The Bioremediation of Mine-Site Pit Lakes: Considerations, Limitations and Case Studies

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Outline

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- Introduction
- Considerations/limitations for pit lake bioremediation
- Case Studies
- Data requirements (basis of any action)
- Take-Away Messages

Bioremediation - Introduction

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- Offers attractive alternative to traditional in-situ treatments (liming) and active treatment given potential lower costs, "benign nature" and sustainability (passive or semi-passive level of effort)

- Typically involves:
  1. Addition of nutrients (inorganic or organic)

     and/or

  2. Addition of organic matter

WATER QUALITY OBJECTIVES

Beneficial Mechanisms

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1. Increased particle concentration and biological scavenging
   - → Biological assimilation
   - → Sorption to algal surfaces

2. Particle settling
   - → Algal detritus (organic flocs)
   - → Zooplankton feacal pellets

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DECREASED [TOTAL] AND [DISSOLVED]

Beneficial Mechanisms

3. Oxygen Demand

- Increased sediment/water oxygen demand which can lead to suboxic/reducing conditions

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Alkalinity generation – <u>acid neutralizing potential</u>

e.g., $\underline{(CH_20)_{106}(NH_3)_{16}(H_3PO_4)} + 53SO_4^{2-} \leftrightarrow 39CO_2 + 16NH_4^{+} + HPO_4^{2-} + 39H2O + 53\ HS^{-} + \underline{\mathbf{67HCO_3}}^{-}$

Sulphate reduction – <u>metal sulphide precipitation</u>

(*e.g.*, $Cu_{(aq)} + HS^{-} \leftrightarrow CuS_{(s)}$)

Algal Growth

- Algal growth limited by available phosphorus
- Phytoplankton assimilate C and P at a ratio of ~ 106:1
- Therefore, only trace quantities of P addition are required to generated “eutrophic” conditions

Bioremediation

Who does the work?

Algae AND Bacteria

Take advantage of incredible metabolism and assimilative capacity

Pit Lakes Well Suited to Bioremediation

- natural algal communities
- respond well to nutrient amendments

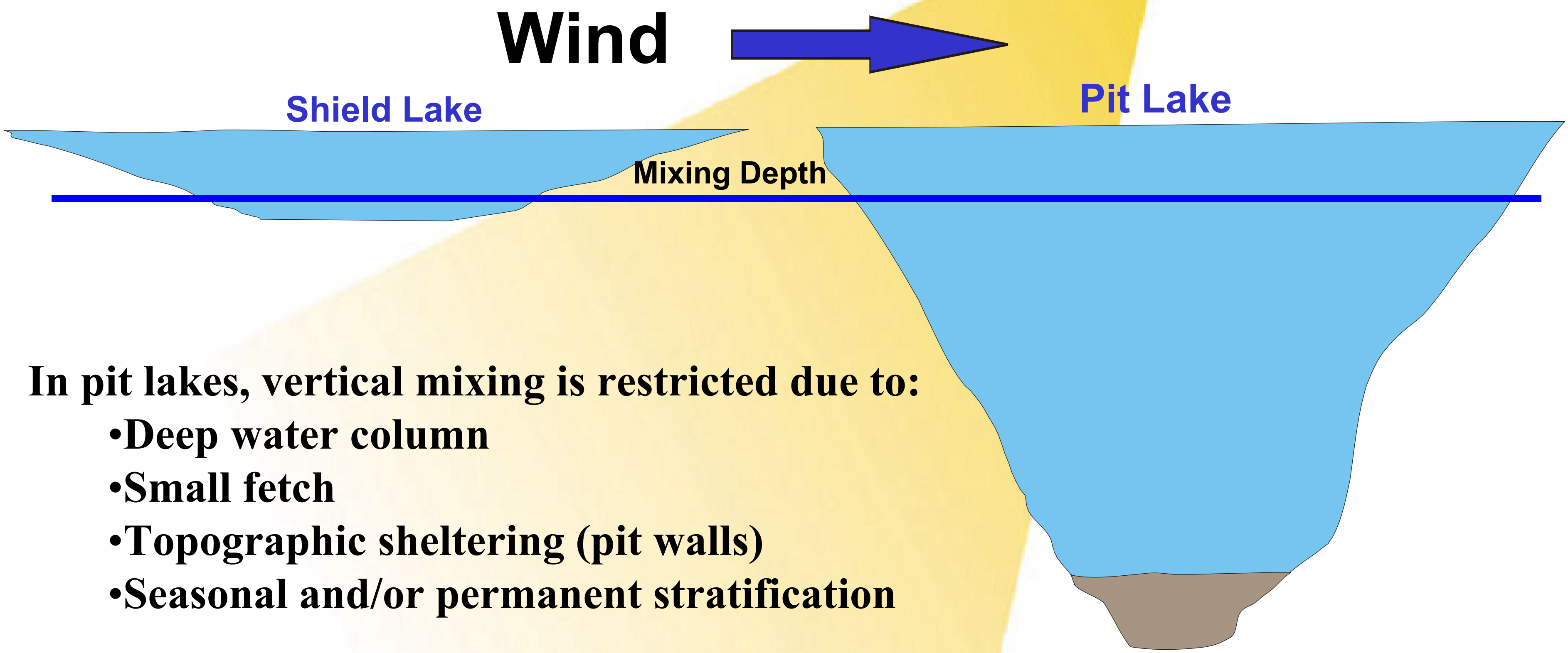
Bioremediation: Considerations/limitations

- Water quality (parameters of concern)
- Lake morphometry
- Water/Chemical mass balance (flow and chemistry of all inflows and outflows)
- Physical Limnology (e.g., stratification)
- Waste management (backfill, tailings, ARD, treatment sludges)

Considerations – Water Quality

- Parameters of Concern
  - Parameters such as pH , NH_3, Zn, Cu, Ni, Cd, sulphate are amendable to bioremediation
  - Parameters such as Se, Mo, and Ra less so
- Toxicity may limit effectiveness of bioremediation
  - pH
  - Trace elements
  - Ammonia

Considerations - Lake Mixing

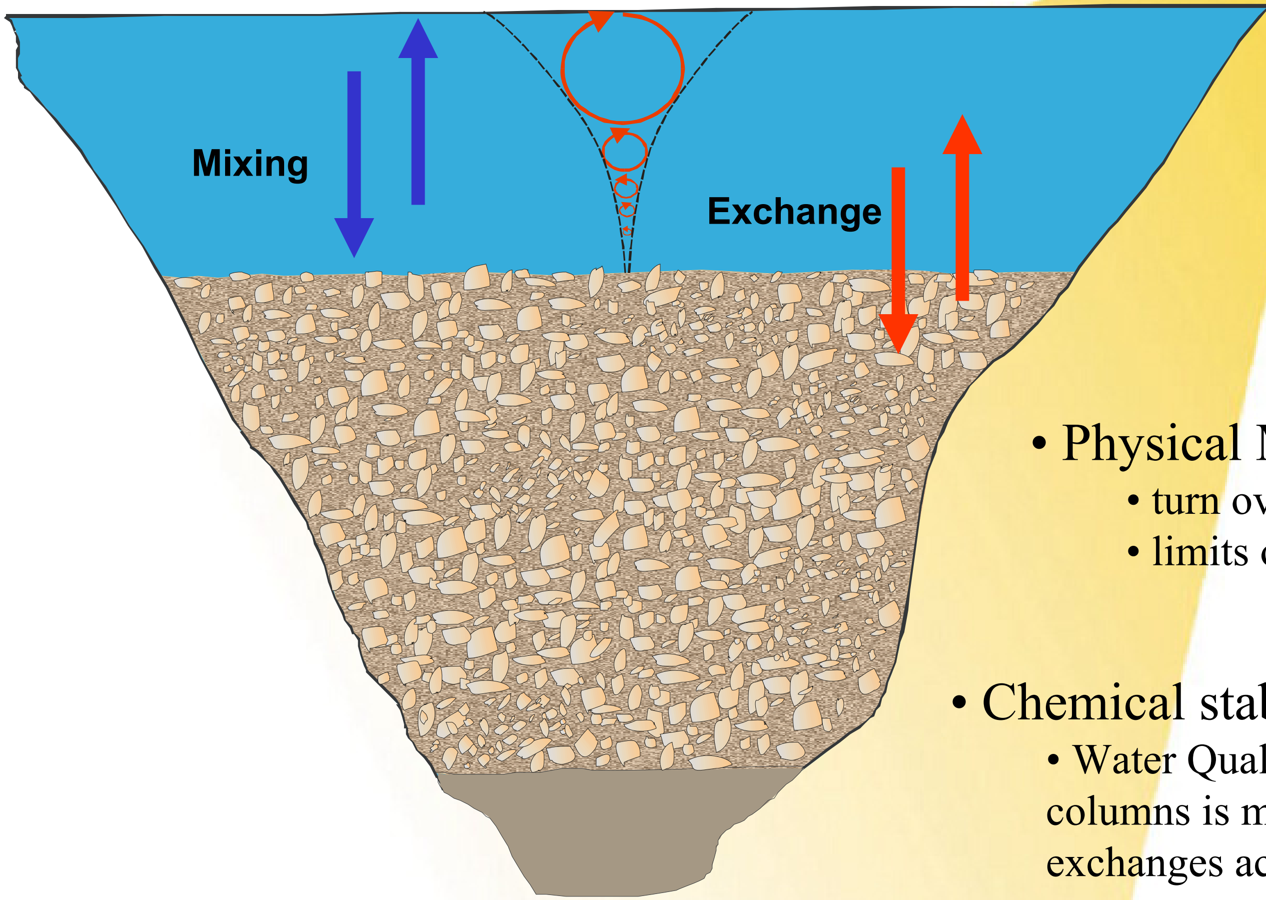


In pit lakes, vertical mixing is restricted due to:

- Deep water column
- Small fetch
- Topographic sheltering (pit walls)
- Seasonal and/or permanent stratification

- Vertical structure has important chemical implications

Considerations – Backfill
Tailings/Wasterock/Treatment Products



- Physical Mixing
  - turn over more likely
  - limits on geochemical evolution

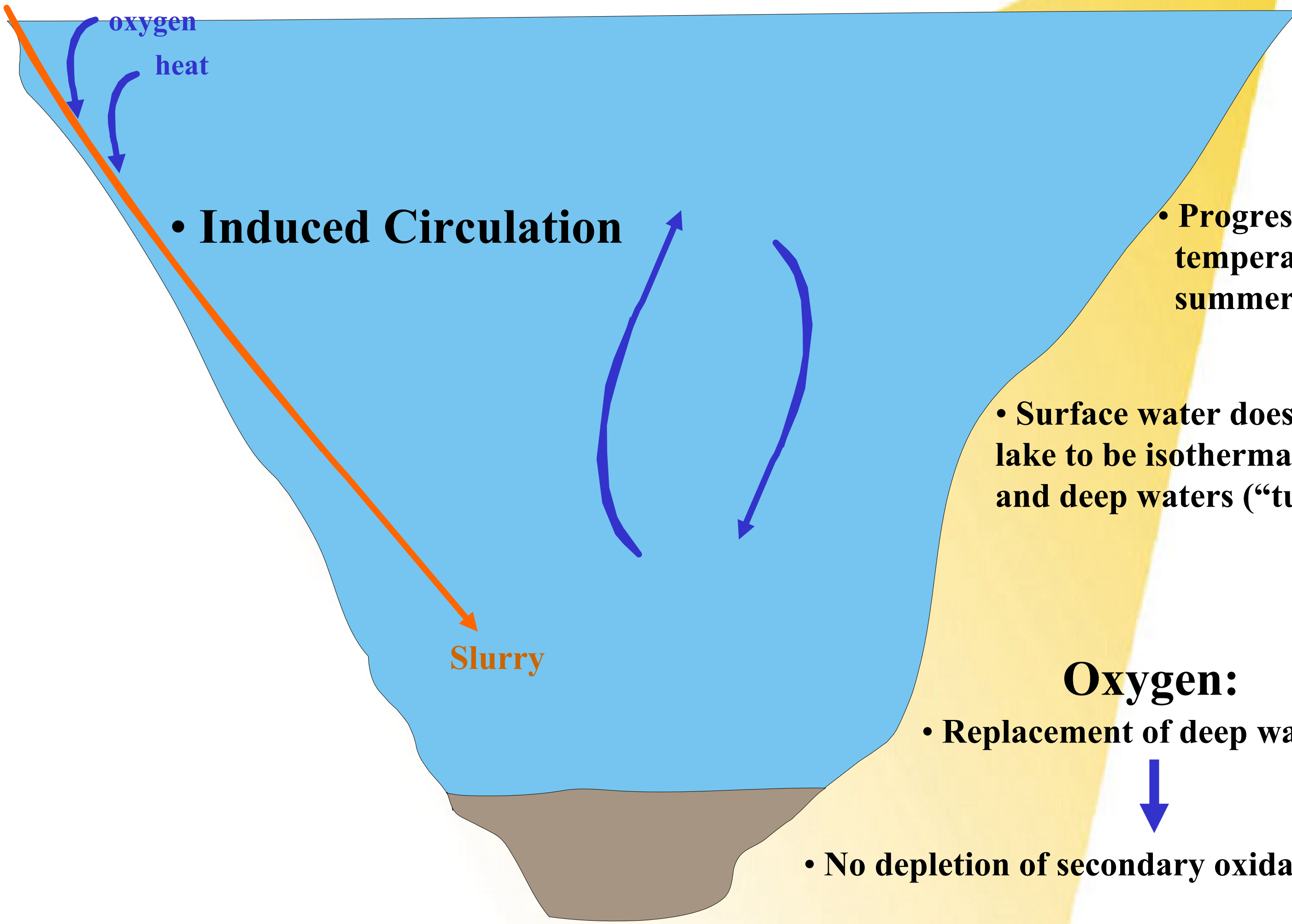
- Chemical stability of solids
  - Water Quality in shallow water columns is more susceptible to exchanges across waste-water boundary

Considerations

Disposal of treatment sludges

Considerations – Sludge/ARD Disposal

Conceptual Model



Heat:

- Progressive increase in deep water temperature through spring and summer

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- Surface water does not have to cool as much for lake to be isothermal = Earlier mixing of surface and deep waters ("turn-over")

Oxygen:

- Replacement of deep water oxygen via slurry

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- No depletion of secondary oxidants = limits redox gradient

Case Studies – Field Scale Using Enclosures

- **Carbon Sources**
  - Sewage sludge
  - Straw
  - Green wastes
  - Carbokalk: by product of sugar industry
  - Others: pyruvate, ethanol, whey, molasses, potatoes
- **Nutrient sources:**
  - Liquid fertilizers (inorganic P and N)
  - Organic fertilizers
  - Pellet-based fertilizers
  - Phosphate rock
- **Results:**
  - Increase in algal biomass, organic carbon, total phosphorus
  - Increased sediment/water oxygen demand
  - Development of suboxic conditions
  - Mitigation of acidic pH (acid neutralizing potential)
  - Metal removal

Case Studies – Whole Lake

Bioremediation Considered – not implemented

- Mt. Nansen Tailings Pond - Yukon

Bioremediation Implemented

- Island Copper Mine – B.C.
- Colomac – North West Territories
- Lake Koyne 113 – Germany
- Rävlidmyran Pit Lake - Sweden
- Grum Pit Lake – Yukon

Case Study 1 – Mt. Nansen

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- **Mt. Nansen Tailings Pond**
  - 4 ha tailings facility
  - Contaminants of concern: ammonia (>10 mg/L)
  - Objective: enhance ammonia removal through stimulation of algal growth

However, numerous secondary arsenic-bearing phases were identified which will become more soluble under more reducing sediment conditions, including:

- Fe oxyhydroxides present as isolated particles
- Fe oxyhydroxides present as alteration rims on sulphide grains
- Fe-arsenate ($FeAsO_4$) as oxidation rims on arsenopyrite

Mt. Nansen – Tailings Pond

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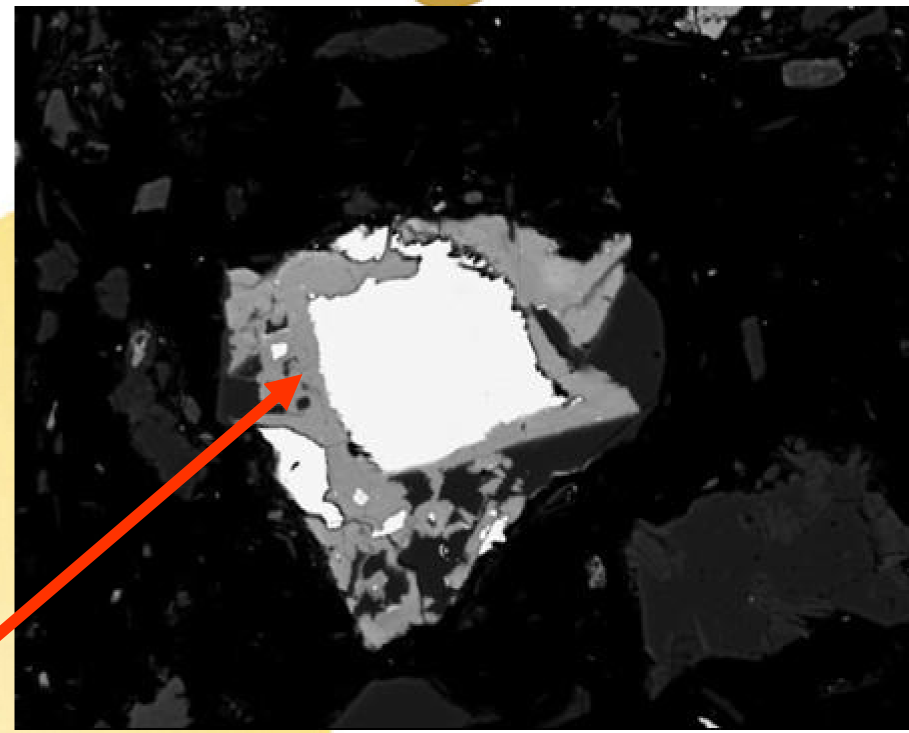

As-bearing Fe oxyhydroxide

Fe-arsenate rim on arsenopyrite

Summary: The prevalence of redox-sensitive secondary phases in the tailings deposits, and the abundance of associated arsenic, precluded the recommendation of fertilization as a viable form of bioremediation for the tailings pond.

Case Study 2

Lake Koyne 113: Whole-lake bioremediation

- **Study Site: Lake Koyne 113**
  - Lusatian mining lake in Germany
  - Open-cast lignite mine
  - Shallow (maximum depth of 2.5 m)
  - Acidic (pH=2.5), high concentrations of major ions and trace elements
- **Treatment:**
  - "Biobags": jute bags (50 x 60 cm) filled with cut-up beer and water bottle labels (source of oganic carbon)- 5 tons per hectare
  - Objective: reversal of acidification (via formation of anoxic microbial reaction compartments and increase primary production)
- **Results:**
  - Increase in algal biomass, organic carbon, total phosphorus,
  - No change in pH
  - Unsuccessful in meeting objective in increasing pH
  - Limited by high acidity of inflowing groundwater

Case Study 3

Rävlidmyran Pit Lake: Whole-lake bioremediation

- **Study Site: Rävlidmyran Pit Lake**
  - Skellefte ore district of northern Sweden
  - Open pit/underground mining (1953-1974). Flooded since 1975.
  - Area = ~5 ha, and mean depth of 11 m
  - Low pH (pH=3), oligotrophic, and meromictic
- **Treatment:**
  - Pre-treatment with lime (200 tonnes in a three week period)
  - Followed by addition of 300 tons of sewage sludge
  - Objectives: Metal sorption to sewage particles
    Development of sulphate reduction in hypolimnion and metal removal
- **Results:**
  - Liming increased pH to 6 to 8, removal of dissolved trace elements (Fe, Mn, Zn, Cu)
  - Sewage treatment: No evidence of enhanced metal scavenging by particles
    No evidence of sulphate reduction in bottom waters
    Unsuccessful in meeting objectives

Case Study 4 – Faro Mine Grum Lake Bioremediation

Surface area: 100,000 m^2

Max. depth: 50 m

Ice-cover in winter

Oxygenated water column

Seasonal turnover

10-12 mg/L Zn

Grum Lake (Bioremediation)

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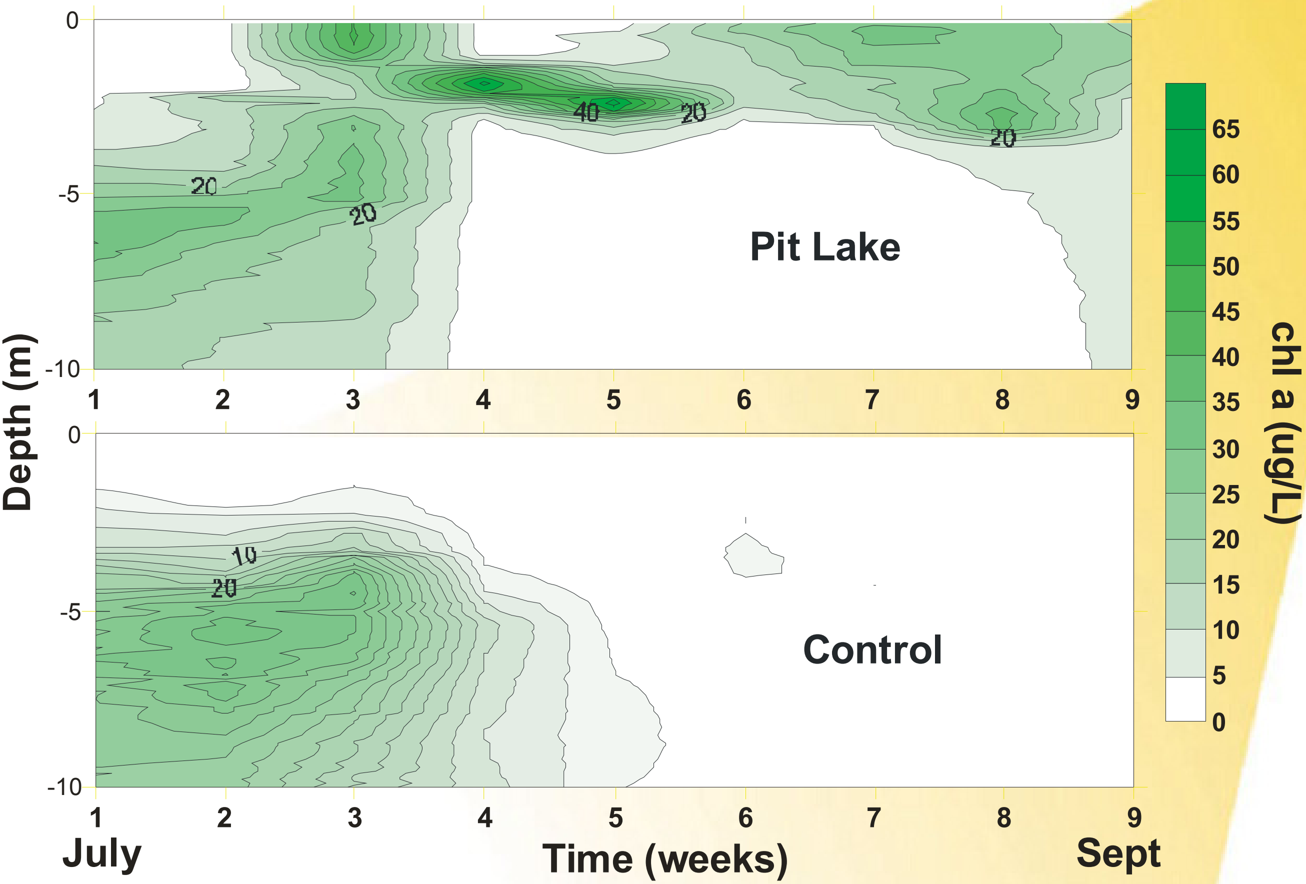
- **Characterization of Grum Pit Lake**
  - **physical limnology**
  - **geochemical limnology**

- **Remediation and Monitoring Program**
  - **one season – focus on Zn uptake by algal growth**
  - **fertilization with customized liquid nutrient best suited to lake (weekly)**
  - **semi-weekly sampling**

Grum Lake (fertilization)

Response of Algal Community - Chlorophyll



Algae in surface waters responded to nutrient addition

Existing algae

Grum Lake (fertilization)

Response of Algal Community - Chlorophyll

Algae in surface waters responded to nutrient addition

Existing algae

1 2 3 4 5 6 7 8 9

July Time (weeks) Sept

Grum Lake (fertilization)

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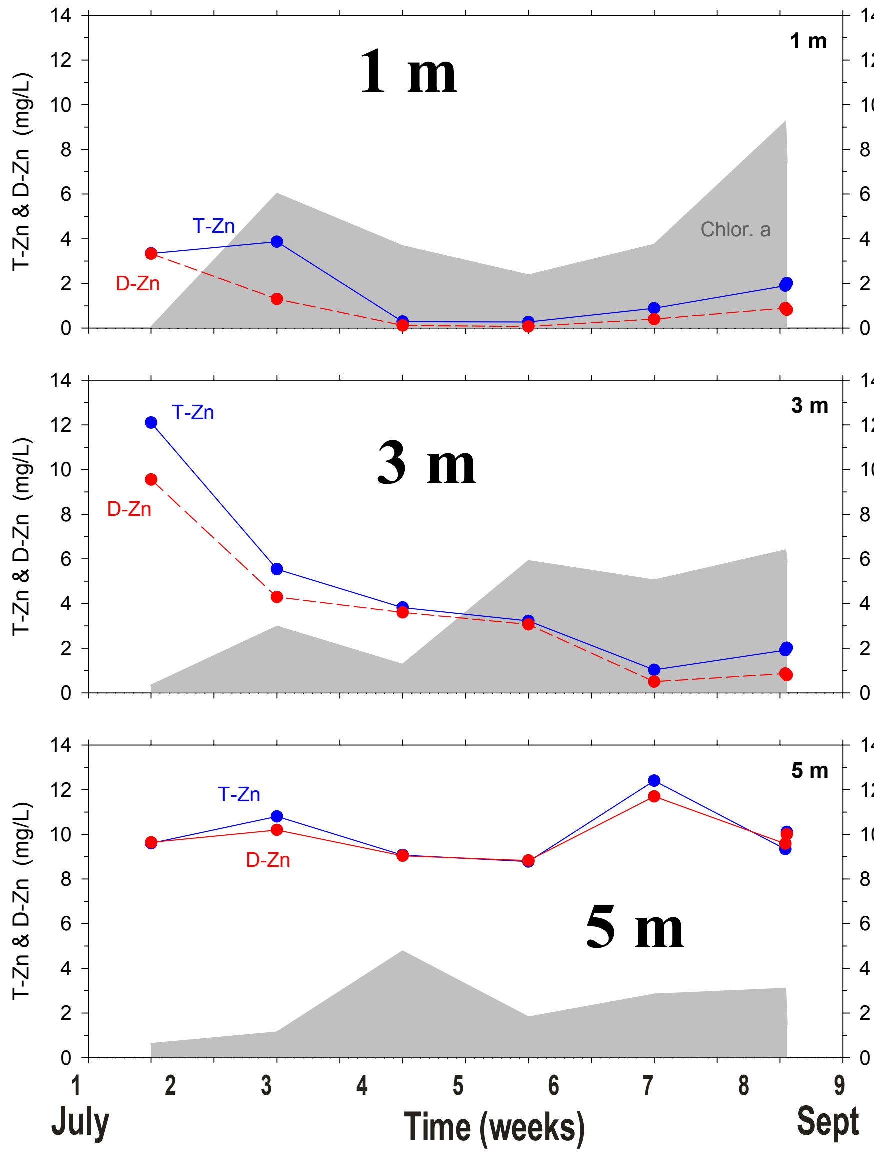
Grum Lake – Zinc Response



- **Zn decrease to <100 ug/L at 1 m**
- **Largest net decrease at 3 m depth from 12 mg/L to ~1 mg/L**
- **No Zn loss at 5 m depth (no effect below mixed layer)**

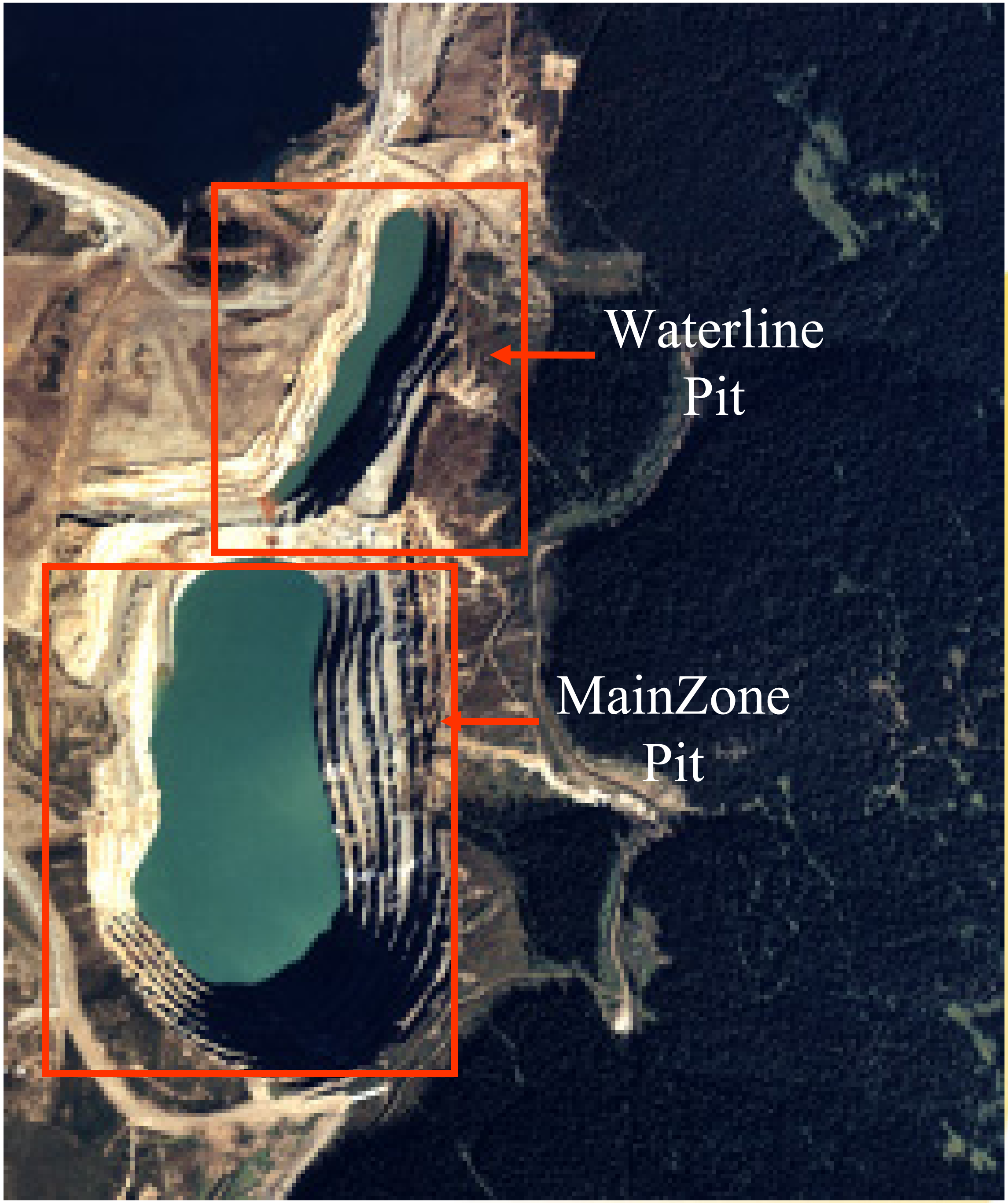
Data Requirements

- **Site-Specific Meteorology**
  - very affordable (< $10,000)
  - data are invaluable at closure
- **Inflows and Outflows**
  - WQ, temperature and salinity
  - Flows
  - Dewatering program (assess chemistry)
- **Pit Geometry/Bathymetry**
- **Pit Lake Elevation Data**
  - (once pit begins to fill)

- **These data are Required to Make Robust Predictions**
  - Proxy data must be found where data do not exist
  - Weakens accuracy of predictions

Emphasis – Site Specific Management

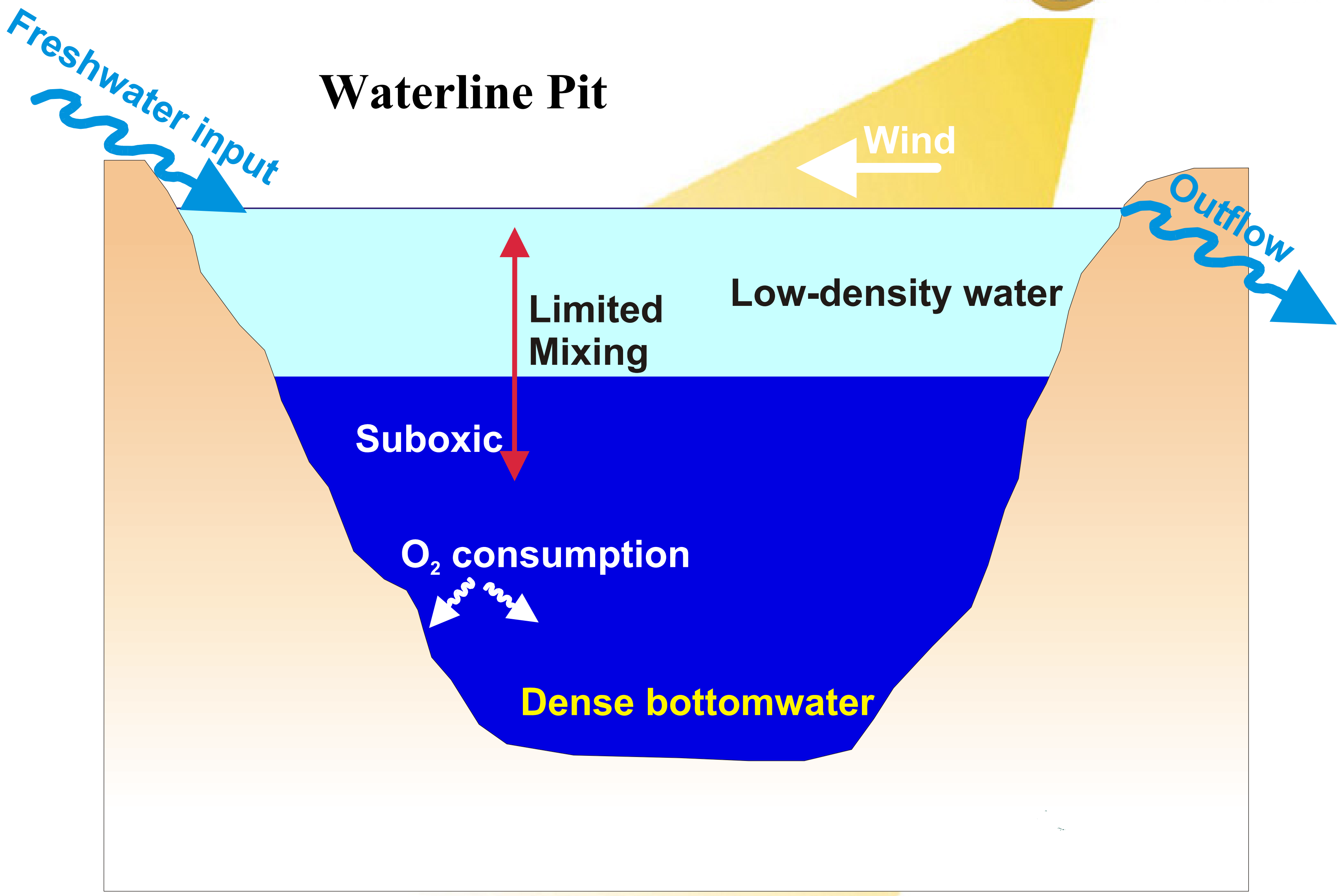
- **Pit-lake management strategies are strongly dependent on site-specific factors, including**
- Pit geometry
- Physical mixing
- Climate
- Water balance
- Parameters of concern
- Management practices
- Water quality objectives



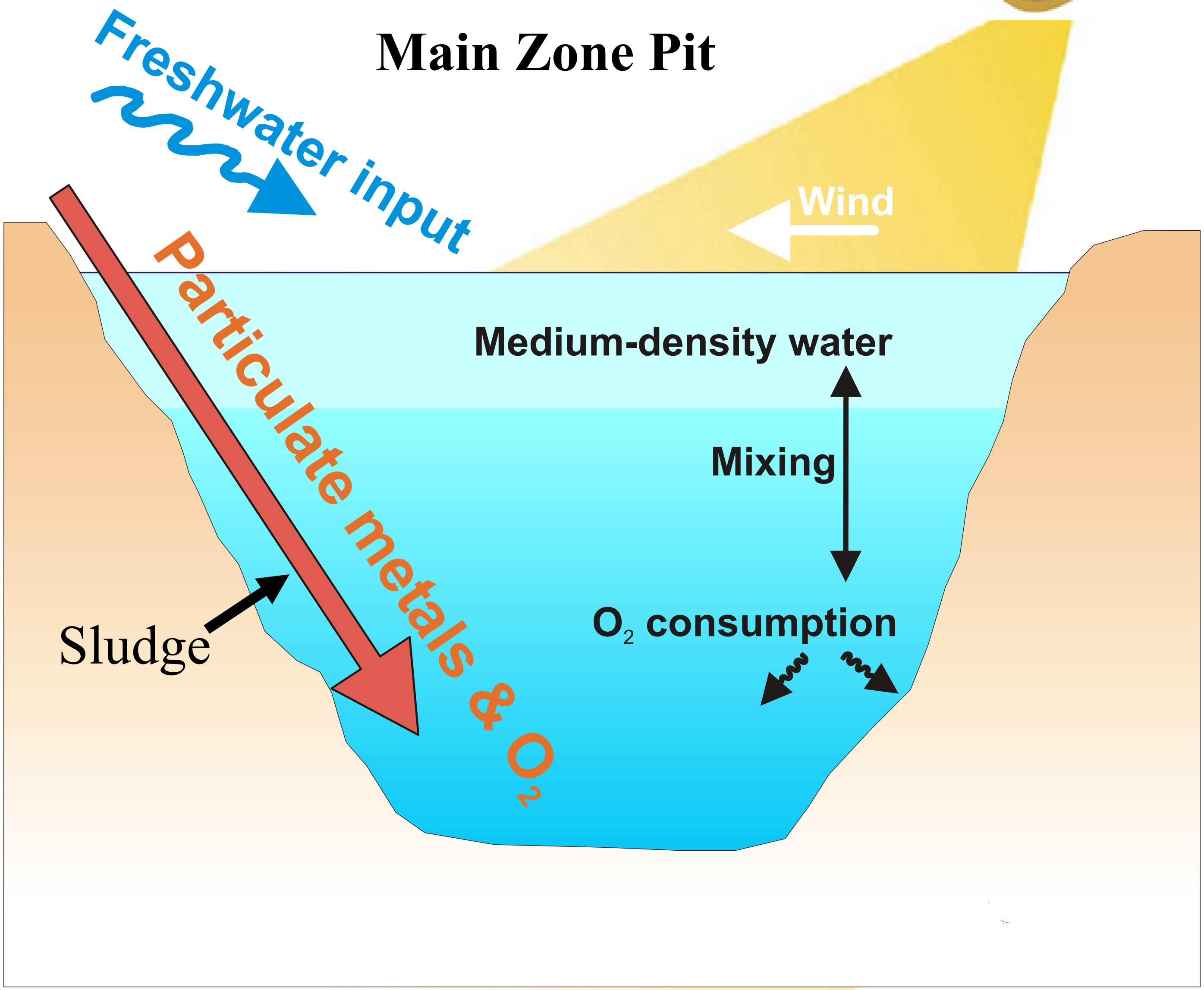
Equity Silver Mine

Example of within-region pit lake contrasts

Pit Lake Comparison
Equity Silver Mine



Pit Lake Comparison Equity Silver Mine



Conclusions - Bioremediation

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• Bioremediation through fertilization (enhancing algal growth) has been shown to provide effective management of pit lakes at whole-lake scale.

• Bioremediation through other means (addition of organic matter) has shown mixed results at full scale.

• Successful bioremediation requires careful consideration of site specific physical and biogeochemical variables (enormous degree of pit-lake specificity, based on both regional and within-region variables).