Biogeochemical Treatment of ARD at the Island Copper Mine Pit Lake

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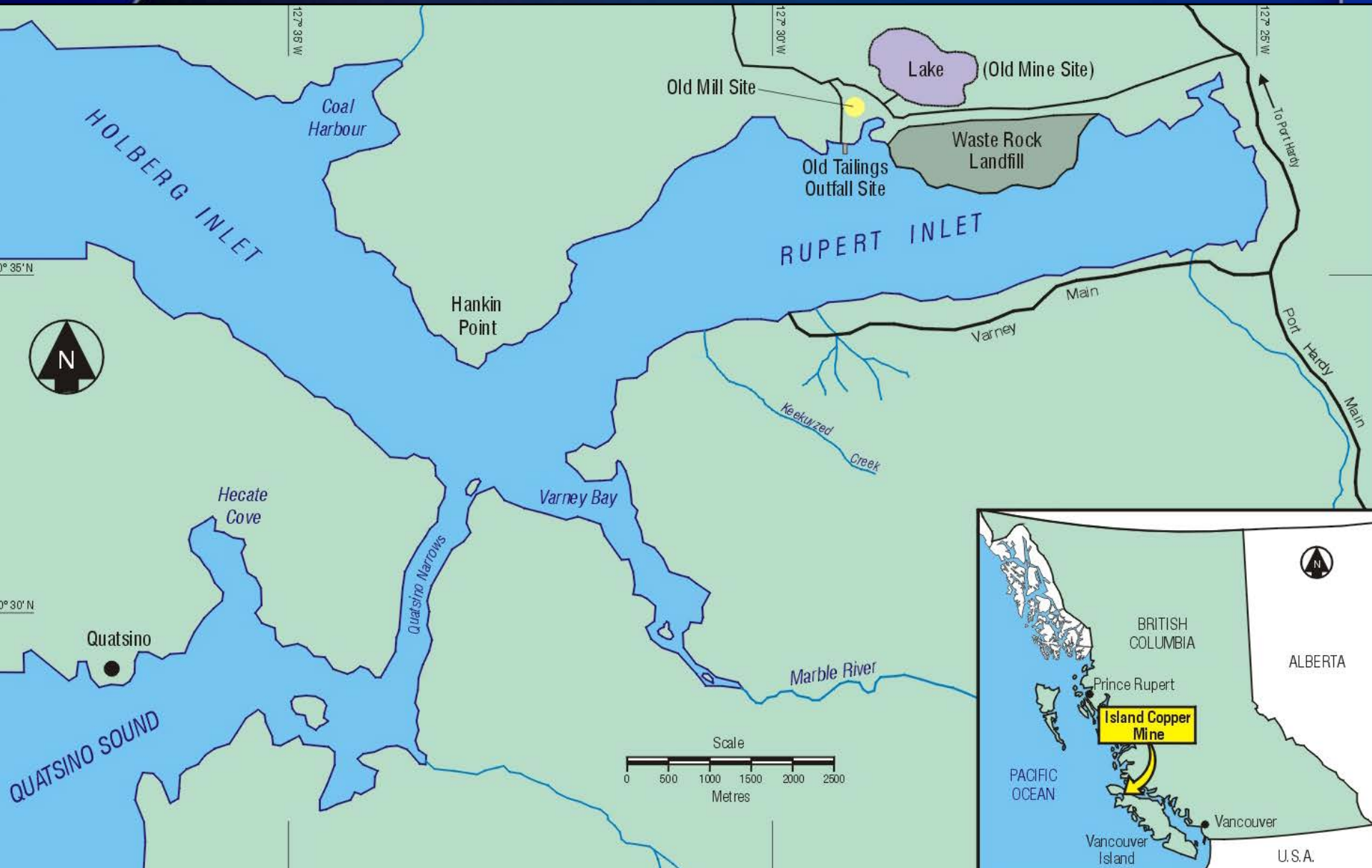
Rupert Inlet and Island Copper Mine Site



Island Copper Mine

Open Pit Closure:

- Approved closure plan included filling open pit with seawater to control ARD from pit walls.
- Open pit was filled with seawater to approximately 30 meters from the top and a freshwater cap was allowed to develop.
- Pit Lake to become a passive treatment for run-off coming from the land waste rock dumps.
- Pit flooding was completed in July 1996 over a period of approximately 30 days.

ICM - Pit Infilling, July 1996

ICM Mine Site - Summer 1999

ICM – ARD Qualities (Avg. Quarterly Values during 2001)*

		NIS	SIS
pH		7 – 8	4 – 5
SO_4	ppm	400 – 700	1,200 – 1,600
Ca	ppm	140 – 230	280 – 410
Mg	ppm	20 – 35	60 – 100
Cu	ppm	0.012 – 0.023	0.320 – 1.3
Zn	ppm	1.1 – 2.4	4.8 – 7.3
Cd	ppm	0.007 – 0.014	0.016 – 0.035
Mo	ppm	0.008 – 0.012	0.0005 – 0.001

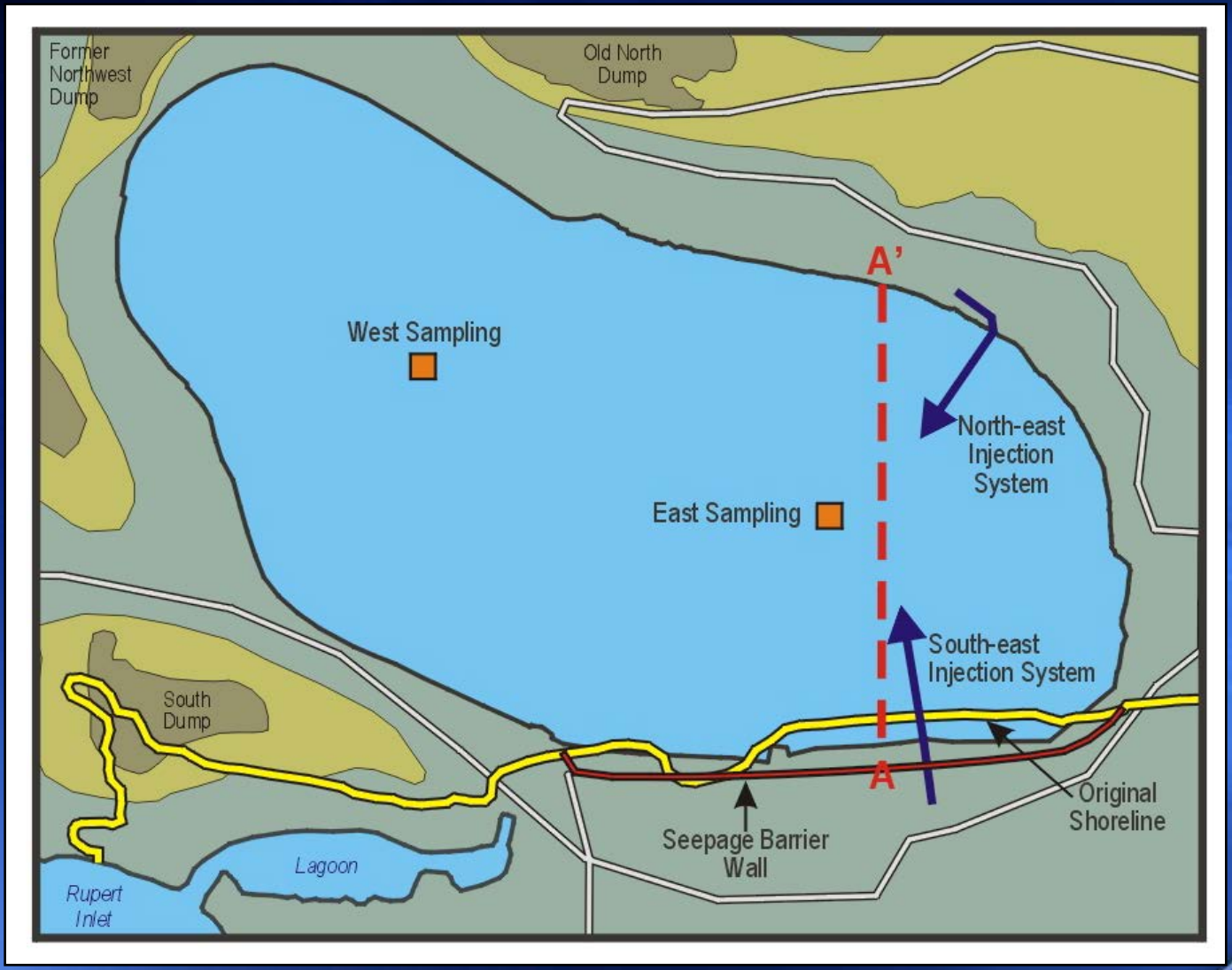
* Island Copper Mine Annual Environmental Assessment Report

Pit Lake Basic Physical Parameters

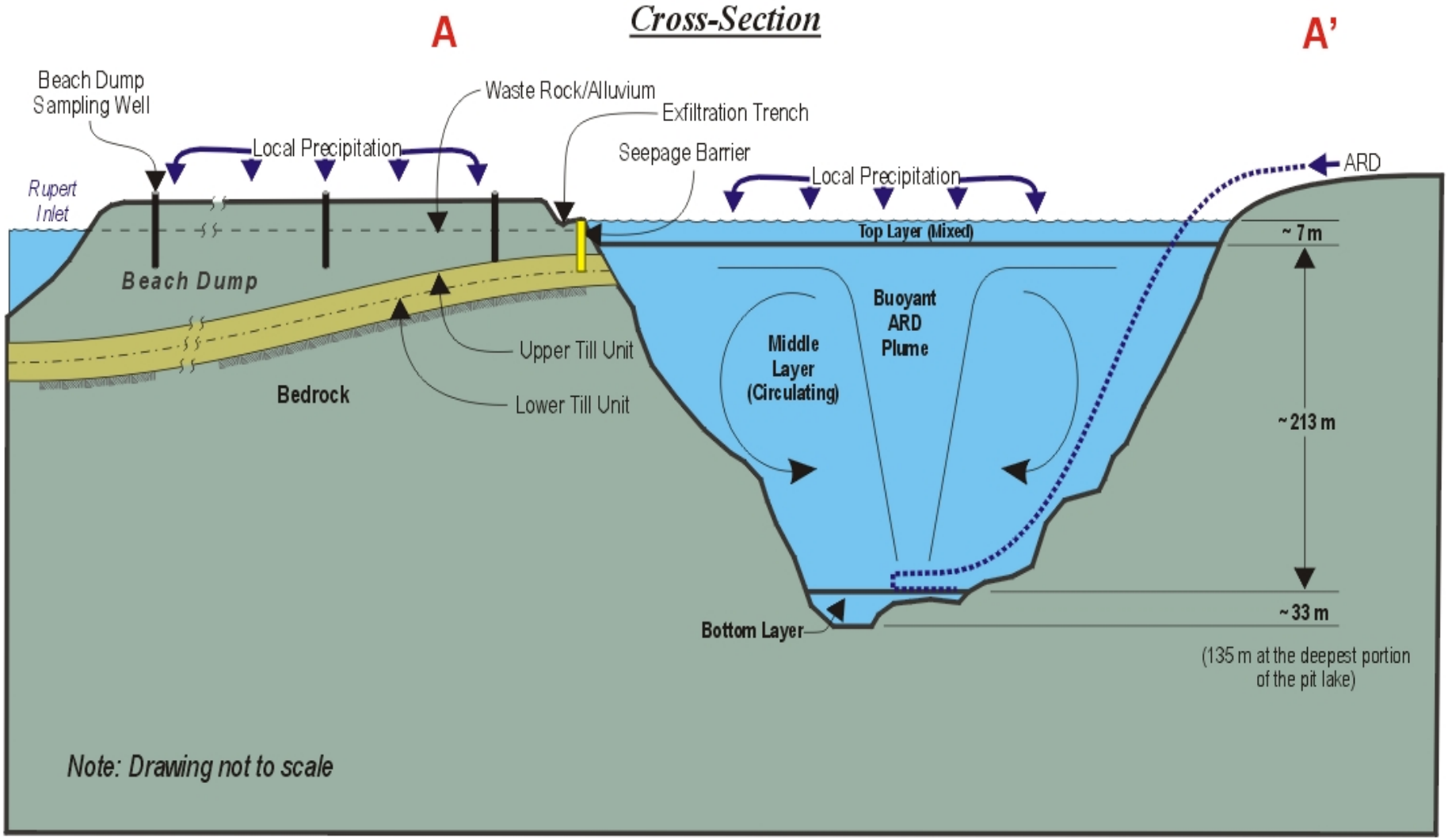
BASIC DATA

Approximate total water volume of lake		**241,000,000 m^3**
Surface area of pit lake		**1,720,000 m^2**
Volume of top brackish layer (current at 8M depth)		**13,760,000 m^3**
Volume of intermediate layer		**212,400,000 m^3**
Volume of bottom layer		**14,700,000 m^3**
Volume of ARD flows into pit lake combined N & S	1998:	**4,500,000 m^3**
	1999:	**5,200,000 m^3**
Volume of direct rainfall on pit lake @ 1.78 m/y		3,060,000 m^3
Volume of run-in, not included in ARD estimate		300,000 m^3
	Total	**3,360,000 m^3/y**

Island Copper Mine: Plan View of Pit Lake

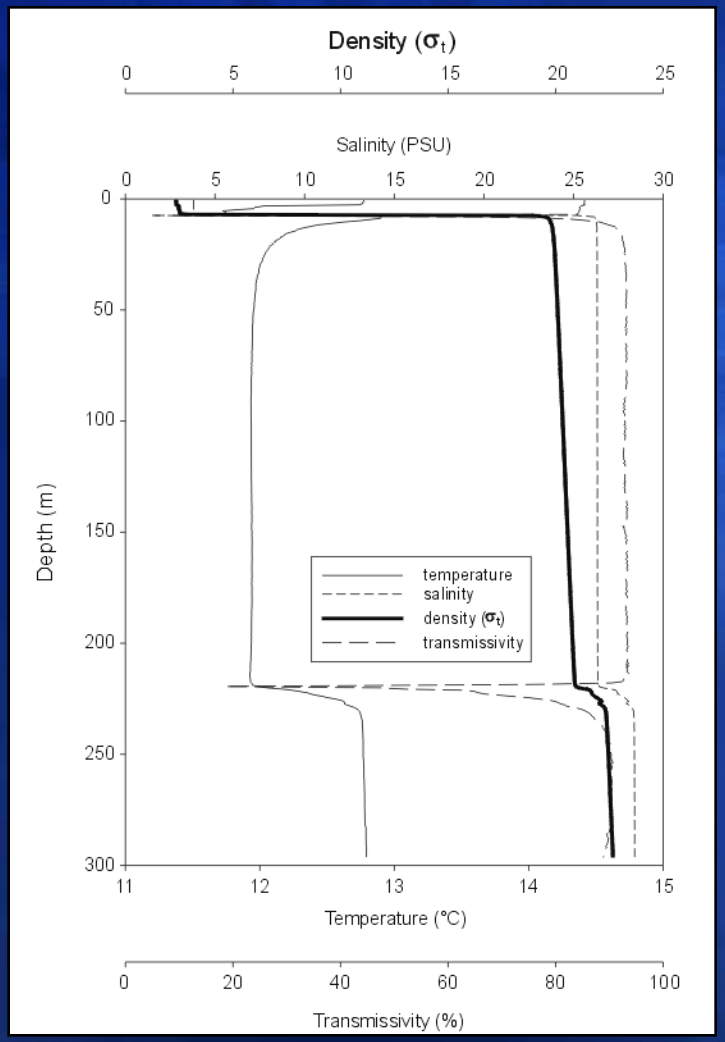


Cross-section of Pit Lake showing Injectors

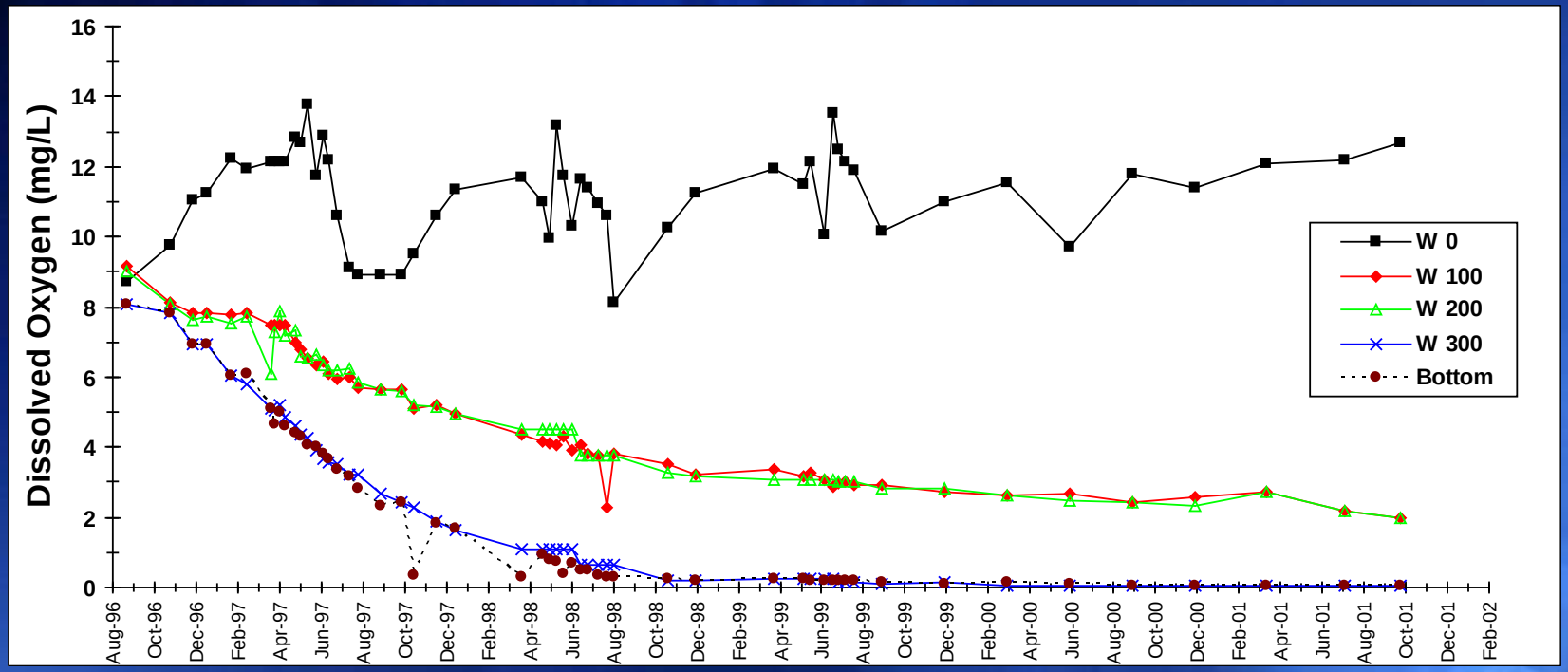


Pit Lake Fertilization Study

Vertical Profiles of Temperature, Salinity, Density and Transmissivity, Pit Lake Station 11, May 24, 2001



ICM Pit Lake - Year 2000 Water Column Chemistry



Fertilization of the Pit Lake: General Background

Current Application Details

- Apply mixture of liquid ammonium polyphosphate (10-34-0) and urea ammonium nitrate (28-0-0)
- Introduce fertilizer to top layer of Pit Lake by mixing into propwash
- Fertilizer is applied to lake every 10 days
- Monitoring occurs 5 days after application

Pit Lake: Fertilization Study

Baseline Sampling

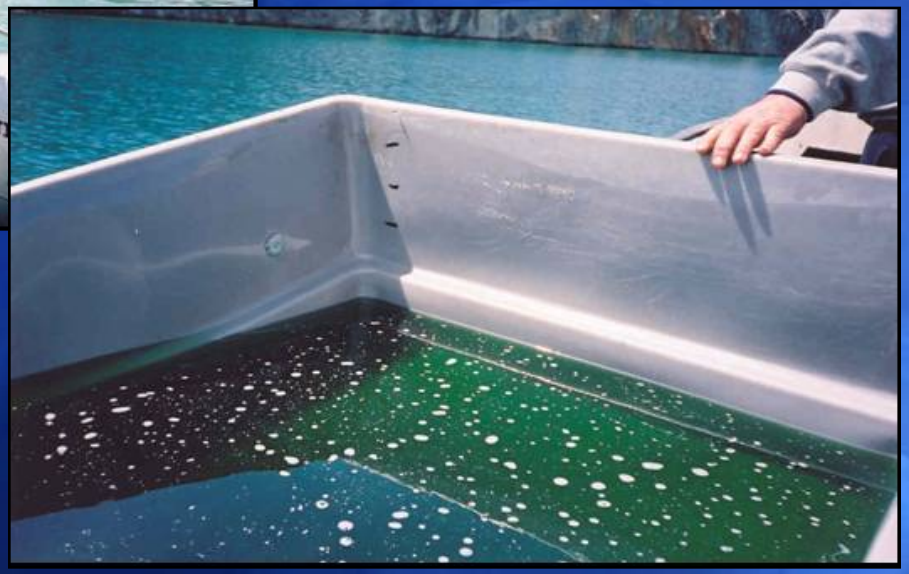
- 11 Stations
- 7 Depths (surface, 1, 3, 5, 7, 10, 50 m)
- CTD, Transmissivity, DO, Secchi, Total and Dissolved Metals, Physical Parameters, Nutrients, Chlorophyll *a,* Phytoplankton and Zooplankton Taxonomy

Post Fertilization Sampling

- 11 Stations
- 7 Depths, decreasing to 3 depths (1, 5, 10 m)
- CTD, Transmissivity, DO, Secchi, Total and Dissolved Metals, Physical Parameters, Nutrients, Chlorophyll *a,* Phytoplankton and Zooplankton Taxonomy

Pit Lake Fertilization Study

Fertilizer container on boat

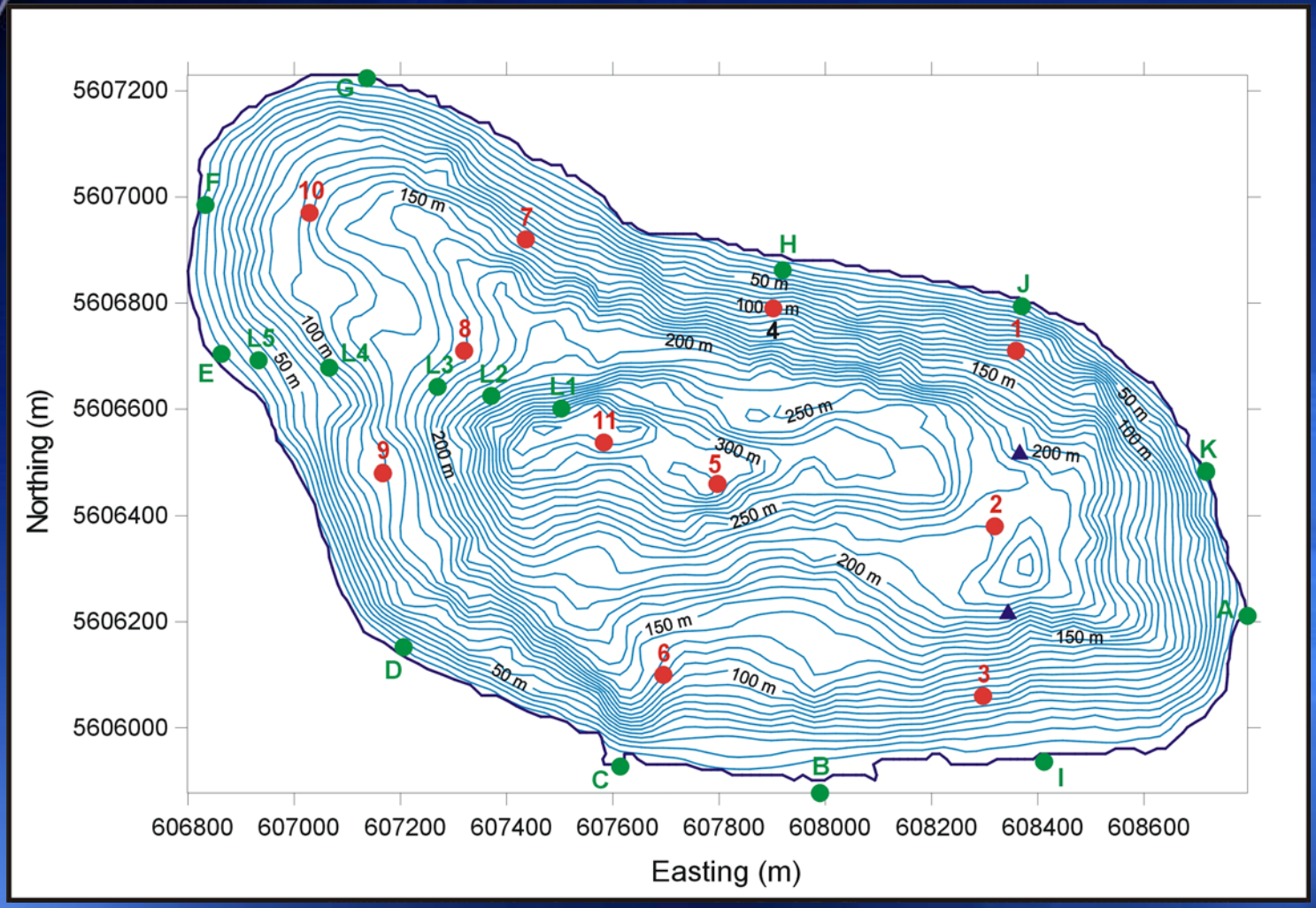


Liquid Fertilizer

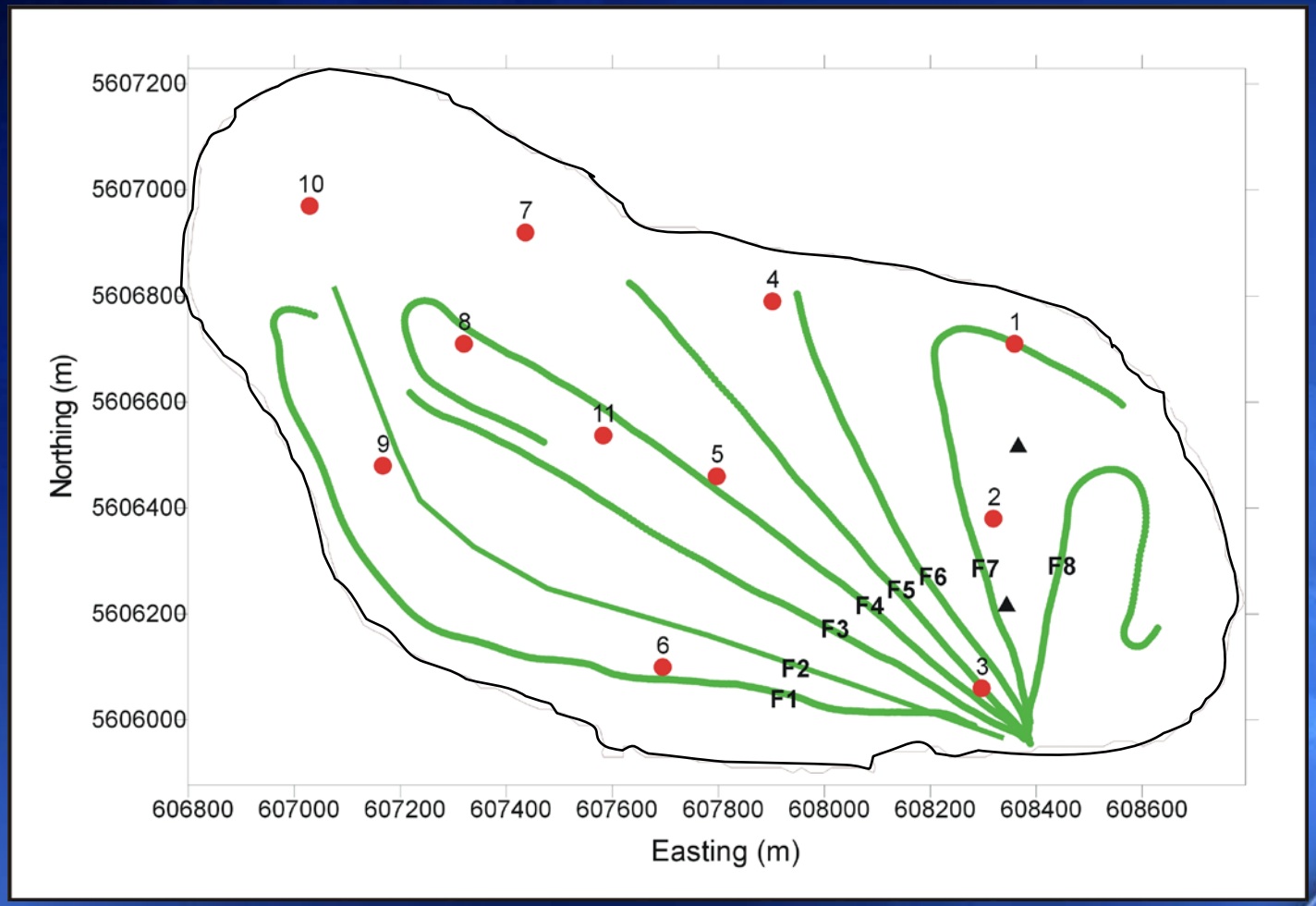
Pit Lake Fertilization Study

Application of fertilizer to Pit Lake

ICM - Pit Lake Stations



Pit Lake: Fertilization Tracks, May 25, 2001



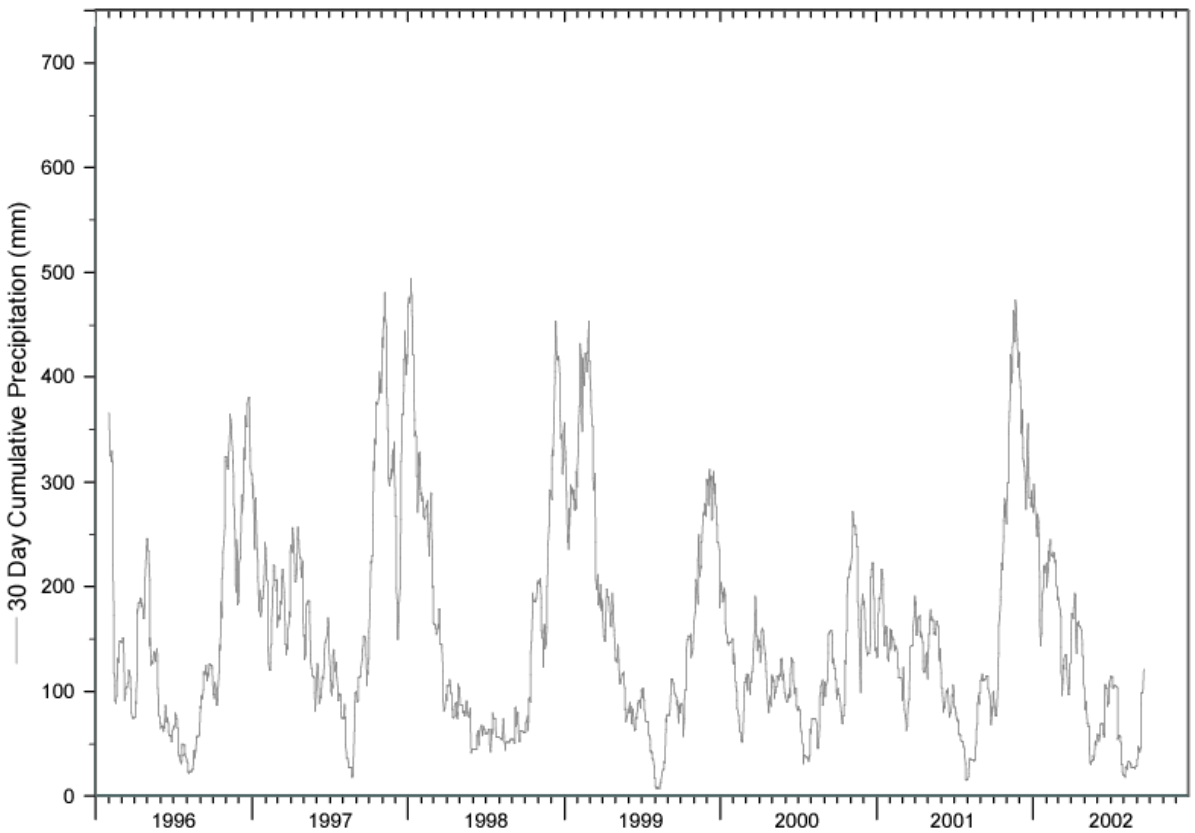
Pit Lake Fertilization

Fertilization 1 (May 25, 2001)

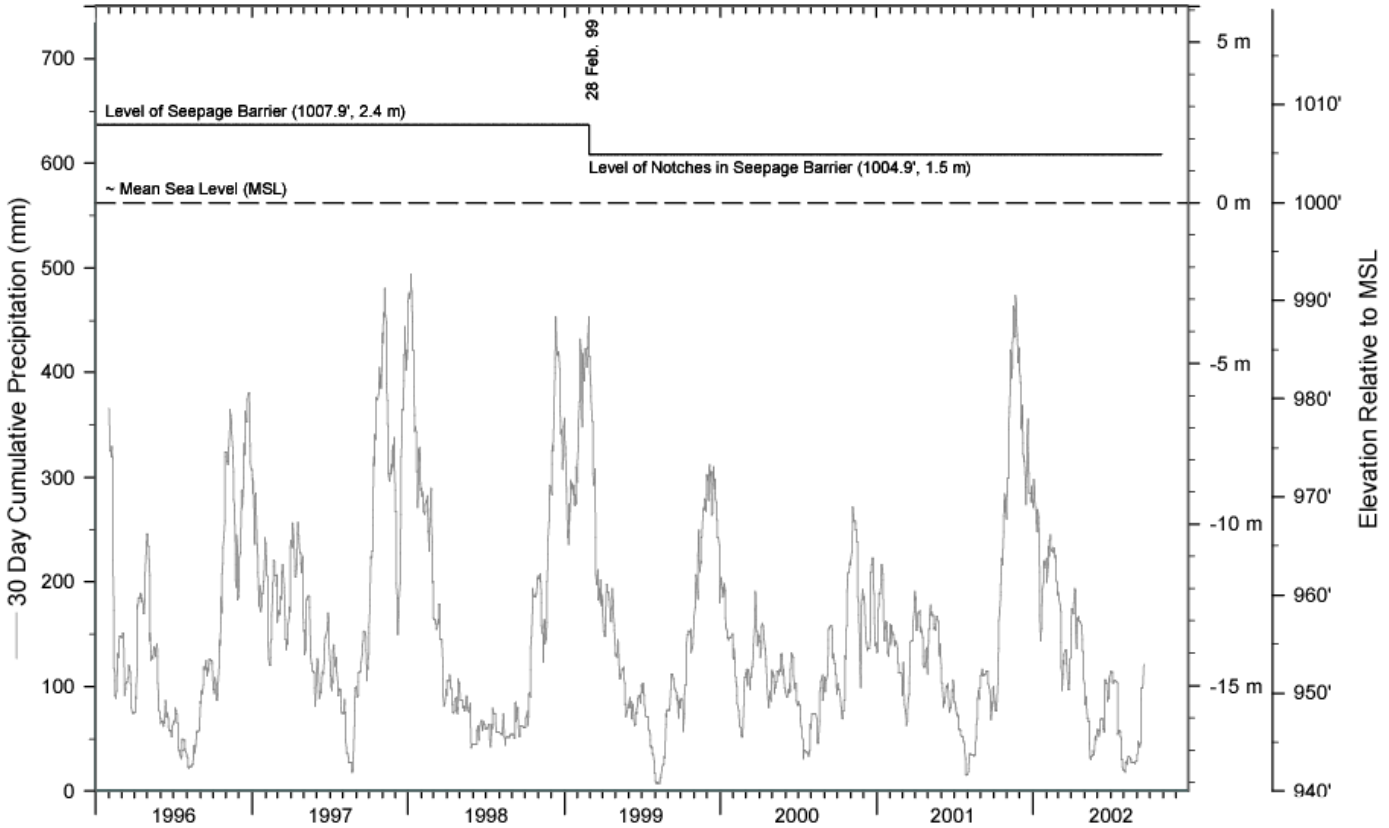
	Volume (gallons)	Time (min)	Distance (m)	Area (m^2)
Line 1	80	7.02	1807	7228
Line 2	80	*5.11*	*1313*	5252
Line 3	80	4.38	1335	5340
Line 4	80	6.07	1802	7208
Line 5	80	3.52	1146	4584
Line 6	80	3.37	965	3860
Line 7	80	4.1	1139	4556
Line 8	80	3.32	995	3980
Total	**640**	**36.89**	**10,502**	**42,008**

2.4% of lake area fertilized, assuming 4 m wide lines

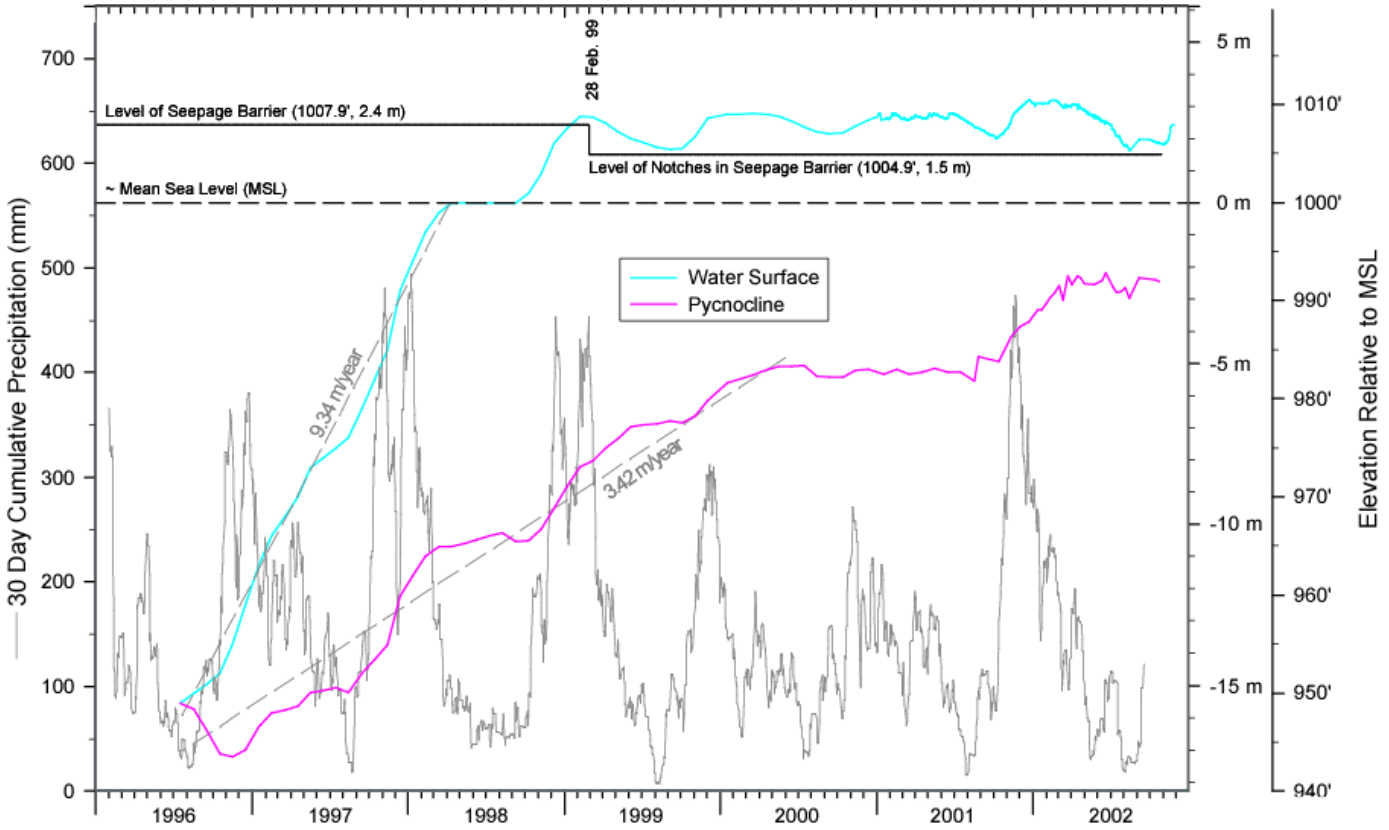
Evolution of Pit Lake - Precipitation



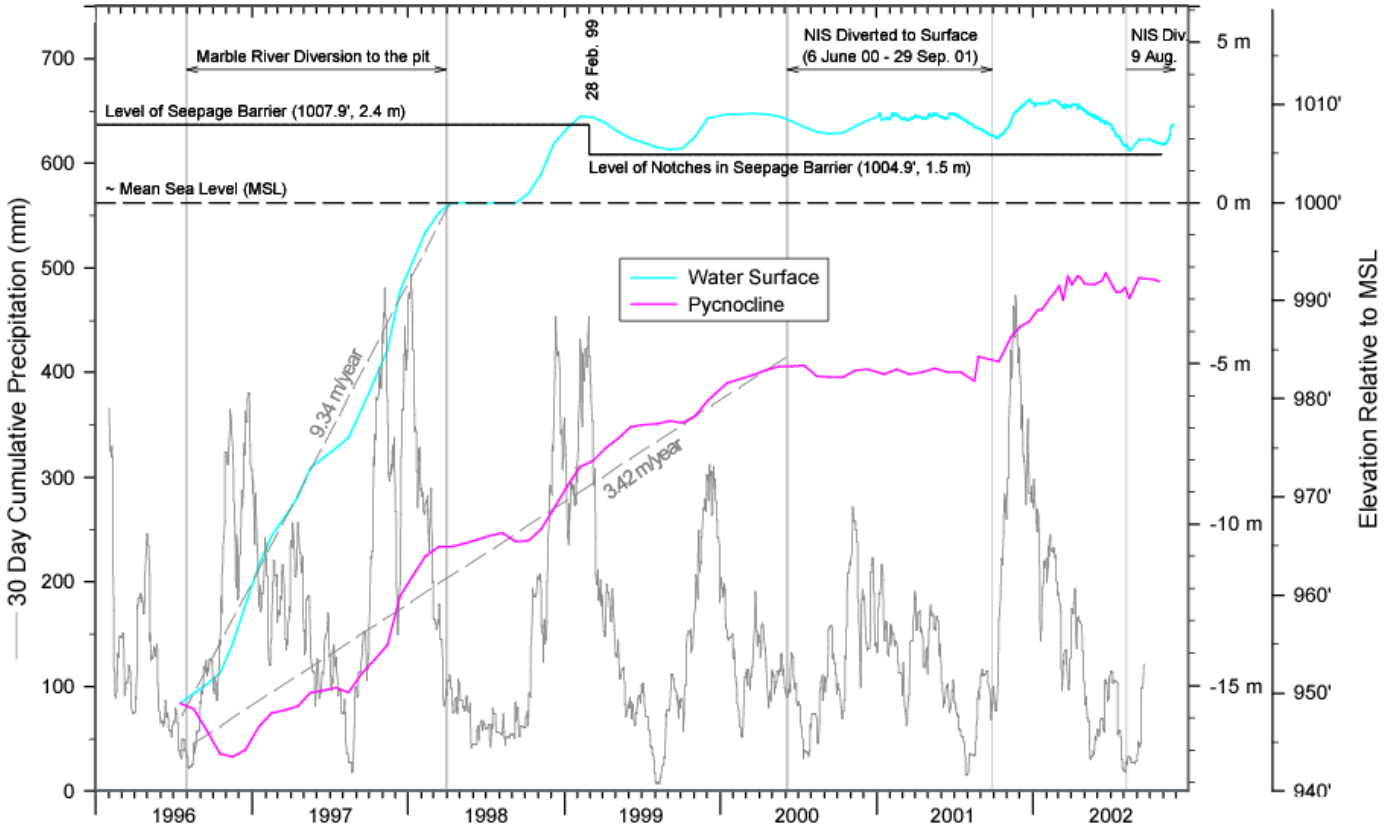
Evolution of Pit Lake – Slurry Wall with Notch Cuts



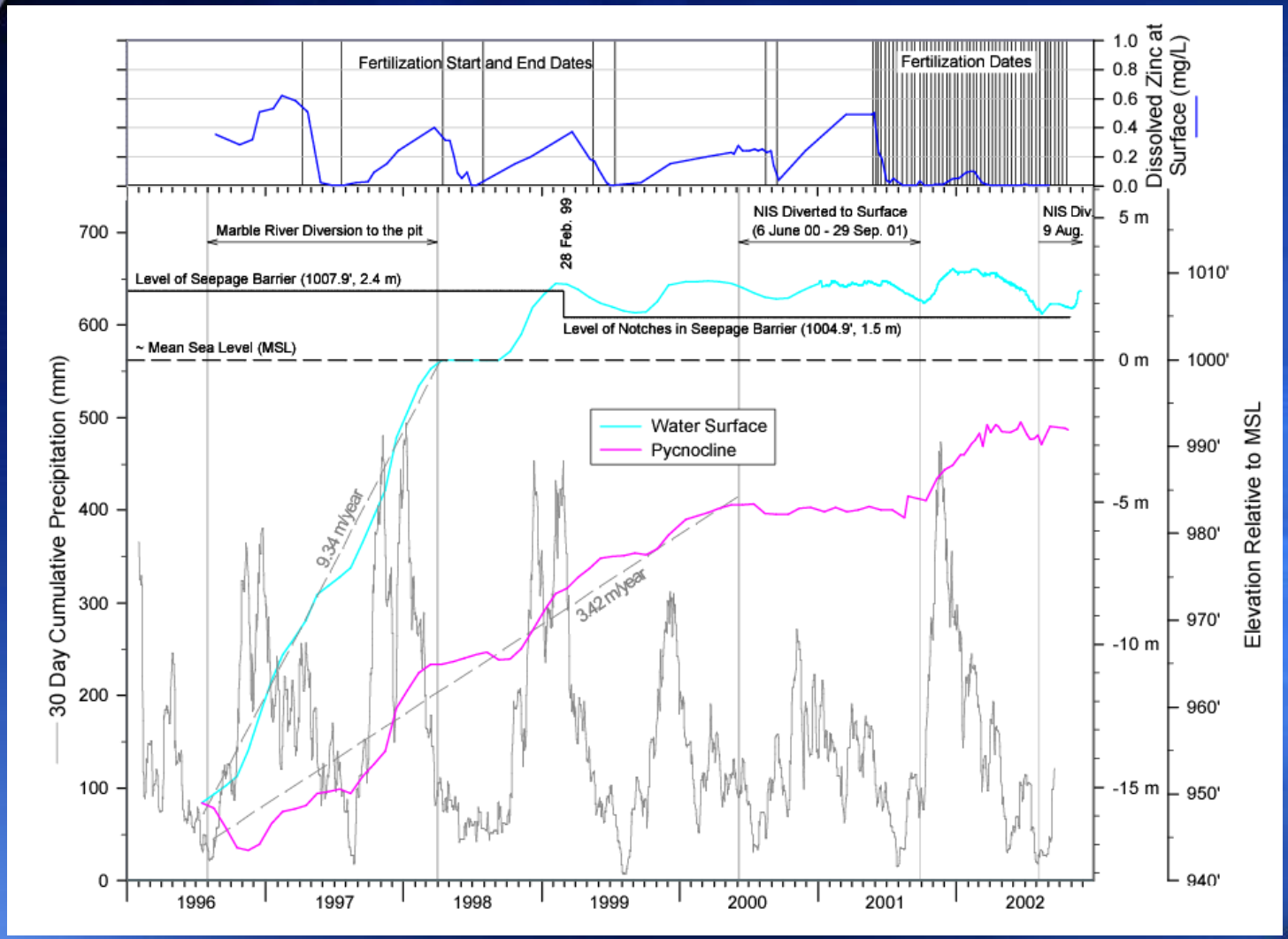
Evolution of Pit Lake – Water Surface & Pycnocline



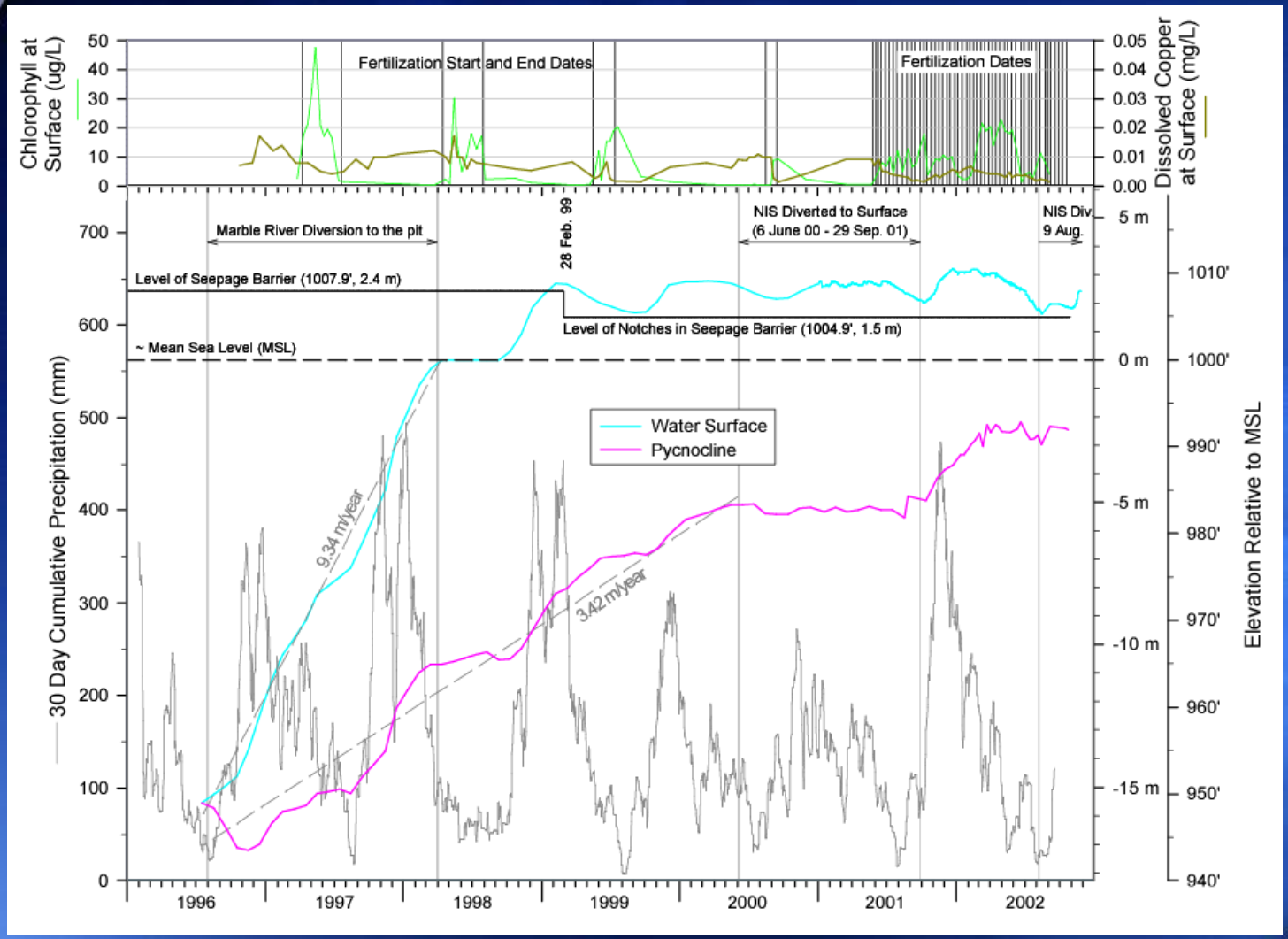
Evolution of Pit Lake – Events Effecting Levels



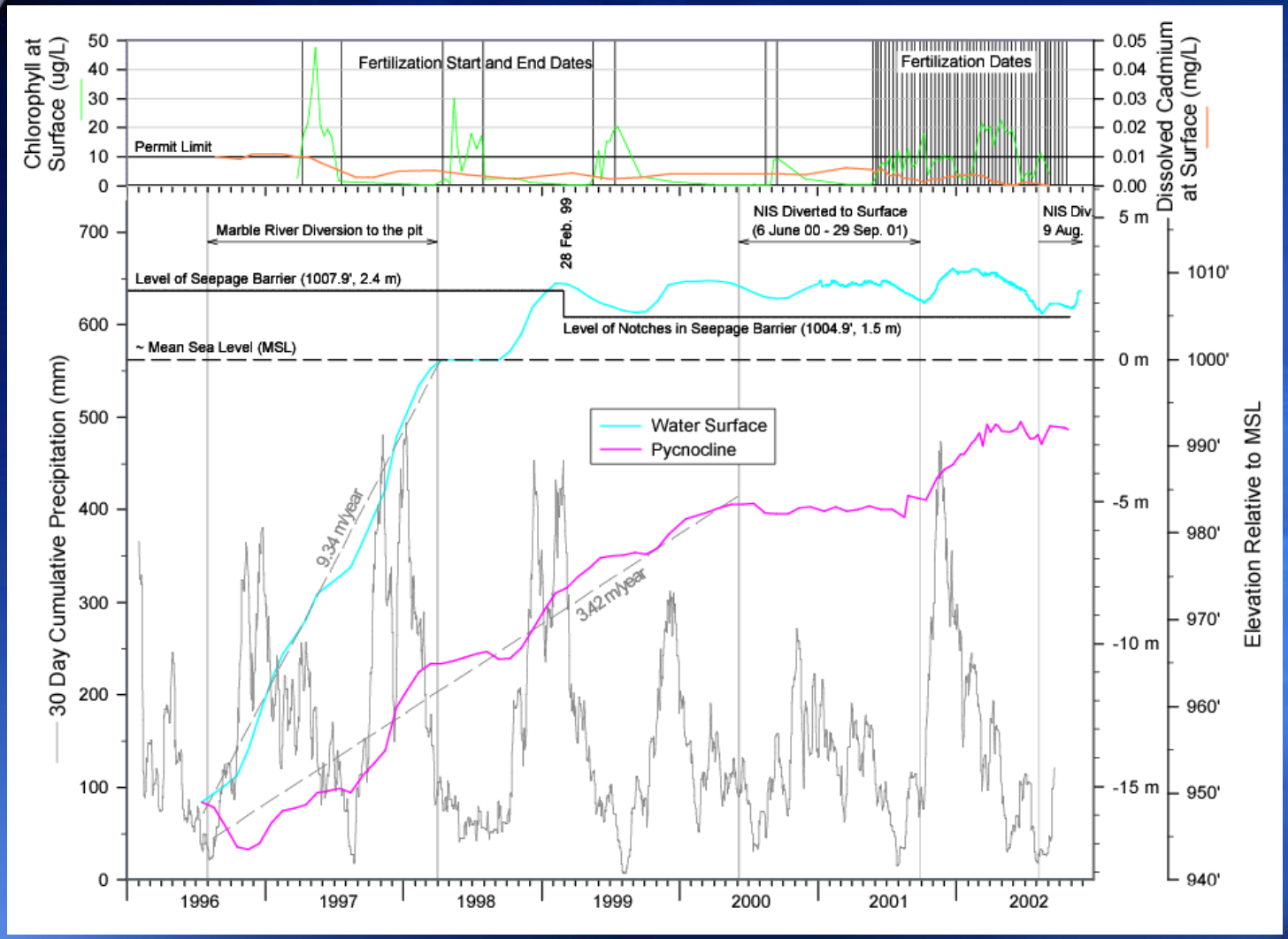
Evolution of Pit Lake – Zinc Concentrations & Fertilization Periods



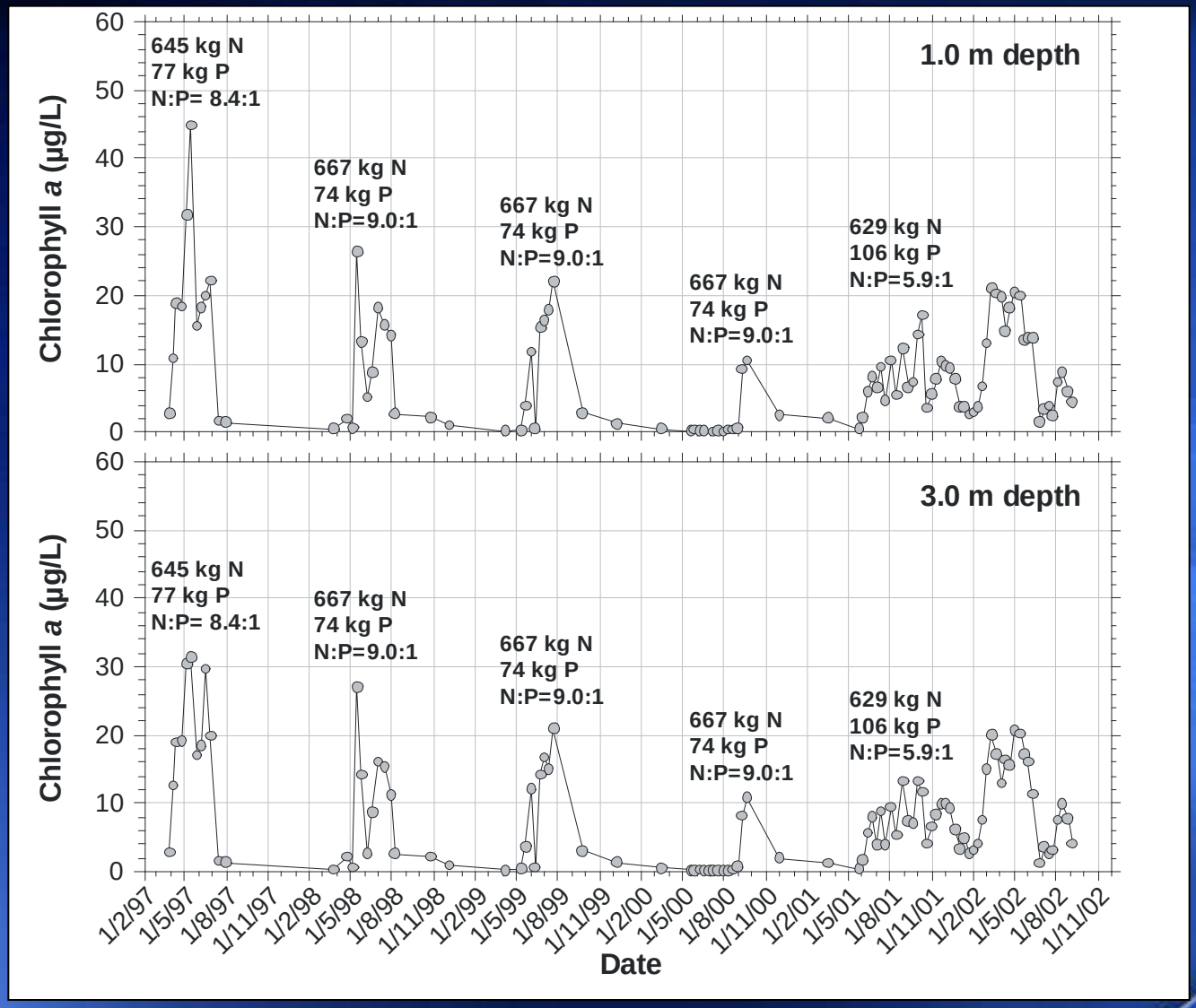
Evolution of Pit Lake - Dissolved Copper with Fertilization Periods



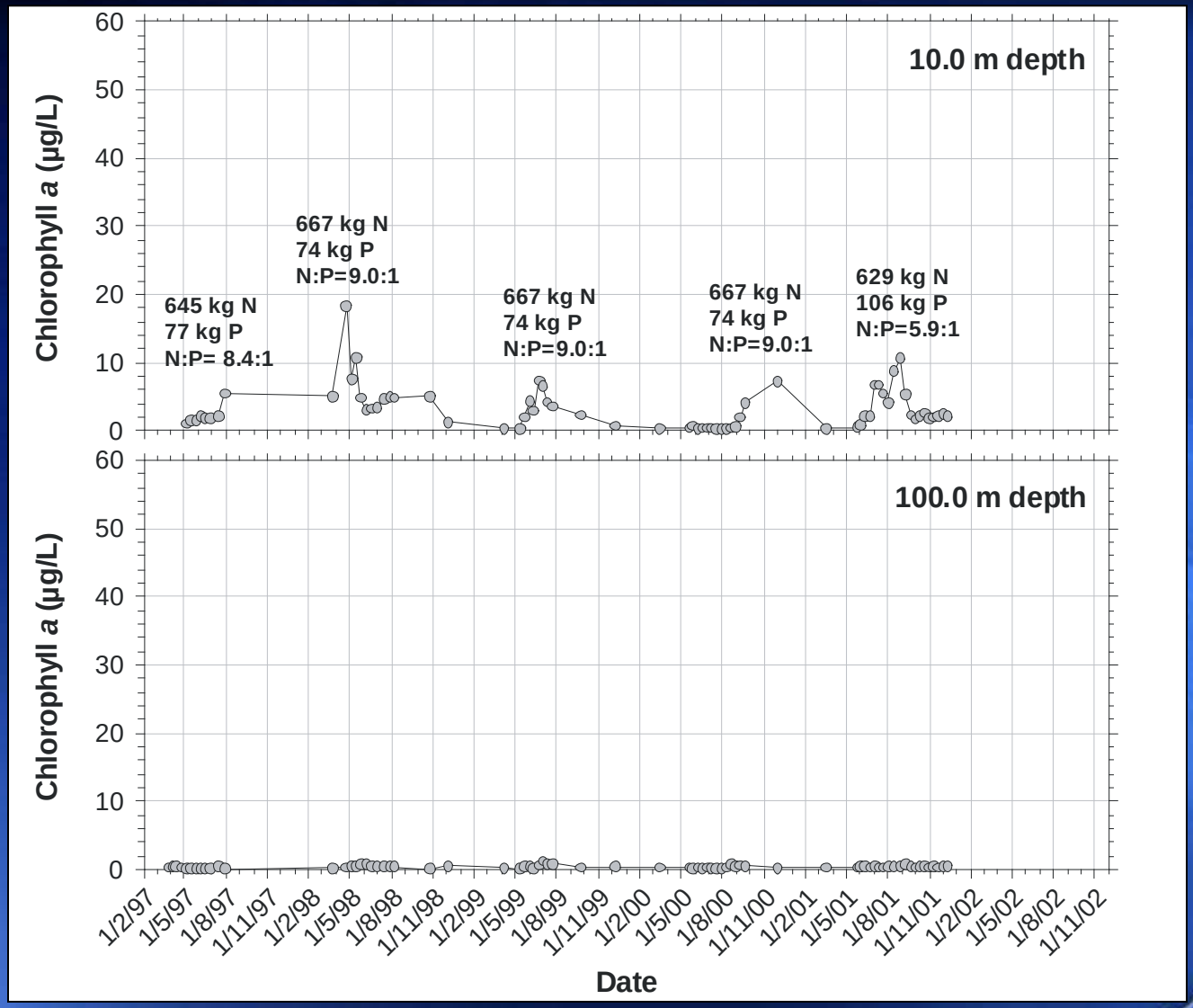
Evolution of Pit Lake – Cadmium with Fertilization Periods



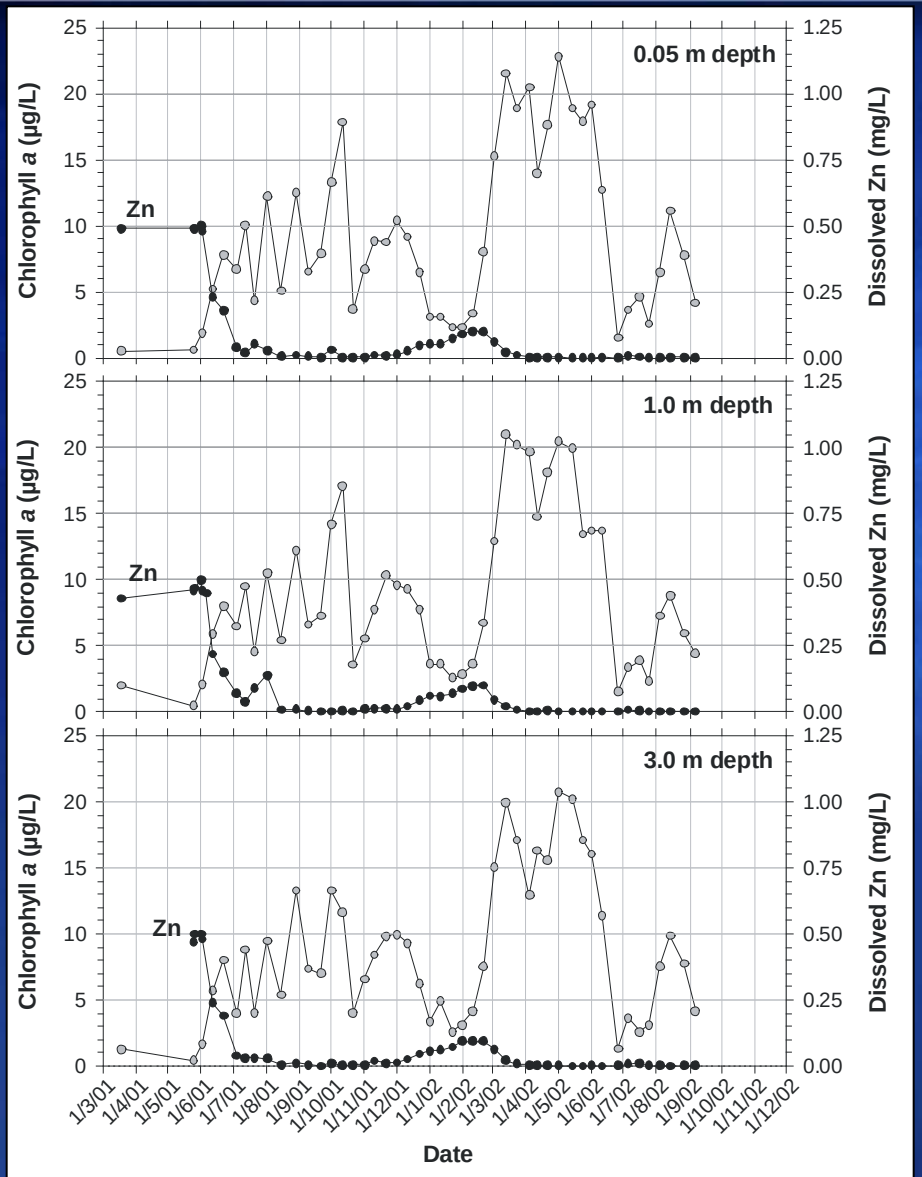
Chlorophyll *a* (1 and 3 m) and Fertilizer Applications in Pit Lake, 2001-2002



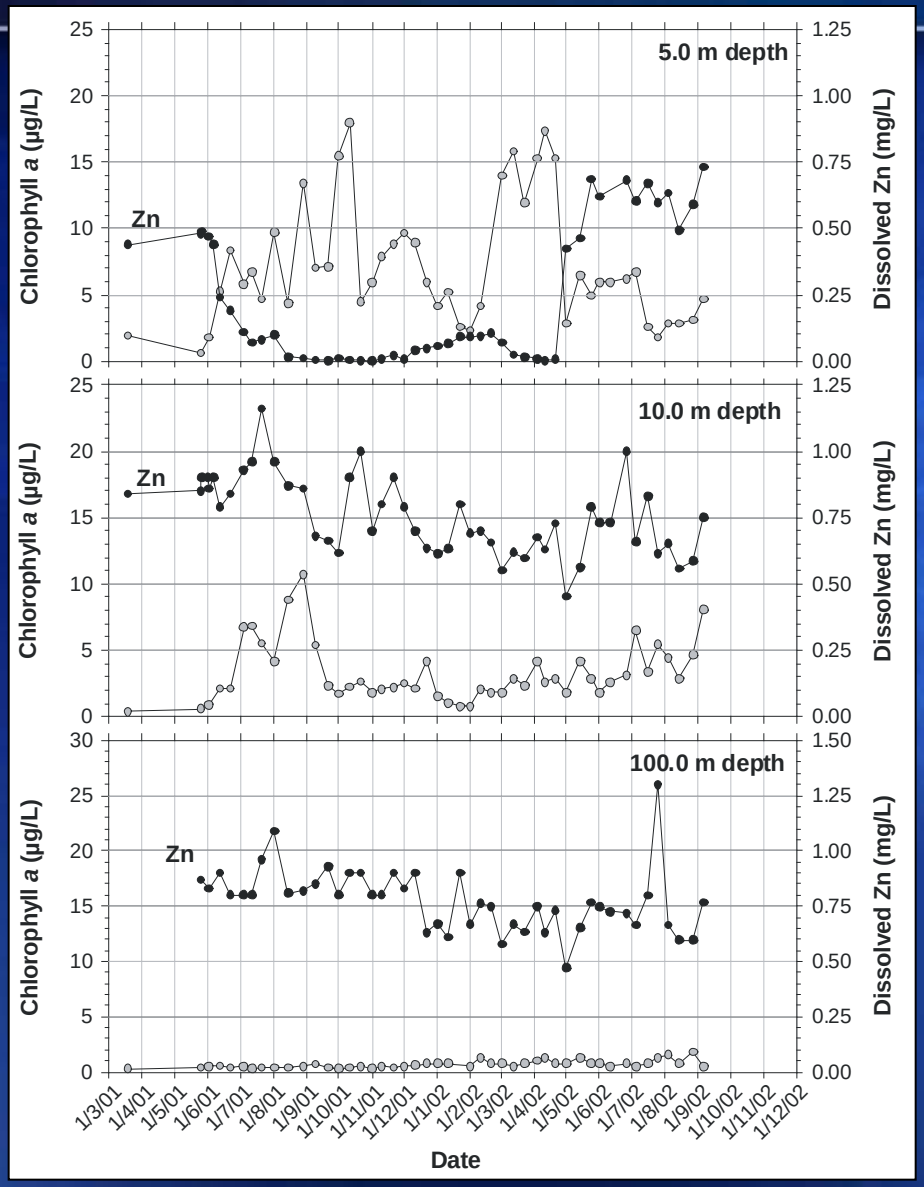
Chlorophyll *a* (10 and 100 m) and Fertilizer Applications in Pit Lake, 2001-2002



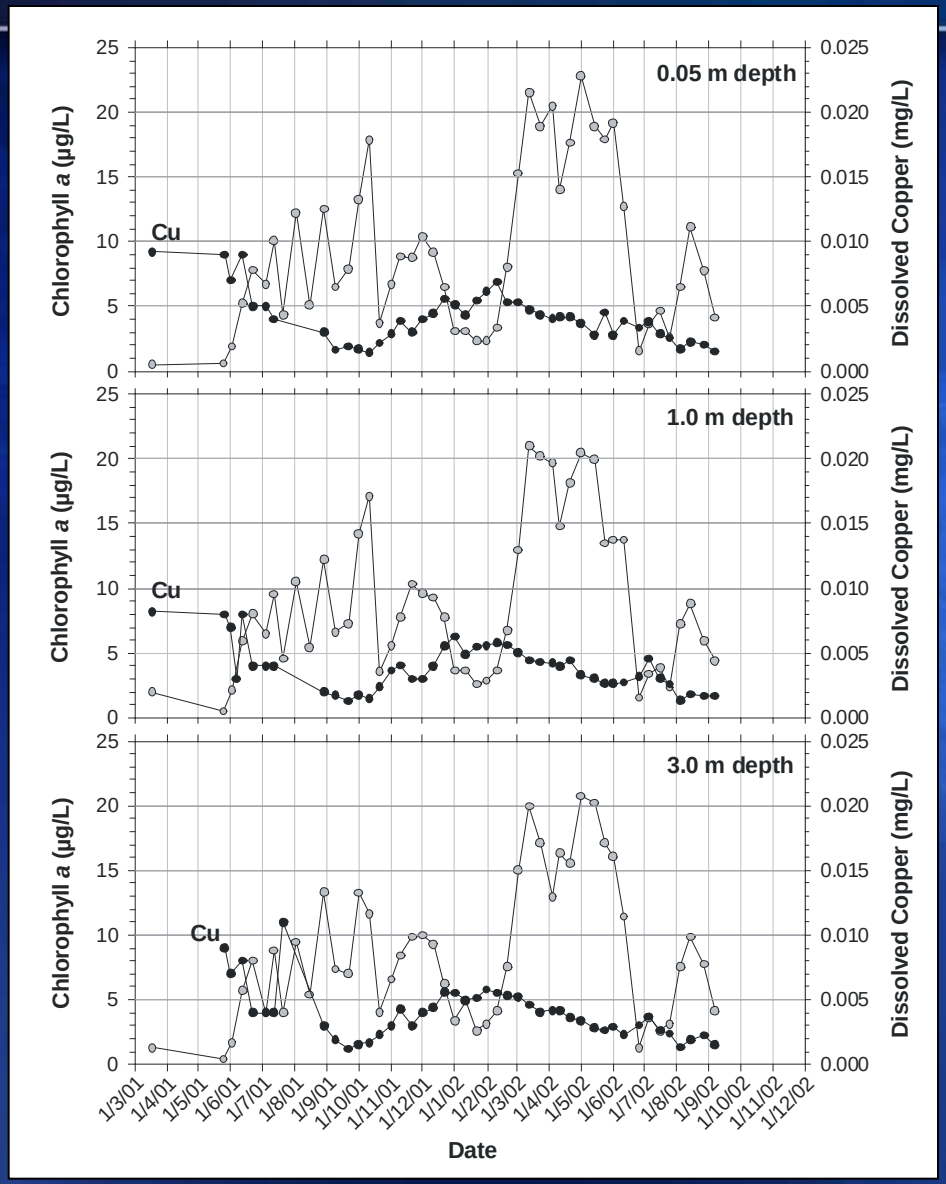
Phytoplankton Biomass and Dissolved Zinc (0.05, 1 and 3 m) in Pit Lake, 2001-2002



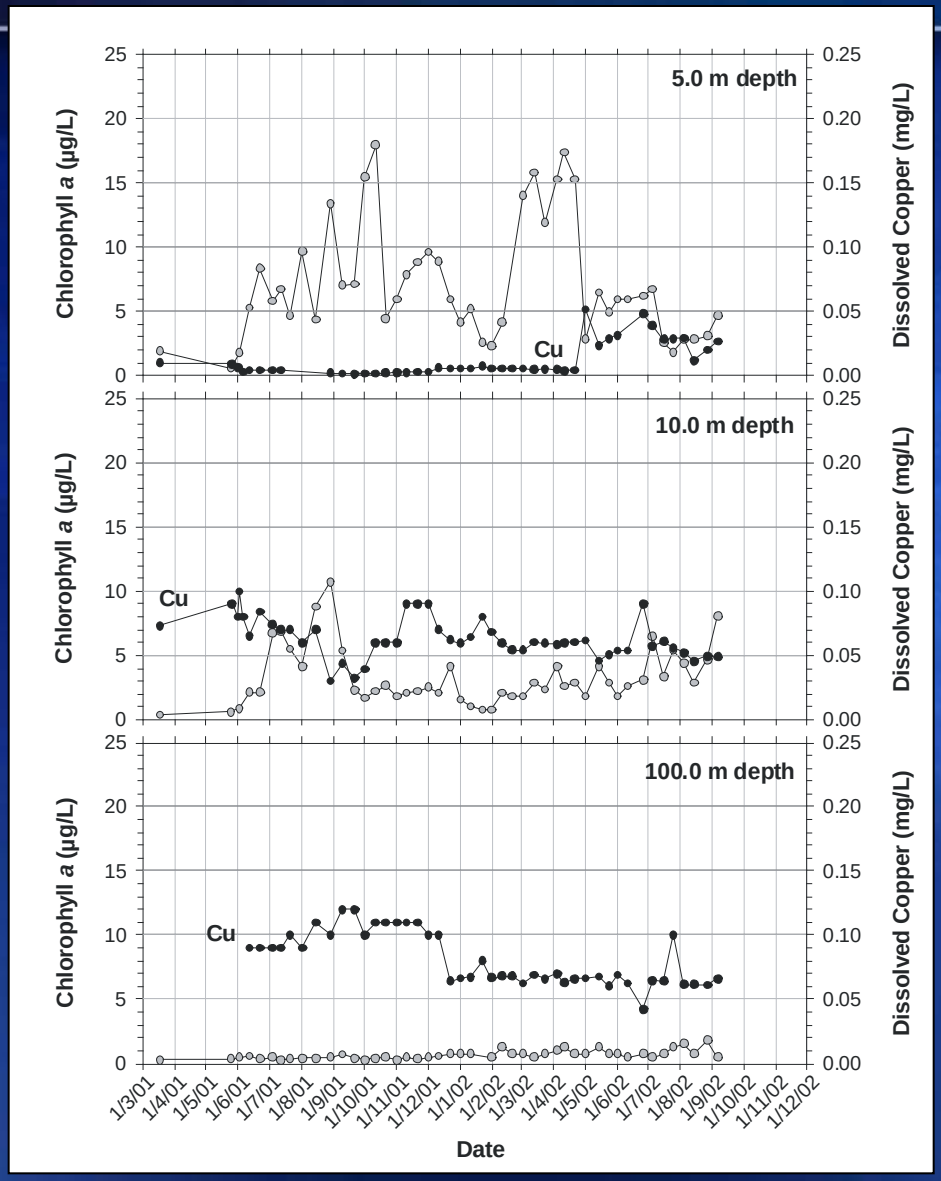
Phytoplankton Biomass and Dissolved Zinc (5, 10 and 100 m) in Pit Lake, 2001-2002



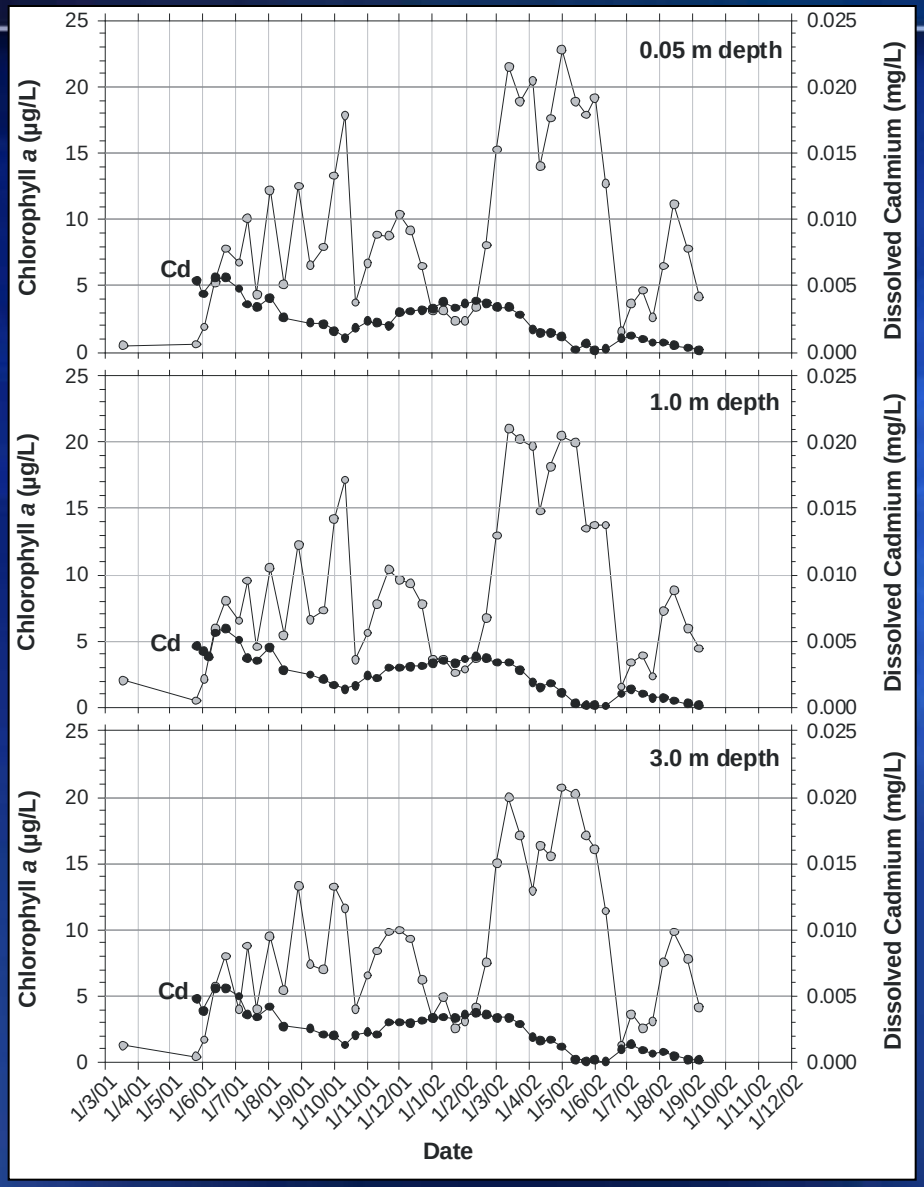
Phytoplankton Biomass and Dissolved Copper (0.05, 1 and 3 m) in Pit Lake, 2001-2002



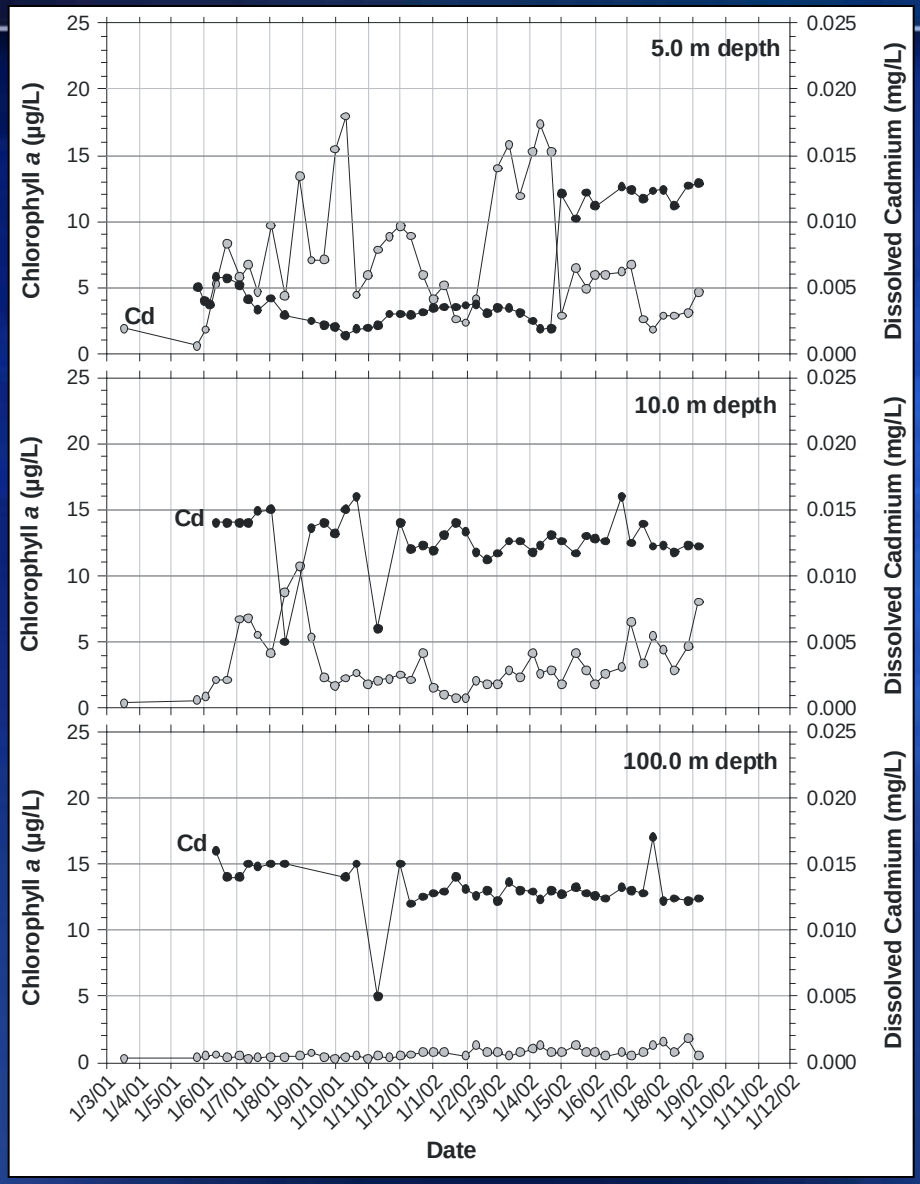
Phytoplankton Biomass and Dissolved Copper (5, 10 and 100 m) in Pit Lake, 2001-2002



Phytoplankton Biomass and Dissolved Cadmium (0.05, 1 and 3 m) in Pit Lake, 2001-2002



Phytoplankton Biomass and Dissolved Cadmium (5, 10 and 100 m) in Pit Lake, 2001-2002



Phytoplankton/Bacteria Cell Density Above and Below Pycnocline

	February		March		April	
	A	B	A	B	A	B
Diatoms (# cells/mL)	13.2	2	23	2.3	27	4.6
Green Algae (# cells/mL)	101242	14942	125945	10188	181261	7013
Cyanobacteria (# cells/mL)	1086	159	3212	131	3923	190

	May		June		July	
	A	B	A	B	A	B
Diatoms (# cells/mL)	7.2	6.5	0.8	5.6	375	3.1
Green Algae (# cells/mL)	188431	12519	165245	8421	133607	9518
Cyanobacteria (# cells/mL)	3552	216	6337	95	8923	17

A = Above Pycnocline, B = Below Pycnocline

Fertilization of the Pit Lake: Controlling Factors

- Dissolved Zn concentrations are influenced by the phytoplankton population residing in the upper water layer
- Elevated phytoplankton biomass levels result in low dissolved Zn concentrations
- To maintain elevated phytoplankton biomass levels, need the following conditions:
  - Adequate nutrients (N, P, C, others)
  - Adequate light and temperature
  - Minimal grazing pressure
  - Non-toxic conditions

Fertilization of the Pit Lake: Optimization: Fertilizer Use by Phytoplankton

- Fertilizer use by phytoplankton: phytoplankton biomass since 2001 fertilization began (see following figure)
- Nutrient requirements of phytoplankton: require N, P, Si (some species), C, micro-nutrients
- Liquid fertilizer adds the following nutrients:
  - nitrate
  - total ammonium
  - urea (not an important N source for phyto.)
  - orthophosphate
- Examined Residual Nutrients in Upper Layer
  - (only data for nitrate, orthophosphate, silicic acid)

Fertilization of the Pit Lake:
Optimization: Fertilizer Use by Phytoplankton

Summary

- From examining residual nutrients:
  - Excess nitrate was being added to the system initially
    - waste of liquid fertilizer
    - was not contributing to enhanced biomass
    - was adding a potential ‘contaminant’ to the middle layer (e.g. an oxygen source)
    - Adjusted N:P ratio as a result (late July 2001)
  - Orthophosphate was being used up; good, as similar to natural situation; also indicated no other major limiting factor (e.g. a micronutrient)

Fertilization of the Pit Lake:
Optimization: Nutrient Limitation of Phytoplankton

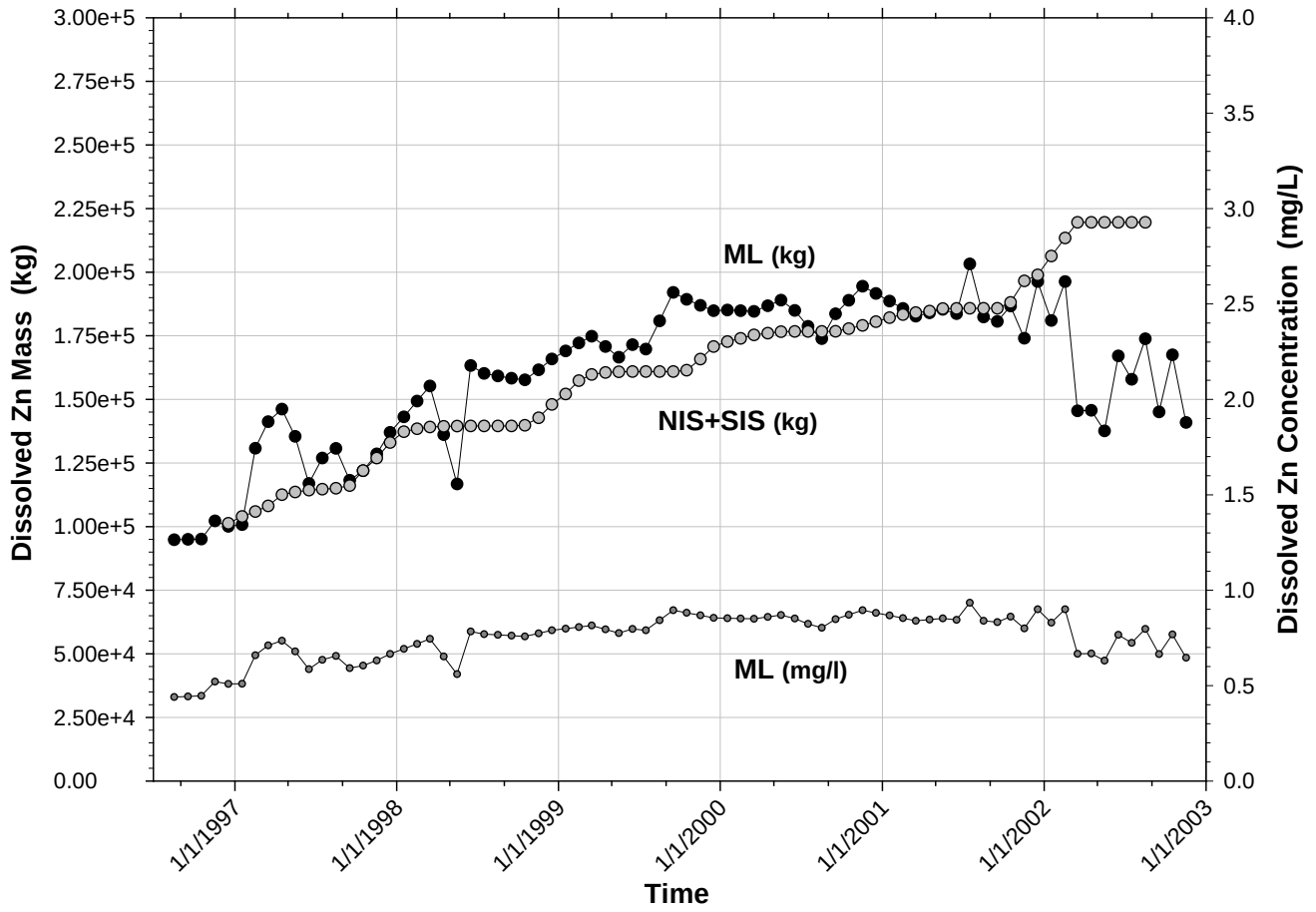
- In order to access nutrient status of resident population, compared phytoplankton composition to the Redfield Ratio
- Redfield Ratio=7 N: 1 P by weight
- Used N and P content of particulate matter as estimate of phytoplankton content
- In nature, lake phytoplankton populations are typically P-limited

Fertilization of the Pit Lake: Optimization: Nutrient Limitation of Phytoplankton

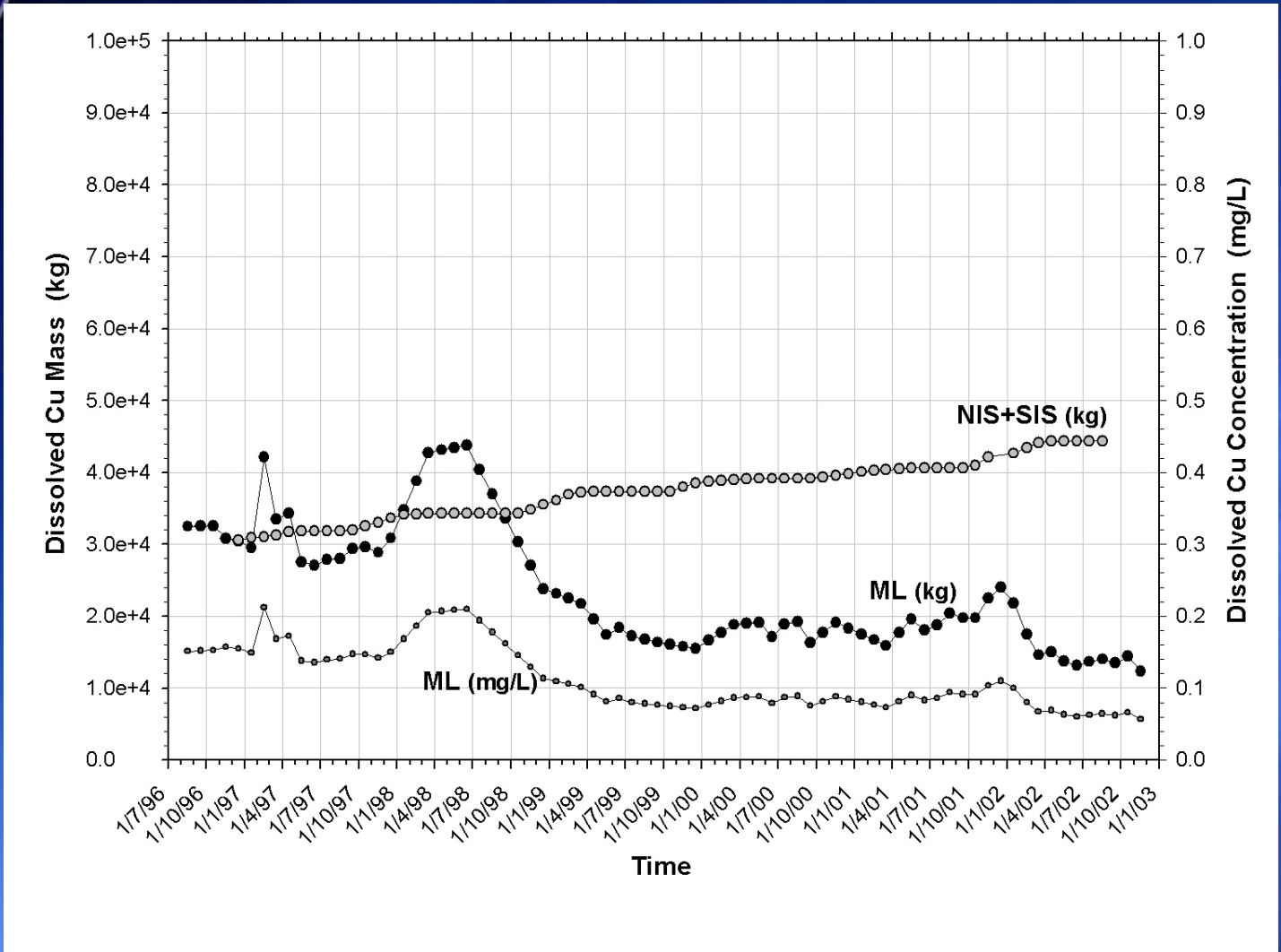
Summary

- Nutrient-status of resident phytoplankton (in situation where adding liquid fertilizer with a 6 N:1 P composition)
- Likely N-limited during the summer
- Likely P-limited all other times
- (P-limitation is more desirable; N-limitation could result in undesirable shifts to cyanobacteria)
- Conclude: increasing the N content of the fertilizer during the summer months may result in higher phytoplankton biomass levels; extra N would not be wasted

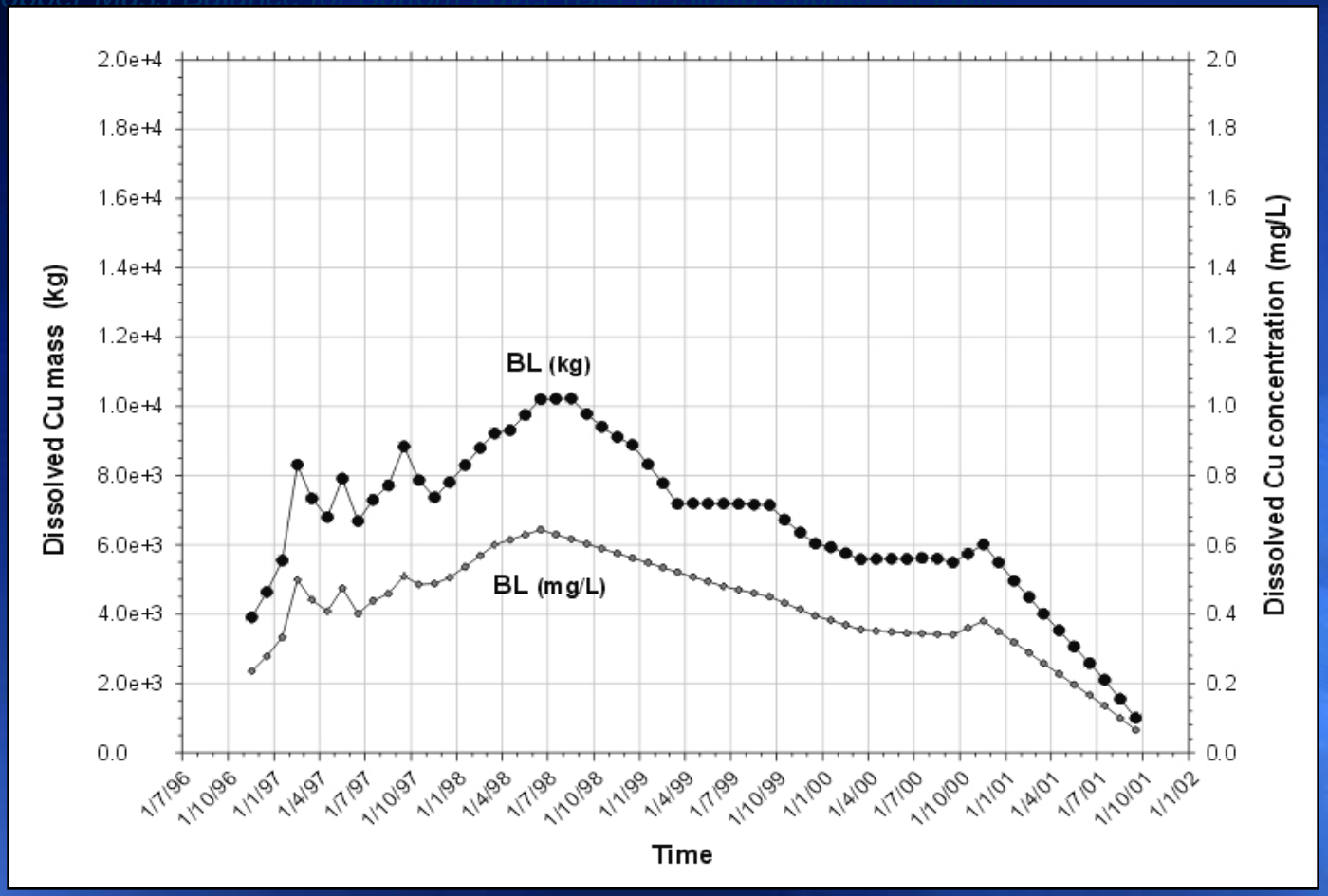
Zinc Mass Balance for Middle Layer (ML)



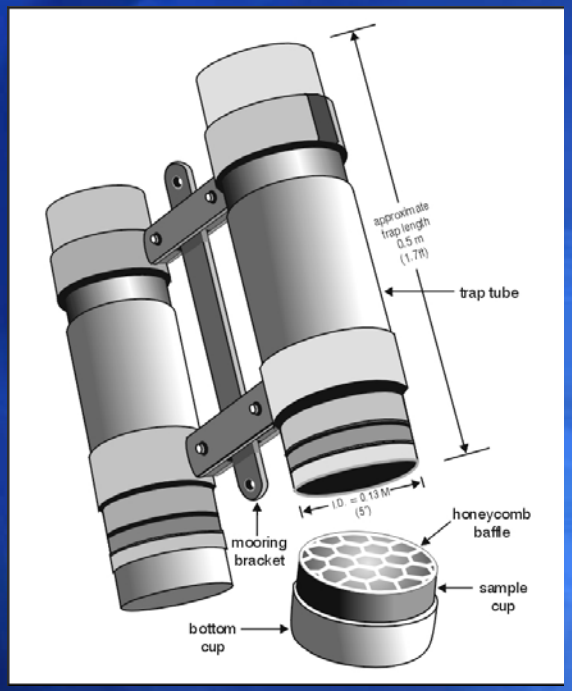
Copper Mass Balance for Middle Layer (ML)



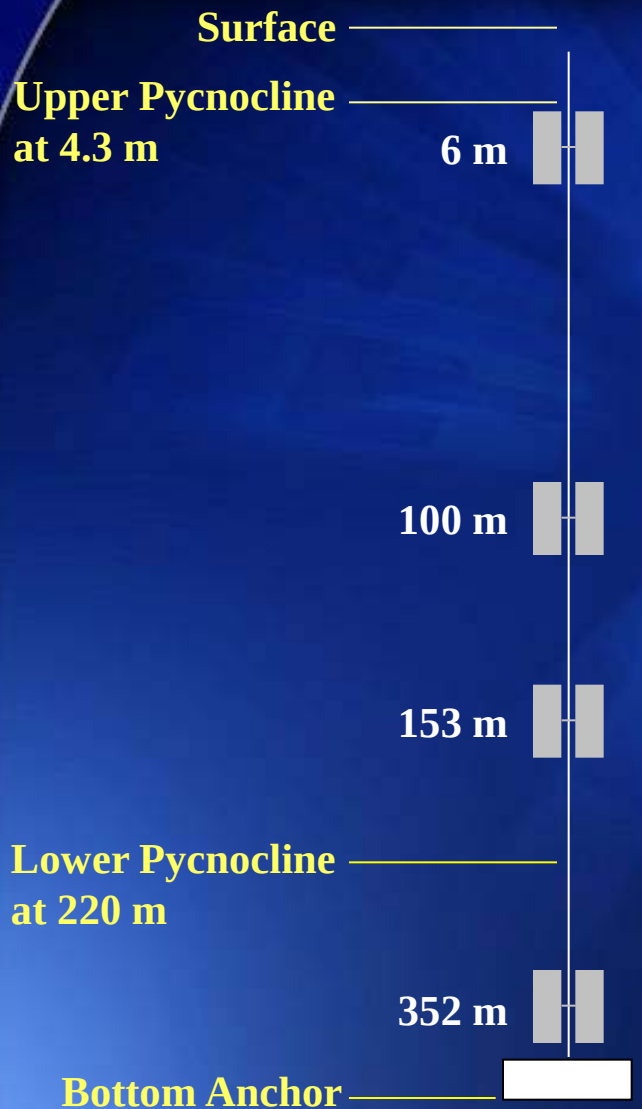
Pit Lake Metal Mass Balance Bottom Layer Copper

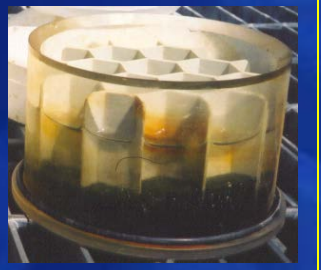
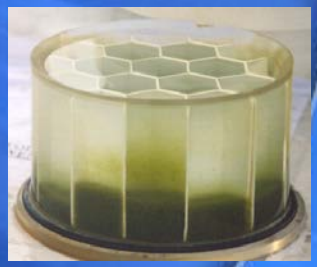
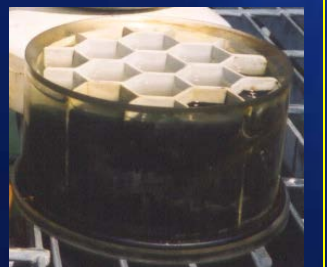


Sediment Trap Deployed at Deepest Spot in Lake



Sediment Trap Samples

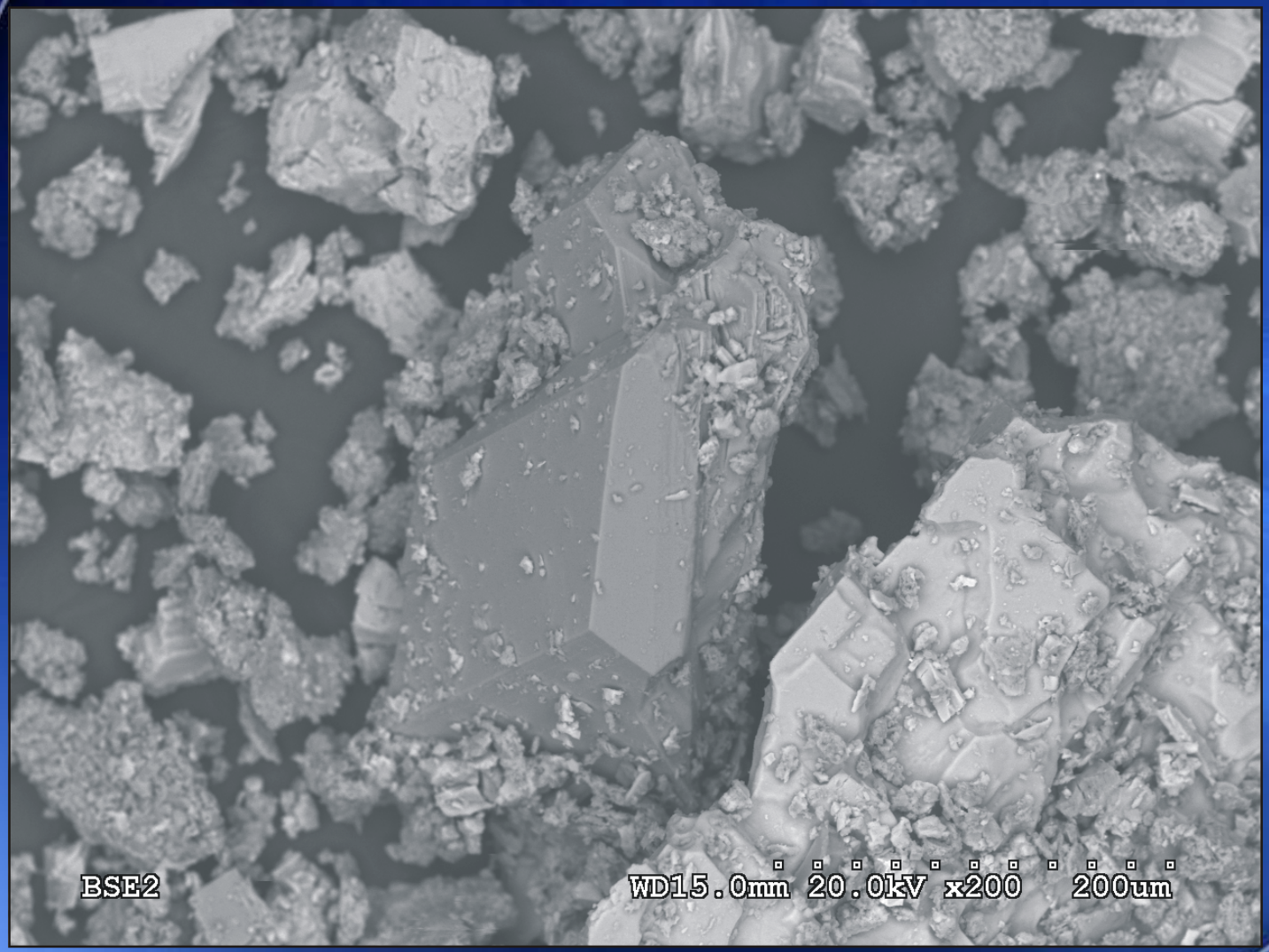


138 days Dec 21, 2001 - May 8, 2002	125 days May 8-Sep 10, 2002	71 days Sep 10-Nov 20, 2002
	Not Available	
	Not Available	
		
		

Diatom, Bacteria and Organic Debris in Sediment Trap at 6 m Depth

Bacteria (unidentified) in Sediment Trap at 6 m Depth

Gypsum in Sediment Trap at 153 m Depth

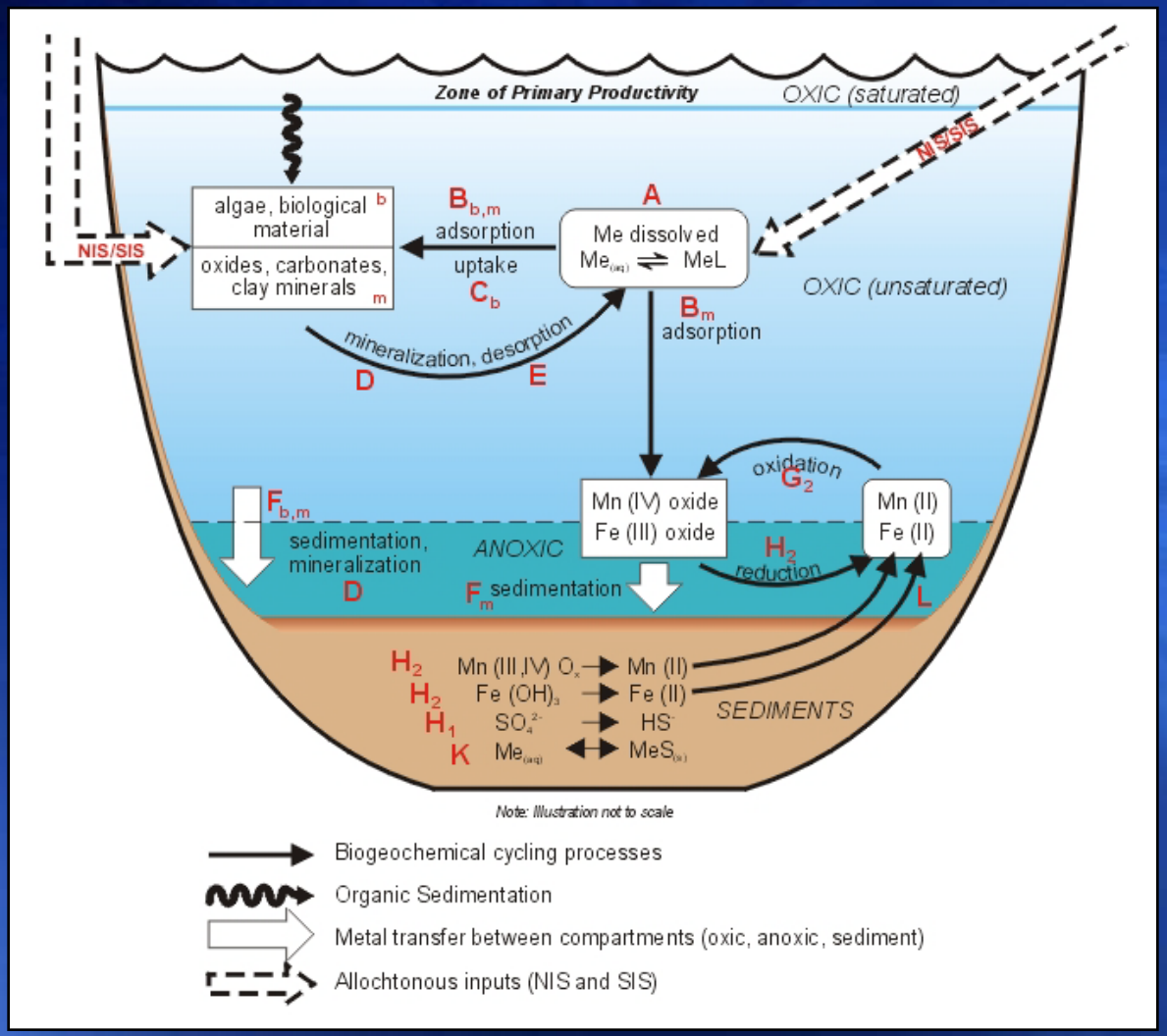


Conclusion

- Fertilization of top layer of pit lake on semi-continuous basis is very effective as a removal mechanism for zinc, copper and cadmium
- Geochemical processes (precipitation & adsorption) in the middle layer is removing large amounts of zinc, copper and cadmium
- The anoxic conditions in the bottom layer promote the iron and manganese cycle which appears to be removing significant quantities of zinc. Copper and cadmium
- Sulphate reduction is starting to develop in the bottom sediments of the pit lake

Island Copper Mine

Schematic of Biogeochemical Processes in Pit Lake



Plant Site with Major Buildings Removed