Evaluation of Mine Water Treatment by Monitored Natural Attenuation at the Troy Mine, NW Montana

Scott Mason

Hydrometrics, Inc

Hydrometrics, Inc.
Consulting Scientists and Engineers

Why Care About Natural Attenuation of Metals

- It happens and it works!
- It can be an effective and economical part of a mine water management plan

Hydrometrics, Inc.
Consulting Scientists and Engineers

What Is Natural Attenuation

- Reduction of metal concentrations in water by “natural” mechanisms:
  - Mineral precipitation
  - Adsorption
- In “natural” settings:
  - Soils and sediments
  - Groundwater

Hydrometrics, Inc.
Consulting Scientists and Engineers

Troy Mine Natural Attenuation = Completion of Mineral Weathering Cycle

•Ore sulfide minerals (chalcocite, bornite, digenite) weather to release Cu ions to mine water (50 – 100 ppb)….

•Cu reacts with other ions in water to form more stable, low solubility copper minerals (carbonates, oxides, silicates) …

•Which precipitate in sediments at the disposal site resulting in mine water/groundwater with low Cu concentration (5 ppb)

Monitored Natural Attenuation

It's Science!

not Magic!

Hydrometrics, Inc.
Consulting Scientists and Engineers

Monitored Natural Attenuation

Science:

1. **Need to understand attenuation mechanisms**
2. **Factors controlling mechanisms**
3. **Conditions that might reduce attenuation effectiveness**

Hydrometrics, Inc.
Consulting Scientists and Engineers

Monitored Natural Attenuation

It's Management!

Not "Set it and forget it"

Hydrometrics, Inc.
Consulting Scientists and Engineers

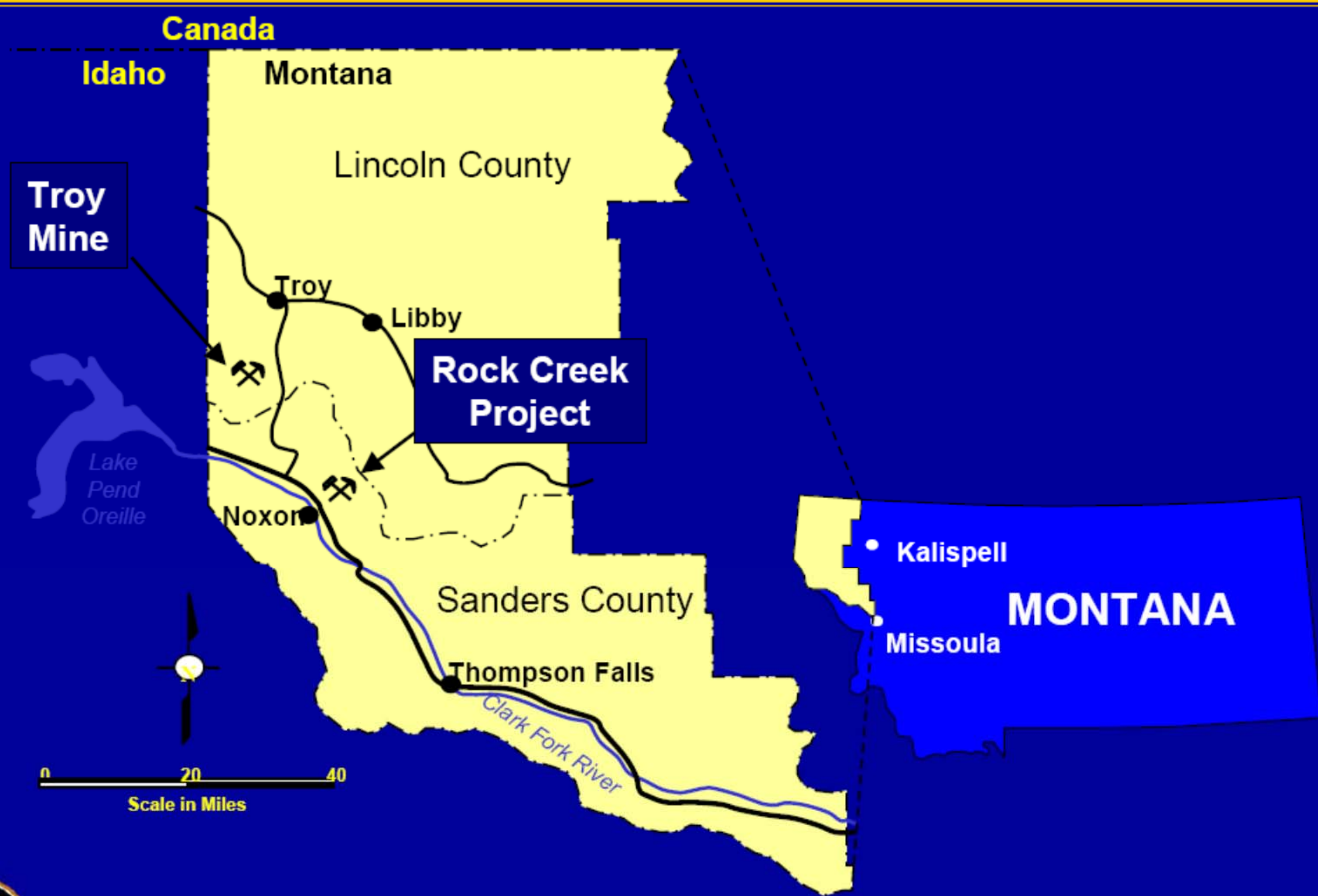
Monitored Natural Attenuation

Management:

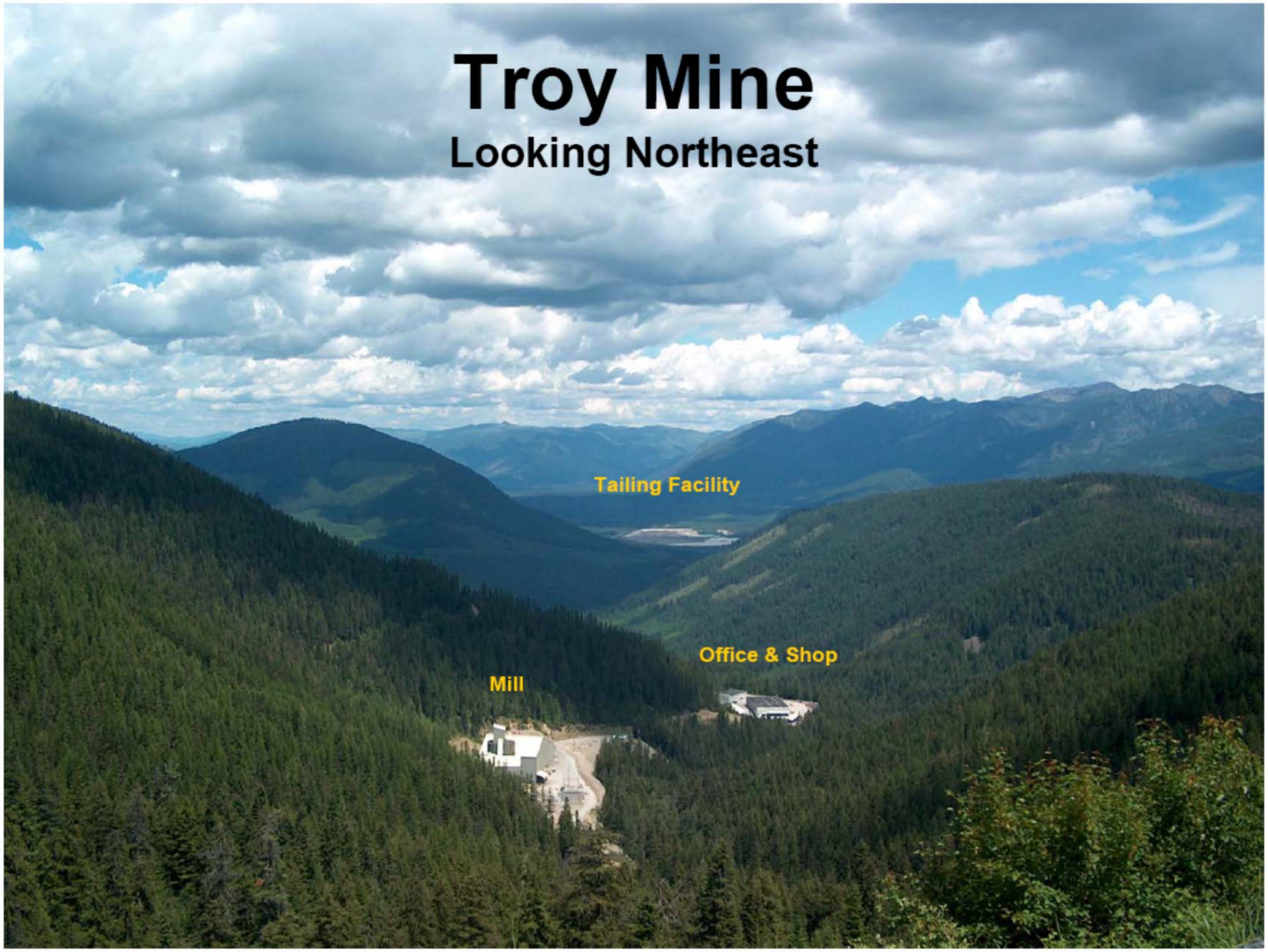
1. **Monitoring**
2. **Maintenance**
3. **Mitigation**

Not really "passive"

LOCATION



Canada
Idaho
Montana
Lincoln County
Troy Mine
Troy
Libby
Rock Creek Project
Lake Pend Oreille
Noxon
Sanders County
Thompson Falls
Clark Fork River
0
20
40
Scale in Miles
Kalispell
MONTANA
Missoula



Hydrometrics, Inc.
Consulting Scientists and Engineers

6,500 TPD; 0.75% Cu

Sediment-hosted stratiform Cu (chalcocite/digenite, bornite, native silver)

Hydrometrics, Inc.
Consulting Scientists and Engineers

Hydrometrics, Inc.
Consulting Scientists and Engineers

Hydrometrics, Inc.
Consulting Scientists and Engineers

Troy History and Production Profile

- Mine operated by Asarco from 1981 - 1993
- Troy Returned to production in late 2004
- 2009 production was 1.1M oz Ag and 8.6M lbs Cu
- 2010 production guidance: 1.1M oz Ag and 9.2M lb Cu

Interim Closure in 1993

Challenge:

- 1,000 gpm mine water w/ 50-100 ppb Cu
- Too much flow & too much Cu for discharge at mine site

Interim Closure in 1993

Interim plan:

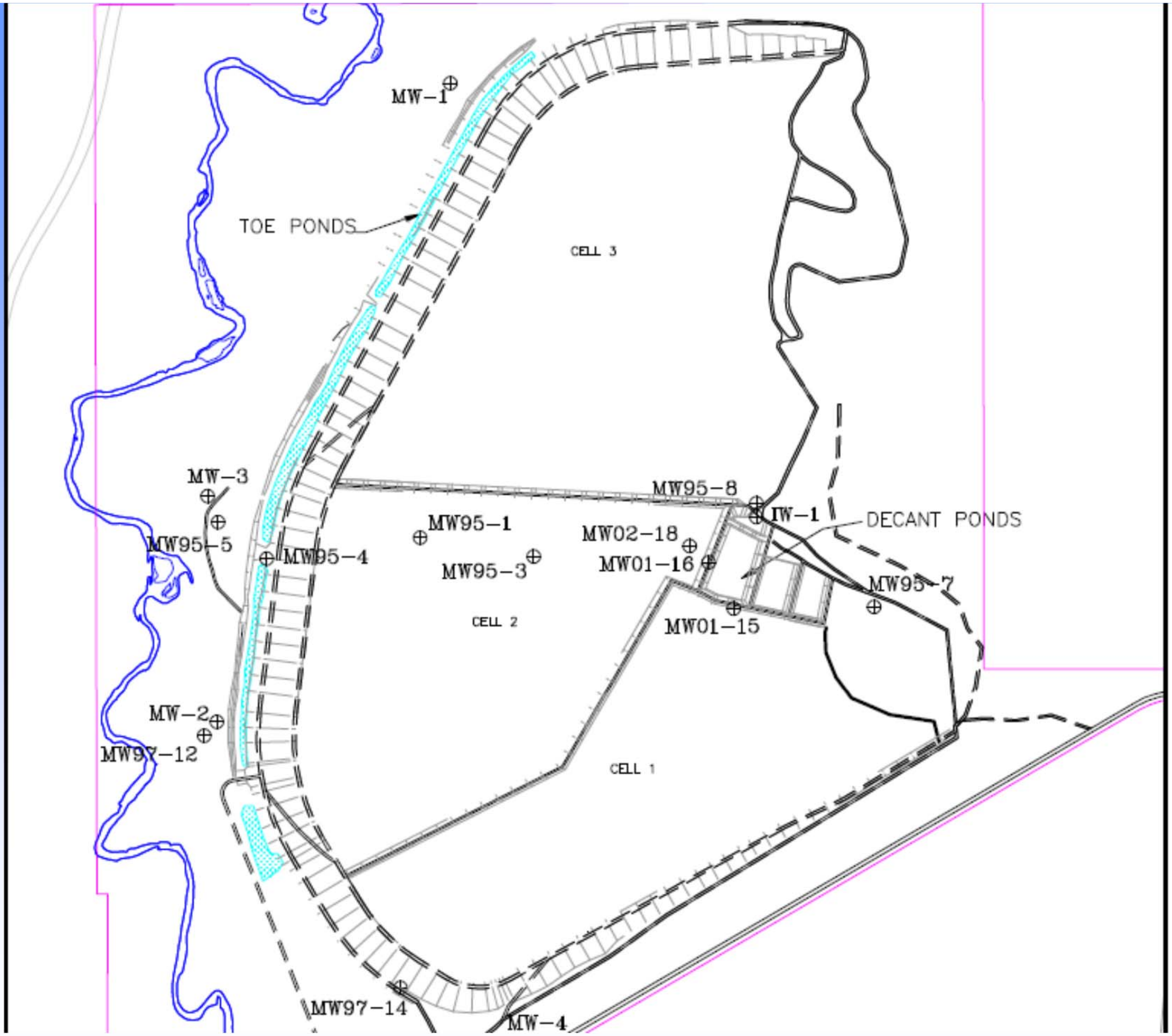
- Allow partial mine flood
- Pump and pipe mine water to tailing impoundment for irrigation/dust control use
- Excess water allowed to pond on surface and infiltrate through decant pond

Hydrometrics, Inc.
Consulting Scientists and Engineers

Troy Mine – Tailing Reclamation Area

Hydrometrics, Inc.
Consulting Scientists and Engineers

Hydrometrics, Inc.
Consulting Scientists and Engineers



Hydrometrics, Inc.
Consulting Scientists and Engineers

Revisions to Final Closure Plan Began in 2000

- Observed copper goes in decant ponds but is not found in groundwater
- Looks like natural attenuation?
- Is it real?
- Need framework to prove it's happening, understand why and how it's happening, and plan to manage it.

Hydrometrics, Inc.
Consulting Scientists and Engineers

Framework for Evaluation- Tiered Analysis Approach recommended by EPA (2007)

1. Demonstration of active contaminant removal from ground water;
2. Determination of the mechanism(s) and rate of attenuation;
3. Determination of the long-term capacity for attenuation and stability of immobilized contaminants;
4. Design of performance monitoring program.

Step 1 - Evidence for Active Contaminant Removal:

1. Comparison of copper with conservative "tracer" elements (i.e., nitrate from blasting) demonstrates that mine water is traveling to wells but Cu is not
2. Analysis of pond sediments demonstrates enrichment in Cu – some sediments have 3x more Cu than ore!

Hydrometrics, Inc.
Consulting Scientists and Engineers

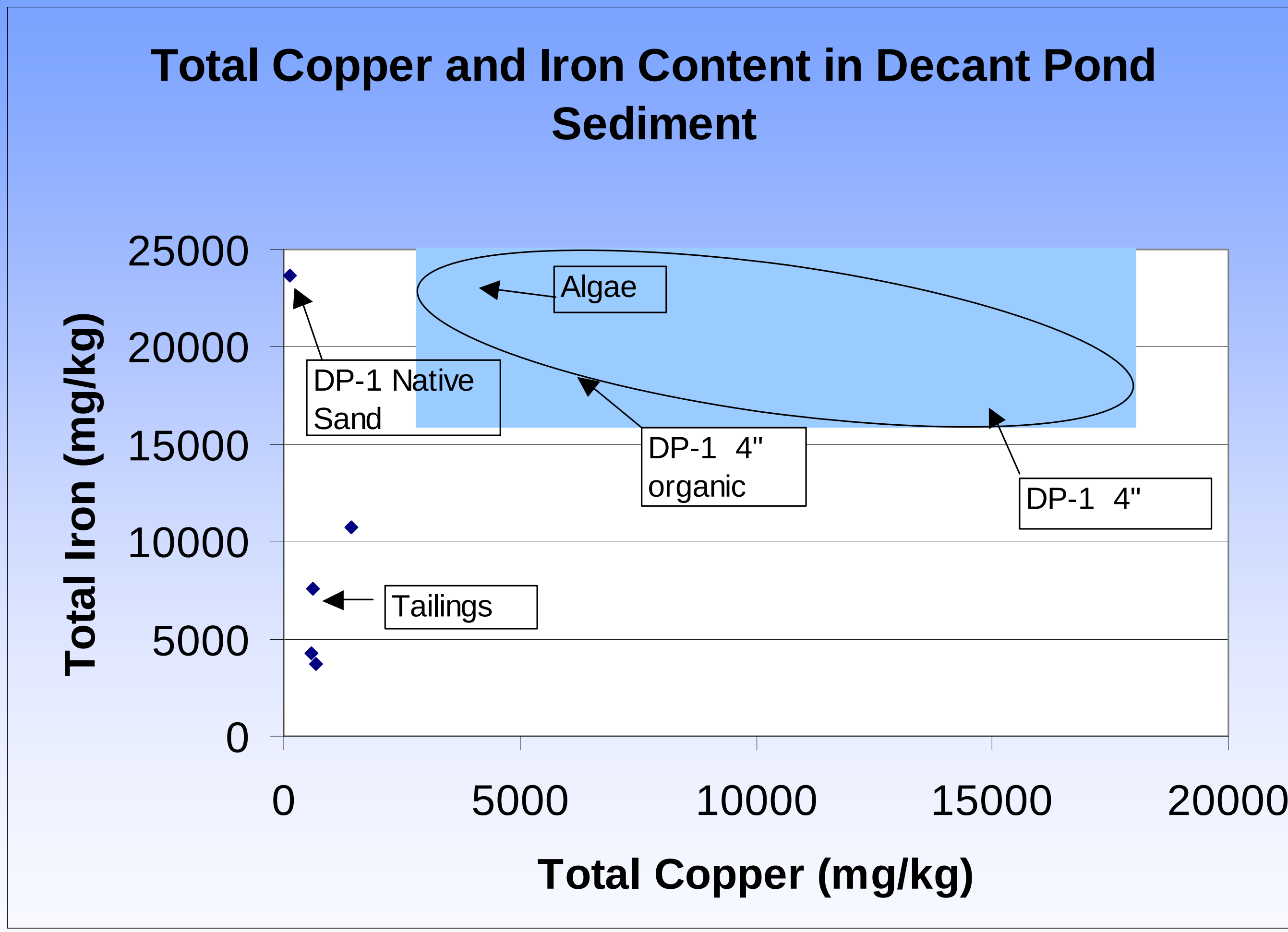
Hydrometrics, Inc.
Consulting Scientists and Engineers

Hydrometrics, Inc.
Consulting Scientists and Engineers

Hydrometrics, Inc.
Consulting Scientists and Engineers

Hydrometrics, Inc.
Consulting Scientists and Engineers

Hydrometrics, Inc.
Consulting Scientists and Engineers



Hydrometrics, Inc.
Consulting Scientists and Engineers

Step 2 - Demonstration of Mechanisms of Removal:

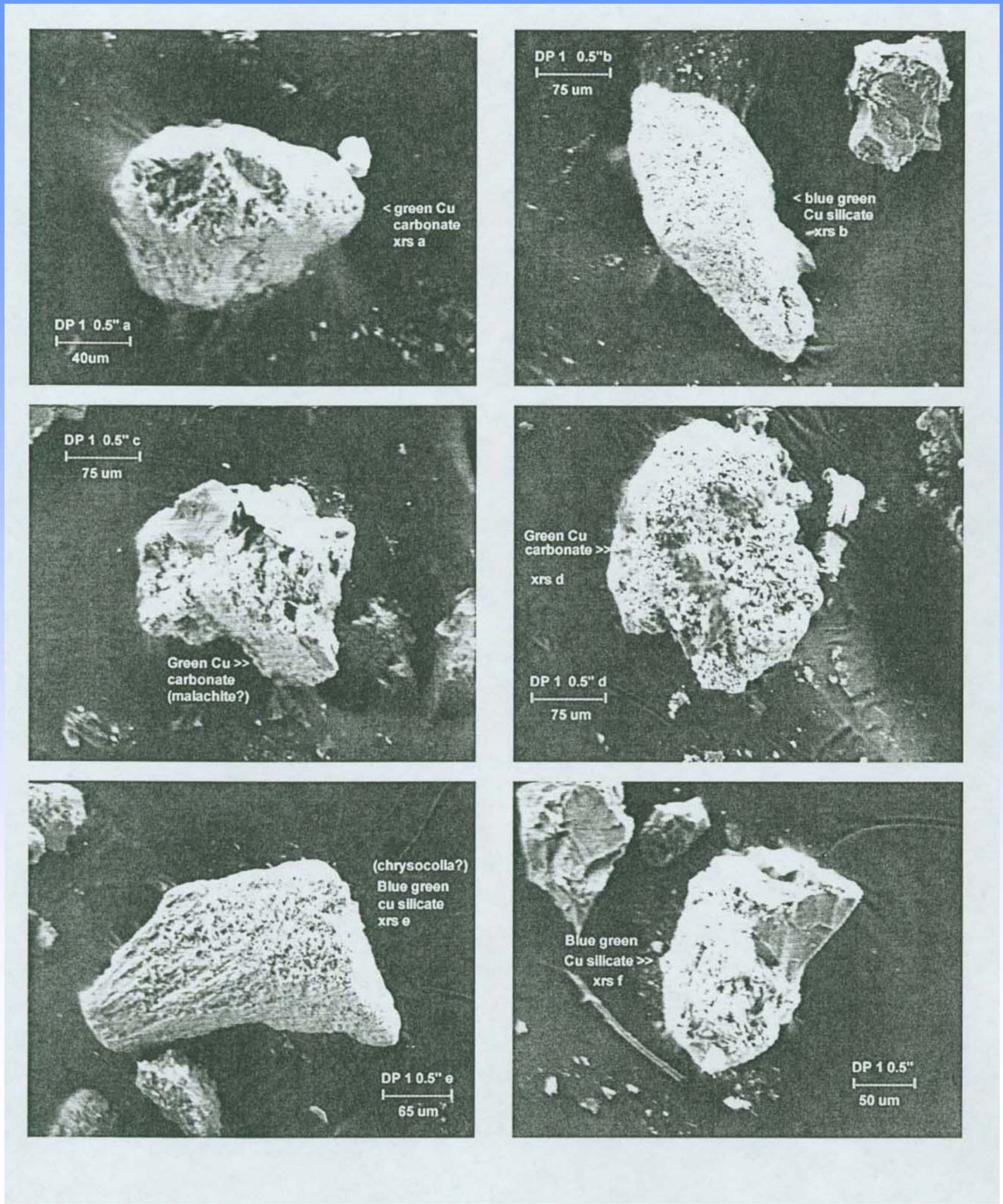
Mineralogical and Geochemical Analyses:

•Optical Microscopic evaluation

•SEM and microprobe analysis

•Whole rock analysis

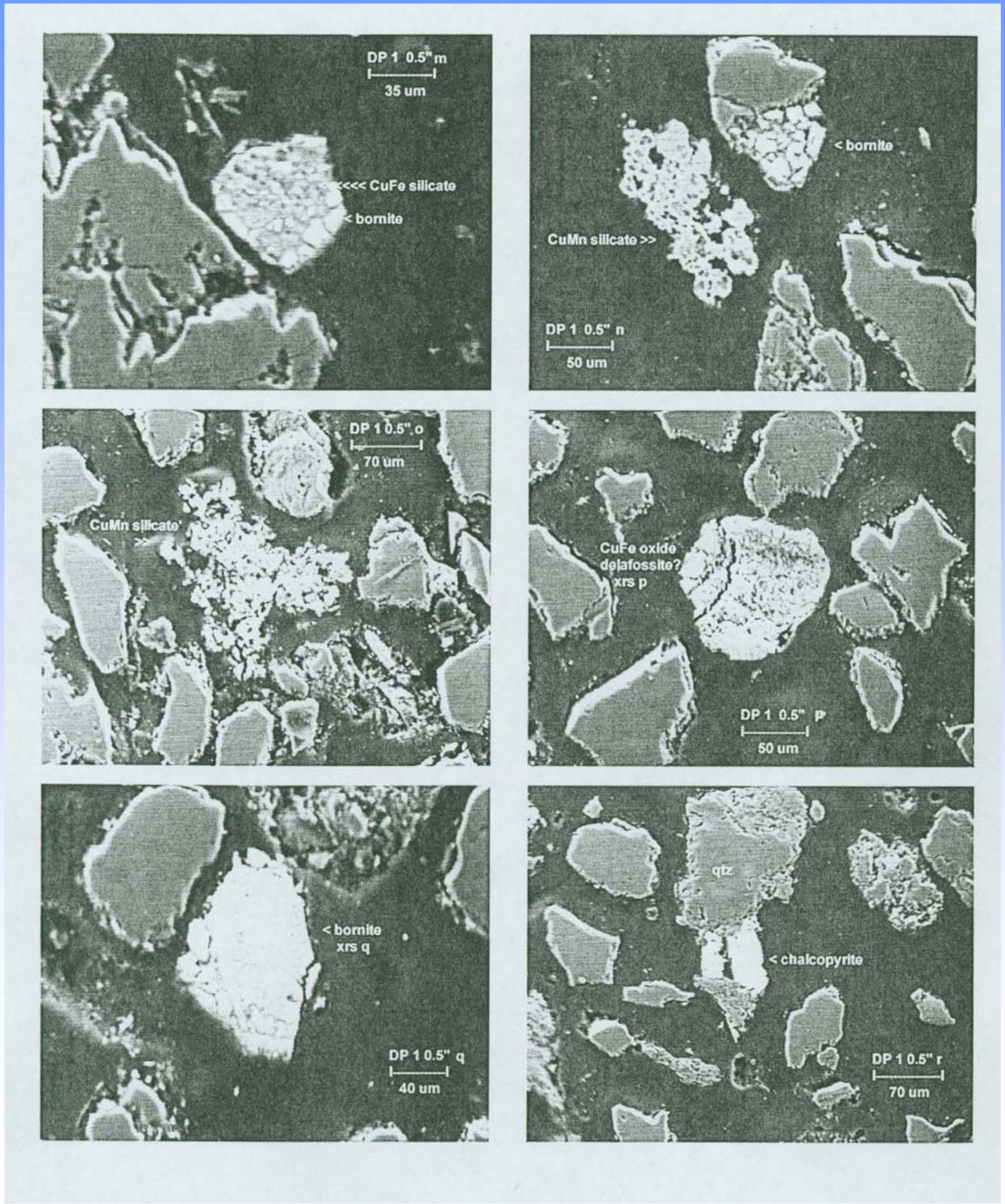
•Sequential extraction analysis



SEM images of copper carbonates and silicates

AKA the pretty blue and green stuff

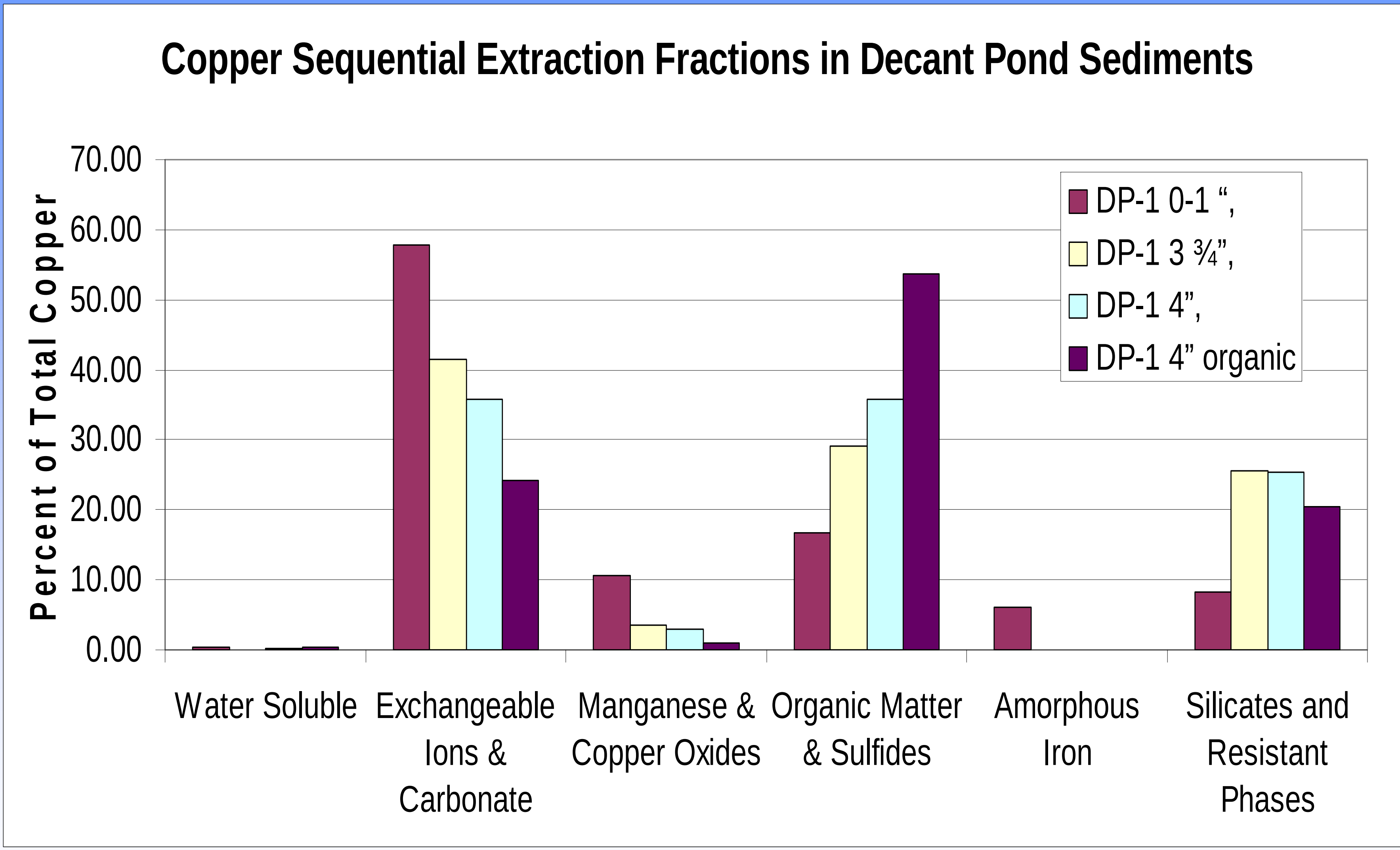
Hydrometrics, Inc.
Consulting Scientists and Engineers



SEM images of CuFe & CuMn silicates; CuFe oxides

AKA the brown stuff

Hydrometrics, Inc.
Consulting Scientists and Engineers



Hydrometrics, Inc.
Consulting Scientists and Engineers

Summary of Attenuation Mechanisms

Mechanism	Evidence
Carbonate Mineral Formation (malachite)	Sequential extraction Visual identification Electron microprobe analysis
Silicate Mineral Formation (chrysocolla and CuMn silicate=Mn-rich hisingerite?)	Sequential extraction Visual identification Electron microprobe analysis
Oxide Mineral Formation and Co-precipitation with Iron oxides (tenorite, delafossite? copper ferrite?)	Sequential extraction Visual identification Electron microprobe analysis
Ion Exchange/Adsorption	Sequential extraction
Organic Matter (Adsorption)	Sequential extraction Whole rock analyses

Hydrometrics, Inc.
Consulting Scientists and Engineers

Step 3 - Long-term Capacity of Attenuation and Stability of Immobilized Contaminants

Copper Mineral Formation

- Are there limiting conditions?
- Are there limiting chemical reactants?

Hydrometrics, Inc.
Consulting Scientists and Engineers

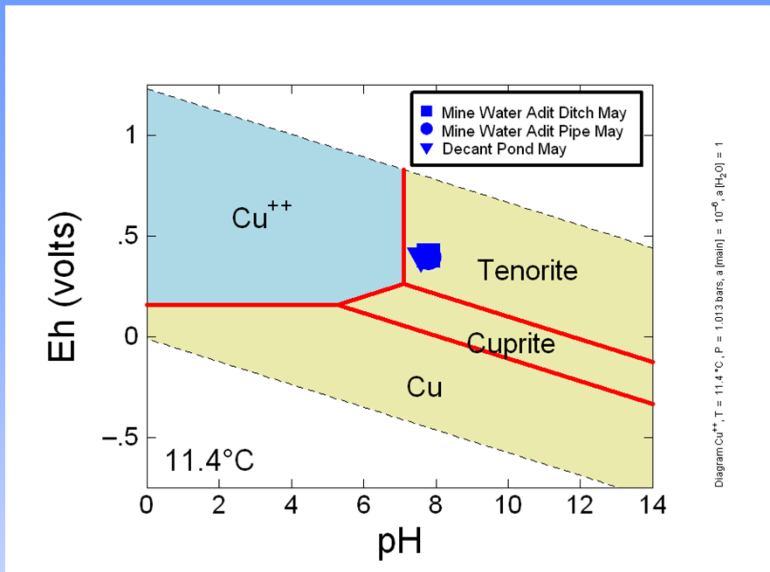
Mineral Formation Evaluated by Geochemical Equilibrium Modeling

1. Determine the geochemical conditions in water (redox, activities, saturation indices etc)
2. Identify the geochemical controls on copper mineral formation
3. Identify the potential geochemical changes that could impede or preclude copper mineral formation and identify potential mitigation methods.
4. Provide format for communication of conclusions

Copper Phases Evaluated

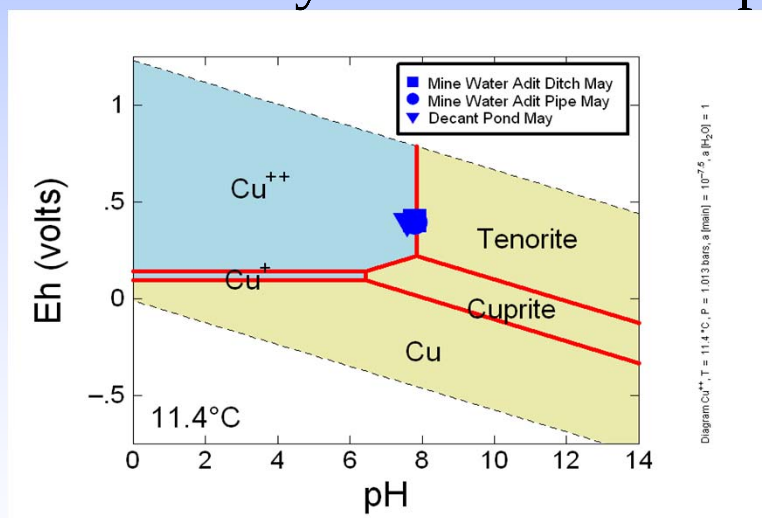
	Field Evidence	Model Predicted
Cu carbonate	malachite	malachite
Cu oxide & CuFe oxides	delafossite?	delafossite, tenorite, Cu ferrite
Cu silicate	chrysocolla? CuMn silicate	dioptase

Cu activity = 10^{-6} = 0.08 ppm



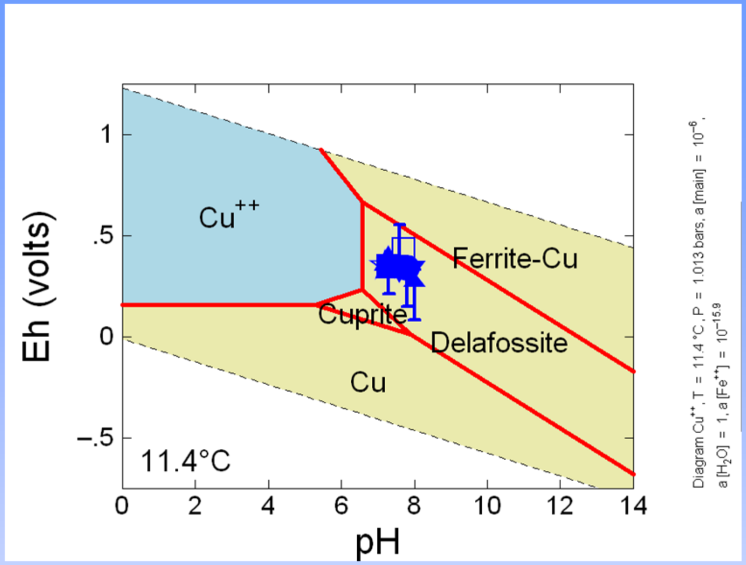
Cu-O system

Cu activity = $10^{-7.5}$= 0.006 ppm



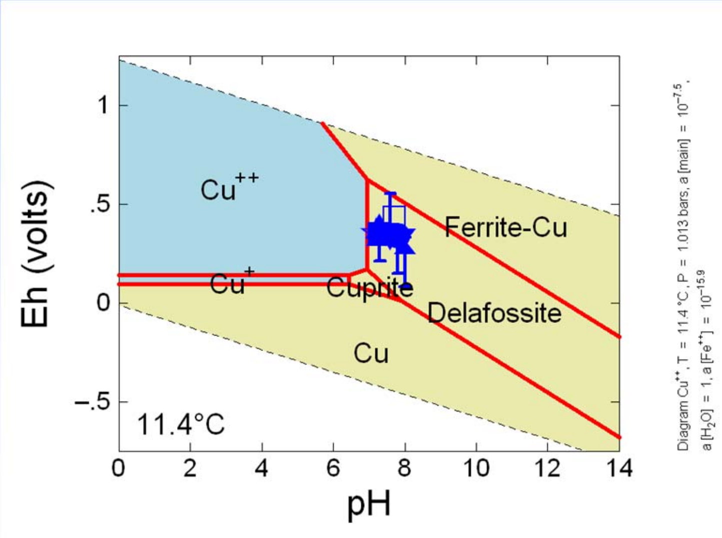
Hydrometrics, Inc.
Consulting Scientists and Engineers

Cu activity = 10^{-6} = 0.08 ppm



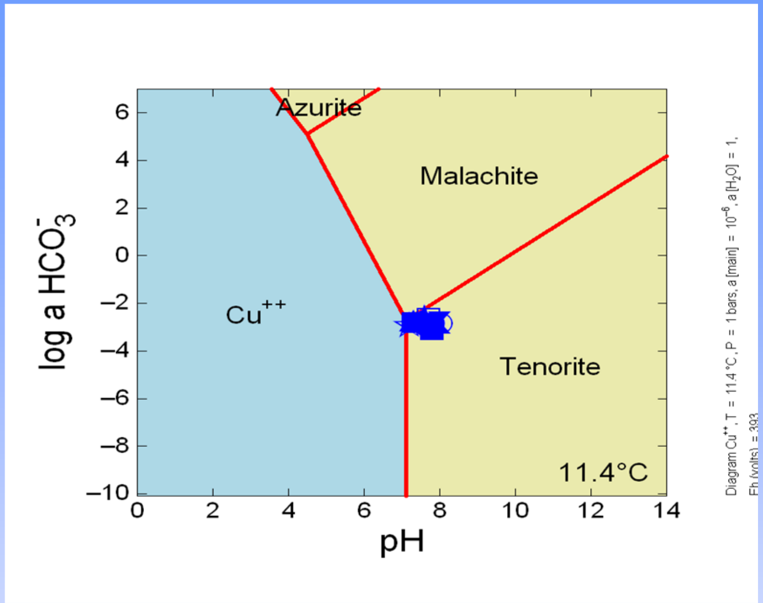
Cu-Fe-O system

Cu activity = $10^{-7.5}$ = 0.006 ppm



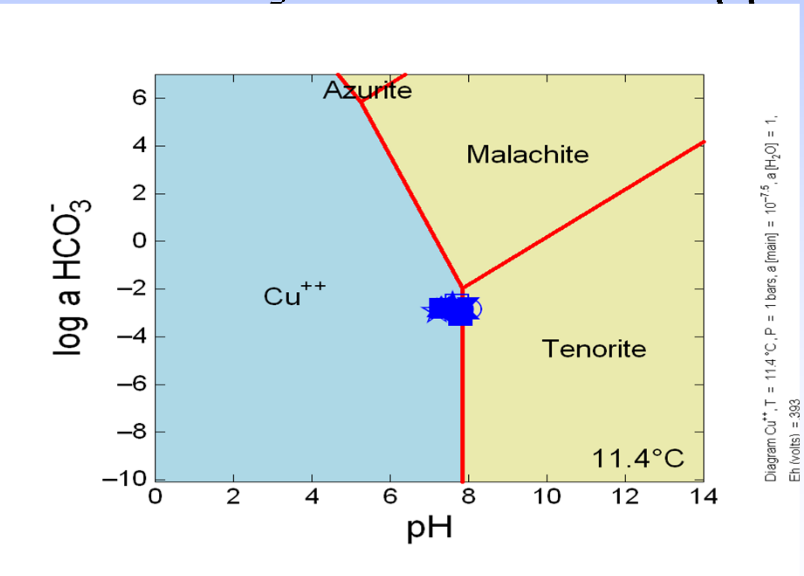
Hydrometrics, Inc.
Consulting Scientists and Engineers

Cu activity = 10^{-6} = 0.08 ppm



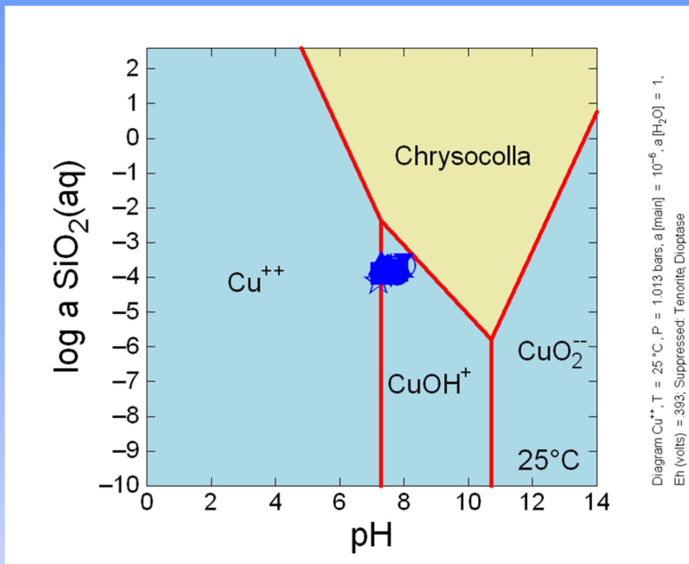
$Cu\text{-}O\text{-}CO_3$ system

Cu activity = $10^{-7.5}$= 0.006 ppm



Hydrometrics, Inc.
Consulting Scientists and Engineers

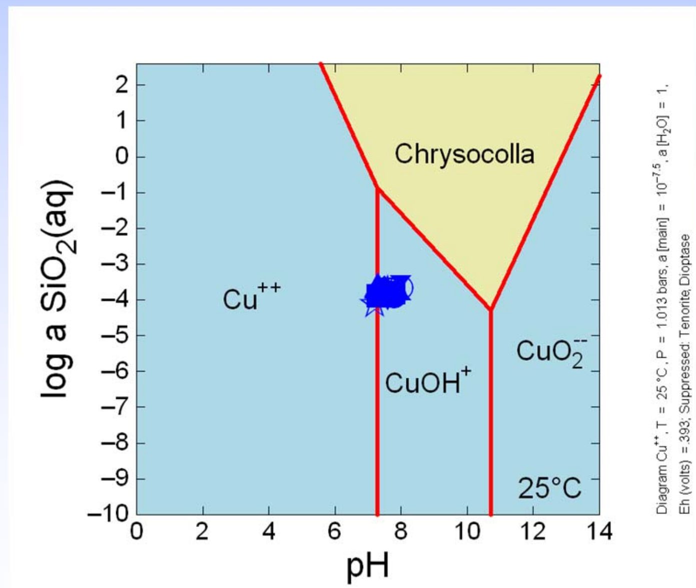
Cu activity = 10^{-6} = 0.08 ppm



Cu-SiO_2 system

(dioptase suppressed)

Cu activity = $10^{-7.5}$ = 0.006 ppm



Hydrometrics, Inc.
Consulting Scientists and Engineers

Summary of Mineral Formation

Required Conditions	Limiting Factor?
Neutral/alkaline pH;	No, mine water expected to be neutral in perpetuity
Oxidizing redox conditions	No, abundant oxygen
Moderate amounts of silica (8 – 12 ppm)	No, abundant silica in tails
Moderate amounts of Bicarbonate (100 ppm)	No, abundant atmospheric CO_2, carbonate in mine and tails

Hydrometrics, Inc.
Consulting Scientists and Engineers

Step 4 - Performance Monitoring and Maintenance Program

Required Conditions	Maintenance	Contingency
Neutral/alkaline pH;	Monitor	Alkaline addition
Oxidizing redox conditions	Monitor & prevent over buildup of organic matter in pond	Aeration, dredge ponds
Moderate amounts of silica	Monitor	Increase contact with tailings
Moderate amounts of bicarbonate	Monitor	Alkaline addition

Hydrometrics, Inc.
Consulting Scientists and Engineers

Step 5 - Regulatory Approval

Ongoing NEPA review and pending Agency approval …

Hydrometrics, Inc.
Consulting Scientists and Engineers

Keys to Using Natural Attenuation for Treatment at Troy Mine

Good rock ! So …

- Very good mine water quality initially – neutral pH, low metals
- Tailings do not negatively affect water quality

Keys to Using Natural Attenuation for Treatment at Troy Mine

Time …

1. For reactions to happen: in mine pool, in pipeline, running across tails, north cell pond, decant pond, percolation to groundwater
2. Interim closure : allowed full-scale proof and evaluation

Hydrometrics, Inc.
Consulting Scientists and Engineers

Thermodynamics wins ….

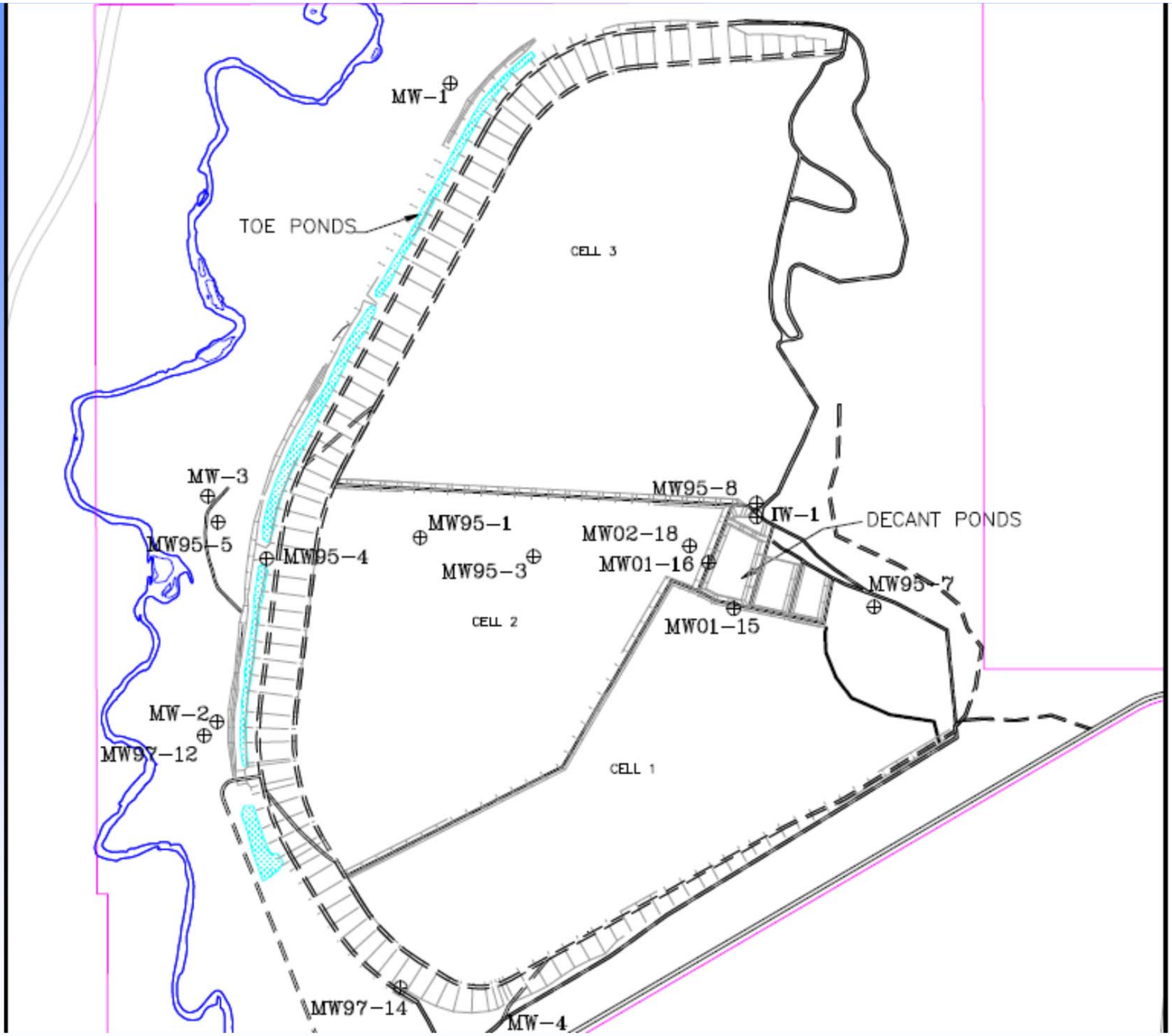
Chemical equilibrium may be achieved (or close enough) …

In the right conditions …

If you have enough time …

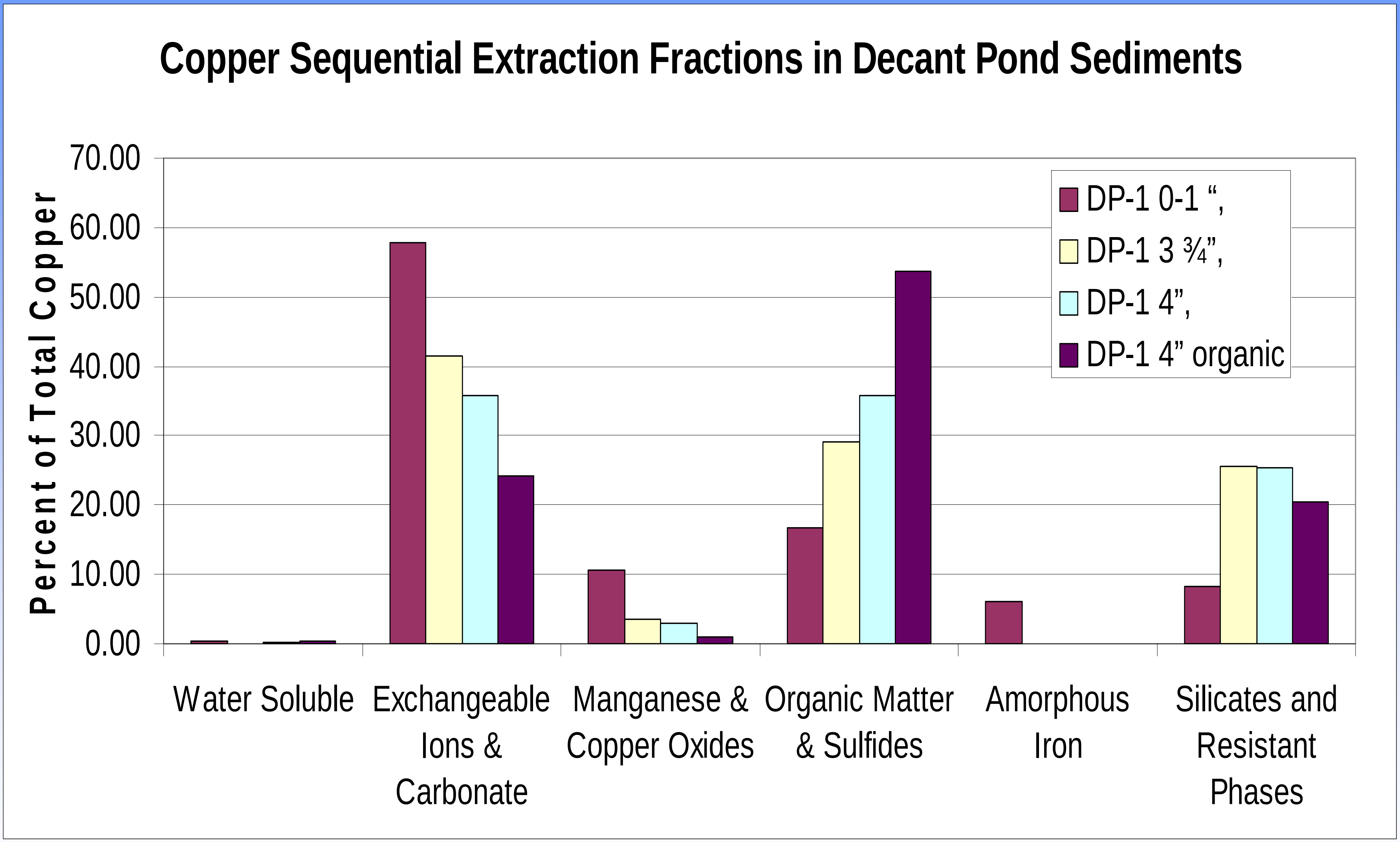
Questions?

Hydrometrics, Inc.
Consulting Scientists and Engineers



Hydrometrics, Inc.
Consulting Scientists and Engineers

Hydrometrics, Inc.
Consulting Scientists and Engineers



Hydrometrics, Inc.
Consulting Scientists and Engineers