Mechanisms of Arsenic Attenuation in a Gold Mill Tailings Impoundment

[1] Alan Martin, [1]Jonathan Mackin, [2]Trevor Crozier, [2]Stephen Hedberg, [2]Dawn Paszkowski, [3]John Jambor, [4]Shawn Hiller and [4]David Gelderland

[1] Lorax Environmental Services Ltd., Vancouver, B.C., Canada
[2] BGC Engineering Inc., Vancouver, B.C., Canada
[3] Leslie Research and Consulting, Tsawwassen, B.C., Canada (Deceased)
[4] Goldcorp Inc., Red Lake Gold Mines, Balmertown, Ontario, Canada

Overview

- Background and Site Setting
- Objectives
- Arsenic Attenuation Mechanisms
  - Diffusive pathway
  - Advective pathway
- Implications for tailings/water management

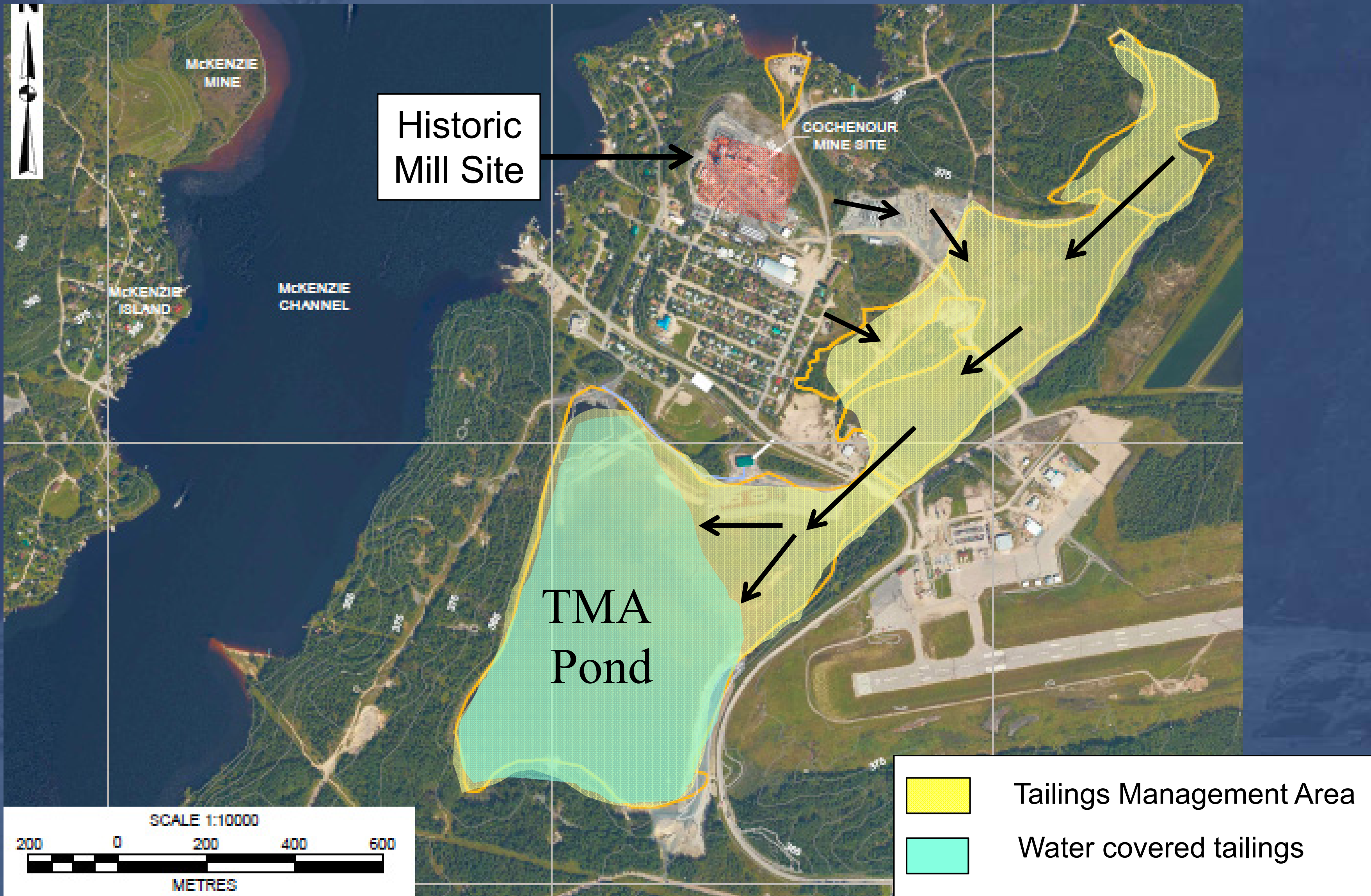
Site Setting – Cochenour, ON

Cochenour Wilanour Mine (Goldcorp)

Cochenour Wilanour Mine - Site History

- The milling of gold ores was conducted continuously at the site between 1939 and 1975, and for a brief period in 1982.
- Approximately 2.3 million tonnes of tailings were generated, with ores subjected to roasting and cyanidation.
- Site employs a ferric sulphate treatment system to reduce soluble arsenic in surface waters prior to discharge (Red Lake).
- Project re-activated in 2009, with production scheduled to commence in 2014 (20 year mine life). To supply ore to Campbell Mine.

Historic Tailings Deposition



LORAX ENVIRONMENTAL

Study Objectives

- Quantify the various sources of arsenic to the Pond Area (arsenic mass balance); and
- Define the controls governing the remobilization and attenuation of arsenic and other tailings-related parameters.

Water/waste management strategies to:

- Reduce arsenic loadings to Pond Area
- Reduce volume/loading to treatment plant

Study Components

Water Balance

- Climate
- Hydrology
- Water management

Hydrogeology

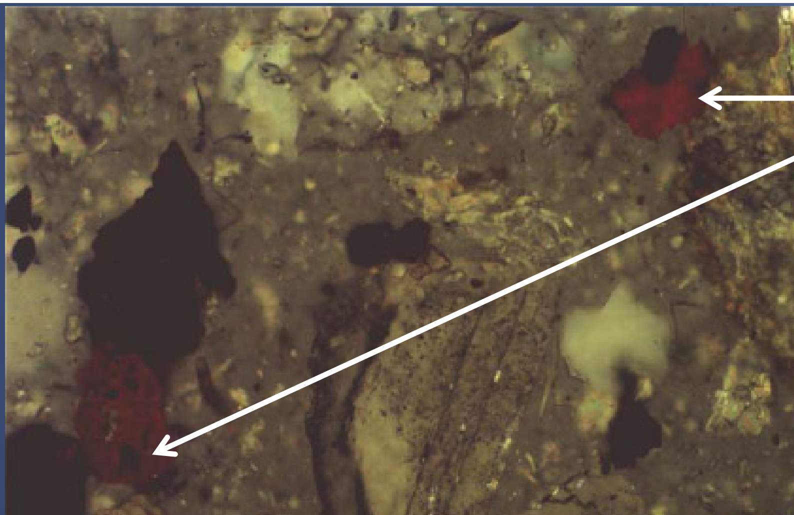
- Hydrostratigraphy
- Water levels
- Hydraulic conductivity
- Water and As Flux
- 2-D Modelling (Seep/W)

Geochemistry

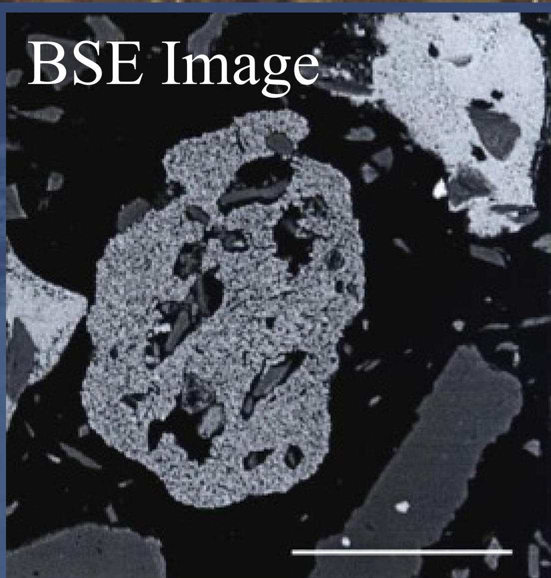
- Surface water quality
- Porewater chemistry
- Mineralogy (Petrography, XRD, SEM, XAS)

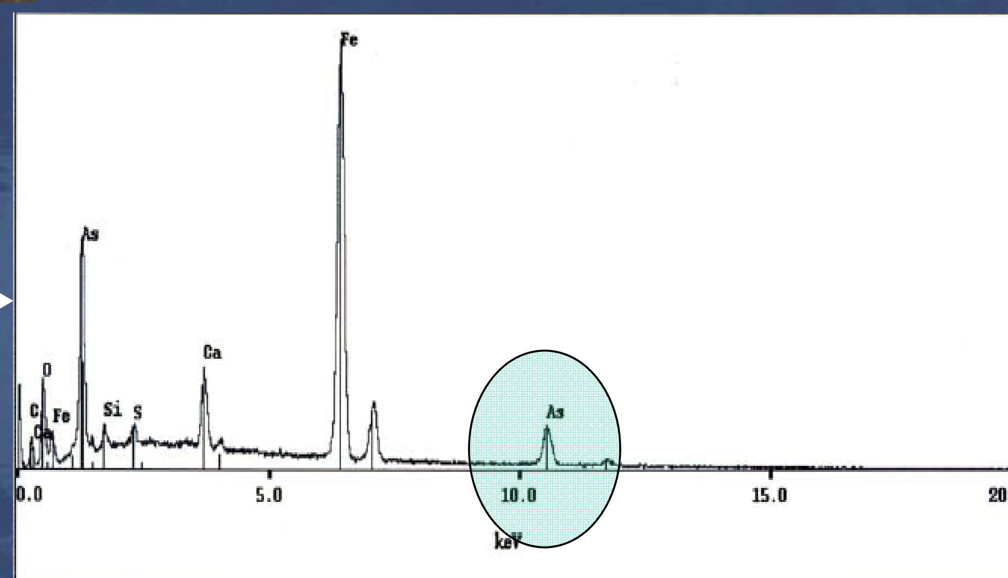
LORAX ENVIRONMENTAL

Arsenic Source – reductive dissolution of roaster products



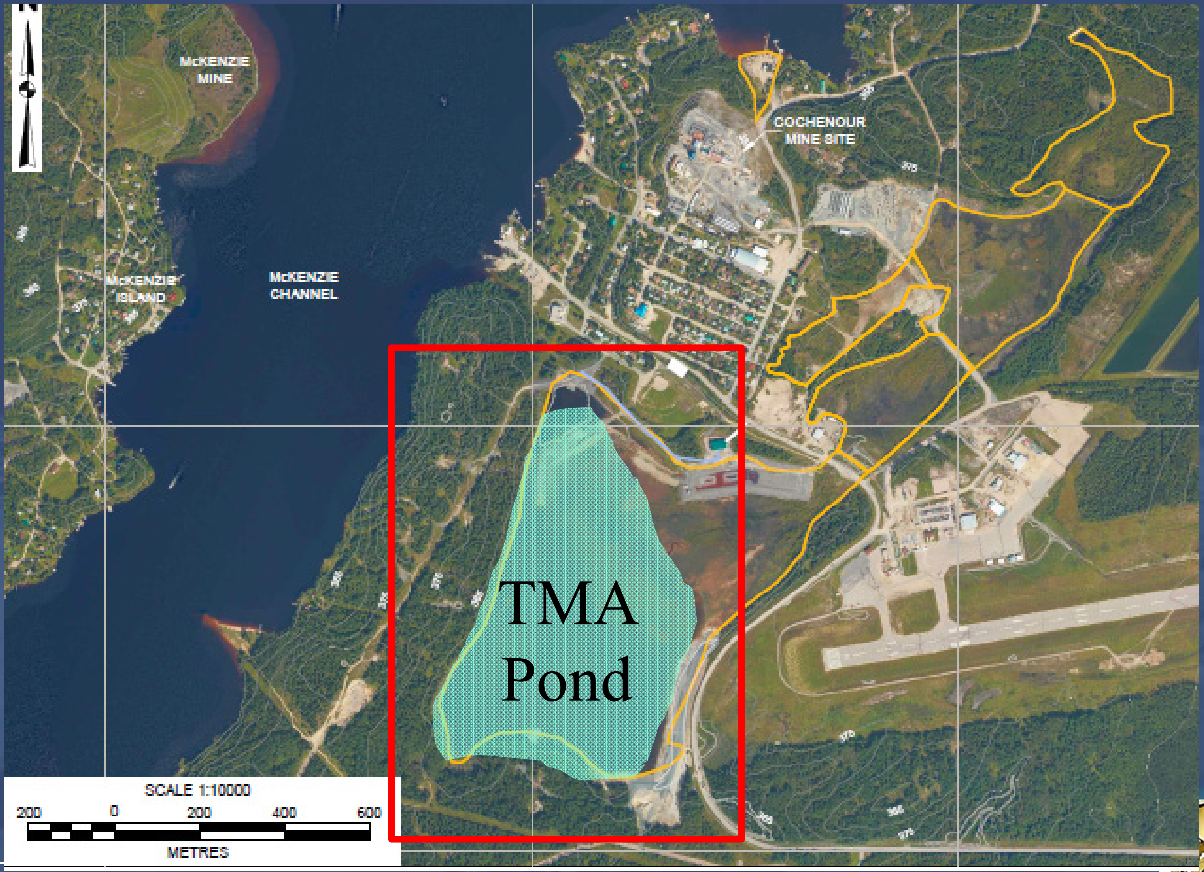
Roaster Fe oxides
(porous texture hematite)





Arsenic Attenuation Mechanism #1

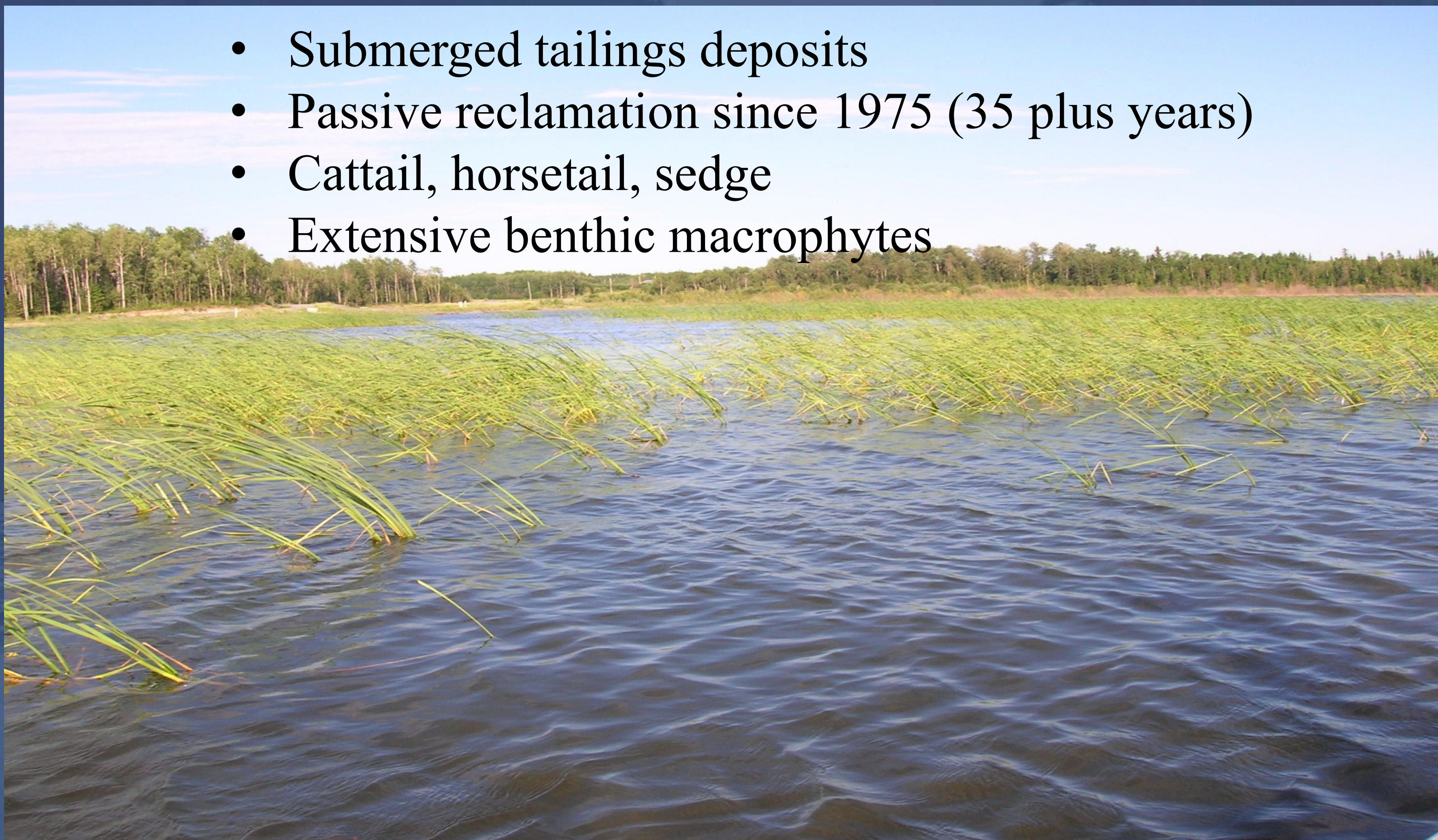
Diffusive pathway: removal of dissolved As within porewaters of submerged tailings in Pond Area (natural bioremediation).



LORAX ENVIRONMENTAL

Pond Area

- Submerged tailings deposits
- Passive reclamation since 1975 (35 plus years)
- Cattail, horsetail, sedge
- Extensive benthic macrophytes



LORAX ENVIRONMENTAL

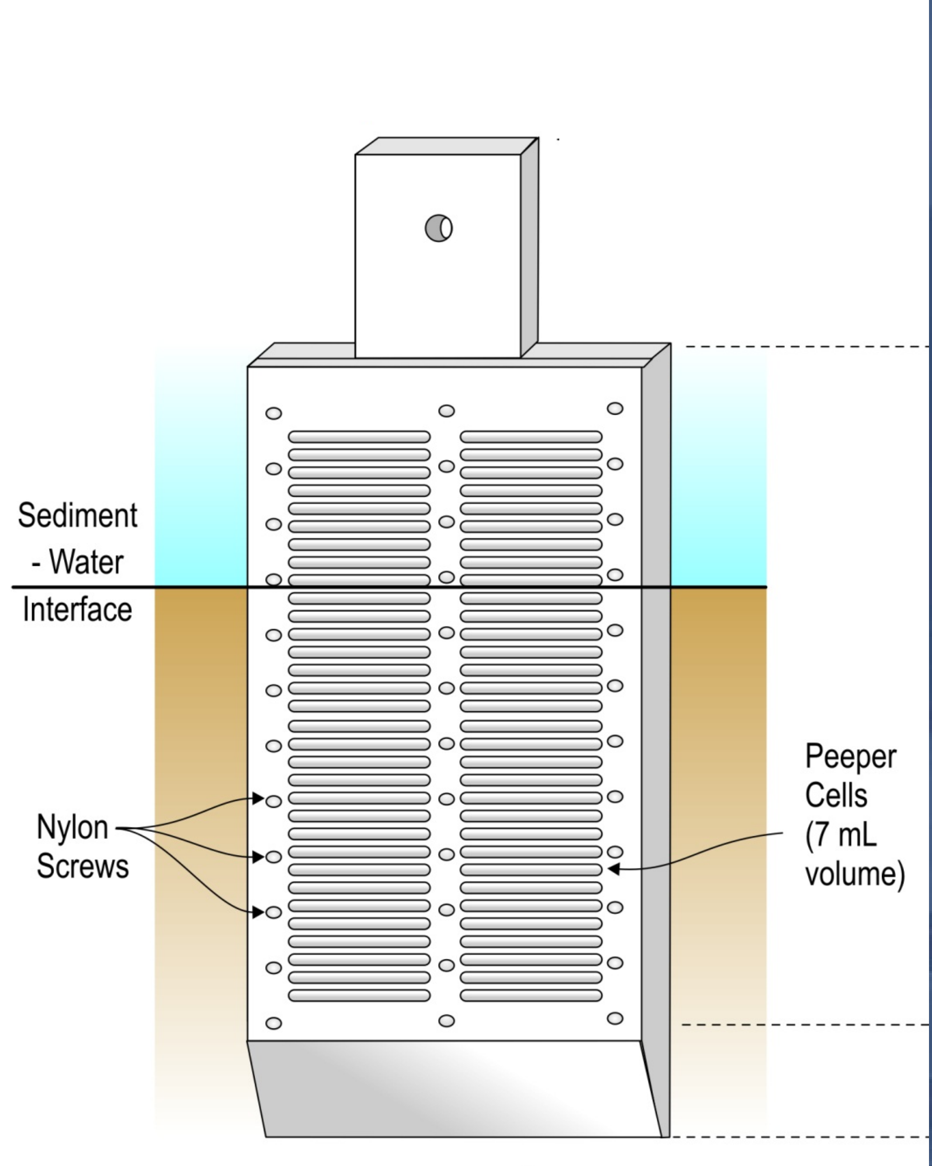
Pond Area – abundant benthic flora

Pond Area - Tailings

- quartz, plagioclase, muscovite, chlorite, and dolomite
- Sulfides: arsenopyrite, pyrrhotite
- Arsenic rich: 1,000-11,000 mg/kg

Split core showing pervasive root masses in tailings

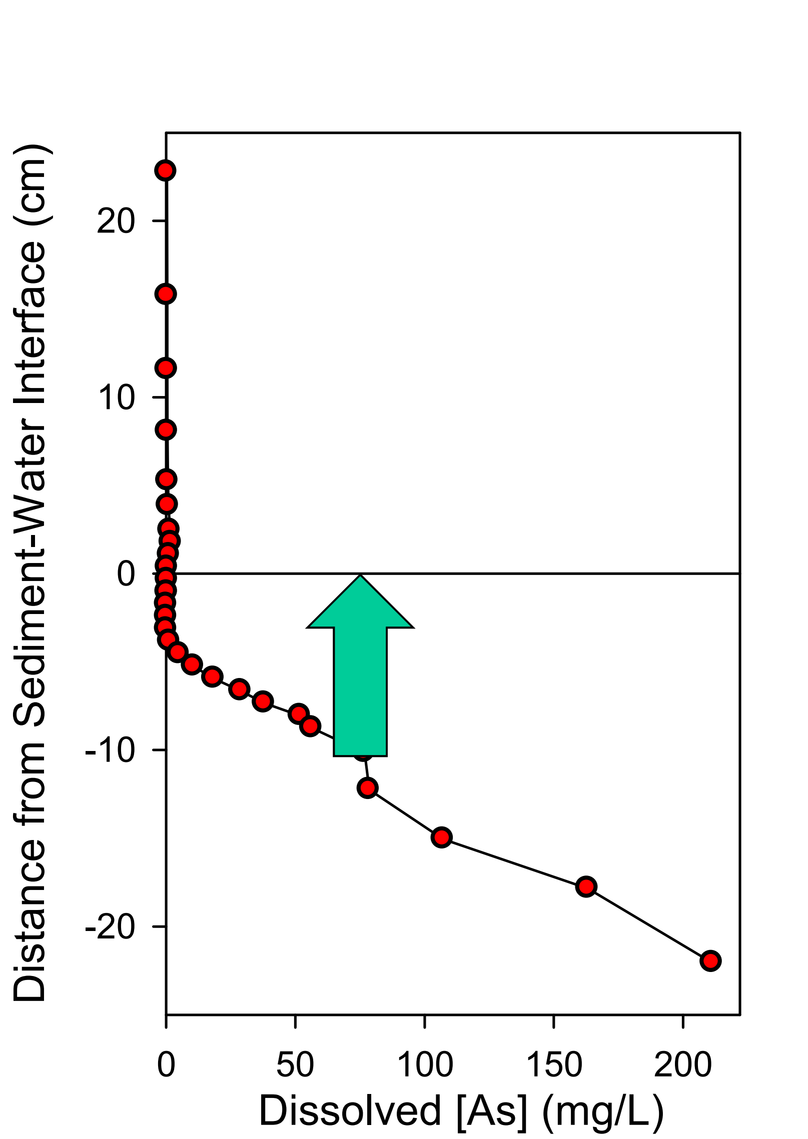
Porewater - Methods



- Dialysis Arrays (peepers)
- 7 mm resolution profiling of dissolved species
- Parameters:
  - Metals/metalloids
  - pH, alkalinity
  - Redox sensitive species (Fe, Mn, nitrate, H2S)
- Data used to define biogeochemical mechanisms and flux

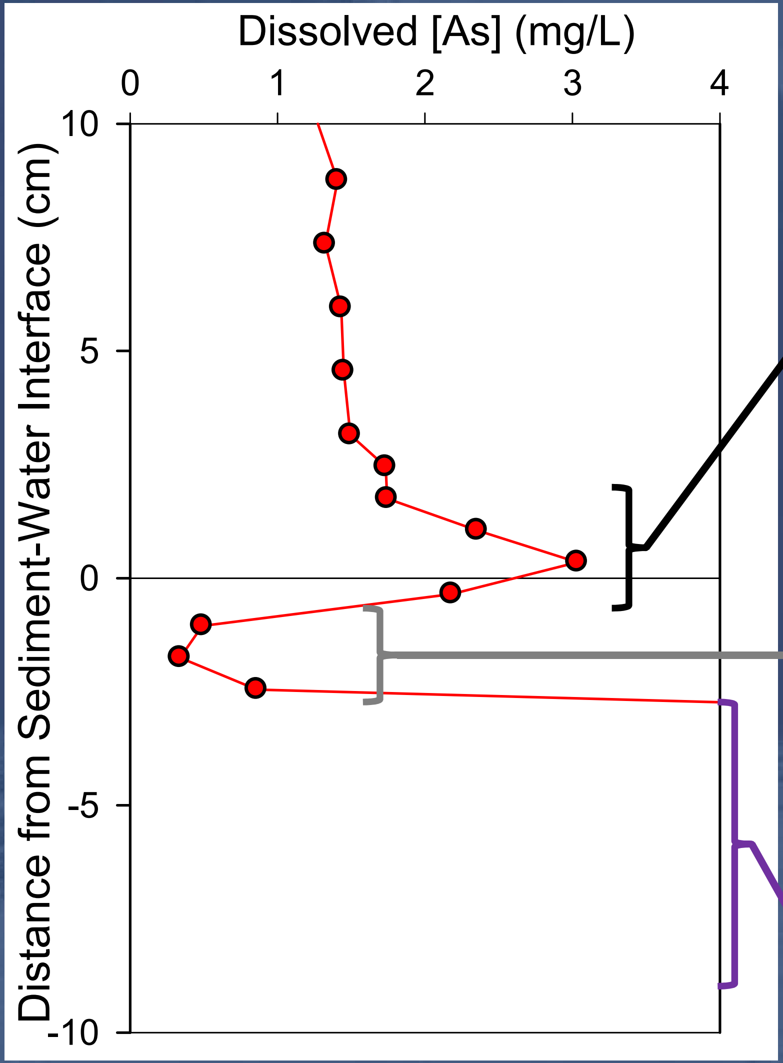
LORAX ENVIRONMENTAL

Pond Area – As Porewater Profiles



- Elevated concentration of dissolved As in tailings porewaters (100-300 mg/L)
- Concentration gradient drives large upward diffusive flux towards benthic boundary.

Pond Area – As Porewater Profiles

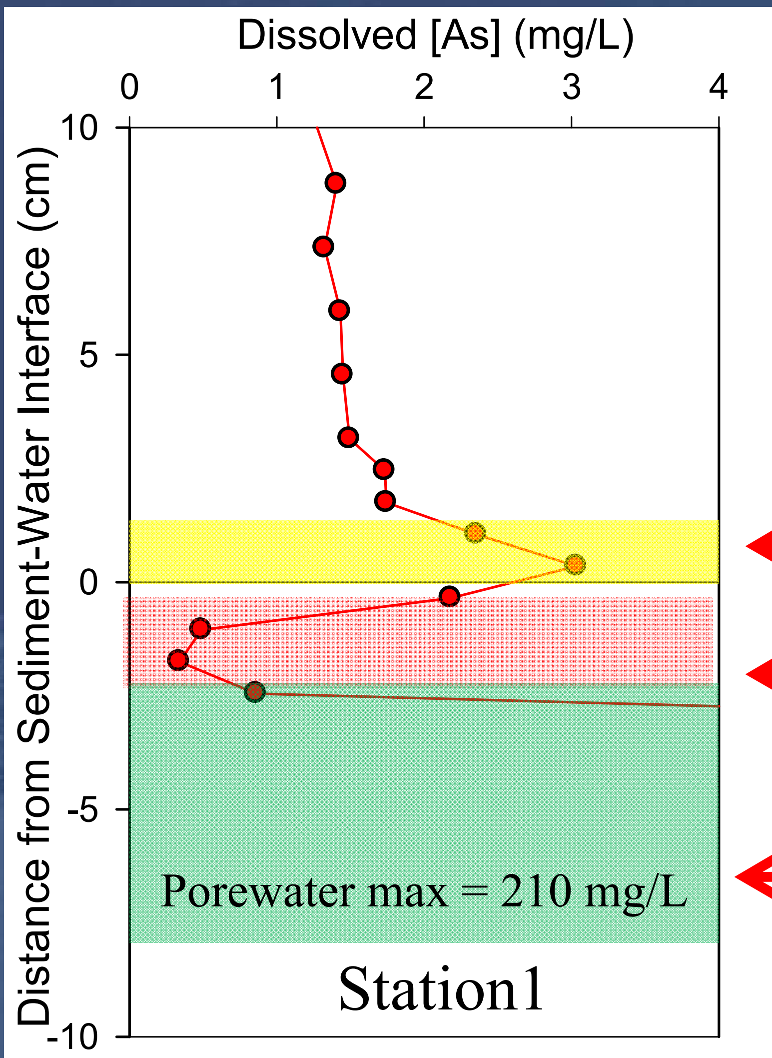


Three principal mechanisms controlling the mobility of As:

1. Remobilization via reductive dissolution of Fe-oxides at or near the sediment-water interface
2. Removal from pore solution via *in situ* precipitation.
3. Re-supply of dissolved arsenic from deeper tailings horizons.

LORAX ENVIRONMENTAL

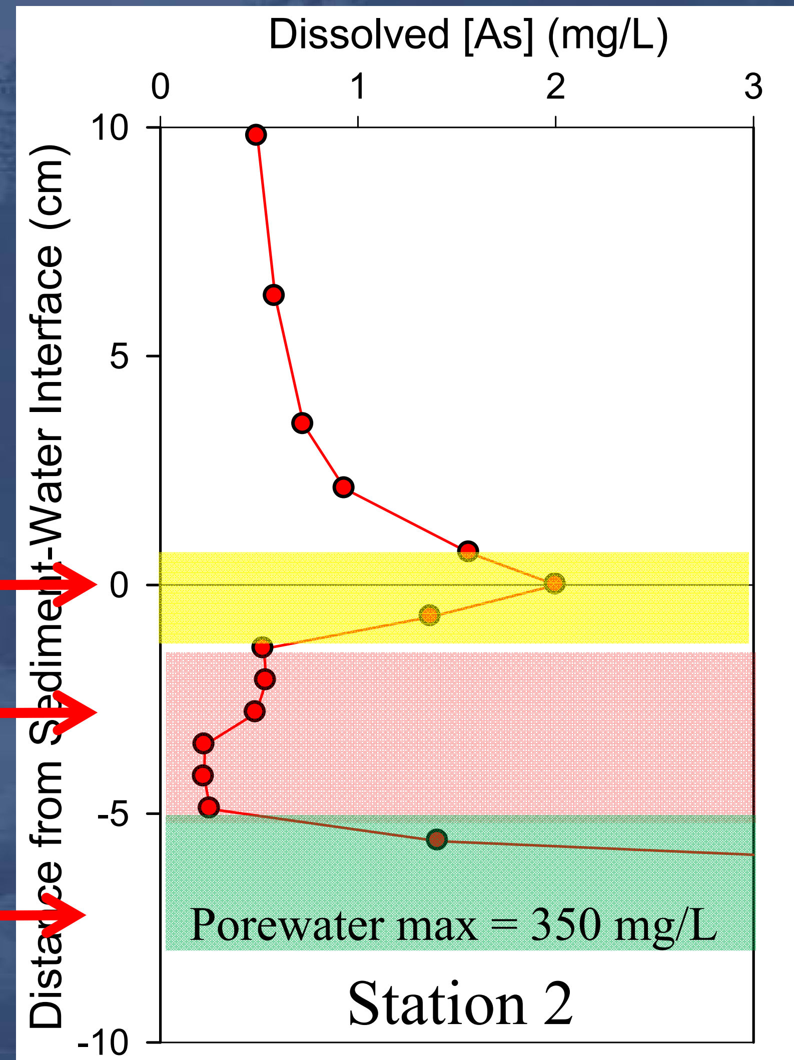
Pond Area – As Porewater Profiles
Spatial homogeneity



Interfacial release

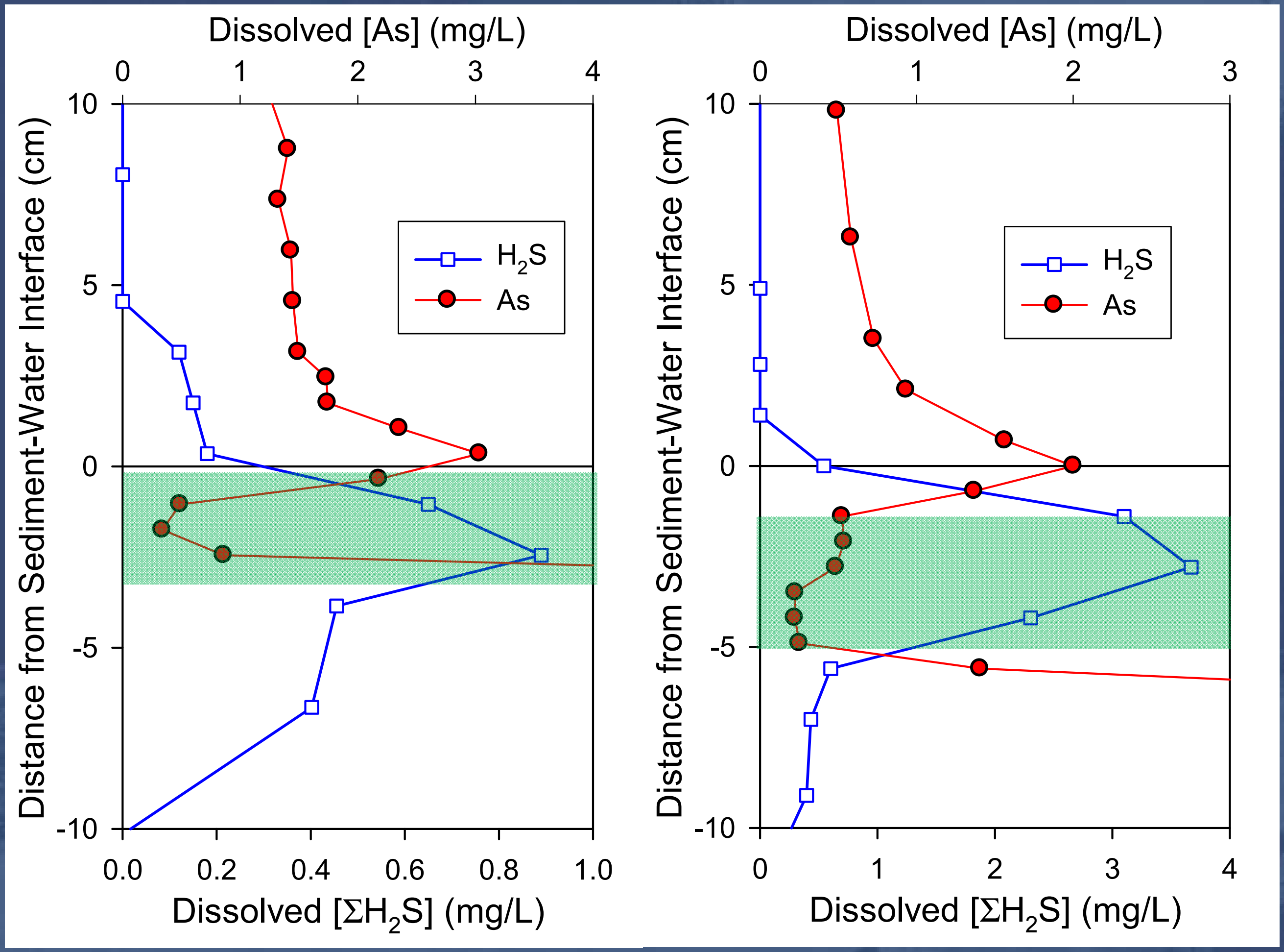
Removal

Re-supply



LORAX ENVIRONMENTAL

Pond Area – Diffusive Sink Mechanism: Precipitation of secondary sulfides



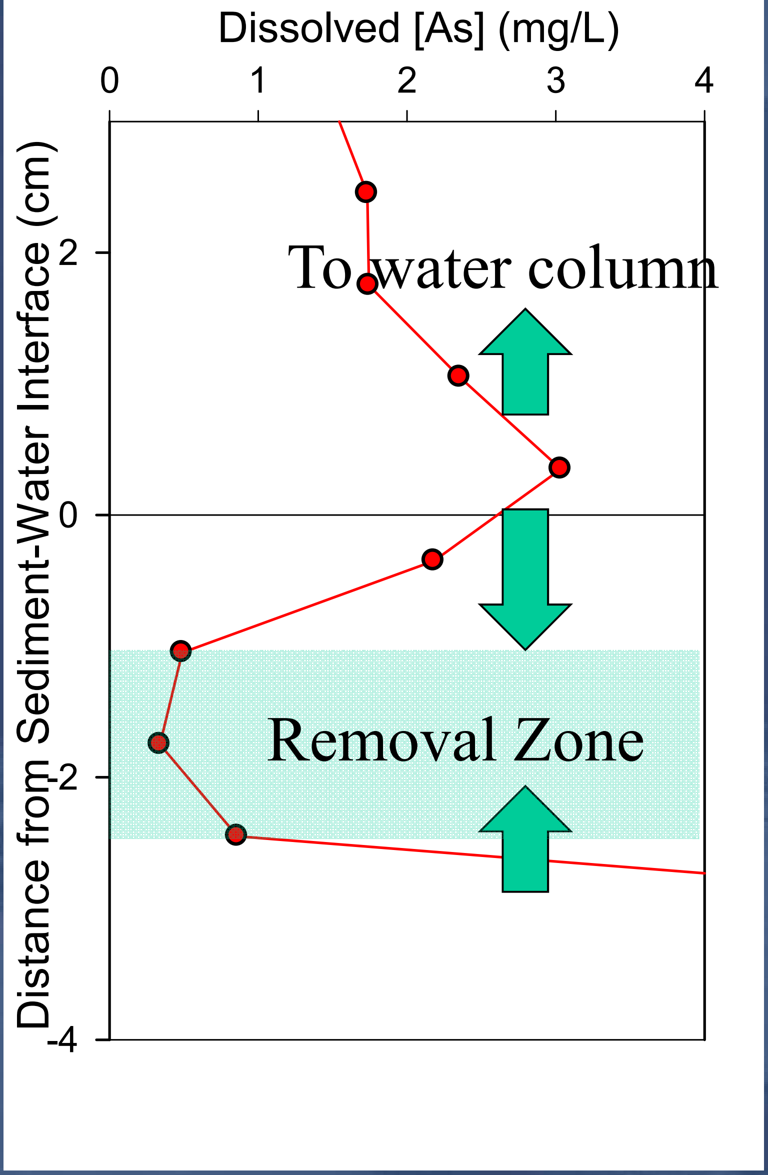
- Secondary phase could not be identified.

Possibilities:

- Discrete As sulfides
- Co-precip with Fe-sulfides.

LORAX ENVIRONMENTAL

Pond Area – Diffusive Sink



- Bi-directional diffusion of dissolved As to localized zone of removal.
- Diffusive sink acts acts to chemically isolate deeper As-rich porewater (200-300 mg/L) from the water column.

Pond Area – As Removal Rate

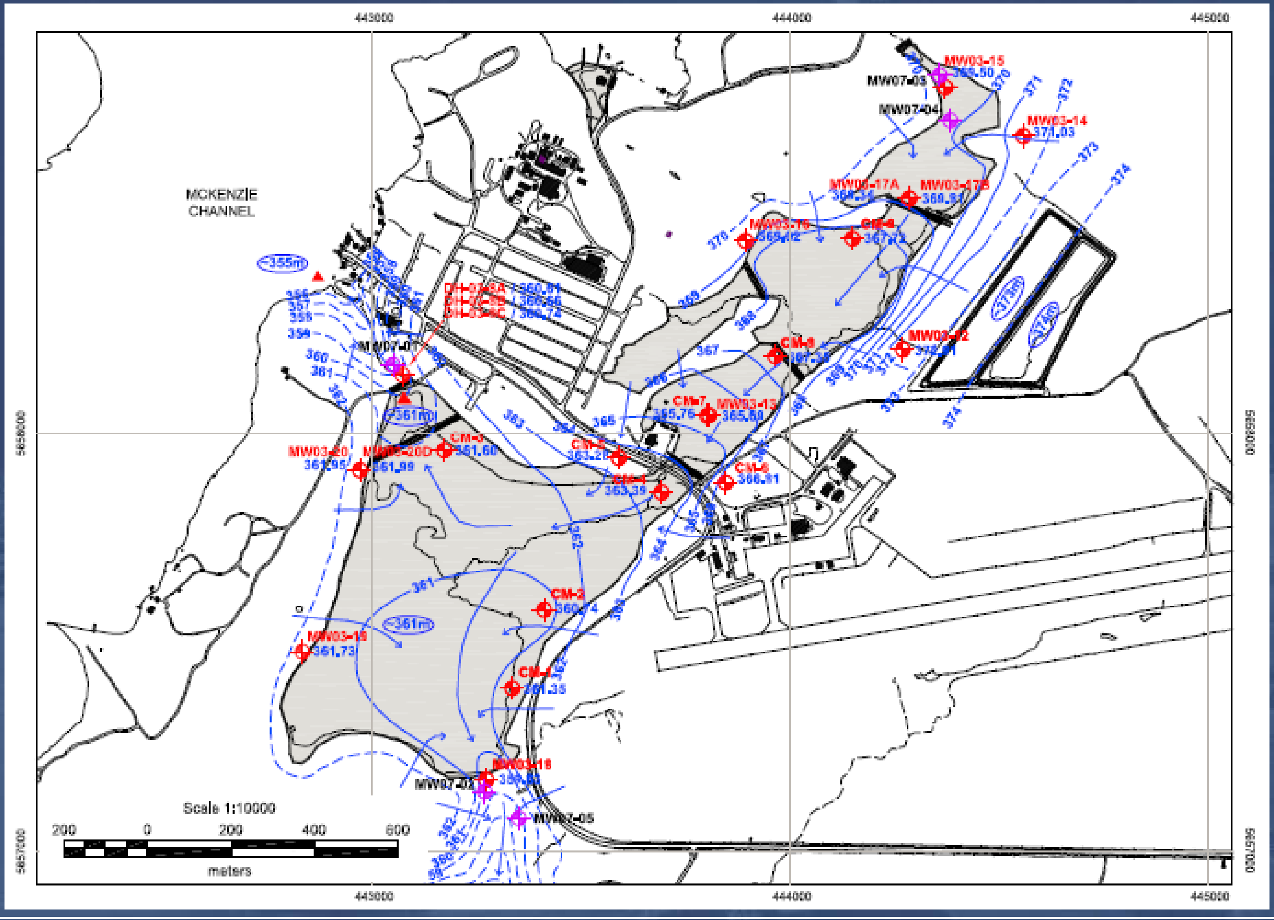
- Per unit area = 13 $mg/m^2/day$ (based on mean of 4 profiles)
- Area of Pond = 150,000 m^2
- Annual removal rate = **~700 kg/year**

- Current treatment system (ferric salt precipitation):
  - ~800,000 m^3/year (~25 L/s)
  - Mean [As] feed = 0.7 mg/L
  - Mean [As] effluent = 0.03 mg/L
  - Annual removal rate = **~540 kg/year**

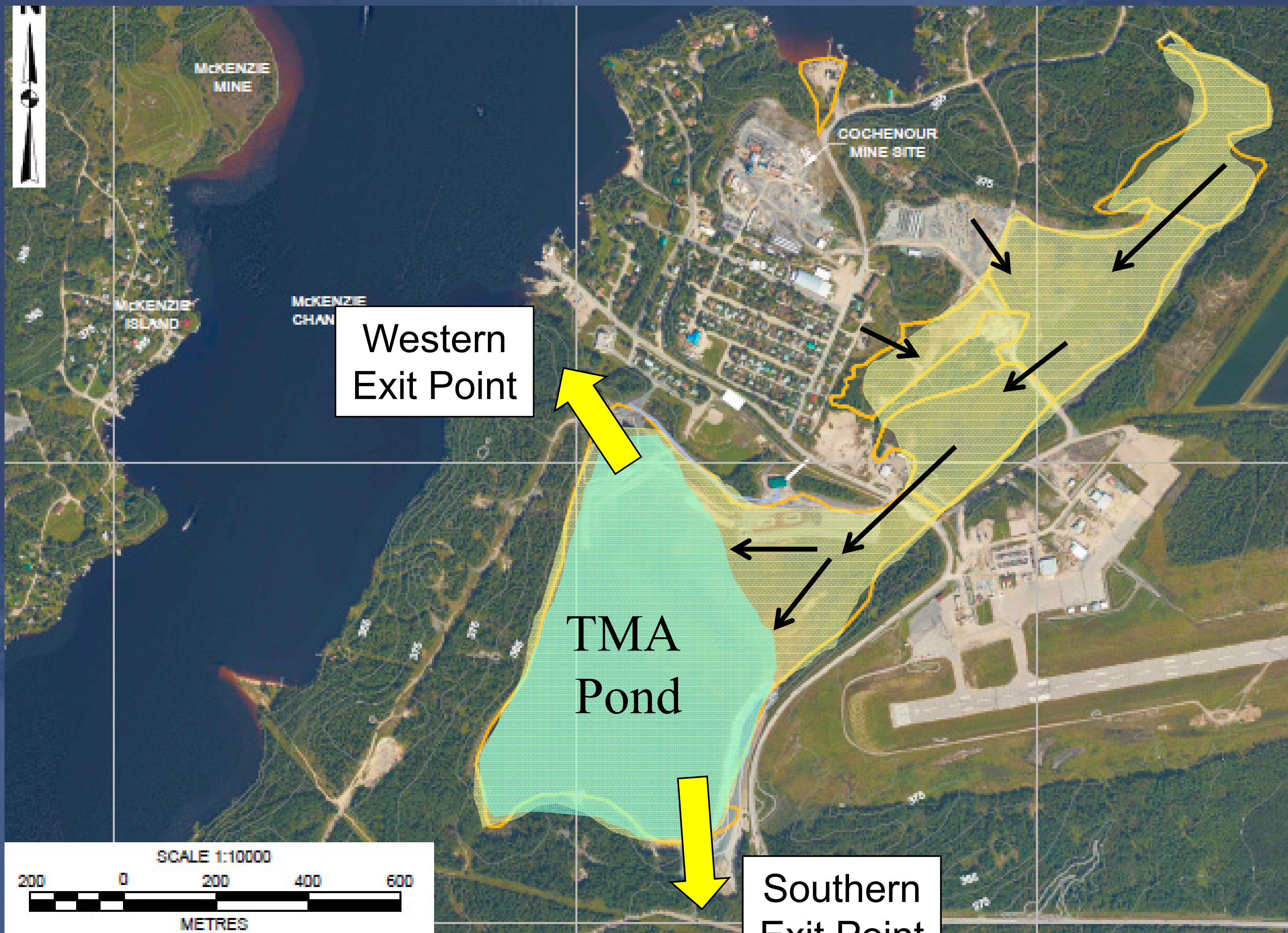
Passive removal comparable to active treatment

Arsenic Attenuation Mechanism #2

Advective pathway: removal of dissolved As along groundwater flow paths at exit points from the facility (adsorption/precipitation)

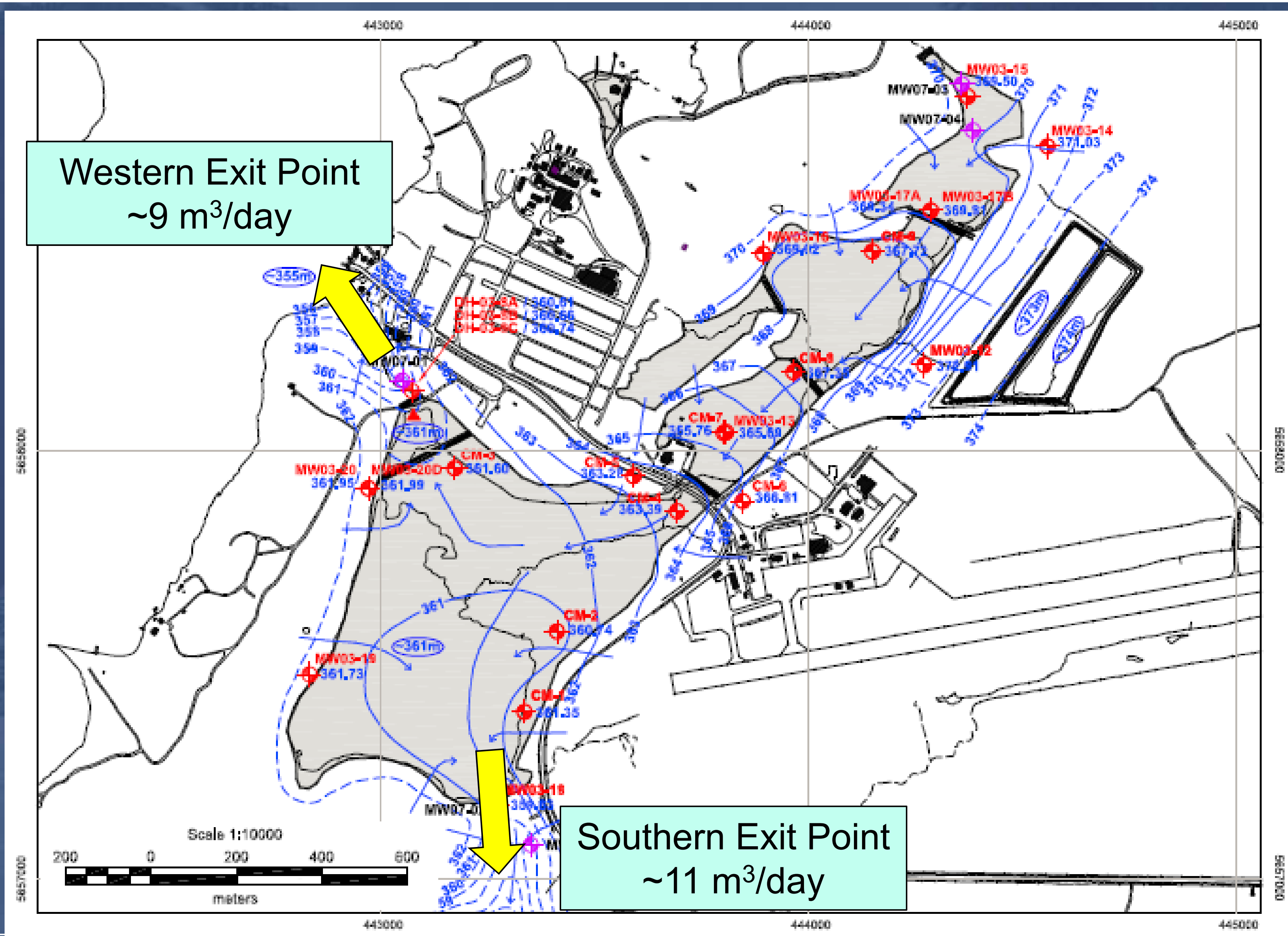


Groundwater Exit Points



LORAX ENVIRONMENTAL

Groundwater Elevations and Flux



Attenuation along Groundwater Flow Paths

Exit of tailings-related groundwater based on:

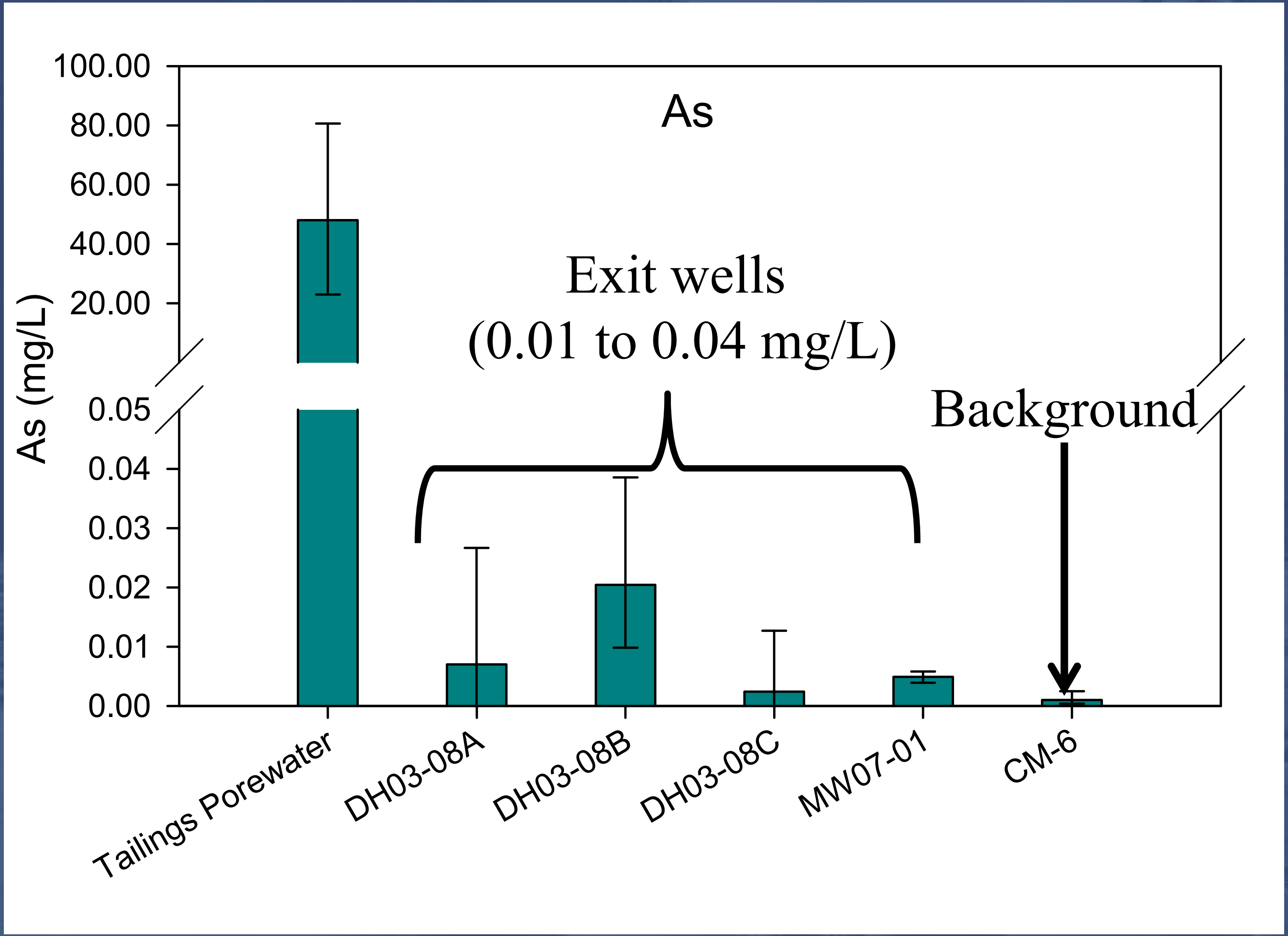
- Hydraulic gradients, permeability and hydrostratigraphy
- 2-D seepage analysis
- Major ion signatures (TDS, Cl, SO_4)

Evidence for attenuation of several parameters along flow path:

- Arsenic
- Ammonia
- Other trace elements

All MOE compliance criteria are being met

Attenuation along Groundwater Flow Paths - Arsenic



LORAX ENVIRONMENTAL

Attenuation along Groundwater Flow Paths – Arsenic Removal

Based on:

- Total groundwater flow of 20 m^3/day
- Average [As] in tailings porewater = 50 mg/L
- Average [As] in tailings-influenced flow path downgradient of facility= 0.03 mg/L

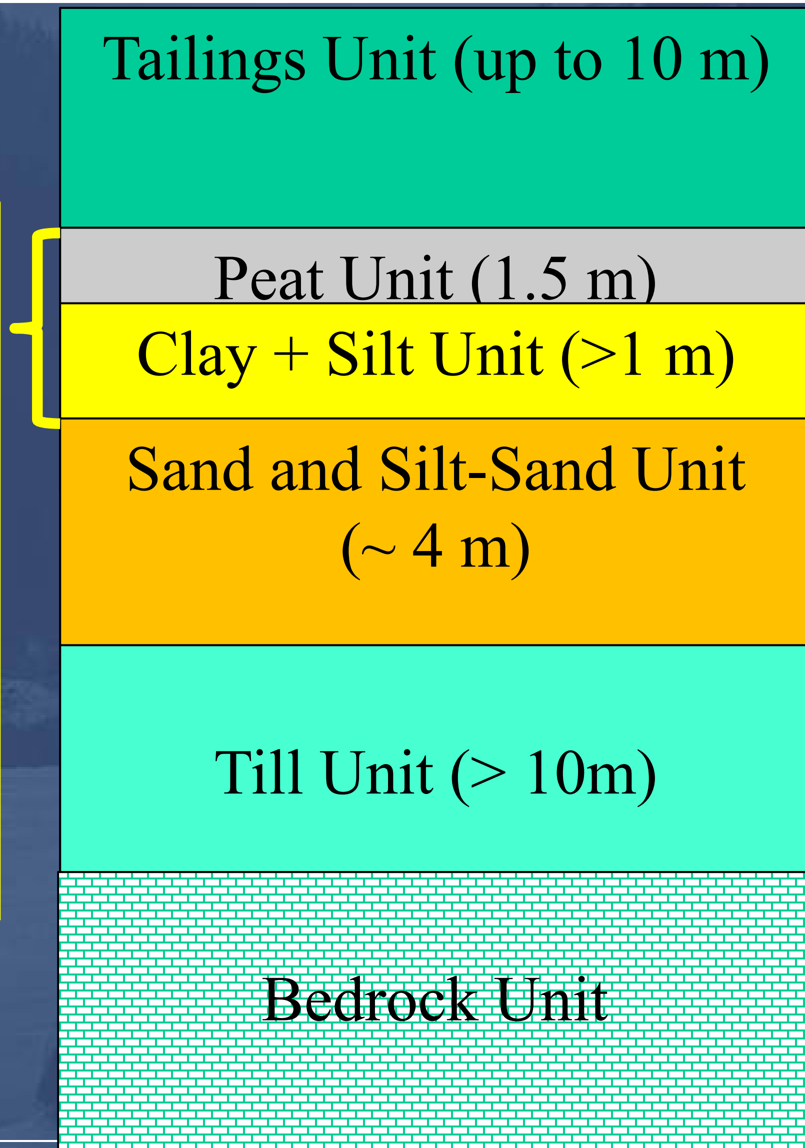
Annual removal rate = ~370 kg/year

Groundwater Attenuation Mechanism? Clues from Hydrostratigraphy

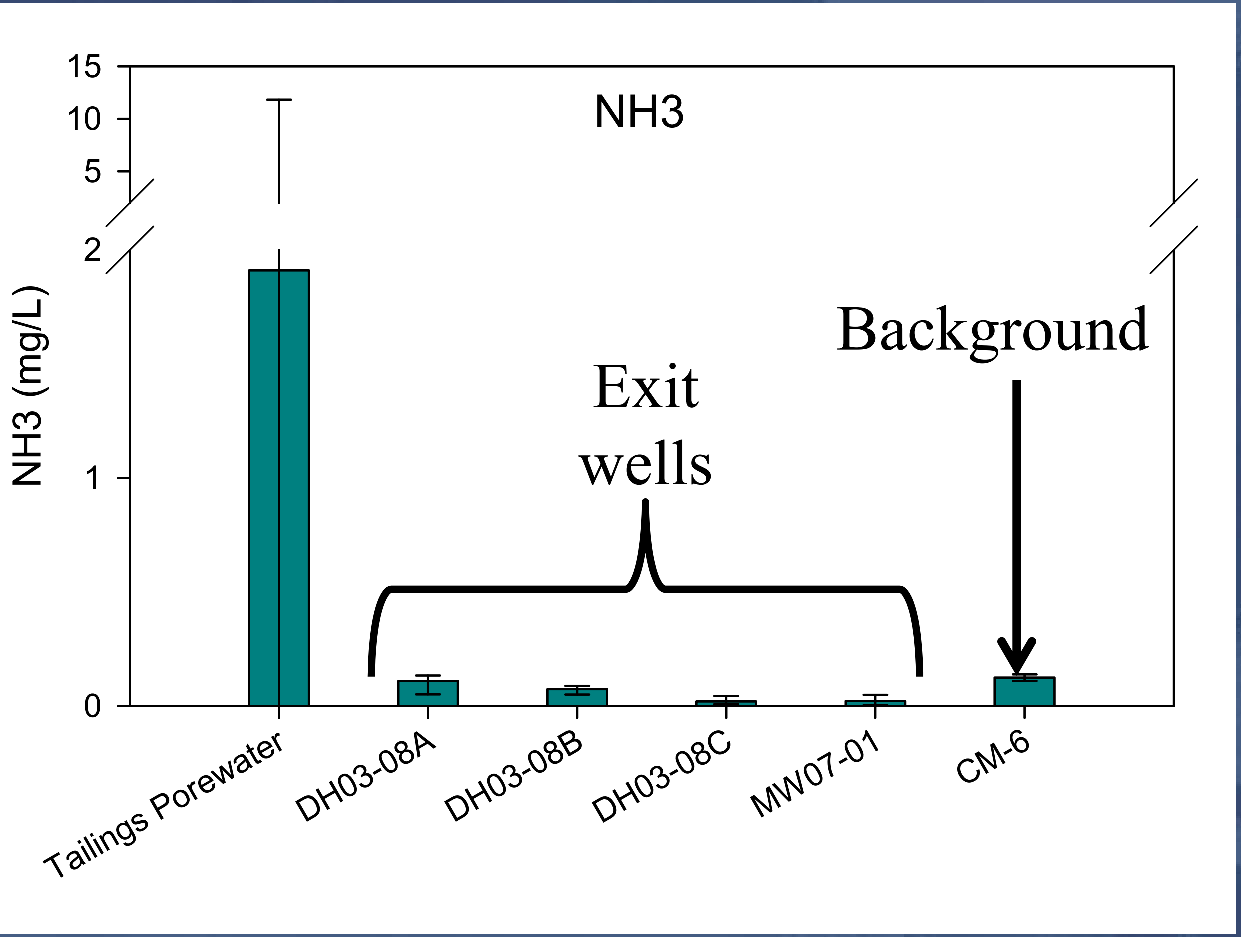
Strong likelihood attenuation is associated with either Peat and/or Clay+Silt Unit.

Mechanism not known:

- Adsorption of As(III)?
- Sulfide mineral precipitation?



Attenuation along Groundwater Flow Paths - Ammonia



NH_4^+ is strongly adsorbed by clay minerals through cation exchange. Suggests adsorption is important.

Summary & Implications for Tailings Management

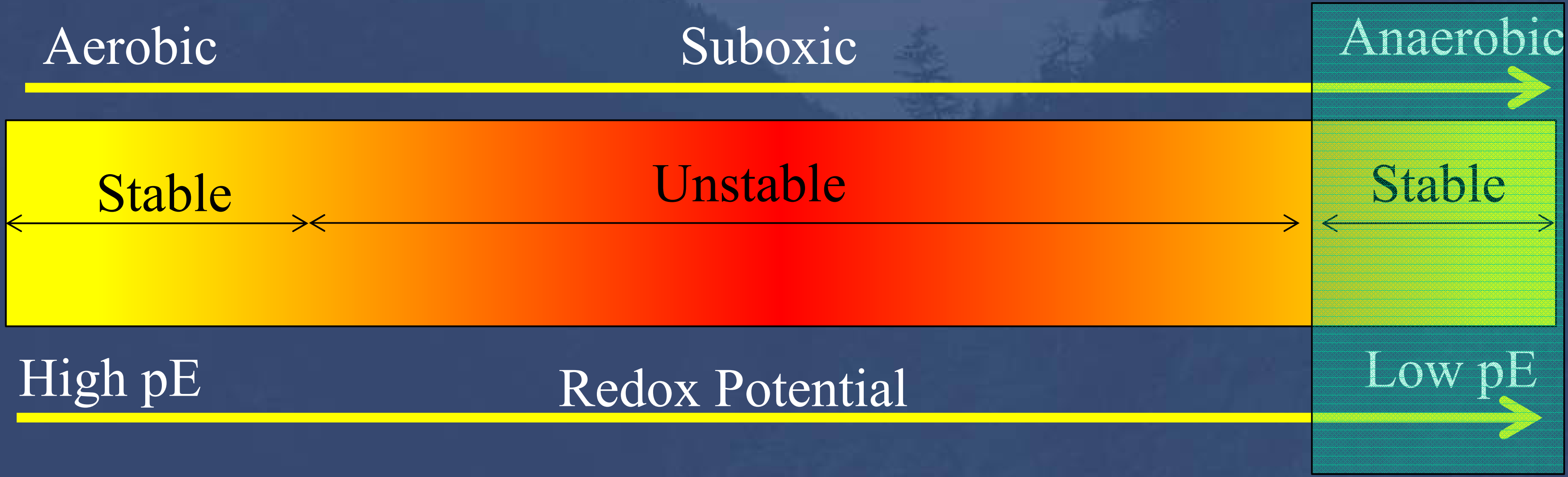
Three forms of treatment at Cochenour Wilanour Mine:

1. Active treatment (~540 kg As/year)
2. Passive bioremediation - diffusive pathway (~700 kg As/year)
3. Passive removal - groundwater pathway (~370 kg As/year)

- Passive removal mechanisms contribute significantly to reducing loadings to surface water receptors, and contribute to lower active treatment costs.

LORAX ENVIRONMENTAL

Implications for Tailings Management: Bioengineering for As Stability



- Arsenic mobility is limited under strongly oxidizing and strongly reducing conditions.
- Mobility strongly enhanced under suboxic conditions.
- Practitioners must carefully consider risks associated with bioremediation efforts.

Thank you!
Questions?