The Geochemical and Biological Recovery of a Gold Mine Polishing Pond (Balmer Lake, Ontario)

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Balmer Lake, March 1993

Presentation Overview

- Background and site setting
- History of mine-related inputs
- Pathway to Recovery
  - Mine water/tailings management
  - Passive/active treatment
  - Natural processes
- Recovery Indicators
  - Water quality
  - Sediment quality
  - Aquatic biota

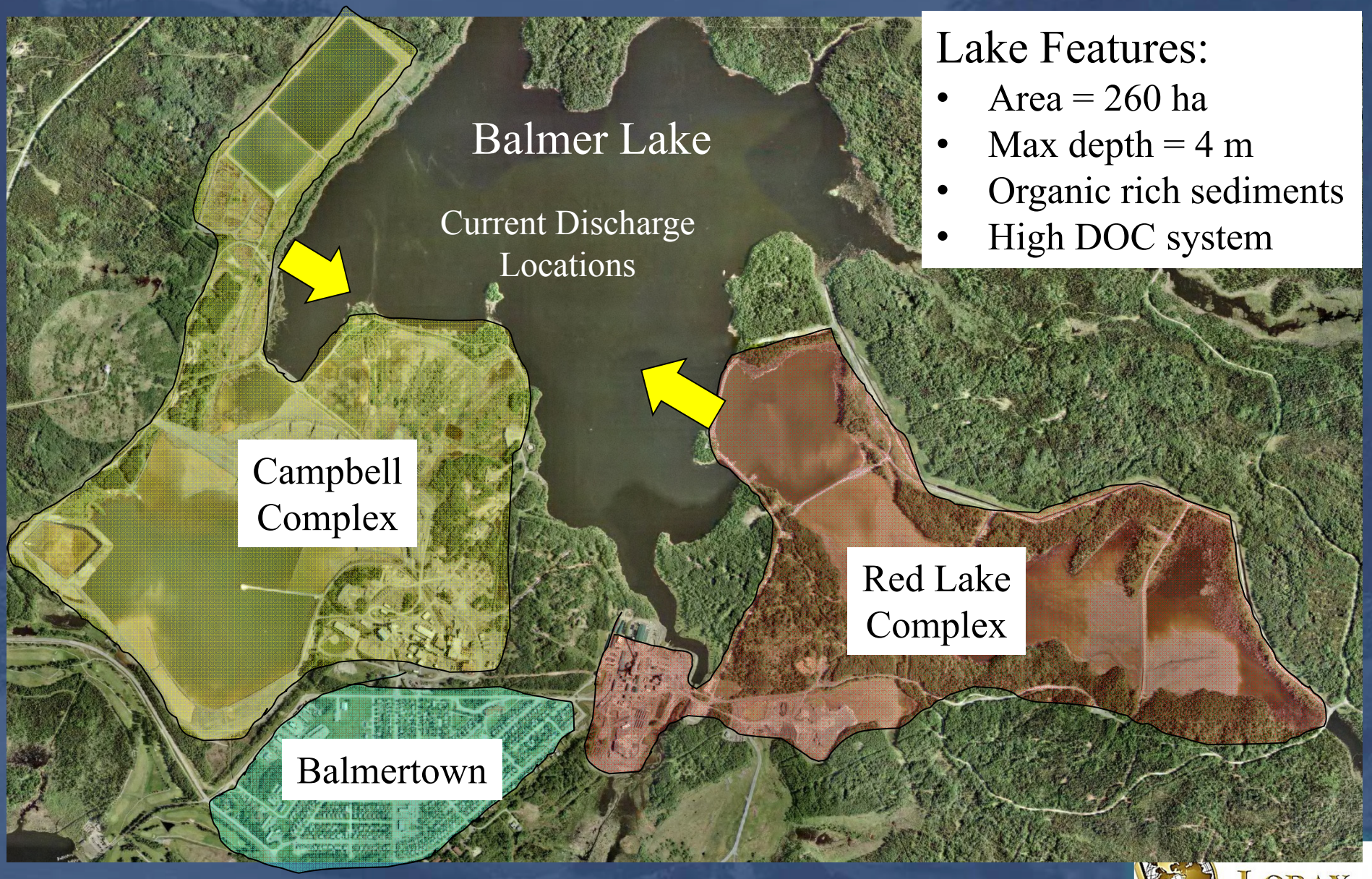
Study Location

- Goldcorp's Red Lake Gold Mines.
- Balmertown (Ontario) 7 km northeast of the town of Red Lake.

Mine History

- Continuous gold mining since 1948.
- Originally two separate mines (Campbell and Dickenson Mines).
- In 2006, Goldcorp Inc. acquired the Canadian assets of Placer Dome Ltd. In the amalgamation, Red Lake Gold Mines was expanded to include the neighbouring Campbell Mine.
- Mines now referred to as “Campbell Complex” and “Red Lake Complex” of Goldcorp’s Red Lake Gold Mines.

Site Setting



Lake Features:

- Area = 260 ha
- Max depth = 4 m
- Organic rich sediments
- High DOC system

History of Mine-Related Inputs

- Balmer Lake was originally designated as a "Tertiary Polishing Pond" to allow for:
  - Natural degradation of cyanide and ammonia
  - Particle settling
- Direct deposition of tailings to Balmer Lake prior to 1980 (predominantly roaster tailings).
- Discharge of untreated tailings pond overflow (1959 to 1992).
- Discharge of treated and untreated effluents (1992 to 2003).
- Discharge of treated effluent (2004 to present).

Contaminant Sources

- External loadings

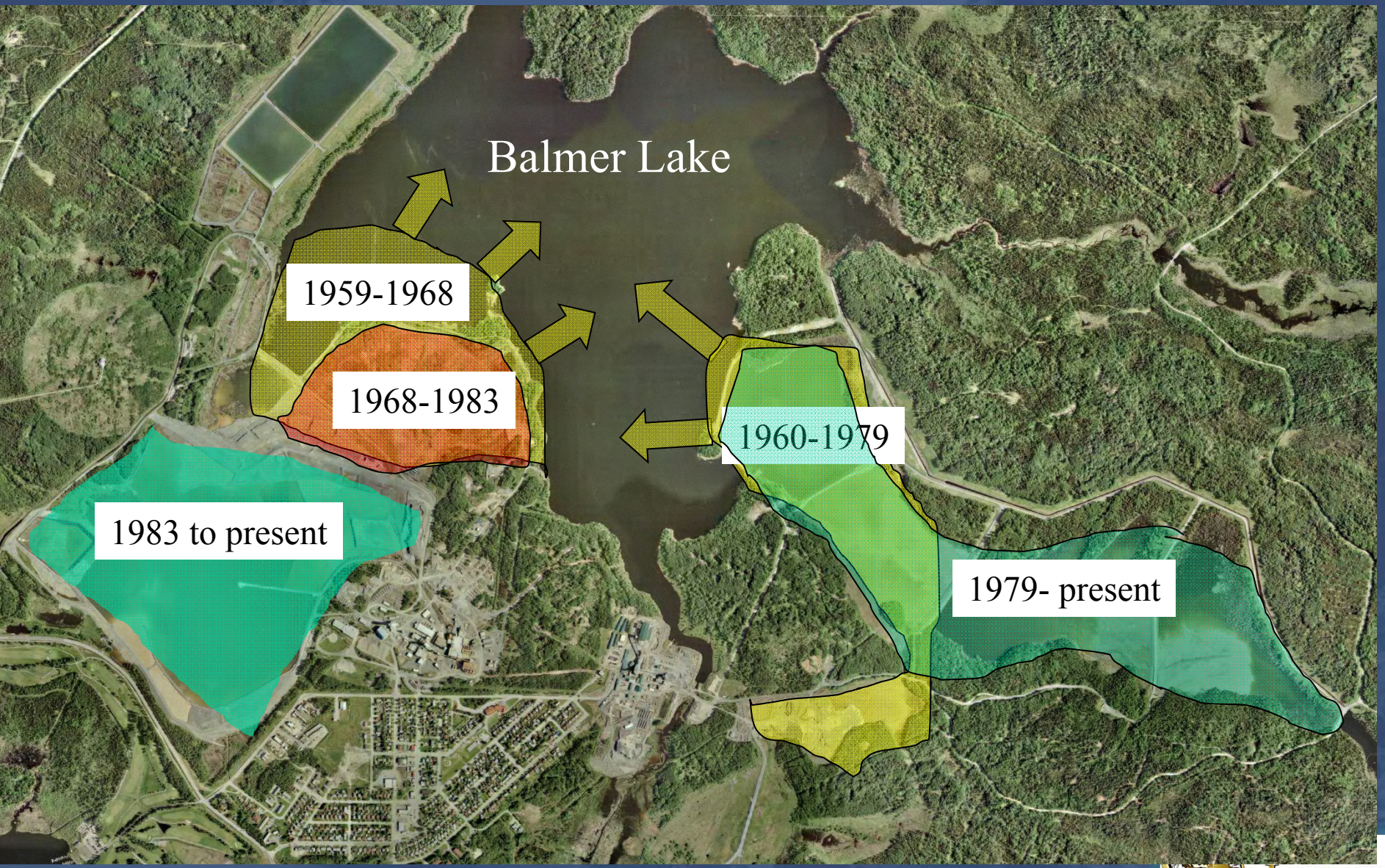
  Direct discharge of tailings solids to lake (1959-1979).

  Discharge of mine-related effluents (1959 to present). Historically elevated levels of cyanide, ammonia, arsenic, and heavy metals.

- Internal loadings

  Post-depositional remobilization of arsenic from tailings/sediments in Balmer Lake.

Historic Tailings Deposition



Pathway to Recovery: Water/Tailings Management

- Increase in tailings/water storage:
  - Dam raises
  - Construction of addition settling/polish ponds
  - Construction of internal dykes to maximize tailings/water retention
- Implementation of clean water diversions (ditches circumventing tailings management areas)
- Construction of flow control weirs
- Dam upgrades to low permeability structures

Pathway to Recovery: Passive/Active Treatment

- 1992: SO_2-Air cyanide treatment (Campbell). Upgraded in 2010.
- 1992: Replacement of roaster with pressure oxidation (Campbell).
- 2000: Pressure oxidation (Red Lake Complex)
- 2000: SO_2-Air cyanide treatment (Red Lake Complex).
- 2002: Implementation of wetland treatment (Campbell Complex).
- 2003-2007: batch ferric salt addition to tailings pond (Red Lake Complex)
- 2007: Arsenic treatment system (Red Lake Complex).
- 2009: Implementation of wetland treatment (Red Lake Complex).

Pathway to Recovery: Wetland Treatment

- Campbell Complex Wetland Area: 16 ha
- Capacity: 30,000 m^3/day.
- Parameters: Ammonia, phosphorus, trace elements, toxicity.

Pathway to Recovery: Natural Processes in Balmer Lake

- Natural degradation of ammonia and cyanide.
- Biogenic scavenging: Metal assimilation/binding to organics followed by particle settling.
- Precipitation of secondary sulfides in reducing lake sediments (As, Cu, Ni, Zn, Co)
- Precipitation of secondary metal-bearing cyanide phases in reducing lake sediments (Cu, Ni, Zn)
- Natural sedimentation (dilution of mine-impacted sediments)
- Release of arsenic and heavy metals from sediments to the water column and export from Balmer Lake.

Lake Recovery:

Water Quality

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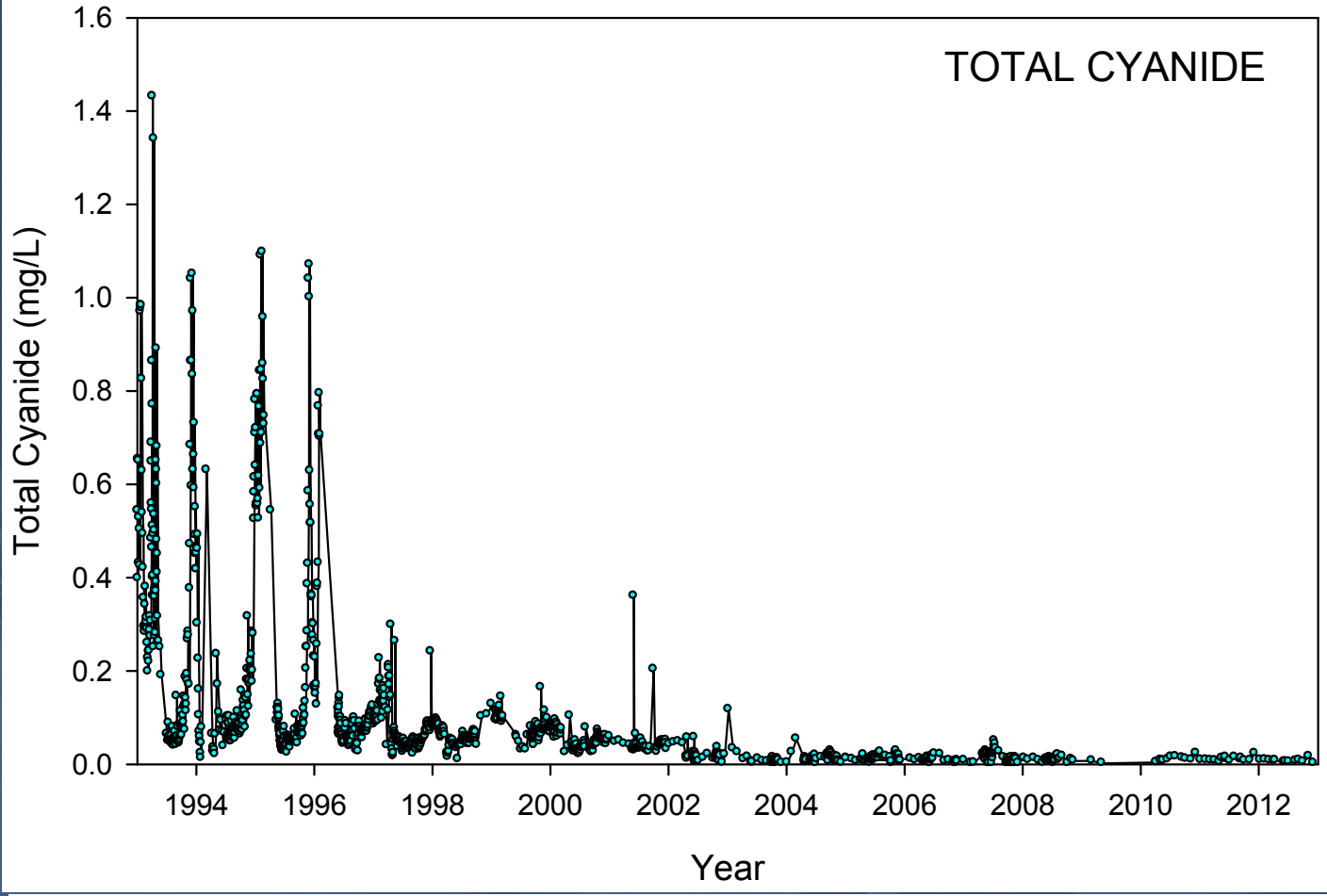
Balmer Lake Water Quality: 1993-2012 Total Cyanide



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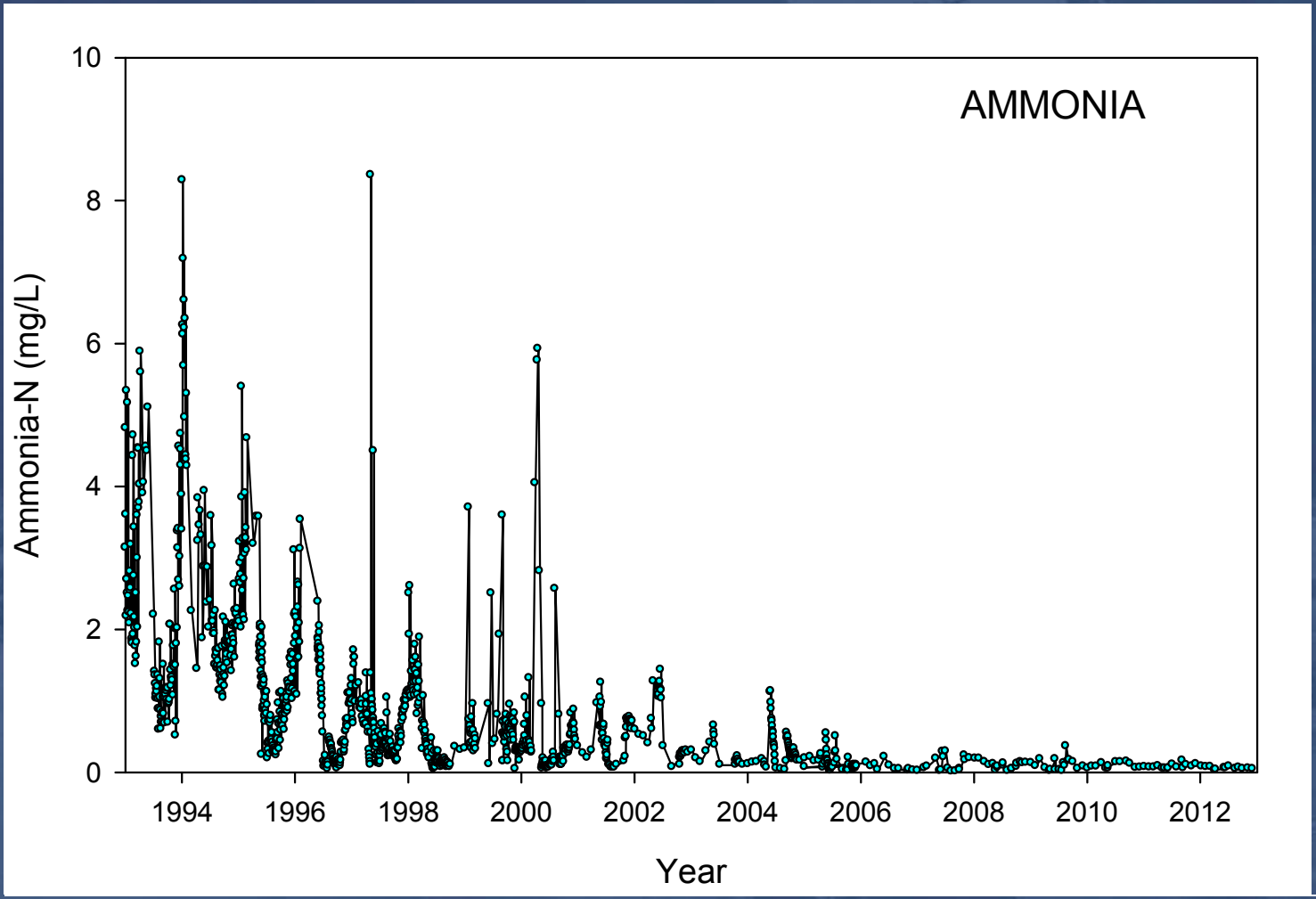
Balmer Lake Water Quality: 1993-2012 Ammonia



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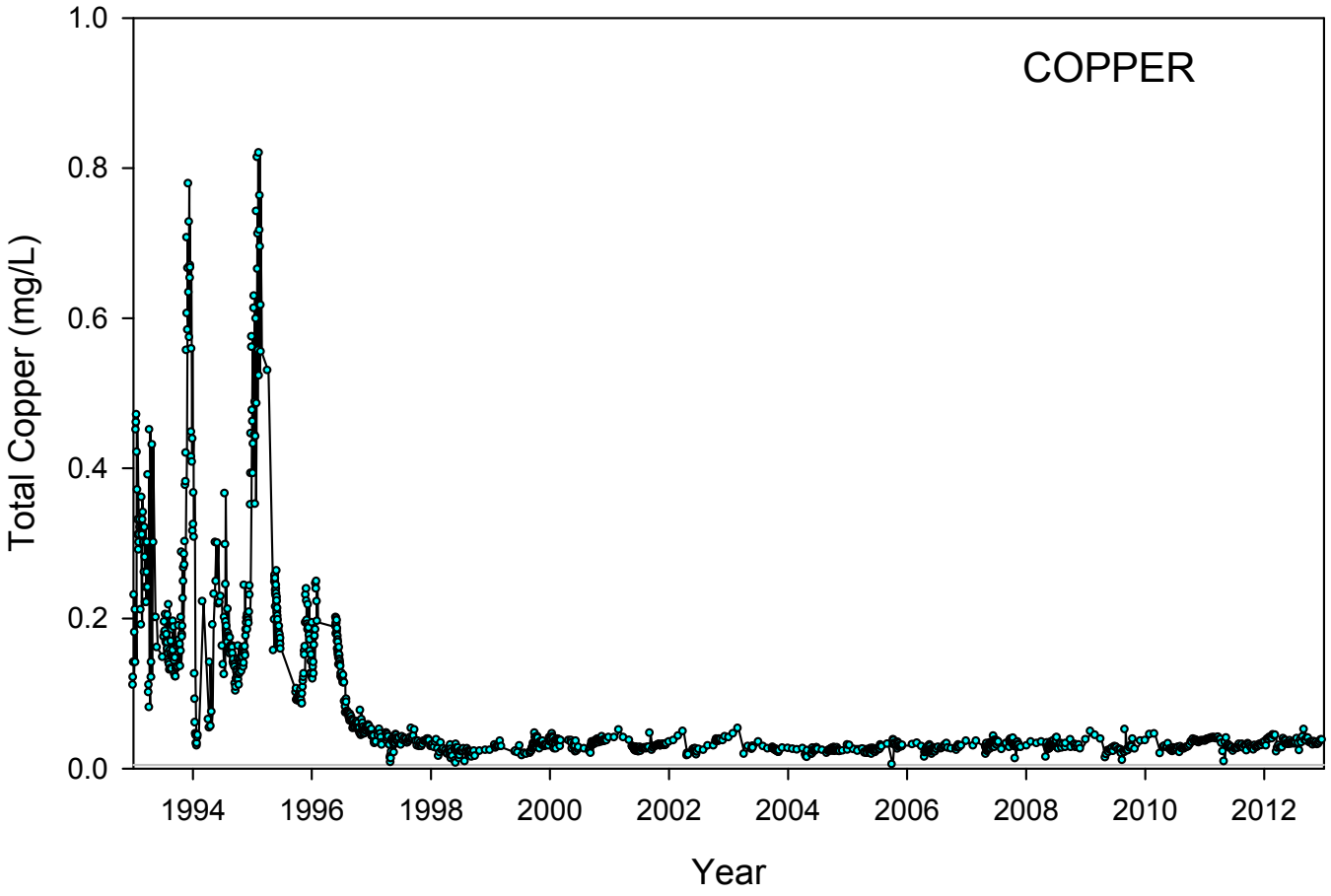
Balmer Lake Water Quality: 1993-2012 Total Copper



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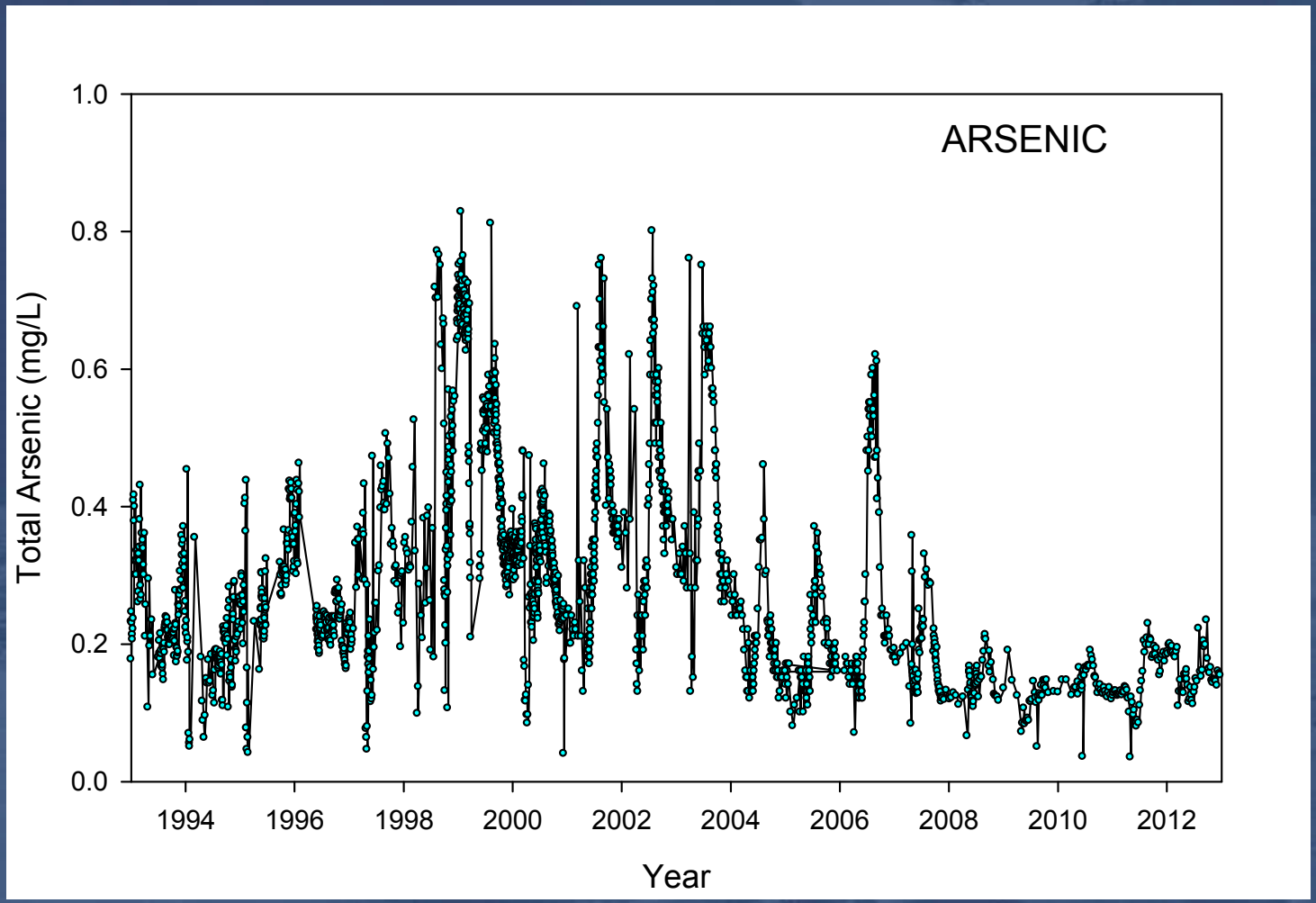
Balmer Lake Water Quality: 1993-2012 Total Arsenic



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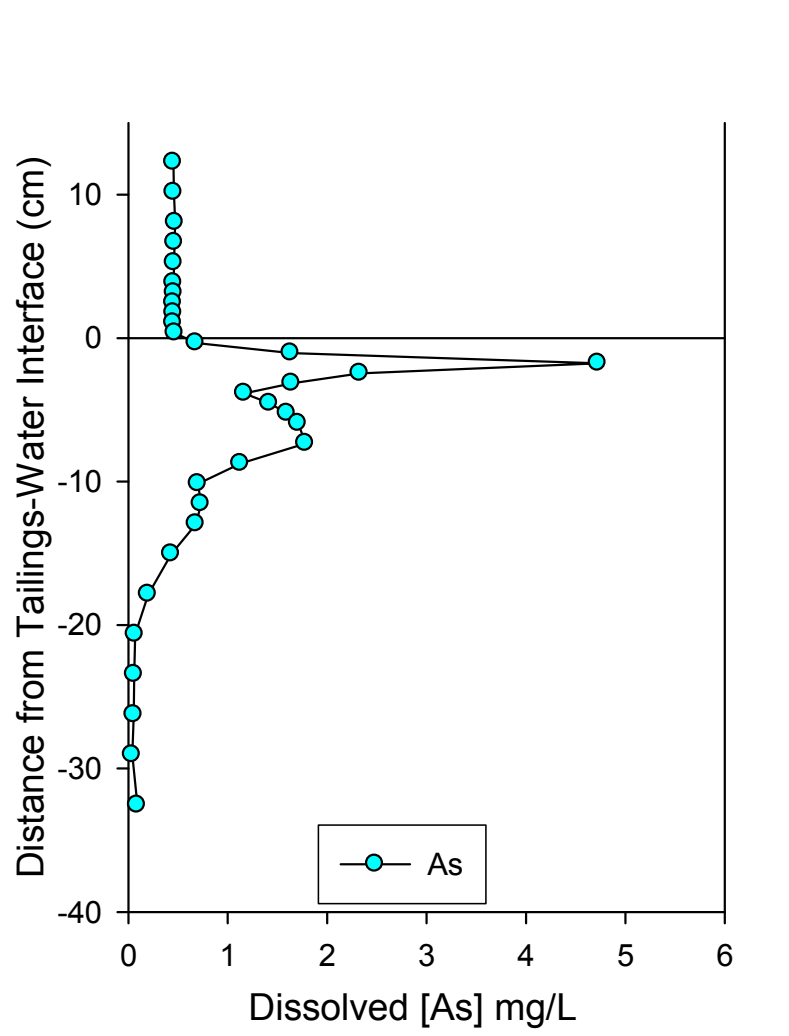
Arsenic Remobilization from Sediments: Reductive Dissolution of Fe oxides



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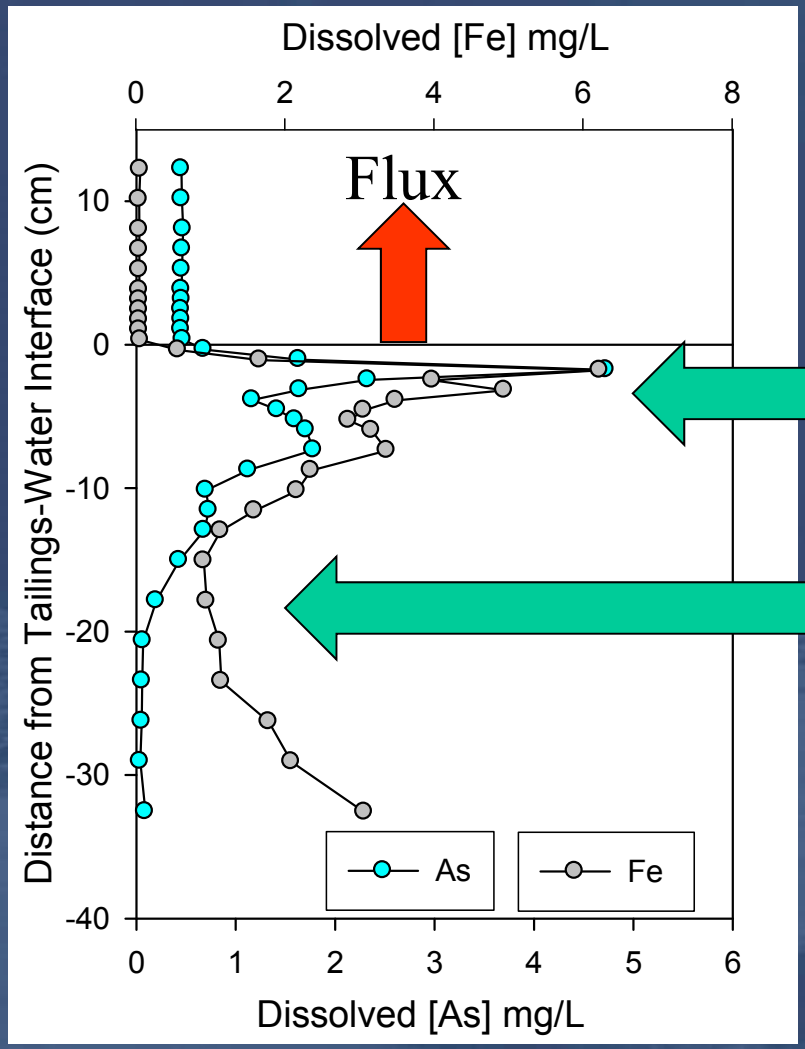

Reductive dissolution of As-bearing Fe oxides

Removal from porewaters via precipitation of secondary sulfide minerals

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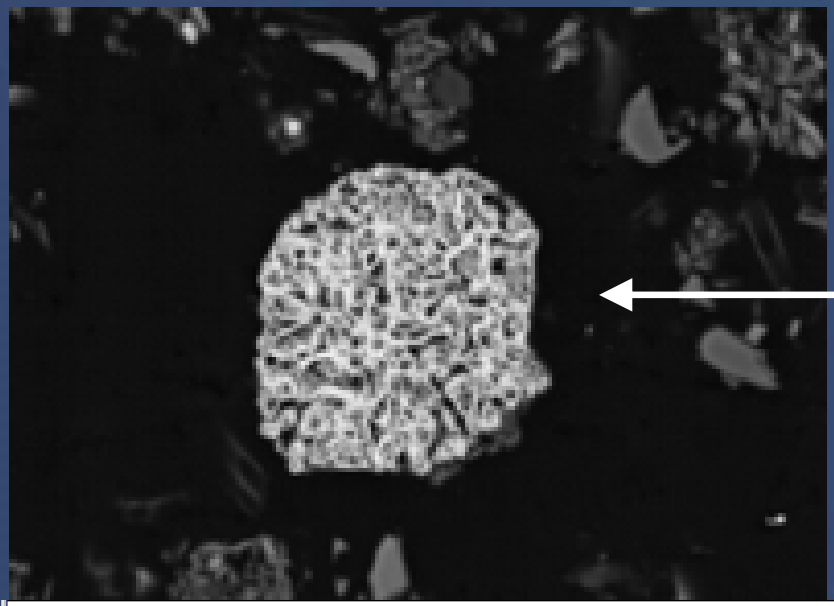
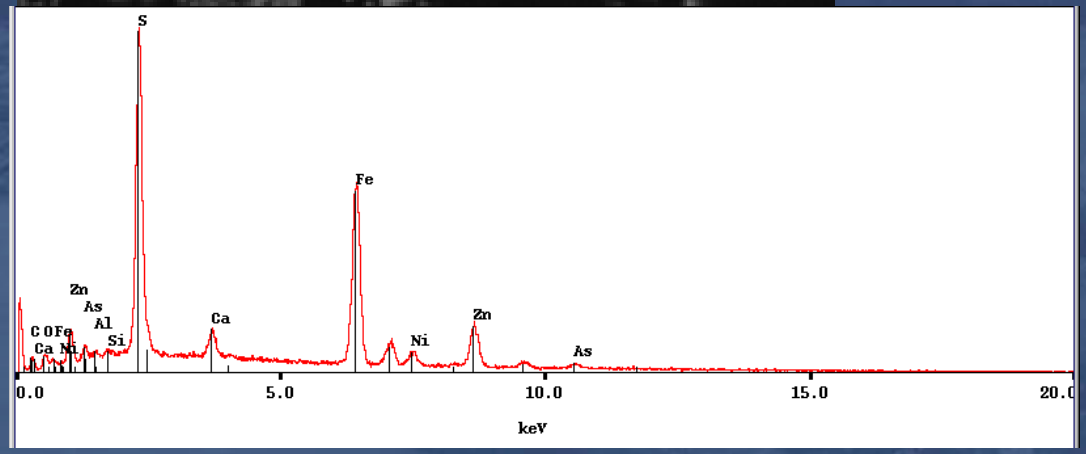
Source of Arsenic: Fe oxides



BSE Image of roaster Fe oxides: Sponge-texture hematite, hosting between 0.6 to 6.4 wt.% arsenic.



EDS spectra showing presence of sorbed As, Ni and Zn.

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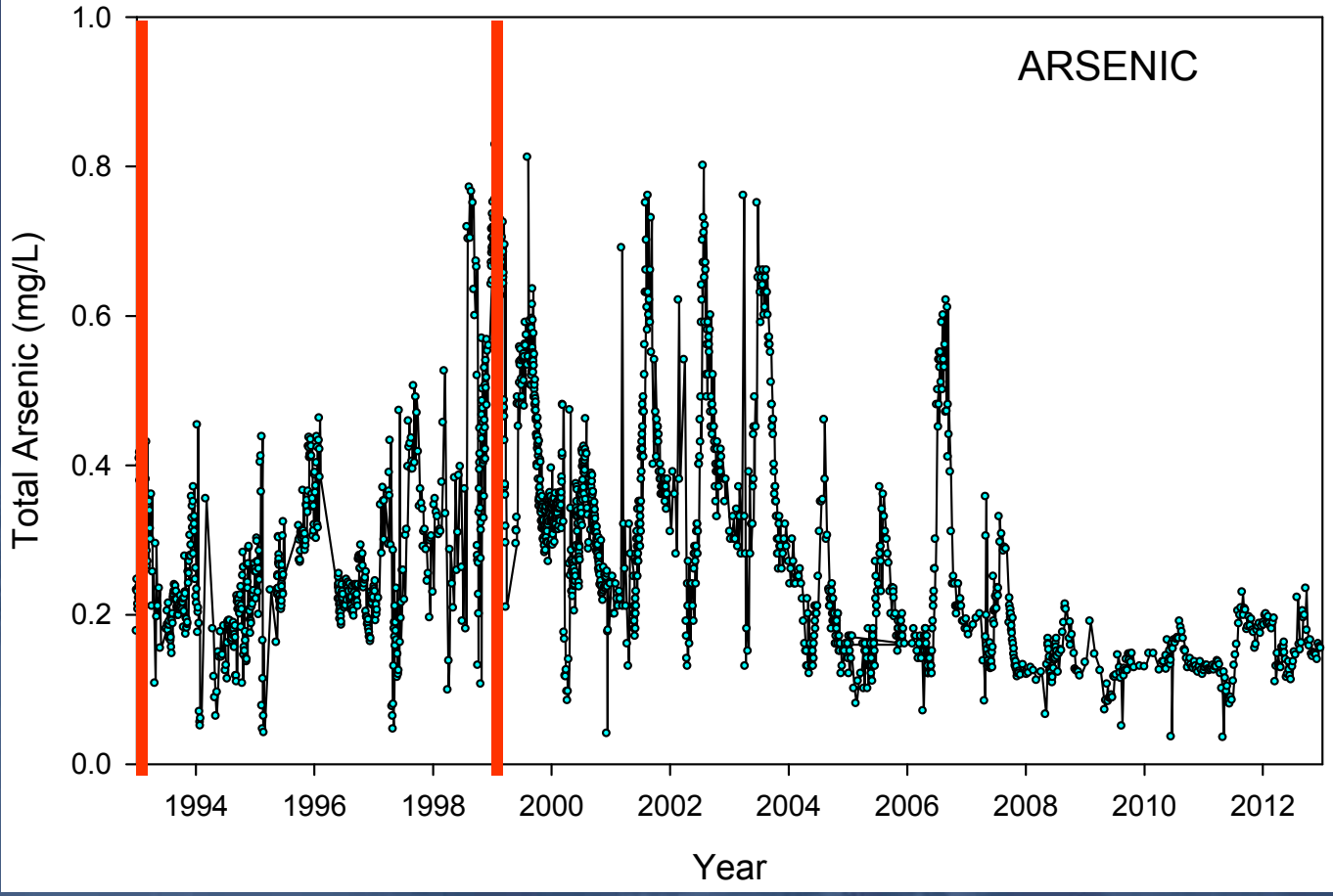
Balmer Lake Water Quality: 1993-2012 Total Arsenic



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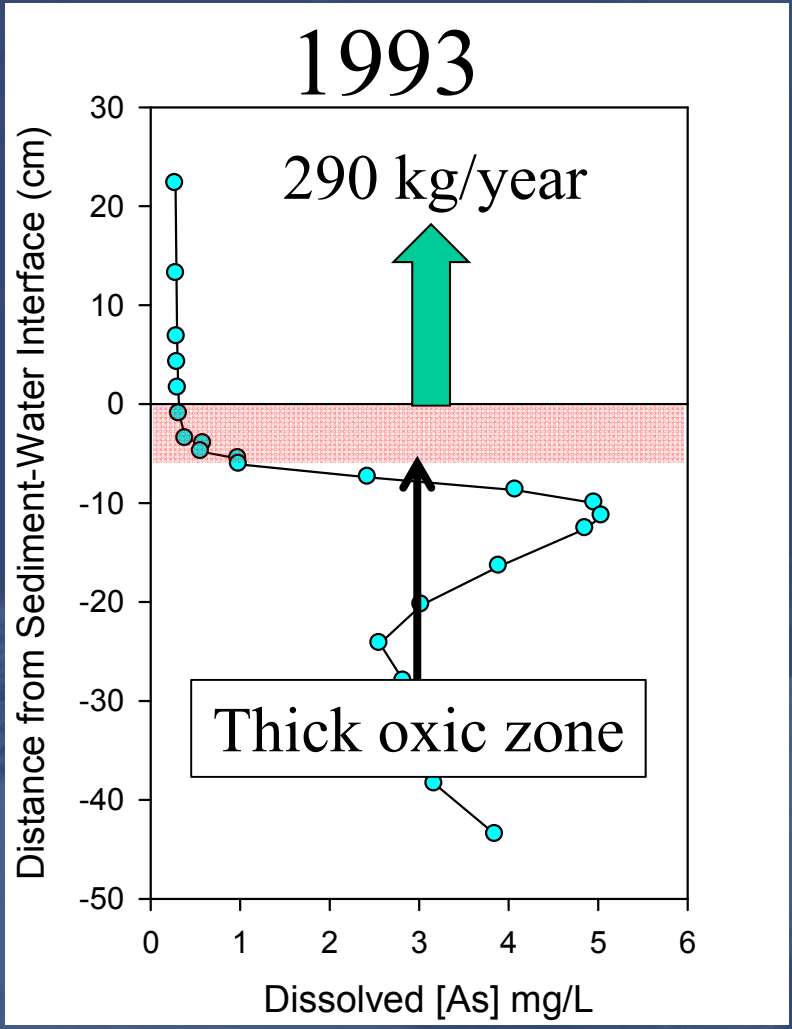
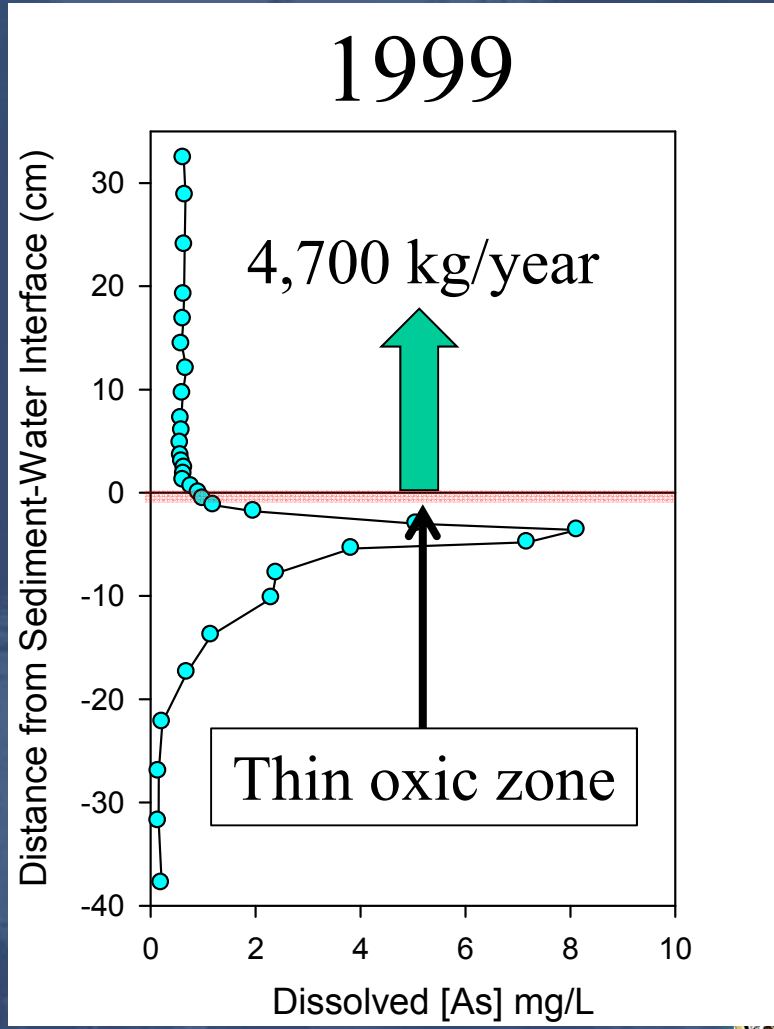
Arsenic Flux to Sediments





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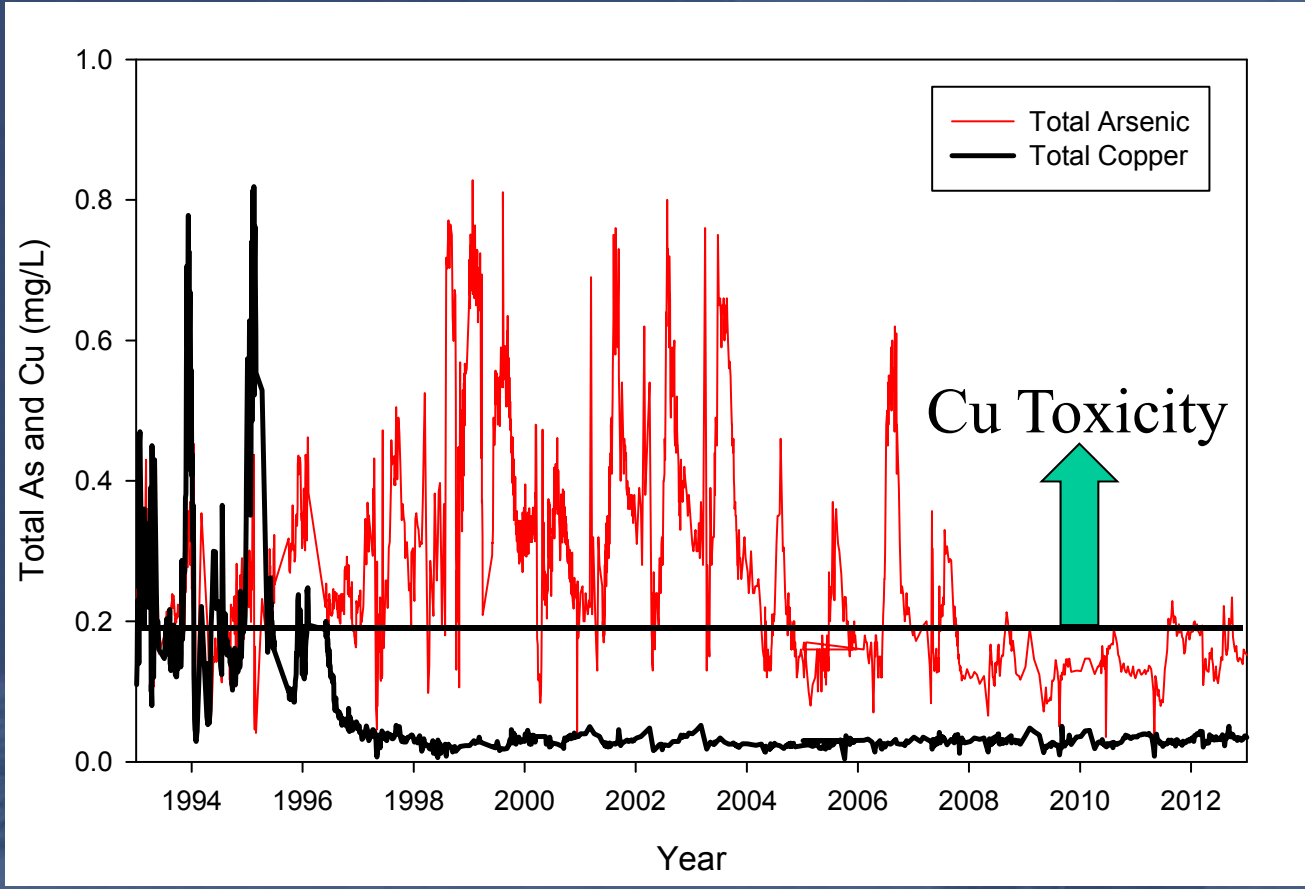
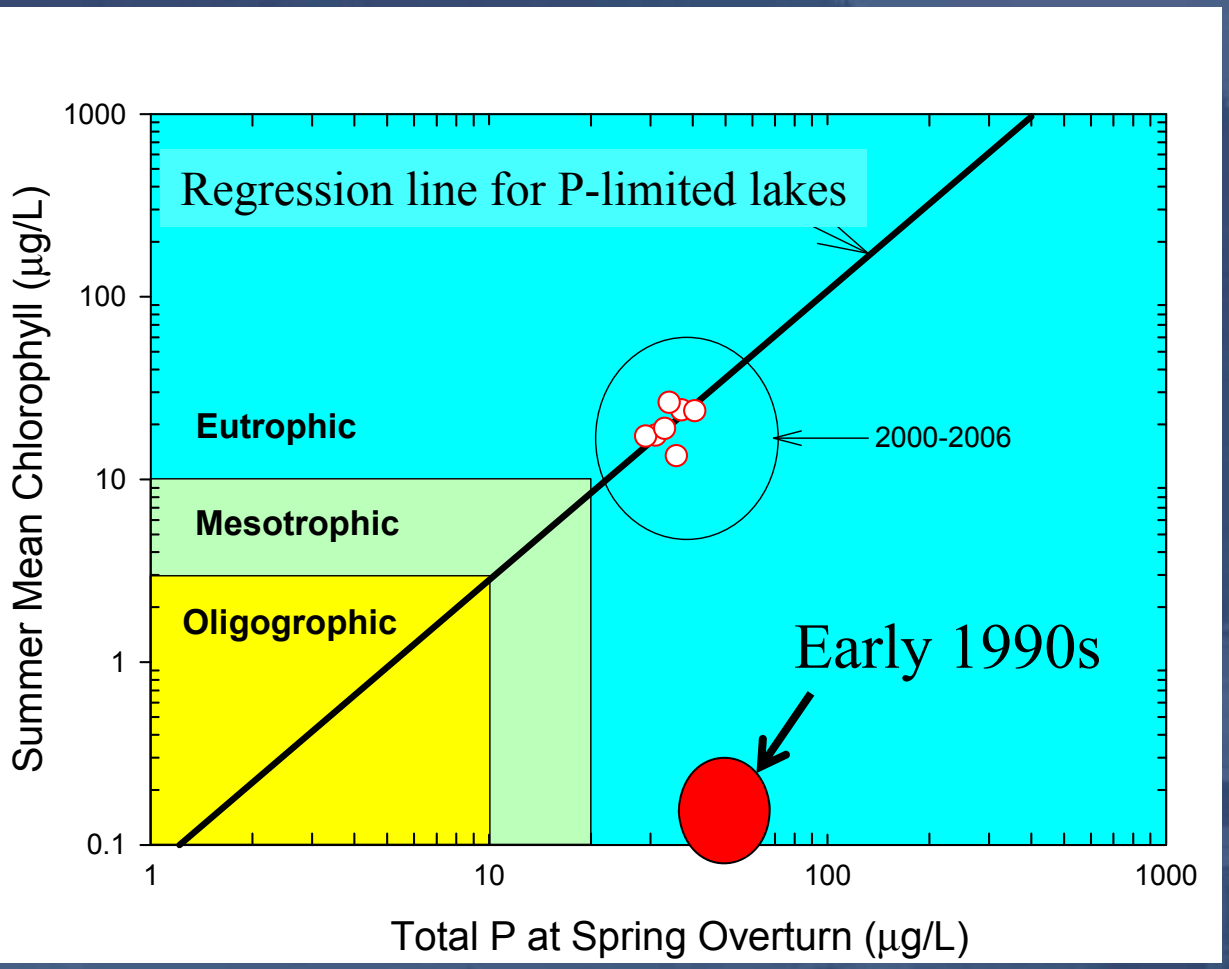
Arsenic *versus* Copper



Increase in As mobility coincident with a decrease in Cu and NH_3 levels.

Decrease in toxicity likely allowed for enhanced algal growth.

Lake Trophic Status



By 2000, eutrophic conditions had developed in Balmer Lake.

High algal productivity sustained by sewage inputs.

Lake Recovery:

Sediment Quality

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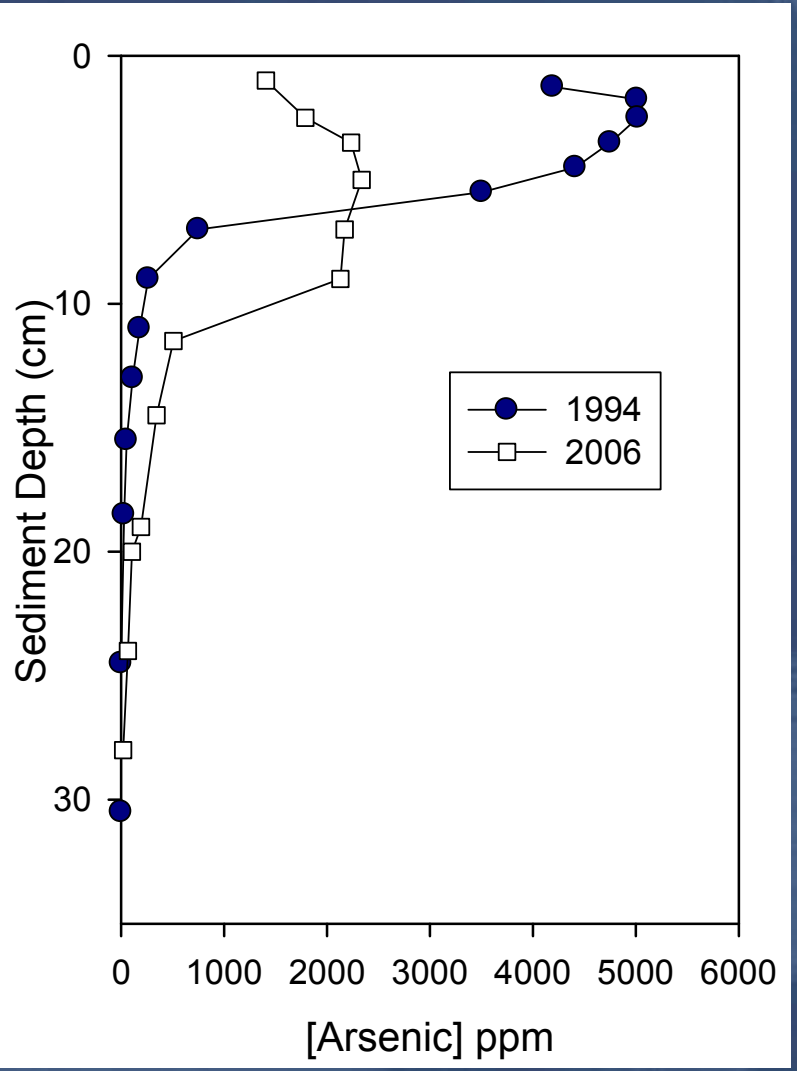
Sediments – Metal Content

Trace Element Content (mean in uppermost 10 cm)

Parameter	Year	
	1994	2006
As (mg/kg)	4,817	2,012
Cu (mg/kg)	4,156	1,873
Ni (mg/kg)	3,320	3,241
Zn (mg/kg)	3,513	2,316

- Concentrations of As, Cu, Ni and Zn strongly elevated in surface sediments (tailings-related signature).
- High metal content likely responsible for impairment of benthic invertebrate community.
- Rate of sediment recovery predicted to be low, in low sedimentation rate systems.

Sediments – Arsenic Content



Concentration of arsenic in surface sediments decreased by factor of >2 between 1994 and 2006.

Related to loss of arsenic via:

1. Dissolution of solids and release to water column.
2. Vertical mixing in the sediment column (likely owing to bioturbation).

Lake Recovery:

Fish Resources

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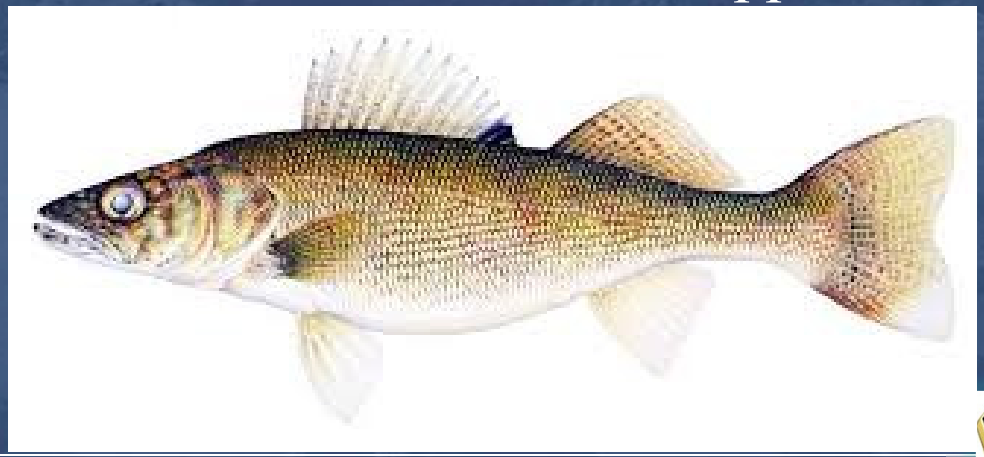
Fisheries Resources

- The fish community in Balmer Lake has been assessed on six occasions: 1978, 1996, 2000, 2005, 2008 and 2012.
- 1978: No fish were caught, likely owing to the presence of elevated concentrations of cyanide, ammonia and trace elements (*e.g.*, Cu).
- 1996: a number of small forage fish species including pearl dace, fathead minnows and ninespine stickleback caught for first time.

Fisheries Resources cont.

- In the spring of 1999, 19 adult walleye were released to Balmer Lake as part of a radio telemetry study. The majority of fish survived at least 12 months, at which time the tracking devices expired.
- 2000: three of the telemetry fish were captured and re-released.
- 2000: first capture of white suckers and large schools of forage fish evident.
- 2002: the federal government removed Balmer Lake from the tailings management system and now the *Fisheries Act* applies to the lake.

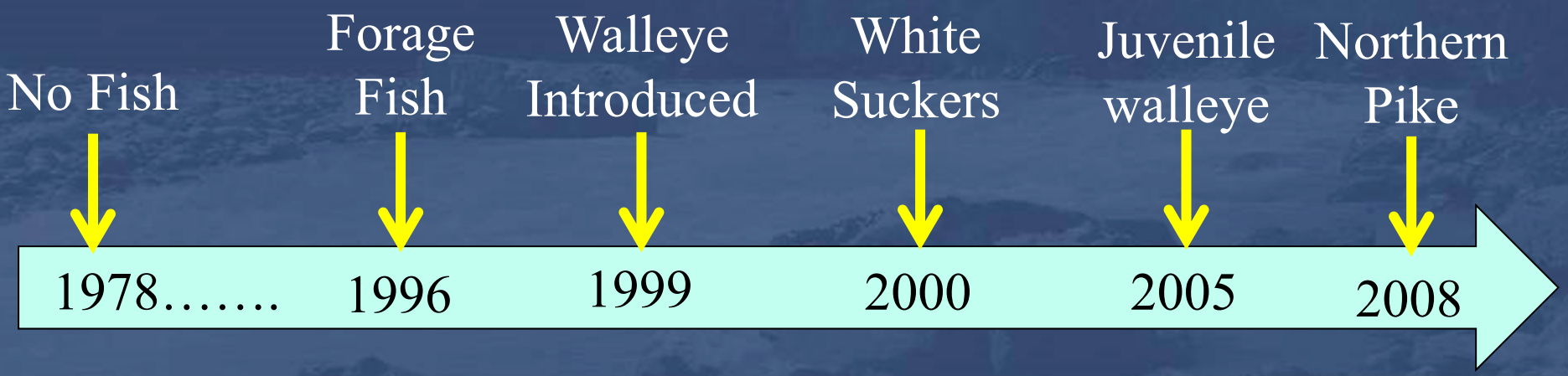


Fisheries Resources - 2005

- 2005: juvenile walleye were captured for the first time indicating recent reproductive success of the 1999 introduced population.
- 2008: documented northern pike for the first time.

Summary

- Overall, Balmer Lake has transitioned from a non-productive water body in the 1980's to one containing a representative species assemblage for shallow lakes in northern Ontario.
- Fish community is relatively healthy despite continued impairment of benthic community assemblage.



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Summary cont.

- Rate of WQ recovery can be rapid for parameters governed by external loading mechanisms (e.g., CN, NH_3, Cu).
- Rate of WQ recovery can be slow for parameters governed by internal loading mechanisms (e.g., As). Relevant factors:
  - Type of mine waste generated (phase associations)
  - Conditions of depositional environment (Eh, pH)
- Sediment recovery is slow in systems characterized by low sedimentation rate and bioturbation.
- "Recovery" of the system can result in unexpected consequences.

Thank You!

Martin A. J. and T. F. Pedersen, 2002. Seasonal and inter-annual mobility of arsenic in a lake impacted by metal mining. *Env. Sci. Tech.*, 36:1516-1523.

Martin A. J., McNee J. J., Crusius J., Pedersen T. F., and Yanful E. K. (2003) Mechanisms of metal release from subaqueous mine waste at circum-neutral pH: examples from four case studies. *International Conference on Acid Rock Drainage, Cairns, Australia, July 2003.*

Martin A. J. and Pedersen T. F. 2004. Alteration to lake trophic status as a means to control arsenic mobility in a mine-impacted lake. *Wat. Res.* 38, 4415-4423.

Jambor, J. L., Martin, A. J., and Gerits, J., 2009. The post-depositional accumulation of metal-rich cyanide phases in submerged tailings deposits *Appl. Geochem.* 24, 2256-2265.