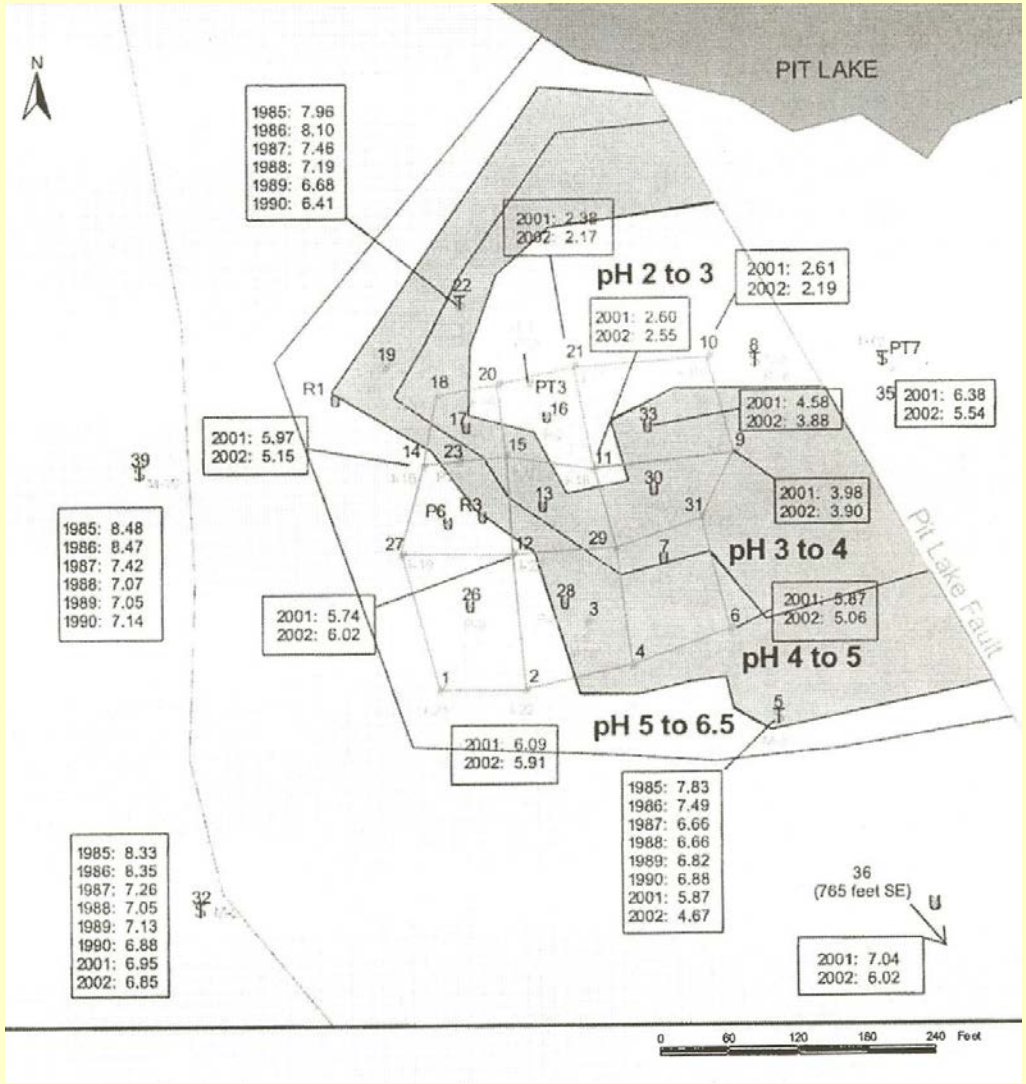
Nacimiento Mine



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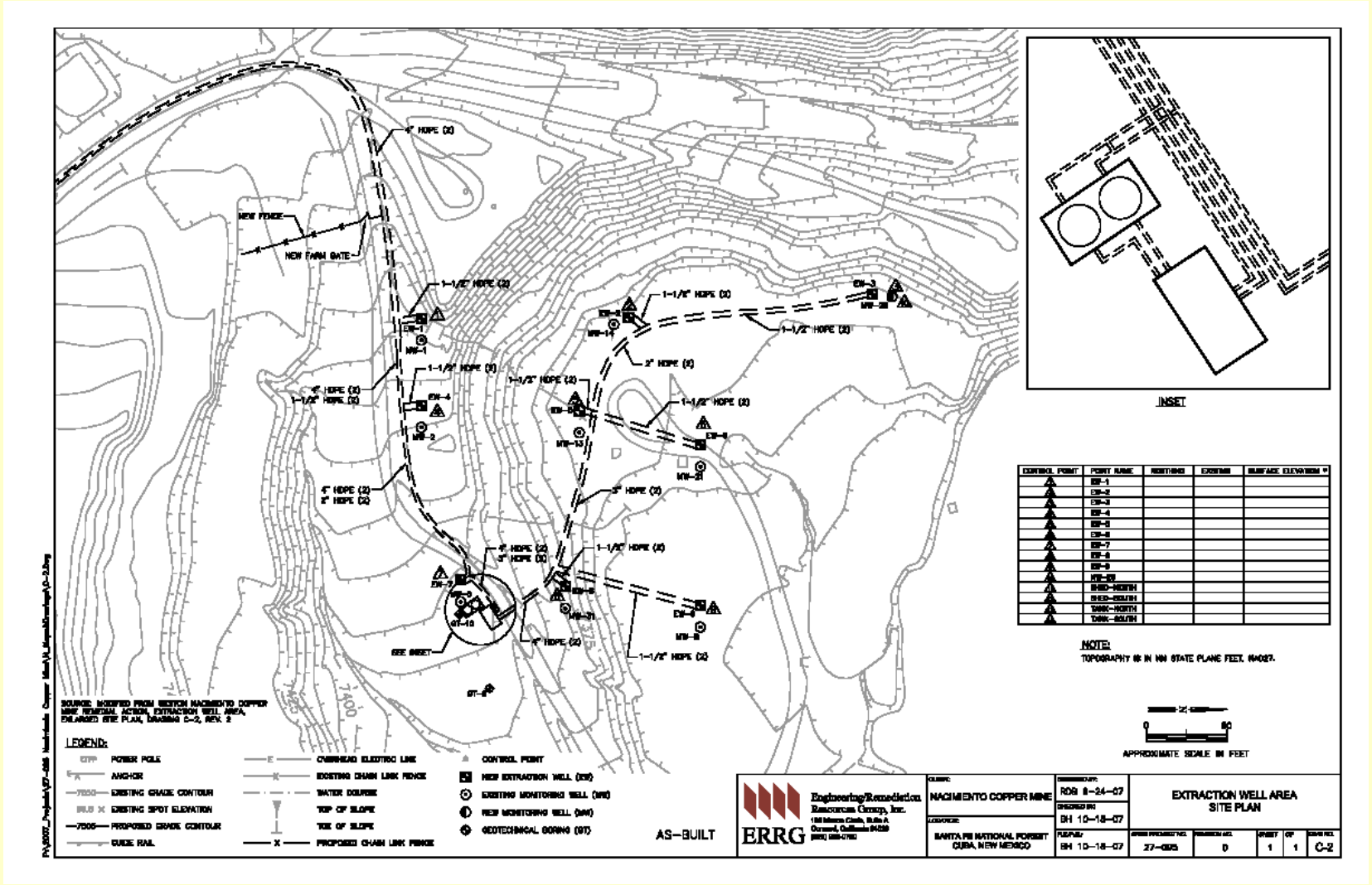
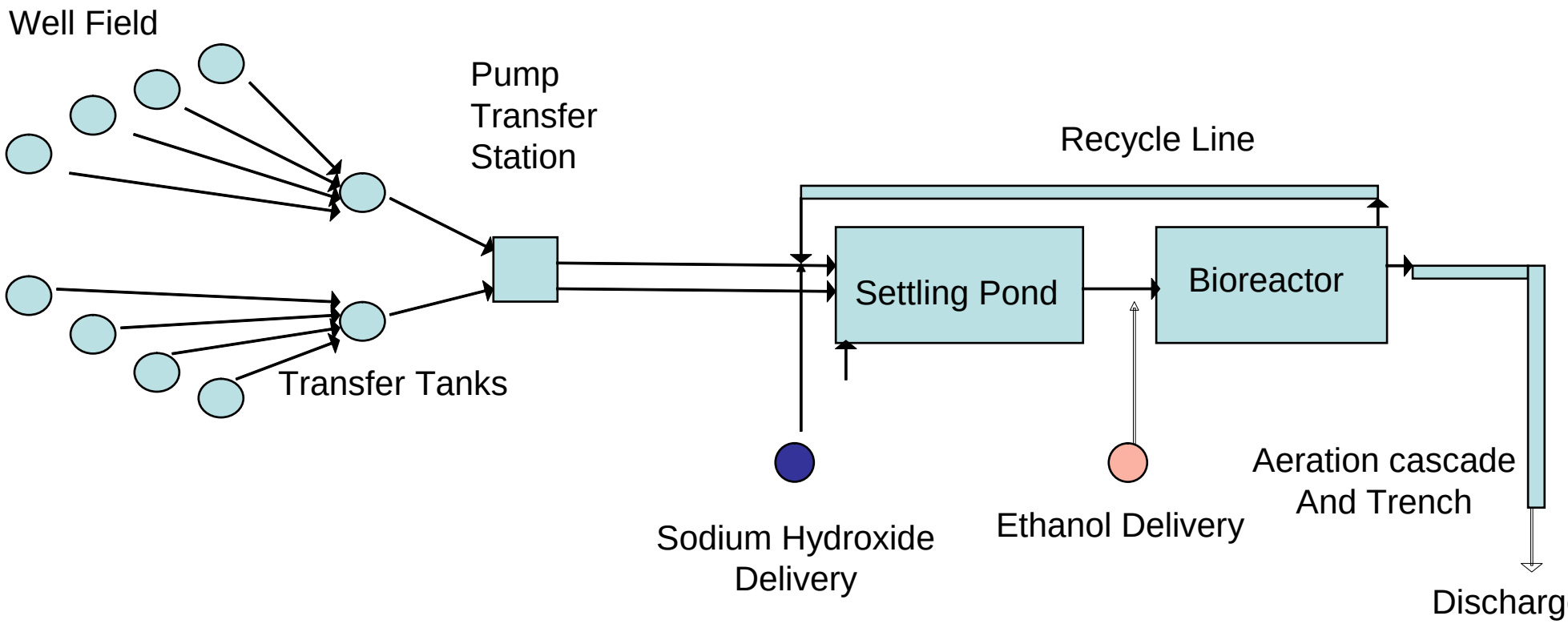
Nacimiento Mine



Nacimiento Mine



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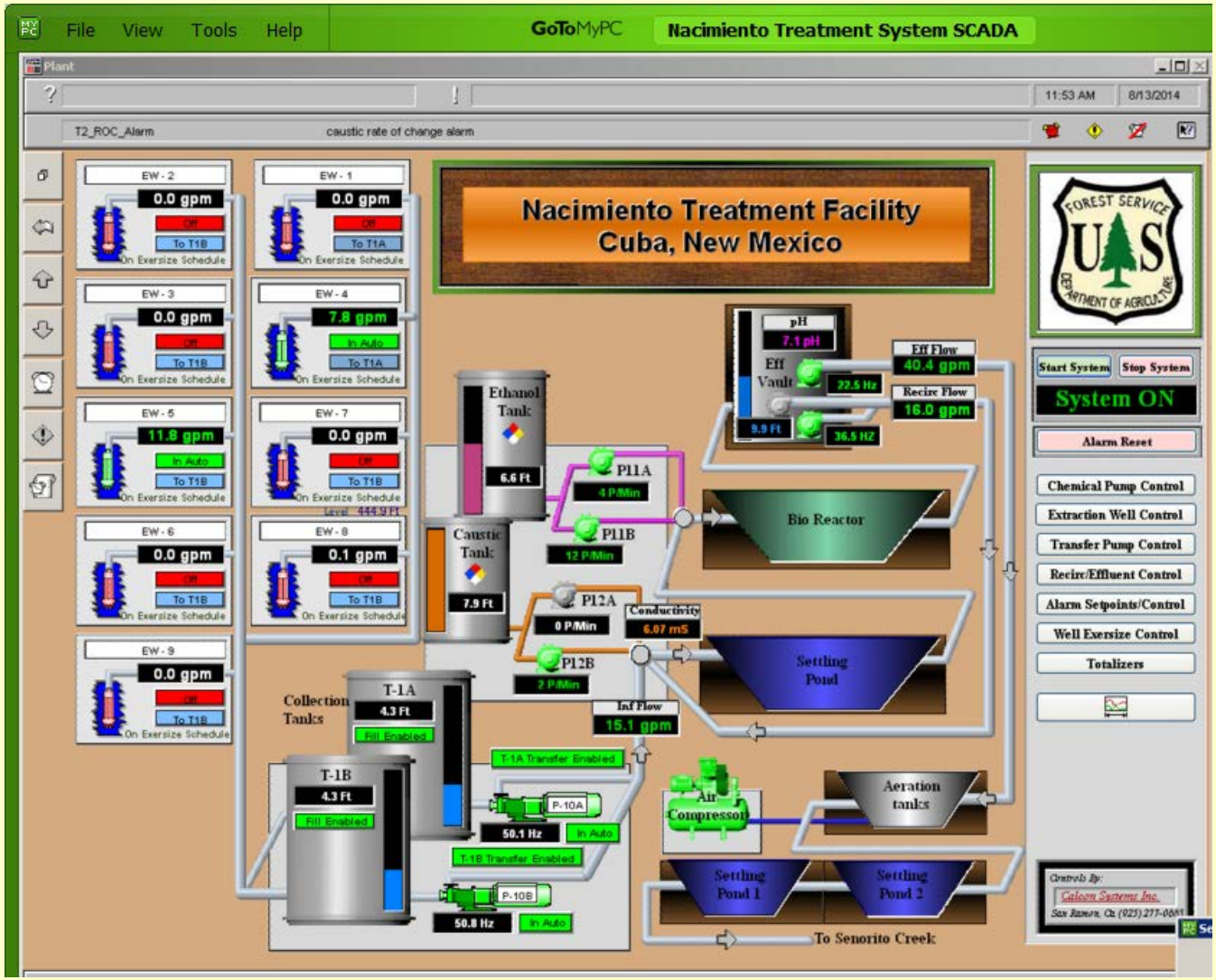

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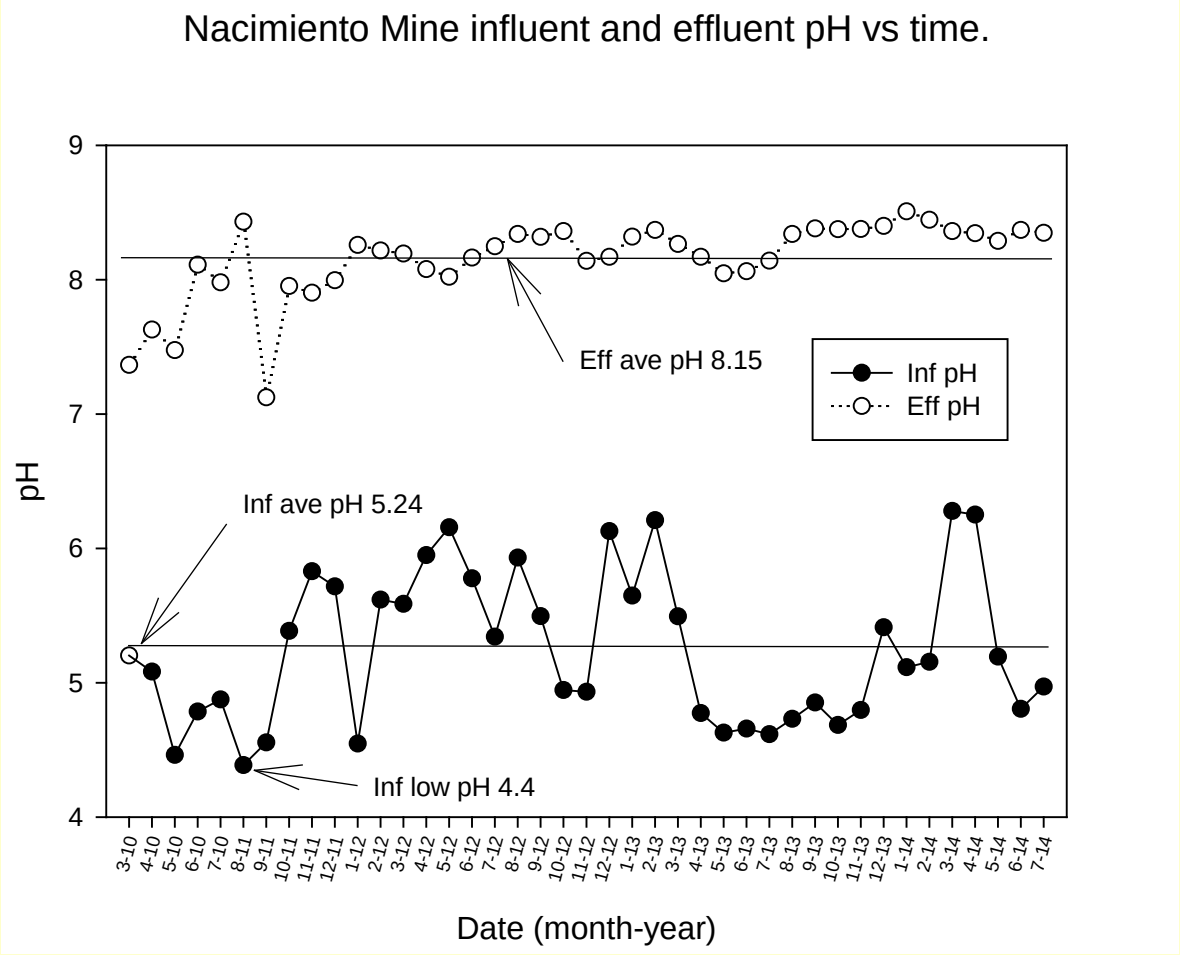
Component Volumes

System Component	Working Volume
Primary Settling Pond	117,000 ft3
Bioreactor	50,000 ft3
Aeration Ponds	134,000 ft3

Results


Nacimiento Mine influent and effluent pH vs time.
pH
9
8
7
6
5
4
Eff ave pH 8.15
Inf pH
Eff pH
Inf ave pH 5.24
Inf low pH 4.4
3-10
4-10
5-10
6-10
7-10
8-11
9-11
10-11
11-11
12-11
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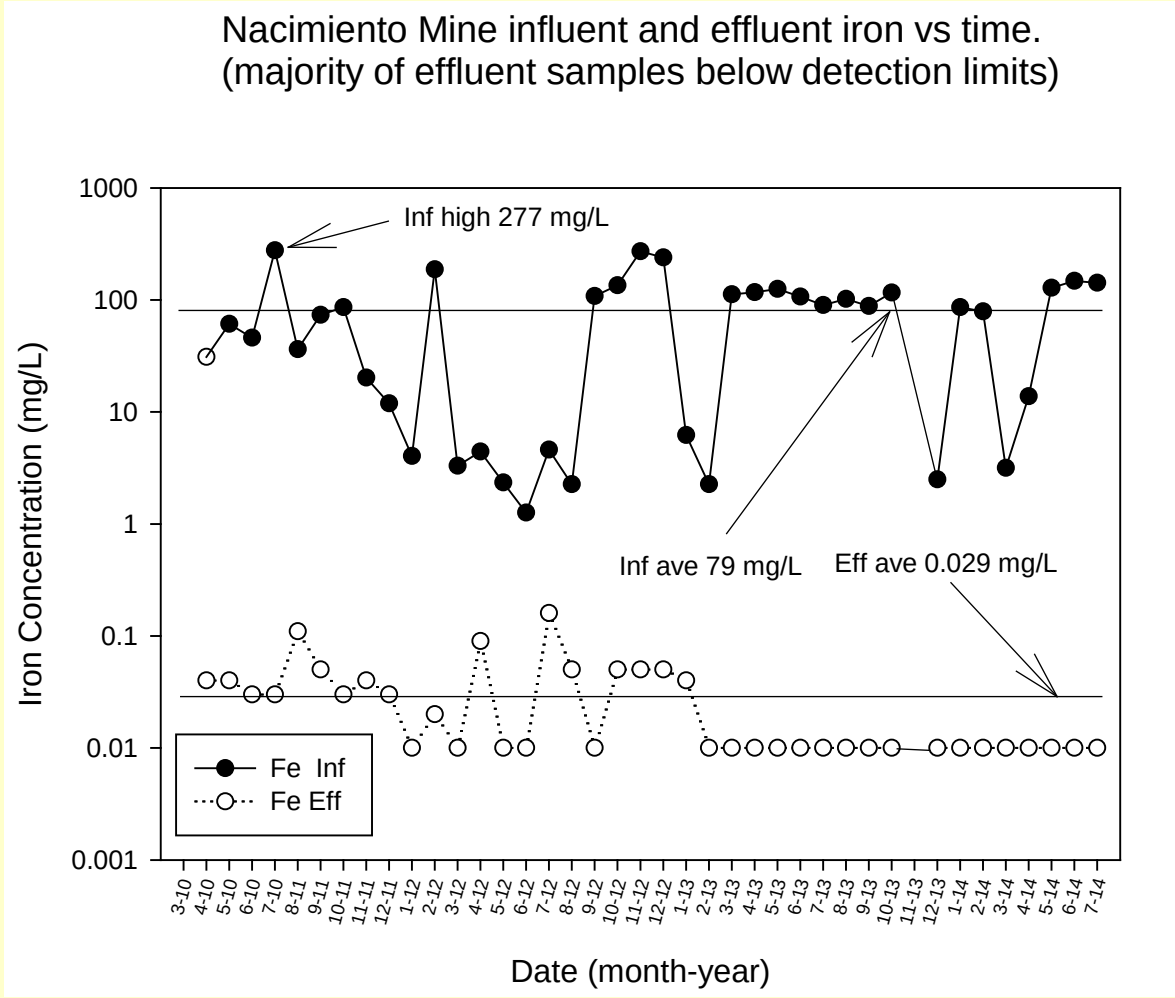
7-14
Date (month-year)

Results


Nacimiento Mine influent and effluent iron vs time.
(majority of effluent samples below detection limits)
Iron Concentration (mg/L)
1000
100
10
1
0.1
0.01
0.001
Inf high 277 mg/L
Inf ave 79 mg/L
Eff ave 0.029 mg/L
Fe Inf
Fe Eff
3-10
4-10
5-10
6-10
7-10
8-11
9-11
10-11
11-11
12-11
1-12
2-12
3-12
4-12
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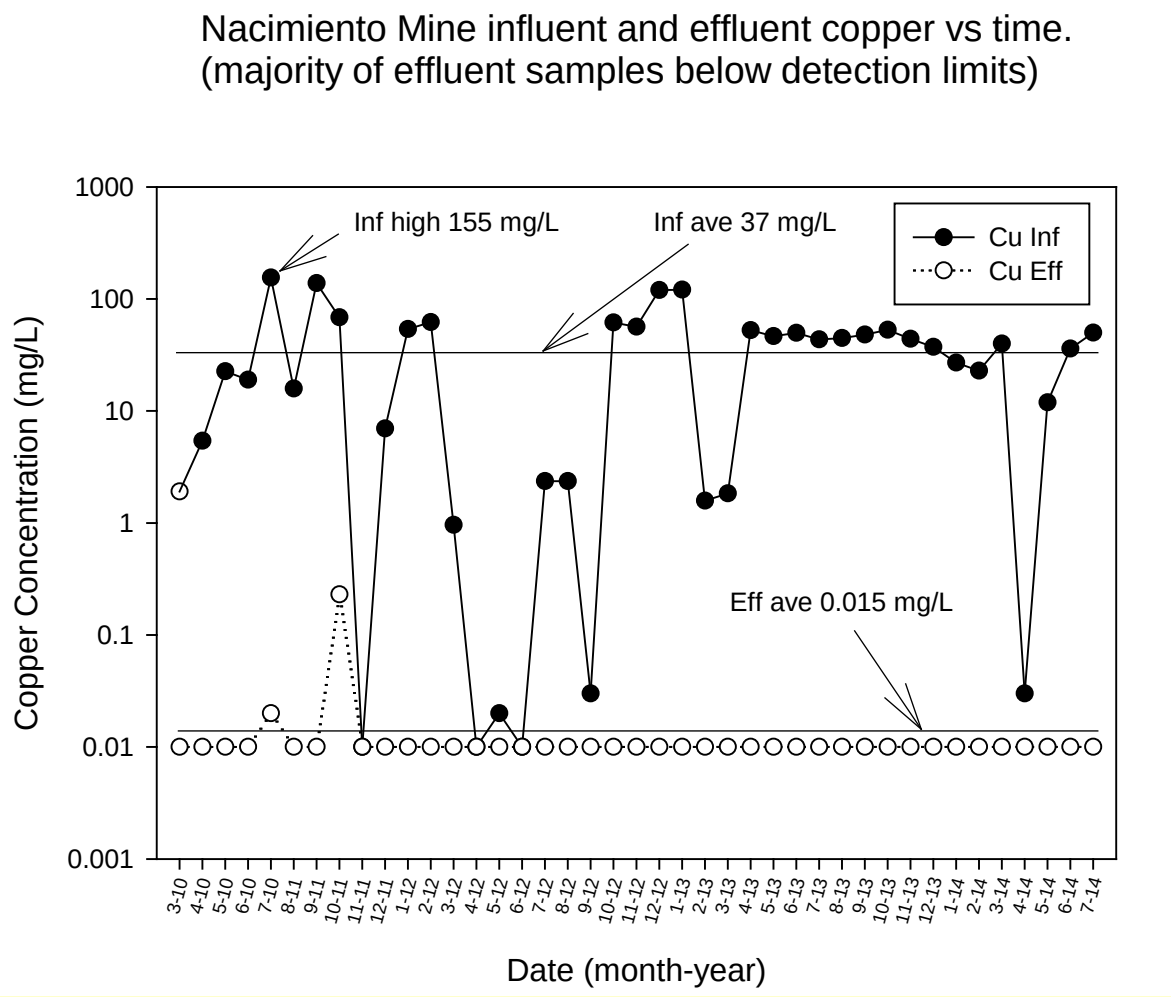
7-14
Date (month-year)

Results


Nacimiento Mine influent and effluent copper vs time.
(majority of effluent samples below detection limits)
Copper Concentration (mg/L)
1000
100
10
1
0.1
0.01
0.001
Inf high 155 mg/L
Inf ave 37 mg/L
Eff ave 0.015 mg/L
Cu Inf
Cu Eff
3-10
4-10
5-10
6-10
7-10
8-11
9-11
10-11
11-11
12-11
1-12
2-12
3-12
4-12
5-12
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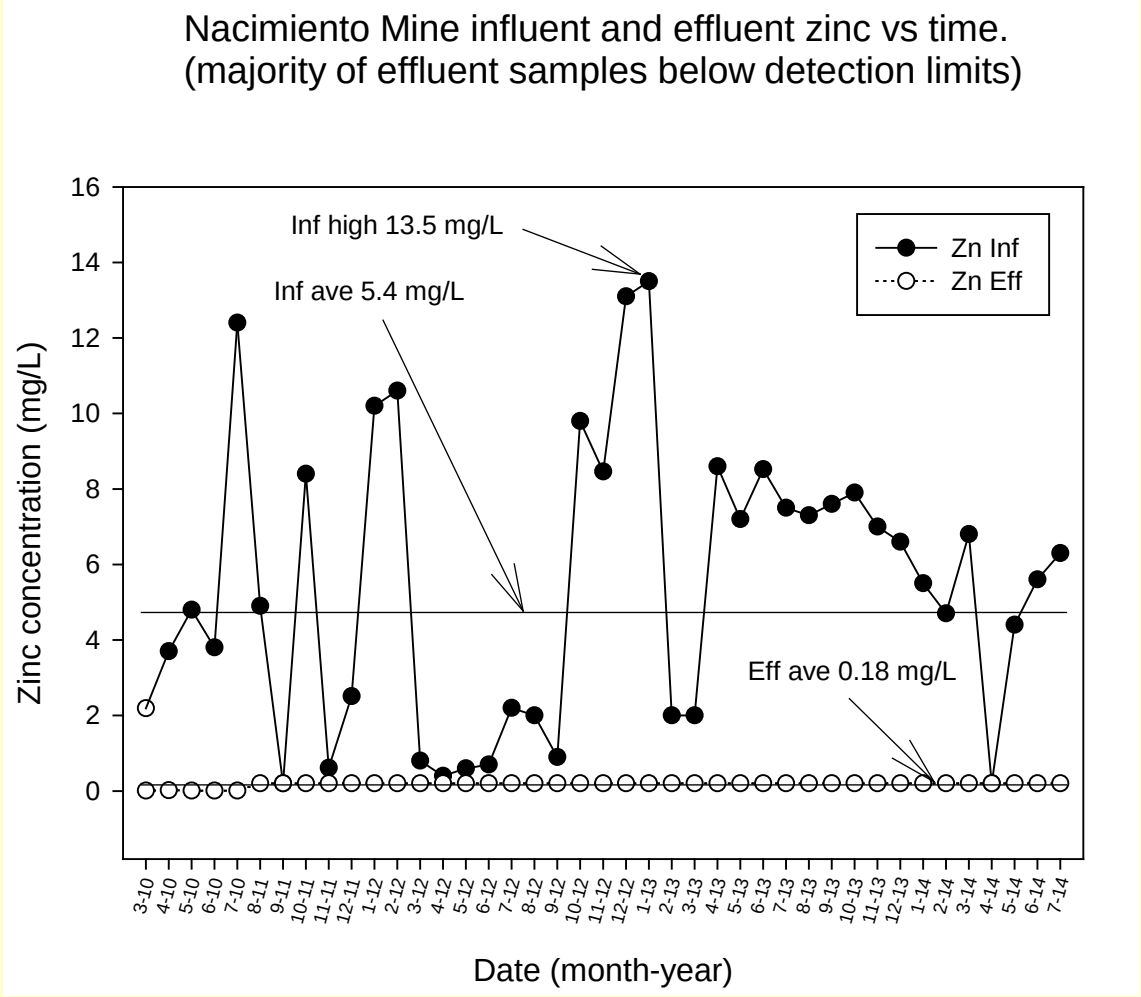
7-14
Date (month-year)

Results


Nacimiento Mine influent and effluent zinc vs time.
(majority of effluent samples below detection limits)
Inf high 13.5 mg/L
Inf ave 5.4 mg/L
Eff ave 0.18 mg/L
Zn Inf
Zn Eff
Zinc concentration (mg/L)
Date (month-year)
0
2
4
6
8
10
12
14
16
3-10
4-10
5-10
6-10
7-10
8-11
9-11
10-11
11-11
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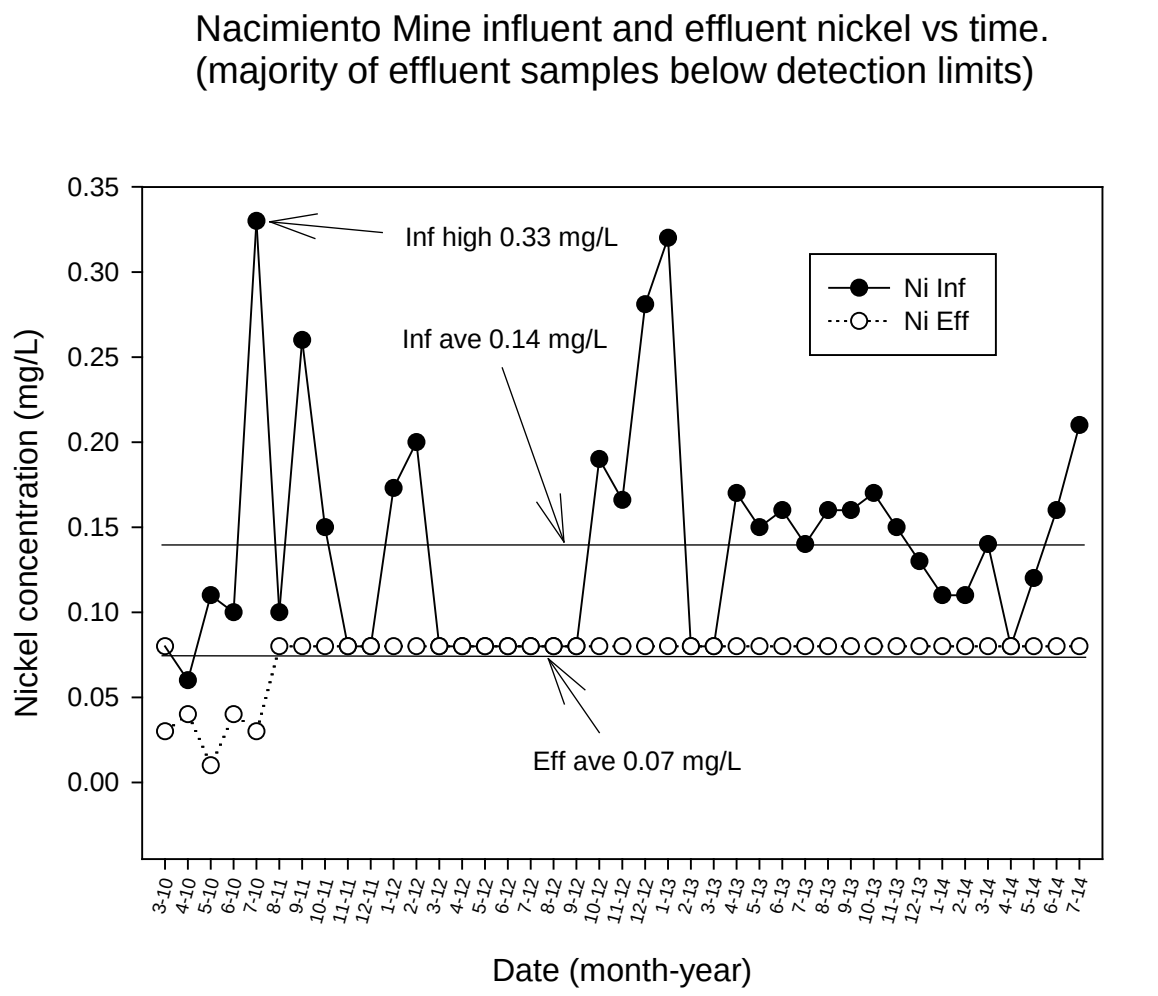
6-14
7-14

Results


Nacimiento Mine influent and effluent nickel vs time.
(majority of effluent samples below detection limits)
Nickel concentration (mg/L)
0.35
0.30
0.25
0.20
0.15
0.10
0.05
0.00
Inf high 0.33 mg/L
Inf ave 0.14 mg/L
Eff ave 0.07 mg/L
Ni Inf
Ni Eff
3-10
4-10
5-10
6-10
7-10
8-11
9-11
10-11
11-11
12-11
1-12
2-12
3-12
4-12
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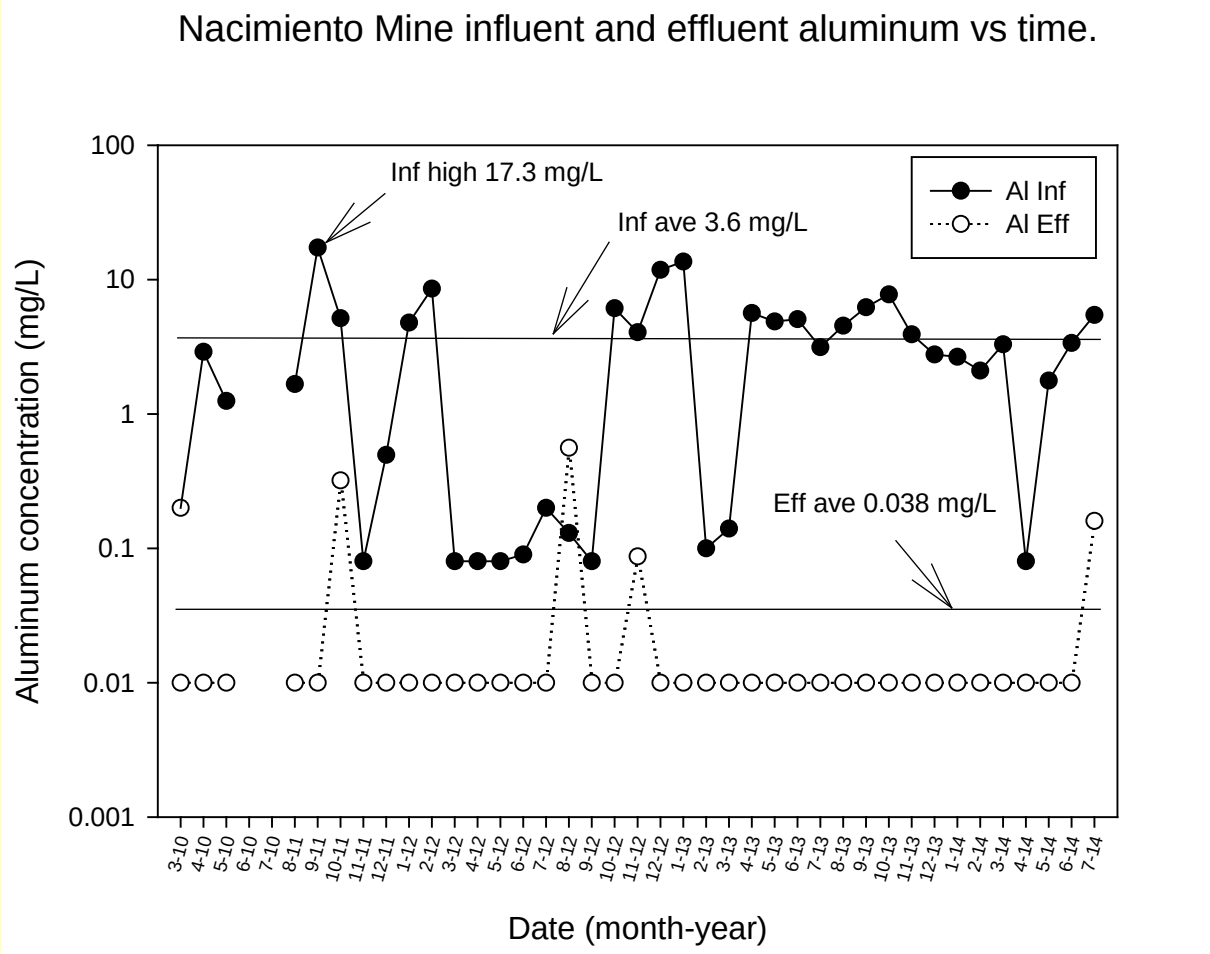
7-14
Date (month-year)

Results


Nacimiento Mine influent and effluent aluminum vs time.
Aluminum concentration (mg/L)
100
10
1
0.1
0.01
0.001
Inf high 17.3 mg/L
Inf ave 3.6 mg/L
Eff ave 0.038 mg/L
Al Inf
Al Eff
3-10
4-10
5-10
6-10
7-10
8-11
9-11
10-11
11-11
12-11
1-12
2-12
3-12
4-12
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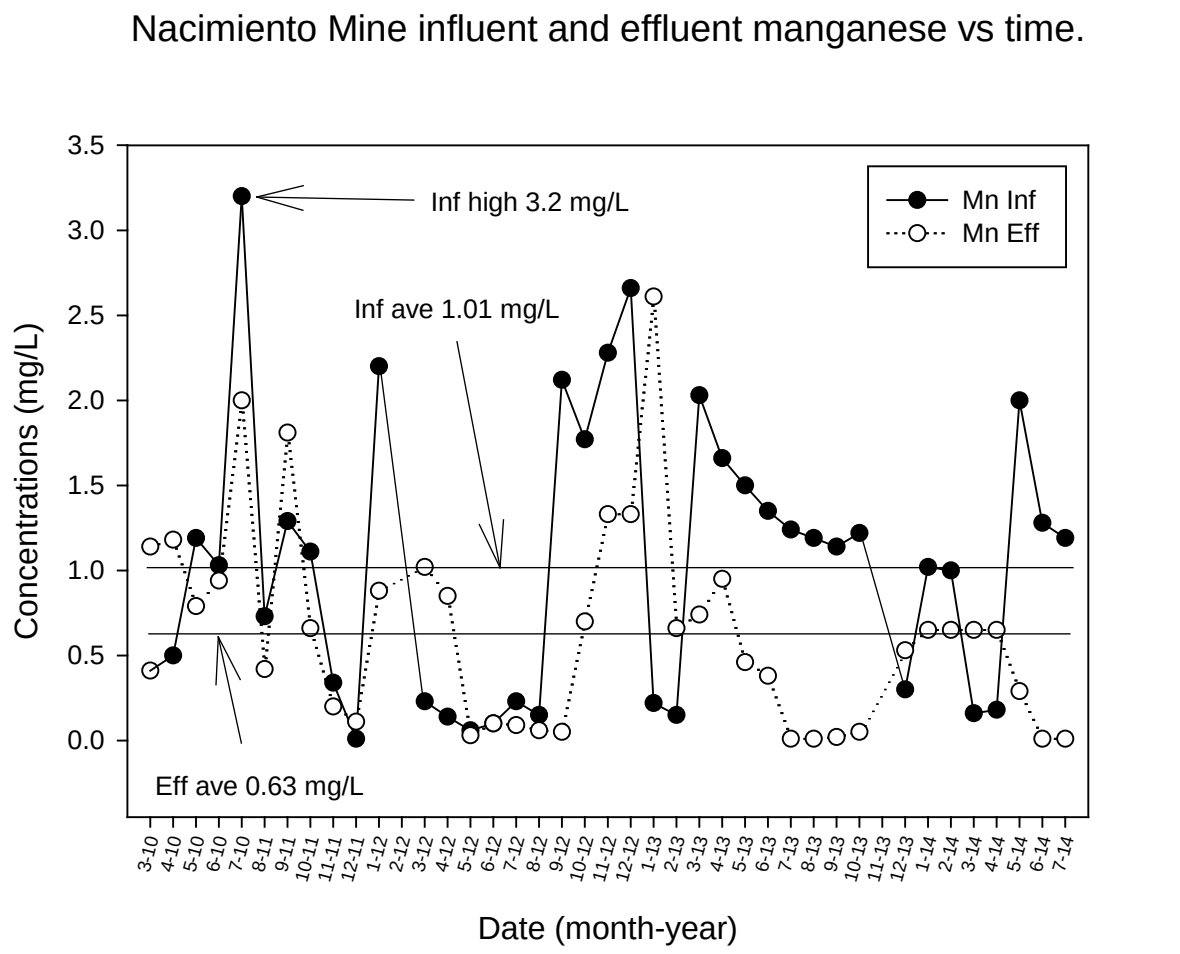
6-14
7-14
Date (month-year)

Results


Nacimiento Mine influent and effluent manganese vs time.
Concentrations (mg/L)
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
Inf high 3.2 mg/L
Inf ave 1.01 mg/L
Eff ave 0.63 mg/L
Mn Inf
Mn Eff
3-10
4-10
5-10
6-10
7-10
8-11
9-11
10-11
11-11
12-11
1-12
2-12
3-12
4-12
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11-13
12-13
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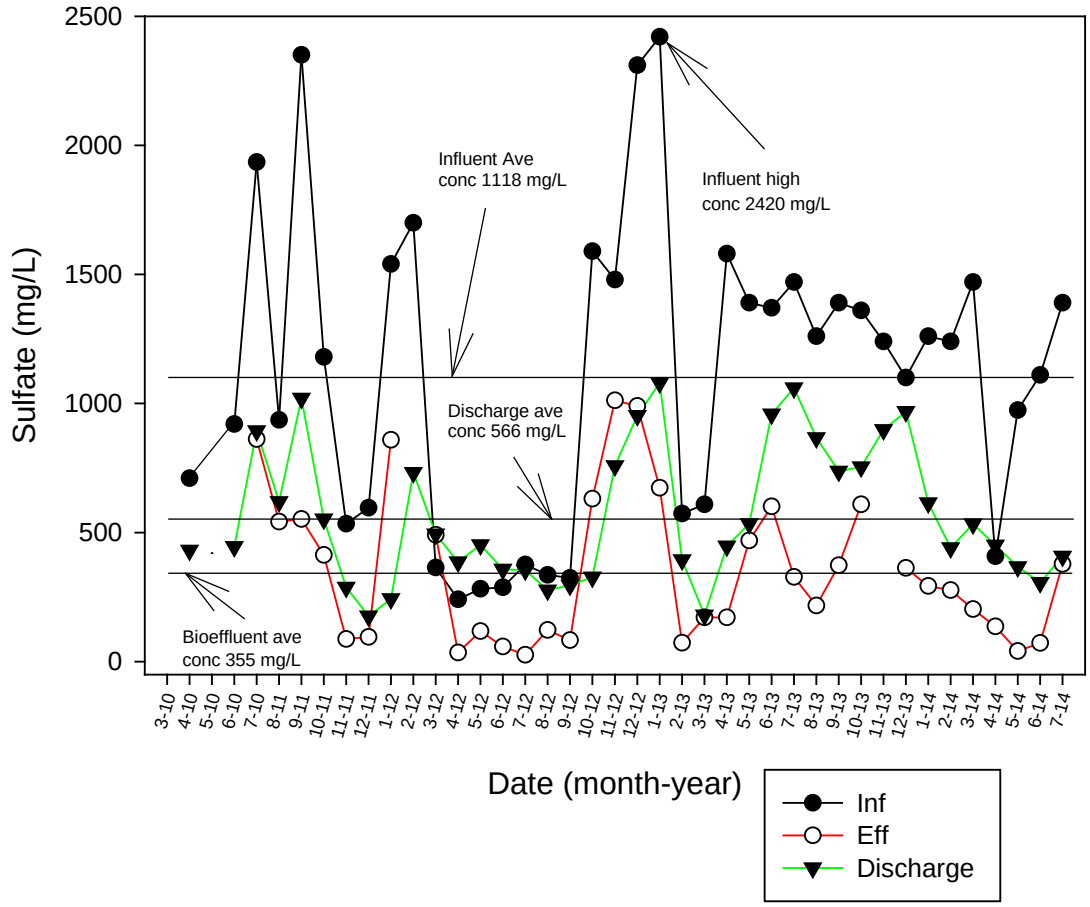
7-14
Date (month-year)

Results

Nacimiento Mine influent, bioreactor effluent and discharge sulfate vs time.



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Extraction Well Results

Table 1. Extraction Well Data for December 2008, September 1013 and August 2014 Pump Tests and Data from Ecology and Environment "Design Report, Nacimiento Mine Site, March 2005"

Extraction Well	Gallons Treated	Temp (°C)	Cond (µS/cm²)	DO(mg/L)	ORP (mV)	pH field (s.u.)	Acidity (mg/L)	Sulfate (mg/L)	Al(dis) (mg/L)	Cd (dis)(mg/L)	Cu(dis)(mg/L)	Fe(dis)(mg/L)	Pb(dis)(mg/L)	Mn(dis)(mg/L)	Ni(dis)(mg/L)	Zn(dis)(mg/L)
EW-1 (12-10-08)		15.24	732	0.75	49	6.68	19	227	ND	ND	0.03	0.11	ND	0.16	ND	0.37
(9-17-13)	2,705,264	15.26	436	0.87	162	6.59	11	165	<0.08	<0.0003	0.02	1.42	<0.004	0.06	<0.08	<0.2
(8-4-14)	2,763,416		1111	1.78	177	6.65		171			0.01	<0.01		0.04	<0.01	0.08
No Change		-15.24	379	1.03	128	-0.03		-56			-0.02	-0.11		-0.12		-0.29
EW-2 Initial		16.09	3460	4.05	114	4.11	706	2750	24.00	0.0050	44.20	408.00	ND	5.98	0.48	5.13
(9-17-13)	907,962	15.36	2569	2.06	330	3.89	1560	3650	28.90	0.0272	201.00	535.00	0.006	3.65	0.55	27.70
(8-4-14)	1,697,101		1351	3.44	277	4.16		1107			87.00	157.00		2.15	0.31	5.87
Slightly More contaminated		-16.09	-2109	-0.61	163	0.05		-1643			42.80	-251		-3.83	-0.17	0.74
EW-3 (12-10-08)		16.67	1895	2.07	28	5.60	484	1380	5.80	0.0030	48.20	176.00	ND	2.09	0.17	5.64
(9-17-13)	997,429	15.09	817	3.51	217	6.90	12	513	<0.08	<0.0003	0.04	1.70	<0.004	0.07	<0.08	<0.2
(8-4-14)	1,860,819	15.00	1189	6.18	180	6.83		498			0.03	0.12		0.07	<0.01	0.05
Significantly Improved		-1.67	-706	4.11	152	1.23		-882			-48.17	-176		-2.02	-0.16	-5.59
EW-4 (12-10-08)		14.30	7	0.49	25	6.88	8	185	ND	ND	ND	0.36	ND	0.25	ND	0.02
(9-17-13)	6,244,876	15.96	418	1.03	117	6.98	9	179	<0.08	<0.0003	0.03	0.54	<0.004	0.25	<0.08	<0.2
(8-4-14)	8,503,638	16.20	1106	3.00	96	6.63		213			<0.01	0.04		0.13	<0.01	0.25
No Change		1.90	1099	2.51	71	-0.25		28			0.00	-0.32		-0.12	0.00	0.23
EW-5 (12-10-08)		14.86	1413	3.49	-32	5.67	182	866	1.70	ND	4.79	57.40	ND	1.49	0.11	2.26
(9-17-13)	4,900,372	15.41	1896	1.71	305	4.20	569	2000	10.90	0.0027	70.00	190.00	<0.004	1.75	0.22	10.30
(8-4-14)	7,379,618	15.63	1297	2.67	266	4.39		1180			51.00	105.00		0.43	0.15	6.26
Significantly More Contaminated		0.77	-116	-0.82	298	-1.28		314			46.21	48		-1.06	0.04	4.00
EW-6 (12-10-08)		11.73	2353	4.36	105	4.04	799	2100	23.80	0.0040	83.80	229.00	ND	3.94	0.26	10.50
(9-17-13)	1,650,087	14.28	996	1.65	282	4.59	267	1280	4.84	0.0200	0.00	84.70	<0.004	0.85	0.12	7.80
(8-4-14)	1,650,840	14.35	1210	2.88	262	5.27		712			9.80	18.20		0.06	0.02	3.09
Significantly Improved		2.62	-1143	-1.48	157	1.23		-1388			-74.00	-211		-3.88	-0.24	-7.41
EW-7 (12-10-08)		16.39	674	1.61	47	6.41	15	226	ND	ND	ND	3.09	ND	0.23	0.01	0.33
(9-17-13)	4,793,785	13.36	355	1.04	146	6.05	9	217	<0.08	<0.0003	0.39	4.20	<0.004	0.07	<0.08	0.80
(8-4-14)	6,039,856	13.85	993	2.74	182	6.16		151			0.12	0.80		0.05	<0.01	0.91
No Change		-2.54	319	1.13	135	-0.25		-75			-0.12	-2.29		-0.18	-0.01	0.58
EW-8 (12-10-08)		13.92	570	3.33	52	6.62	16	193	ND	ND	0.21	ND	ND	0.15	0.01	0.50
(9-17-13)	3,526,510	13.21	250	1.60	161	6.45	13	75	<0.08	<0.0003	0.06	1.43	<0.004	0.06	<0.08	<0.2
(8-4-14)	3,791,821	14.42	957	2.89	144	6.52		64			0.04	0.04		0.05	<0.01	0.07
No Change		0.50	387	-0.44	92	-0.10		-129			-0.17	0.04		-0.10	-0.01	-0.43
EW-9 (12-10-08)		16.38	1496	0.96	56	5.12	206	951	2.20	ND	1.15	41.10	ND	0.65	0.08	1.32
(9-17-13)	4,543,814	14.33	981	1.03	176	5.69	33	644	0.22	0.0018	0.68	13.90	0.004	0.26	<0.08	2.00
(8-4-14)	4,872,670	13.56	1107	2.25	86	6.16		384			0.03	3.60		0.18	<0.01	0.42
Significantly Improved		-2.82	-389	1.29	30	1.04		-567			-1.12	-38		-0.47	-0.07	-0.90
Ave		15.06	1400	2.35	49	5.68	271	986	6.39	0.0013	20.26	101.67	0.000	1.66	0.12	2.90
Ave (9-17-13)		14.70	969	1.61	211	5.70	276	969	4.98	0.0057	30.25	92.54	0.001	0.78	0.10	5.40
Ave (8-4-14)		11.45	1147	3.09	186	5.86		498	0	0	16.45	32		0.35	0.06	2
		-3.62	-253.25	0.75	136.26	0.18		-489			-3.82	-70.03		-1.31	-0.06	-1.01
Discharge Objective						6 to 9		500	5.00	0.0100	0.50	1.00	0.05	0.20	0.20	10.00
2005 Ecology and Env																
Ave		15.50	2357	2.82	184	3.59	485	1353	13	ND	93.99	131	ND	2.86	0.18	25.10
Worst-case		16.38	3079	3.51	226	2.19	1000	1970	24	ND	276.00	282	ND	13.00	0.43	57.00
* denotes analysis in TKT Laboratory																

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