Water Quality Predictions in 1992 – How do they Compare to Current On-site Conditions at the Closed Bell Mine Site in BC?

by
Ron Nicholson and Erin Clyde, EcoMetrix Incorporated
Jacques Moulins, John Stroiazzo and Charles See, Xstrata Copper

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Porphyry Copper Mine Background

- Porphyry Copper Deposit
  - Intrusive volcanogenic with hydrothermal alteration
  - Pyritic halo
- Staked first claims in 1962
- Mining started in 1970
- Milling started in 1972 with up to 15,500 tonnes per day
- Mine operated until March 1992

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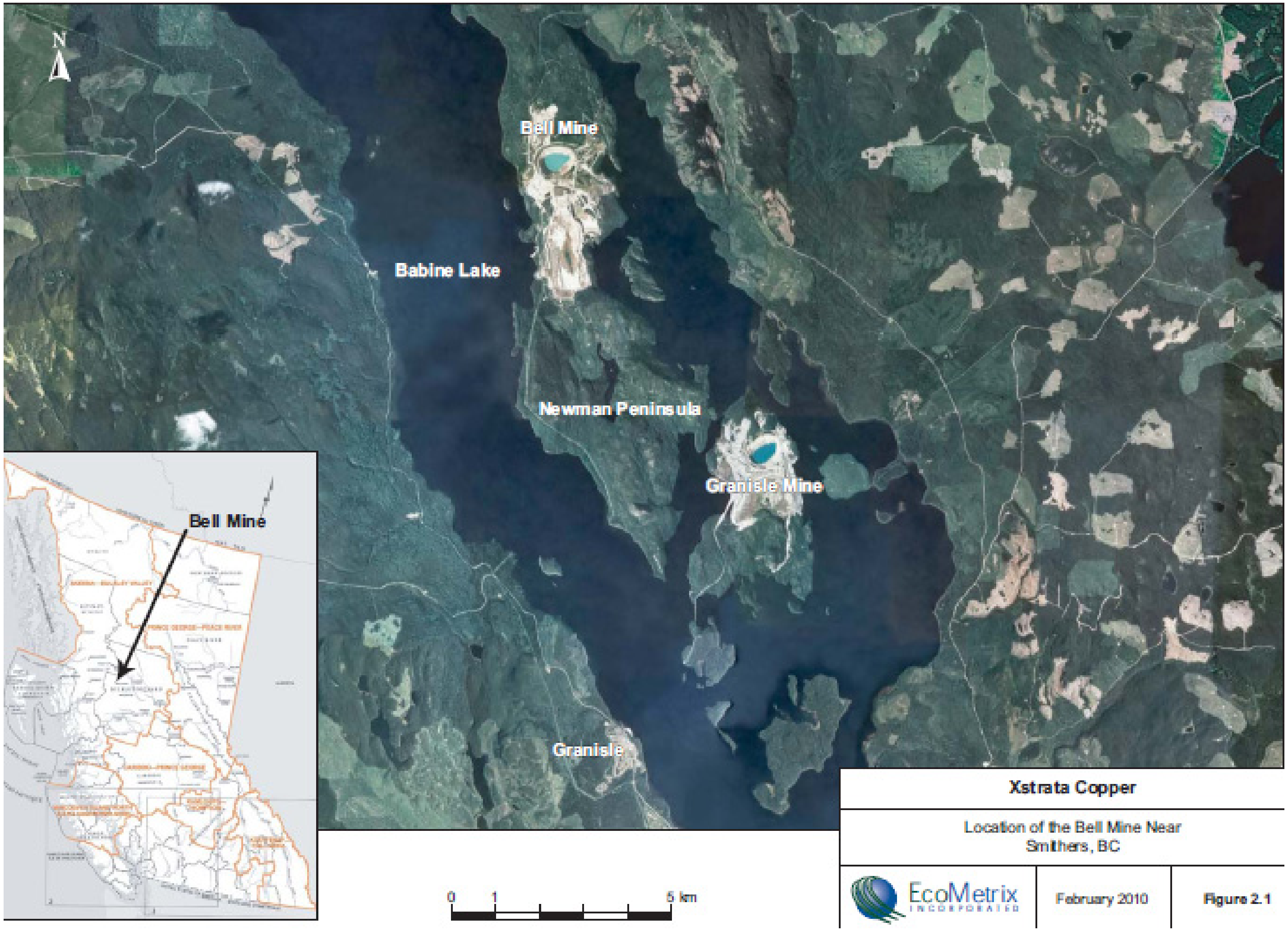
Porphyry Copper Mine Background

Site History

- Operations
  - Open pit measures 2100 meters in diameter and is approximately 320 meters in depth
  - Total pit Volume of 61 Million cubic-metres
  - About 152 million tonnes (Mt) of material removed from pit (~ 79 Mt of ore , ~ 73 Mt of mine rock)
  - Tailings Management Area (TMA) just to the south of the pit (contains ~ 77 Mt of tailings)

Location



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Mine Site
– Key Features

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Porphyry Copper Mine Background

- Mine Closure
  - Earlier ARD work by regulator in 1980s focused on tailings
  - Systematic ML/ARD assessment in 1991-93 for closure
  - Key focus points included mine rock and tailings geochemistry, prediction of long term water quality, water management, pit filling and site reclamation
  - Mine closed in 1992

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Exploration Sample Pulps

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Porphyry Copper Mine Background

- Current Conditions
  - ~ 30% of the site has been reclaimed (wildlife habitat)
  - ~ 62 Mt of potentially acid generating (PAG) rock and 77 Mt of tailings stored on site
  - Water management includes collection ponds and pump houses that collect and transfer water to the pit for storage with plans for treatment when discharge required
  - 3 permitted discharges of diverted clean water

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Tailings

ML/ARD Assessment – 1991

- Rock types identified and inventories established
- Mineralogy and metal content analysis
- Acid base accounting (ABA) that included;
  - Sulphur species (S_T, S^{2-}, SO_4)
  - Sobek NP
  - Carbonate content
- Kinetic tests (Humidity cells)
- Interpretation of Heap Leach column test results
- Interpretation of on-site water quality
- Water quality modelling

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Rock Types and Inventories

- 6 Major rock types
- 4 stockpiles

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Summary of ABA Results

Data Set -Number of Samples	Year	NNP (t/1000t)			Paste pH			NP/AP		
		Low	Mean	Max	Low	Mean	Max	Low	Mean	Max
38	99	-87	-32	+13	2.4	7.5	9.2	-0.39	0.59	1.31
16	91	-86	-35	-5	7.9	8.1	8.2	0.26	0.59	0.90
5 (Tailings)	91	-120	-96	-14	3.3	4.2	5.3	-0.11	-0.06	0.01
10	91	-111	-43	-6	7.8	7.9	8.0	0.28	0.55	0.90
1 Composite	90		-28			8.1			0.68	
17	87	-388	-44	+18	2.6	6.8	8.0	-0.21	0.79	2.63
7	87	-141	-8	+42	1.8	5.6	7.2	-0.40	1.74	3.47
16	91	-86	-35	-5	7.9	8.1	8.2	0.26	0.59	0.90
5 (Tailings)	91	-120	-96	-14	3.3	4.2	5.3	-0.11	-0.06	0.01
10	91	-111	-43	-6	7.8	7.9	8.0	0.28	0.55	0.90

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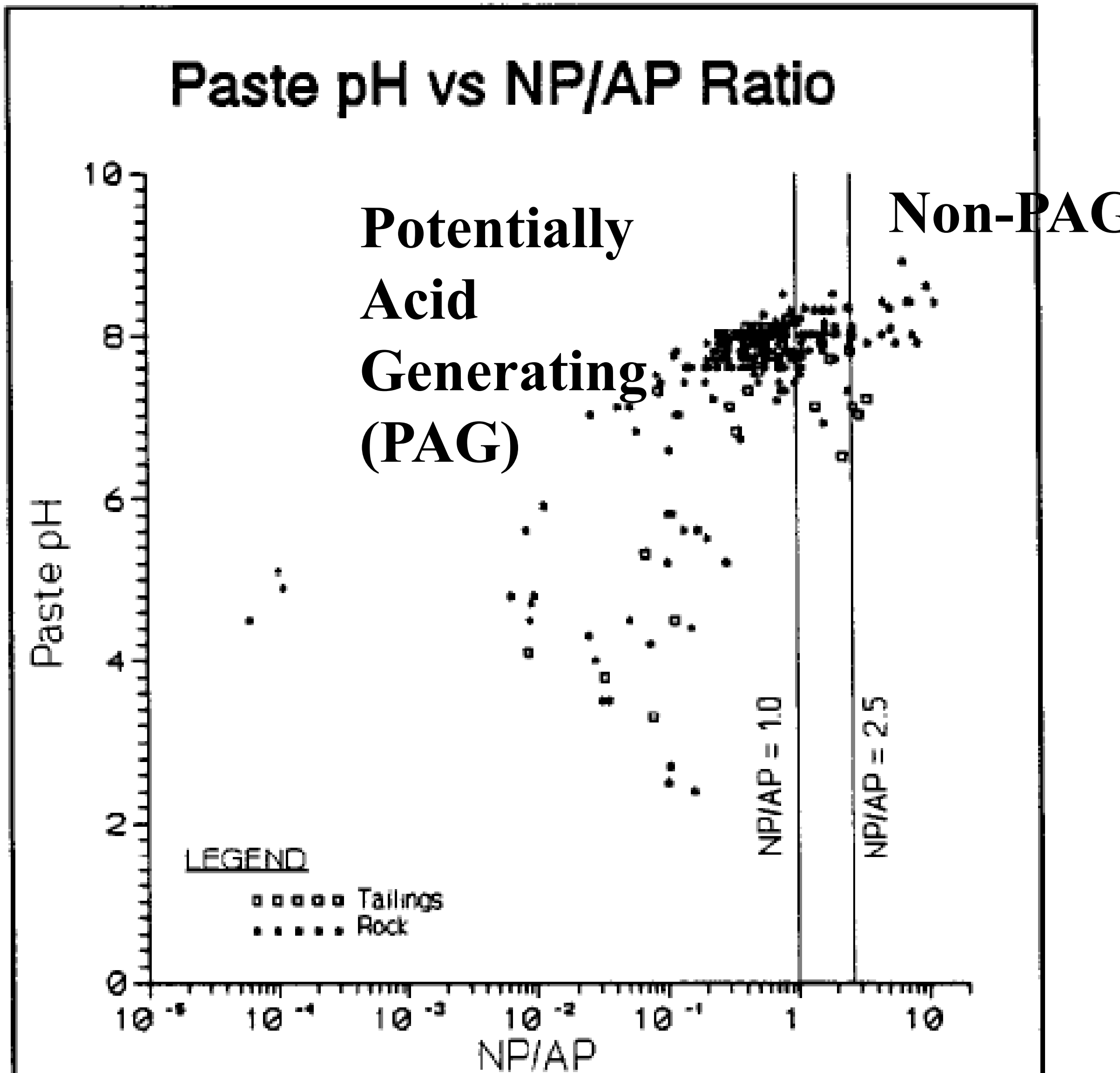
Paste pH vs NP/AP Ratio (NPR)

Consistent with NNP



Morjwik, 1992

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Kinetic Test Program

- Heap leach test program established during operation to assess feasibility
- Three (3) additional humidity cells established specifically to assess:
  - Rates of acid generation, acid neutralization and metal leaching at neutral pH
  - Rates of acid generation and metal leaching at acidic pH values

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Heap Leach Tests

- 4 – 4 inch diameter columns (25 kg)
- 12 – 24 inch diameter columns (2500 kg)
- 8 – 30 tonne cribs

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Humidity Cell Tests

Humidity Cell	Material	Conditions
1	A-Frame	Acidic
2	North Dump	Neutral
3	Dam #1	Neutral
TS-7, T1, T2,	Tailings	Neutral
OTB	Tailings	Acidic

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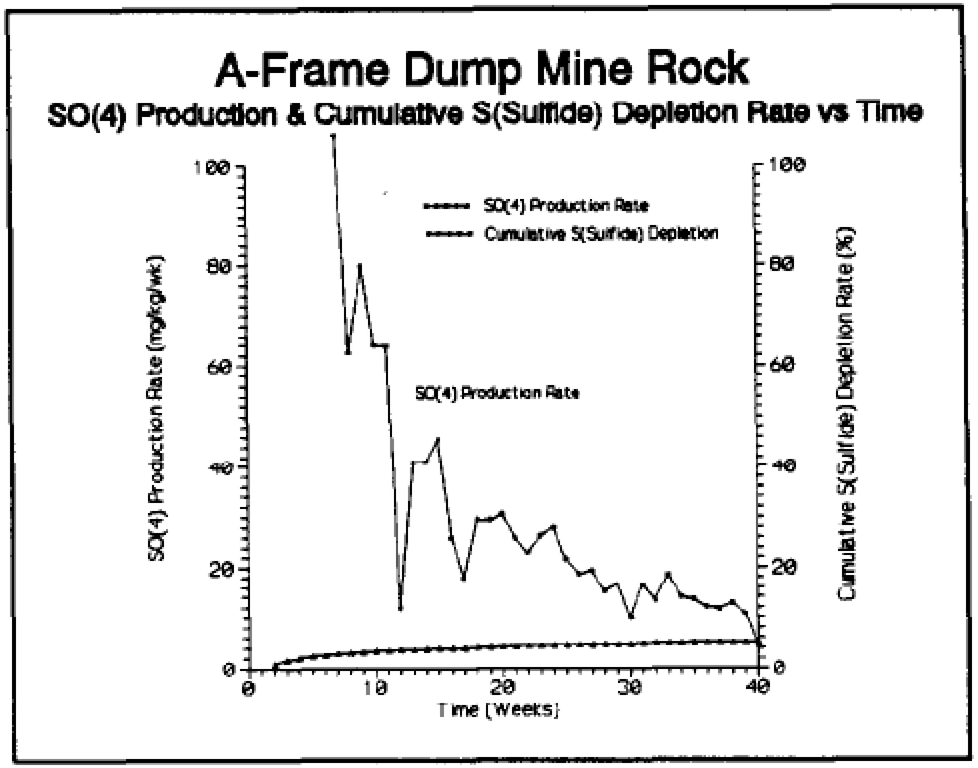
Sulphide Depletion Rates

- Sulphide depletion rates derived from SO_4^{2-} loading rates in Humidity Cells



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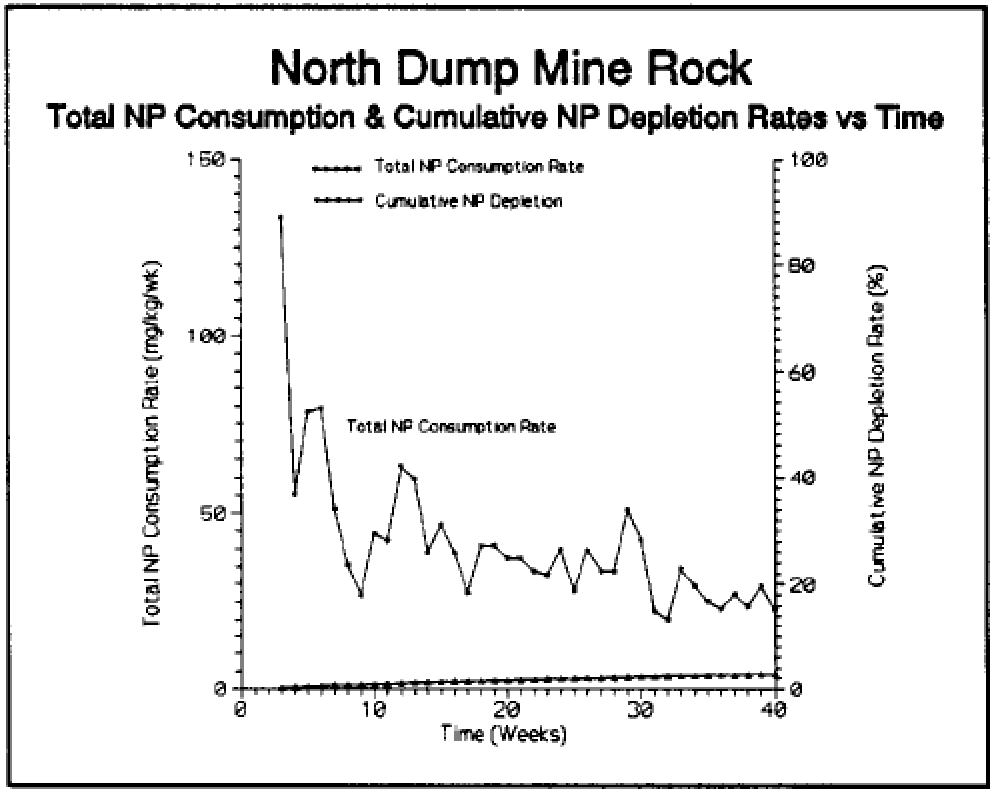
NP Depletion Rates

- Theoretical NP depletion rate from SO_4^{2-} production rate
- Estimated Carbonate NP depletion rate from Carbonate Molar Ratio ($[Ca+Mg]/SO_4$) * Theoretical depletion rate



From MDAG, 1992

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Sulphide and NP Depletion Times – Mine Rock

- Calculated times for onset of acid conditions ranged from 0 to 40 years

- Sulphide depletion times ranged from 10 to 125 years

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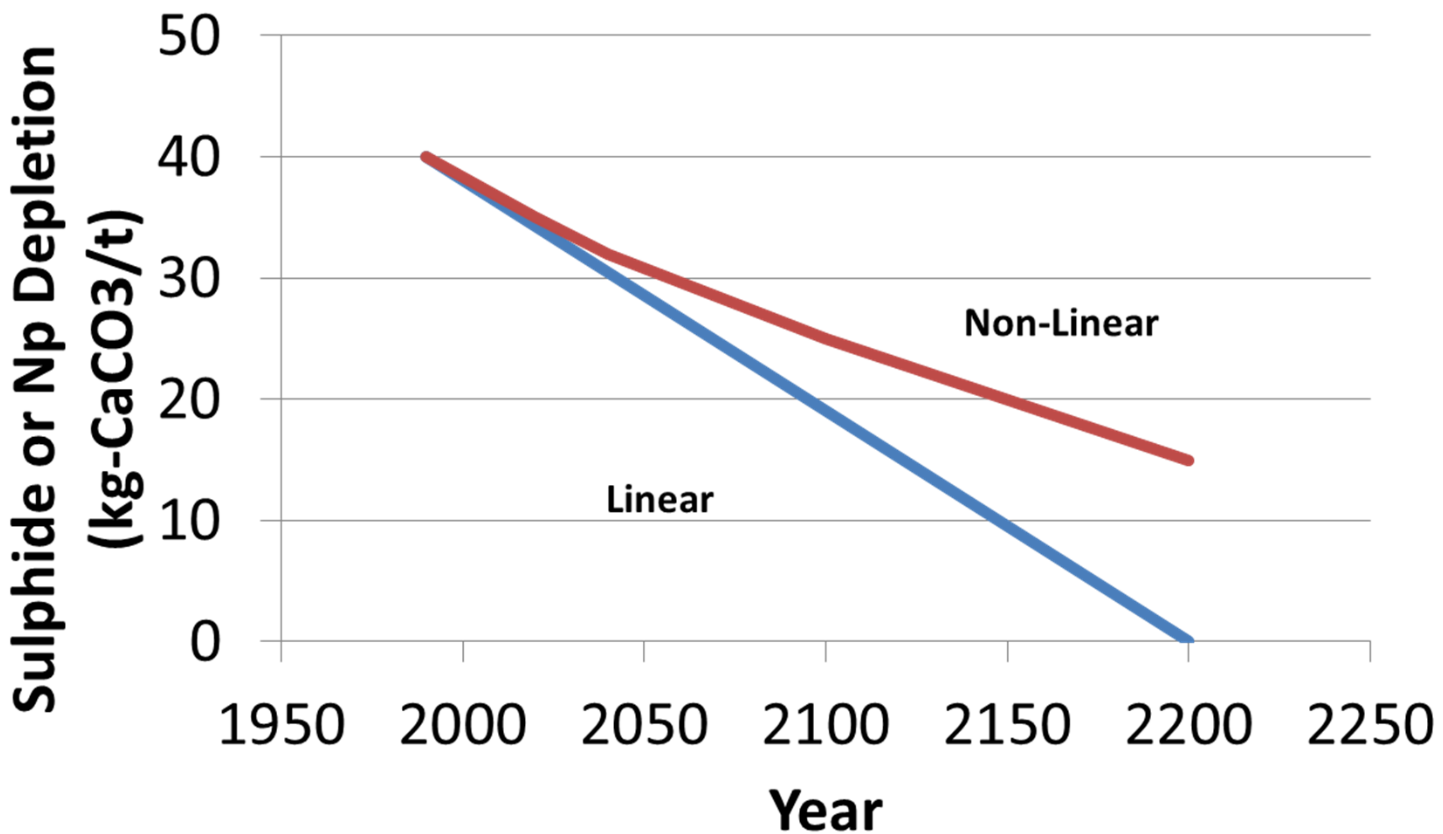
Sulphide and NP Depletion Rates



Predicted "<u>times</u>" strongly depend on which model is selected

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Acid Generation Predictions

- Mine rock predicted to start generating acid between 2010 and 2030 – depending on available NP – assumed Linear model
- Water in tailings may become acidic in future but water moving down in tailings was expected to be neutral as a result of NP in tailings below the oxidation zone
- Water from tailings can be managed on site with storage in open pit

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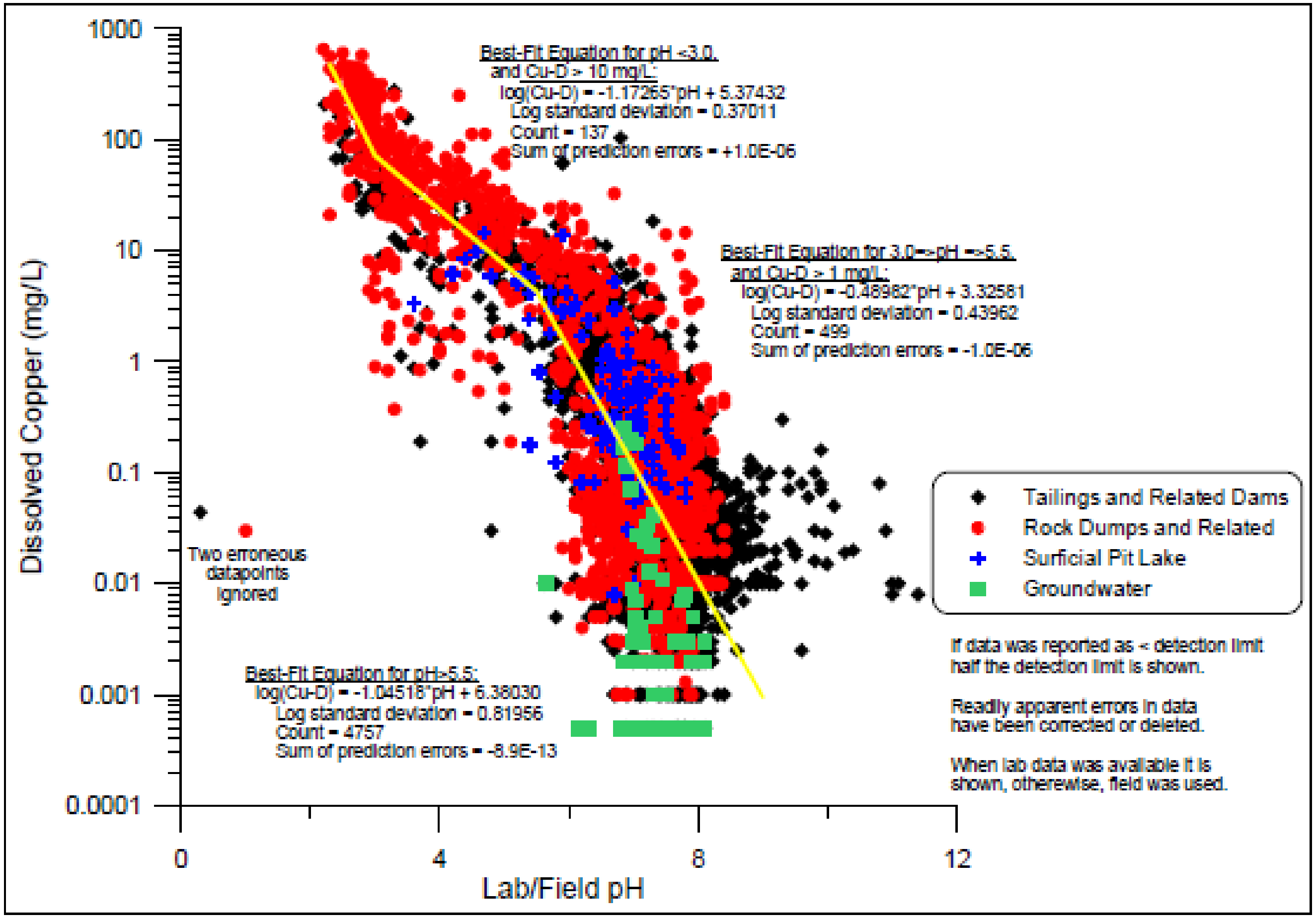
Empirical Drainage Chemistry Model (MDAG.com Case Study #33, 2010)



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Site Water Quality

- Collection pond water sampled and analyzed regularly for;
  - pH, specific conductance, sulphate, hardness
  - Metals (copper, iron, zinc)
- Water quality prediction made in 1992 as part of closure plan

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Collection Ponds

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Collection Ponds

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Water Quality

- Clean diversion water released to lake is permitted through strict monitoring protocols
- Any water exceeding limits remains on site
- Water quality in collection ponds reflects the release of oxidation products and ongoing neutralization of acid as predicted in Closure Plan
- Monitoring program is effective at identifying compliance with permits and managing discharges to lake

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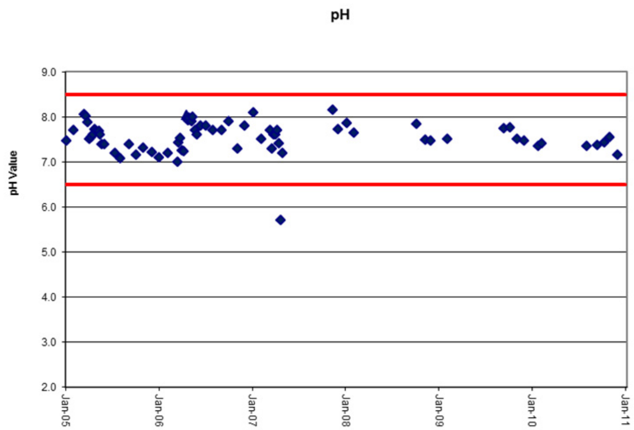
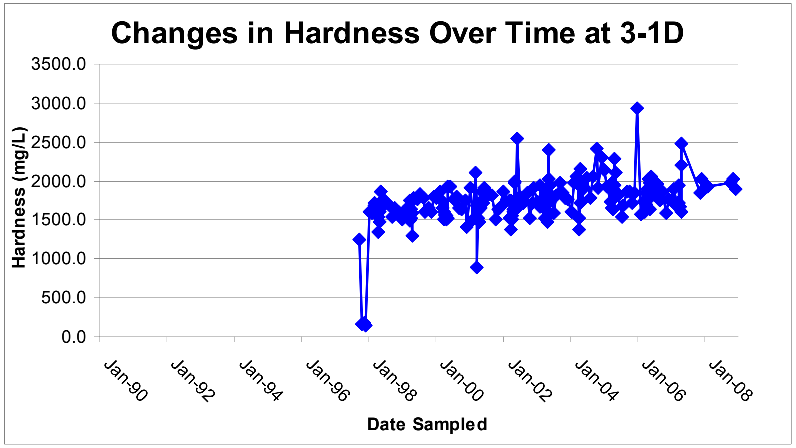
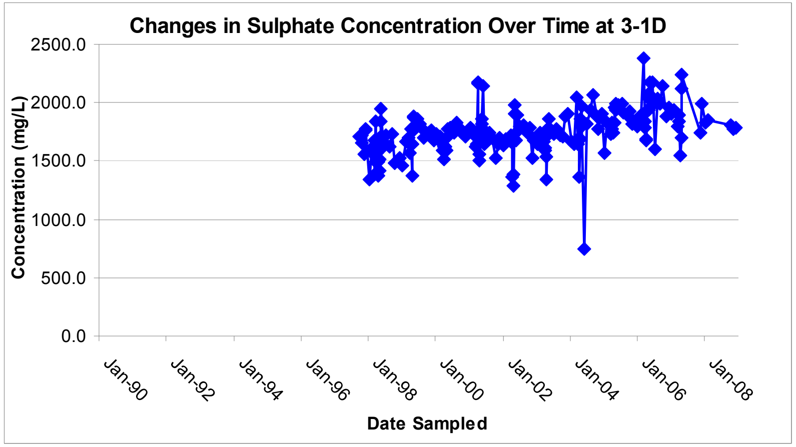
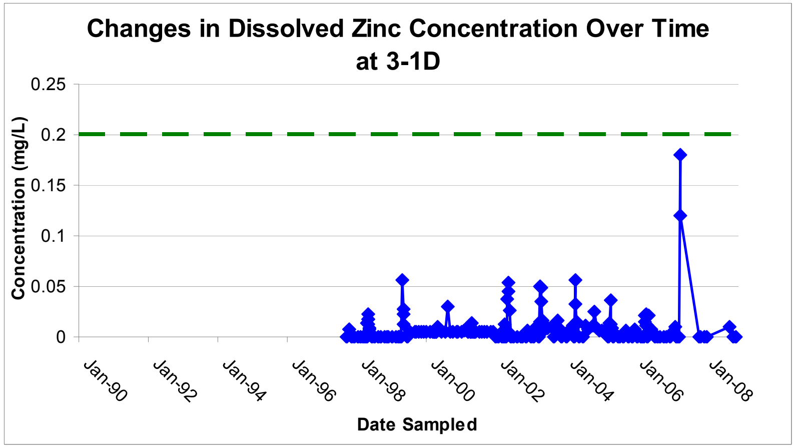
Chemistry in Collection Pond 3-1D

Dashed Lines represent Permit Limits









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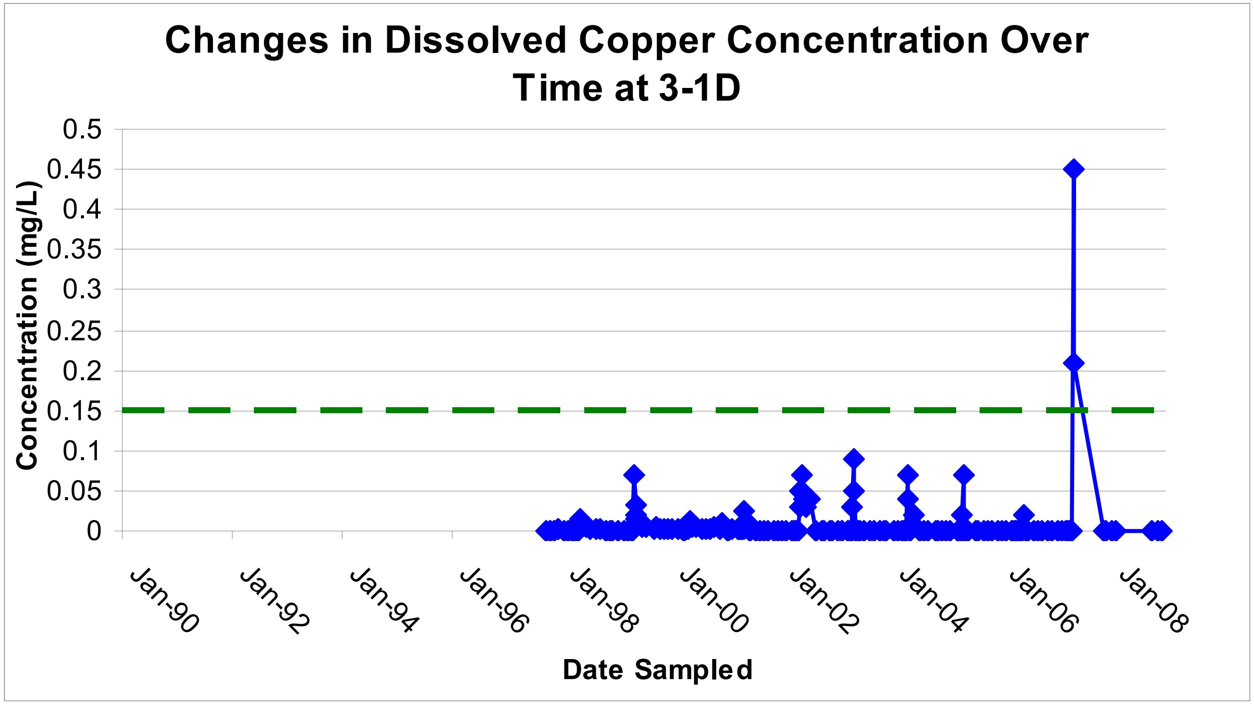
Bell - Chemistry in Collection Pond 3-1D

Dashed Lines represent Permit Limits



If concentrations exceed Permit Limits then water is directed to the Tailings Pond (3-1D) or to the Open Pit (8D, 4-1)

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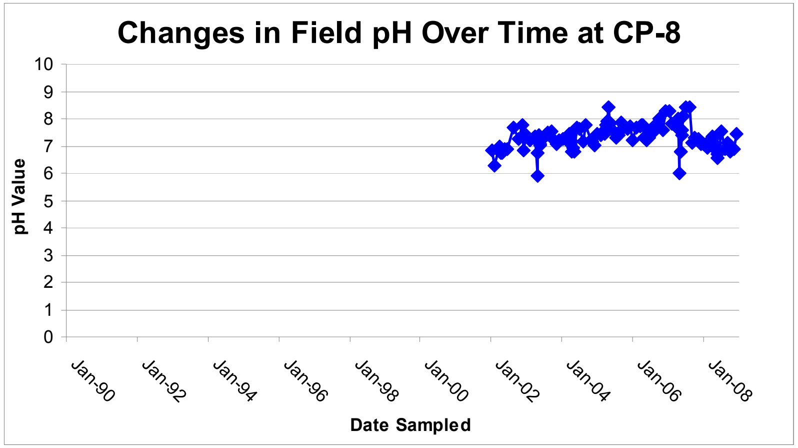
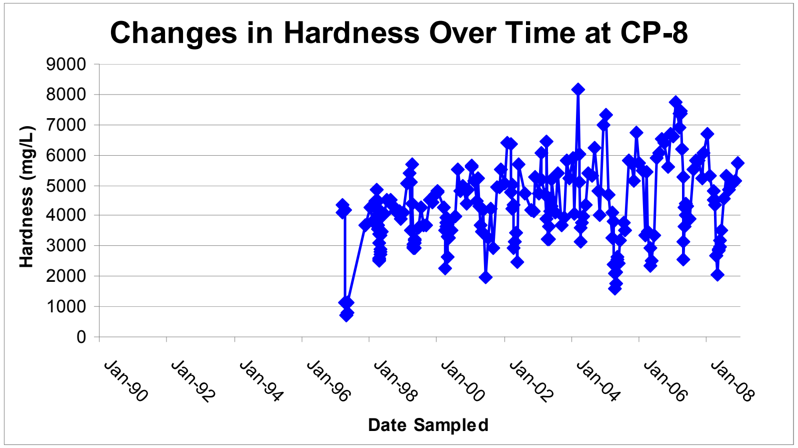
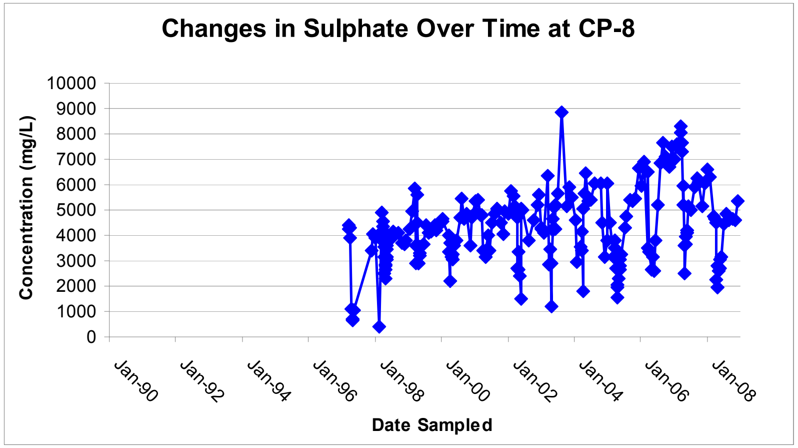
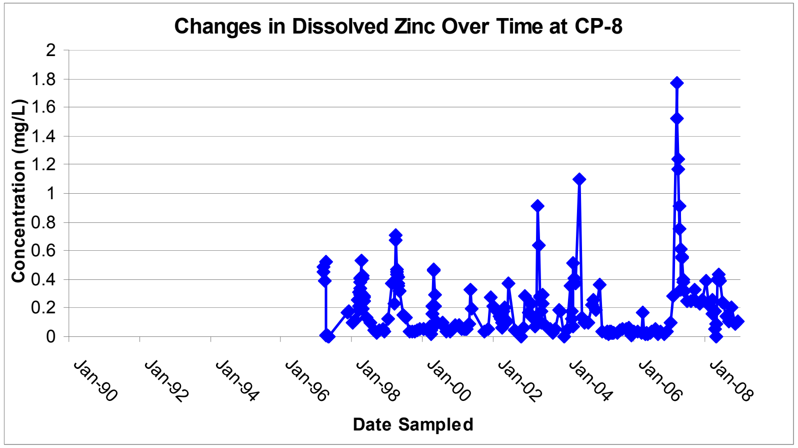
Bell - Chemistry in Collection Pond 8 (always directed to Open Pit)









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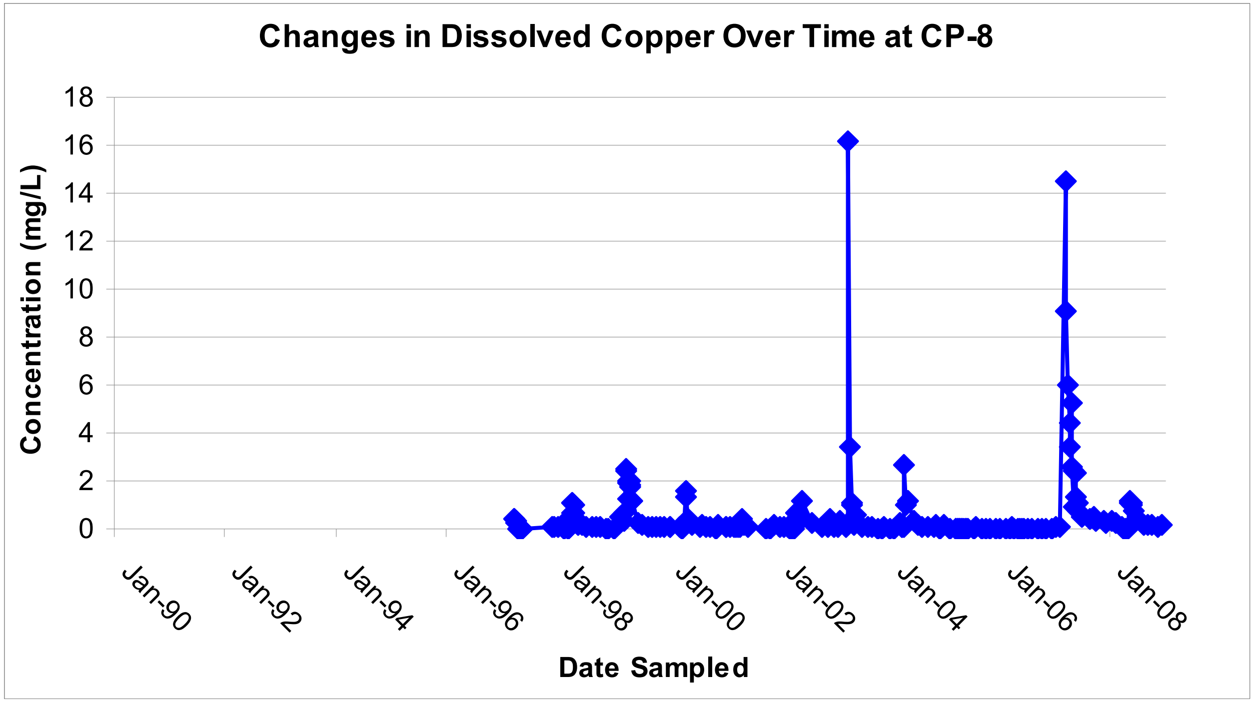
Bell - Chemistry in Collection Pond 8 (always directed to Open Pit)



All water directed to the Open Pit

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Filling Pit

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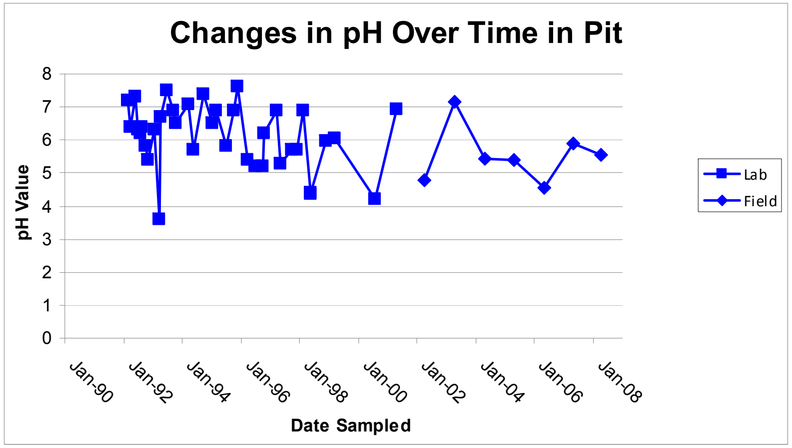
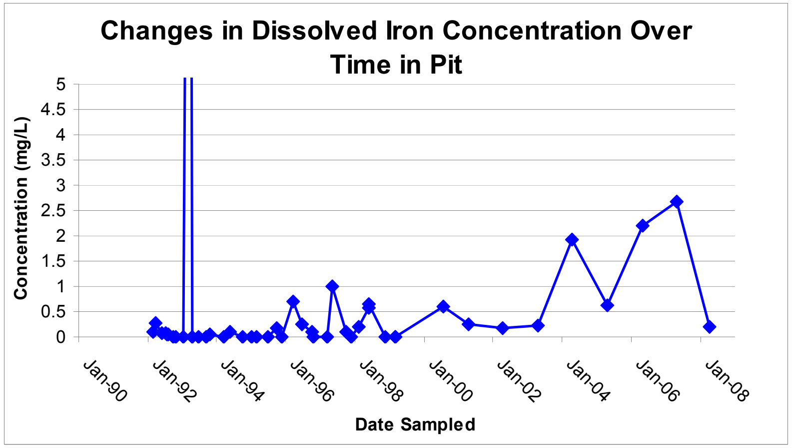
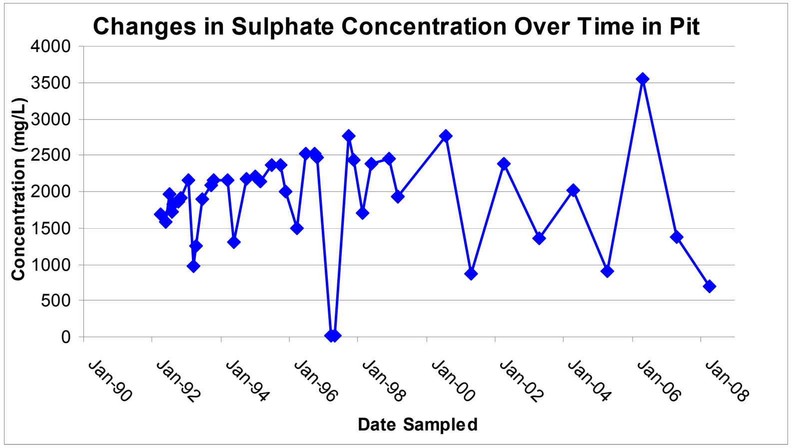
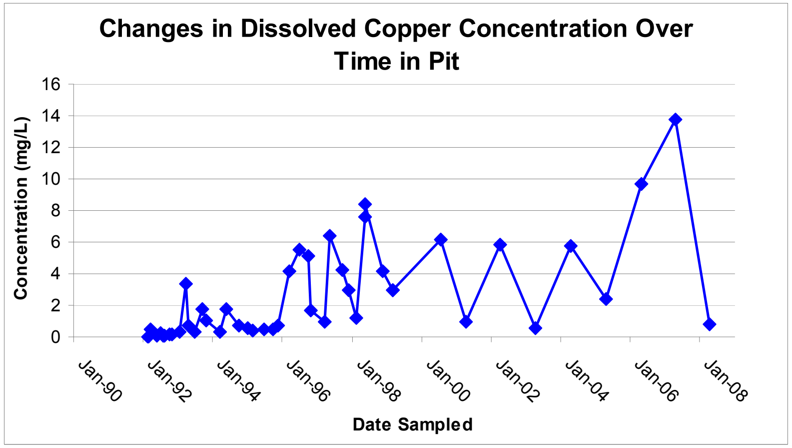
Water Quality in Pit Water









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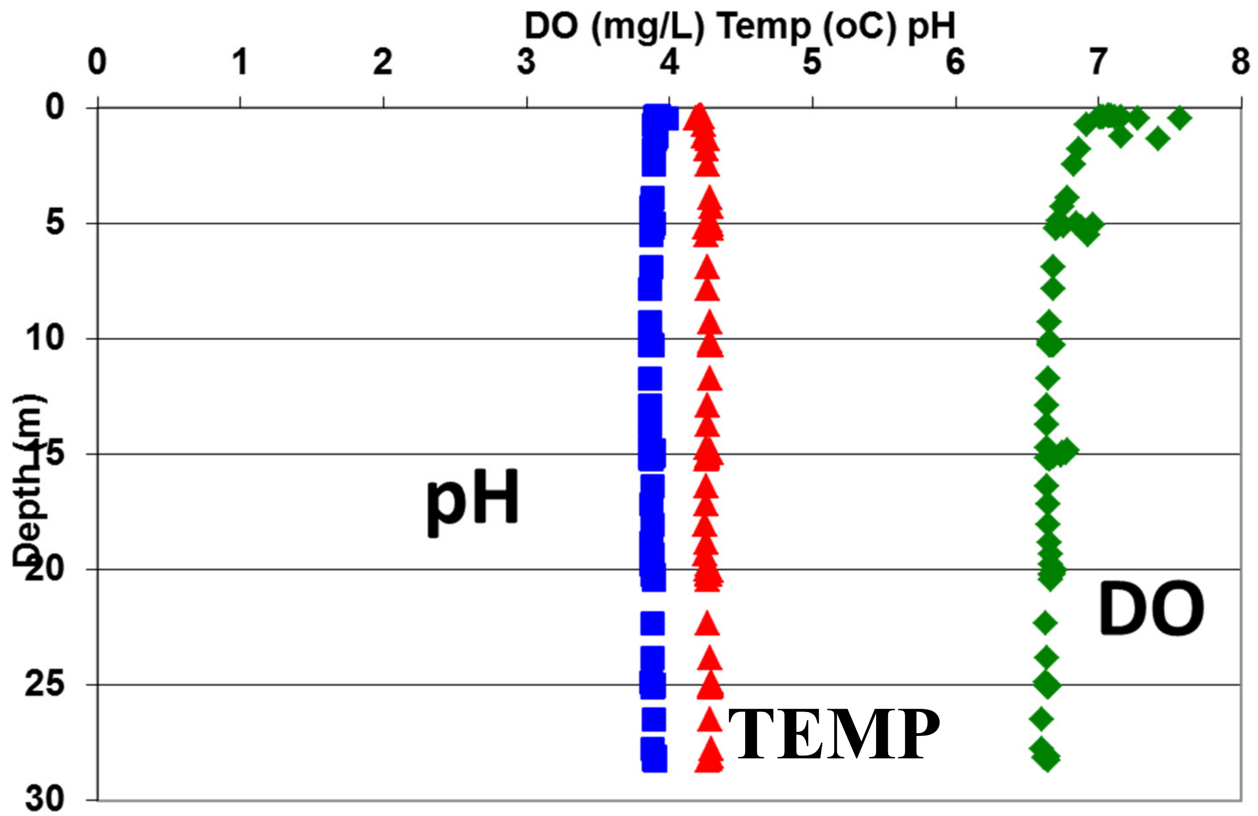
Pit Water Profiles in October 2009



Pit Water Quality with Depth

Sample ID		BMPW-0	BMPW-50	BMPW-100	BMPW-150	BMPW-200	BMPW-250	BMPW-300	BMPW-350	BMPW-400	BMPW-450	Average
Depth (m)		0	15	30	46	61	76	91	107	122	137	Values
Constituent	**Units**											
pH	--	3.89	4.02	4.07	4.04	4.04	4.03	4.00	4.00	4.00	3.98	4.01
Hardness (as CaCO3)	mg/L	3010	2870	2840	2830	2770	2800	2770	2830	2780	2940	2844
Sulfate	mg/L	2940	2960	2960	2940	2970	2950	2960	2960	2970	2930	2954
Copper (dissolved)	mg/L	9.10	8.67	8.80	8.47	9.03	8.43	9.00	9.08	9.00	9.12	8.87
Iron (dissolved)	mg/L	0.41	0.70	0.69	0.68	0.69	0.70	0.68	0.71	0.69	0.30	0.62
Zinc (dissolved)	mg/L	1.32	1.26	1.29	1.23	1.30	1.22	1.32	1.32	1.27	1.32	1.29

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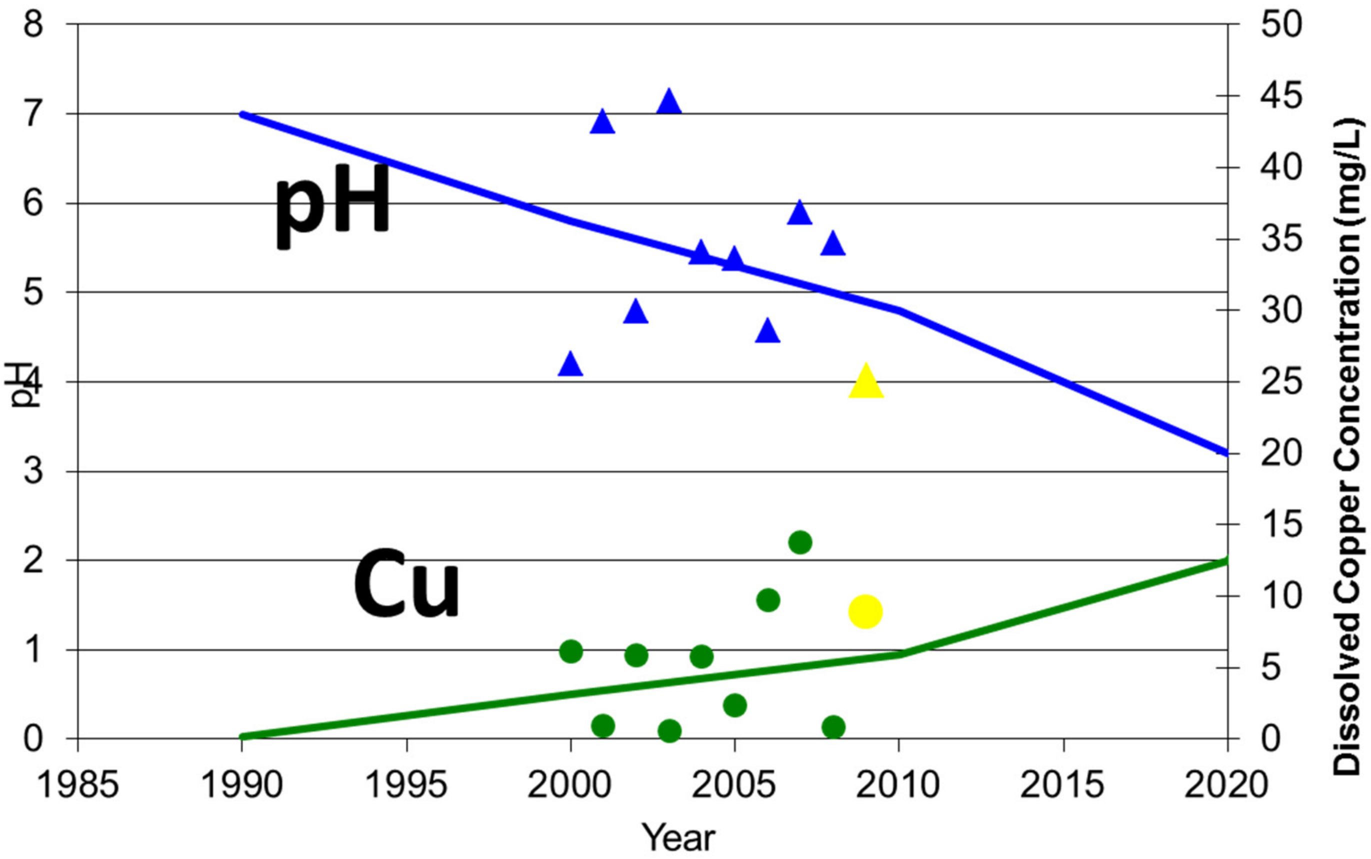
Pit Water Predictions



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Water Quality Predictions

Example – South Dump

Location	*	pH	Copper Dissolved (mg/L)	Iron Dissolved (mg/L)	Zinc Dissolved (mg/L)	Sulphate (mg/L)
South Dump Plant Site (CP 2)	a	7.0	4.0	<0.03	0.4	1000
	b	7.0	0.20	0.08	0.06	2000
	c	2.5	800	500	5.0	10,000
	d	5.8	10.8	2.0	0.92	5230

a = Measured in 1992
b = Predicted for neutral pH conditions
c = Predicted at full NP Depletion when pH becomes acidic
d = Measured in 2008

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Predictions in Tailings

- Tailings near surface will become acidic
- Acid front will advance 2 m in 11 years
- Sulphide depletion rate of 0.7 m/a

- Not net acidic seepage from tailings because shallow acidic pore water will be neutralized when moving through unoxidized tailings below the water table

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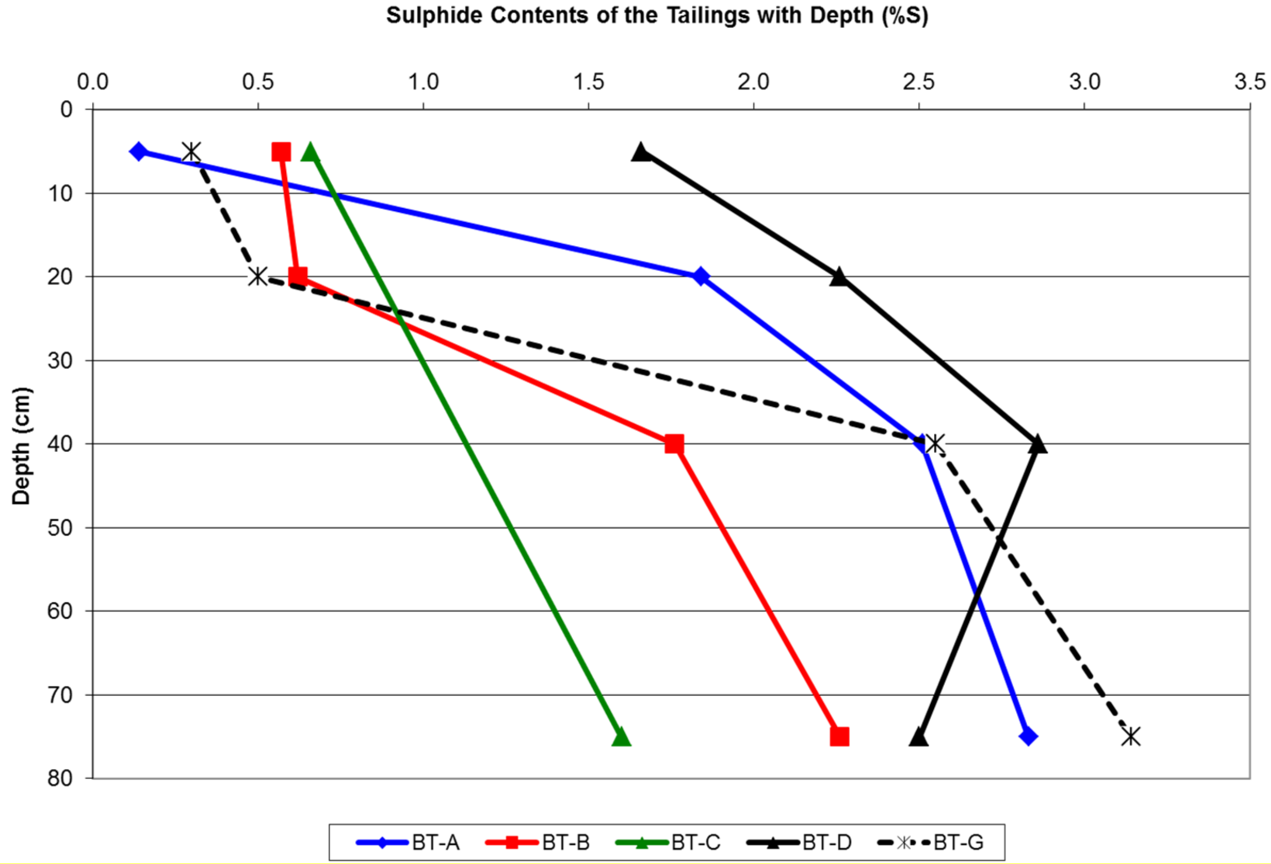
Sulphide Depletion in Tailings 2009



Observed sulphide depletion much slower than predicted

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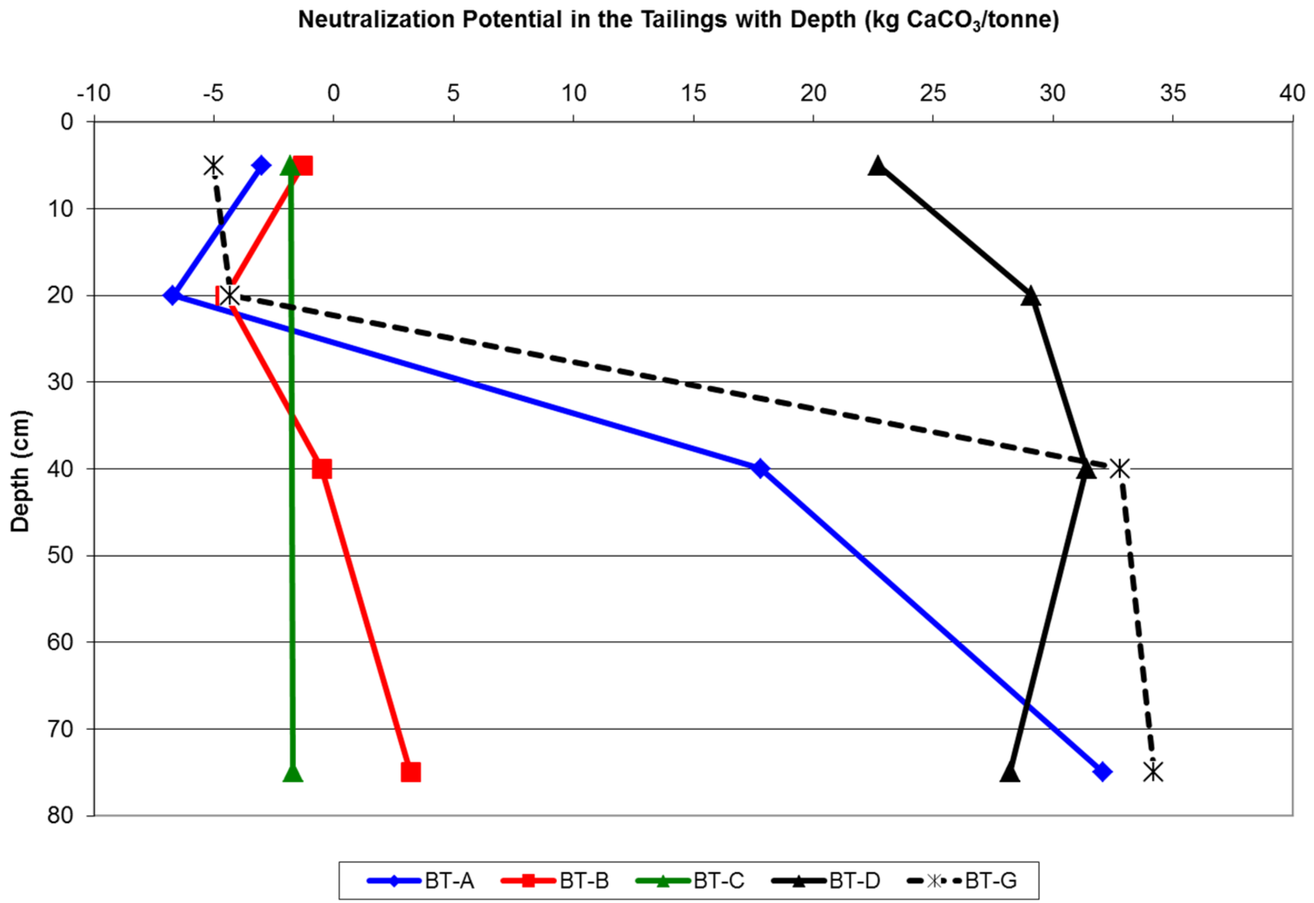
NP Depletion in Tailings 2009



Observed NP depletion much slower than predicted

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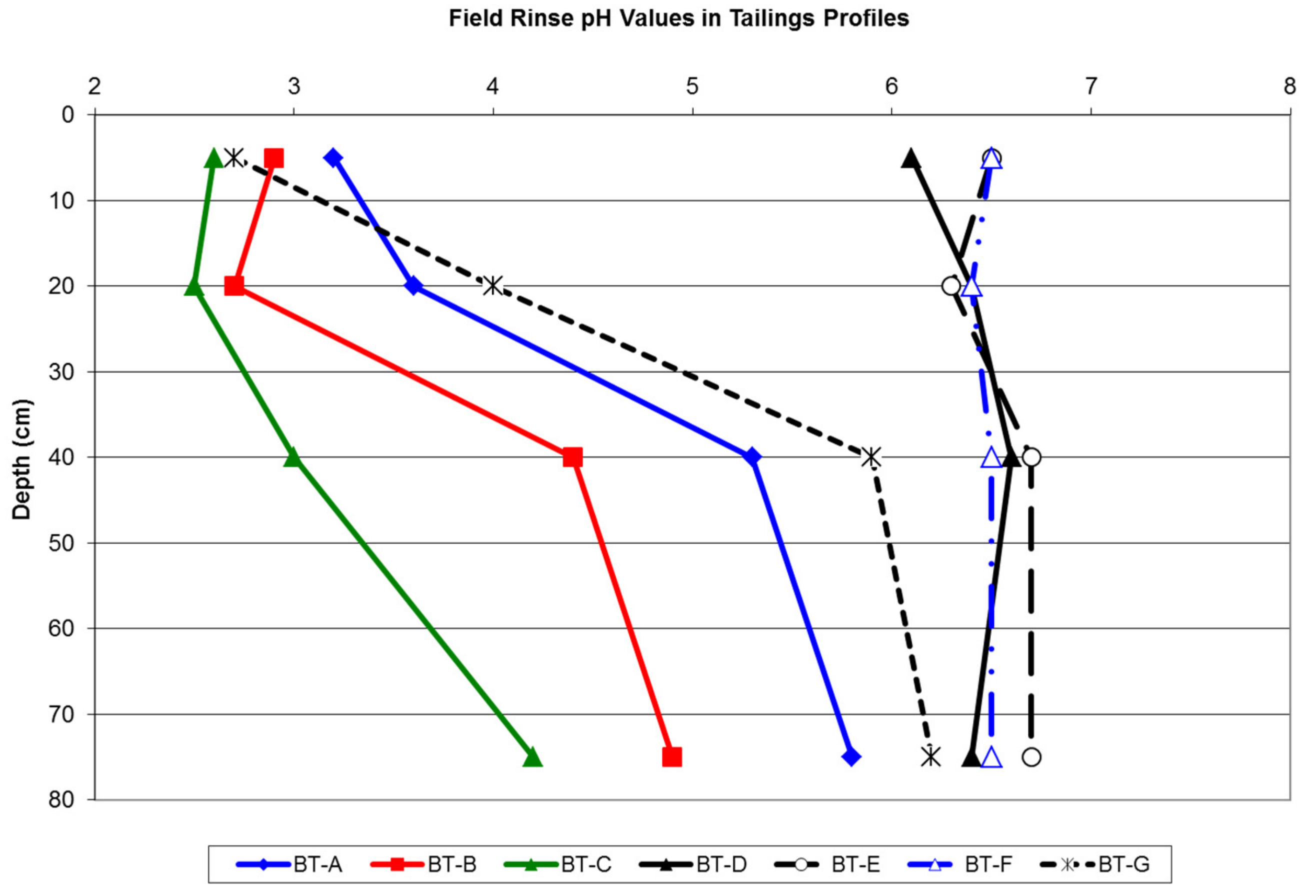
Rinse pH in Tailings 2009



Observed acid front advancing much slower than predicted

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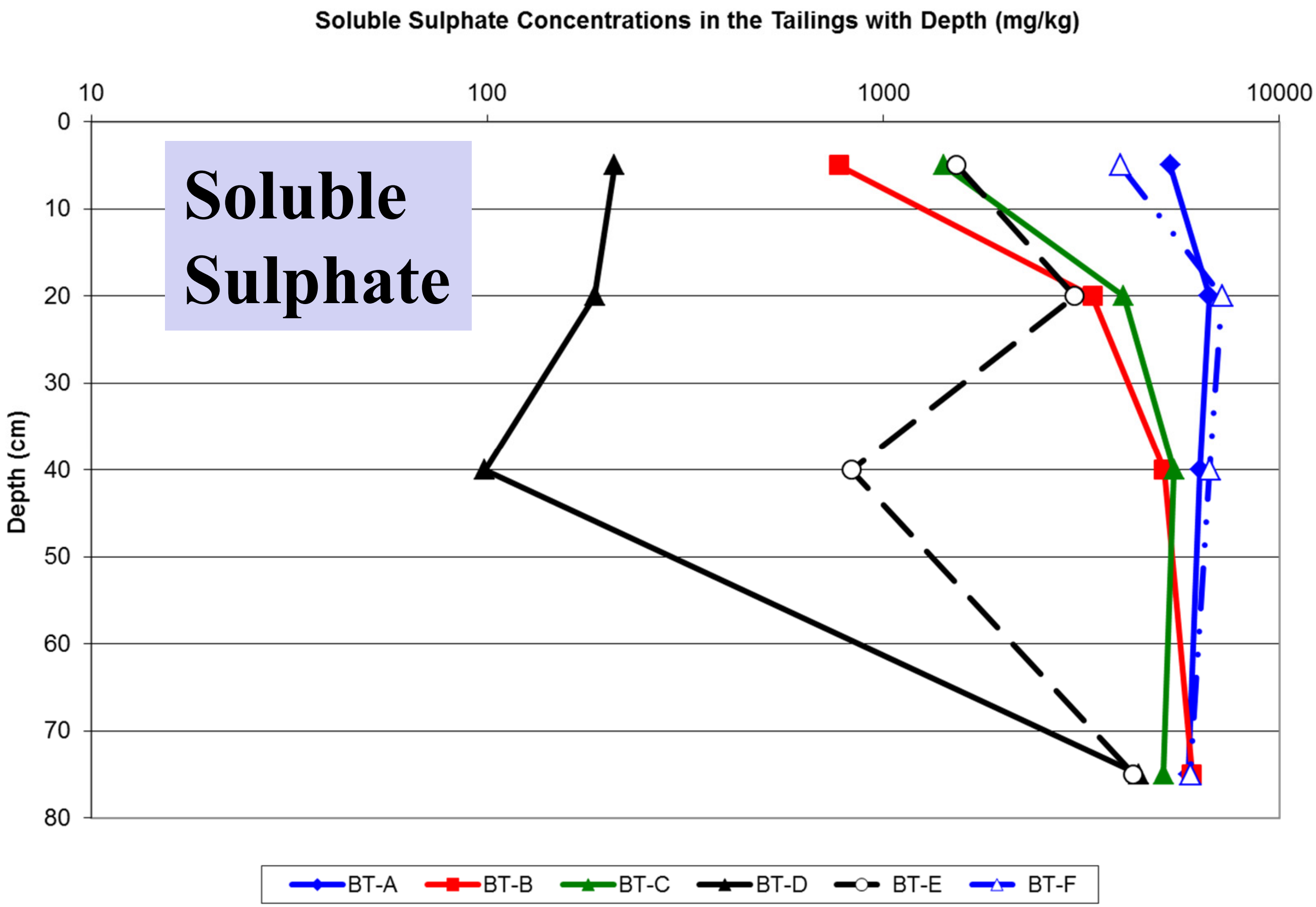
Water Quality in Tailings Pore Water 2009



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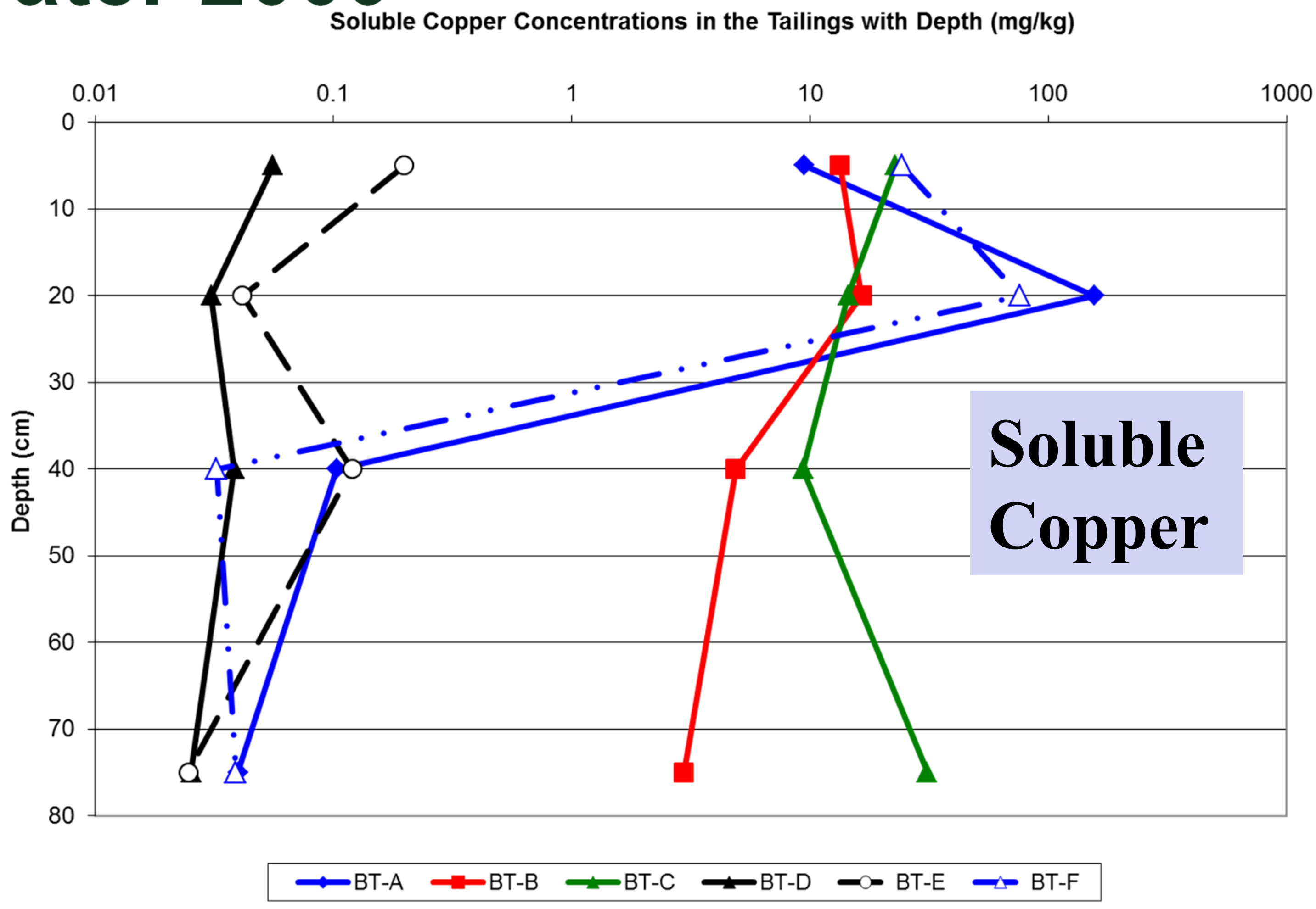
Water Quality in Tailings Pore Water 2009



Tailings Water Quality

- Some shallow tailings porewater has is acidic with elevated acidity and metals
- Wetter areas of tailings remain neutral with low acidity and metals
- Porewater pH is partially to completely neutralized within 1 m from surface
- Oxidation and acidification progressing much slower than predicetd
- Prediction of “no acidic tailings seepage” remains valid

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Conclusions

- Extensive ABA and kinetic testing combined with available field data from 20 years of operation provided a basis for water quality predictions
- Static tests predicted acid generating conditions
- Kinetic data from several sources used to predict;
  - WHEN - acidic conditions will begin
  - WHEN – sulphide will be depleted
  - Water quality at <u>neutral</u> and <u>acidic</u> pH values

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Conclusions

- Almost 20 years after predictions made;
  - Water quality associated with mine rock predictions remain valid and appear reasonable
  - Predictions for tailings were overly conservative for timing of acidification but remain valid fo long-term seepage quality

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