Using Pit Lakes as Bio-Reactors

Overcoming Their “Crater Lake” Tendencies
Highland Valley Copper
HVC Mine Site
ARD/ Metal Leaching

- Acid Rock Drainage
  - Not an issue
  - Neutralization Potential $>>$ Acid
  - Generation Potential

- Metal Leaching
  - Molybdenum leaching is an issue
Molybdenum Leaching

- Molybdenum
  - Can affect ruminants
  - Not a significant issue for aquatic life at HVC levels

- Two possible areas of impacts
  - Vegetation
  - Water
Mo Leaching - Water

- Elevated levels of molybdenum
  - Seepage from tailings dams
  - Seepage from some waste dumps
  - Water in pit lakes

- Currently not an issue
  - All problematic water is used in process

- Post closure - water will be an issue
Bethlehem Pit Lakes
Valley & Lornex Pits
Water Management Options

- Conventional Treatment
- Diversion
- Biological Treatment
Using Pit Lakes as Bioreactors Part 2

Overcoming their Crater Lake Tendencies
Both lakes have crystal-clear fresh water
All we at HVC want is:

- thick, preferably diverse metal-adsorbing plankton algae blooms (a cheap grown-in-place organic amendment) during every ice-off period, even better during ice cover too…

- The sedimenting organic-metal complexes should be received by a thriving, cold adapted SRB consortia…

- And while we’re at it, we want to achieve a natural ecosystem capable of growing trophy fish and suitable for waterfowl…
<table>
<thead>
<tr>
<th>Type of Particle</th>
<th>Role in Metal Removal</th>
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</table>
| Phytoplankton                        | - Many algal surfaces have affinity for heavy metals such as Cu(II) Pb(II) Zn(II) Cd(II) Ni(II) via surface complex formation.  
- Microflora absorb nutrient metals such as Cu(I) Zn(II) Co(II) and metal ions mistaken as nutrients such as Cd(II) and As(V).  
- Aging microflora mineralizes and sediments                                                                                                                   |
| Biological debris                    | - Metals adsorb to negatively charged organic particle surfaces esp –COOH -NH₃ -OH groups  
- Metals also attach to cation/anion ligands already attached to the surface of the particles                                                                 |
| CaCO₃                                | - Heavy metals and phosphates are adsorbed as calcium carbonate crystals grow. Their large size and therefore small surface area limits the amount of metal CaCO₃ co-precipitates. |
| Fe(III) hydroxides and oxides        | - pH dependent, ferric hydroxides/oxides have a strong affinity for heavy metals, phosphates, silicates and oxyanions of As Se Fe(III) oxides  
- Even if ferric hydroxides/oxides are present in small proportions they can exert significant removal of trace metals  
- At an oxic/anoxic boundary, Fe(III) can represent a large part of settling particles                                                                          |
| Mn(III,IV) oxides                    | - pH & redox-dependent, manganese oxides have a high affinity for metals and high specific surface area and is usually important in regulating trace metals in the lower portions of lakes and sediments |
| Aluminum Silicates Clays, oxides     | - Ion exchange, binding of phosphates and metal ions (usually minor)                                                                                                                                                    |
Microflora differ greatly in their requirements, size, and external composition.
In a pit or crater lake, the algal component often contributes less than half of the total primary productivity with photosynthetic bacteria as the main contributor.
Freshwater Microfloral Surfaces and Exudates that Adsorb Aqueous Metal Ions

- **Gram +ve bacteria** Lipid sheath
- **Gram –ve bacteria** Peptidoglycan cell walls
- **Cyanobacteria** Mucilage sheath in filamentous types, excrete complex protein-based toxins
- **Euglenoid algae** Mucous coatings
- **Chrysophyte algae** External gelatinous matrix
- **Diatom algae** Frustules (shells) made of silica dioxide, excrete organic molecules
- **Desmid algae** Silicate surfaces, some species form calcareous coatings as well
- **Dinoflagellates** Cellulose walls
- **Cryptomonad algae** Periplast protein coat with mucous
The interactions between micro nanno and pico plankton components (algae, bacteria, fungi), their predators and their interaction with particulates and water chemistry is too complex to dissect and we can treat it collectively as microfloral biochemistry.

It works; sedimenting material is the main “conveyor belt” transporting aqueous metals to the sediments in all lakes.
Crater lakes are incredibly clear with secchi depths as deep as 120 m and routinely in the 50 m range – doubling that gives us water so clear that there is sufficient light at 100 m to support benthic plant growth thus oxygen concentrations hover near 100% saturation. They are crystal clear non-productive tourist destinations.

Crater Lakes are NOT good at producing organic conveyor particulates

Pit lakes share their tendencies.
What are the limitations on crater and pit lake productivity?

- Major (e.g. N P C Si) and/or minor (e.g. Fe Mn Cu S) nutrient limitations
- Limited substrate-water column interaction due to basin shape
- Limited shoreline for recruitment of benthic/planktonic microflora and growth of rooted aquatic macrophytes
- Lack of turbulence for nutrient upwelling, cell suspension
- Microfloral enzymes denature in excessive sunlight
- Homogenous environment compared to natural lakes thus a restricted potential species pool.
Turbulence and seiches show as jogs in the 5 – 25 m lines
In Contrast the smooth lines from pit lakes show little turbulence and no seiches.
Sporadic mixing of surface water into deep water can occur in a non-mixing pit via:

- **Fall Overturn Turbulence** During the fall overturn, turbulent energy fluxes penetrate deep into the hypolimnion, eroding the monimolimnion and potentially re-distributing water throughout the water column, which lowers the developing chemocline.

- **Ice Melt Thermals** In the spring, cold water from freshly melted ice is near the temperature of maximum density (4°C) and tends to sink, carrying dissolved oxygen and solutes with it.

- **Density Plumes** Density plumes of silt-laden rainwater are observed during storms. Density plumes carry warmer surface water into deeper water.

- **Pit Wall Seepage** Groundwater seepage through the pit walls accumulates in a bottom pool. Groundwater seepage affects pit water chemistry directly or through dissolution from fines lining the pit benches. For seepage to be considered a significant influence, water chemistry in the deepest water should move toward the chemistry of local groundwater.

- **BUT RETURN OF DEEP WATER TO THE SURFACE IS RESTRICTED**
Surface water is transported down with ice melt thermals and with sediment density plumes; upwelling is restricted.
Correcting Iona’s Major Nutrient Deficiency

- We used 100 gallons of liquid Agrium 10-34-0 per application
- If ammonia slid below detection we also had liquid 28-0-0 urea + ammonium nitrate
- Low metals GVRD biosolids was also available
Year One of Iona fertilization

- We got a green flagellate bloom that reached 26 ug/L chlor-a and lasted all summer. When it collapsed and sank to the bottom, the cells continued to live and were still viable during the following spring.
Dissolved Oxygen Profiles 2004 & 2005

- The upper 2004 graph shows oxygen supersaturation during the first-year bloom.

- The lower 2005 graph shows a much smaller bloom below the thermocline. Note the small anoxic zone in the bottom water.
Water quality profiles were collected in the spring and fall to bracket the growing season.

There was a measurable removal of aqueous N, Mo, Cu, Ca, Si and Na with the 2004 Iona algae+bacteria bloom.

All nutrients were in luxurious supply again in 2005 but no bloom and no metal removal resulted.
Copper Profiles
Iona Pit 2004

Total & Diss Mo Profiles
Iona Pit 2004

Total & Diss Mo Profiles
Iona Pit 2005

Copper Profiles
Iona Pit 2004

Copper Profiles
Iona Pit 2005
In year 2 we get luxurious growth of benthic algae but it can’t affect the entire pit volume chemistry the way plankton algae can...
Chlorophyll-a at HVC Pit Lakes
Through 2005 Growing Season

Average chlorophyll-a ug/L

- Heustis
- West Pit
- Iona Pit
- Jersey

Dates:
- 18-May
- 31-May
- 14-Jun
- 21-Jun
- 29-Jun
- 12-Jul
- 19-Jul
- 27-Jul
- 10-Aug
- 16-Aug
- 23-Aug
- 31-Aug
- Sept 20
- Sept 29
- Average
Plant diversity in Heustis Pit Lake helps support spring plankton blooms

<table>
<thead>
<tr>
<th>S code</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Deep water</td>
</tr>
<tr>
<td>2</td>
<td>Deep b/g benthic on rock</td>
</tr>
<tr>
<td>3</td>
<td>Deep microfloral scum</td>
</tr>
<tr>
<td>4</td>
<td>Microfloral scum + SAMs - Pp</td>
</tr>
<tr>
<td>5</td>
<td>Brown benthic algae + SAM's</td>
</tr>
<tr>
<td>6</td>
<td>Shallow SAMs Pp+Ra, dense</td>
</tr>
<tr>
<td>7</td>
<td>Rock benthic blue-gr algae Osc/Aph</td>
</tr>
<tr>
<td>8</td>
<td>Filamentous green Chlad + Ulothix</td>
</tr>
<tr>
<td>9</td>
<td>Fil green on surfacing Pp+Ra</td>
</tr>
<tr>
<td>10</td>
<td>Surfacing SAMs Pp+Ra shallow</td>
</tr>
<tr>
<td>11</td>
<td>Bare substrate</td>
</tr>
</tbody>
</table>

(After Borstad)
Heustis spring bloom 2006
(Dactylococcopsis Chlorella flagellates)
What did we know going into 2006?

- Mixing HVC pit lakes grow a variety of algal types (mostly diatoms and flagellates) as soon as the ice comes off but the blooms stall during June despite luxuriant macro and micro nutrient supplies.
- Non-mixing HVC pit lakes bloom for one year but if they are mixed by pumping, intense blooms result.
- Washing in fine silts did not restore productivity.
- Adding biosolids on a pit ramp increases productivity but not to bloom status.
- Benthic microfloral growth is invariably excellent and grows on many surfaces; it diversifies with years of fertilization.

Chlorophyll-a in Iona Surface Water 2006

Chlorophyll-a ug/L

May-09 May-23 Jun-09 Jun-21 Jul-05 Jul-19 Aug-02 Aug-16 Aug-31 Sep-13 Sep-27 all season
Molybdenum Profiles in Iona Pit Lake 2004 & 2006

Total & Diss Mo Profiles Iona Pit 2004

Mo Profiles Iona Pit 2006
HVC Container Studies
Many algae supplement their growth by taking in organic substrates, particularly the made-by bacteria B vitamins: B12, thiamine and biotin.

Adsorption and removal of B12 by particulate calcium occurs in natural lakes.

Biosolids helps pit productivity and it has B vitamins (and much more).

Therefore we tested a B12 source that floats...
Iona Containers Summer 2006
Iona Containers Oct. 2006
## 2006 Iona Container Study

<table>
<thead>
<tr>
<th>Type of Addition</th>
<th>Chlor-a ug/cell count</th>
<th># species</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>ug/L</td>
<td>cell/mL</td>
</tr>
<tr>
<td>Iona Spring (peak)</td>
<td>12</td>
<td>1700</td>
</tr>
<tr>
<td>Iona Summer/Fall</td>
<td>0.7</td>
<td>50</td>
</tr>
<tr>
<td>Fertilizer + Innoculation</td>
<td>37</td>
<td>1300</td>
</tr>
<tr>
<td>Mud + Fertilizer</td>
<td>23.4</td>
<td>255</td>
</tr>
<tr>
<td>Biosolids</td>
<td>405</td>
<td>3500</td>
</tr>
<tr>
<td>Biosolids + Compost</td>
<td>1350</td>
<td>4700</td>
</tr>
<tr>
<td>Whole Egg</td>
<td>497</td>
<td>5,000</td>
</tr>
<tr>
<td>Egg Yolk</td>
<td>550</td>
<td>3,000</td>
</tr>
<tr>
<td>Egg White (bacteria)</td>
<td>(bacteria) 55</td>
<td></td>
</tr>
<tr>
<td>Vitamin B12</td>
<td>348</td>
<td>4000</td>
</tr>
<tr>
<td>Multi-vitamin pill</td>
<td>160</td>
<td>4000</td>
</tr>
</tbody>
</table>
Iona Enclosures
Enclosures hosted 16 different types of algae as well as bacteria and fungi on the walls of the enclosures and on the additions.
Material Collected from the Iona Enclosures
2006

[Graph showing the comparison of total solids (TS), volatile solids (VS), and chlorophyll a (Chlor A) for different materials collected from the Iona Enclosures in 2006.]
Metals in Enclosure Material

- Control (Benthic)
- SA macrophytes
- Duckweed
- Filament algae

Metals mg/kg:
- Copper
- Molybdenum
- Volatile Solids

Chlor-a ug/L VS mg/L

Graph showing the concentration of metals in different enclosure materials.
Introduced Substrates
(collectively grew 17 algal species)
What did we learn?

- Bacteria resident on fines provided the initial bloom with their missing growth factors—probably B vitamins.
- These bacteria apparently grow on all substrates and supply the benthic microflora.
- Returning bottom water to the surface replenishes these growth factors.
- Supplementing the B vitamins allows excellent algae growth.
Various introduced substrates grew 17 benthic algae in varying combinations.

Aquatic macrophytes grew 30 periphytic algae species in the Iona enclosure.

Duckweed looks promising for aqueous Mo removal.

Enclosures with intense photosynthesis precipitated calcium.
• Benthic algae and photosynthetic bacteria provide much of the primary production in HVC pit lakes
• Spring HVC pit blooms tend to become more diverse over time
• SRB colonize the substrate once organic carbon from microflora accumulates (1-3 years)
  ▪ By the 2nd summer of fertilization, the benthic “scum” supported chironomids sufficient to support a limited fishery in every pit.
  ▪ Eagles, osprey and goldeneyes now utilize HVC pit lakes.
Solution to Craterish Pit Lakes
#1: add artificial upwelling
Solution #2: Diversify your habitats: add nutrients, plants & substrates
Benthic microflora / Aquatic macrophytes / Duckweed
Solution #3: Add B vitamins