# AMD Contaminated Lakes and Sediments

**Source Control: South Bay , Ontario**

**In situ treatment of sediments and ground water**

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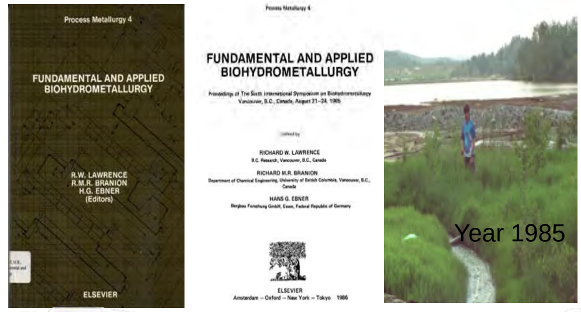
Boojum Research LTD

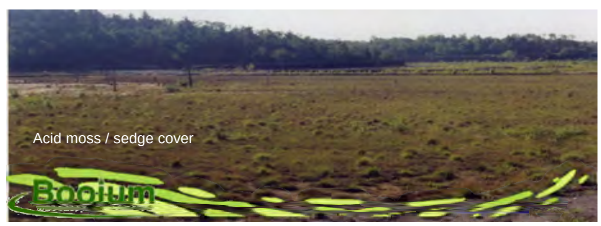
Presented in IMWA, 2010

## ECOLOGICAL ENGINERING FIRST EVIDENCE OF A VIABLE CONCEPT




**Levack before Ecological Engineering**


10 years after Ecological Engineering concept implemented





Technologies tool kit for ecological engineering

| Boojum Expertise |
| --- |
| • Acid Reduction Using Microbiology (ARUM)<br>• Biological Polishing<br>**• Reduction of Acid Generation using phosphate mining wastes** |
| **•Inhibit Precipitate With Phosphate (PWP)**<br>**• With Phosphate (IWP)**<br>**• Phosphate-Heterotroph Inhibition of Tailings Oxidation** (PHITO) |

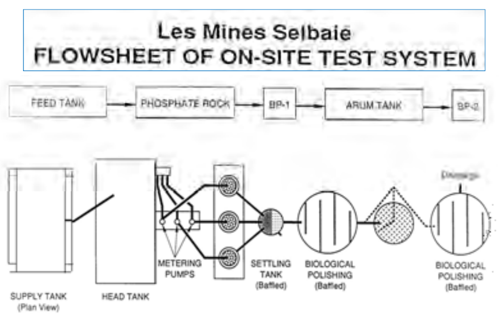
## Ecol. Eng. Is Based on Natural Processes

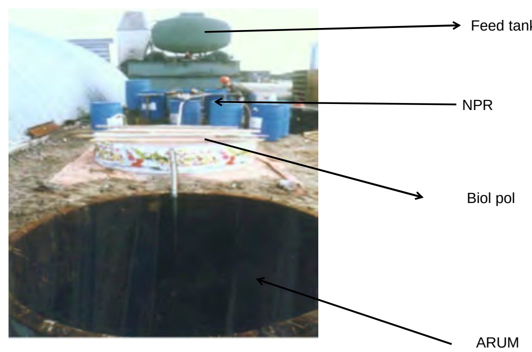
- **Oxygen** produces the problem, oxygen has to be CONSUMED –biofilm on rocks surfaces: ***INHIBITION OF WEATHERING***
- **Hydrogen ions** have to be CONSUMED and hydroxyls have to be generated: ***ARUM***
- **Metals** have to be REMOVED from water to the sediments–adsorption/precipitation: **BIOLOGICAL POLISHING**
- **Metals** have to be STABILIZED inside the sediments: BIOMINERALISATION

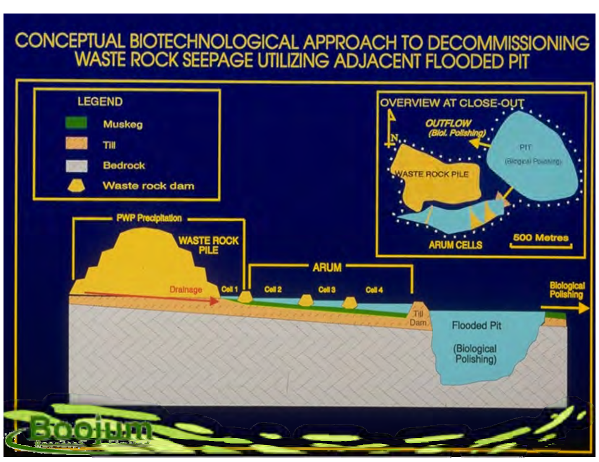
## Technologies tool kit for ecological engineering

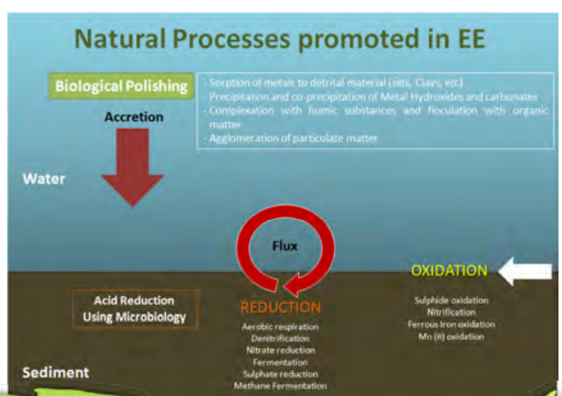
**BOOJUM EXPERTISE**

- Acid Reduction Using Microbiology (ARUM)
- Biological Polishing
- **Reduction of Acid Generation using phosphate mining wastes**
- **Inhibit Precipitate With Phosphate (PWP)**
- **With Phosphate (IWP)**
- **Phosphate-Heterotroph Inhibition of Tailings Oxidation** (PHITO)



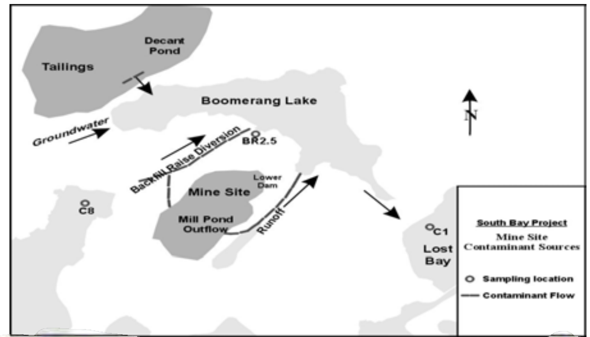



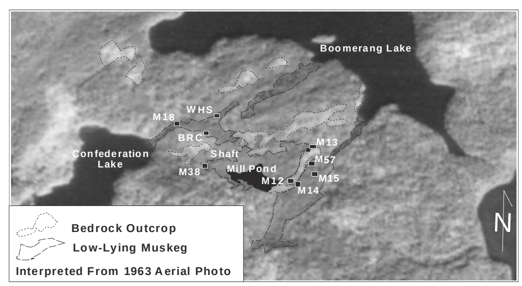
## Field demonstration site - Southbay


## South Bay Contaminants Sources



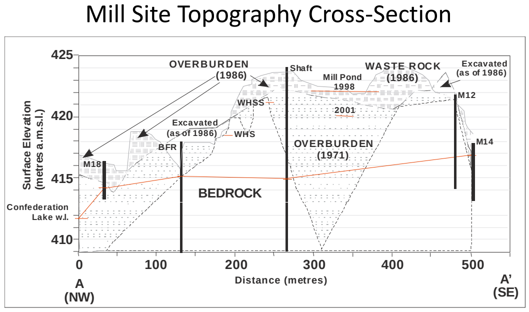

## Mill Pond and upper Dam


## Original Topography




Schematic xx: Original topography of Mill-Mine site, with outlines of bedrock outcrops and low-lying muskeg areas.

## Mill Site Topography Cross-Section




Schematic 3: Cross section of Mine-Mill site, showing original and mining-modified topography, shallow and deep groundwater elevations and bedrock and overburden strata (see Map xx for A-A').

## Backfill Raise Ditch 2006

## South Bay Mine/Mill Site Contaminant Loads

| | Flow ($m^3/y$) | LOADS (t/y) | | | | |
|---|---|---|---|---|---|---|
| | | Cu | Fe | S | Zn | Acidity |
| **BACKFILL RAISE** | | | | | | |
| Pre - Mill Pond Draining | 6,200 | 0.0002 | 0.5 | 3.9 | 1.4 | 3.8 |
| Pre - Mg Metal | 5,500 | 0.003 | 0.3 | 3.3 | 1.4 | 3.6 |
| **Present - with Mg Metal** | 5,200 | **0.0001** | **0.4** | 3.1 | **0.9** | 4.5 |
| **WAREHOUSE SEEP** | | | | | | |
| Pre - Mill Pond Draining | 5,200 | 0.24 | 0.7 | 6.1 | 4.4 | 11.0 |
| Pre - Mg Metal | 1,500 | 0.02 | 0.2 | 1.7 | 1.1 | 3.0 |
| **Present - with Mg Metal** | 900 | **0.01** | **0.1** | **1.0** | **0.7** | **1.7** |
| **BACKFILL RAISE DITCH** | | | | | | |
| Pre - Mill Pond Draining | 36,800 | 0.2 | 2.3 | 26 | 12 | 36 |
| Pre - Mg Metal | 15,800 | 0.1 | 0.8 | 11 | 5 | 15 |
| **Present - with Mg Metal** | 15,800 | **0.1** | **0.6** | **7** | **3** | **17** |

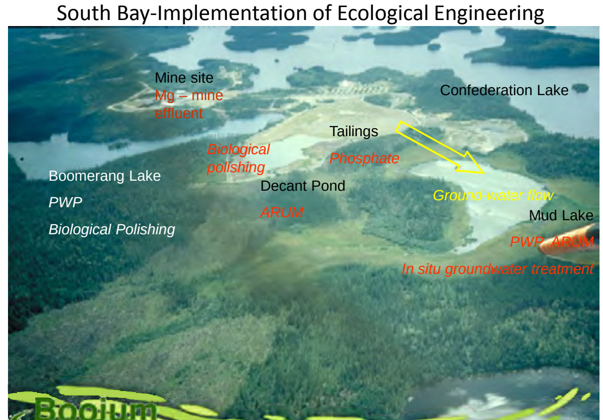
## Lower dam and run-off bay in Boomerang lake

## Mill Pond Outflow and Lower Dam Load (t/y)

| **MILL POND OUTFLOW** | Cu | Fe | S | Zn | Acidity |
|---|---|---|---|---|---|
| | Annual Flow ($m^3/y$) 31,536 | | | | |
| No treatment 1987-91 (365 days flow) | 0.59 | 1.09 | 17.34 | 8.55 | 19.1 |
| After NPR and fertilizer 1992-98 (365 days flow) | 0.38 | 0.61 | 13.33 | 6.61 | 16.2 |
| After siphoning to drain pond 1999 (185 days flow) | 0.46 | 0.46 | 9.22 | 3.78 | 10.1 |
| After blasting 2000-02 (185 days flow) | 0.15 | 0.94 | 8.09 | 4.83 | 11.7 |
| Cumulative load in sediment (1987-1998), t/y | 0.07 | 0.24 | 0.11 | 0.15 | na |
| **LOWER DAM** | Annual Flow ($m^3/y$) 33,990 | | | | |
| No treatment 1987-91 (365 days flow) | 0.04 | 0.36 | 2.78 | 1.03 | 4.88 |
| After NPR and fertilizer 1992-98 (365 days flow) | 0.04 | 0.33 | 5.20 | 2.14 | 5.68 |
| After siphoning to drain pond 1999 (185 days flow) | 0.05 | 0.02 | 6.29 | 3.06 | 6.60 |
| After blasting 2000-02 (185 days flow) | 0.04 | 0.06 | 3.75 | 2.20 | 4.87 |
| Cumulative load in sediment (1987-1998), t/y | 0.02 | 0.17 | 0.02 | 0.03 | na |

Total air-dried sediment weight in the Mill Pond area (2200 $m^3$): 287 ton.
Area of Upper Dam is 300m(length) x 50m(width) x 0.1m(depth)+(75m x30m x0.1m)=1725$m^3$
Area of Lower Dam is 100m(length) x 25m(width) x 0.1m(depth)+(75m x30m x0.1m)=475$m^3$

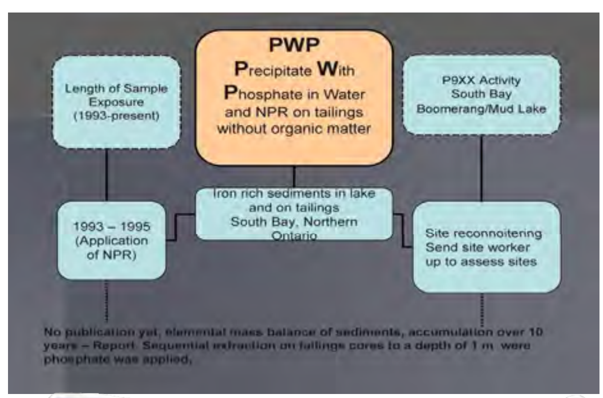
## South Bay-Implementation of Ecological Engineering



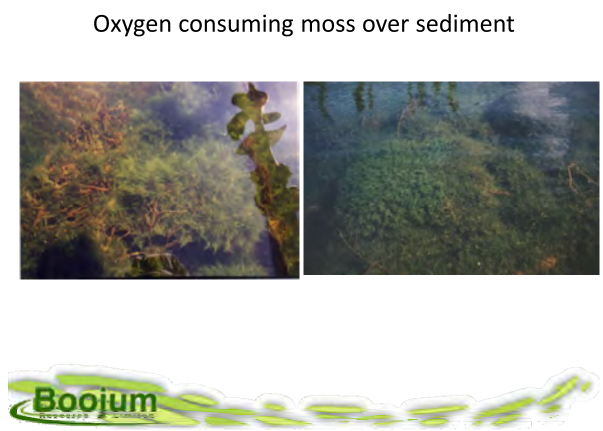

# Boomerang Lake

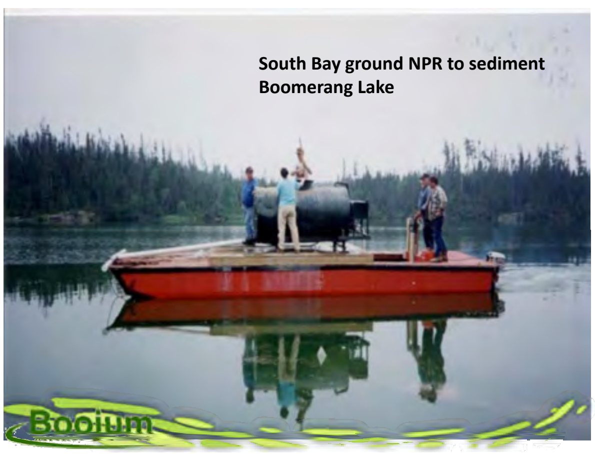
## Total Contaminant Loads and Sediment Sink

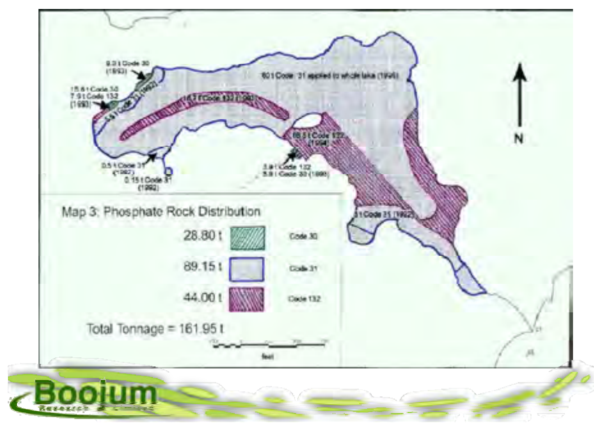
| | Cu | | | Fe | | | S | | | Zn | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Boomerang Lake Load in total tons** | | | | | | | | | | | | |
| | in | out | retain | in | out | retain | in | out | retain | in | out | retain |
| **No Treatment (1987-1994)** | 2.6 | 0.7 | 1.9 | 355 | 9 | 345 | 461 | 239 | 221 | 101 | 22 | 79 |
| **Phosphate and Brush (1995-1999)** | 1.1 | 0.5 | 0.6 | 416 | 9 | 407 | 466 | 228 | 238 | 98 | 41 | 57 |
| **Magnesium (2000-2003)** | 0.8 | 0.6 | 0.2 | 314 | 11 | 303 | 339 | 244 | 95 | 88 | 47 | 41 |
| **Sediment Sink in total tons** | | | | | | | | | | | | |
| Sediment (1998) | | | 2 | | | 468 | | | na | | | 51 |

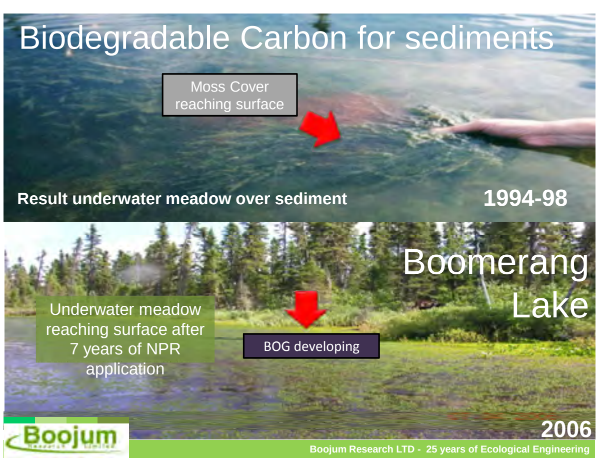


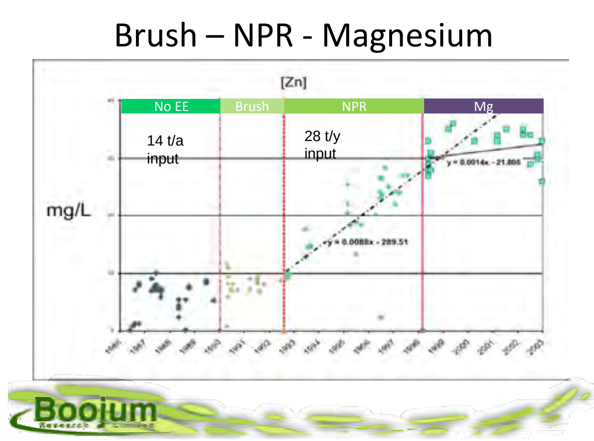

Pilot-scale application
Full-scale application
Boojum


Oxygen consuming moss over sediment
Boojum

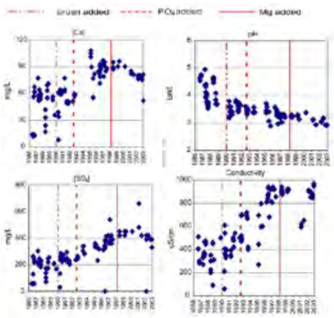

South Bay ground NPR to sediment
Boomerang Lake
Boojum


N
Map 3: Phosphate Rock Distribution
28.80 t
89.15 t
44.00 t
Total Tonnage = 161.95 t
Boojum


Biodegradable Carbon for sediments
Moss Cover reaching surface
Result underwater meadow over sediment
1994-98
Boomerang Lake
Underwater meadow reaching surface after 7 years of NPR application
BOG developing
2006
Boojum
Boojum Research LTD - 25 years of Ecological Engineering


Brush – NPR - Magnesium
[Zn]
No EE
Brush
NPR
Mg
14 t/a input
28 t/y input
mg/L
Boojum

## Boomerang Lake



## Future research : The fate of phosphate and bio-minerals in the sediments and organic matter productivity in the system

**(i) Microbial ecology and diversity of freshwater ecosystems.**

**Phosphorus Cycling**

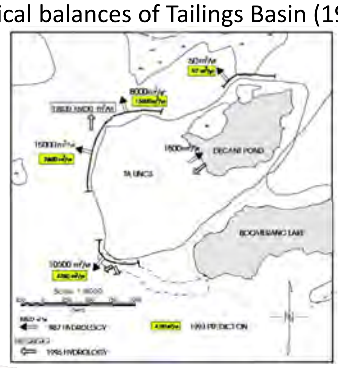
Key words: eutrophication, lake sediments, anoxia, iron-phosphate complexes, microbial iron cycle, phosphate release, sedimentation, biomass enrichment.

Description: Phosphorus retention and release is tightly coupled to iron cycling which in turn is linked to the microbially mediated cycles of sulfur and carbon. Phosphate is scavenged by ferric precipitates under oxic conditions and transported as an integral component of the iron particles. Upon reduction of the ferric matrix by ferriphilic bacteria the phosphate and ferrous iron are released. Both products can serve as nutrients for biomass formation thus driving an ecosystem production cycle. We were studying these processes *in situ* in the sediments of the oligotrophic Jöri lakes III and XIII. In laboratory microcosms we simulate seasonal changes under controlled conditions with the aim to disect coupled biogeochemical cycles and to understand microbial adaptation to seasonal transients. Amorphous iron-phosphate particles were detected in sediments and then produced in the laboratory. These particles are being characterized employing methods of solid state chemistry. Back in the field, we try to quantify and model the cycles for entire lakes in order to become able to understand the role of ferric-iron-covered erosion particle as nutrient scavenging enrichment agents in oligotrophic high mountain lakes.

Contacts: Matthias Wagner, Kurt Hanselmann

Collaboration: Barbara Sulzberger, Federal Institute for Environmental Sciences, EAWAG,

## Hydrological balances of Tailings Basin (1987-1995)



## Ground water AMD plume

Drilling in a Floating Muskeg

## Kalin Canyon and Boomerang Lake

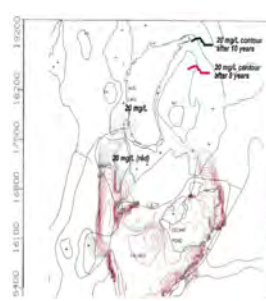
**Load Reduction**

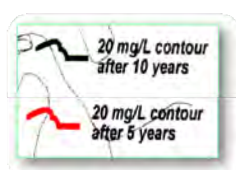
from Tailings from ***1996 to 2002***

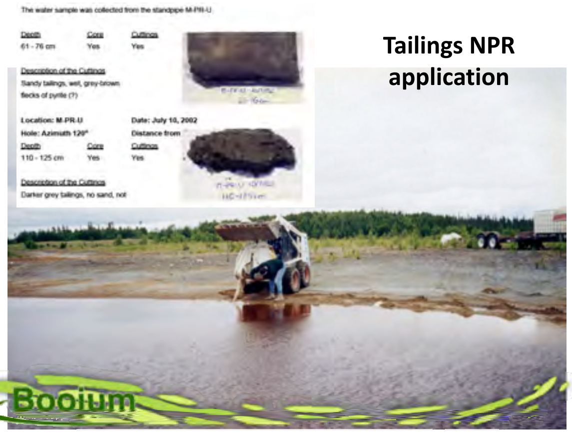
| | Layer | Flow $m^3/y$ | Fe t/y | S t/y | Zn t/y | Acidity t/y |
|---|---|---|---|---|---|---|
| Kalin Canyon | 1 | 391 | 2.20 | 1.30 | 0.04 | 1.75 |
| | 2 | 3,485 | 19.6 | 11.1 | 0.44 | 21.5 |
| | 3 | 5,507 | 28.6 | 14.9 | 6.2 | -19.3 |
| | 4 | 11,173 | 4.58 | 1.84 | 1.03 | 4.70 |
| Boomerang Lake (South of Tailining | 1 | 189 | 1.06 | 0.63 | 0.02 | 0.85 |
| | 2 | 3,615 | 2.96 | 1.27 | -0.07 | 1.68 |
| | 3 | 1,453 | 7.56 | 3.92 | 1.63 | -5.08 |
| | 4 | 11,875 | 19.1 | 12.8 | 0.86 | 29.2 |

## Tailings Area Model: 10 years prediction

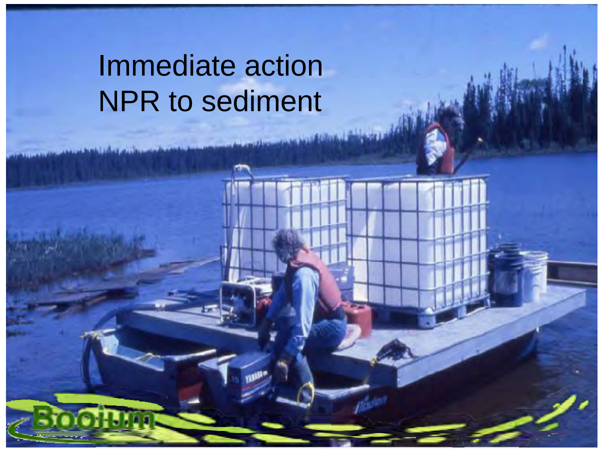
Zinc Concentrations








**Tailings NPR application**





***Bio-remediation Concept***

***ARUM – Underground***

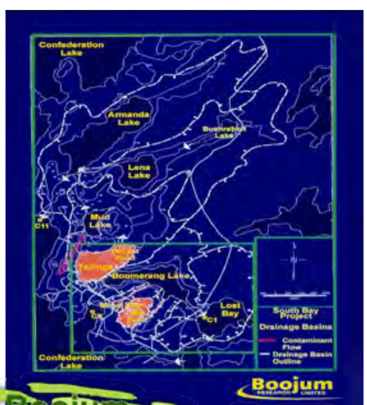
TAILINGS PORE WATER MG/L:
$SO_4$ 35 – 20,180; FE <1 - 9,938 ; ZN <1- 1,123

**UREOLYTIC BACTERIA?**

1 mol of hydrolyzed urea is converted to only metabolicly

2 mol of ammonium

**PH INCREASE**
**METAL PRECIPITATION**




It does not work because :

- Oxidation of ground water
- Hydrology too complex
- Microbes don't live there
- No control over reactions
- Enzyme does not work
- Changes in hydraulic
- Conductivity
- etc .

No is easy to say collaborators – and I thank them all:

P.Lau BRI, G. Ferris U of T and National Research Council Talisman Energy INC, A. Buchnea, A. Vanhof

Adressing selected key questions
(from the investigations 1996-2003)

✓Do the microbes survive and grow in AMD?

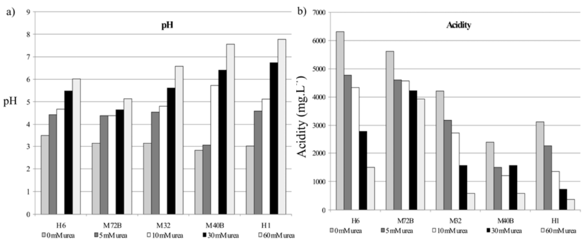
✓Would urease-producing microbes be stimulated to activity in this metal laden groundwater ?

✓What rate must they produce urease to facilitate pH increase and thus metal precipitation?

**Consulting the extensive literature did not help!!!**

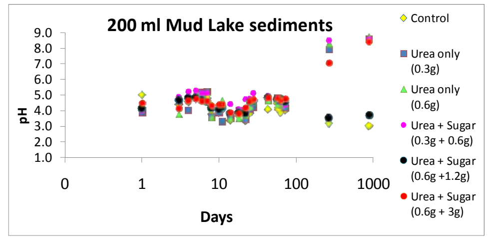
## Rapid pH / Eh changes will destroy the enzyme?

Tests with black bean urease in the field different pH / Eh –increasing urease concentrations



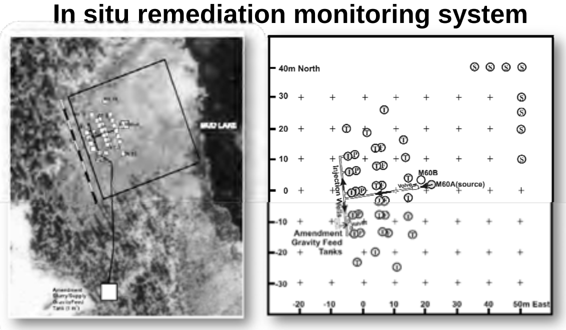

Urease activity **not** impressive – quantities needed **not** encouraging **BUT**
In the presence of substrate for biofilm formation – may work !!

## Additions of urea and sugar to gyttia type lake sediment – or substrate for biofilm growth




Well patience until the microbes are acclimated BUT no response to concentration of additions !!

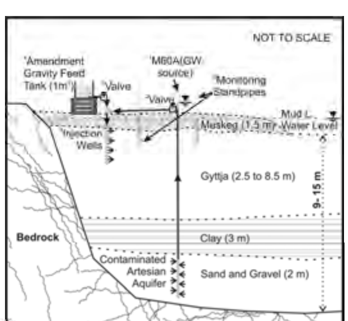
## In situ remediation monitoring system




80 m by 90 m grid in 10 m intervals

## Piezometers, injection system

## Below the in- situ system



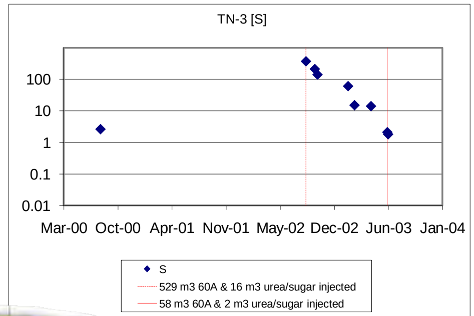

## *Field Test – Chronology*

| *Background Survey* | | M60A GW | Urea + Sugar |
|---|---|---|---|
| | | $m^3$ | |
| **Year 2000: Installation and Background Survey** | | | |
| July 23 to 28 | Water Sampling, Overwintered test (no AMD), surveying standpipes, water level measurements | | |
| **Year 2001: Hydrological Tests - AMD injections** | | | |
| May 23 to Sep 16 | **Inj. # 1** (1.3 days)/Rod survey A | 17.8 | 0 |
| | **Inj. #2** (0.8 days)/Rod survey B and C | 14.7 | 0 |
| | **Inj # 3** (58 min)/Flow test (M60-Inj. Wells) | 0.3 | 0 |
| ***Biostimulation*** | | | |
| **Year 2002: M60A Injection Tests** | | | |
| July 5 to Oct 16 | **Inj. # 4** (12 hours)/Rod survey D, E, F ,G | 31 | 0.2 |
| | **Inj. # 5** (20 days)/Rod Survey H and I | 529 | 16 |
| | **Inj. # 6** (7 days)/Rod Survey H and I | 212 | 6 |
| **Year 2003: M60A Injection Tests** | | | |
| May 2 to Aug 27 | Rod Survey J and K | | |
| | **Inj. # 7** (2.8 days)/Rod survey L | 58 | 2.8 |
| | Inj. M60A (3 days/clear system) | 78 | 0 |

**Changes in elemental concentration (> detection limit) with time at TN 3**

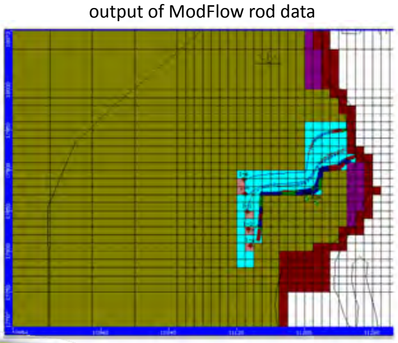
| Elements (mg/L) > Detection Limits | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Ba | 0.071 | 0.049 | 0.11 | 0.16 | 0.12 | 0.099 | 0.29 | 0.42 | 0.11 |
| Ca | 26 | 250 | 150 | 170 | 120 | 54 | 140 | 150 | 38 |
| Cu | 0.006 | 0.025 | 0.013 | 0.018 | 0.015 | 0.012 | 0.026 | 0.025 | 0.013 |
| Fe | 1.7 | 130 | 4.3 | 13 | 0.87 | 9.3 | 8.7 | 6.9 | 4.6 |
| K | 1 | 9 | 12 | 9 | 5 | 1.2 | 3.7 | 4.7 | 1.5 |
| Mg | 2.3 | 34 | 24 | 19 | 16 | 5.3 | 13 | 14 | 3.5 |
| Mn | 0.12 | 8.3 | 1.9 | 3.7 | 1.2 | 0.8 | 1.6 | 1.6 | 0.37 |
| Na | 2 | 7 | 5 | 5 | 4.9 | 1.6 | 4.7 | 4.4 | 1.8 |
| P | 0.06 | 0.45 | <0.05 | <0.05 | <0.05 | <0.01 | 0.07 | <0.05 | <0.05 |
| S | 2.6 | 370 | 210 | 140 | 60 | 15 | 14 | 2.1 | 1.8 |
| Si | 12 | 8.3 | 4 | 8.2 | 8.2 | 4.3 | 11 | 11 | 9.8 |
| Sr | 0.059 | 0.48 | 0.3 | 0.34 | 0.24 | 0.099 | 0.26 | 0.3 | 0.079 |
| Zn | 0.019 | 11 | 0.07 | 0.09 | 0.011 | 0.3 | 0.059 | 0.013 | 0.078 |
| $NH_3$ | 3.30 | 52 | 184 | 131 | 162 | 328 | 218 | 16 | 337 |
| | | 54 | 817 | 123 | | | | | |
| $NO_2+NO_3$ | <0.1 | 3 | 2.5 | 1.4 | 0.11 | 0.19 | 0.1 | 0.32 | 1.3 |
| | | 2.9 | 2.4 | 1.2 | | | | | |
| TKN | 4.88 | 1340 | 964 | 820 | 148 | 273 | 218 | 266 | 331 |
| | | 1360 | 942 | 7.4 | | | | | |
| OC | 13.5 | 3400 | 2200 | 1260 | 300 | 490 | 390 | 500 | 560 |
| | | 3100 | 1600 | 1600 | | | | | |

Microbial sulphate reduction induced




AMD and biostimulant plume :

output of ModFlow rod data



Planning
Full scale
Plume
Treatment
Spacing of
Injection
Wells

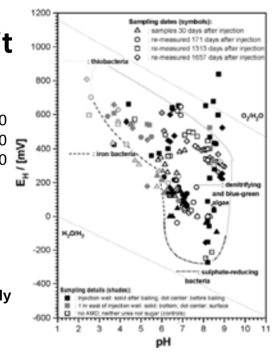
**To define growth limit**

Eh/pH diagram – Baas Becking

Total Eh/pH couples measured: 6200
Microbes identified : 2100
Aquatic ecosystems mesured: 4100

pH / Eh Range

Use Eh/pH diagram to determine **likely** presence and activity of microbes




Baas Becking, Kaplan and Moore (1960). "Limits of the natural environment in terms of pH and Oxidation-reduction potentials. The journal of Geology, Vol.68, N°3, 243-284pp

How long does treatment lasts ?

**Bottles stored for 4.5 years !**

Conclusions

✓Based on the literature of the growth conditions required for ureolytic microbes to thrive the concept had limited credibility.

✓The ability of microbes to adapt is essentially unlimited.

✓The enzyme is not affected by the adverse chemical conditions and the metal concentrations are not toxic, ureolytic activity degrades urea to ammonia.

✓The hydrology is site specific and engineering ingenuity is needed to devise injection systems of the nutrients without adding oxygen.

**PROOF OF CONCEPT HAS BEEN DOCUMENTED - THANK YOU**

Boojum Research: Virtual Library