Terra Mine Site Reclamation, NWT: The Importance of Understanding Contaminant Mass Balance and Predicted Changes in Environmental Flux

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October 2015

HEMMERA

Phase 1

Review history of site use

Phase 2

Screen areas and contaminants of potential concern

Phase 3

Delineate

Environmental Risk Assessment

Examine site issues especially from perspective of exposure pathways and receptors

Remedial Options Analysis

Engineered Design

Remediation

Overall Objectives

- ***Discuss role of contaminant mass balance / flux estimates as decision making tools for complex contaminated sites, using the abandoned Terra mine site as an example***


Great Bear Lake
Deline
Northwest Territories
Silver Bear Mine
tory
Mackenzie Mountains
Selwyn Mountains
Yellowknife
Great Slave Lake

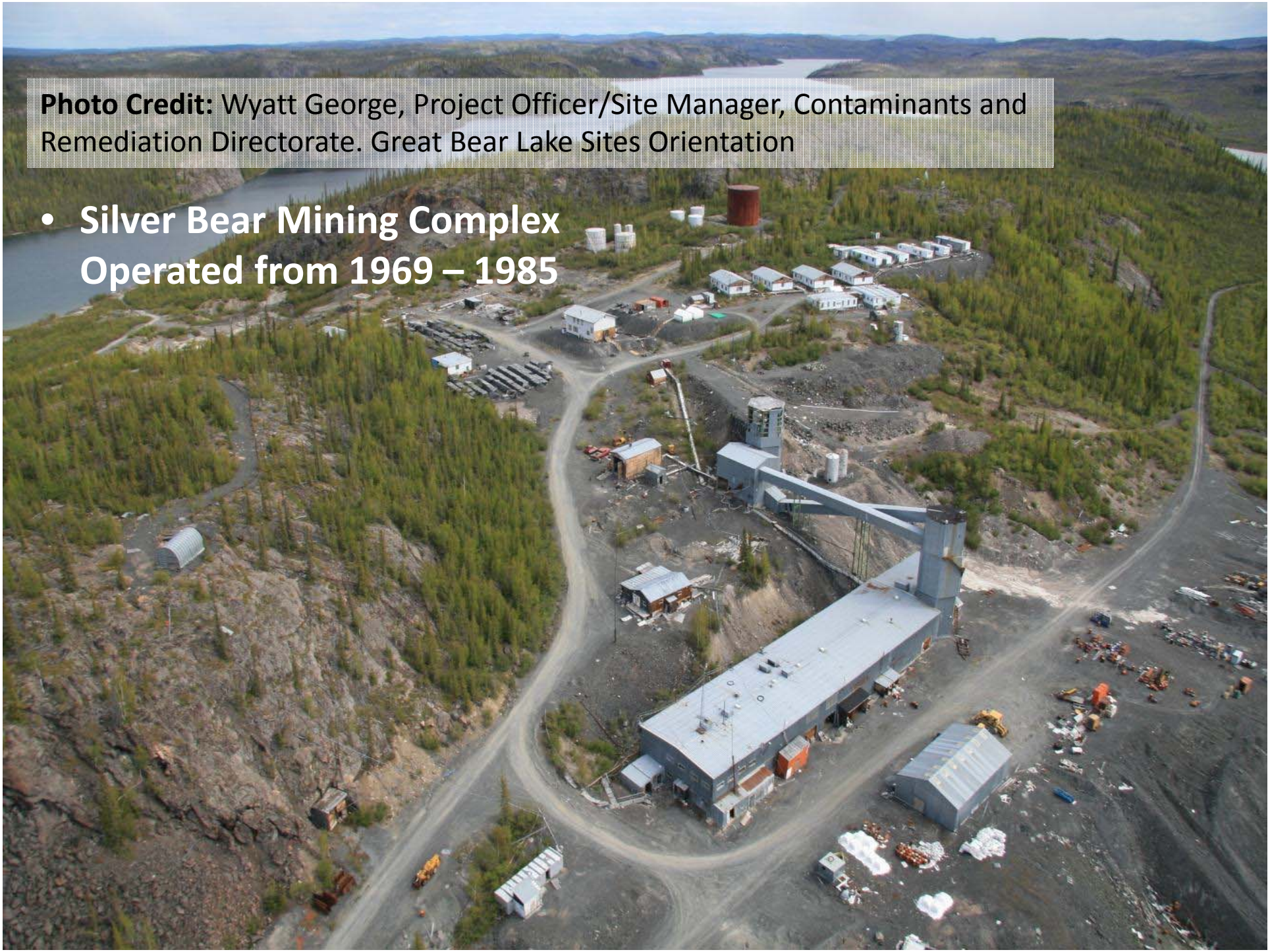
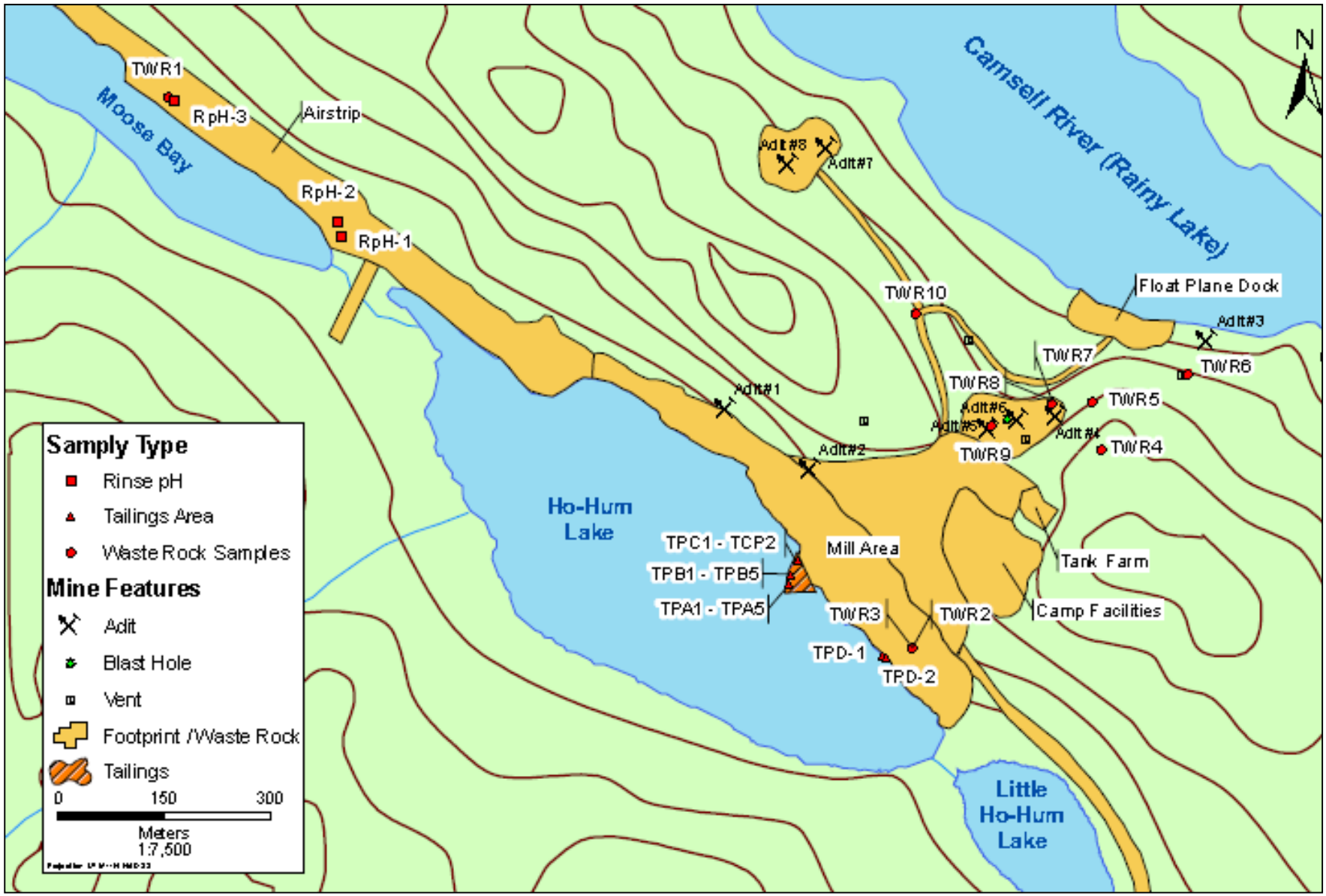


Photo Credit: Wyatt George, Project Officer/Site Manager, Contaminants and Remediation Directorate. Great Bear Lake Sites Orientation

- **Silver Bear Mining Complex Operated from 1969 – 1985**



Credit: Rescan, March 2005. Silver Bear Mines Geochemistry Assessment.

Photo Credit: Katherine Silcock, AANDC, Sept 2007. Silver Bear Remediation Plan Consultations

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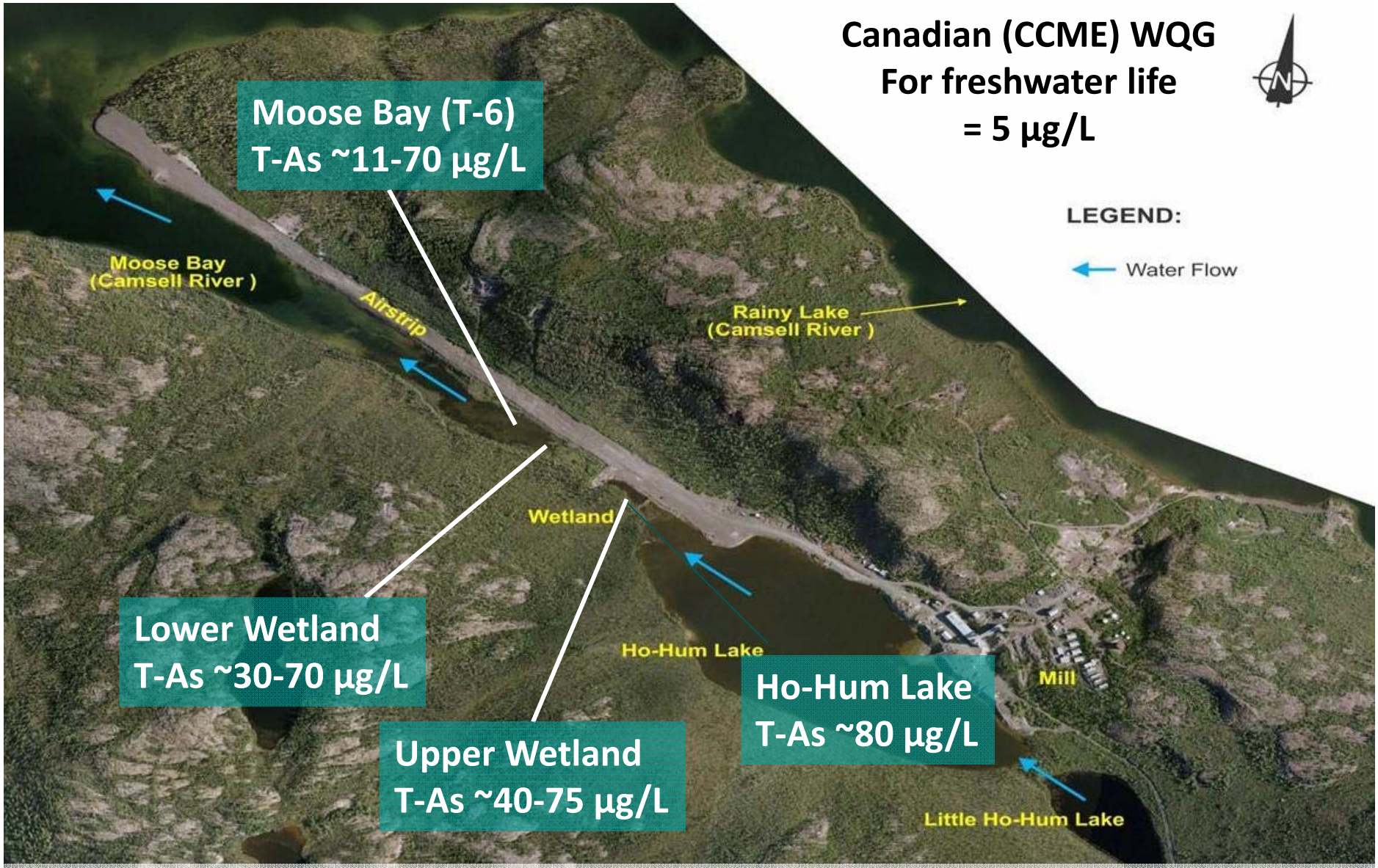
Photo Credit: Laurie McEachern, Water Resources Division, AANDC, Nov. 2006. Silver Bear Mine Sites, Northwest Territories Water Quality Monitoring Program – 2006.

Ho Hum Lake catchment into which most surface and groundwater from mine spoils and workings are transported



Arsenic, and to a lesser extent, copper elevated in Ho-Hum Lake and Moose Bay of Camsell River

Senes, 2008. Final Remedial Action Plan, Silver Bear Mines, NT

(excerpts – Table E/1 Summary of Preferred Remedial Plan

Site Component	Terra Mine
Mine Openings	• Backfill open stopes and horizontal openings with waste rock • Seal vertical shaft and raises with concrete caps or slabs or backfill
Waste Rock	• Improve drainage • Monitor
Tailings	• Cover exposed tailings with waste rock • Lower Ho-Hum Lake level and outlet dykes; construct spillway • ***Use natural wetland to reduce arsenic in Ho-Hum Lake***

Proposed remediation approach for Terra assumes

- Above-water tailings deposit not a significant source of arsenic to HoHum Lake,
- Waste rock deposits, adits, pit and any associated groundwater-mediated transport not a significant source of arsenic to HoHum Lake,
- Existing wetland at HoHum outflow is having a positive influence on water quality by removing from dissolved-phase transport some of the As.

And…

- **Sub-aqueous tailings deposit in HoHum Lake does not require any form of remediation to reduce the flux of arsenic and other trace elements into the watershed**

Specific Objectives

- Summarize mass distribution of As in potential source materials;
- Evaluate the absolute and relative flux of As from different source materials,
- Estimate current annual As mass loadings to the outlet wetland and Moose Bay from Ho Hum Lake,
- Predict future annual As mass loading,
- Evaluate long-term temporal trends is dissolve-phase As in Ho Hum Lake and Moose Bay; and
- Provide recommendations on the merits of implementing an augmented, engineered wetland between the Ho Hum Lake outflow and Moose Bay

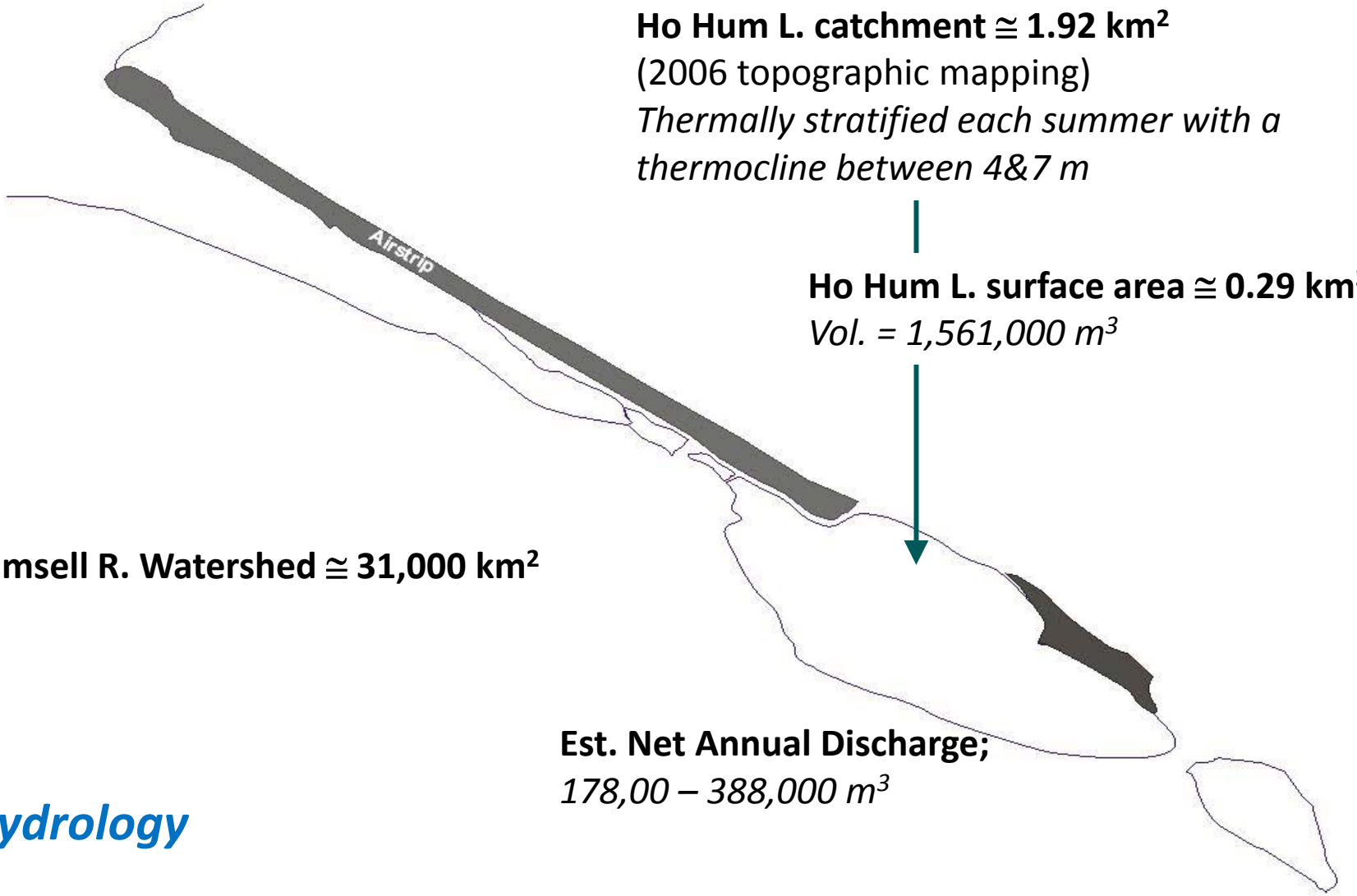
Mass balance & flux approach is highly relevant for site remediation since –

- **Virtually all important exposure routes via aqueous transport are directed through HoHum Lake, and**
- **Unacceptably high ecological risks evident primarily for aquatic ecosystems that receive watershed inputs**

Mass Balance Conceptual Model

Ho Hum L. catchment ≅ 1.92 km²
(2006 topographic mapping)
Thermally stratified each summer with a thermocline between 4&7 m

Ho Hum L. surface area ≅ 0.29 km²;
Vol. = 1,561,000 m³

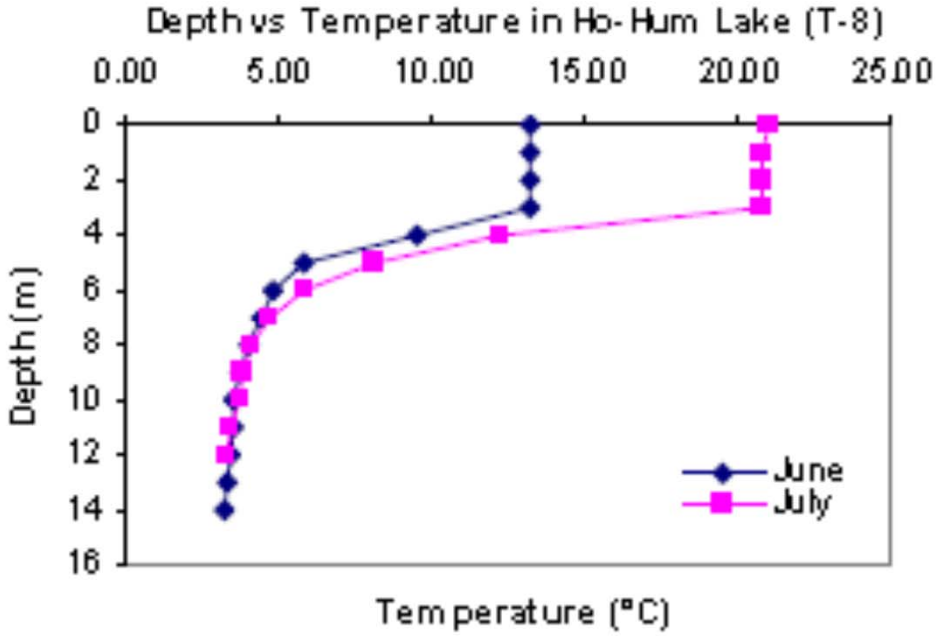


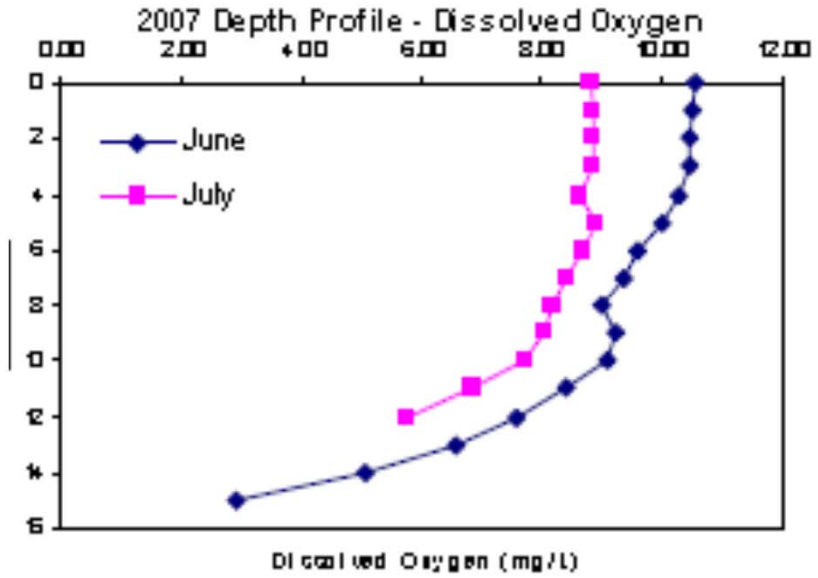
Camsell R. Watershed ≅ 31,000 km²

Est. Net Annual Discharge;
178,00 – 388,000 m³

Hydrology

Summertime Stratification

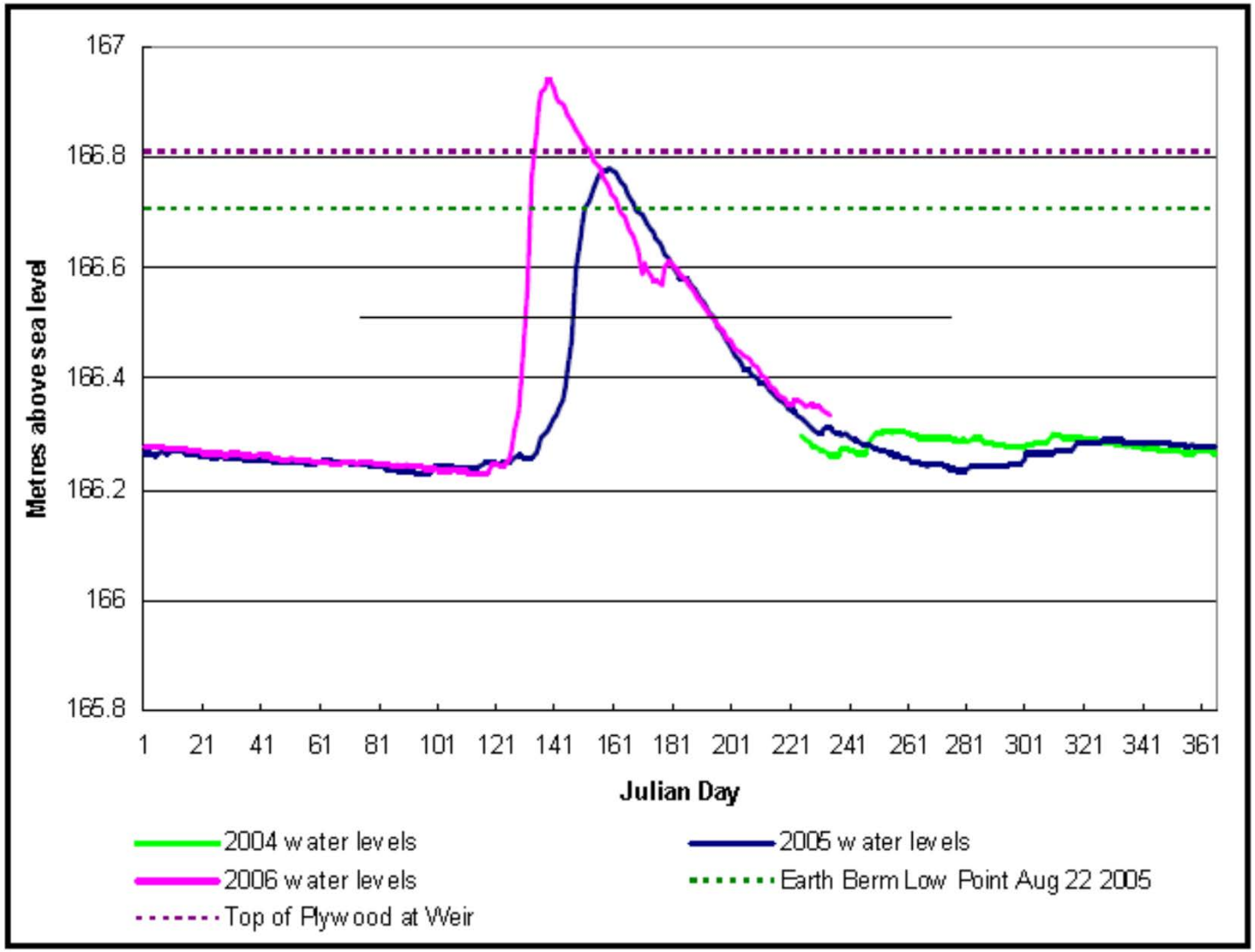




…still unclear what happens during under-ice conditions, or at spring thaw

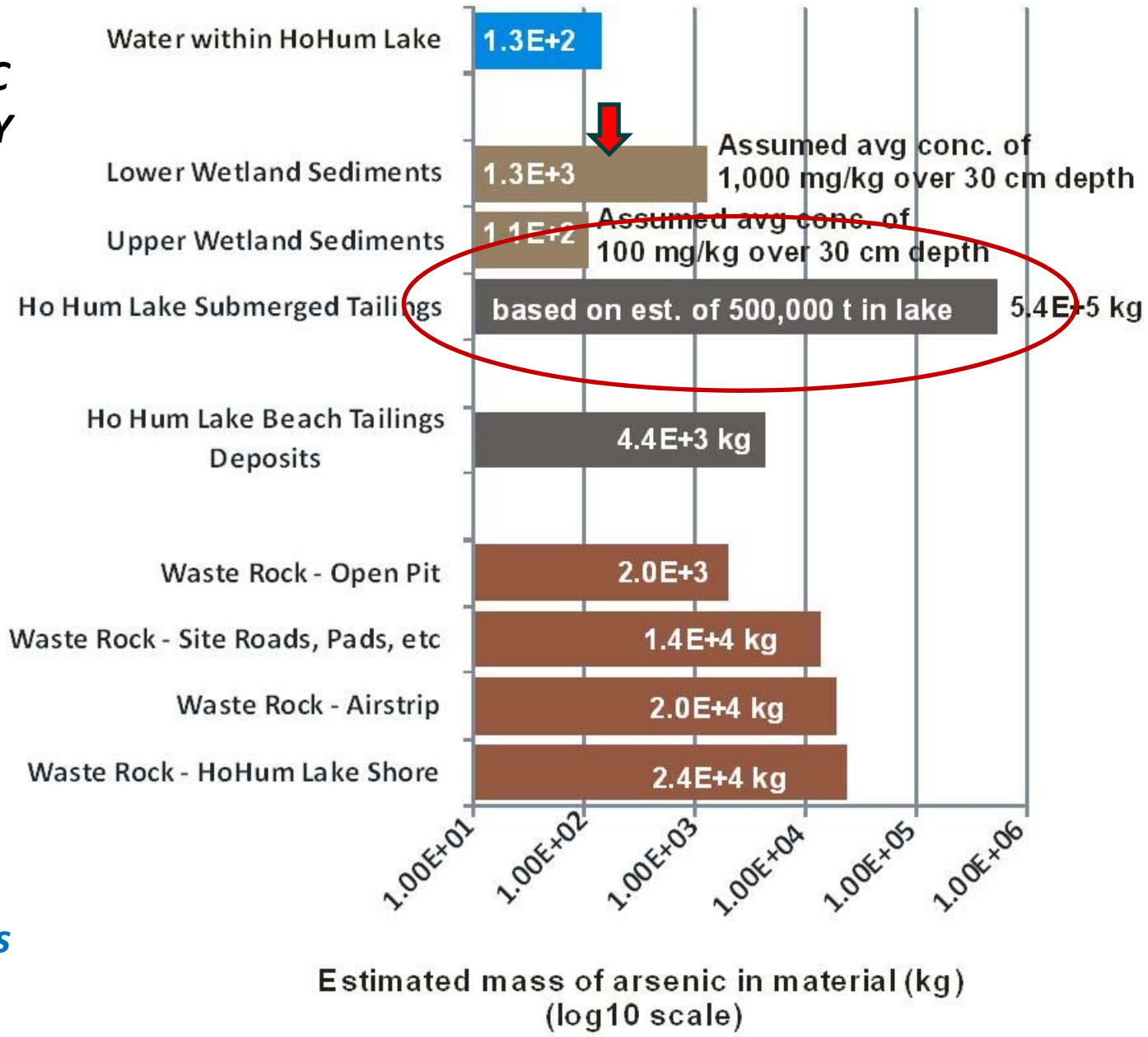
Hydrology

Seasonal variation in water elevation – Ho Hum Lake (Kokelj and Morgan, 2007)



Hydrology

BUT IS THE THE ARSENIC POTENTIALLY MOBILE?



Arsenic Mass Distribution

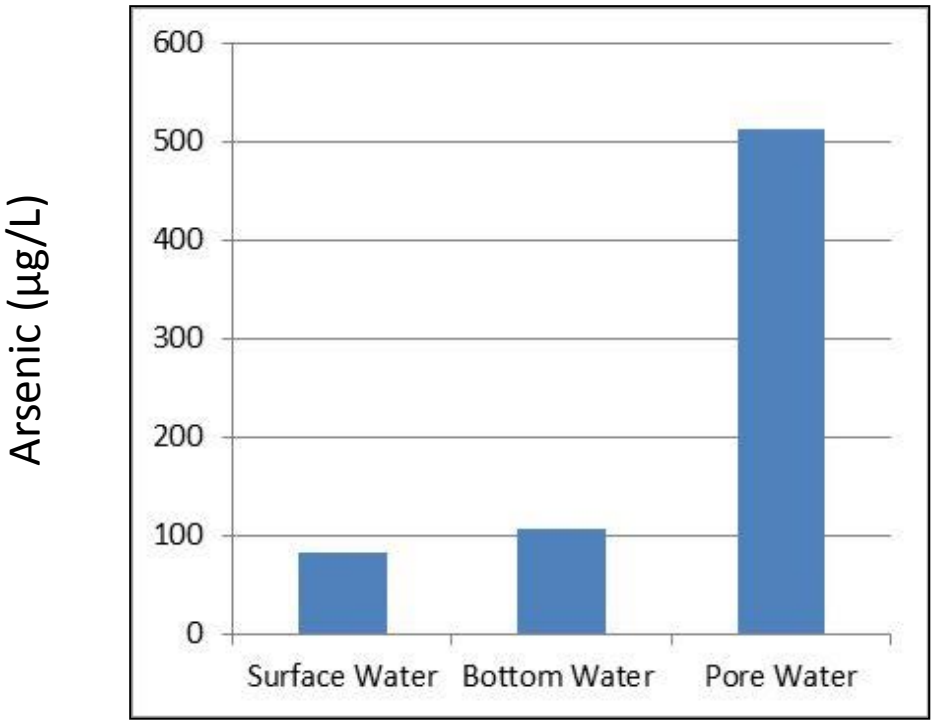
2006 sediment geochemical studies

- Vigorous sulfate reduction occurring at or near benthic boundary.

- *"rate of As remobilization to the water column… shallow site… 35 µg cm^{-2} y^{-1}"*

(based on Fick's First Law).

- *"translate to a steady state water column concentration of 50 µg/L, given a mean depth of 7 m and a lake residence time of 1 year"*



Comparison of dissolved phase As in HoHum Lake water and sediment porewater

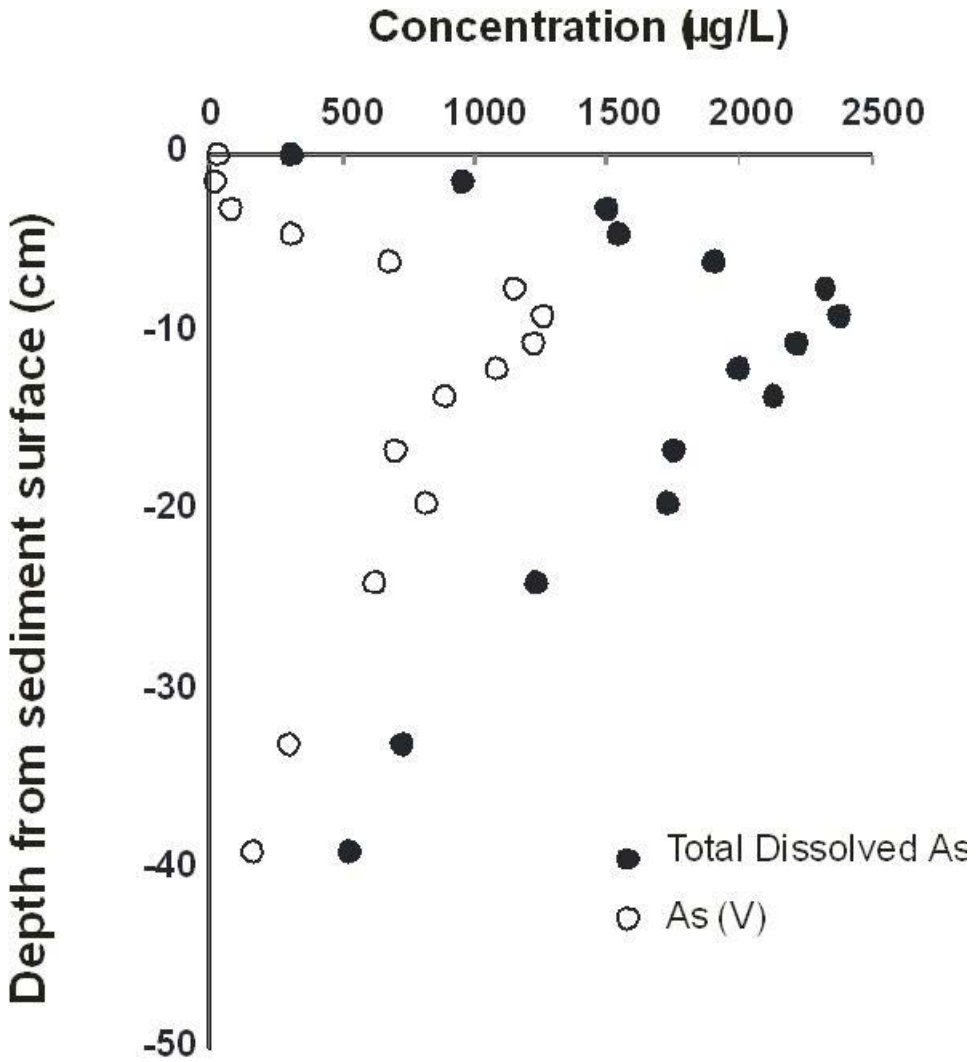
Arsenic Flux – Subaqueous Tailings

Preliminary Peeper Data – near beach deposit

Water column [As]Total in 80 µg/L range

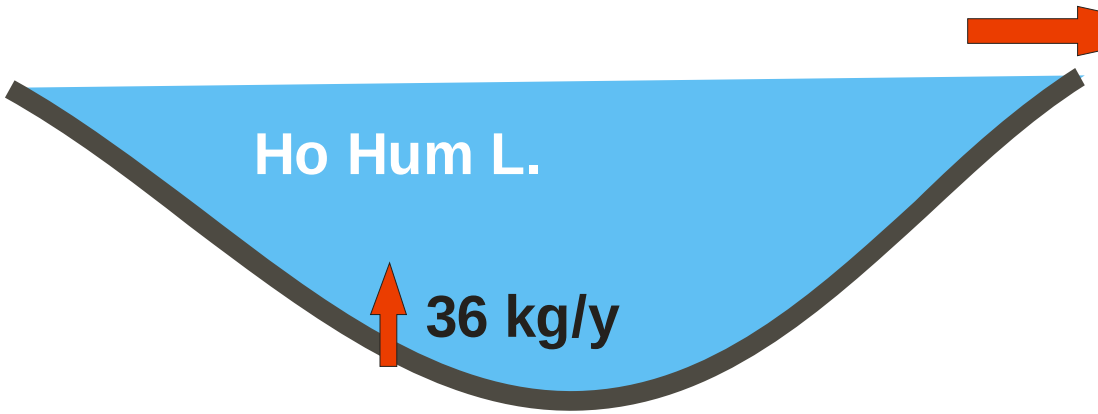
Near surface pore water concentrations in range of 300 – 2,000 µg/L As

Fall 2013 data provided by Andrew Bubar and Heather Jamieson, Queens University



(Based on average water column As conc. of 80.7 µg/L
& estimated net annual discharge in range of 178,000 to 388,000 m3 y-1)

14 to 31 kg/y



existing mass of As in wetland sediments of ~1,500 kg (??)

From sub-aqueous tailings:
assume -
35% of lake bed has tailings deposits
As flux at interface of ***35 µg cm^{-2} y^{-1}***

Milling commenced in early 1970s; therefore, total flux from ~1970 to 2012 est. at 30 kg/y x 42 yr = approx. 1,300 kg total

Arsenic Flux – Subaqueous Tailings

However, water residence time in Ho Hum Lake is much longer than 1 year

- Ho Hum Lake Volume: 1,560,000 m^3
- Estimated maximum net annual discharge, HoHum Catchment: 388,000 m^3
- Estimated minimum water resident time: ~4.0 y
- Virtually entire Ho Hum lake bed covered with tailings.

Arsenic in Surface Sediments:

Average:	**930 mg/kg**
Min.:	**295 mg/kg**
Max.:	**1,560 mg/kg**

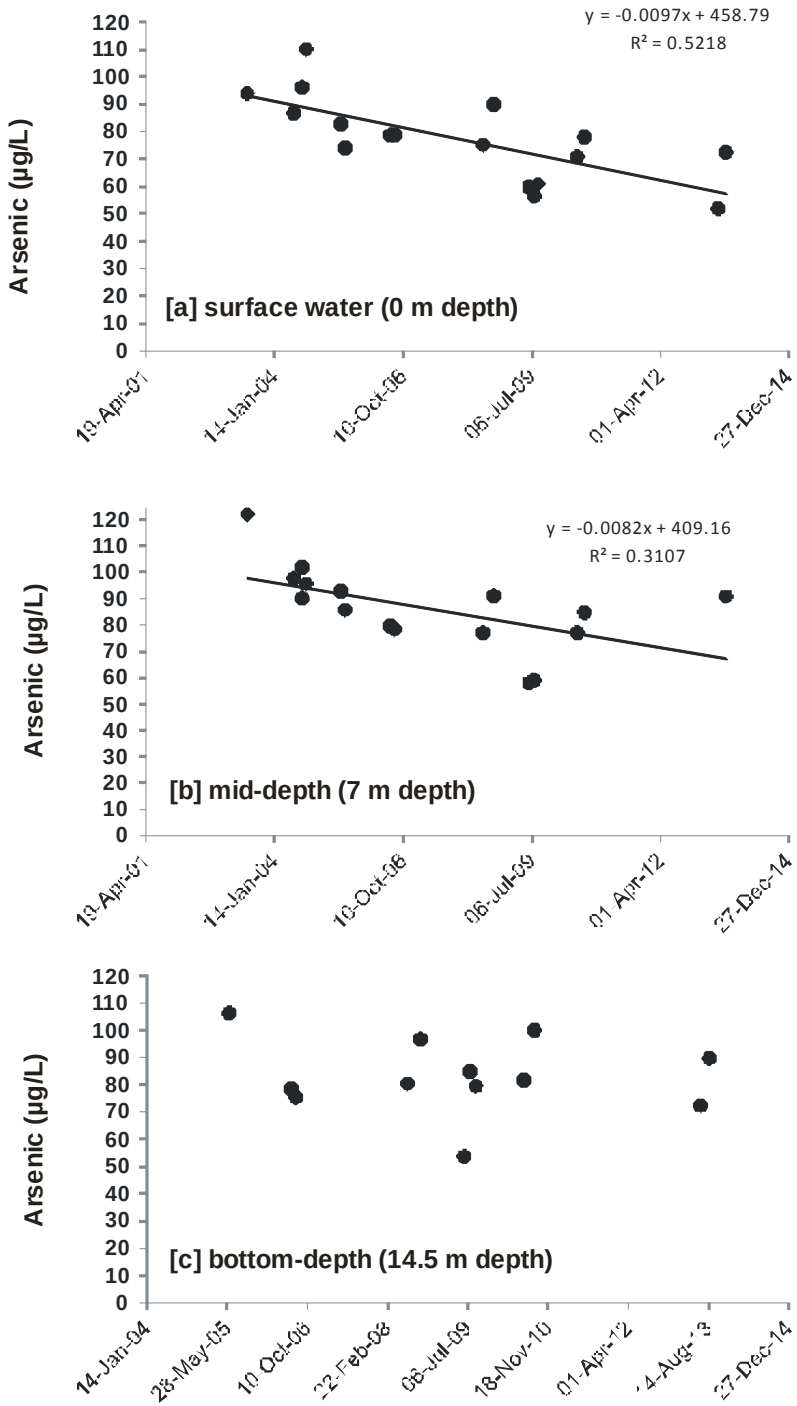
Arsenic Flux – Subaqueous Tailings

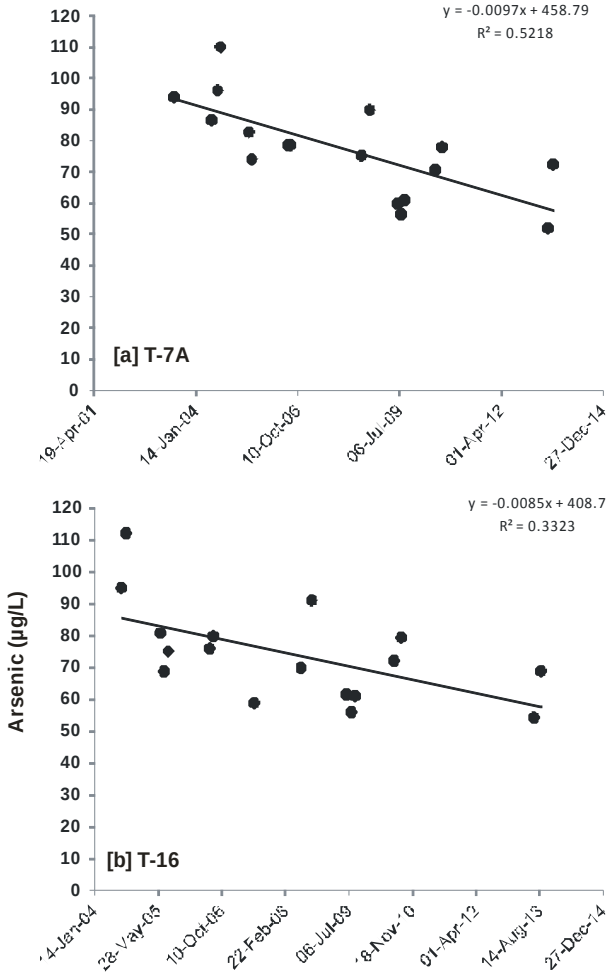
Implications for Site Remedial Plans

- Previous flux estimates likely an under-estimate relative to more recent data
- Porewater dissolved As concentrations near sediment-water interface very high! (in range of 500 to 2,000 µg/L As)
- Annual flux from submerged tailings exceeds current wetland sorptive capacity (net export to Moose Bay water and bed sediments)
- Flux through and beyond wetland will likely continue at its current rate if remediation as proposed and without further treatment of discharge is implemented

Therefore, risks to aquatic life in Moose Bay likely to increase in the future unless risk management strategies implemented

Station T-8: Ho Hum Lake middle of Lake, west of tailings beach pipe





Stations T-7A (middle of lake at east end) and T-16 (middle of lake east of tailing pipe)

Predicted rate of decrease in water-borne As concentration

- Station T-3: 5.0 µg L^{-1} yr^{-1}
- Station T-5: 2.9 µg L^{-1} yr^{-1}
- Station T-7: 3.5 µg L^{-1} yr^{-1}
- Station T-8A: 3.5 µg L^{-1} yr^{-1}
- Station T-8B: 2.7 µg L^{-1} yr^{-1}
- Station T-16: 3.2 µg L^{-1} yr^{-1}

Therefore,

- Augmented wetland, with new sorptive capacity, will substantially reduce flux of As from Ho Hum Lake into the Camsell River.
- Assume an engineered wetland will have similar or better As retention capacity to the existing native wetlands.
- Rates of As flux through Ho Hum Lake decreasing. Mechanism not well understood.


Thank you. Questions?
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