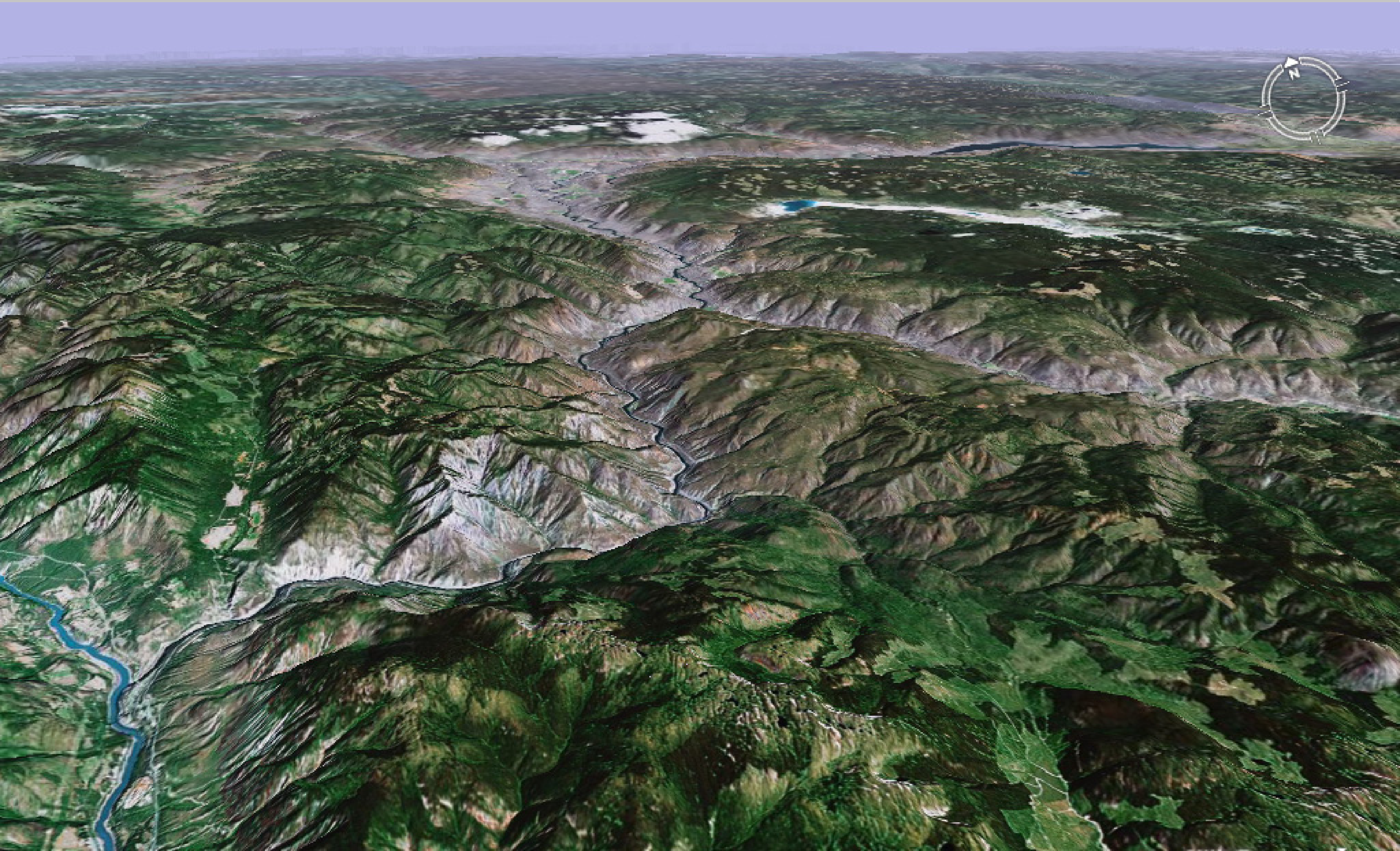
Using Pit Lakes as Bio-Reactors

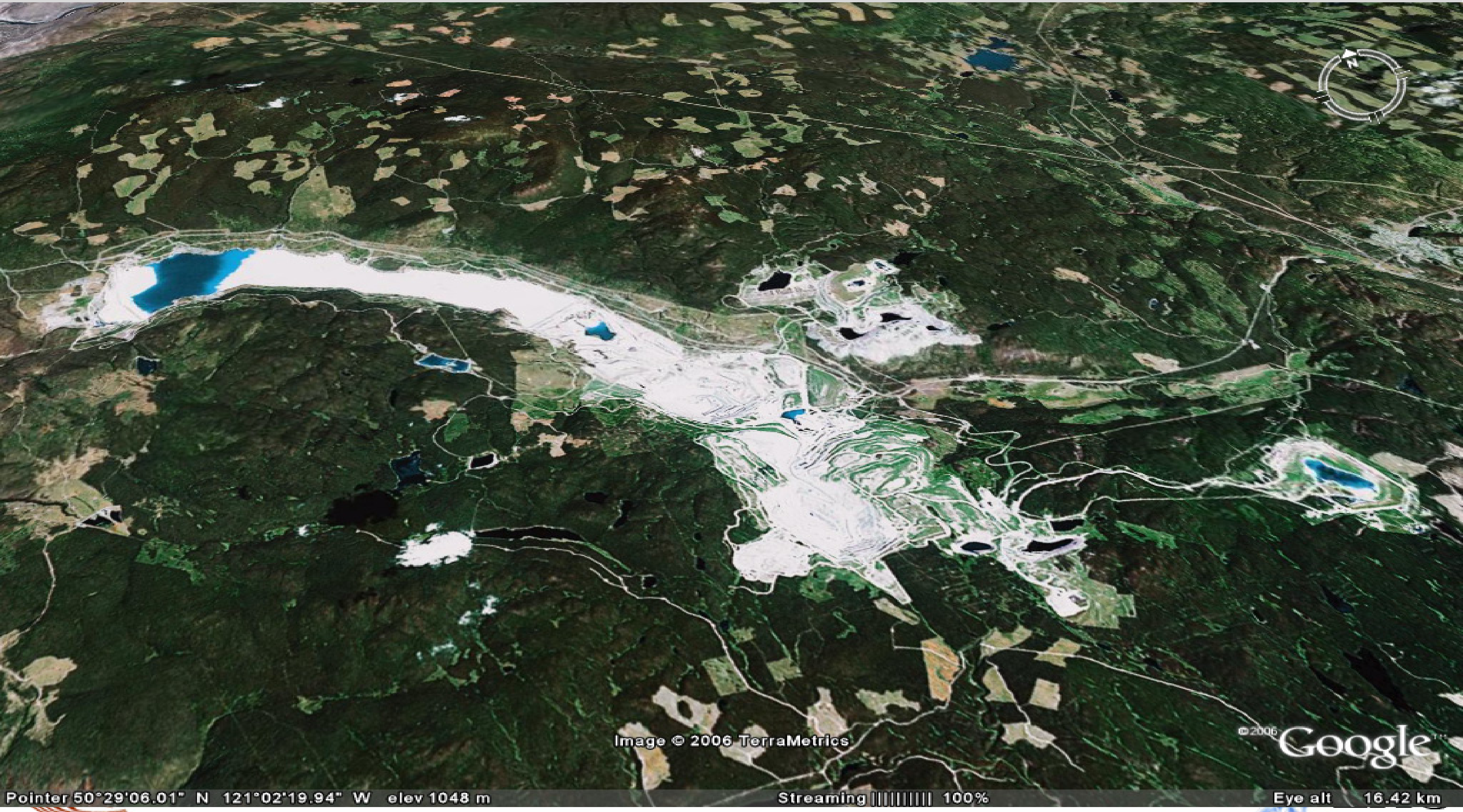
Overcoming Their "Crater Lake" Tendencies

LAC

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

LAC

Molybdenum Leaching

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

- Two possible areas of impacts
  - Vegetation
  - Water

LAC

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

LAC

Bethlehem Pit Lakes

LAC

Highmont Pits

LAC

Valley & Lornex Pits

LAC

Water Management Options

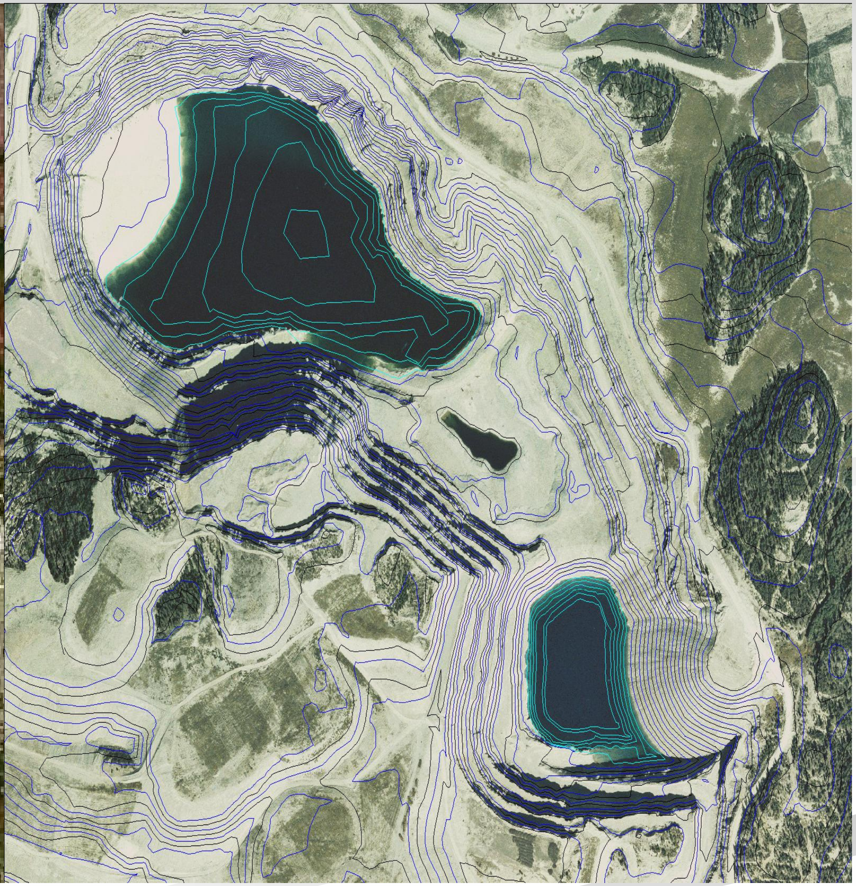
- Conventional Treatment
- Diversion
- Biological Treatment

Using Pit Lakes as Bioreactors Part 2

Overcoming their Crater Lake Tendencies

LAC

Crater Lake | Pit Lake



LAC

Both lakes have crystal-clear fresh water

LAC

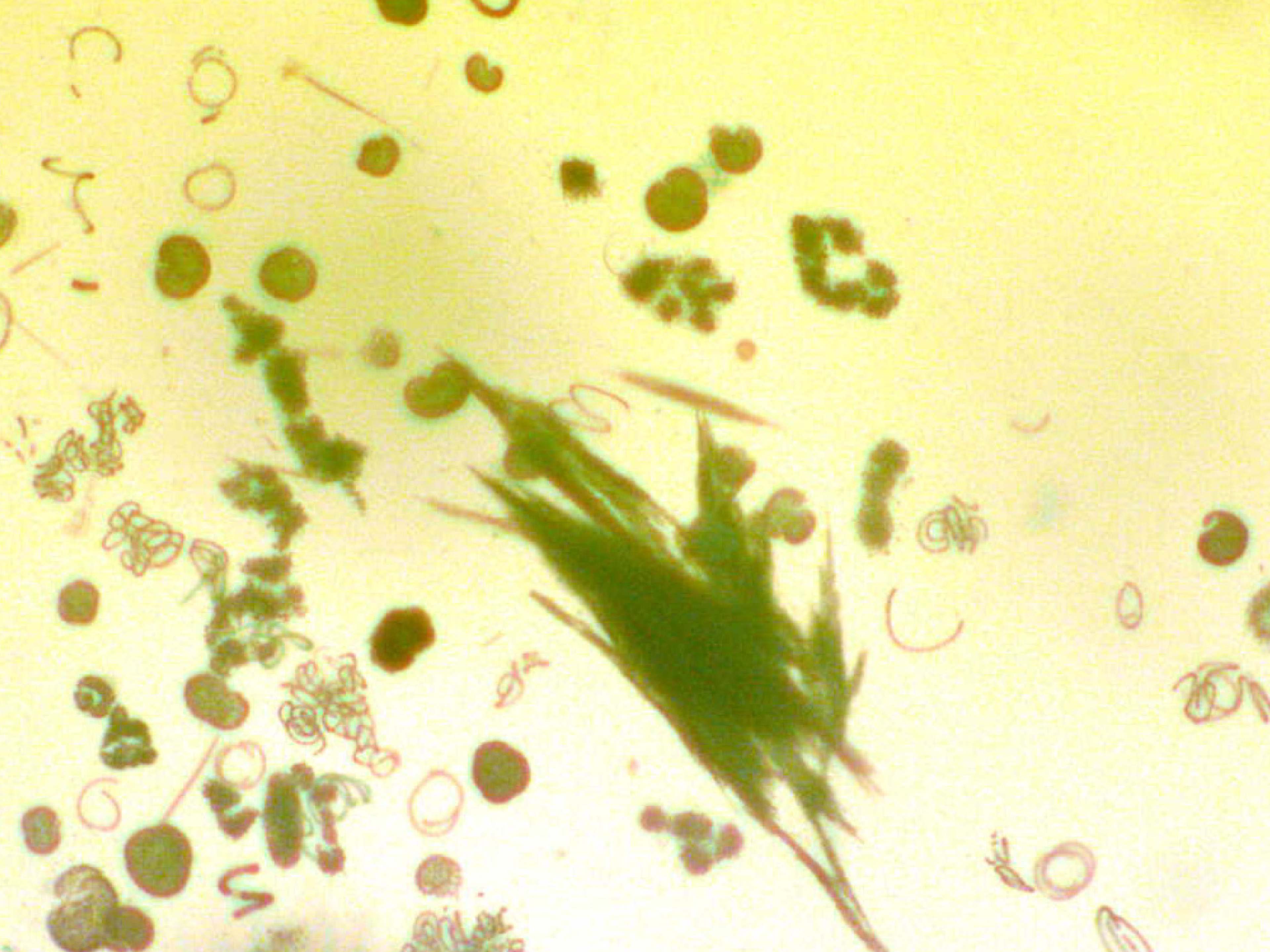
All we at HVC want is:

- 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…

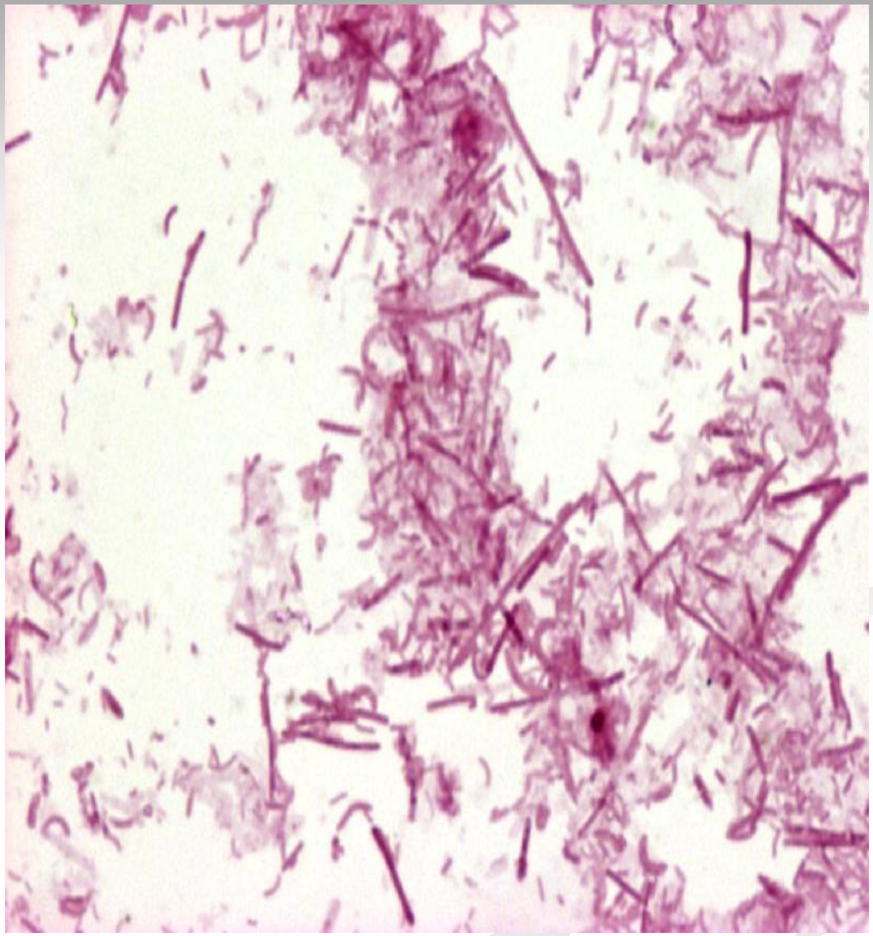
LAC

Type of Particle	Role in Metal Removal
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 -NH_3 -OH groups -metals also attach to cation/anion ligands already attached to the surface of the particles
$CaCO_3$	- Heavy metals and phosphates are adsorbed as calcium carbonate crystals grow. Their large size and therefore small surface area limits the amount of metal $CaCO_3$ 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 portionds of lakes and sediments
Aluminum Silicates Clays, oxides	-Ion exchange, binding of phosphates and metal ions (usually minor)

LAC



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



LAC

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

LAC

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.

LAC

- 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 at producing organic conveyor particulates

Pit lakes share their tendencies.

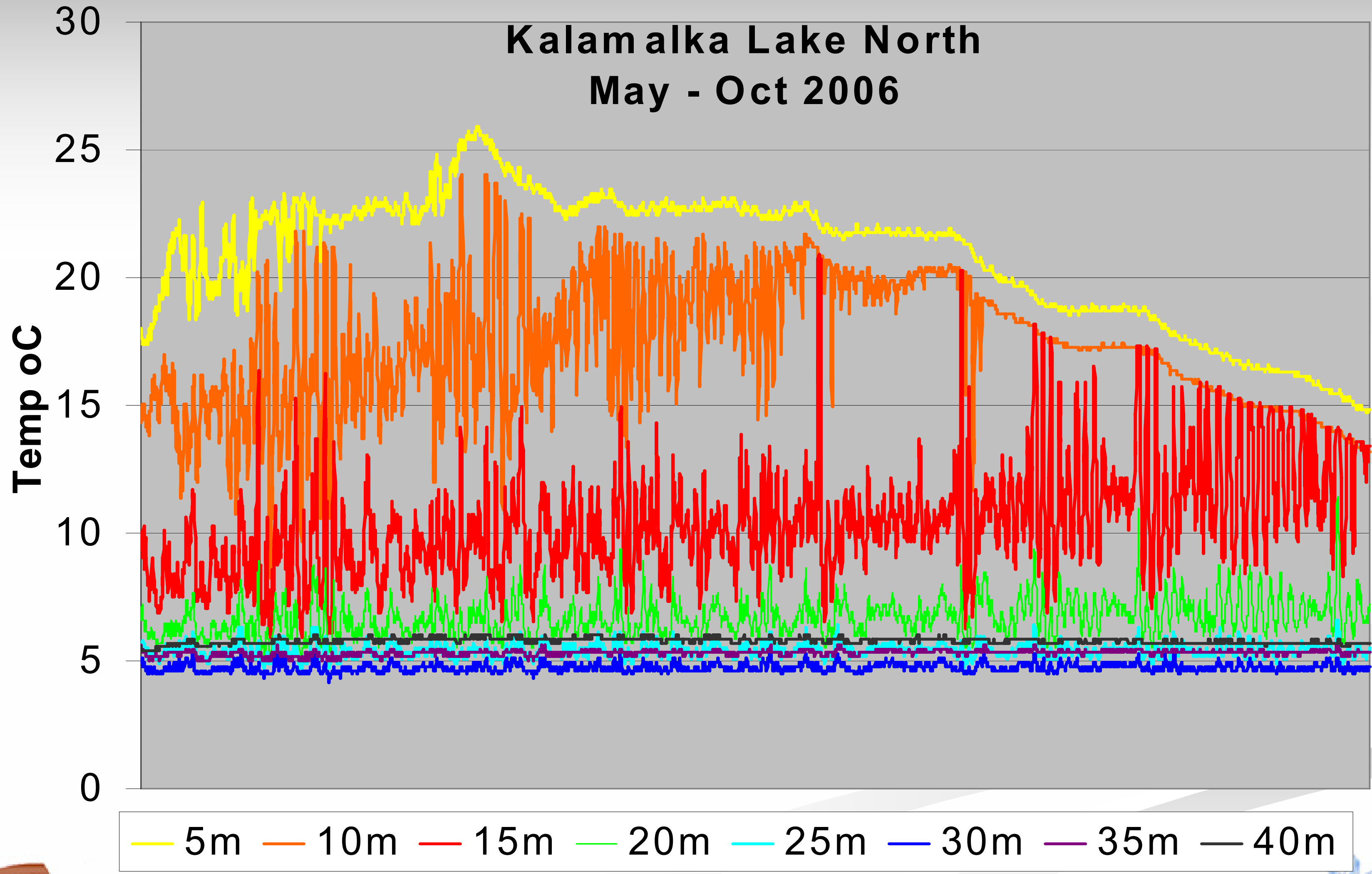
LAC

What are the limitations on crater and pit lake productivity?

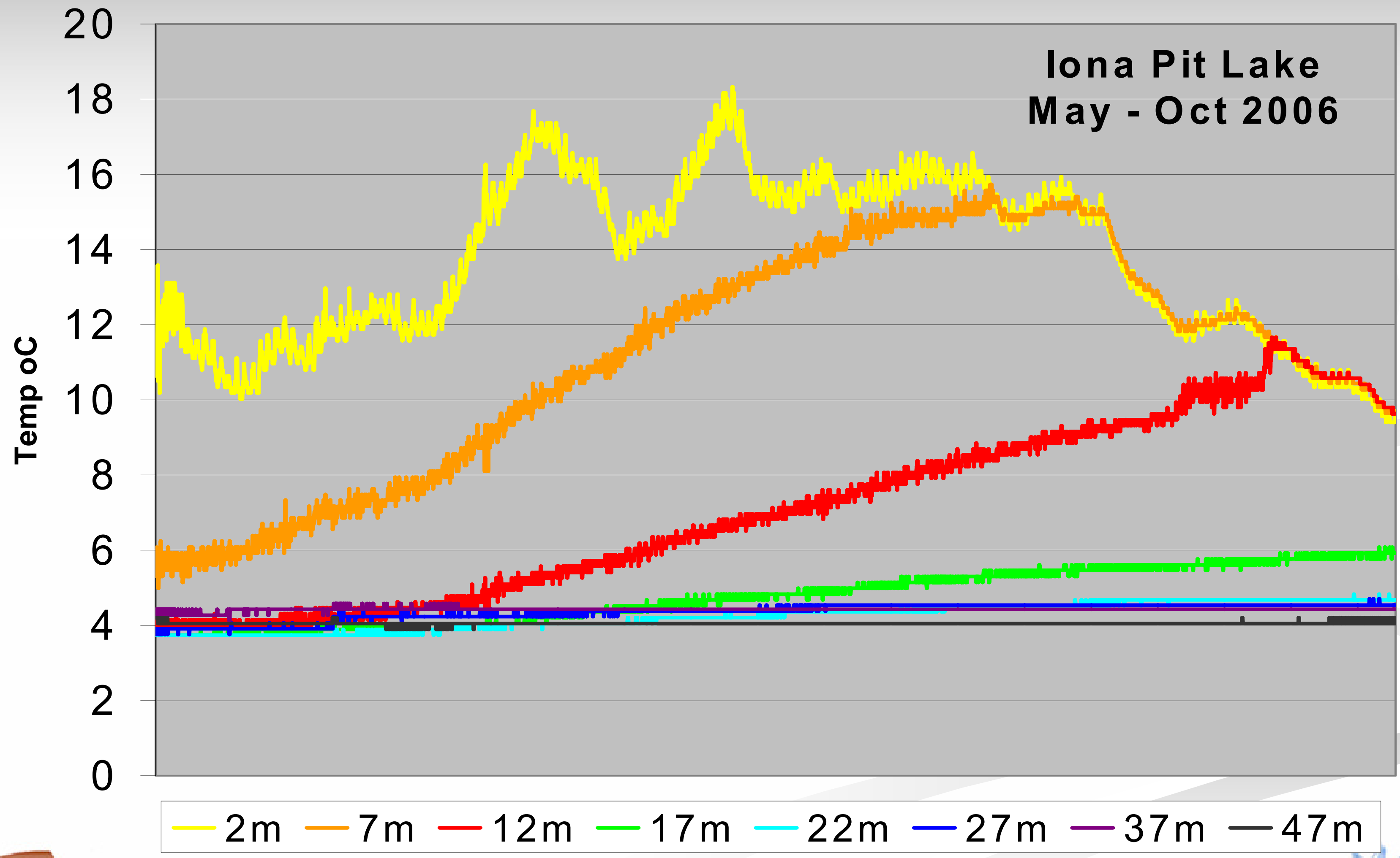
- Major (e.g. N P C Si) and/or minor (e.g. Fe Mn Cu S) nutrient limitations
- Limited substrate-water column interaction due to basin shape
- Limited shoreline for recuitment of benthic/planktonic microflora and growth of rooted aquatic macrophytes
- Lack of turbulence for nutrient upwelling, cell suspension
- Microfloral enzymes denature in excessive sunlight
- Homogenious environment compared to natural lakes thus a restricted potential species pool.

LAC

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:

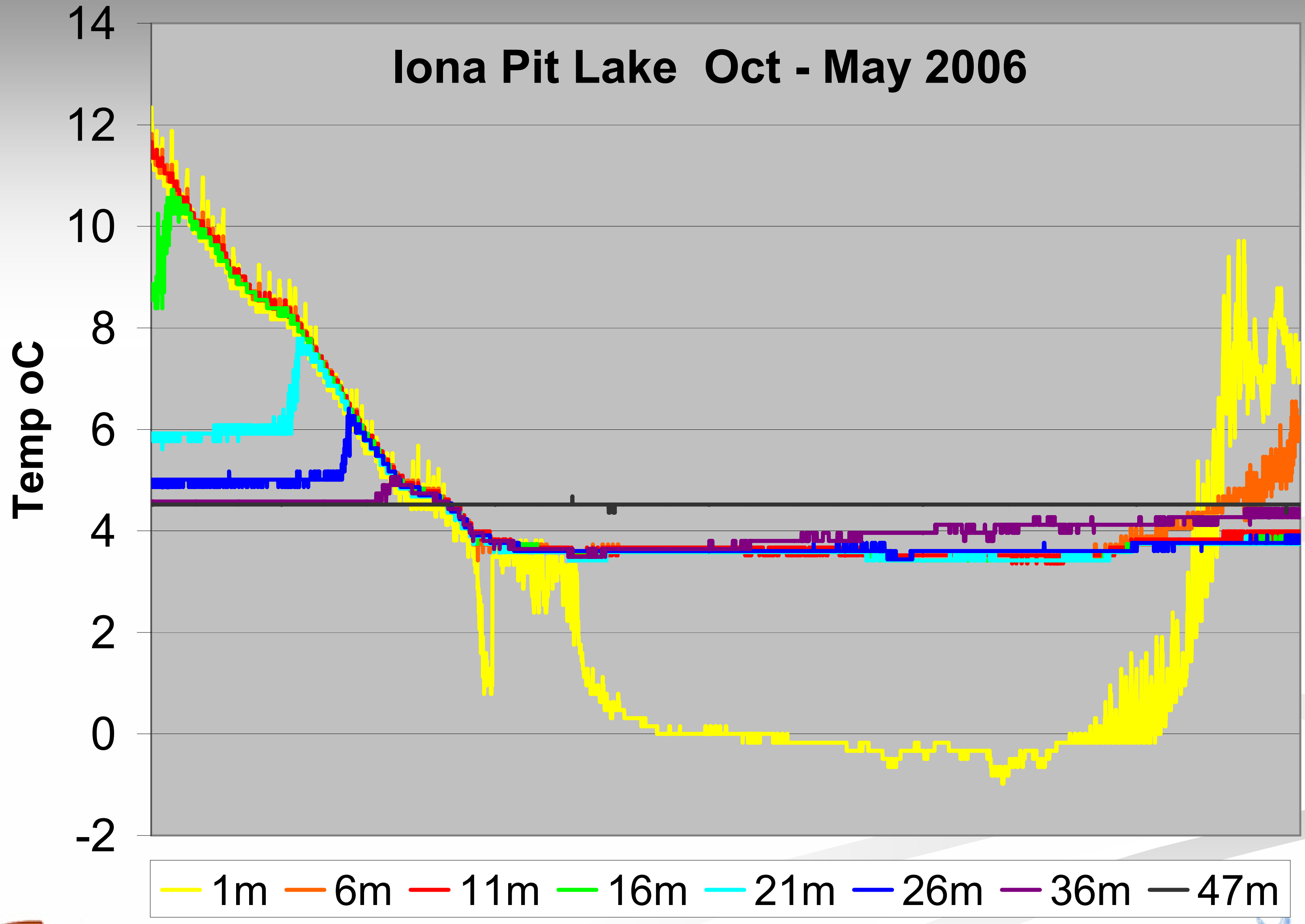
- **Fall Overturn Turbulence** During the fall overturn, turbulent energy fluxes penetrate deep into the hypolimnion, eroding the monimolimnion and potentially re-distributing water throughout the water column, which lowers the developing chemocline.
- **Ice Melt Thermals** In the spring, cold water from freshly melted ice is near the temperature of maximum density (4oC) 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**

LAC

Surface water is transported down with ice melt thermals and with sediment density plumes; upwelling is restricted

LAC



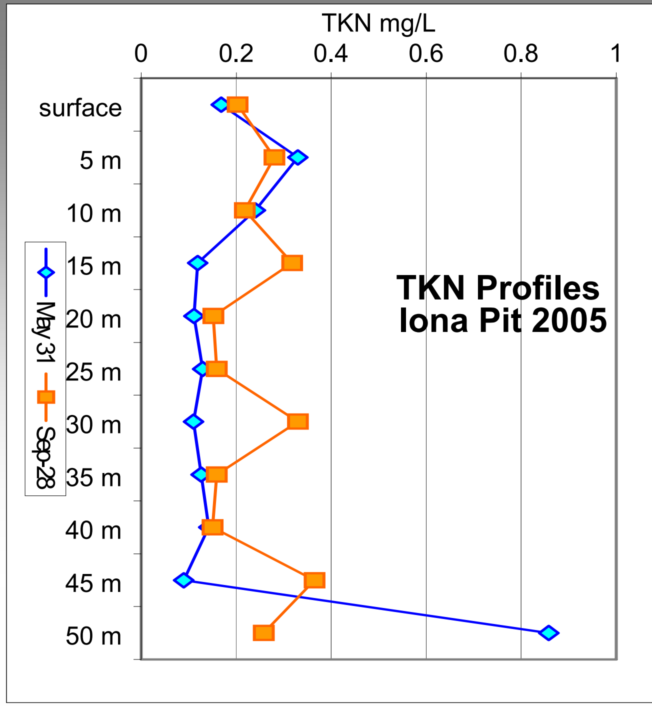
Iona Pit Lake Oct - May 2006
Temp oC
14
12
10
8
6
4
2
0
-2
1m
6m
11m
16m
21m
26m
36m
47m

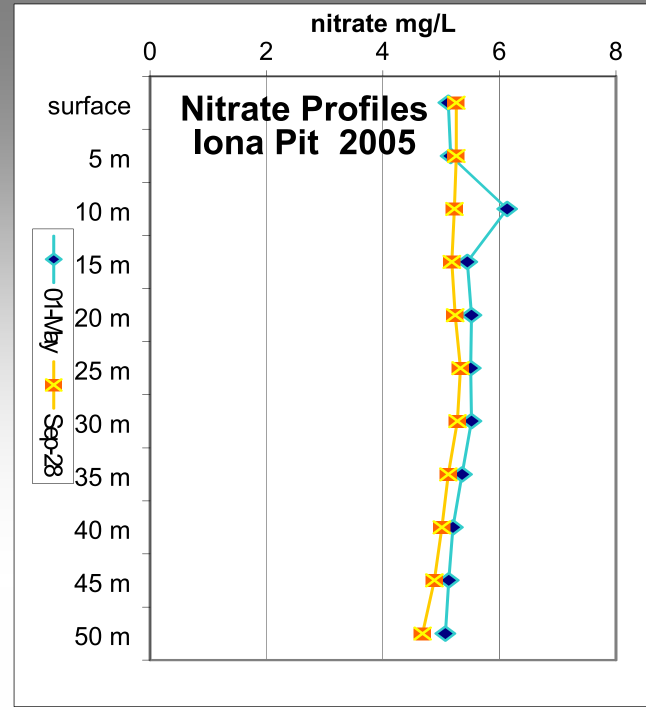
LAC

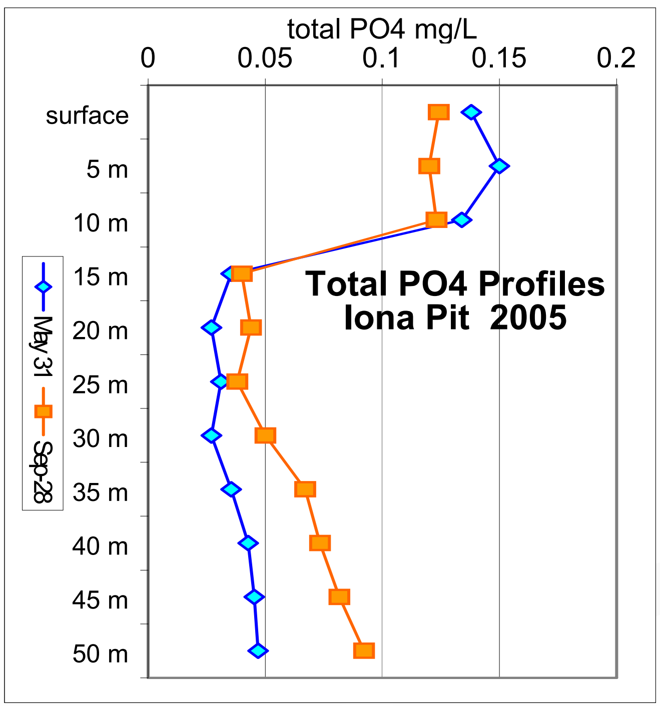
Correcting Iona's Major Nutrient Deficiency

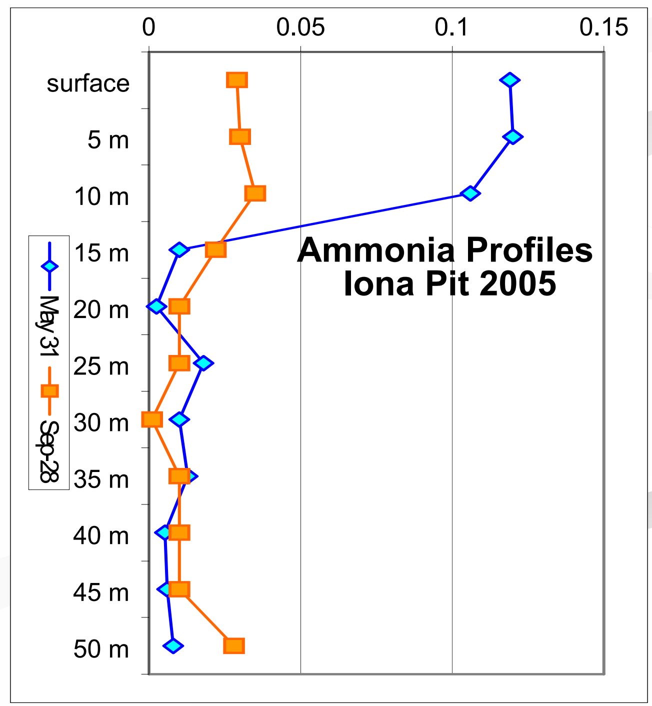
- We used 100 gallons of liquid Agrium 10-34-0 per application
- If ammonia slid below detection we also had liquid 28-0-0 urea + ammonium nitrate
- Low metals GVRD biosolids was also available

LAC


TKN mg/L
0
0.2
0.4
0.6
0.8
1
surface
5 m
10 m
15 m
20 m
25 m
30 m
35 m
40 m
45 m
50 m
May 31
Sep-28
TKN Profiles
Iona Pit 2005


nitrate mg/L
0
2
4
6
8
surface
5 m
10 m
15 m
20 m
25 m
30 m
35 m
40 m
45 m
50 m
01-May
Sep-28
Nitrate Profiles
Iona Pit 2005


total PO4 mg/L
0
0.05
0.1
0.15
0.2
surface
5 m
10 m
15 m
20 m
25 m
30 m
35 m
40 m
45 m
50 m
May 31
Sep-28
Total PO4 Profiles
Iona Pit 2005


0
0.05
0.1
0.15
surface
5 m
10 m
15 m
20 m
25 m
30 m
35 m
40 m
45 m
50 m
May 31
Sep-28
Ammonia Profiles
Iona Pit 2005

LAC

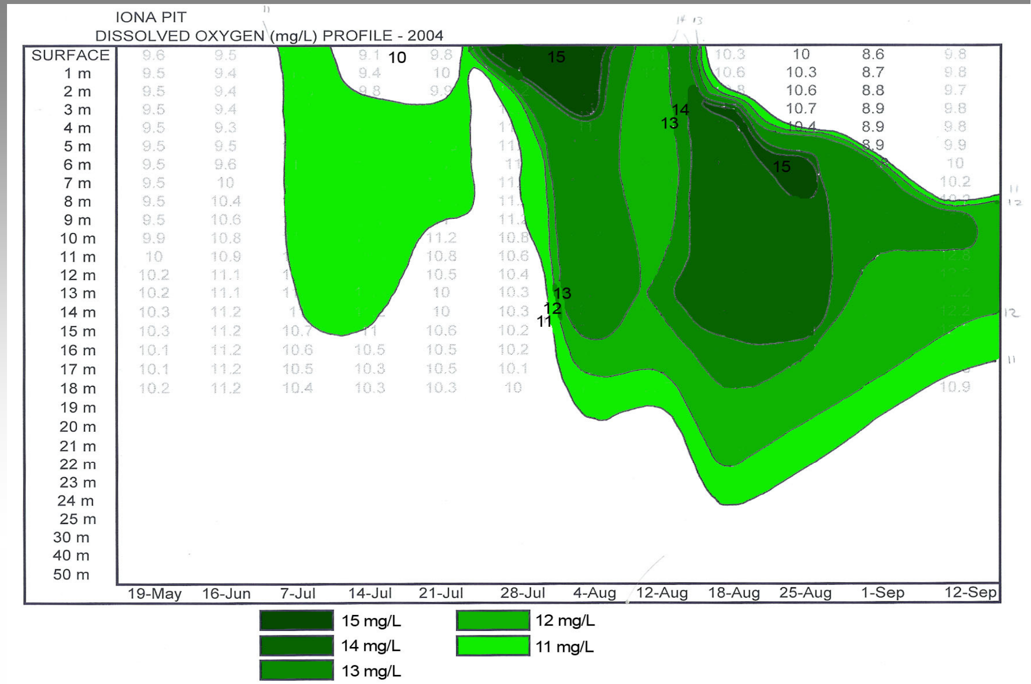
Year One of Iona fertilization

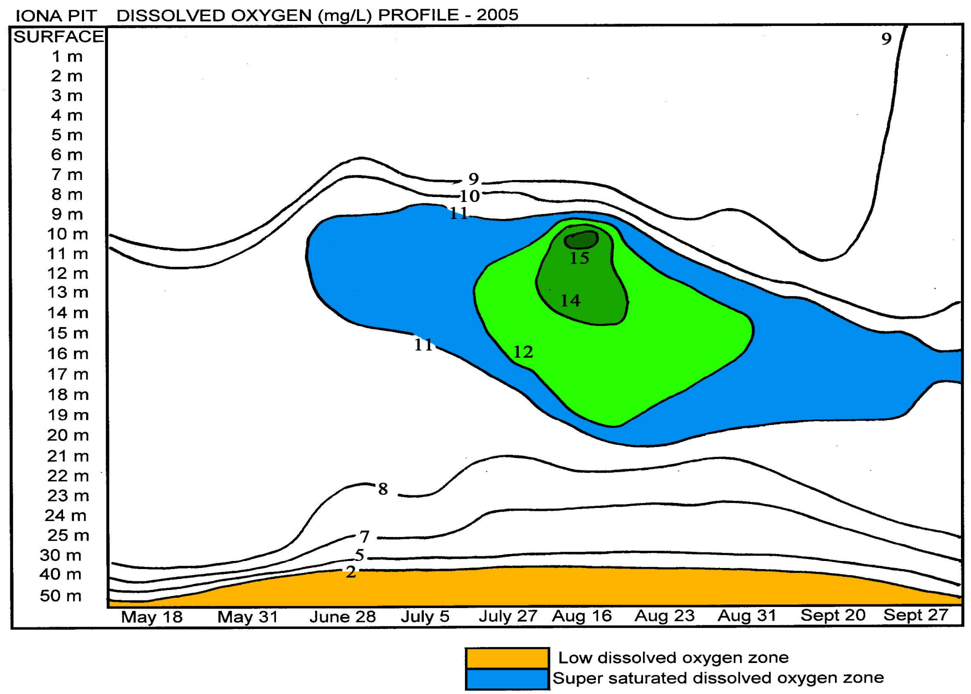
- We got a green flagellate bloom that reached 26 ug/L chlor-a and lasted all summer. When it collapsed and sank to the bottom, the cells continued to live and were still viable during the following spring

LAC

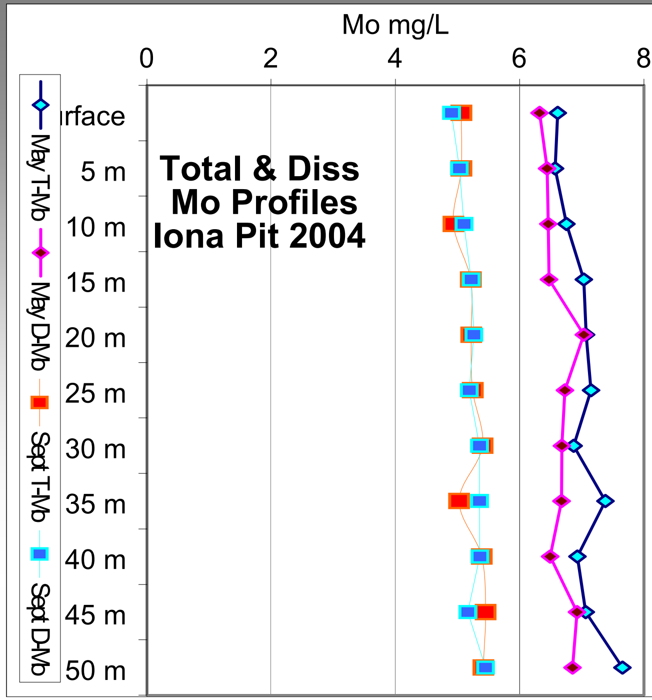
Dissolved Oxygen Profiles 2004 & 2005

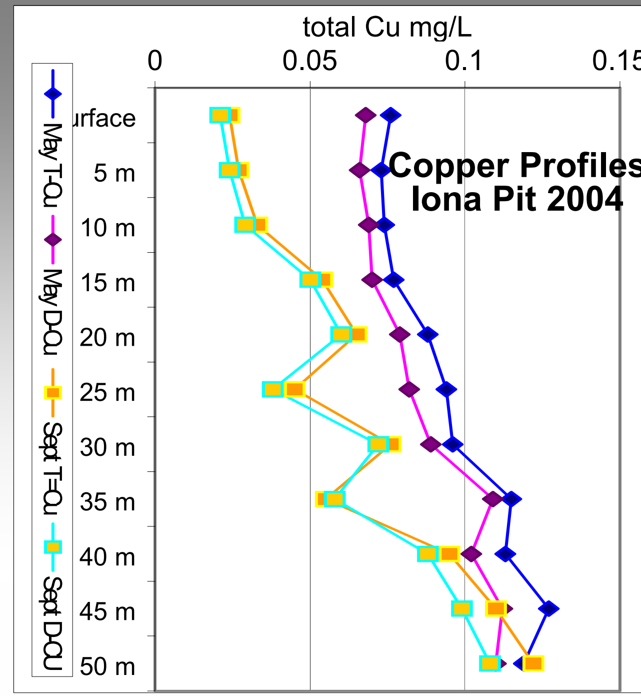
- The upper 2004 graph shows oxygen super-saturation during the first-year bloom
- The lower 2005 graph shows a much smaller bloom below the thermocline. Note the small anoxic zone in the bottom water

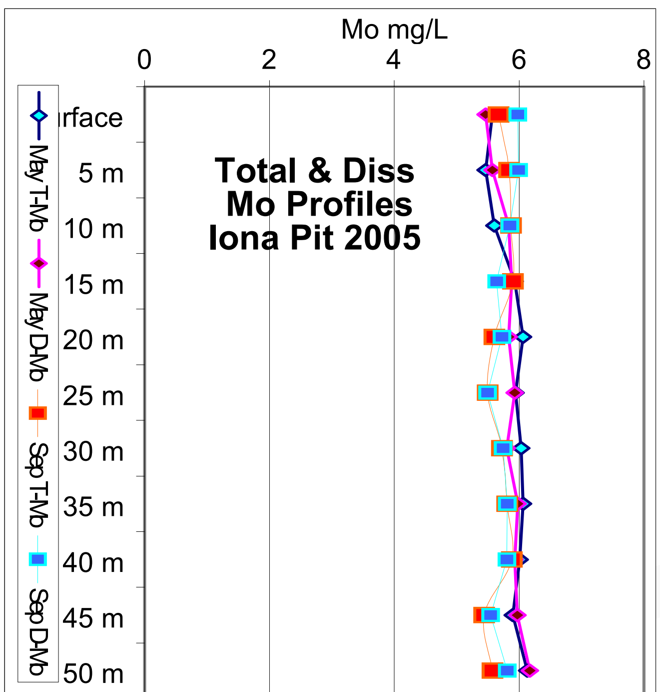


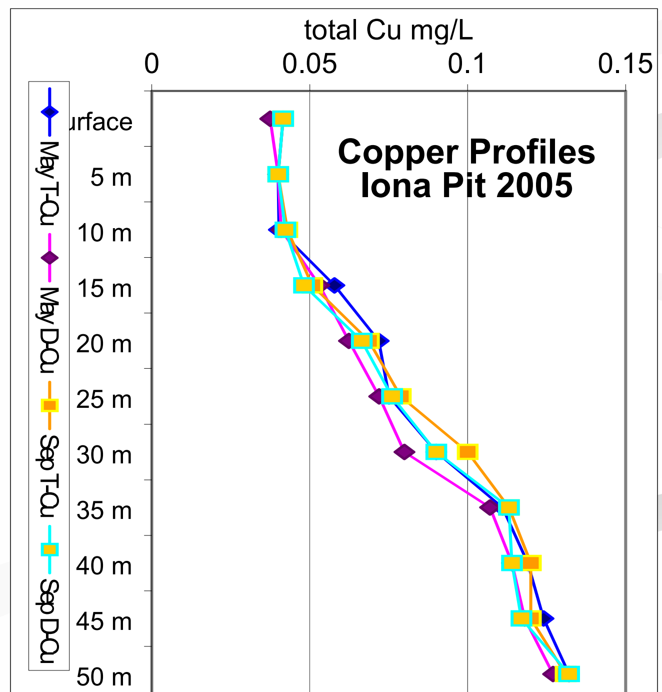


- Water quality profiles were collected in the spring and fall to bracket the growing season.
- There was a measurable removal of aqueous N, Mo, Cu, Ca, Si and Na with the 2004 Iona algae+bacteria bloom.
- All nutrients were in luxurious supply again in 2005 but no bloom and no metal removal resulted.

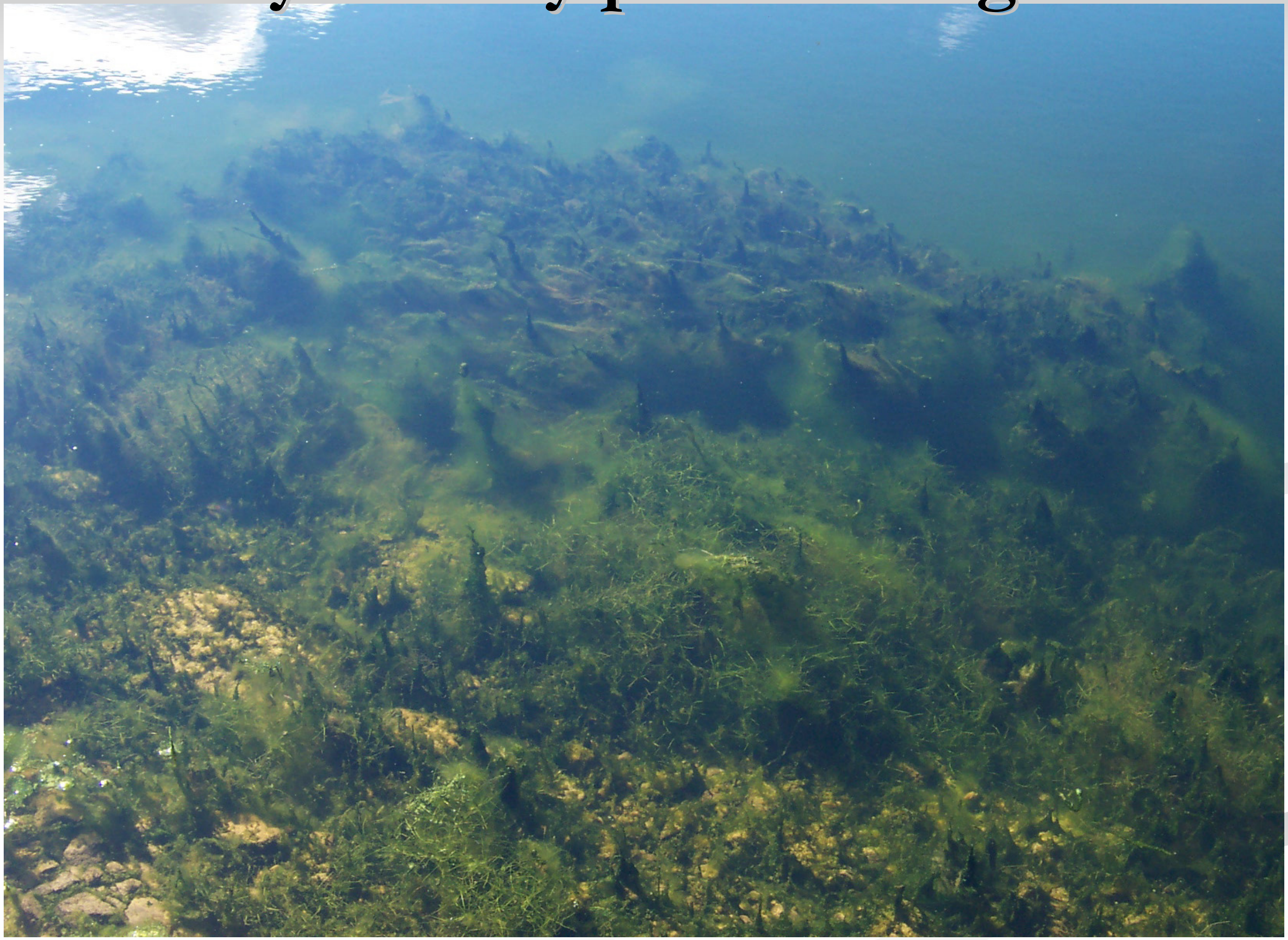

Mo mg/L
0
2
4
6
8
Total & Diss
Mo Profiles
Iona Pit 2004
urface
5 m
10 m
15 m
20 m
25 m
30 m
35 m
40 m
45 m
50 m
May T-Mo
May D-Mo
Sept T-Mo
Sept D-Mo


total Cu mg/L
0
0.05
0.1
0.15
Copper Profiles
Iona Pit 2004
urface
5 m
10 m
15 m
20 m
25 m
30 m
35 m
40 m
45 m
50 m
May T-Cu
May D-Cu
Sept T-Cu
Sept D-Cu

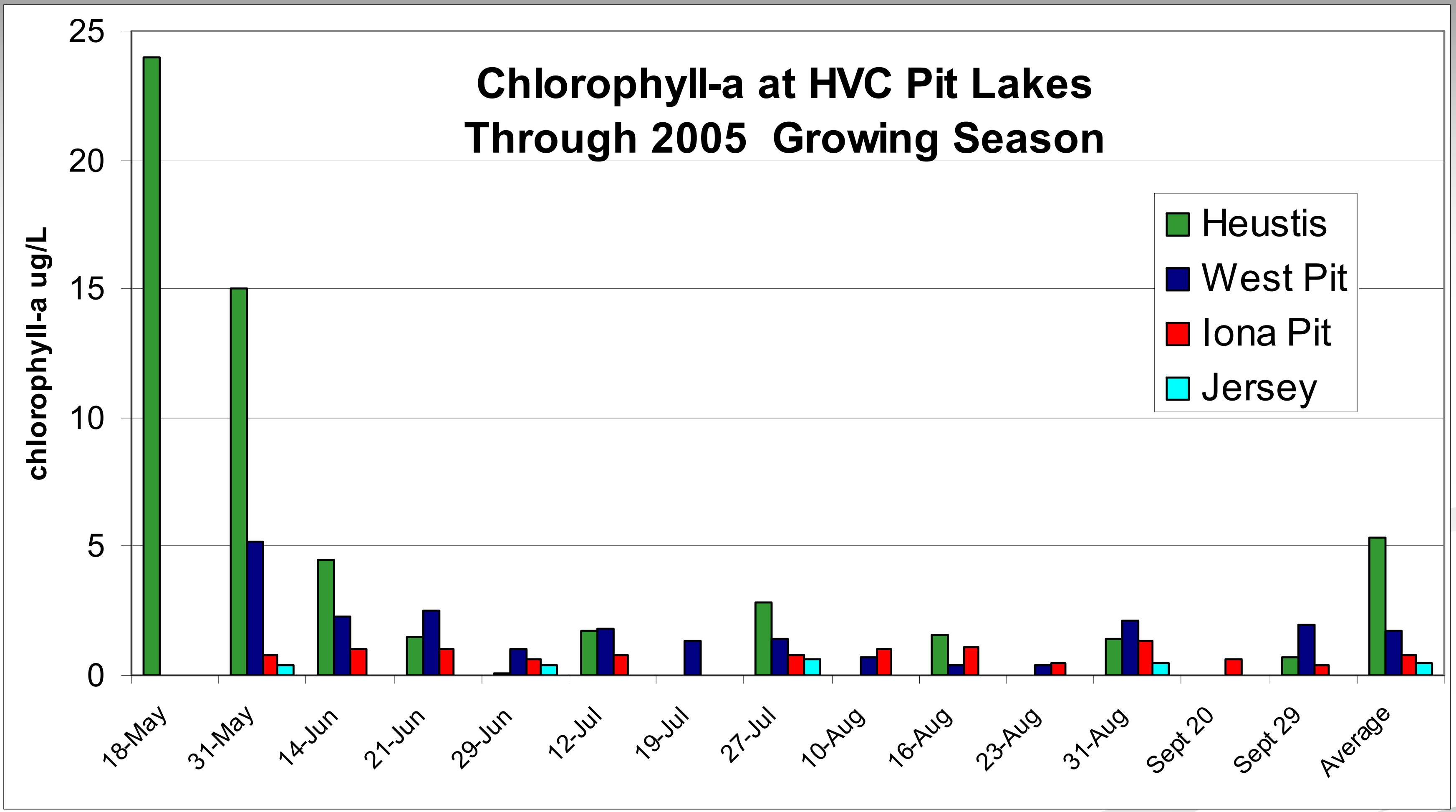

Mo mg/L
0
2
4
6
8
Total & Diss
Mo Profiles
Iona Pit 2005
urface
5 m
10 m
15 m
20 m
25 m
30 m
35 m
40 m
45 m
50 m
May T-Mo
May D-Mo
Sep T-Mo
Sep D-Mo


total Cu mg/L
0
0.05
0.1
0.15
Copper Profiles
Iona Pit 2005
urface
5 m
10 m
15 m
20 m
25 m
30 m
35 m
40 m
45 m
50 m
May T-Cu
May D-Cu
Sep T-Cu
Sep D-Cu

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…

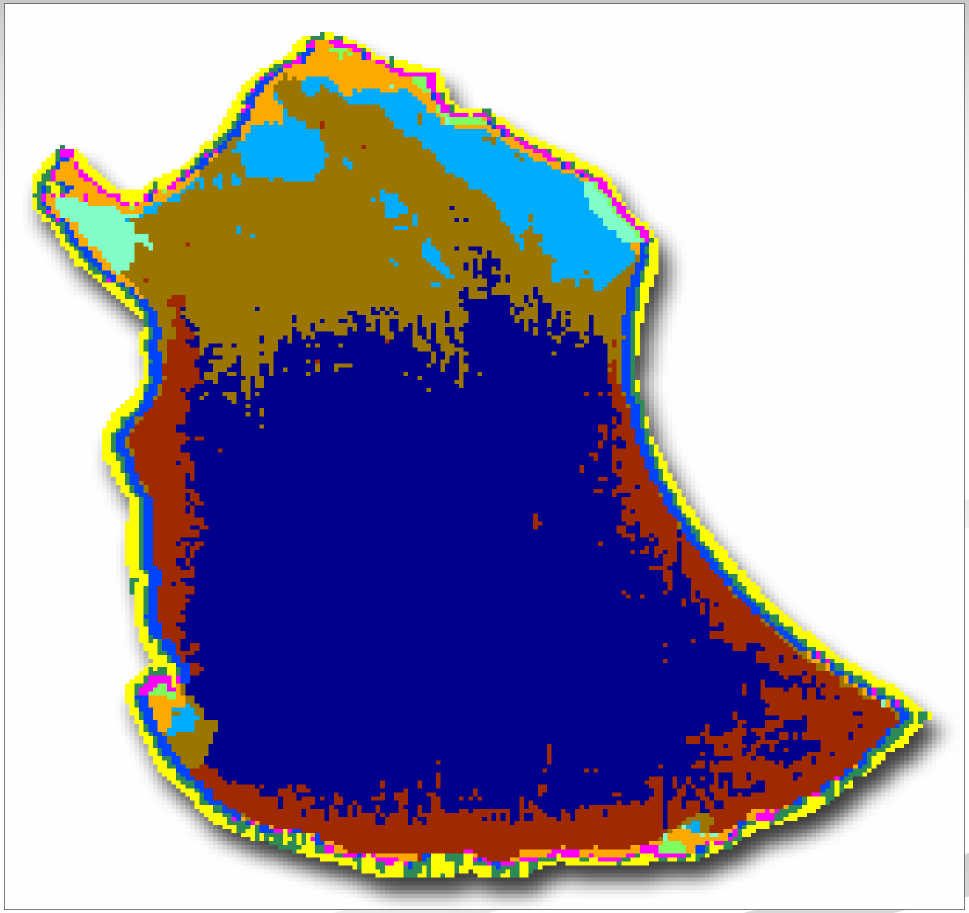


LAC


Chlorophyll-a at HVC Pit Lakes
Through 2005 Growing Season
chlorophyll-a ug/L
25
20
15
10
5
0
Heustis
West Pit
Iona Pit
Jersey
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

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



(After Borstad)

LAC

Heustis spring bloom 2006

(Dactylococcopsis   Chlorella   flagellates)

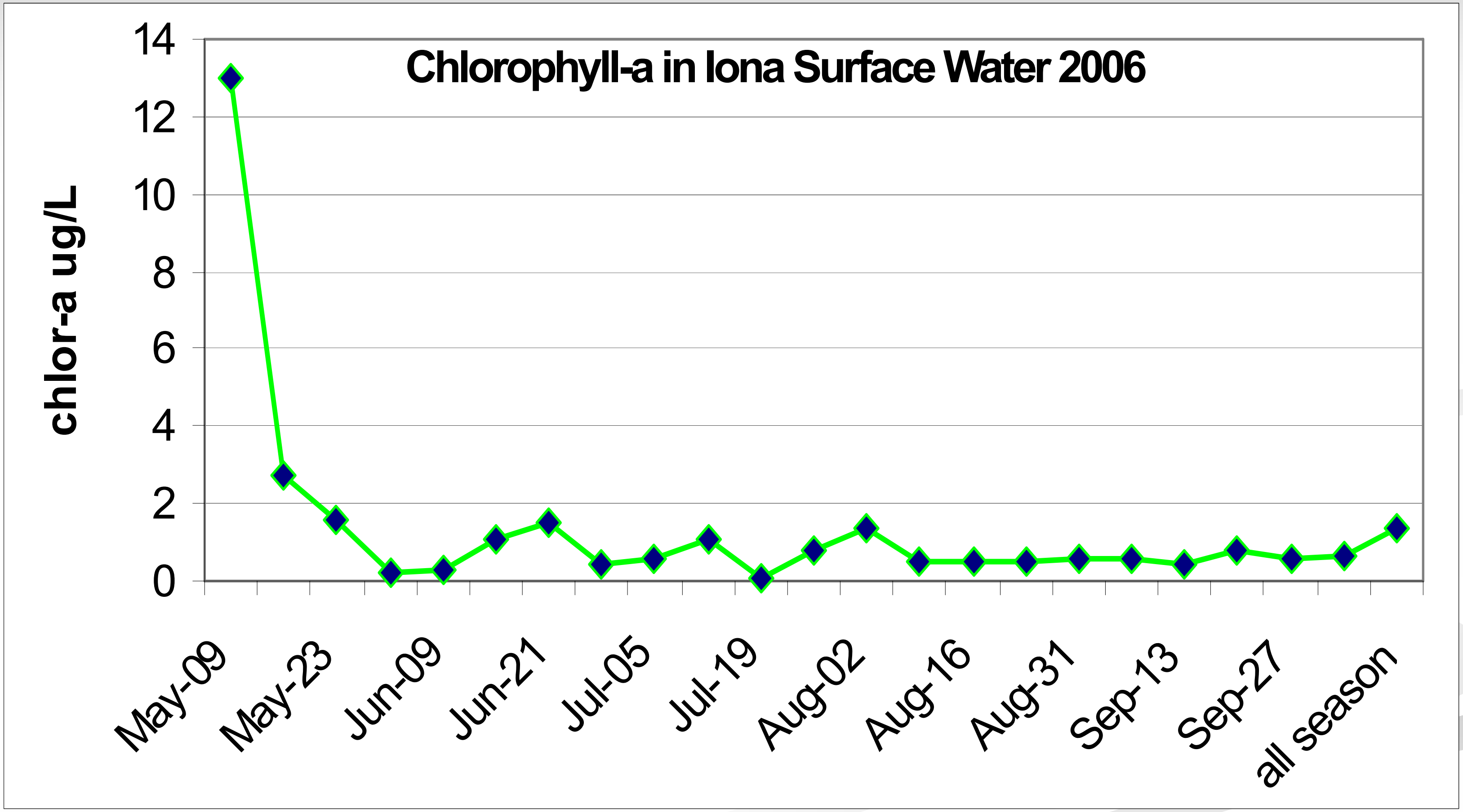
LAC

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

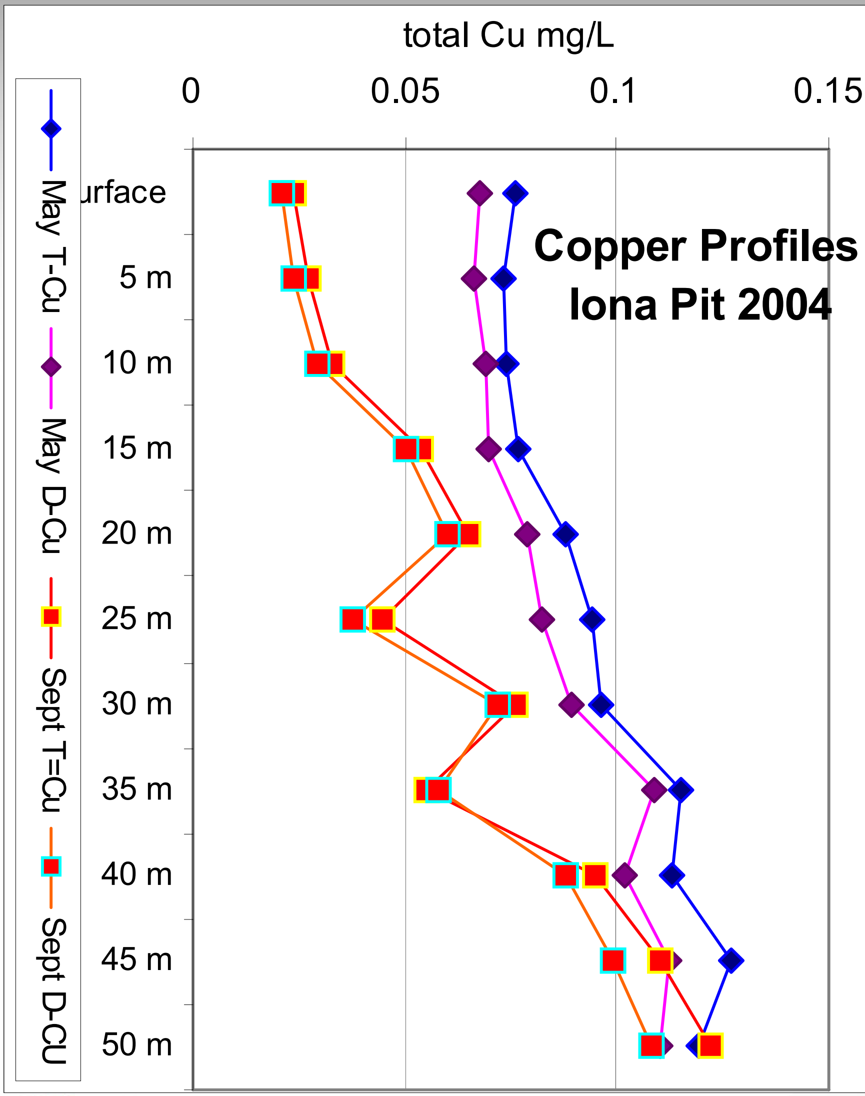
LAC

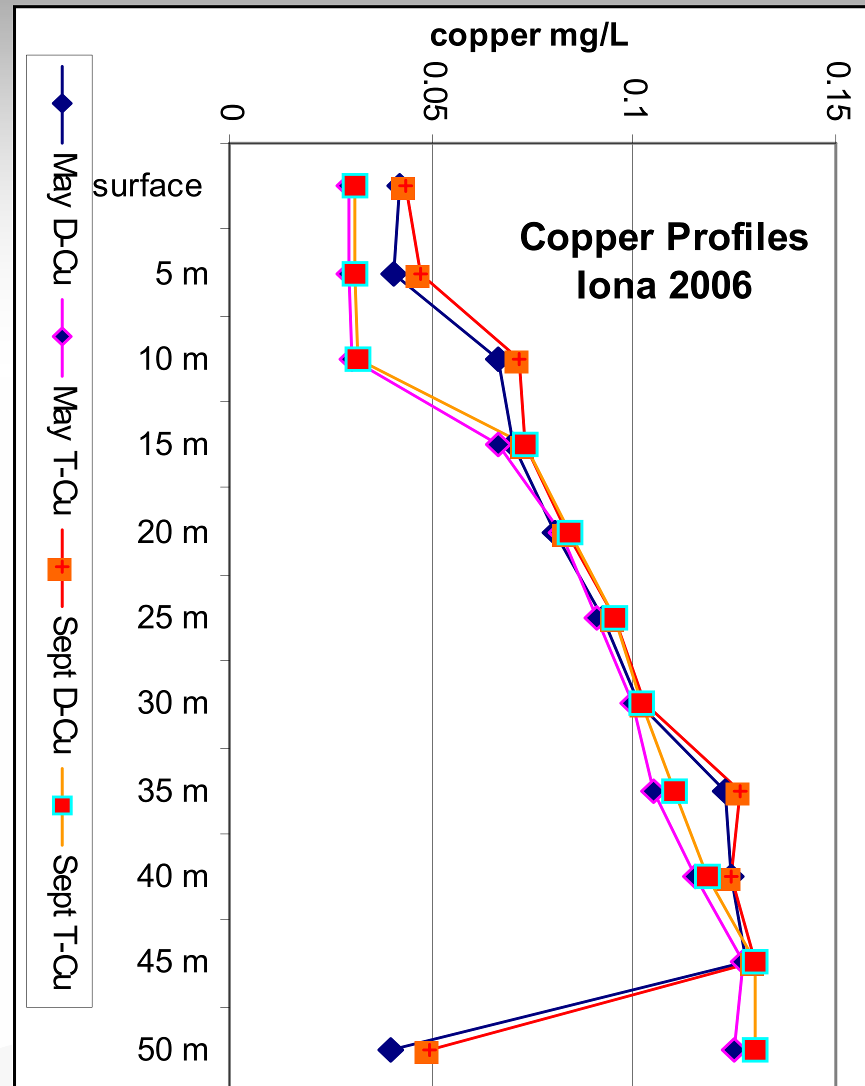
Small flagellate bloom in Iona Pit Lake, May 2006.



LAC

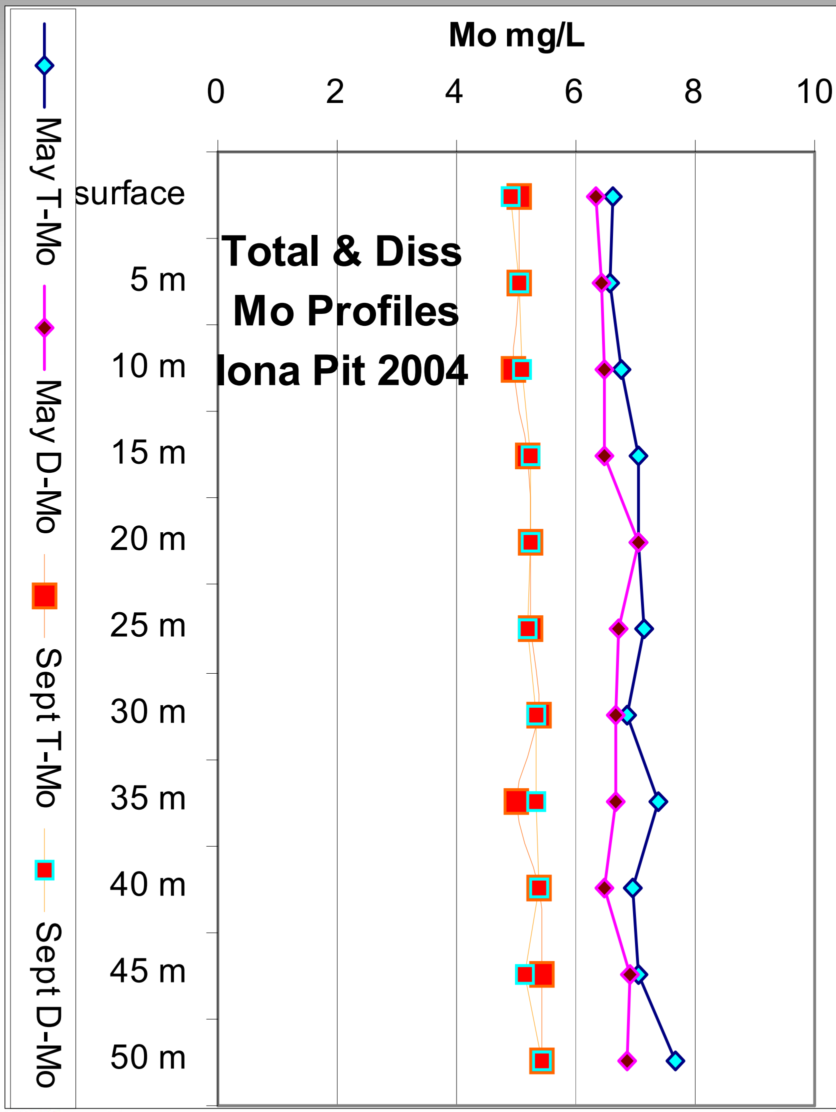
Copper Profiles in Iona Pit Lake 2004 & 2006

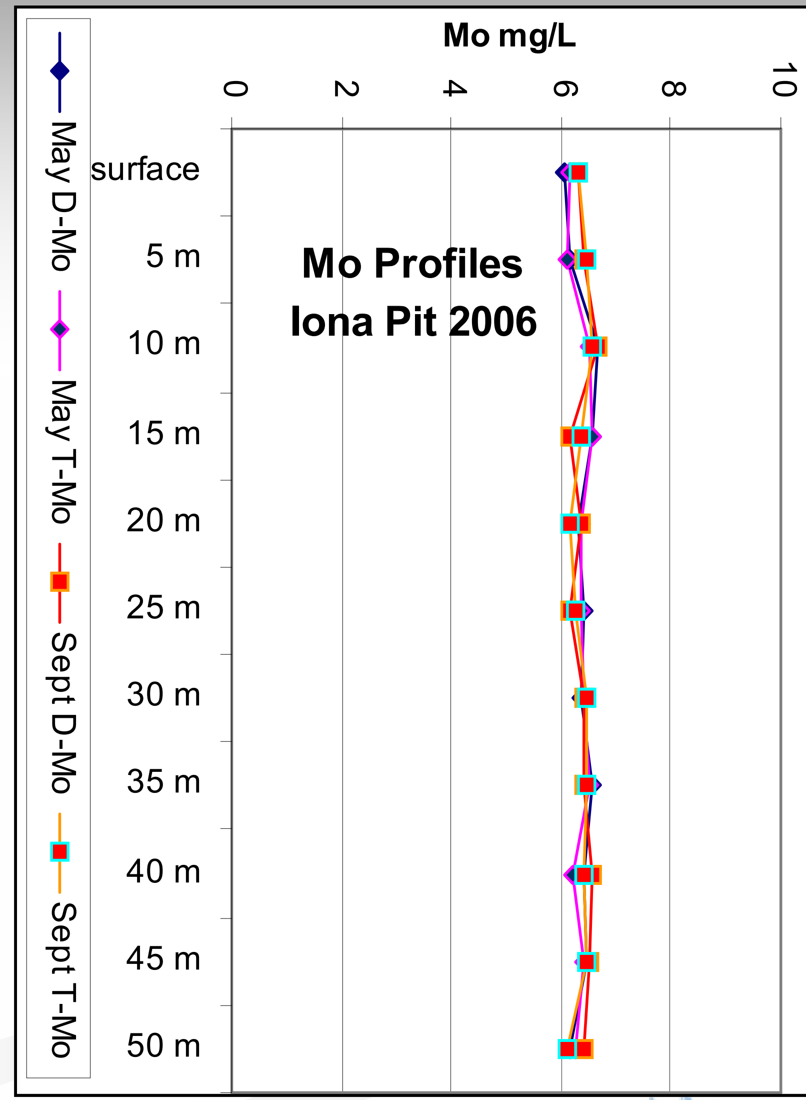




LAC

Molybdenum Profiles in Iona Pit Lake 2004 & 2006





LAC

HVC Container Studies

The Missing Piece

- Many algae supplement their growth by taking in organic substrates, particularly the made-by bacteria B vitamins: B12, thiamine and biotin.
- Adsoprtion 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…

LAC

Iona Containers Summer 2006

LAC

Iona Containers Oct. 2006

LAC

2006 Iona Container Study

Type of Addition	Chlor-a ug/ ug/L	cell count cell/mL	# species
Iona Spring (peak)	12	1700	5
Iona Summer/Fall	0.7	50	3
Fertilizer + Innoculation	37	1300	19
Mud + Fertilizer	23.4	255	9
Biosolids	405	3500	7
Biosolids + Compost	1350	4700	5
Whole Egg	497	5,000	5
Egg Yolk	550	3,000	4
Egg White	(bacteria)	55	2
Vitamin B12	348	4000	6
Multi-vitamin pill	160	4000	6

LAC

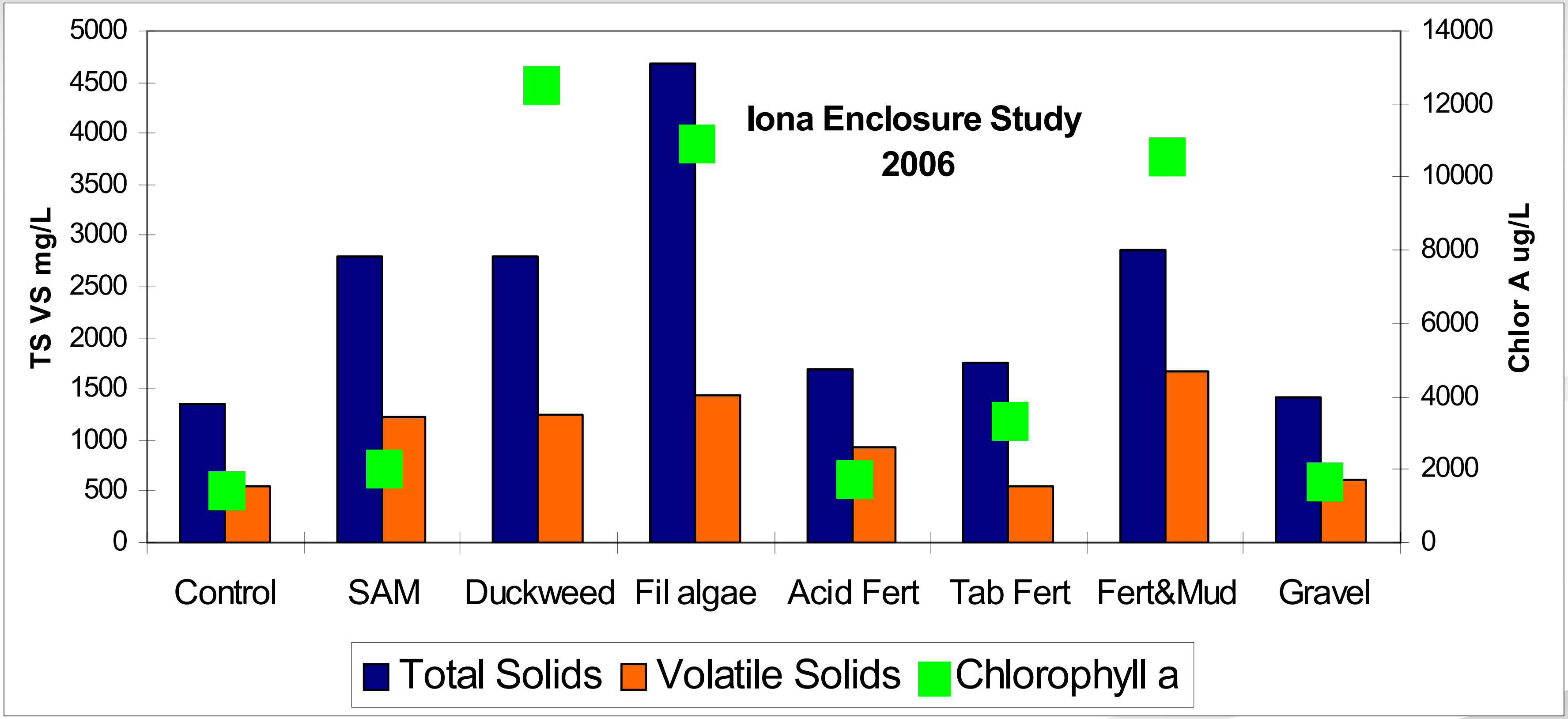
Iona Enclosures

LAC

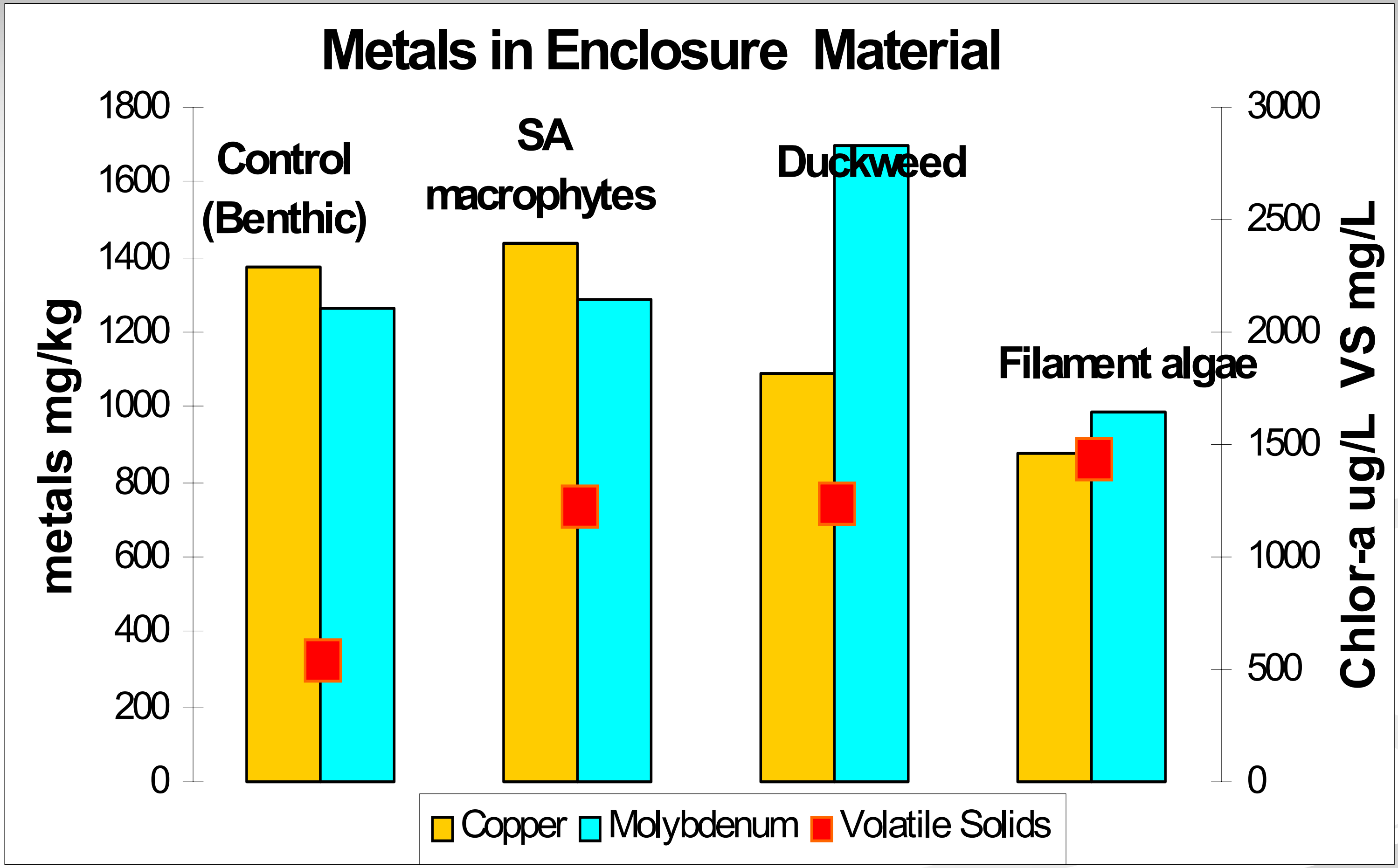
Enclosures hosted 16 different types of algae as well as bacteria and fungi on the walls of the enclosures and on the additions

LAC

Material Collected from the Iona Enclosures 2006



LAC


Metals in Enclosure Material
metals mg/kg
Chlor-a ug/L VS mg/L
1800
1600
1400
1200
1000
800
600
400
200
0
3000
2500
2000
1500
1000
500
0
Control (Benthic)
SA macrophytes
Duckweed
Filament algae
Copper
Molybdenum
Volatile Solids

Introduced Substrates

(collectively grew 17 algal species)

LAC

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.

LAC

- 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.

LAC

- 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.

LAC

Solution to Craterish Pit Lakes
#1: add artificial upwelling

LAC

Solution #2: Diversify your habitats: add nutrients, plants & substrates

Benthic microflora / Aquatic macrophytes / Duckweed

LAC

Solution #3: Add B vitamins