# The Concept of Steady State in Pit Lake Development: Island Copper Case Study

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**Presented to:** ***Mine Environment Neutral Drainage (MEND) Workshop on Challenges with Open Pits and Underground Workings***

***November 28, 2006 in Vancouver***

# The Time to Steady State



- Steady State: *In general terms – the recently observed behaviour of a system will continue into the future.*
- Decision making usually assumes steady state will be achieved in the short term, as does liability estimation associated with mining pit lakes.
- Is this assumption correct?
- What are the consequences of being wrong?

# Island Copper Mine – Case Study





# Ditch System at Island Copper Mine

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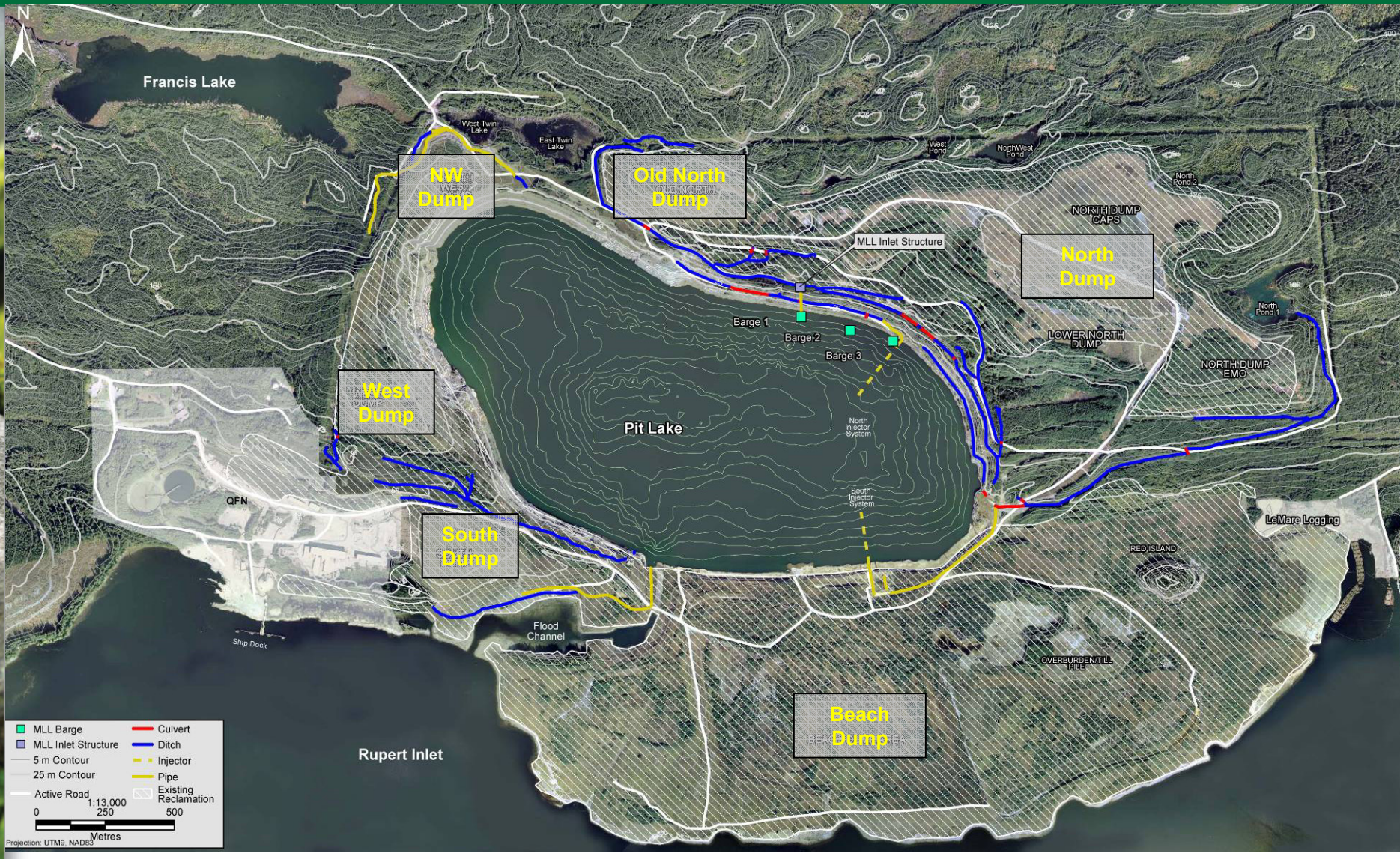
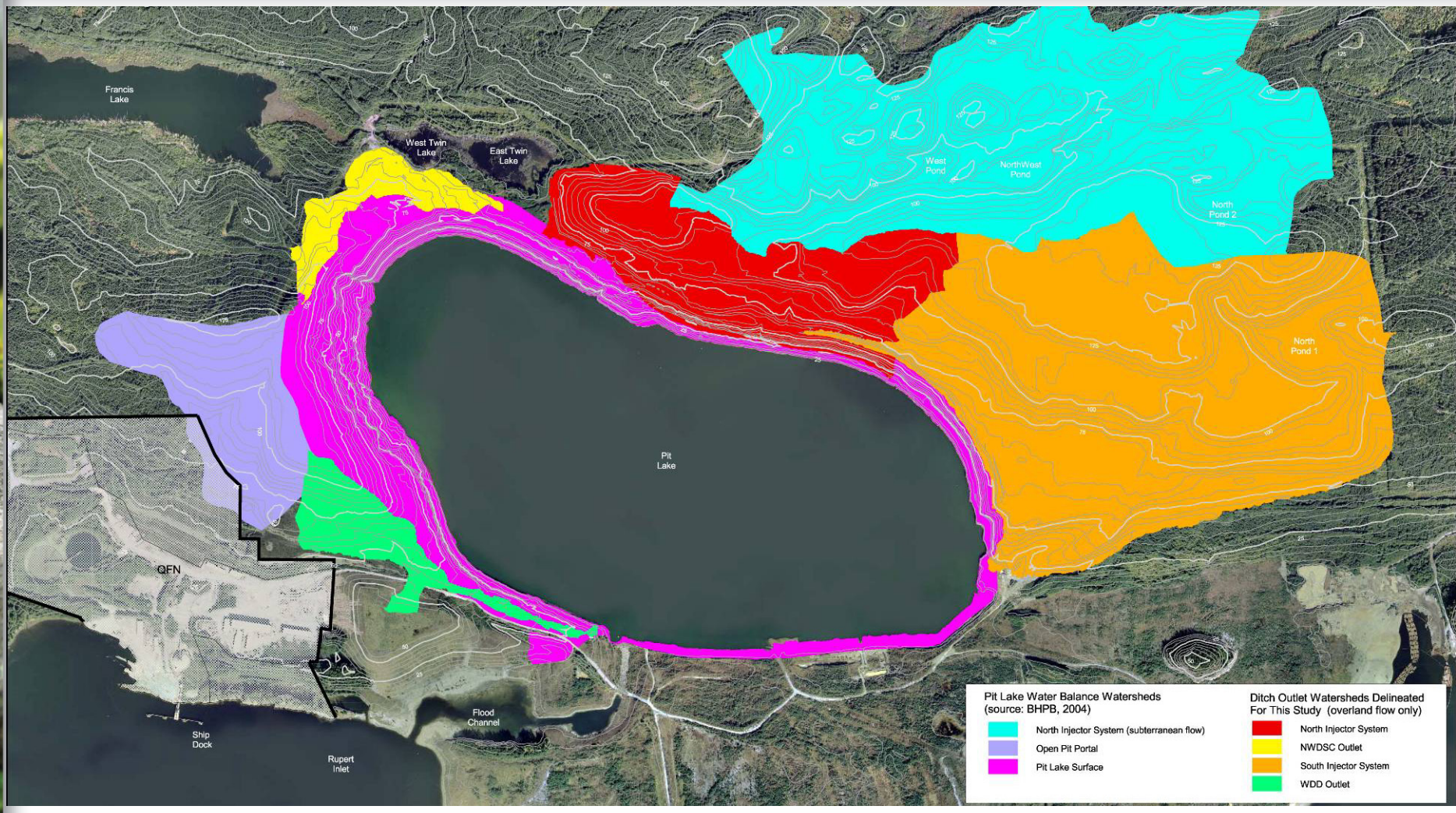


# Island Copper Upland Watersheds (2005)





# Pit Lake Water Balance

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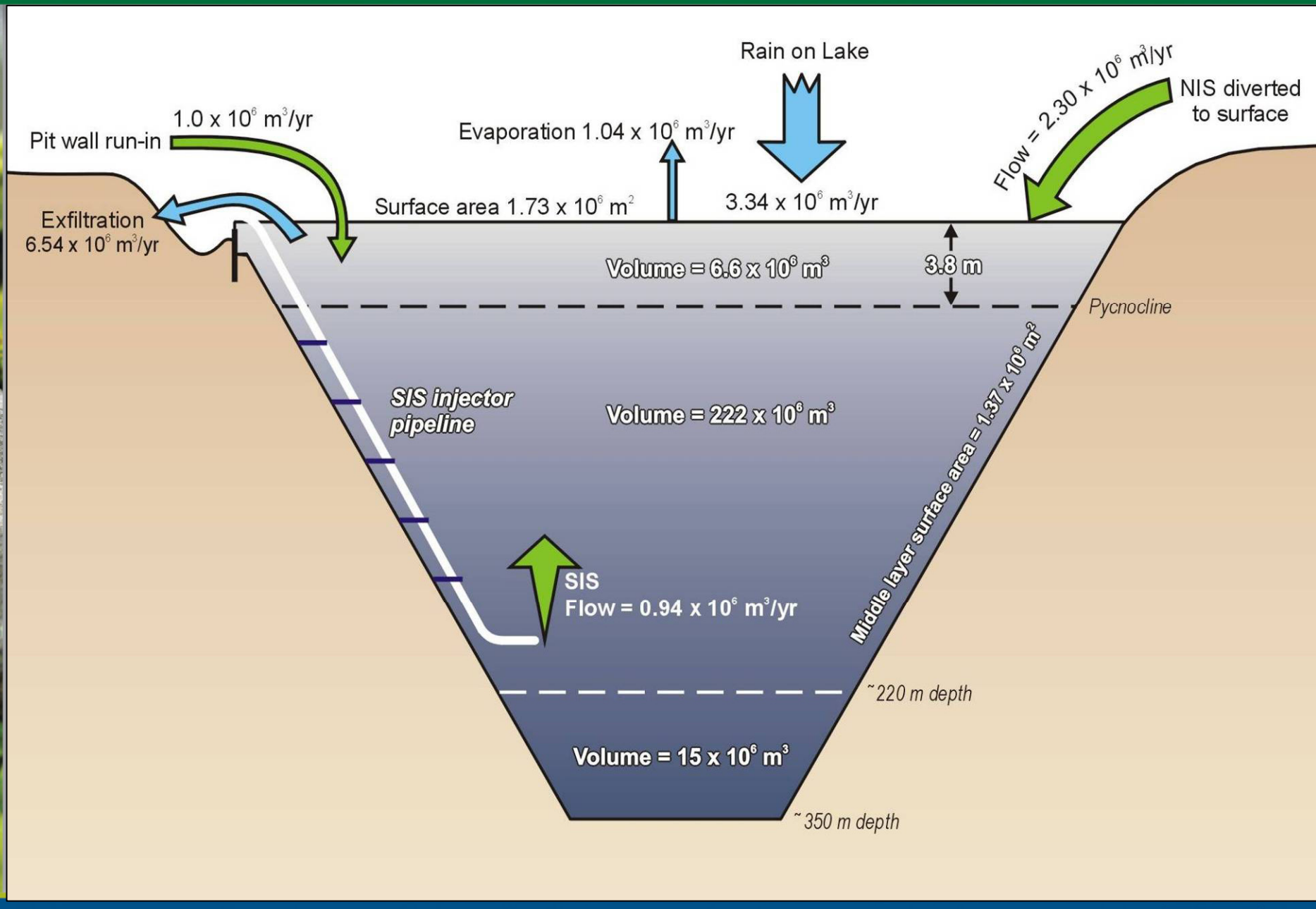
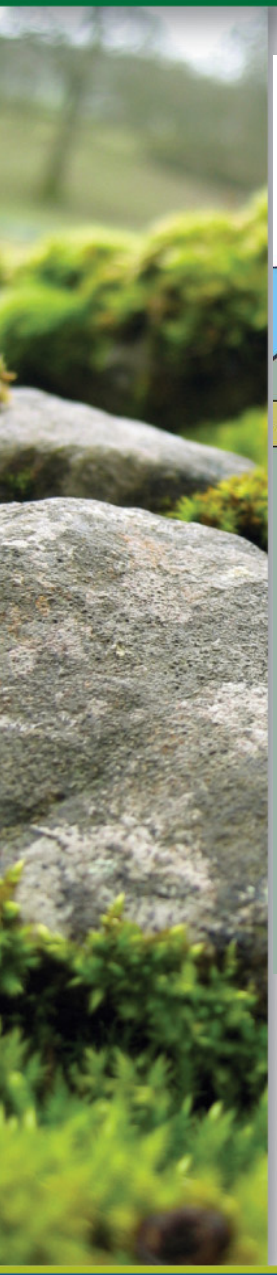


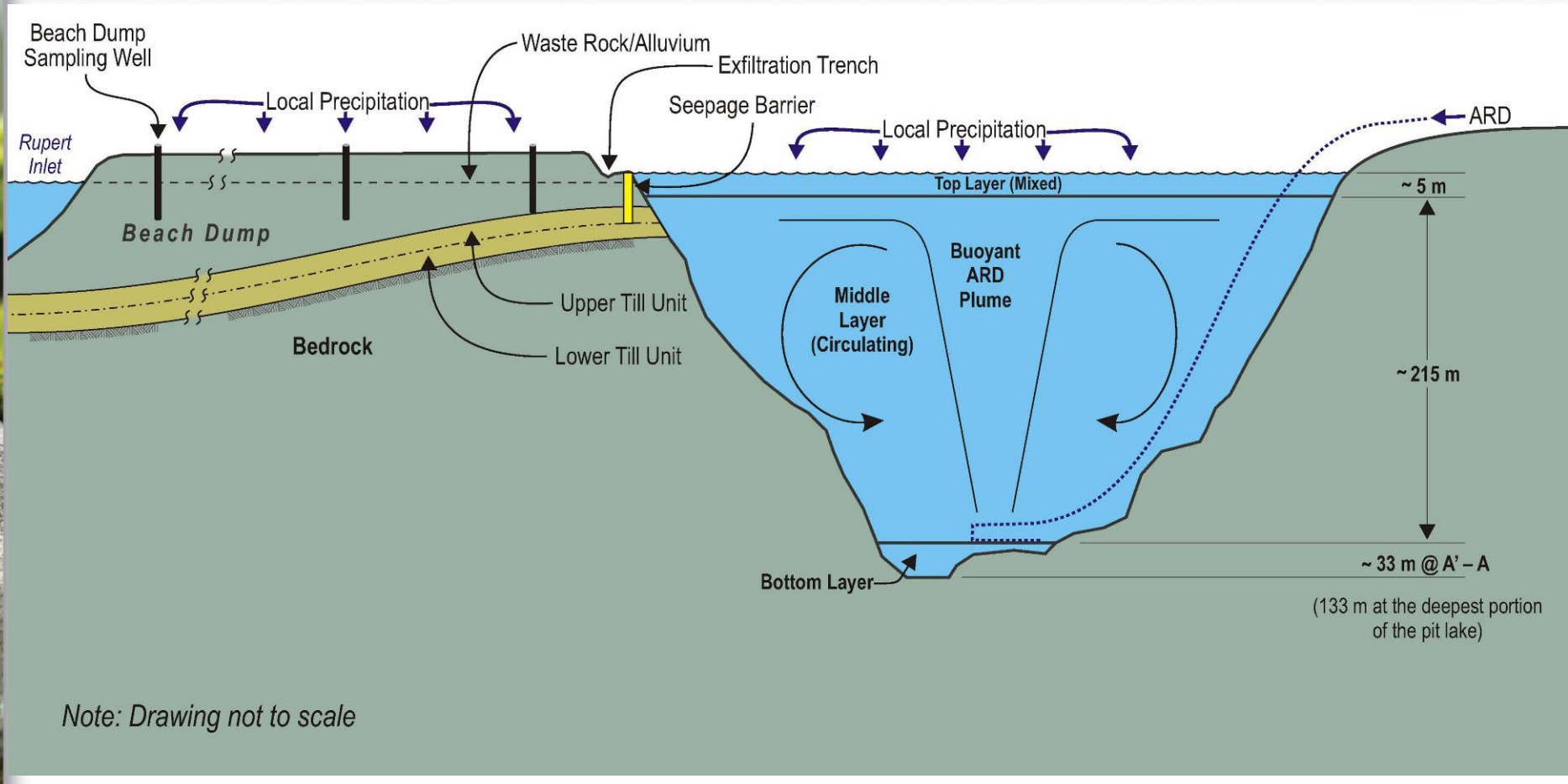
# Pit Lake General Flows



# Pit Lake Cross Section (N-S) Showing Seepage Barrier and Route to Beach Dump

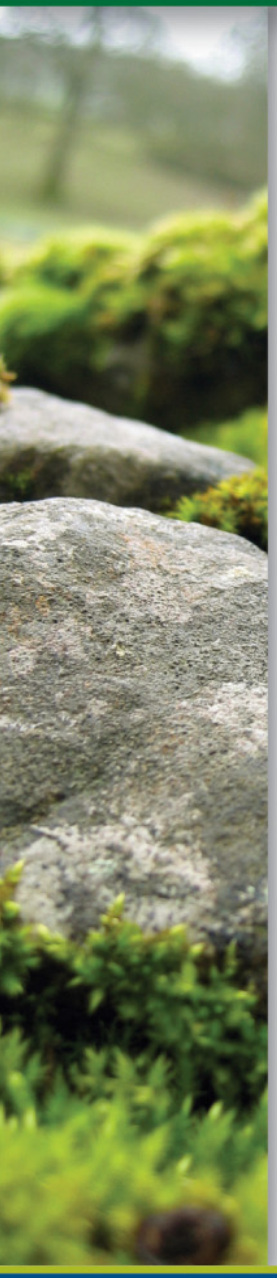






# Average NIS, SIS and MLL Metal Concentrations, 2005



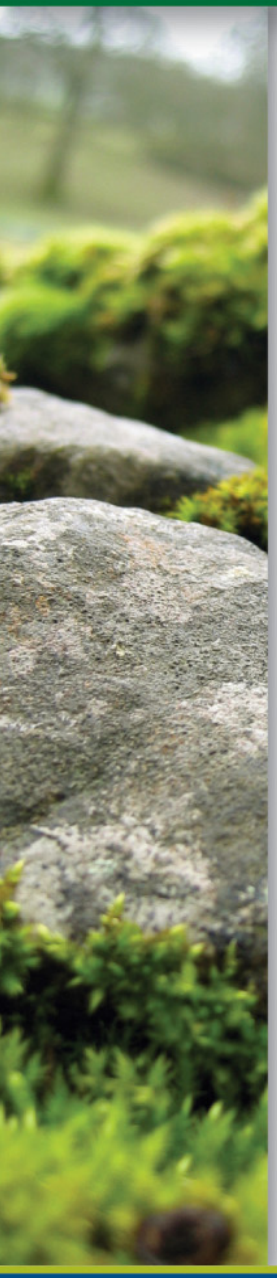


| | Volume Weighted Average (mg/L) | | |
|---|---|---|---|
| | **Dissolved Zinc** | **Dissolved Copper** | **Dissolved Cadmium** |
| NIS (to Top Layer) | 3.176 | 0.044 | 0.020 |
| SIS (to Middle Layer) | 7.492 | 1.407 | 0.040 |

Pit Lake compliance limits:
Zn = 1 mg/L
Cu = 0.05 mg/L
Cd = 0.01 mg/L

# Pit Lake Fertilization Program

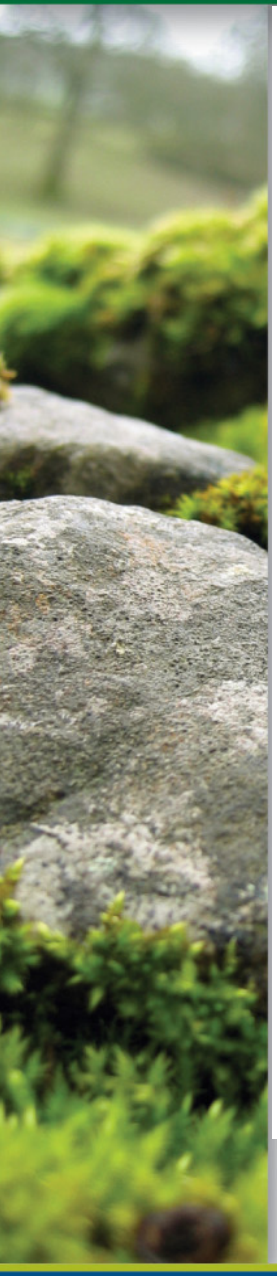


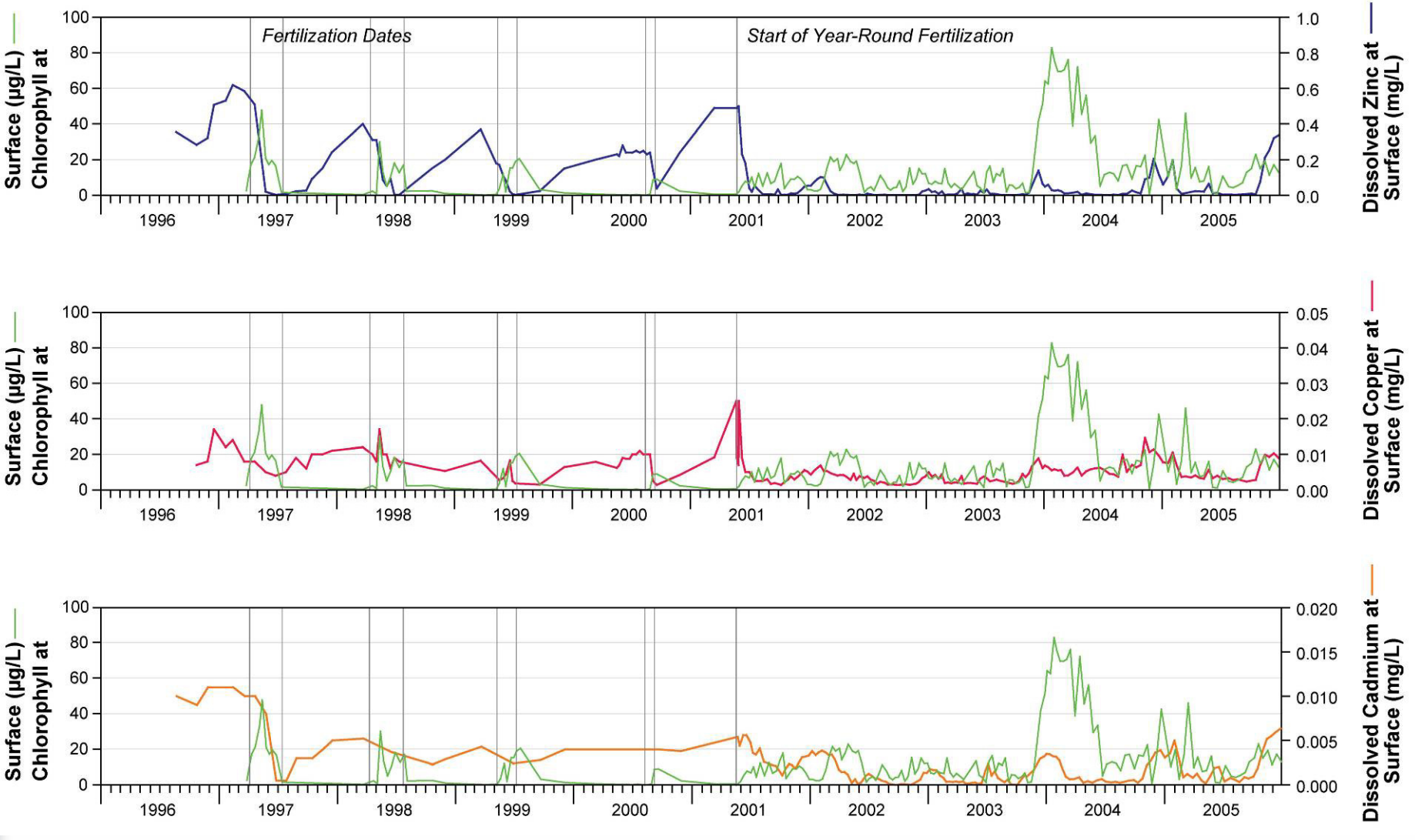


- Weekly addition of liquid fertilizer, year-round since 2001.
- Ammonium Polyphosphate (10-34-0), Urea Ammonium Nitrate (28-0-0).
- Delivered to site by tanker truck.
- 1,700 L of fertilizer is mixed into to surface layer using the propeller wash of a boat.
- Application rate is equivalent to approximately 300 mg $N/m^2$ and 50 mg $P/m^2$ per week.

# Pit Lake Time Series of Chl. *a*, Dissolved Zn, Cu, Cd at 1 m Depth

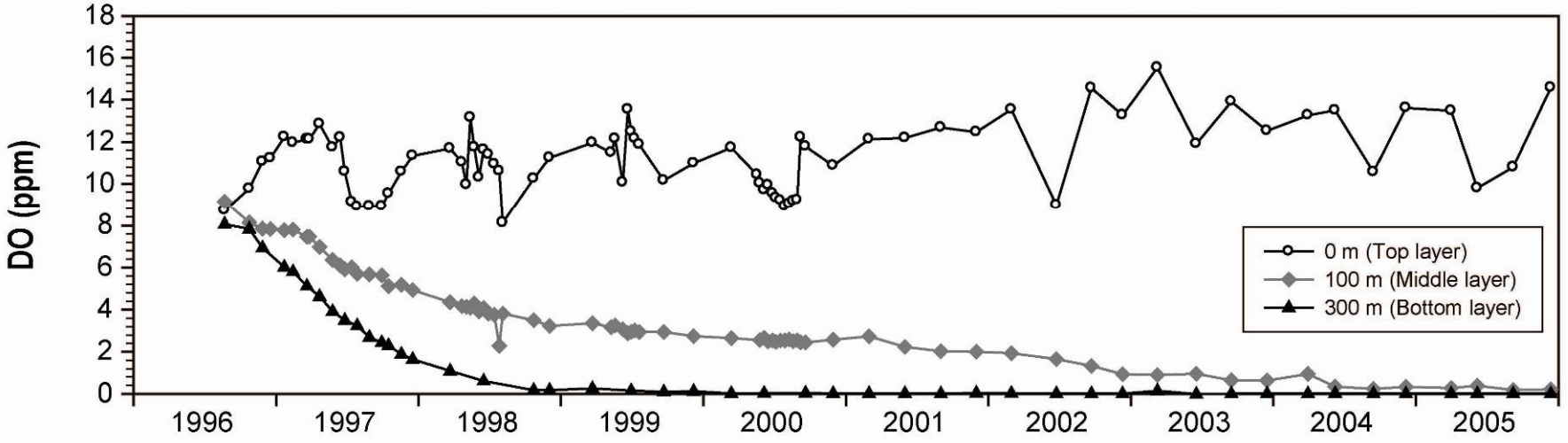






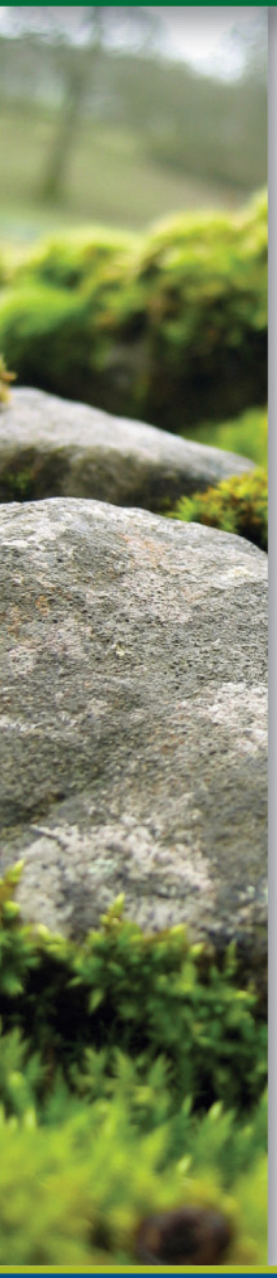
# Pit Lake Dissolved Oxygen, 1996-2005

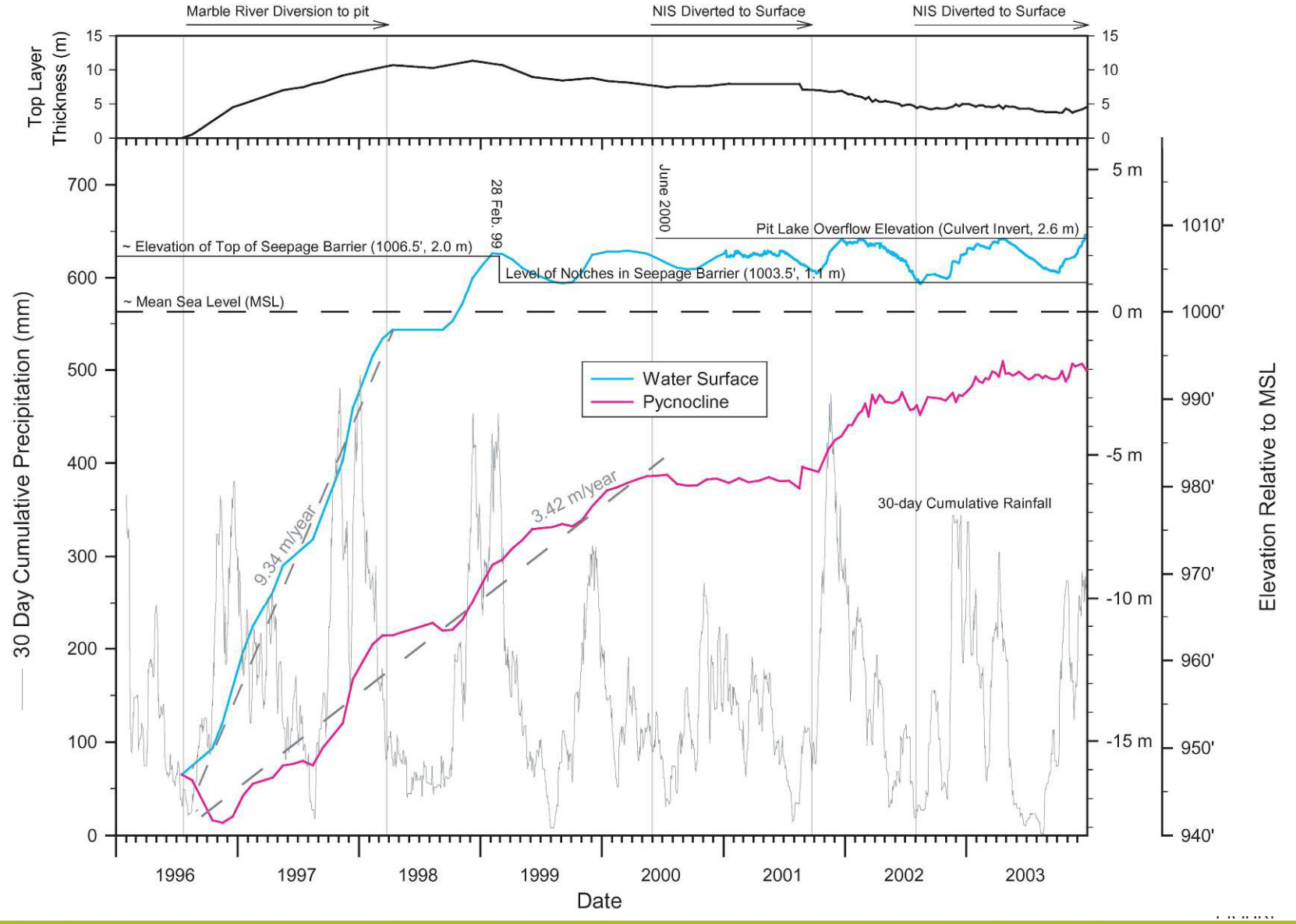




# The Rising Pycnocline Elevation







# Pit Lake Pilot Study to Treat SIS Water and Manage Pycnocline

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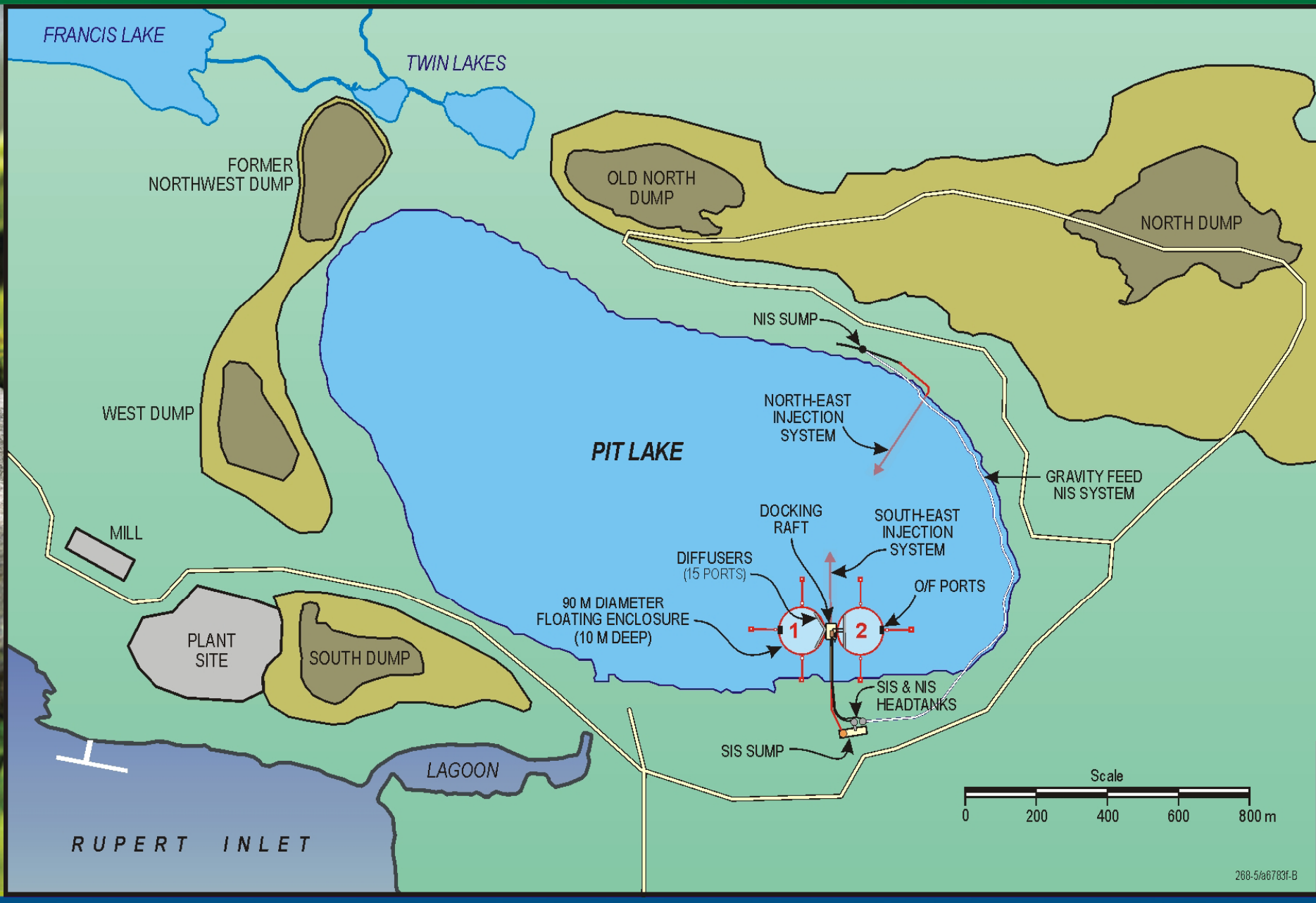

# Pit Lake Pilot Test Facility

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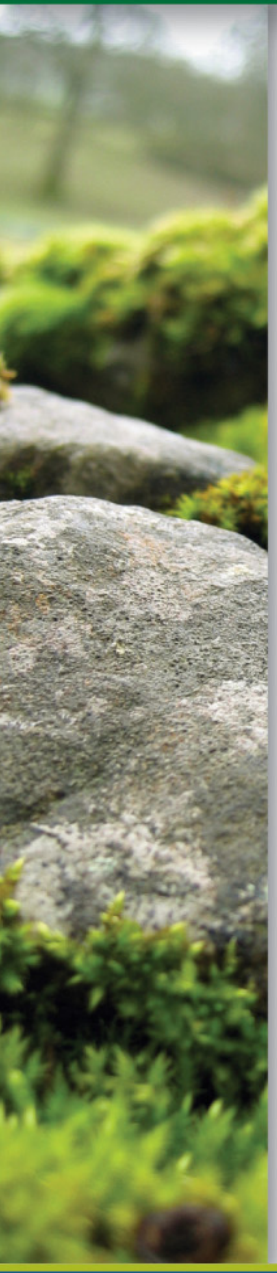
# Pit Lake Pilot Test Facility – Barrier Curtain



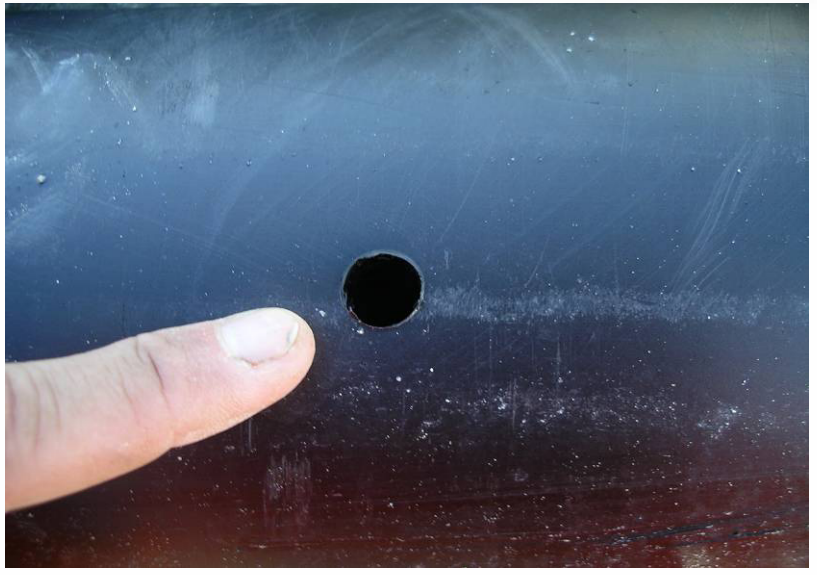
# Pit Lake Pilot Test Facility – Head Tanks and Access

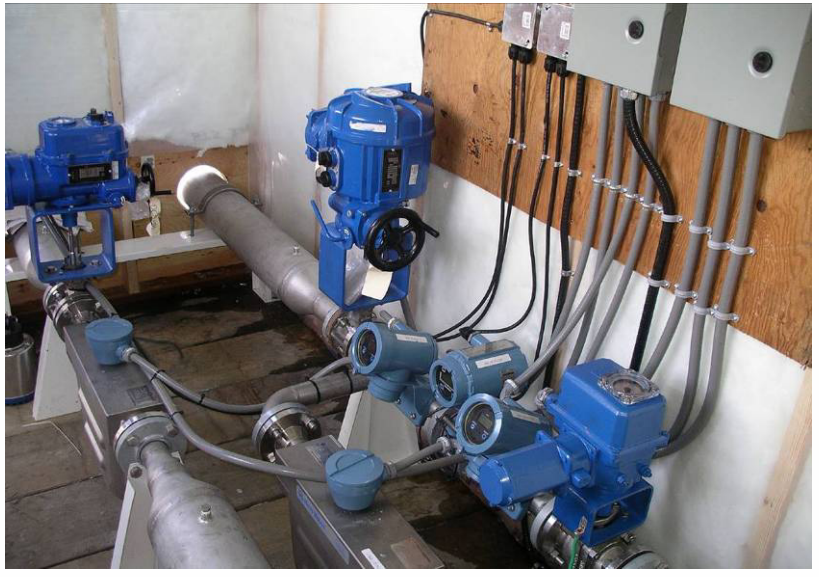





# Pit Lake Pilot Test Facility – Water Distribution

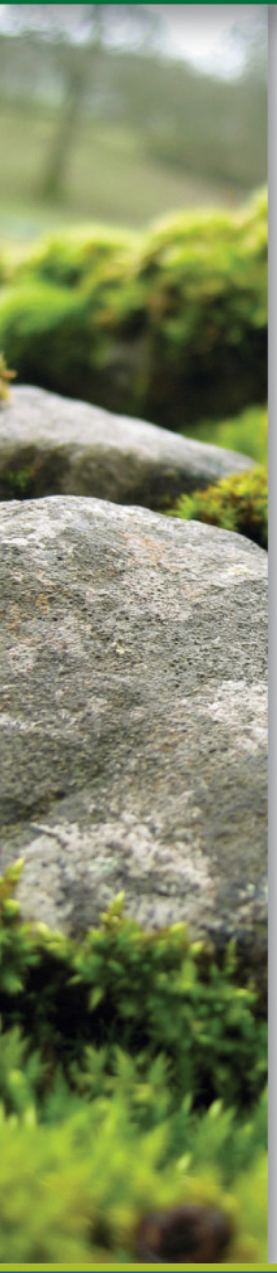


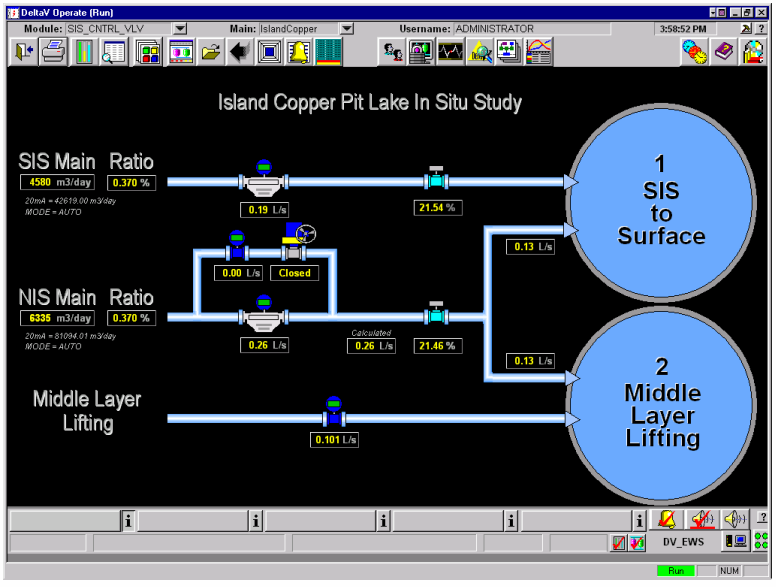




# Pit Lake Pilot Test Facility – Control System







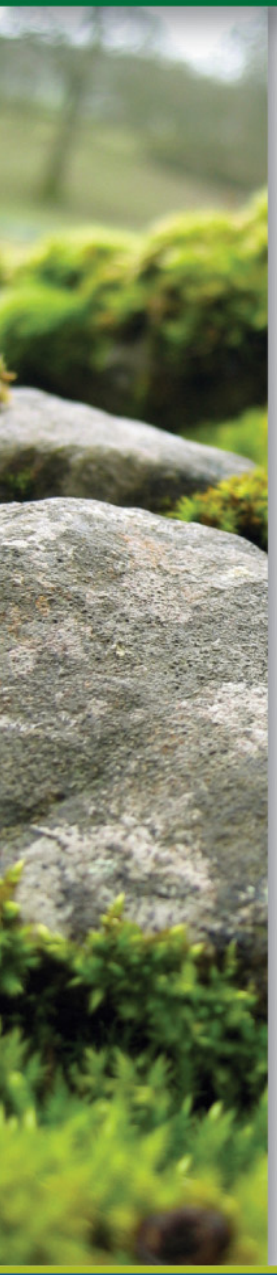
# Construction of Full Scale MLL System

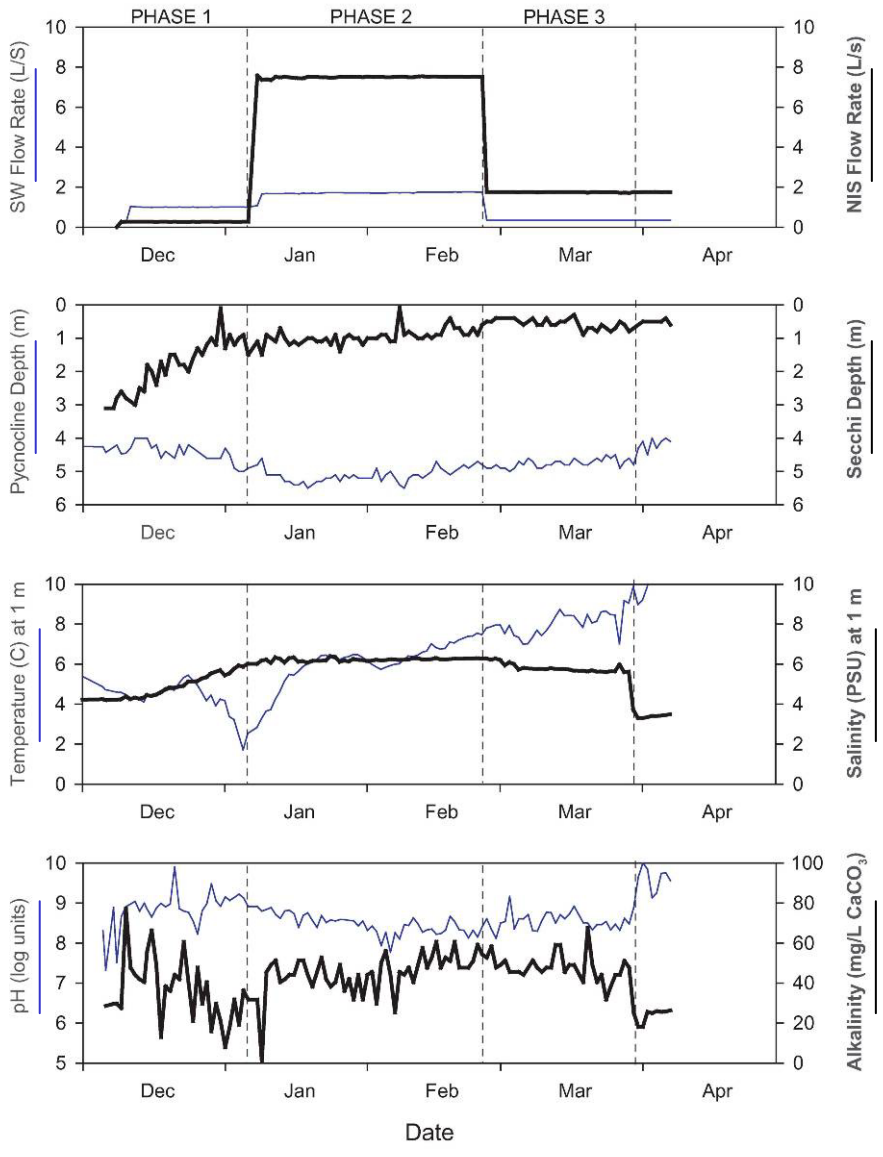


| Description | Enclosure 1<br>SIS + NIS Diversion to Surface | Enclosure 2<br>Middle Layer Pumped to Top Layer + NIS |
|---|---|---|
| Enclosure Diameter (m) | 90 | 90 |
| Enclosure Area ($m^2$) | 6,362 | 6,362 |
| Proportional Area Relative to Lake Area (172 ha) | 0.37% | 0.37% |
| Enclosure Depth (m) | 11 | 11 |
| Enclosure Total Volume ($m^3$) | 69,982 | 69,982 |
| Volume Above Pycnocline ($m^3$) | 24,176 | 24,176 |
| Max Flow Rate 1997-2002 (NIS $m^3/d$) | 63,000 | 63,000 |
| Proportional Max Flow Rate for Study (L/s) | 2.7 | 2.7 |
| Max Flow Rate 1997-2002 (SIS $m^3/d$) | 25,820 | - |
| Proportional Max Flow Rate for Study (L/s) | 1.1 | - |
| Middle Layer Lifting Based on 1 M $m^3/yr$ (L/s) | - | 31.8 |
| Proportional Max Flow Rate for Study (L/s) | - | 0.12 |
| Design Max Capacity for Flows (L/s) | SIS – 8.0<br>NIS – 8.0 | Seawater 4.0<br>NIS 8.0 |

# Middle Layer Lifting Influent and Response

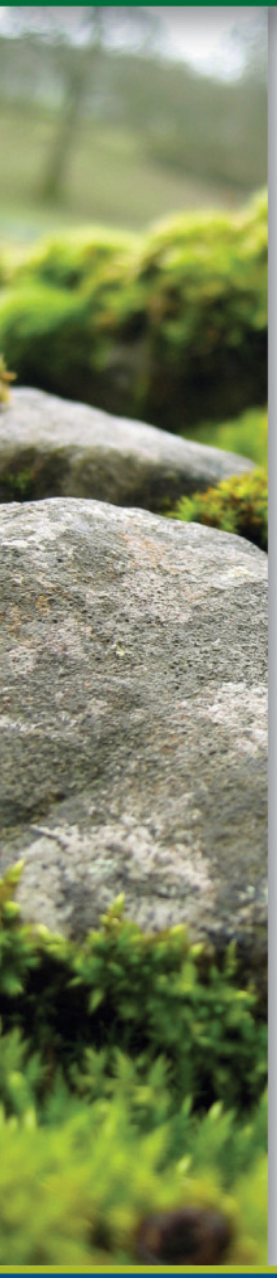


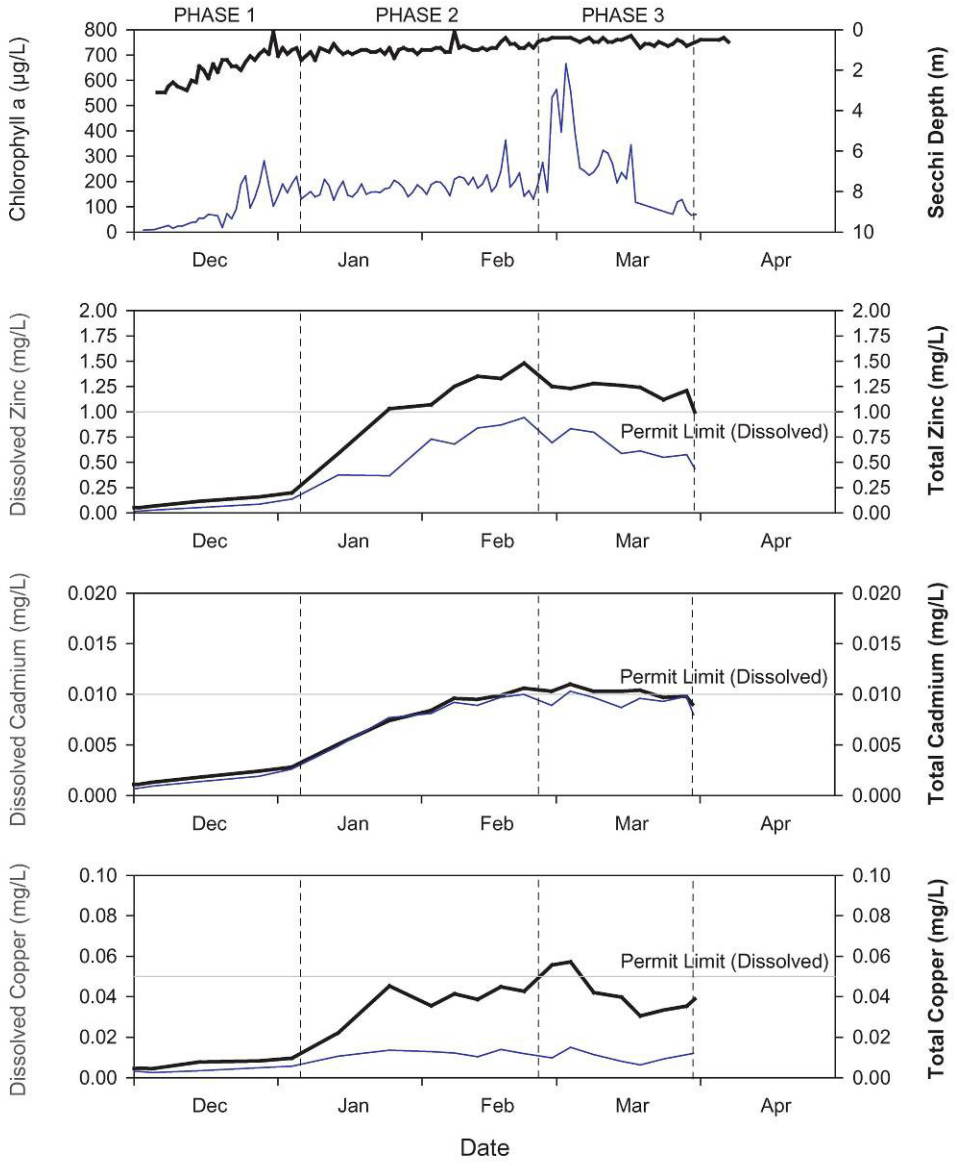




# Middle Layer Lifting Chlorophyll *a*, Secchi Depth, and Dissolved Metals

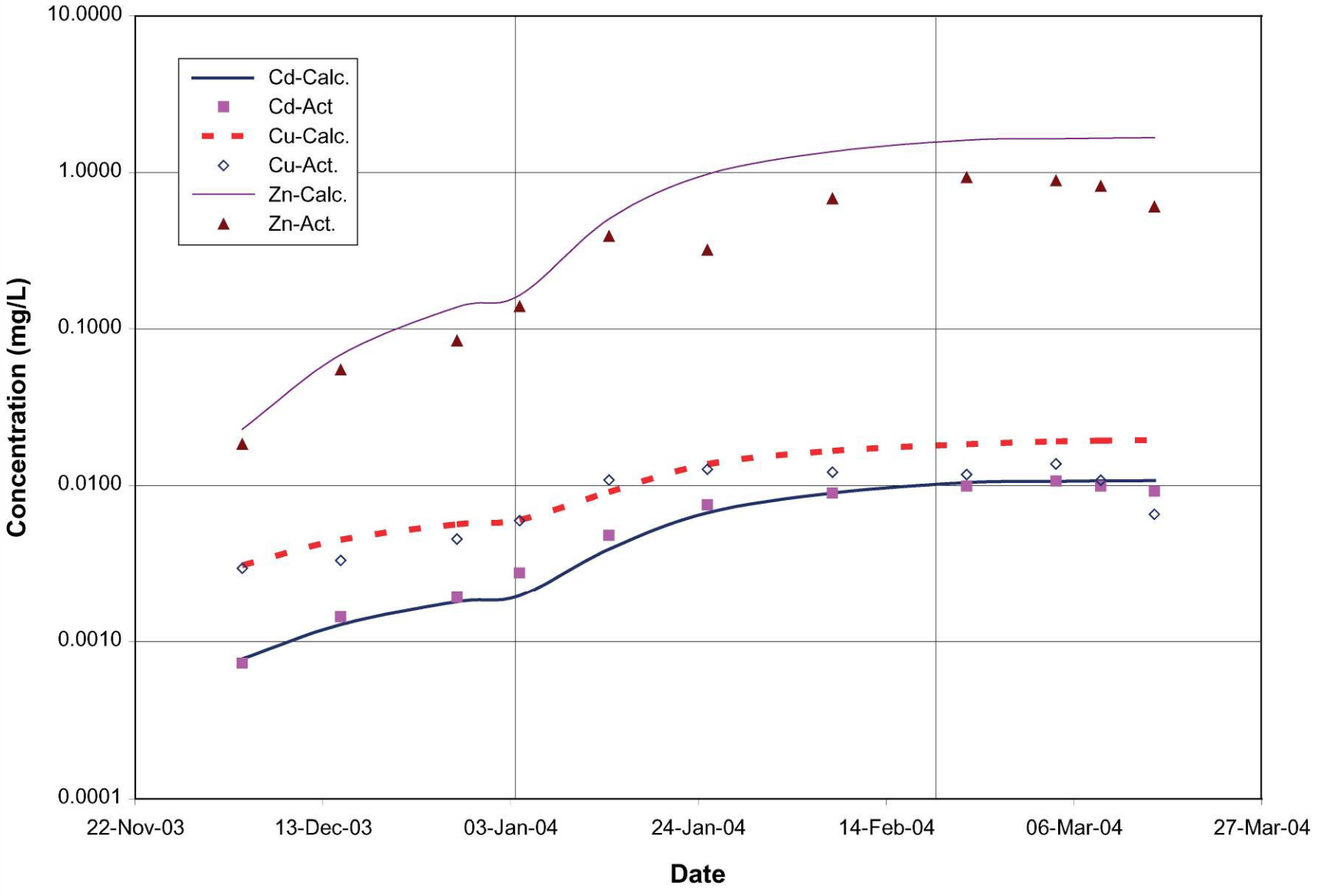






# Mass Balance Calculation and Actual Dissolved Metal Concentrations in the Middle Layer Lifting Enclosure





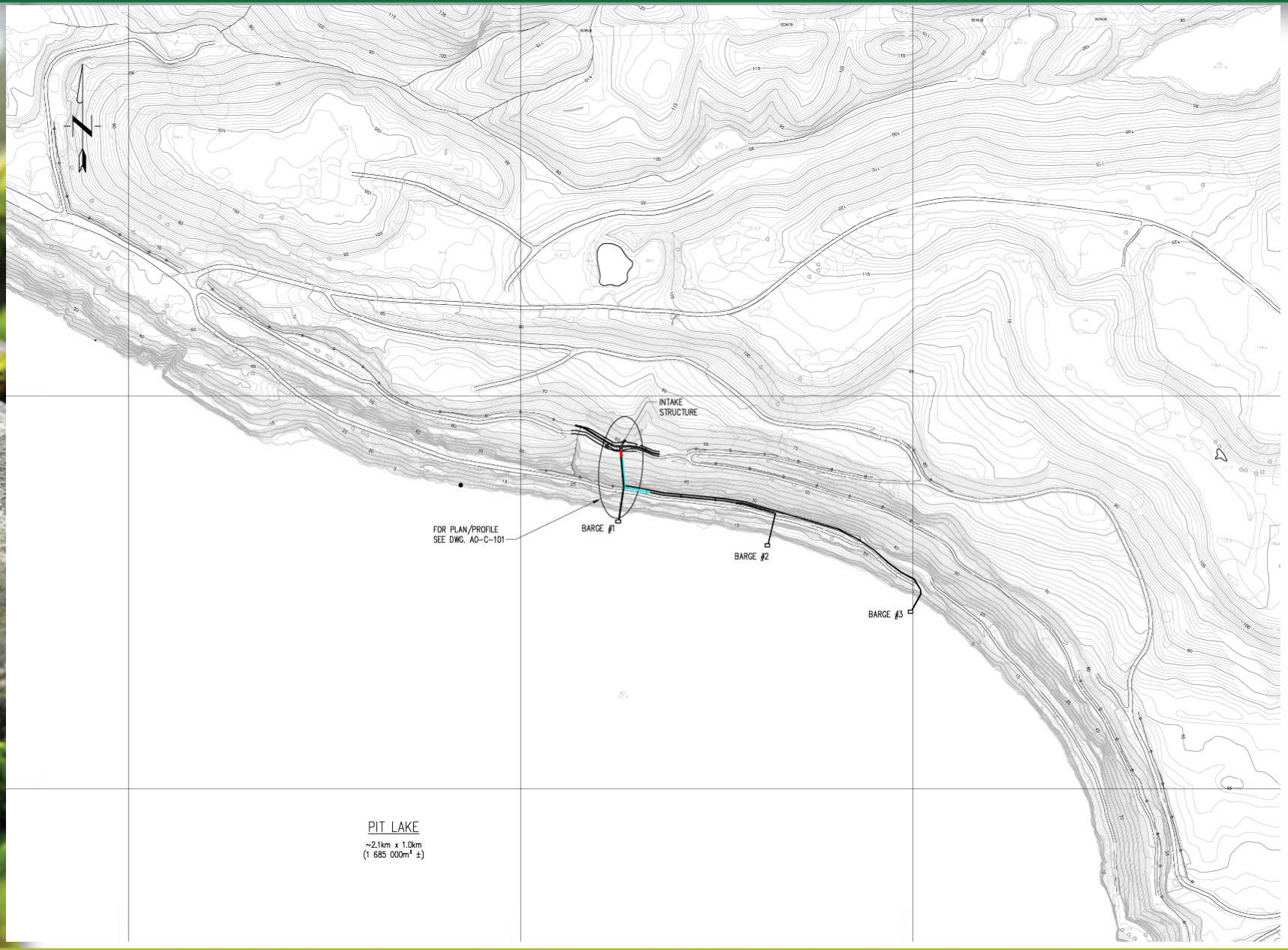
# Middle Layer Lifting Results



| Phase | Date | Estimated Net Removal | | |
|---|---|---|---|---|
| | | D-Cd | D-Cu | D-Zn |
| I (Conditioning) | 04-Jan-04 | 0% | 1% | 15% |
| II (Controlled Accelerated Test) | 14-Jan-04 | 0% | 0% | 23% |
| | 25-Jan-04 | 0% | 7% | 68% |
| III (Long Term Loading Rates) | 08-Feb-04 | 0% | 27% | 50% |
| | 23-Feb-04 | 5% | 36% | 42% |
| | 04-Mar-04 | 0% | 28% | 46% |
| | 09-Mar-04 | **7%** | **44%** | **51%** |
| | 15-Mar-04 | **14%** | **66%** | **64%** |

# Full Scale Middle Layer Lifting Design





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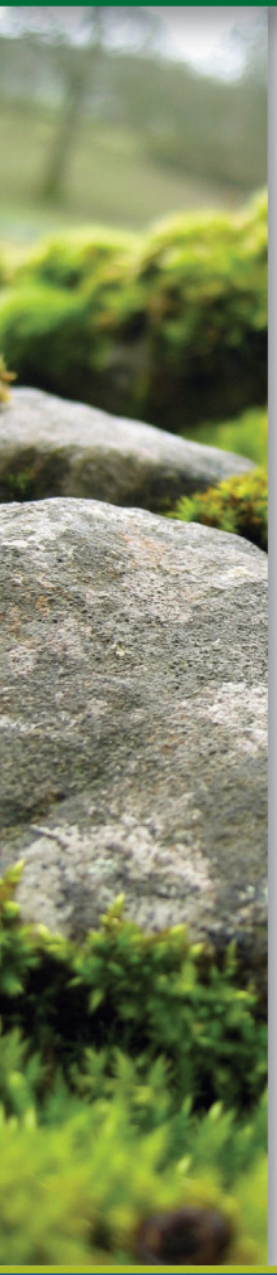
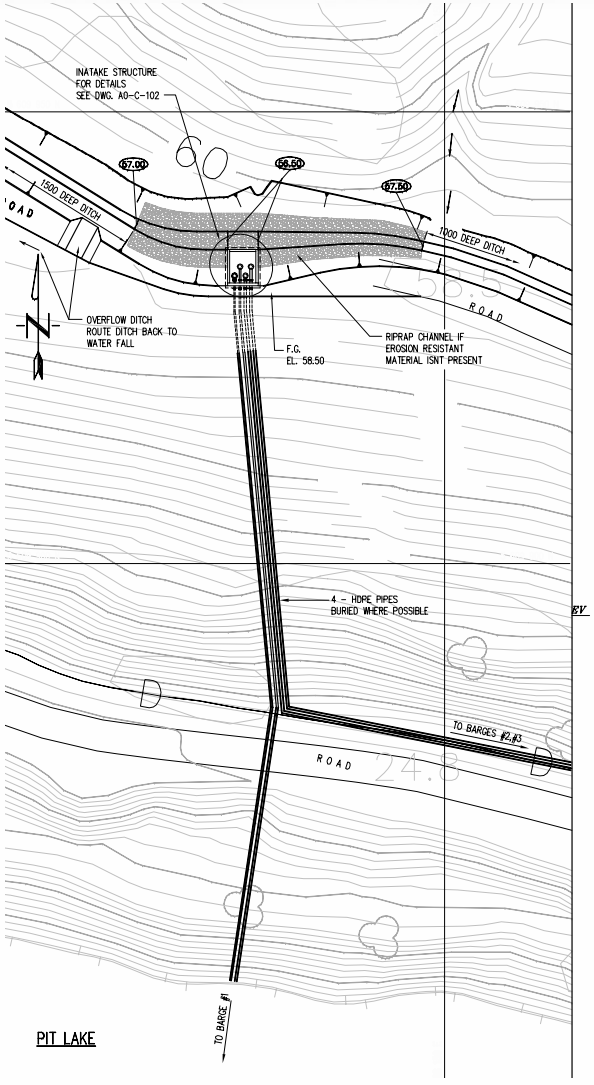
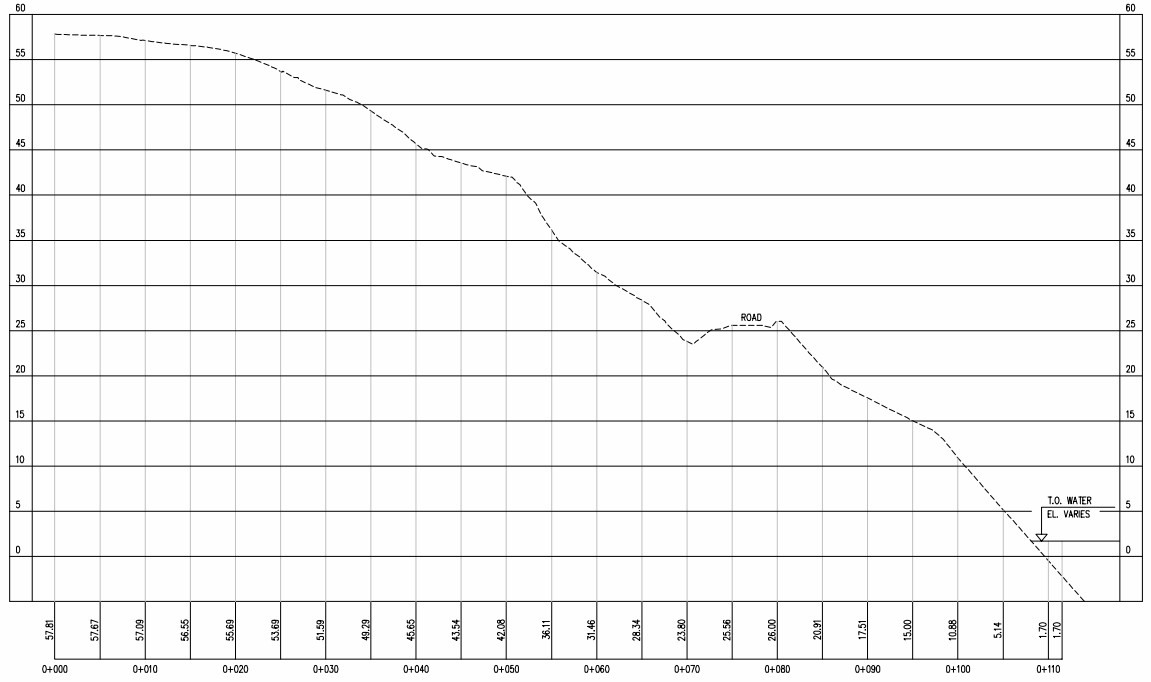


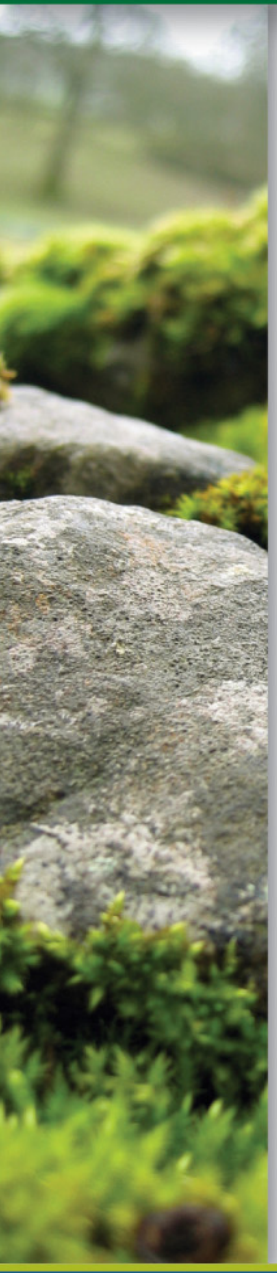


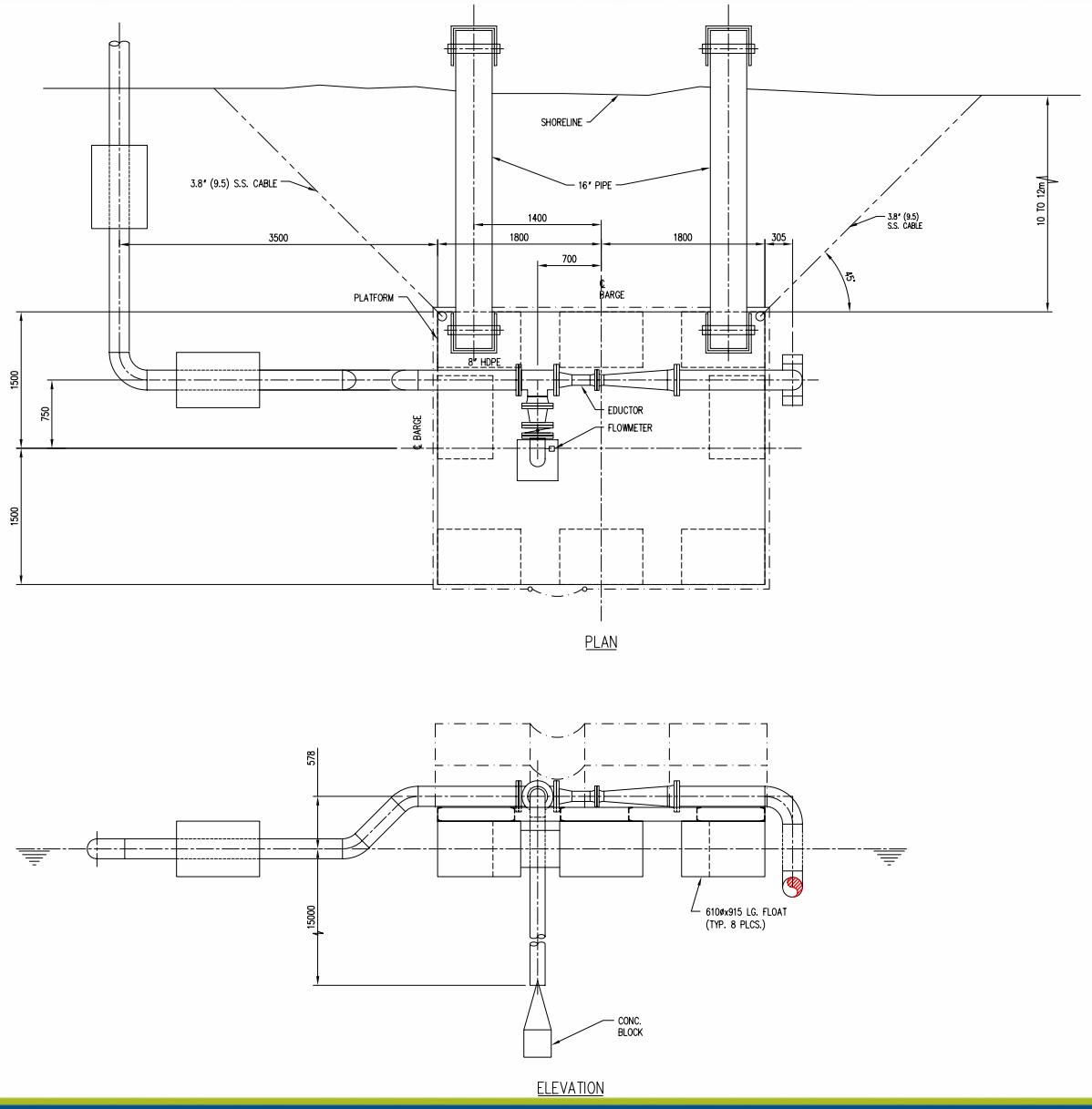




PIPELINE PROFILE

# Full Scale Middle Layer Lifting Design

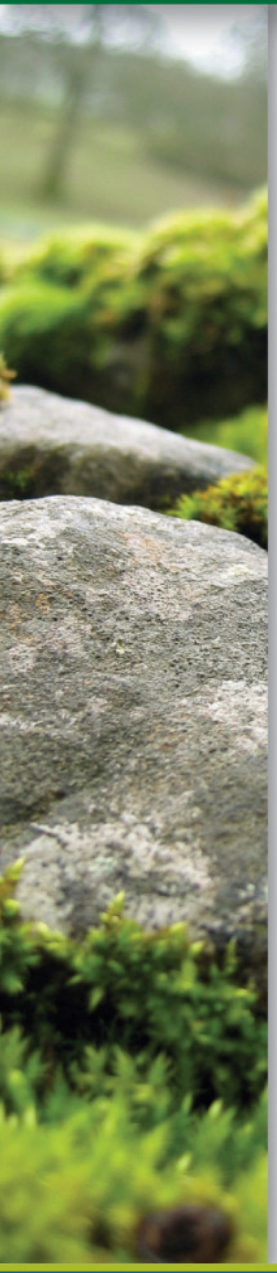


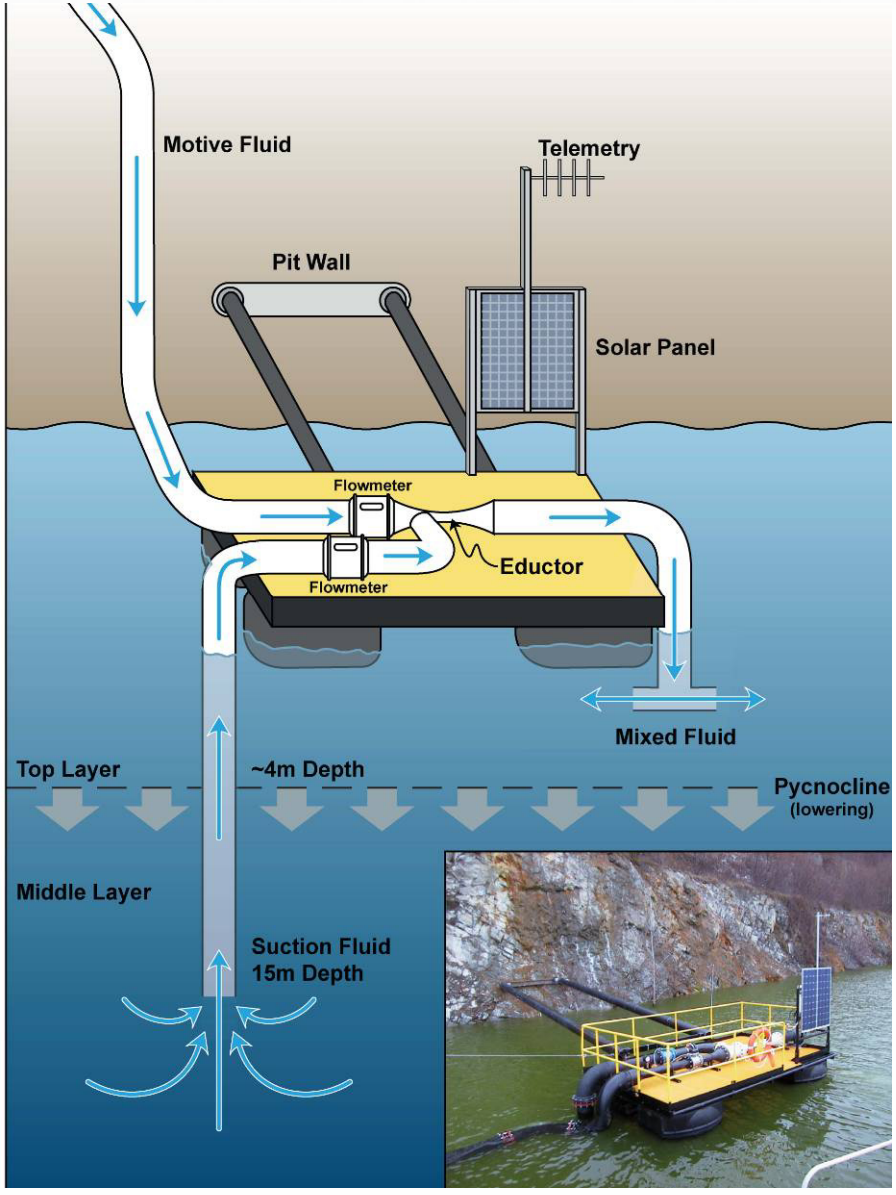




# Schematic of Middle Layer Lifting System







# Middle Layer Lifting System Commissioning, February 2005

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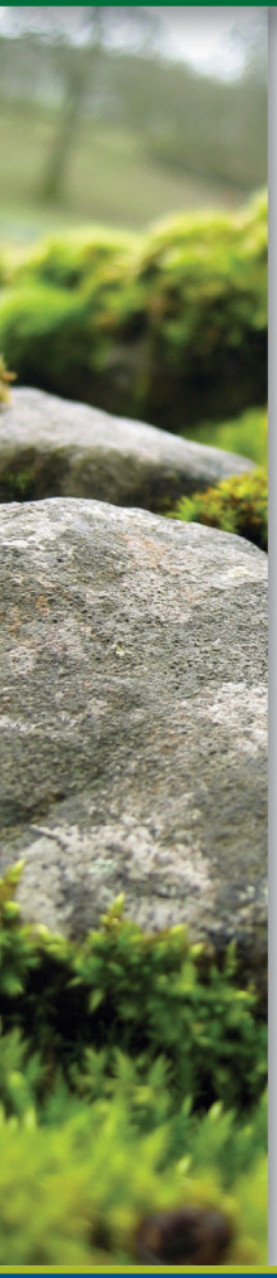
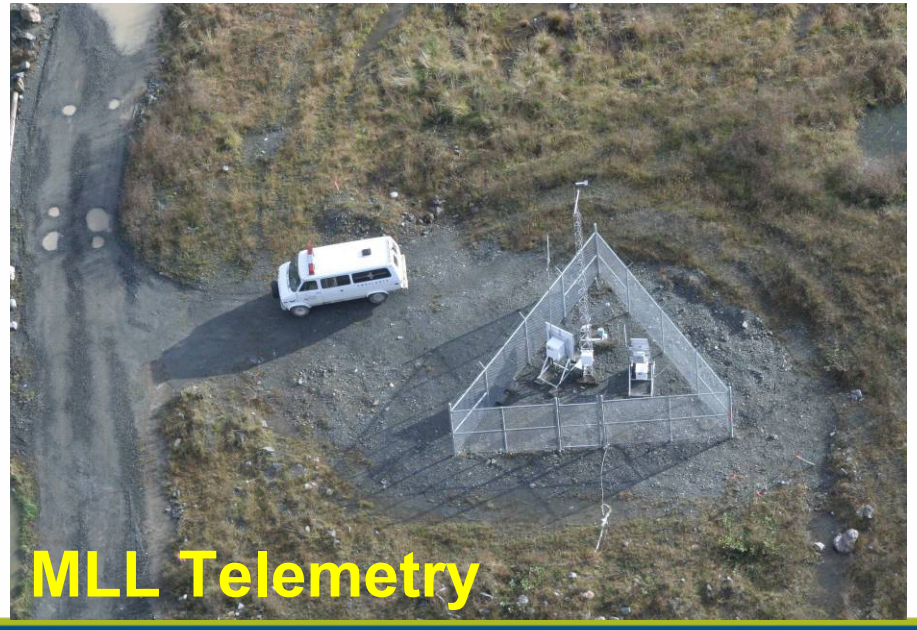
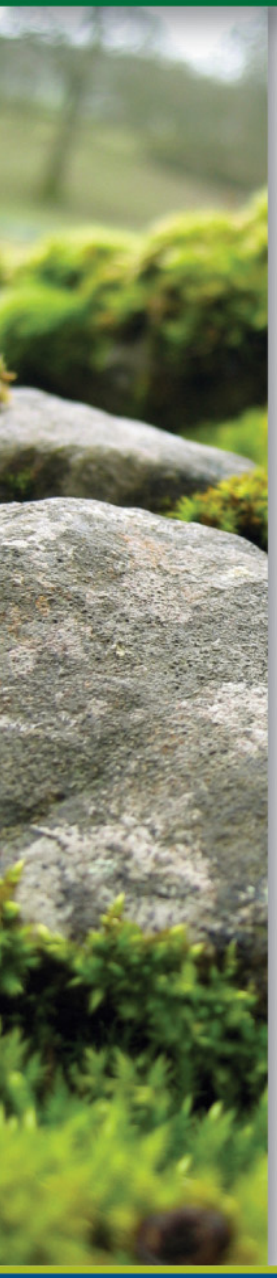


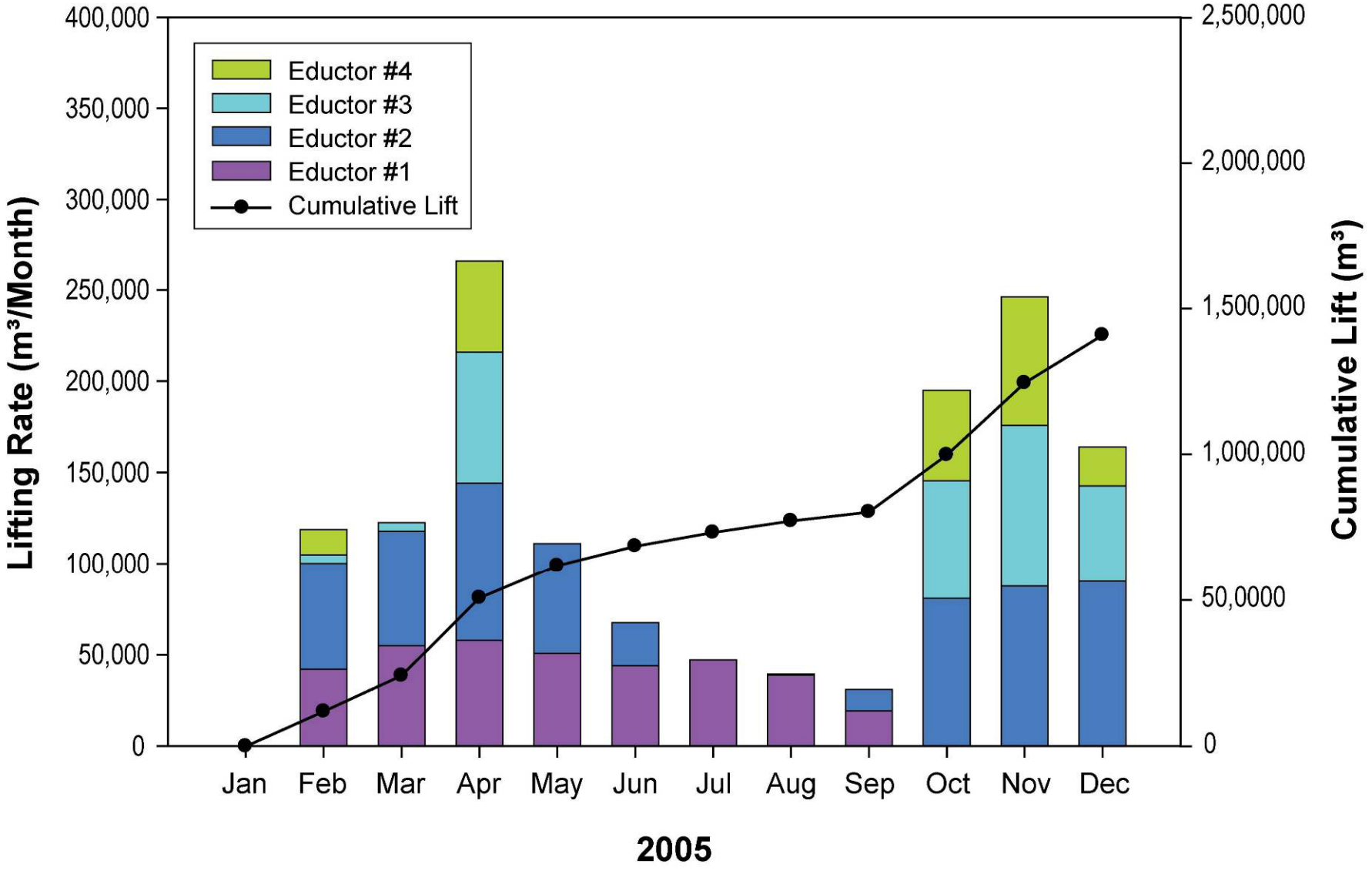


# Middle Layer Lifting Rates in 2005

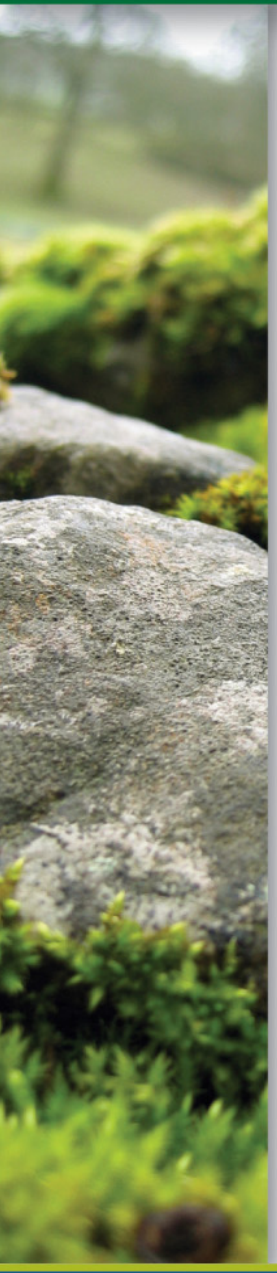


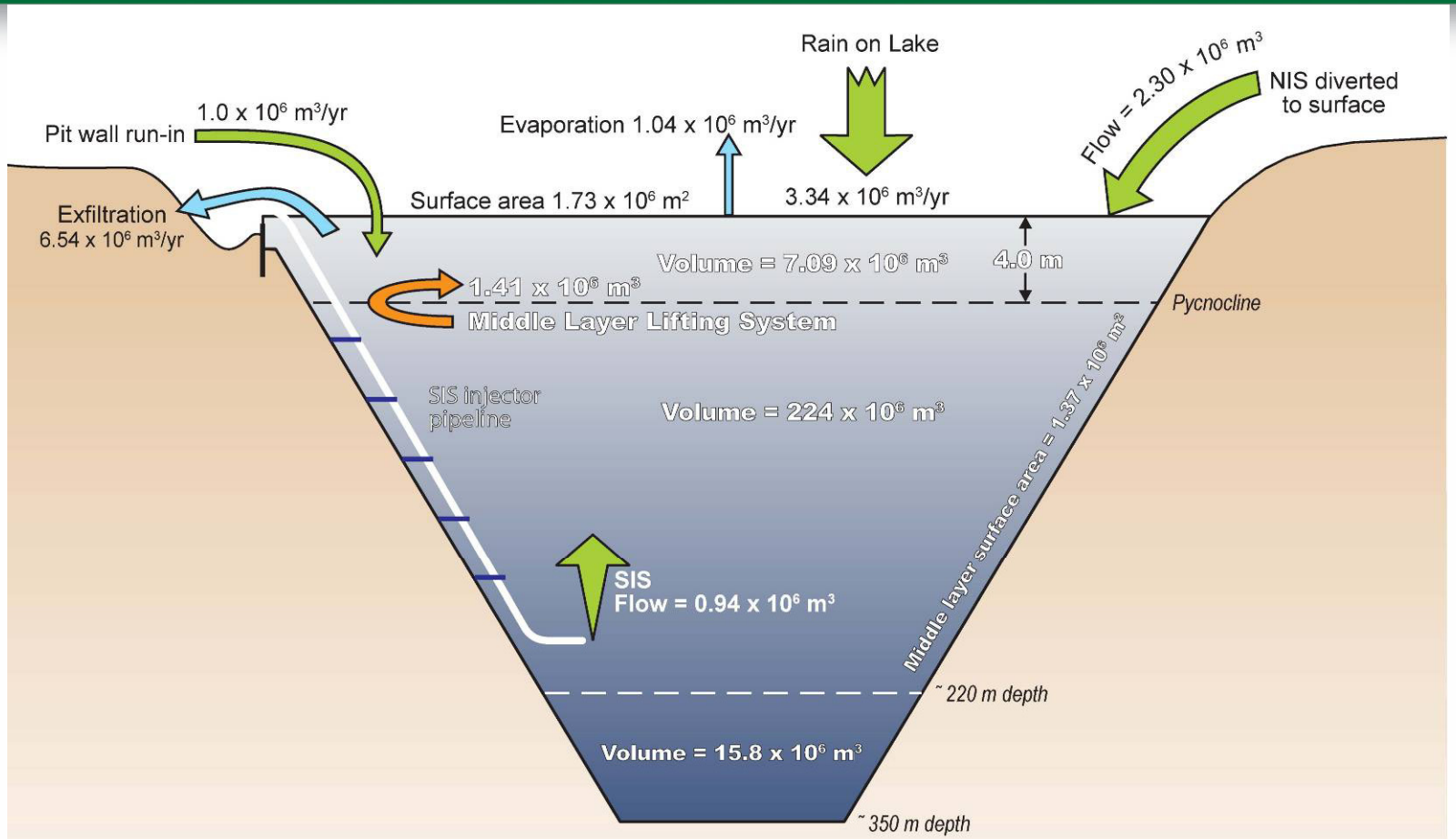




# Pit Lake Water Balance








*References/Souces of Data:*

1) *NIS, SIS and rain on surface are based on averages for 1997 - 2002 (BHPB, 2004b).*
2) *Evaporation loss from Environment Canada - Vancouver Island Estimates.*
3) *Pit wall run-in is equivalent to surface and infiltrating flow estimates (BHPB, 2004b).*
4) *Pit Lake Volumes and top layer thickness are end of 2005 estimates.*
5) *MLL system lifted volume is from 10.5 months of operation.*

# Average NIS, SIS and MLL Metal Concentrations, 2005

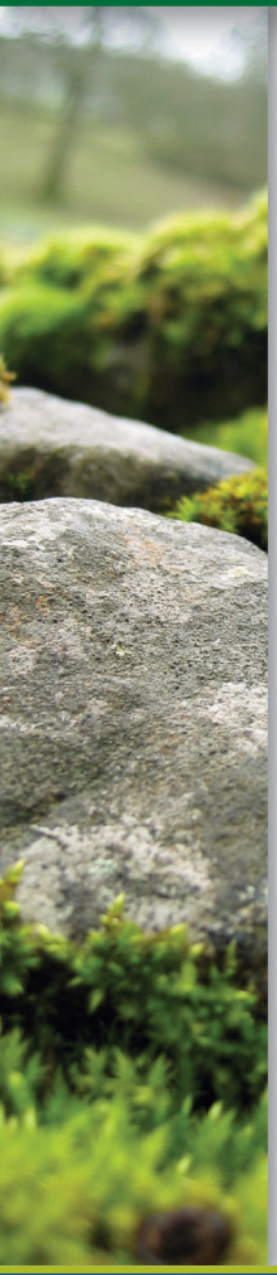


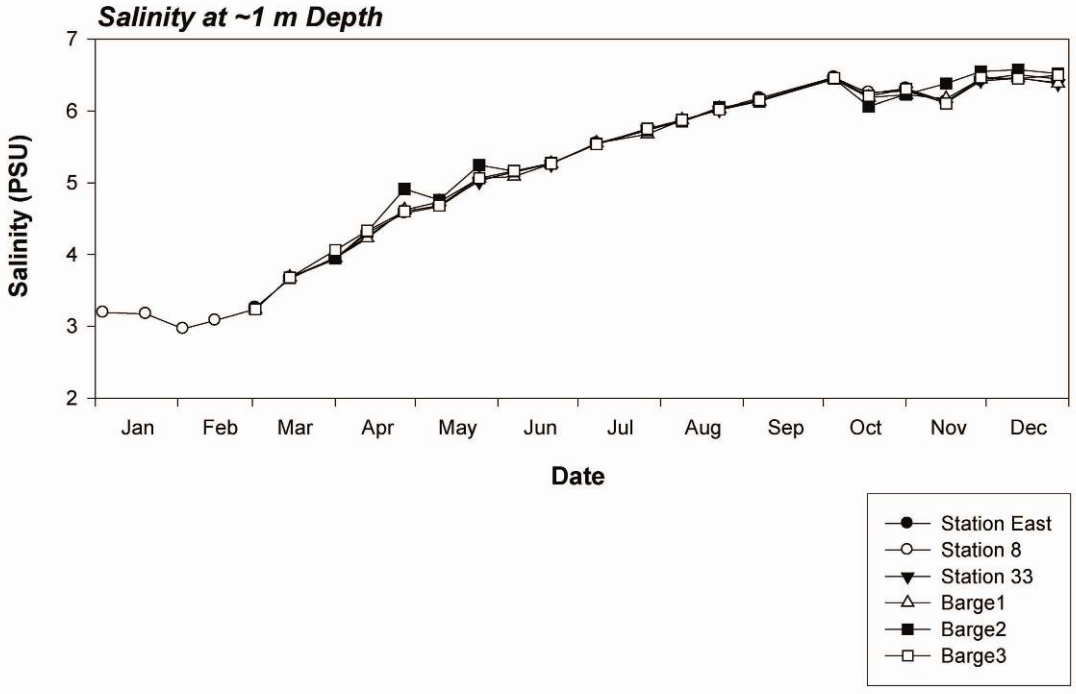
| | Volume Weighted Average (mg/L) | | |
|---|---|---|---|
| | **Dissolved Zinc** | **Dissolved Copper** | **Dissolved Cadmium** |
| NIS (to Top Layer) | 3.176 | 0.044 | 0.020 |
| SIS (to Middle Layer) | 7.492 | 1.407 | 0.040 |
| MLL (to Top Layer) | 0.596 | 0.012 | 0.008 |

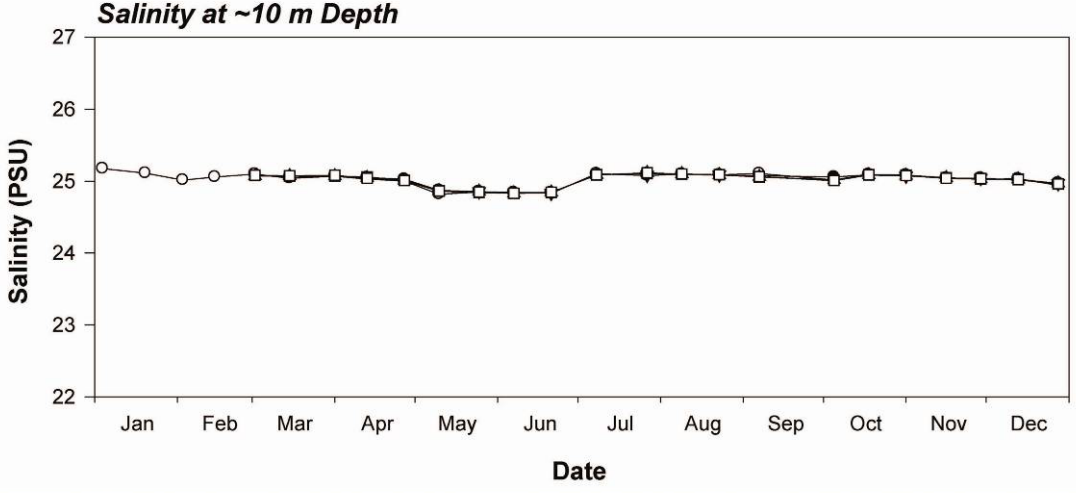
Pit Lake compliance limits:
Zn = 1 mg/L
Cu = 0.05 mg/L
Cd = 0.01 mg/L

# Pit Lake Salinity at 1 and 10 m Depths, 2005





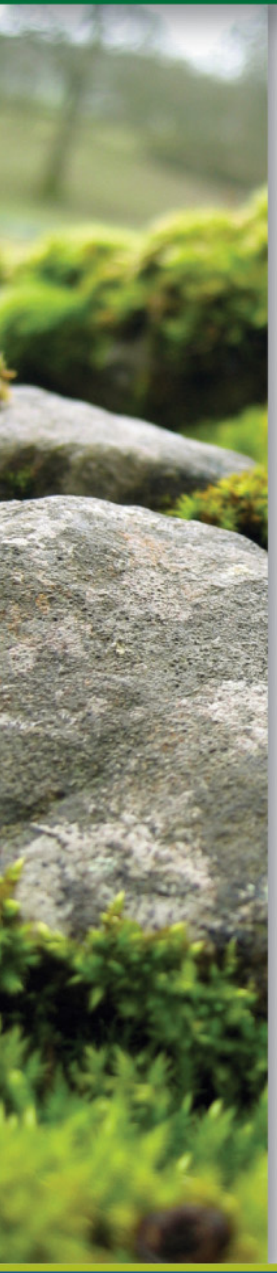


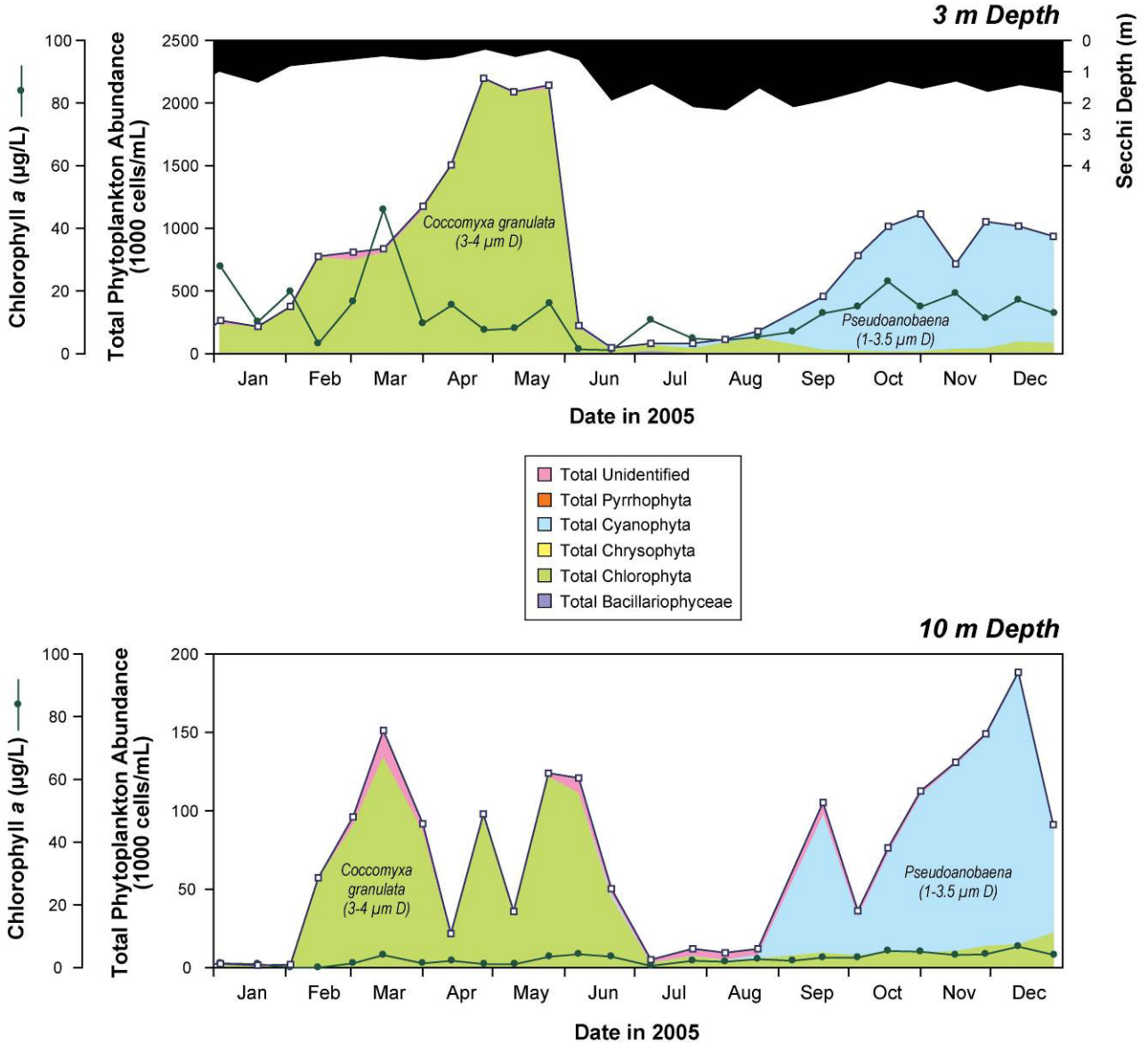




Homogeneous top layer

# Pit Lake Phytoplankton Biomass and Species Composition, 2005

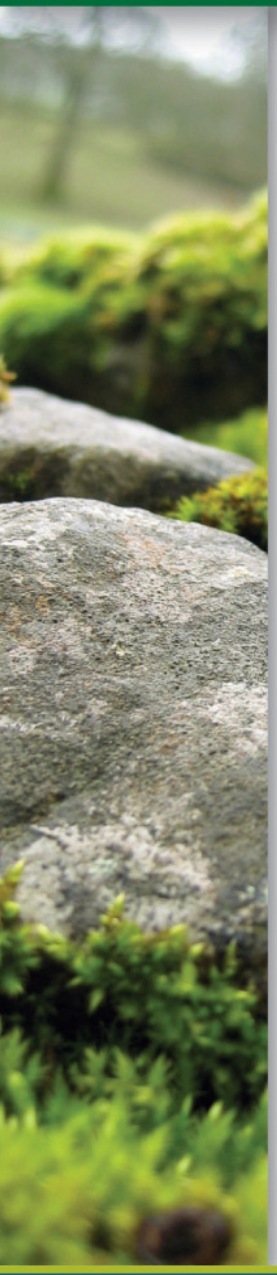


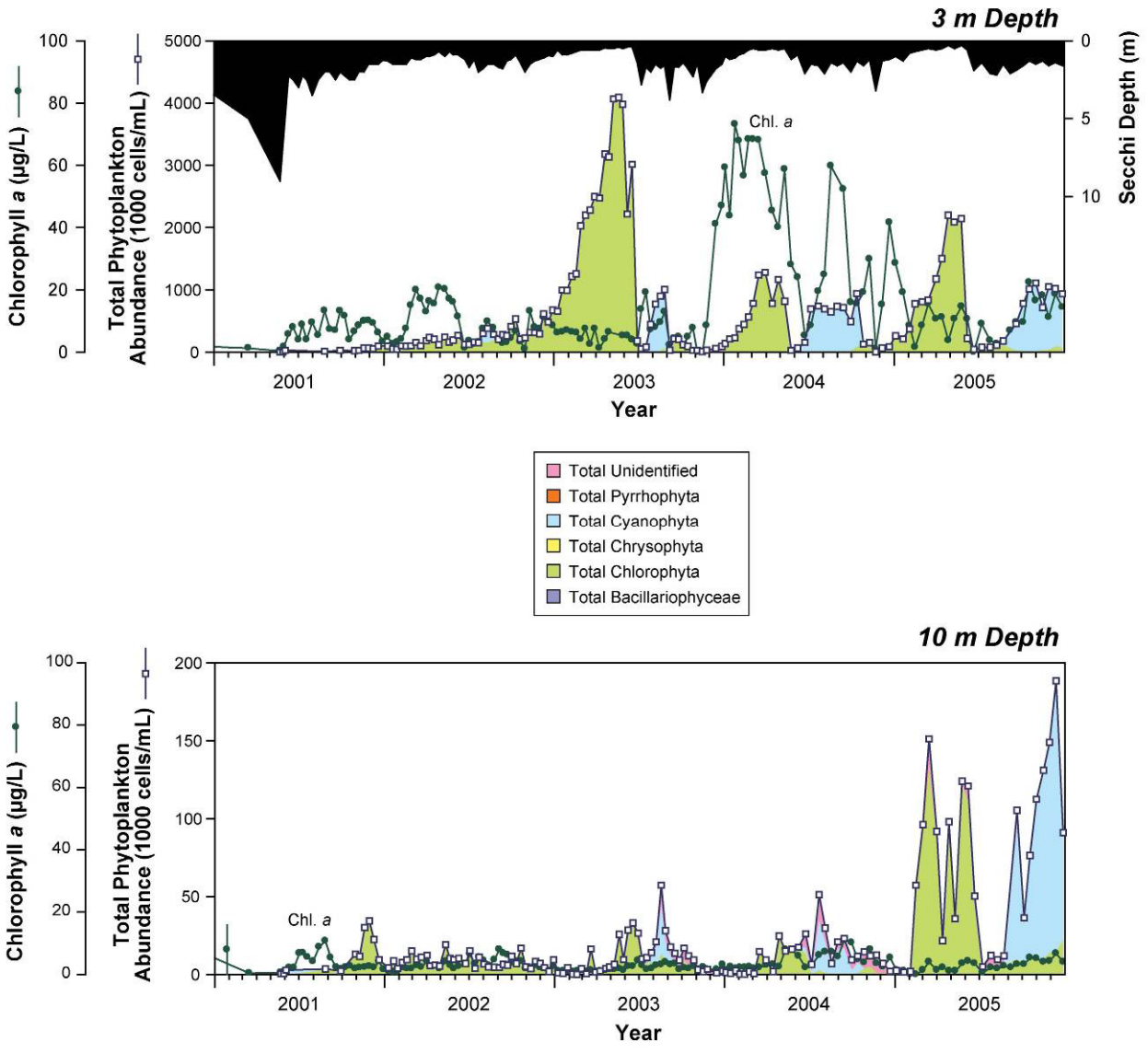




# Pit Lake Phytoplankton Biomass and Species Composition, 2001-05







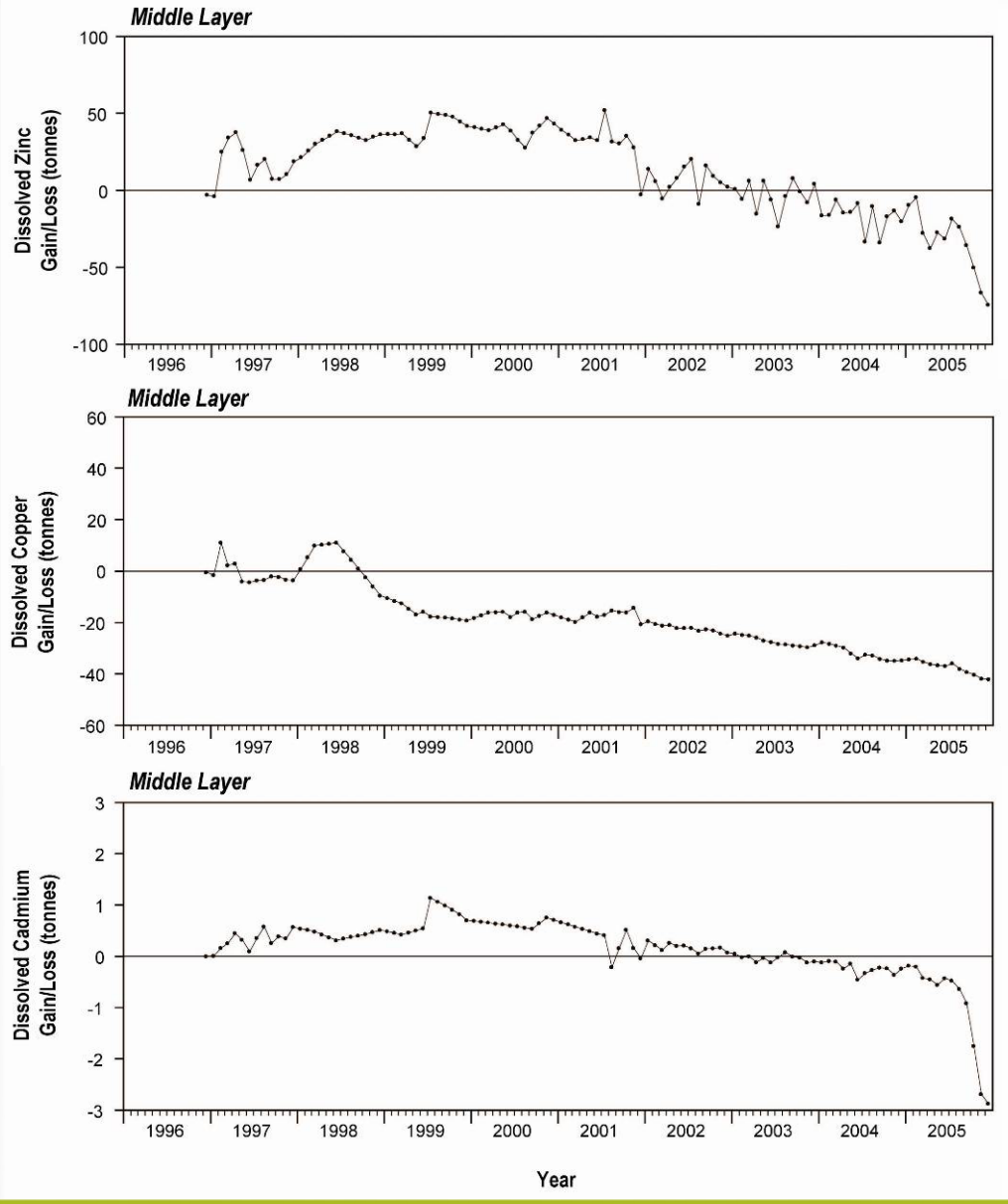
# Metal Removal from the Top Layer



- Metal removal (out of dissolved phase) in the Top Layer is by adsorption to organic particles (phytoplankton cells) and hydr(oxides), and to a much lesser extent through phytoplankton metal uptake - and settling.
- By the end of 2005 a total dissolved phase mass of approximately 27 tonnes Zn, 0.3 t Cu and 0.17 t Cd had been removed.
- Metal removal in the Top Layer is moderate compared to the Middle Layer, however, the Top Layer treatment must be adequate to meet permitted limits (1 mg/L Zn, 0.05 mg/L Cu, and 0.01 mg/L Cd).

# Metal Removal from the Middle Layer



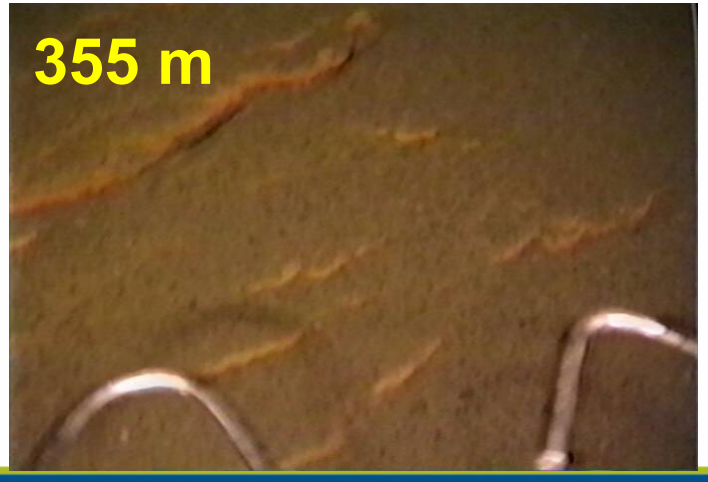



- Primary metal loads occurred at time of pit flooding, 1996.
- Metal removal in Middle Layer is by adsorption to organic and mineral precipitates (Hydrous Ferric Oxide, aluminum hydroxide).
- By the end of 2005 a total dissolved phase mass of approximately 75 tonnes Zn, 42 t Cu and 0.29 t Cd had been removed.
- Middle Layer is the workhorse for water treatment at Island Copper.

# Metal Removal from the Bottom Layer

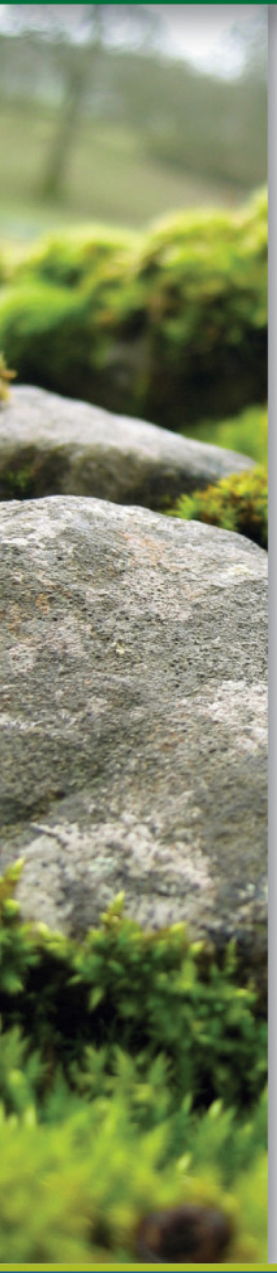


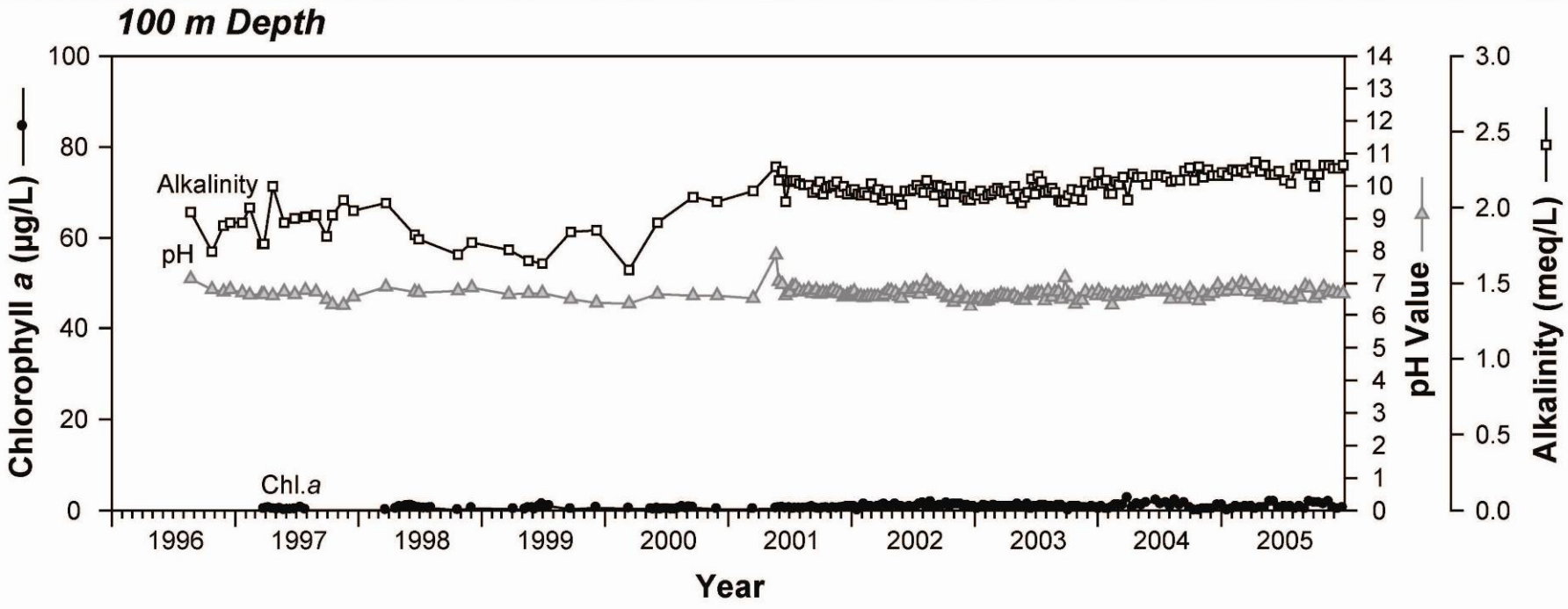
- Metal removal in Bottom Layer is by adsorption to organic and mineral precipitates.
- By the end of 2005 a total dissolved phase mass of approximately 13.5 tonnes Zn, 12.1 t Cu and 0.4 t Cd had been removed.


# Middle Layer pH, Alkalinity and Chl. *a*








- Middle Layer has approximately 30,000 tonnes of residual alkalinity (as $CaCO_3$) from seawater.
- Middle Layer represents approximately 30-50 years of semi-passive treatment.
- After 30-50 years, active treatment may be required.

# Conclusions



- The Island Copper pit lake is a stable pit lake.
- Turn over of the lake is extremely unlikely because of the high contrast in salinity between the Top (4-8 PSU) and Middle (25 PSU) layers.
- The rising pycnocline is being stabilized.
- The biological treatment is effective in removing metals from the dissolved phase and settling particulates to the lake bed.
- However, the pit lake continues to evolve as the alkalinity in the Middle Layer is consumed and treatment may eventually be required.