

# Case Study on PHREEQC Geochemical Modeling for An INAC Abandoned Mines

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- **Background**
- **Modeling capabilities**
- **Case studies**
  - Phase II ESA for Outpost Mine

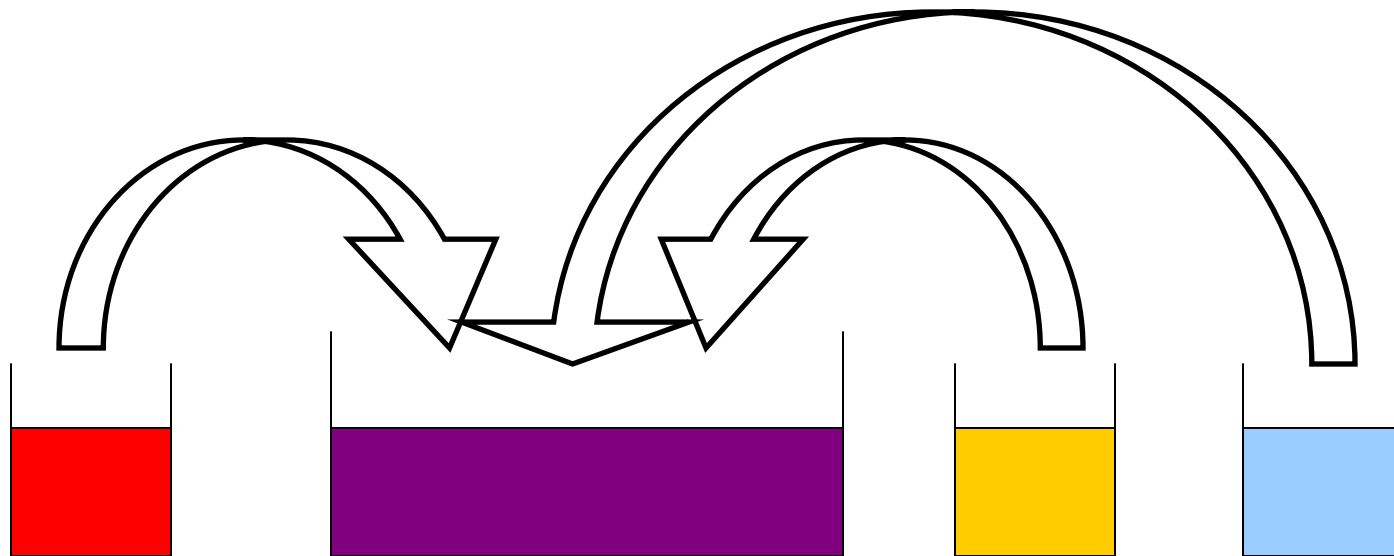
# PHREEQC BACKGROUND

- PH'RE'EQ'C = pH, redox, equilibrium written in C language
- Low-temperature aqueous geochemical calculations
- Version 1.0 was released in 1995
- Latest version is PHREEQC 2.15.0.2697 (Feb 5, 2008)

# MODEL CAPABILITIES

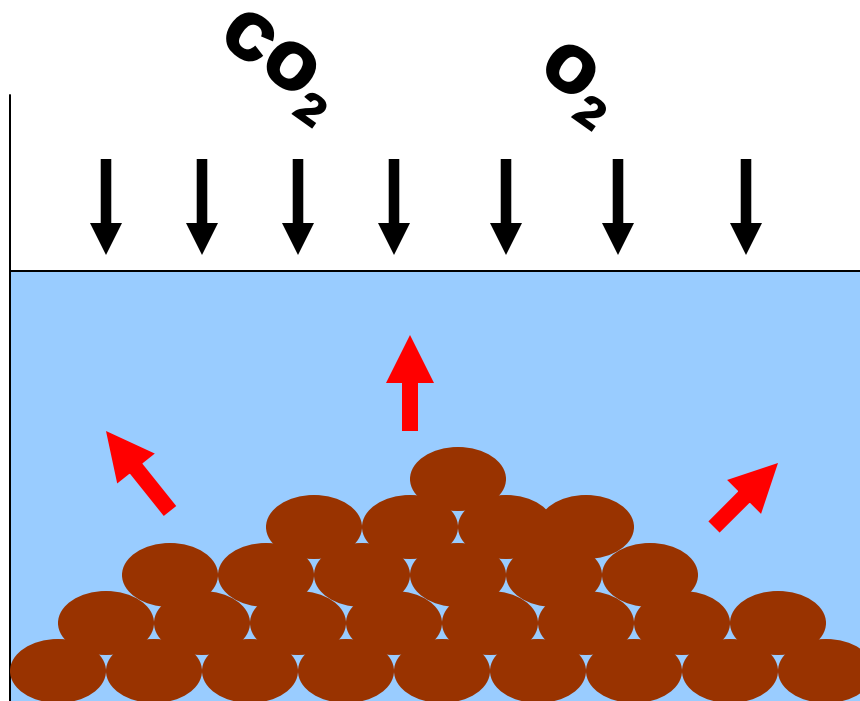
- Mixing Model
- Equilibrium Model
- 1-D Transport Model
- Input and Output
- Advantage and limitations

# MODEL CAPABILITIES – Mixing Model



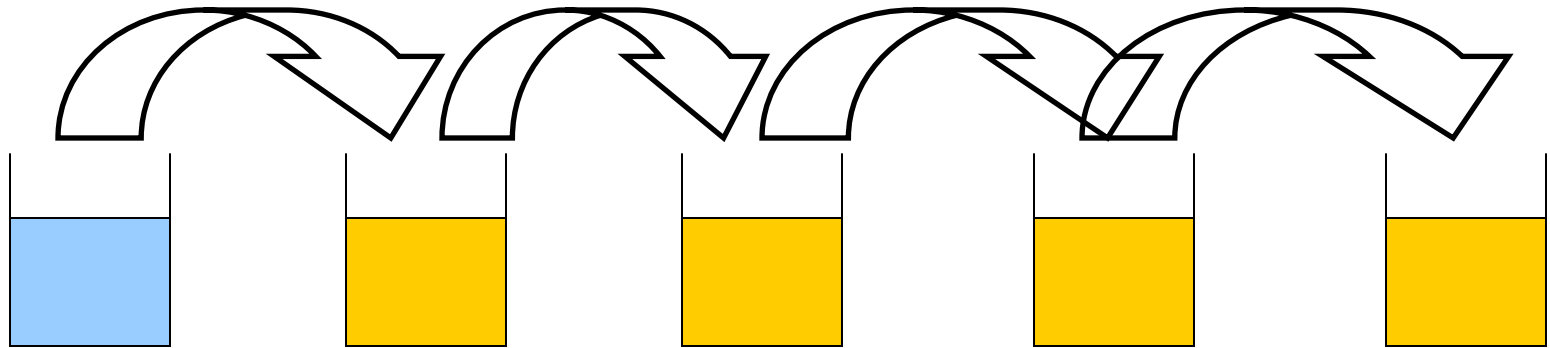
- **Mixing Model Example:**
  - Estimating tailings pond water chemistry (rainfall, runoff, infiltration, new process feed)
  - Estimating mineral precipitation
  - Estimating processing water quality

# MODEL CAPABILITIES – Equilibrium Model



- **Equilibrium Model Example:**
  - O<sub>2</sub>, CO<sub>2</sub> and H<sub>2</sub>O impact on waste rock (ARD)
  - Water through waste rock pile
  - Water in underground working space

# MODEL CAPABILITIES – 1-D Transport



# MODEL CAPABILITIES – 1-D Transport

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- **1-D Transport Mode Example:**
  - Groundwater/Contaminants Transport in the subsurface

- SurWater-RavineDam#6
  - Simulation 1
    - SOLUTION 1 SurfaceWater-F
    - SOLUTION 2 WasteTailing\_L
    - END
  - Simulation 2
    - SOLUTION 3 RainWater\_1\_A
    - EQUILIBRIUM\_PHASES 1 Ec
- Tailing Leach Chem
  - Simulation 1
  - Simulation 2
    - MIX 50 Tailing leach water v
    - END
  - Simulation 3
  - Simulation 4
  - Simulation 5
  - Simulation 6
- Trans\_Mod2\_Eq-Dolomite
  - Simulation 1
    - SOLUTION 0
    - EQUILIBRIUM\_PHASES 0 Ec
    - SAVE solution 0
    - END
  - Simulation 2
    - SOLUTION 1-72
    - EQUILIBRIUM\_PHASES 1-72
    - TRANSPORT
    - SELECTED\_OUTPUT

## SOLUTION 0

```

temp      4
pH        6.91
pe        -2.86
redox     S(-2)/S(6)
units     mg/l
density   1
Alkalinity 292.8 as HCO3
Ca        496
Mg        86.1
Na        36.8
K         4.2
Fe        0.1
Cl        4.3
N         7
S(6)     1360
S(-2)    0.276
-water   1 # kg

```

EQUILIBRIUM\_PHASES 0 Equi with Atmosphere O2 and CO2, Precip Calcite and Iron Hydroxide

```

Calcite   0 0
CO2(g)   -3.42 10
Fe(OH)3(a) 0 0
O2(g)    -0.68 10

```

SAVE solution 0

END

## SOLUTION 1-72

```

temp      4
pH        6.91

```

- **Input Data:**
  - pH , Redox Potential, Temperature, Alkalinity
  - Major Anions: Cl, S<sup>-2</sup>/SO<sub>4</sub>, NO<sub>3</sub>/NO<sub>5</sub>,
  - Major Cations: Ca, Na, K, Fe, Al...
  - Trace Metals: As, Cd, Hg, Pb, Cu, U ....

Trans_Mod2_Eq-Dolomite-Calcite
Reading data base.
Reading input data for simulation 1
Beginning of initial solution calc
Initial solution 0.
Beginning of batch-reaction calc
Reaction step 1.
Phase assemblage
Solution composition
Description of solution
Distribution of species
Saturation indices
End of simulation.
Reading input data for simulation 2
Reading input data for simulation 3
End of run.

## -----Solution composition-----

Elements	Molality	Moles
C	7.094e-004	7.094e-004
Ca	1.067e-002	1.067e-002
Cl	1.216e-004	1.216e-004
Fe	1.227e-009	1.227e-009
K	1.077e-004	1.077e-004
Mg	3.549e-003	3.550e-003
N	5.009e-004	5.009e-004
Na	1.604e-003	1.604e-003
S	1.420e-002	1.420e-002

## -----Description of solution-----

pH = 7.860           Charge balance  
 pe = 14.686         Adjusted to redox equilibrium  
 Activity of water = 1.000  
 Ionic strength = 4.232e-002  
 Mass of water (kg) = 1.000e+000  
 Total alkalinity (eq/kg) = 6.930e-004  
 Total CO2 (mol/kg) = 7.094e-004  
 Temperature (deg C) = 4.000  
 Electrical balance (eq) = 4.304e-004  
 Percent error,  $100 * (Cat - |An|) / (Cat + |An|)$  = 0.98  
 Iterations = 34  
 Total H = 1.110177e+002  
 Total O = 5.556974e+001

## -----Distribution of species-----

Species	Molality	Activity	Log Molality	Log Activity	Log Gamma
OH-	1.460e-007	1.220e-007	-6.836	-6.914	-0.078

# MODEL CAPABILITIES – Outputs

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## -----Description of solution-----

$$\text{pH} = 7.085$$

$$\text{pe} = 13.115$$

$$\text{Activity of water} = 1.000$$

$$\text{Ionic strength} = 3.214\text{e-}003$$

$$\text{Mass of water (kg)} = 1.000\text{e+}000$$

$$\text{Total alkalinity (eq/kg)} = 1.194\text{e-}003$$

$$\text{Total CO}_2 \text{ (mol/kg)} = 1.221\text{e-}003$$

$$\text{Temperature (deg C)} = 10.000$$

$$\text{Electrical balance (eq)} = 4.483\text{e-}004$$

$$\text{Percent error, } 100 * (\text{Cat} - |\text{An}|) / (\text{Cat} + |\text{An}|) = 11.21$$

Output files

- Trans\_Mod2\_Eq-Dolomite-Calcite
- Reading data base.
- Reading input data for simulation 1
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  - Initial solution 0.
  - Beginning of batch-reaction ca
  - Reaction step 1.
    - Phase assemblage
    - Solution composition
    - Description of solution
    - Distribution of species
    - Saturation indices
- End of simulation.
- Reading input data for simulation 2
- Reading input data for simulation 3
- End of run.

-----Distribution of species-----

Species	Molality	Activity	Log Molality	Log Activity	Log Gamma
OH-	1.460e-007	1.220e-007	-6.836	-6.914	-0.078
H+	1.598e-008	1.381e-008	-7.797	-7.860	-0.063
H2O	5.551e+001	9.995e-001	1.744	-0.000	0.000
C(-4)	0.000e+000				
CH4	0.000e+000	0.000e+000	-157.601	-157.596	0.004
C(4)	7.094e-004				
HCO3-	6.463e-004	5.443e-004	-3.190	-3.264	-0.075
CO2	2.511e-005	2.536e-005	-4.600	-4.596	0.004
CaHCO3+	1.910e-005	1.596e-005	-4.719	-4.797	-0.078
MgHCO3+	9.945e-006	8.311e-006	-5.002	-5.080	-0.078
CaCO3	5.393e-006	5.446e-006	-5.268	-5.264	0.004
CO3-2	2.116e-006	1.064e-006	-5.675	-5.973	-0.298
MgCO3	9.929e-007	1.003e-006	-6.003	-5.999	0.004
NaHCO3	3.985e-007	4.024e-007	-6.400	-6.395	0.004
NaCO3-	9.978e-009	8.339e-009	-8.001	-8.079	-0.078
FeHCO3+	9.944e-022	8.311e-022	-21.002	-21.080	-0.078
FeCO3	3.861e-022	3.899e-022	-21.413	-21.409	0.004
Ca	1.067e-002				
Ca+2	7.565e-003	3.815e-003	-2.121	-2.419	-0.297
CaSO4	3.076e-003	3.106e-003	-2.512	-2.508	0.004
CaHCO3+	1.910e-005	1.596e-005	-4.719	-4.797	-0.078
CaCO3	5.393e-006	5.446e-006	-5.268	-5.264	0.004
CaOH+	5.484e-008	4.583e-008	-7.261	-7.339	-0.078
CaHSO4+	2.452e-010	2.049e-010	-9.611	-9.688	-0.078
Cl	1.216e-004				
Cl-	1.216e-004	1.007e-004	-3.915	-3.997	-0.082
FeCl+2	6.249e-022	3.048e-022	-21.204	-21.516	-0.312
FeCl+	2.540e-024	2.123e-024	-23.595	-23.673	-0.078
FeCl2+	3.359e-025	2.807e-025	-24.474	-24.552	-0.078
FeCl3	2.800e-030	2.827e-030	-29.553	-29.549	0.004
Fe(2)	4.172e-020				
Fe+2	3.130e-020	1.527e-020	-19.504	-19.816	-0.312
FeSO4	8.964e-021	9.052e-021	-20.048	-20.043	0.004
FeHCO3+	9.944e-022	8.311e-022	-21.002	-21.080	-0.078
FeCO3	3.861e-022	3.899e-022	-21.413	-21.409	0.004

# MODEL CAPABILITIES – Outputs

## -----Distribution of species-----

Species	Molality	Activity	Molality	Activity	Gamma
H+	8.688e-008	8.218e-008	-7.061	-7.085	-0.024
OH-	3.781e-008	3.560e-008	-7.422	-7.449	-0.026
H2O	5.551e+001	9.999e-001	1.744	-0.000	0.000
Al	4.128e-005				
Al(OH)4-	3.599e-005	3.388e-005	-4.444	-4.470	-0.026
Al(OH)2+	3.410e-006	3.210e-006	-5.467	-5.494	-0.026
Al(OH)3	1.691e-006	1.692e-006	-5.772	-5.772	0.000
AlOH+2	1.798e-007	1.412e-007	-6.745	-6.850	-0.105
Al+3	5.513e-009	3.202e-009	-8.259	-8.495	-0.236
AlSO4+	1.869e-009	1.760e-009	-8.728	-8.755	-0.026
Al(SO4)2-	1.172e-011	1.103e-011	-10.931	-10.957	-0.026

Output files

- Trans\_Mod2\_Eq-Dolomite-Calcite
  - Reading data base.
  - Reading input data for simulation 1
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      - Reaction step 1.
        - Phase assemblage
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        - Saturation indices
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  - Reading input data for simulation 2
  - Reading input data for simulation 3
  - End of run.

FeSO4+	5.099e-022	4.224e-022	-21.292	-21.374	-0.082
Fe(SO4)2-	4.915e-023	4.072e-023	-22.308	-22.390	-0.082
FeHSO4+2	1.803e-028	8.492e-029	-27.744	-28.071	-0.327

-----Saturation indices-----

Phase	SI	log IAP	log KT	
Anhydrite	-0.61	-4.96	-4.35	CaSO4
Aragonite	-0.16	-8.39	-8.23	CaCO3
Artinite	-7.48	3.72	11.20	MgCO3:Mg(OH)2:3H2O
Brucite	-6.45	11.89	18.35	Mg(OH)2
Calcite	0.00	-8.39	-8.39	CaCO3
CH4(g)	-5.77	-8.44	-2.67	CH4
CO2(g)	-1.80	-2.97	-1.18	CO2
Dolomite	0.00	-16.57	-16.57	CaMg(CO3)2
Dolomite(d)	-0.64	-16.57	-15.92	CaMg(CO3)2
Epsomite	-2.45	-4.75	-2.30	MgSO4:7H2O
Fe(OH)2.7Cl.3	-1.70	-4.74	-3.04	Fe(OH)2.7Cl0.3
Fe(OH)3(a)	-6.29	-1.40	4.89	Fe(OH)3
Fe3(OH)8	-14.96	5.27	20.22	Fe3(OH)8
FeS(ppt)	-0.50	-4.41	-3.92	FeS
Goethite	-1.20	-1.40	-0.20	FeOOH
Greigite	0.42	-44.62	-45.03	Fe3S4
Gypsum	-0.36	-4.96	-4.60	CaSO4:2H2O
H2(g)	-8.21	-11.26	-3.05	H2
H2O(g)	-2.09	-0.00	2.09	H2O
H2S(g)	-4.45	-5.20	-0.74	H2S
Halite	-8.42	-6.89	1.53	NaCl
Hematite	-0.50	-2.79	-2.29	Fe2O3
Huntite	-4.38	-32.92	-28.54	CaMg3(CO3)4
Hydromagnesite	-14.95	-20.81	-5.86	Mg5(CO3)4(OH)2:4H2O
Jarosite(ss)	-25.12	-34.95	-9.83	(K0.77Na0.03H0.2)Fe3(SO4)2(OH)6
Jarosite-K	-26.90	-34.37	-7.47	KFe3(SO4)2(OH)6
Jarosite-Na	-29.92	-33.19	-3.27	NaFe3(SO4)2(OH)6
JarositeH	-35.14	-37.47	-2.33	(H3O)Fe3(SO4)2(OH)6
Mackinawite	0.24	-4.41	-4.65	FeS
Maghemite	-9.18	-2.79	6.39	Fe2O3
Magnetite	-0.49	-8.17	-7.69	MgCO3
Magnetite	-1.27	5.27	6.54	Fe3O4

# MODEL CAPABILITIES – Outputs

## -----Saturation indices-----

Phase	SI	log IAP	log KT	
Al(OH)3(a)	0.93	12.76	11.83	Al(OH)3
AlAsO4:2H2O	-7.73	-23.57	-15.84	AlAsO4:2H2O
Albite	-3.17	-22.18	-19.01	NaAlSi3O8
Analcime	-4.04	-17.45	-13.41	NaAlSi2O6:H2O
Anglesite	-7.60	-15.48	-7.87	PbSO4
Anhydrite	-2.62	-6.96	-4.34	CaSO4
Anilite	-120.76	-154.32	-33.57	Cu0.25Cu1.5S
Anorthite	-1.53	-21.69	-20.16	CaAl2Si2O8
Antlerite	0.29	8.58	8.29	Cu3(OH)4SO4

# MODEL CAPABILITIES – Advantages

- Very strong geochemical analytical capabilities
  - Many commercial modelling software use PHREEQC as the calculation core
- Widely accepted by the industry for geochemical calculation
- Users are able to edit databases
- IT IS FREE

# MODEL CAPABILITIES – Limitations

- Not User Friendly
- No visual demonstration (need Excel graphs, need strong geochemistry judgment)
- No kinetics calculation
- Only give qualitative estimate

# CASE STUDY – Phase II ESA at Outpost

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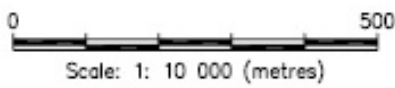
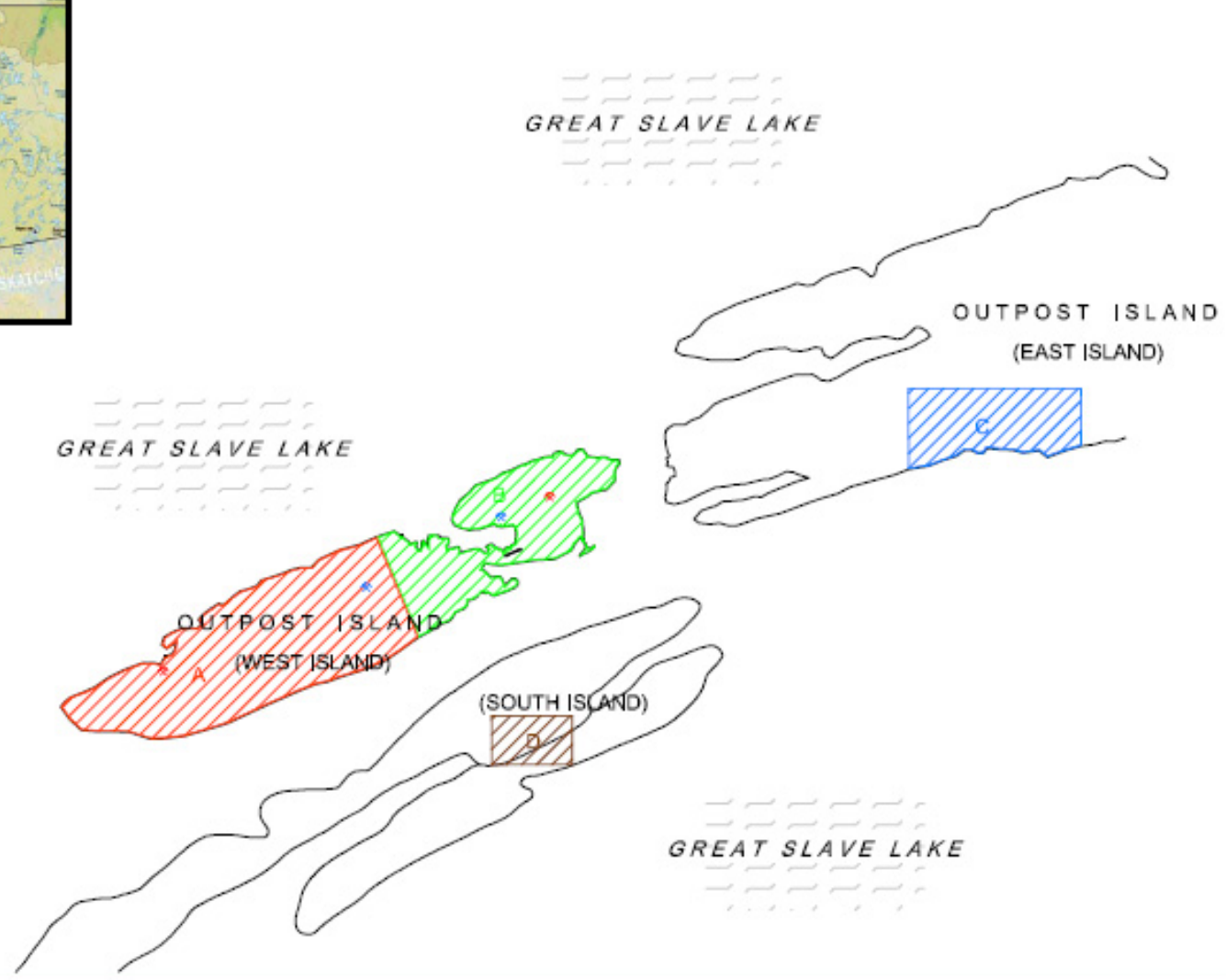
- **Project Name:** Phase II Environmental Site Assessment
- **Mine Name:** Outpost Island (Philmore Mine)
- **Location:** 88 km SE of Yellowknife at Grate Slave Lake
- **Status:** Abandoned
- **Issue:** Runoff water from high ARD potential tailings into Great Slave Lake



# CASE STUDY – Phase II ESA at Outpost



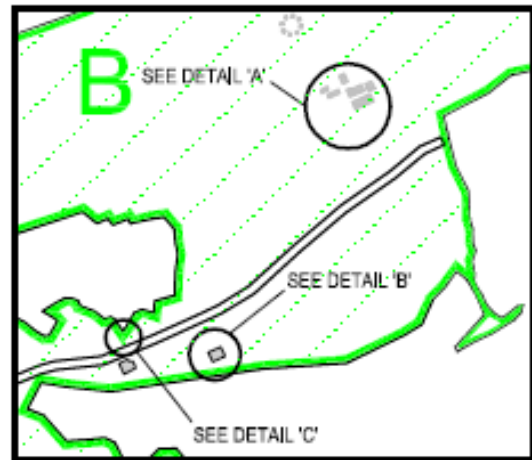
KEY PLAN



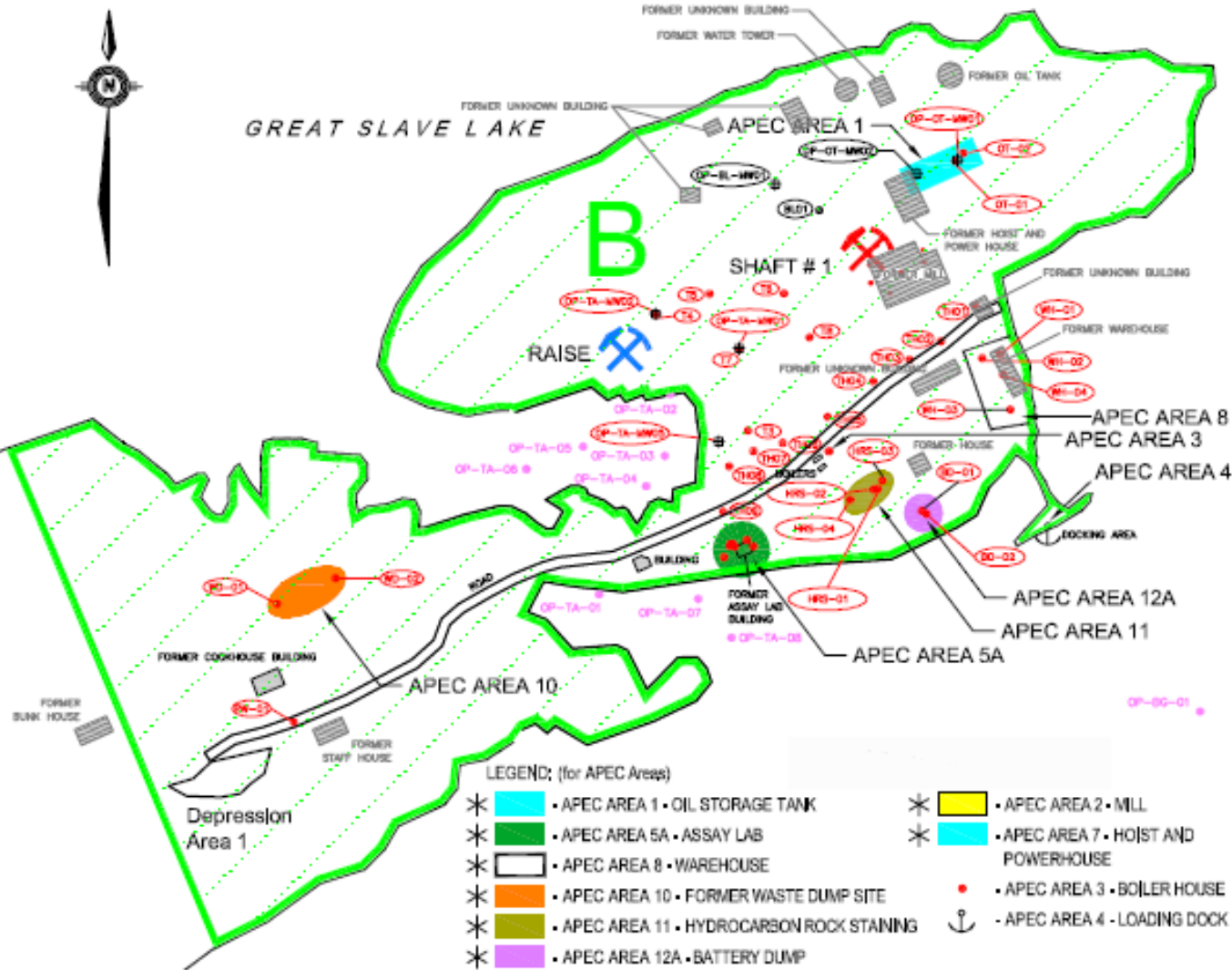
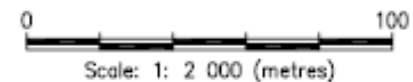
# CASE STUDY – Phase II ESA at Outpost



KEY PLAN



DETAIL PLAN - See Figure 4



# CASE STUDY – Phase II ESA at Outpost

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# CASE STUDY – Phase II ESA at Outpost

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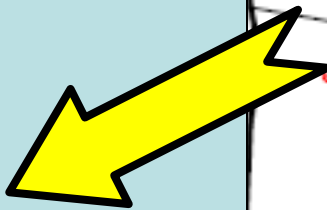


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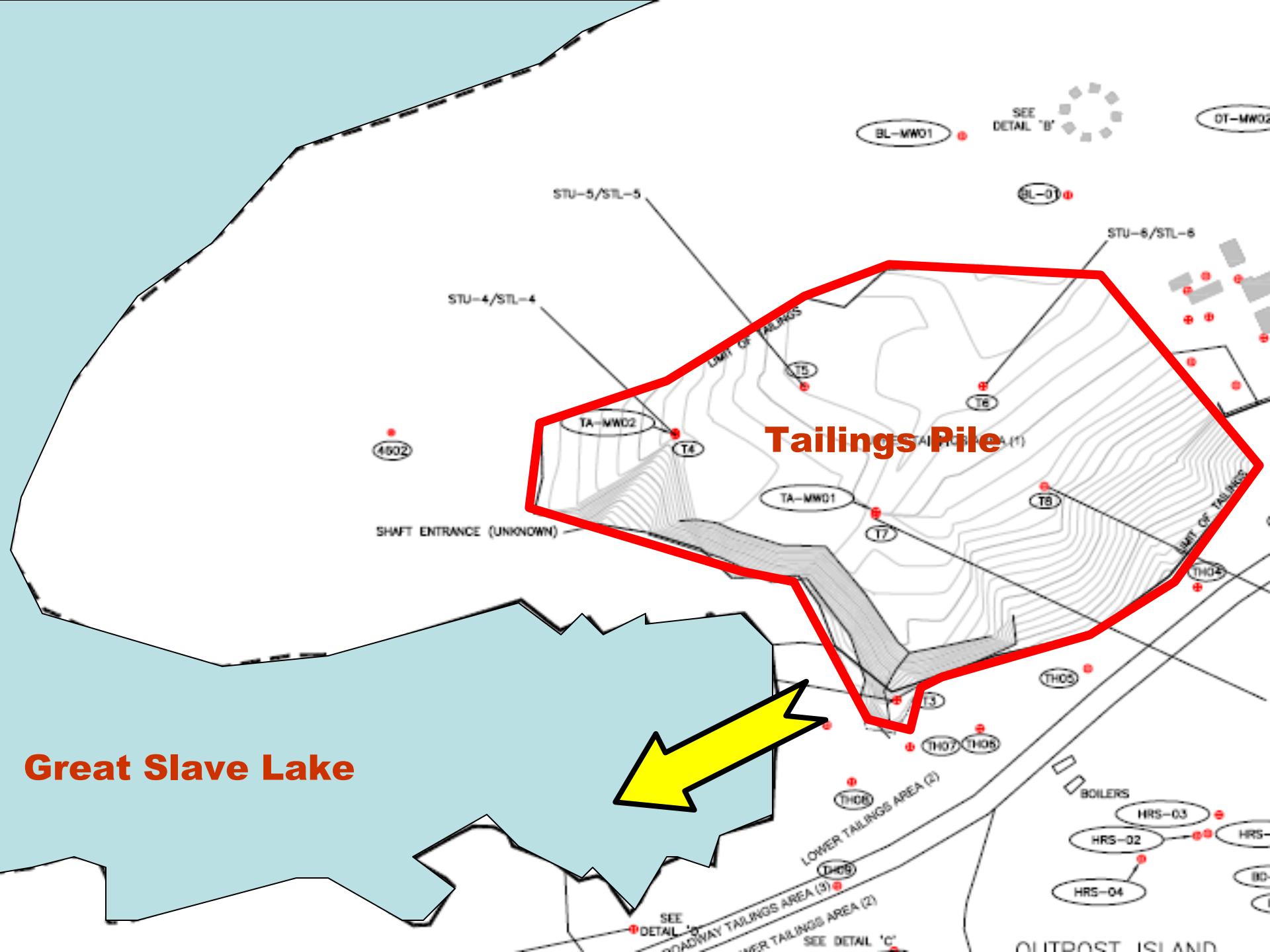
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**Great Slave Lake**



**Tailings Pile**



# CASE STUDY – Phase II ESA at Outpost

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- Data:
  - Tailings Shake Flask
  - Lake Water Routine Parameters
  - Lake Sediment Metals

# CASE STUDY – Phase II ESA at Outpost

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Parameter	Units	Tailings	Shake Flask	Lake Water		
pH	-		3.13	7.93		
Aluminum (Al)	mg/L		<b>101.5</b>	<b>1,000X</b>	0.1	
Arsenic (As)	mg/L		0.009		0.0	
Calcium (Ca)	mg/L		142.0		26.0	
Cadmium (Cd)	mg/L		5.86E-04	<b>35X</b>	0	
Copper (Cu)	mg/L		<b>192</b>	<b>96,000X</b>	0.008	<b>4X</b>
Iron (Fe)	mg/L		3.8	<b>13X</b>	0.08	
Magnesium (Mg)	mg/L		83.4		6.3	
Manganese (Mn)	mg/L		1		0.02	
Sodium (Na)	1 mg/L		0.15		7.50	
Nickel (Ni)	<sup>9</sup> <sub>9</sub> mg/L		0.14	<b>6X</b>	0.000	
Zinc (Zn)	<sup>6</sup> mg/L		0.54	<b>18X</b>	0.012	

CREATING AND DELIVERING BETTER SOLUTIONS



# CASE STUDY – Phase II ESA at Outpost

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- Tailing water quality:
  - Only a few Iron minerals slightly oversaturated
- Lake water quality:
  - Aluminium minerals slightly oversaturated
  - Iron minerals oversaturated ( $SI_{\text{Hematite}}=19$ )

# CASE STUDY – Phase II ESA at Outpost

Mixing Model in Dilution Rate: 1:1, 1:10, 1:20, 1:100 and 1:1000

- For 1:1, 1:10 and 1:20, SI of Aluminium, Copper and Iron minerals increase, as more lake water neutralize the pH of the tailing water

$$(SI_{Al(OH)3(a)}=1.7; SI_{Brochantite}=3.4; SI_{Fe(OH)3}=2.3)$$

- For 1:100 and 1:1000, SI of Aluminium, Copper and Iron minerals decrease, but still above zero, as more lake water starts to dilute the mineral concentration

# CASE STUDY – Phase II ESA at Outpost

Minerals	Mineral	Structure	Tailing Leach (TL) [1] <sup>3</sup>	Lake Water (LW) [2] <sup>4,5</sup>	50 TL : 50 LW [3]	10 TL : 90 LW [4]	5 TL : 95 LW [5]	1 TL : 99 LW [6]	0.1 TL : 99.9 LW [7]	After Al & Cu Precip [8]
Aluminum	Al(OH) <sub>3</sub> (a)	Al(OH) <sub>3</sub>	-6.24	-0.90	-2.11	<u>1.66</u>	<u>1.73</u>	<u>0.93</u>	-0.42	-0.93
	Basaluminite	Al4(OH)10SO <sub>4</sub>	-8.9	<u>1.1</u>	<u>4.6</u>	<u>16.1</u>	<u>15.5</u>	<u>10.5</u>	<u>3.5</u>	<u>1.3</u>
	Boehmite	AlOOH	-4.1	<u>1.2</u>	0.0	<u>3.8</u>	<u>3.9</u>	<u>3.1</u>	<u>1.7</u>	<u>1.2</u>
	Diaspore	AlOOH	-2.2	<u>3.1</u>	<u>1.9</u>	<u>5.6</u>	<u>5.7</u>	<u>4.9</u>	<u>3.6</u>	<u>3.1</u>
	Gibbsite	Al(OH) <sub>3</sub>	-3.4	<u>1.9</u>	<u>0.7</u>	<u>4.5</u>	<u>4.6</u>	<u>3.8</u>	<u>2.4</u>	<u>1.9</u> <sup>3</sup>
	Halloysite	Al <sub>2</sub> Si <sub>2</sub> O <sub>5</sub> (OH) <sub>4</sub>	-11.6	-1.7	-3.6	<u>3.6</u>	<u>3.7</u>	<u>2.0</u>	-0.7	-1.7
	Juzbanite	AlOHSO <sub>4</sub>	0.3	-5.7	<u>1.4</u>	<u>1.6</u>	<u>0.8</u>	-1.9	-4.8	-5.4
	Kaolinite	Al <sub>2</sub> Si <sub>2</sub> O <sub>5</sub> (OH) <sub>4</sub>	-6.3	<u>3.6</u>	<u>1.6</u>	<u>8.8</u>	<u>8.9</u>	<u>7.3</u>	<u>4.5</u>	<u>3.5</u>
	Laumontite	CaAl <sub>2</sub> Si <sub>4</sub> O <sub>12</sub> ·4H <sub>2</sub> O	-19.0	-0.7	-8.7	<u>1.1</u>	<u>1.7</u>	<u>1.3</u>	-0.1	-1.0
	Leonhardite	C <sub>42</sub> Al <sub>4</sub> Si <sub>8</sub> O <sub>24</sub> ·7H <sub>2</sub> O	-29.8	<u>6.9</u>	-9.2	<u>10.5</u>	<u>11.7</u>	<u>10.9</u>	<u>8.1</u>	<u>6.2</u>
	Montmorillonite-Ca	Ca <sub>0.165</sub> Al <sub>2</sub> 33Si <sub>3</sub> 67O <sub>10</sub> (OH) <sub>2</sub>	-11.8	<u>0.8</u>	-2.3	<u>6.4</u>	<u>6.5</u>	<u>4.8</u>	<u>1.8</u>	<u>0.7</u>
Pyrophyllite	Al <sub>2</sub> Si <sub>4</sub> O <sub>10</sub> (OH) <sub>2</sub>	-6.6	<u>2.6</u>	<u>1.1</u>	<u>7.9</u>	<u>8.0</u>	<u>6.3</u>	<u>3.5</u>	<u>2.5</u>	
Copper	Antlerite	Cu <sub>3</sub> (OH) <sub>4</sub> SO <sub>4</sub>	-7.04	-7.94	-2.21	<u>1.79</u>	<u>1.76</u>	<u>0.29</u>	-3.47	-3.8
	Azurite	Cu <sub>3</sub> (OH) <sub>2</sub> (CO <sub>3</sub> ) <sub>2</sub>	-1000.0	-6.5	-6.7	<u>1.1</u>	<u>1.7</u>	<u>1.2</u>	-2.1	-2.4
	Brochantite	Cu <sub>4</sub> (OH) <sub>6</sub> SO <sub>4</sub>	-10.8	-8.2	-3.4	<u>3.2</u>	<u>3.4</u>	<u>2.1</u>	-2.4	-2.8
	Malachite	Cu <sub>2</sub> (OH) <sub>2</sub> CO <sub>3</sub>	-1000.0	-3.3	-3.8	<u>1.3</u>	<u>1.8</u>	<u>1.6</u>	-0.4	-0.6
	Tenonite	CuO	-4.9	-1.5	-2.3	<u>0.2</u>	<u>0.5</u>	<u>0.6</u>	-0.1	-0.2
Copper-Iron	Cupric Ferrite	CuFe <sub>2</sub> O <sub>4</sub>	-2.6	<u>14.5</u>	<u>10.6</u>	<u>15.6</u>	<u>16.0</u>	<u>16.4</u>	<u>15.9</u>	<u>14.5</u> <sup>3</sup>
	Cuprous Ferrite	CuFeO <sub>2</sub>	<u>3.0</u>	<u>5.8</u>	<u>7.7</u>	<u>6.9</u>	<u>7.2</u>	<u>7.5</u>	<u>6.9</u>	<u>5.8</u> <sup>3</sup>
Iron	Fe(OH)2.7Cl3	Fe(OH) <sub>2.7</sub> Cl <sub>0.3</sub>	-1000.0	<u>7.1</u>	<u>6.5</u>	<u>7.4</u>	<u>7.3</u>	<u>7.3</u>	<u>7.2</u>	<u>6.5</u>
	Fe(OH) <sub>3</sub> (a)	Fe(OH) <sub>3</sub>	-4.11	<u>2.70</u>	<u>1.16</u>	<u>2.39</u>	<u>2.45</u>	<u>2.58</u>	<u>2.69</u>	<u>2.0</u>
	Goethite	FeOOH	<u>1.22</u>	<u>8.03</u>	<u>6.49</u>	<u>7.72</u>	<u>7.78</u>	<u>7.91</u>	<u>8.02</u>	<u>7.4</u>
	Hematite	Fe <sub>2</sub> O <sub>3</sub>	<u>4.37</u>	<u>17.99</u>	<u>14.91</u>	<u>17.37</u>	<u>17.49</u>	<u>17.76</u>	<u>17.97</u>	<u>16.7</u>
	Maghemite	Fe <sub>2</sub> O <sub>3</sub>	-4.82	<u>8.79</u>	<u>5.71</u>	<u>8.17</u>	<u>8.29</u>	<u>8.56</u>	<u>8.77</u>	<u>7.5</u>
	Magnetite	Fe <sub>3</sub> O <sub>4</sub>	-2.5	<u>10.5</u>	<u>10.2</u>	<u>9.3</u>	<u>9.5</u>	<u>9.9</u>	<u>10.3</u>	<u>7.9</u>
Manganese	Bixbyite	Mn <sub>2</sub> O <sub>3</sub>	-17.5	<u>5.5</u>	-8.6	<u>3.3</u>	<u>3.7</u>	<u>4.6</u>	<u>5.7</u>	<u>6.6</u>
	Bixbyite	Mn <sub>2</sub> O <sub>3</sub>	-25.8	<u>5.4</u>	-14.3	<u>0.2</u>	<u>1.1</u>	<u>3.0</u>	<u>5.2</u>	<u>6.2</u>
	Hausmannite	Mn <sub>3</sub> O <sub>4</sub>	-36.6	<u>2.7</u>	-22.6	-5.3	-4.1	-1.2	<u>2.2</u>	<u>3.2</u>
	Manganite	MnOOH	-11.7	<u>3.9</u>	-6.0	<u>1.3</u>	<u>1.7</u>	<u>2.7</u>	<u>3.8</u>	<u>4.2</u>
	Nsutite	MnO <sub>2</sub>	-16.4	<u>6.6</u>	-7.6	<u>4.3</u>	<u>4.7</u>	<u>5.6</u>	<u>6.7</u>	<u>7.6</u>

# CASE STUDY – Phase II ESA at Outpost

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## Modeled concentration at 1:1000 Dilution Rate

pH	-	7.75
Aluminum (Al)	mg/L	0.2
Arsenic (As)	mg/L	9.0E-07
Calcium (Ca)	mg/L	26.0
Cadmium (Cd)	mg/L	5.9E-07
Copper (Cu)	mg/L	0.2
Iron (Fe)	mg/L	0.08
Magnesium (Mg)	mg/L	6.4
Sodium (Na)	mg/L	7.5
Nickel (Ni)	mg/L	0.002
Lead (Pb)	mg/L	2.8E-07
Zinc (Zn)	mg/L	0.012



# CASE STUDY – Phase II ESA at Outpost

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- Findings:
  - Aluminium, Cadmium, Copper, and Zinc in the tailing will be carried to the lake water due to low pH of the tailing water
  - Copper, iron and aluminium minerals tend to precipitate from the mixed water into sediments
  - Mixed water and sediments will reach equilibrium in the suspended mineral concentration (exceeding applicable criteria)

# Questions