ARD IS NOT THE APOCALYPSE

A closed iron ore mine characterized by active ARD/ML and good water quality

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22th BC MEND ML-ARD Workshop
Vancouver, BC
2-3 December 2015

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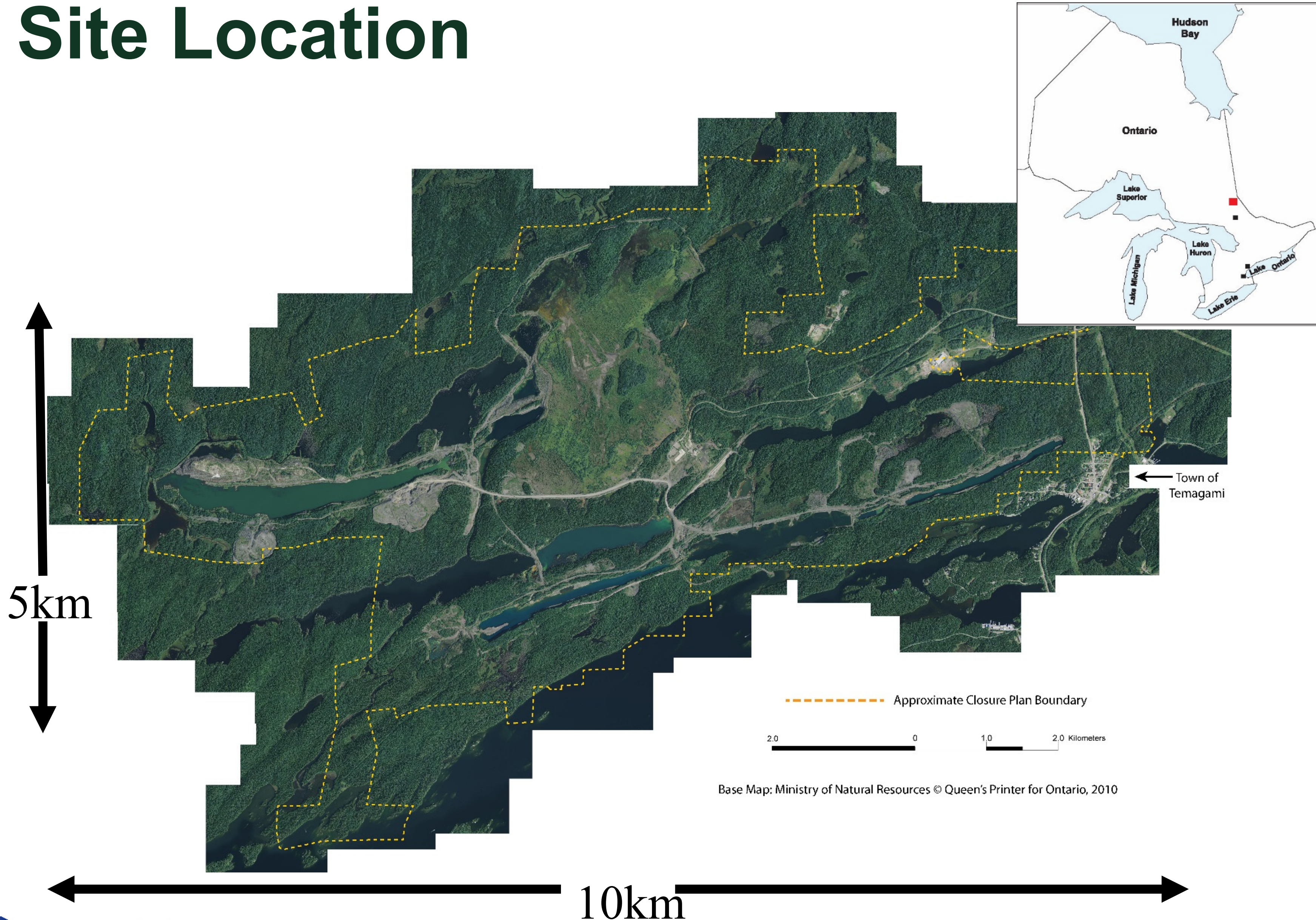
Site Location



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Site History

- Mine opened in 1968
    - Joint venture between Dofasco and Cleveland-Cliffs
- 22 Million tonnes of iron pellets produced
- Shipped to Dofasco’s Hamilton steel-making operations
- Mine Closed in March 1990
- Final Closure Plan “accepted” by Ontario Ministry of mines in 1995
- Numerous environmental studies completed by Dofasco, government agencies and other interested groups

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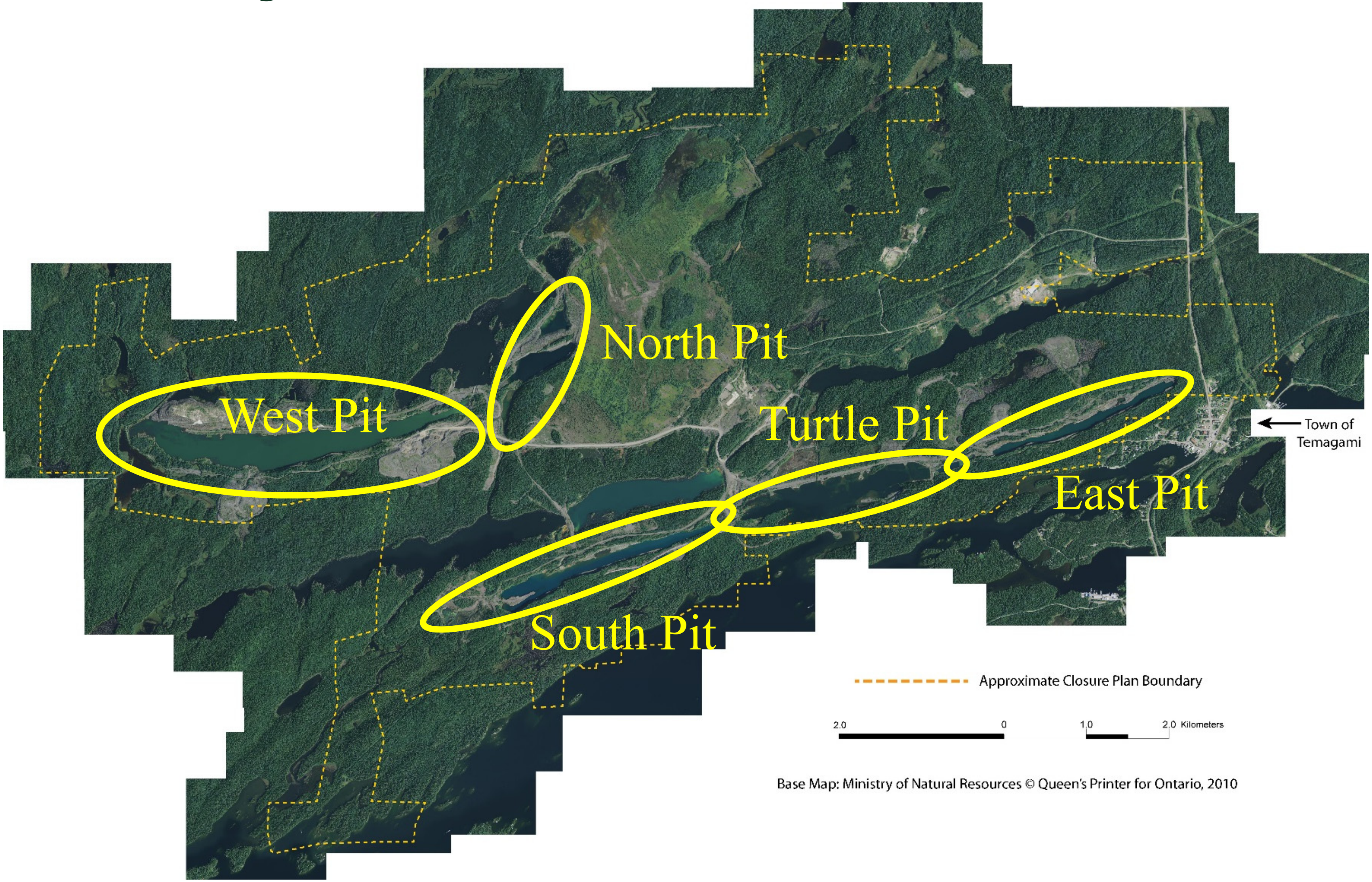
Site Layout



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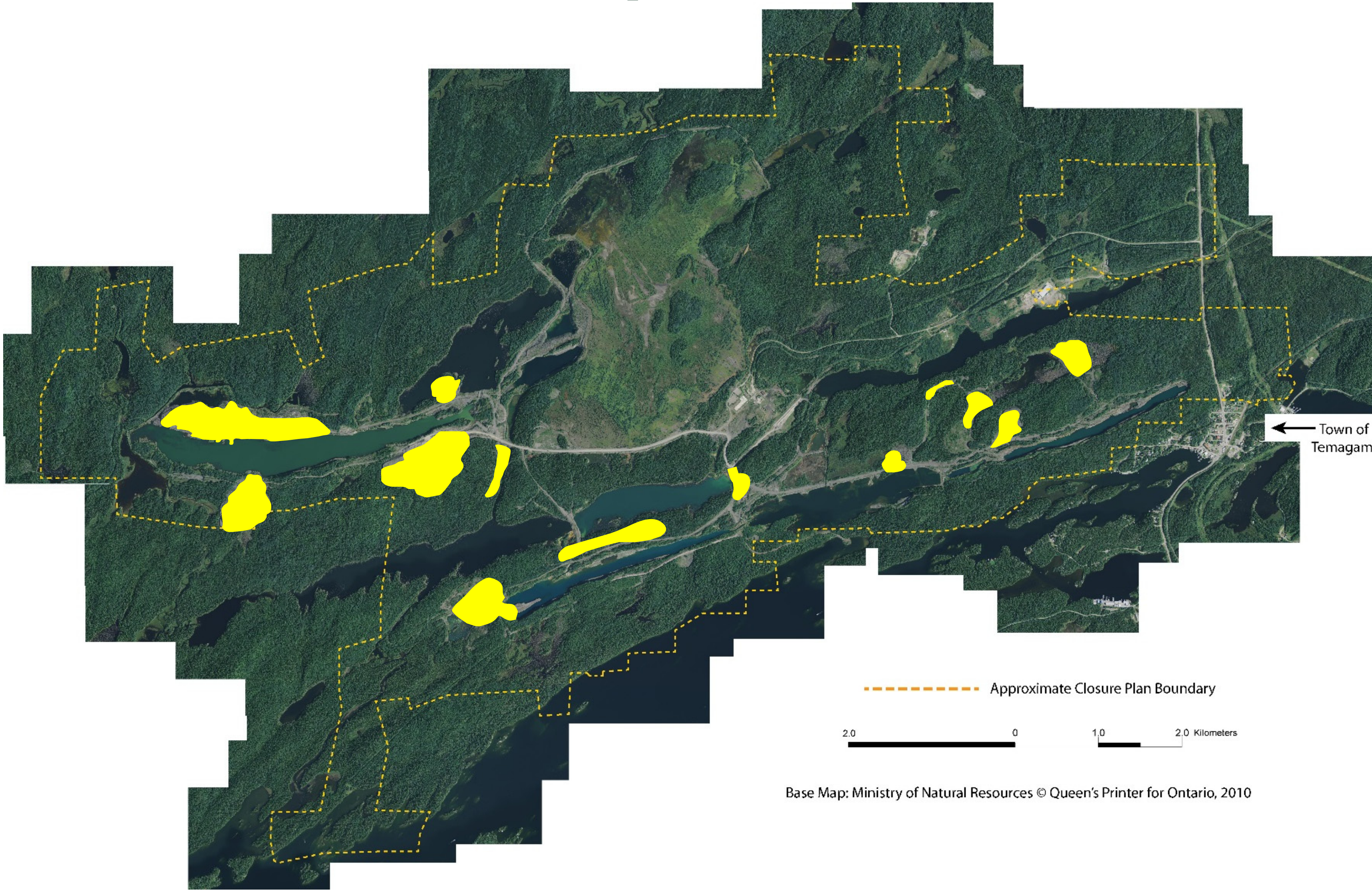
Mine Rock Stockpiles



Mine Waste Management

- ARD/ML was emerging for the metal mine industry at time of mine operations
  - Site closed prior to requirement of Closure Plan’s in Ontario
  - Company implemented a Closure Plan on own accord

- Mine waste management methods
  - Segregation of high sulphide material for storage in the tailings
  - Blasting of sulphide-rich zone above the final flood level in one pit

- Some sulphide mine rock not segregated prior to 1977
  - used for road building or rock stockpiles
  - resulting in local areas of acid drainage on-site

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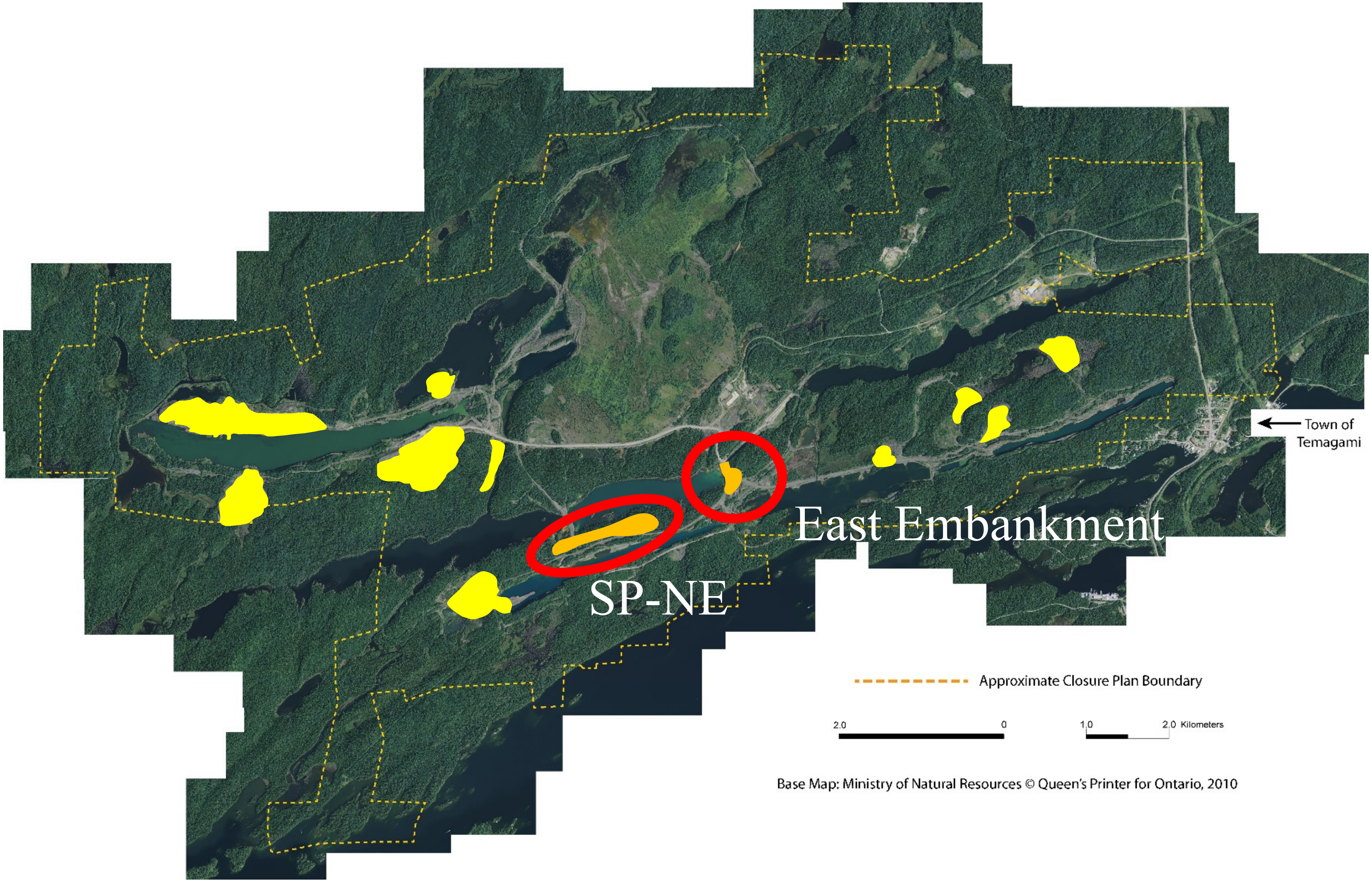
Mine Rock



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Acid Generation

SP-NE Stockpile

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Acid Generation

East Embankment

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Acid Drainage Quality

Parameter	Units	Max or Min Values
pH	-	2.35
Sulphate	mg/L	6720
Aluminum	mg/L	218
Cadmium	mg/L	0.01
Chromium	mg/L	0.3
Cobalt	mg/L	1.2
Copper	mg/L	1.2
Iron	mg/L	265
Manganese	mg/L	85
Nickel	mg/L	2.5
Zinc	mg/L	3.2

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Mine Rock Sampling

- 73.2M tonnes mine rock
- Over 500 samples collected in 2014
- 210 Samples analysed
  - 46 Boreholes
  - 42 Test Pits

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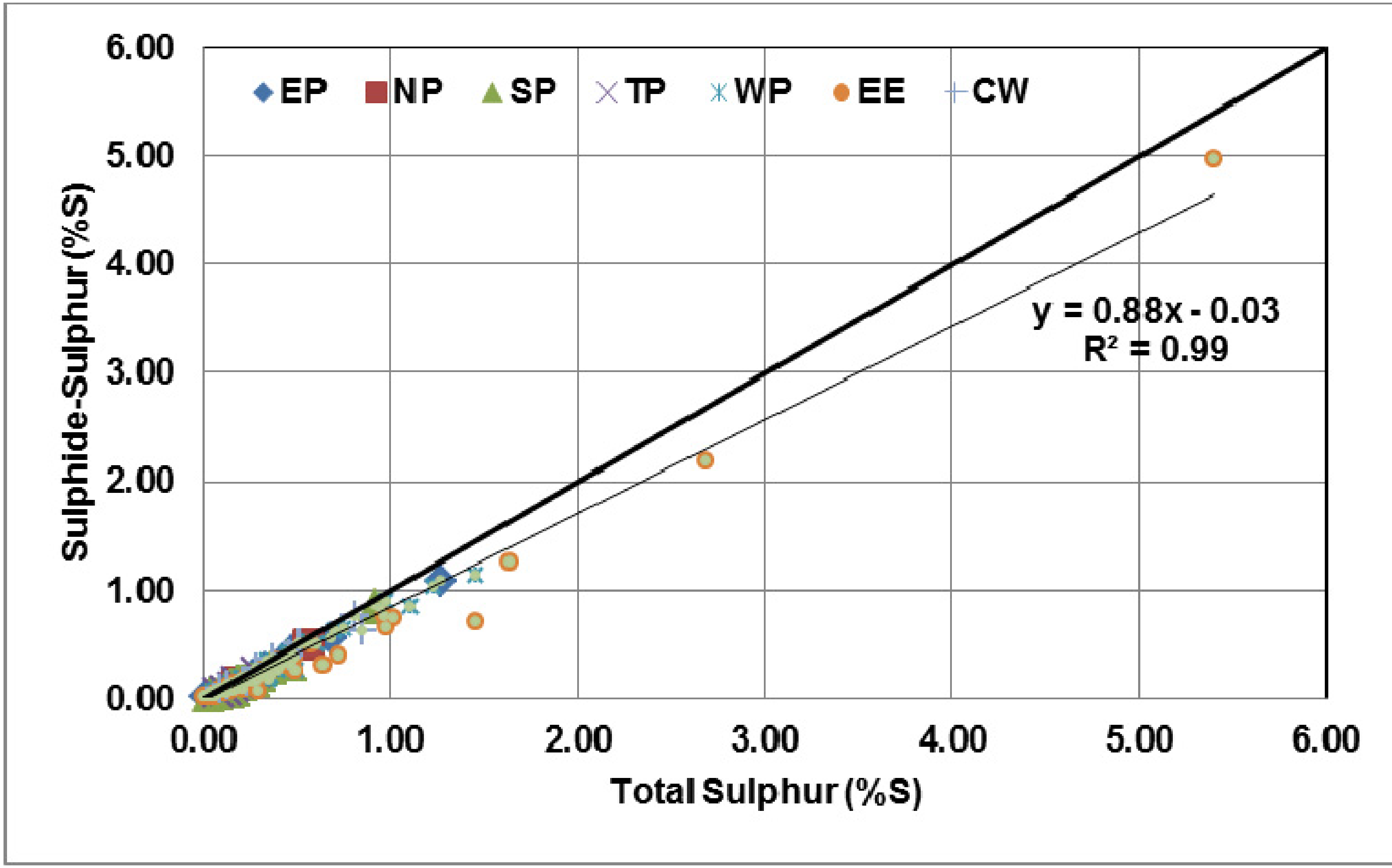
Almost 90% of Sulphur is Sulphide



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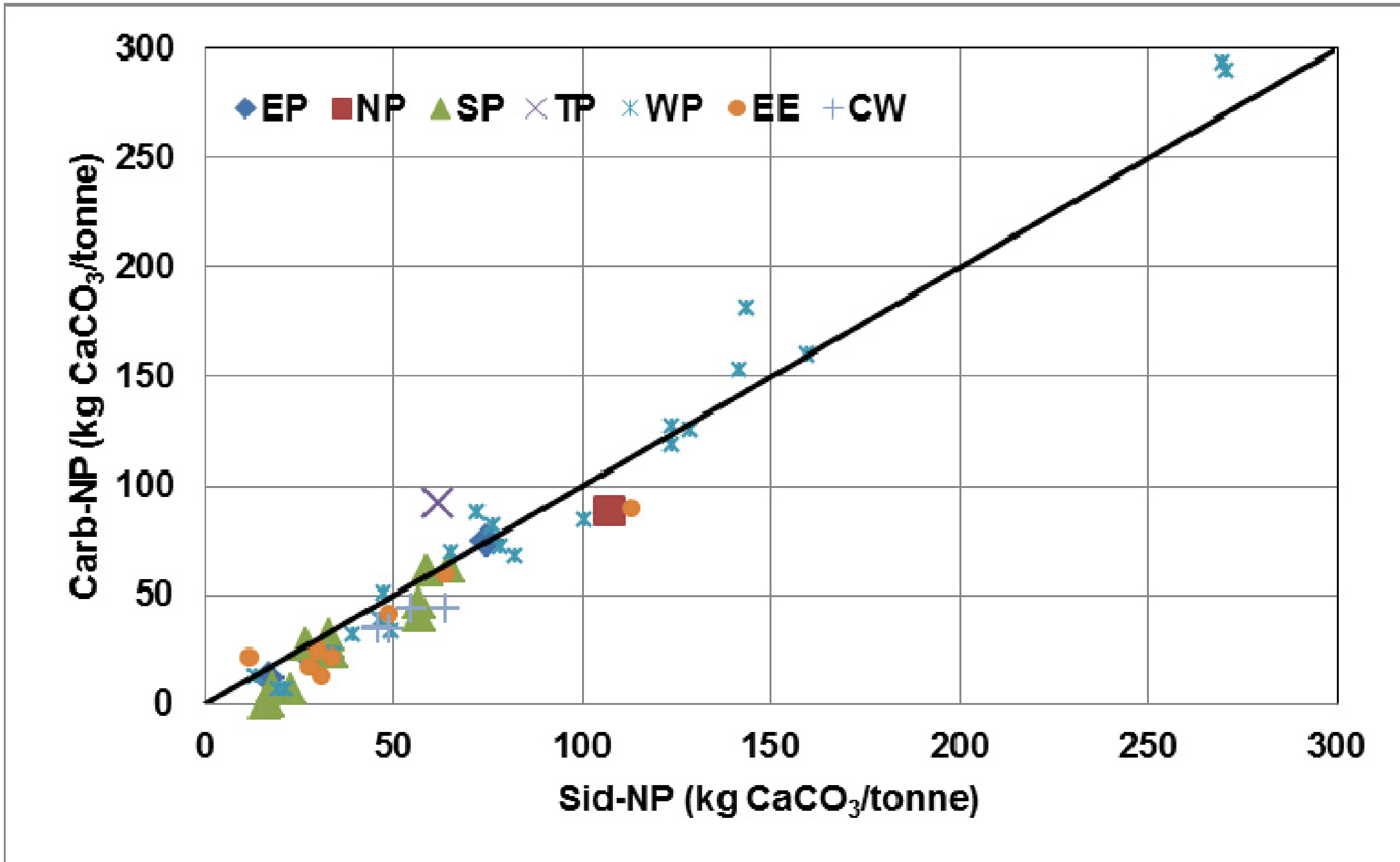
Carbonate is a More Conservative Estimate of Neutralization Potential than Siderite-Corrected Sobek NP



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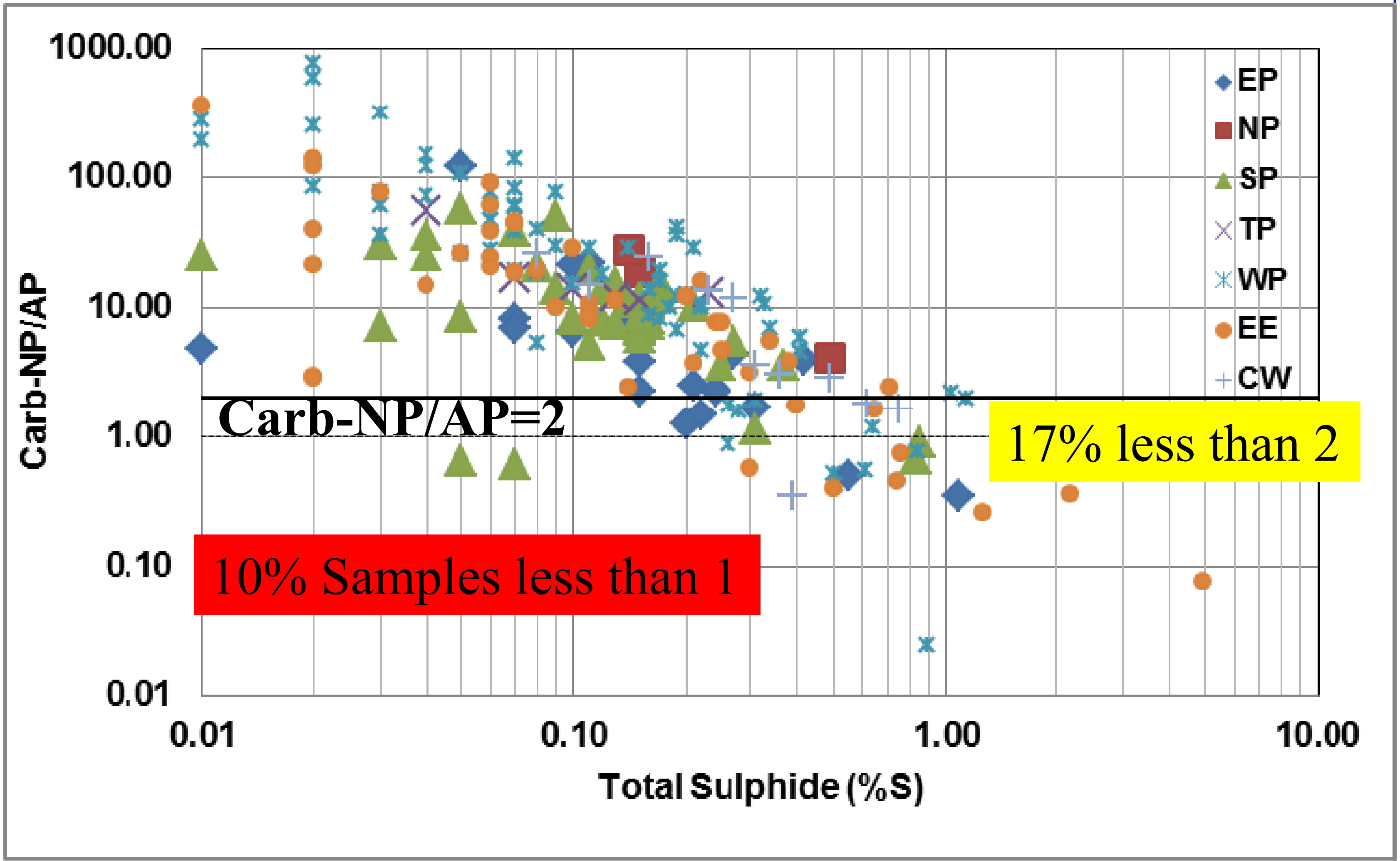
*Sid-NP is Siderite-Corrected Modified Sobek

ARD Potential



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Neutralization Potential Ratios

Mine rock stockpile	Number samples	Geometric mean	Minimum	Maximum	Samples with Carb-NPR < 1.0	
					Number	Percent
NP-N	3	12.8	4.0	27.8	0	0%
EP-N	6	2.9	0.3	8.2	1	17%
EP-NE	6	1.7	0.5	7.0	1	17%
Acidic SP-NE	21	7.8	0.6	56.3	2	10%
SP-SW	15	8.3	0.7	30.6	2	13%
TP-N	2	11.7	11.3	12.2	0	0%
TP-NE	4	20.2	12.8	55.7	0	0%
TP-E	7	10.9	2.5	119.4	0	0%
WP-N	21	7.6	0.02	7.6	2	10%
WP-NE	6	6.0	0.7	18.6	1	17%
WP-S	16	30.3	2.1	733.3	0	0%
WP-SE	8	6.4	0.4	188.8	3	38%
WP-SW	15	62.9	6.7	568.0	0	0%
Acidic East Embankment	50	7.6	0.1	358.9	7	14%
Causeway	12	4.7	0.3	26.2	1	8%
Total	192	9.8	0.02	733	20	10%

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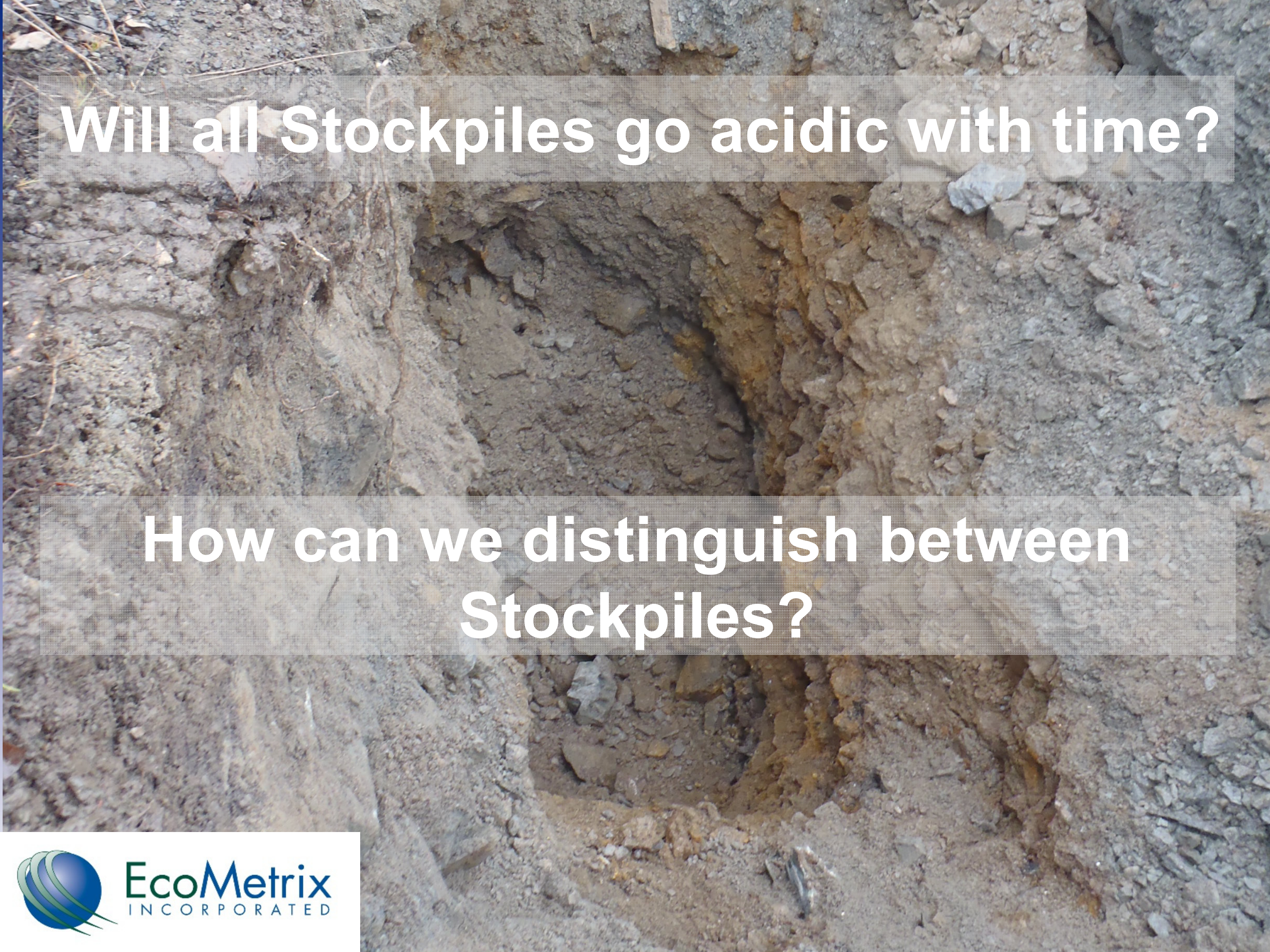
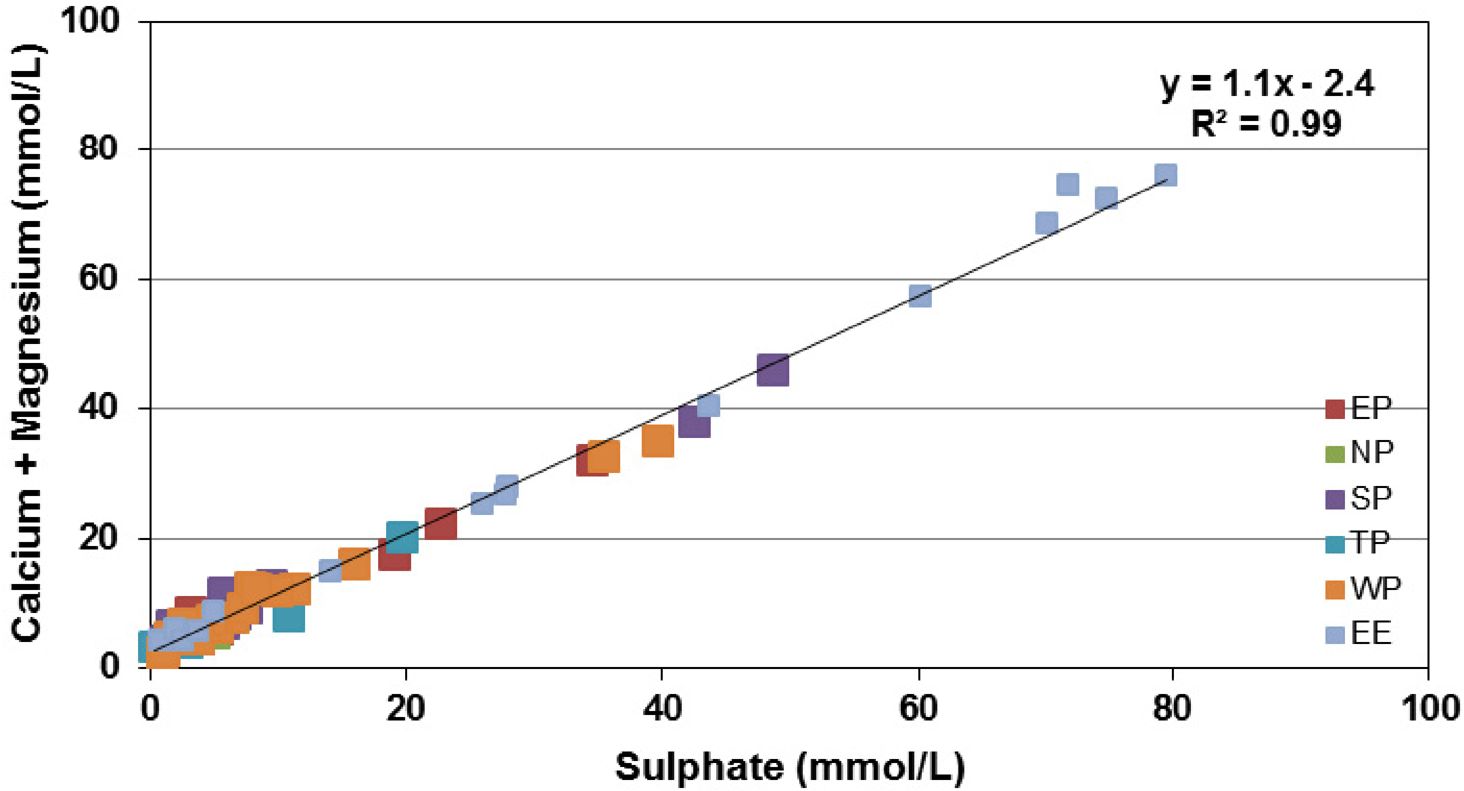
Will all Stockpiles go acidic with time?

How can we distinguish between Stockpiles?



Pore Water Chemistry in Rock Piles



Sulphide oxidation and carbonate consumption rates similar in all stockpiles

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Depletion Rate Calculations

- Acid can be generated when Carbonate is depleted before Sulphide

- Porewater concentrations (SFE) give rates for;
  - Sulphide depletion using sulphate
  - Carbonate Depletion using Calcium (Ca) + Magnesium (Mg)

- Represent realistic rates in 25+ year old rock

- Geometric mean;
  - Ca and Mg concentrations in pore water samples
  - Sulphide and carbonate contents in solids

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Depletion Rates

	Mine Rock Stockpile	Depletion Rate (mgl/kg/a)		Sulphide Depletion Times	Carbonate Depletion Times
		Sulphide	Carbonate	(a)	(a)
	NP-N	38	289	29	278
	EP-N	31	299	34	59
	EP-NE	48	428	24	27
Acidic	SP-NE	44	408	12	59
	SP-SW	47	394	15	84
	WP-N	76	514	14	91
	WP-NE	61	451	20	93
	WP-S	30	292	15	282
	WP-SE	45	372	14	62
	WP-SW	16	185	15	484
	TP-N	119	595	6	79
	TP-NE	11	172	39	302
	TP-E	72	509	6	52
Acidic	East Embankment	118	839	6	36

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Sensitivity Analysis

- Effect of sulphide and carbonate depletion rates
- Ca+Mg/SO_4 ratio constrained between 1 and 2
- Scenarios included:
  - Scenario 1 → geometric mean Ca+Mg and SO_4 rates
  - Scenario 2 → 25th percentile Ca+Mg and SO_4 rates
  - Scenario 3 → geometric mean Ca+Mg and 25th percentile SO_4 rates
  - Scenario 4 → 75th percentile Ca+Mg and geometric mean SO_4 rates

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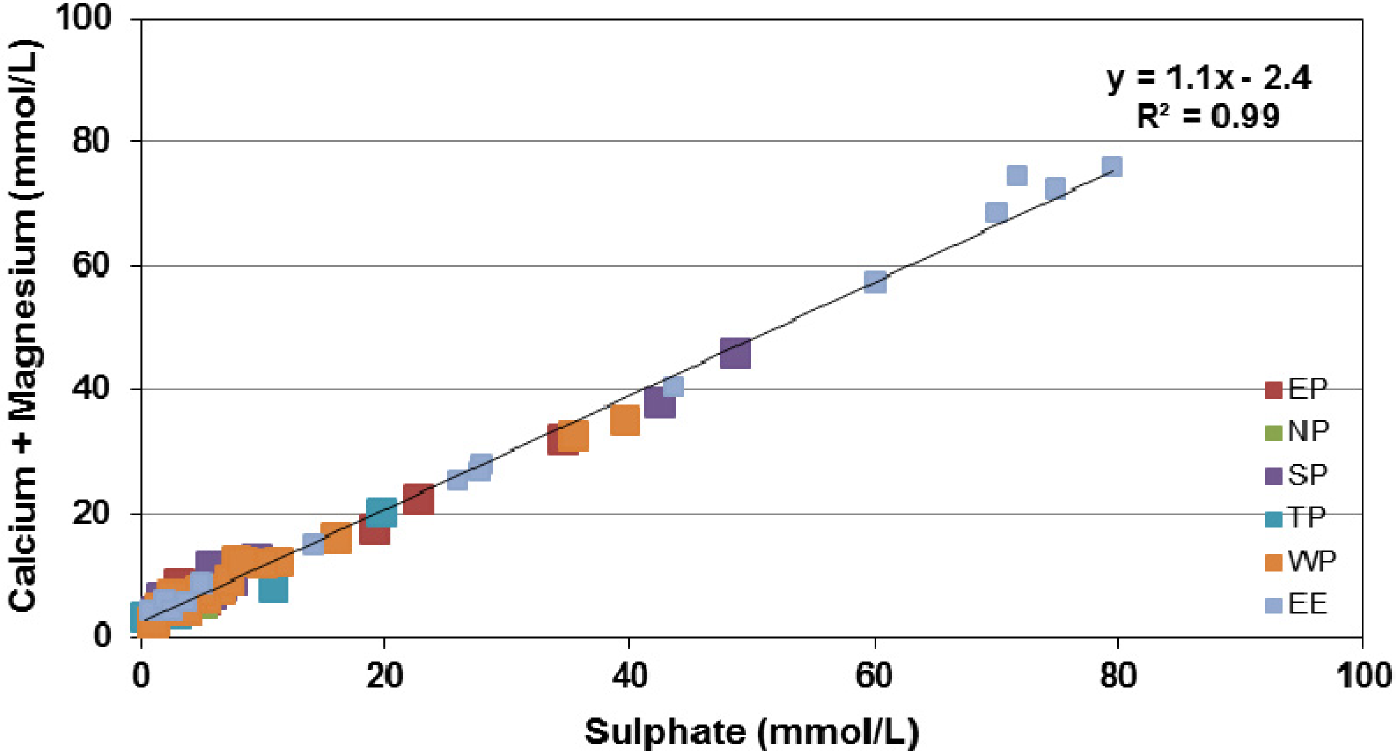
Neutralization Reactions



Median (Ca+Mg)/SO_4 Ratio of about 1.3

Less than 2 NP for 1 AP
(Effective and Efficient NP)

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Sensitivity Results

Mine Rock Stockpile	Geomean Rates Scenario 1 Sulphide Depletion (a)	 Scenario 1 Carbonate Depletion (a)	25th Percentile Rates Scenario 2 Sulphide Depletion (a)	 Scenario 2 Carbonate Depletion (a)	25th Percentile SO_4 Rates Scenario 3 Sulphide Depletion (a)	 Scenario 3 Carbonate Depletion (a)	75th Percentile Ca/Mg Rates Scenario 4 Sulphide Depletion (a)	 Scenario 4 Carbonate Depletion (a)
NP-N	29	278	29	278	29	278	29	278
EP-N	34	59	37	63	37	59	34	54
EP-NE	24	27	49	35	49	27	24	16
SP-NE	12	59	35	129	35	59	12	21
SP-SW	15	84	20	102	20	84	15	64
WP-N	14	91	26	155	26	91	14	56
WP-NE	20	93	23	105	23	93	20	66
WP-S	14	243	20	264	20	243	14	174
WP-SE	14	62	22	78	22	62	14	47
WP-SW	15	484	29	700	29	484	15	388
TP-N	6	79	7	91	7	79	6	58
TP-NE	39	302	74	333	74	302	39	276
TP-E	6	52	11	83	11	52	6	34
East Embankment	6	36	23	110	23	36	6	11

Carbonate Depleted before Sulphide in Solids

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Sensitivity Analysis

- Effect of carbonate availability

- To simulate these conditions:
  - Sulphide contents → geometric mean values
  - Carbonate contents → 50% of the geometric mean values

- Scenarios included:
  - Scenario 5 → geometric mean Ca+Mg and SO_4 rates
  - Scenario 6 → 25th percentile Ca+Mg and SO_4 rates
  - Scenario 7 → geometric mean Ca+Mg and 25th percentile SO_4 rates
  - Scenario 8 → 75th percentile Ca+Mg and geometric mean SO_4 rates

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Sensitivity Results

Mine Rock Stockpile	Geomean Rates Scenario 5 Sulphide Depletion (a)	Geomean Rates Scenario 5 Carbonate Depletion (a)	25th Percentile Rates Scenario 6 Sulphide Depletion (a)	25th Percentile Rates Scenario 6 Carbonate Depletion (a)	25th Percentile SO_4 Rates Scenario 7 Sulphide Depletion (a)	25th Percentile SO_4 Rates Scenario 7 Carbonate Depletion (a)	75th Percentile Ca/Mg Rates Scenario 8 Sulphide Depletion (a)	75th Percentile Ca/Mg Rates Scenario 8 Carbonate Depletion (a)
NP-N	29	139	29	139	29	139	29	139
EP-N	34	29	37	31	37	29	34	27
EP-NE	24	13	49	18	49	13	24	8
SP-NE	12	29	35	65	35	29	12	11
SP-SW	15	42	20	51	20	42	15	32
WP-N	14	45	26	78	26	45	14	28
WP-NE	20	47	23	53	23	47	20	33
WP-S	14	121	20	132	20	121	14	87
WP-SE	14	31	22	39	22	31	14	24
WP-SW	15	242	29	350	29	242	15	194
TP-N	6	40	7	45	7	40	6	29
TP-NE	39	151	74	167	74	151	39	138
TP-E	6	26	11	42	11	26	6	17
East Embankment	6	18	23	55	23	18	6	5

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Stockpile Acid Production

- Acid Production is dependent on:
  - Relative availability of sulphide and carbonate phases in each stockpile
  - Variability in rates of sulphide and carbonate depletion

- For East Embankment, SP-NE, EP-N and EP-NE:
  - Higher depletion rates for carbonates suggest potential risk
  - Less available carbonates suggest potential risk

- Remaining stockpiles not expected to experience net acid production

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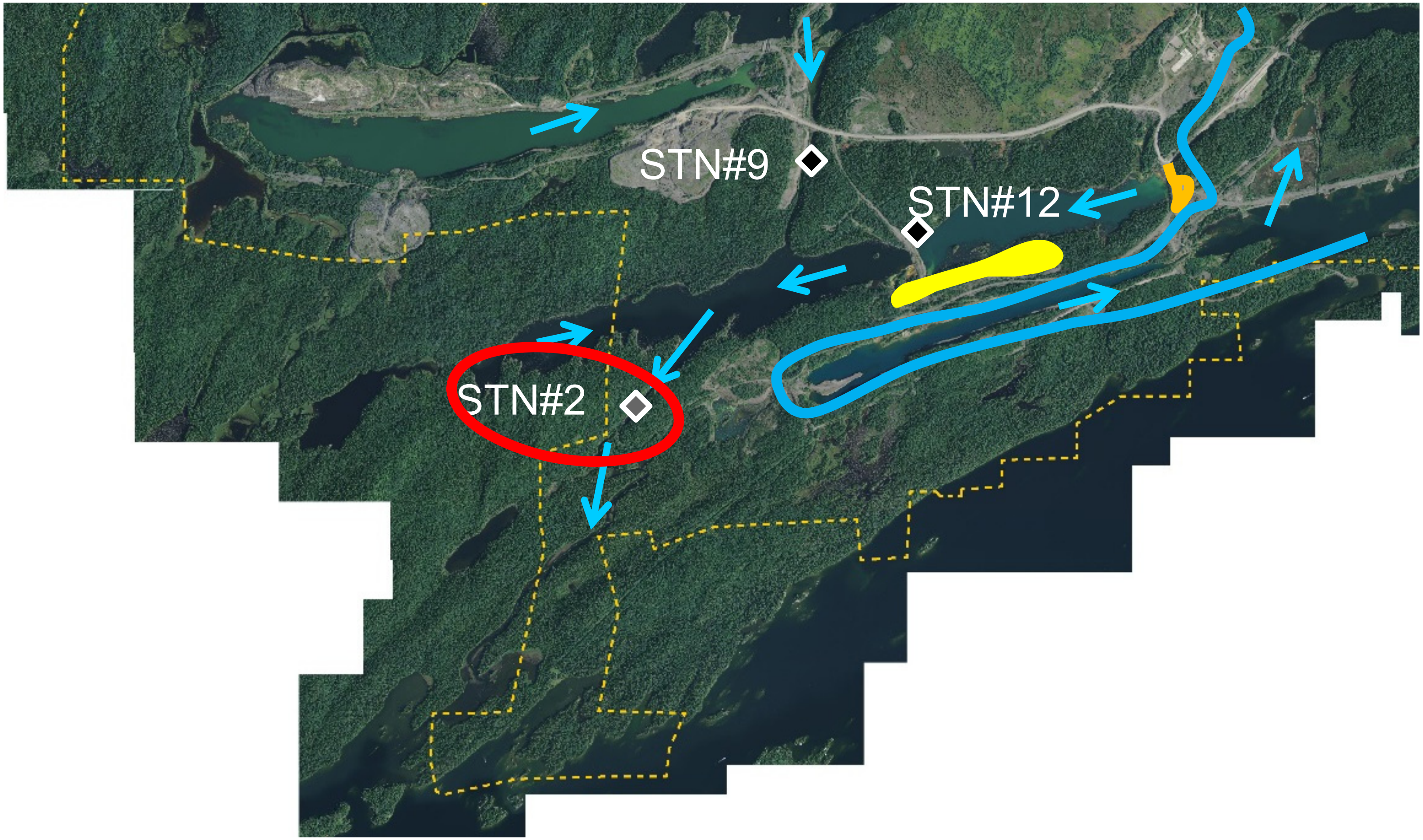
Site Water Quality



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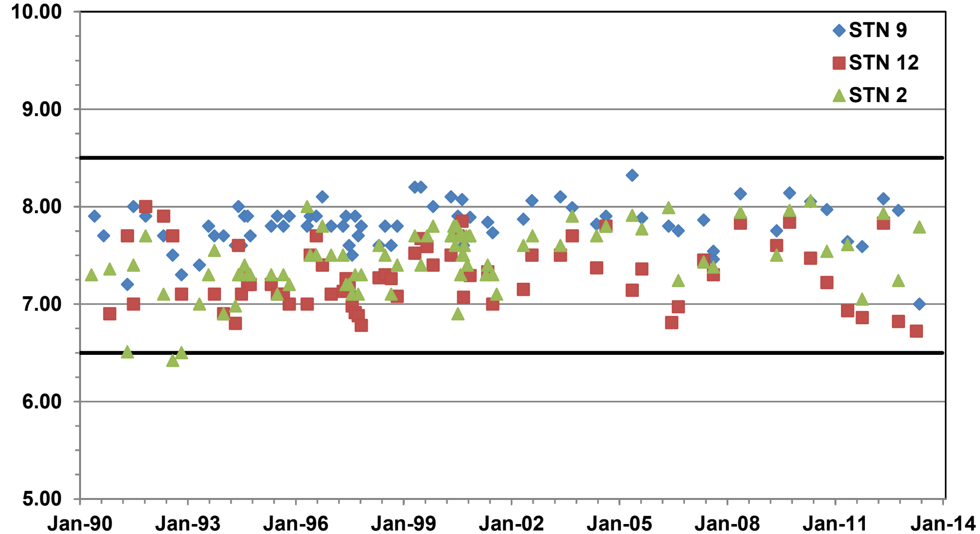
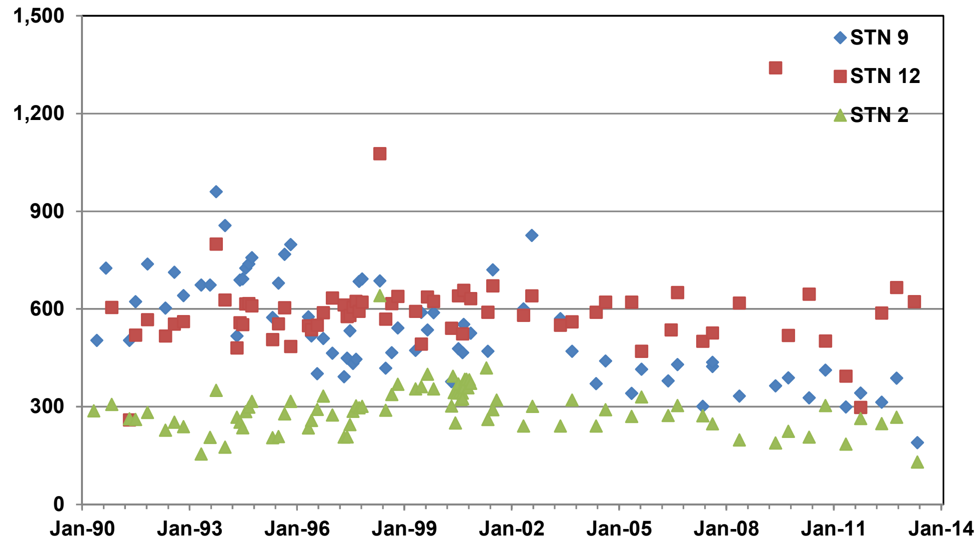
Site Water Quality

pH



SO_4
(mg/L)



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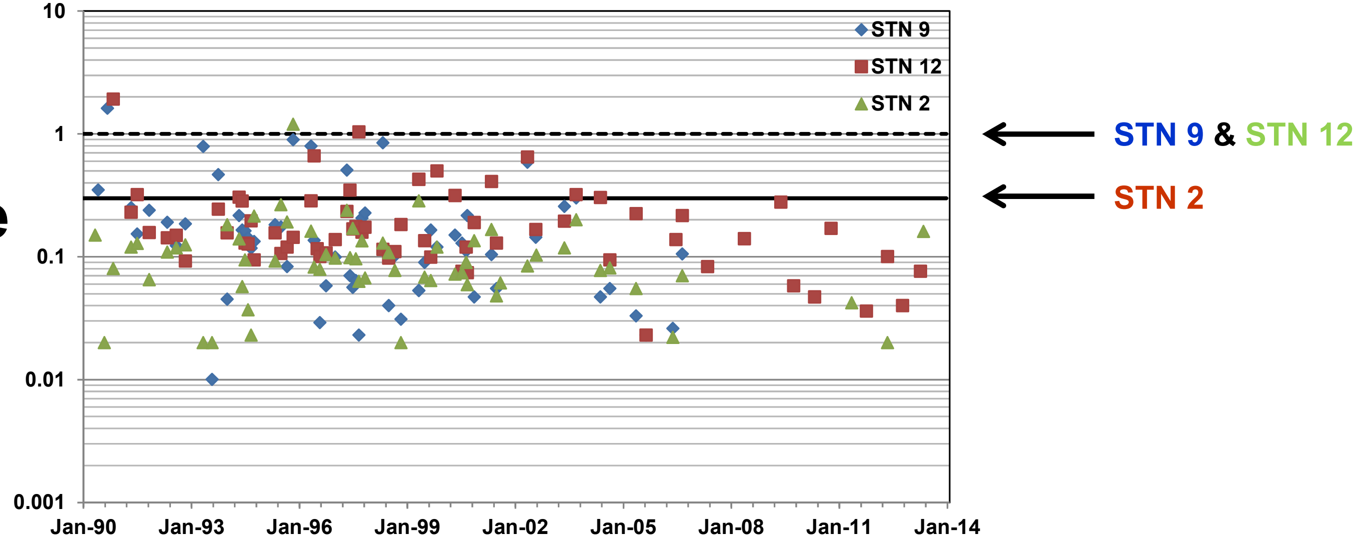
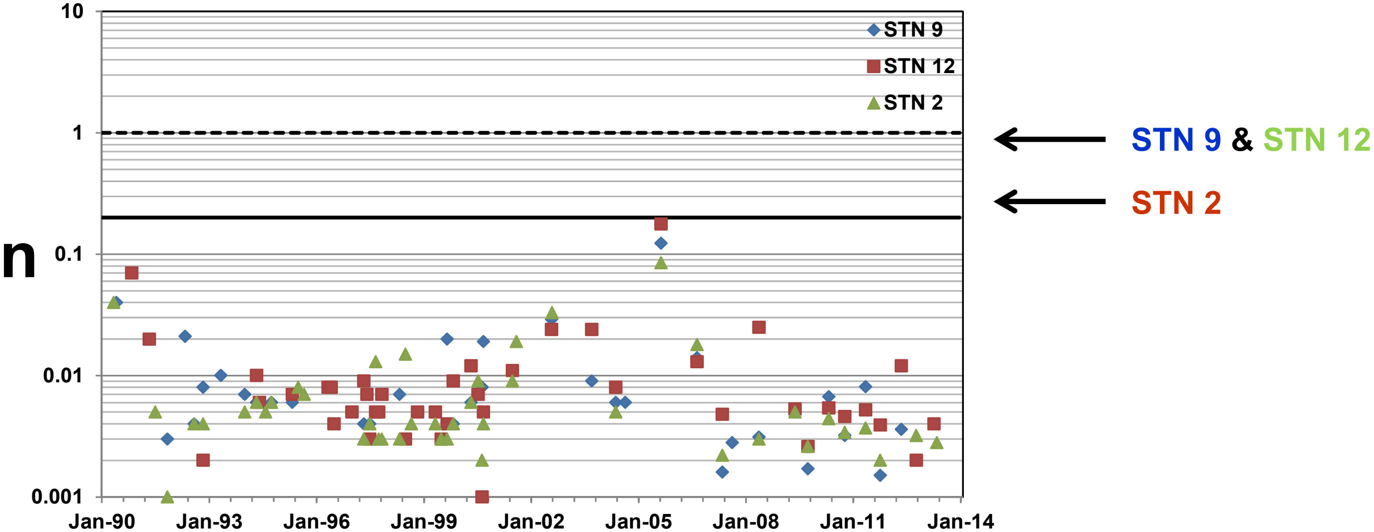
Site Water Quality

Total Fe
(mg/L)



Total Zn
(mg/L)



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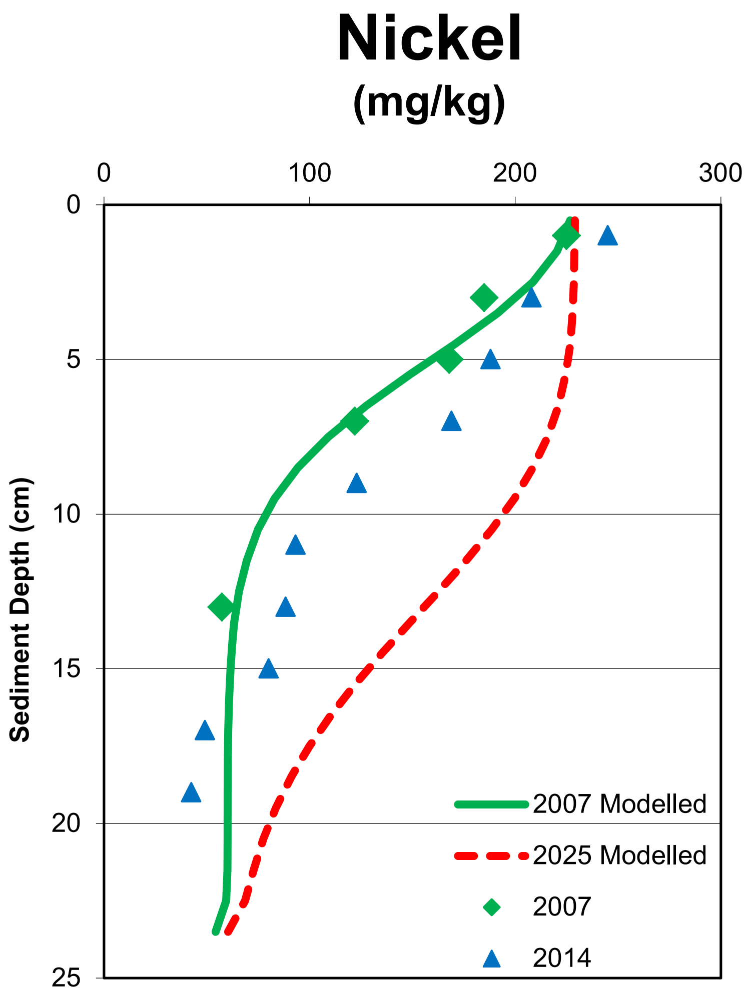
Site Water Quality

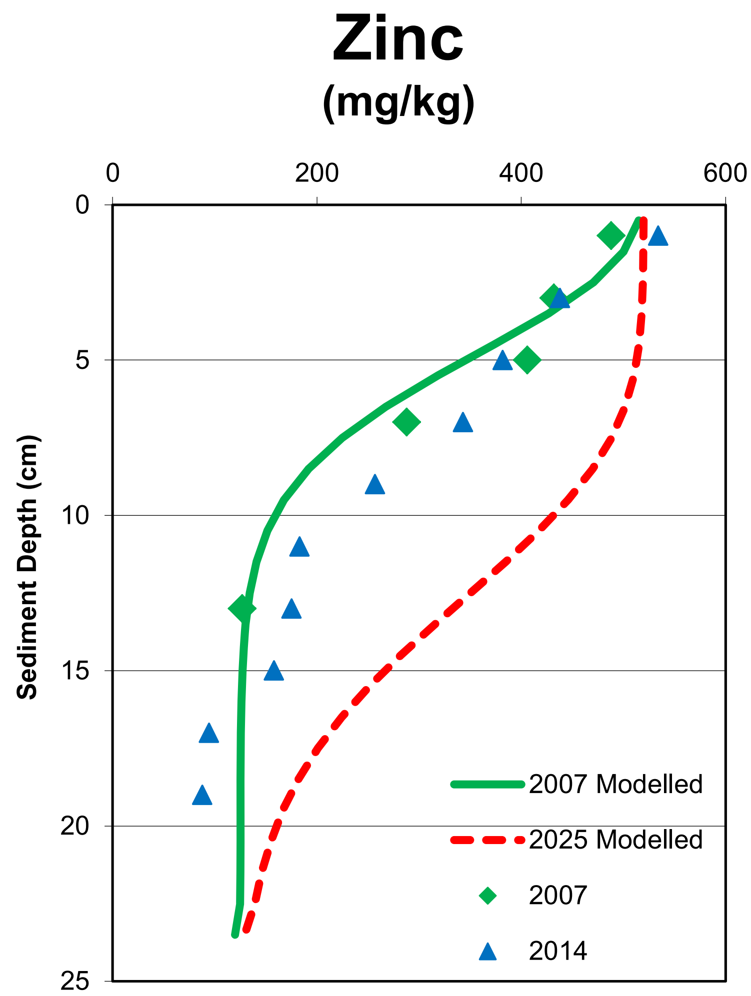
- Water quality has been stable or improving at all sampling sites since mine closure

- Water quality at compliance points were less than PWQO levels for all COPCs

- Acid drainage associated with East Embankment and SP-NE do not negatively influence downstream water quality (STN-2)

Site Sediment Quality





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ArcelorMittal DOFASCO | HAMILTON

Site Sediment Quality

- Similar temporal trends in core samples
  - Elevated concentrations at depths associated with onset of mining
  - Greatest increases associated with cores adjacent to East Embankment and SP-NE
- Stabilized and decreasing concentrations in upper sections at other stations
- 2014 and 2007 measured values reasonably predicted by model predictions
- Stabilization predicted in 10 years followed by declines

Conclusions

- ABA averages or median values in rock piles may not be sufficient to predict ARD in future
- Study results indicate that more in-depth investigations are sometimes required
- Use of realistic variations in calculated depletion rates and sulphide/carbonate availabilities in solids needed
- Demonstrated distinct differences in stockpile characteristics
  - not observed in ABA results

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Conclusions

- Additional work is required to better understand what separates East Embankment, SP-NE, EP-N and EP-NE
- Isolated potential ARD/ML to 4 of 13 stockpiles
- Remaining stockpiles will not become net acid producing
- Monitoring will reduce risk to environment – conditions for potential future ARD no greater than for existing piles

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Conclusions

- Mitigation during operations prevented more potentially severe effects of ARD after closure
- Sulphide rock to tailings and underwater in pits was innovative at that time
- Water quality leaving the site meets closure plan objectives and remains protective of the environment


QUESTIONS?
Water-Filled Pit
(Not a Lake)
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