Passive Treatment Strategies for Selenium at Coal Mines Using Saturated Backfill and Flooded Open Pits

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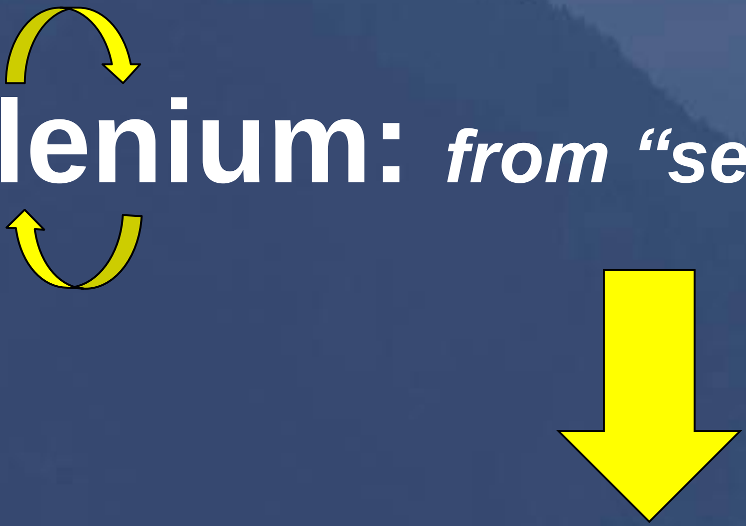
Proposed Name Change



Selenium: *from “selene”, meaning moon*

Senelium: *from “senelis” (latin) meaning to drive one crazy*

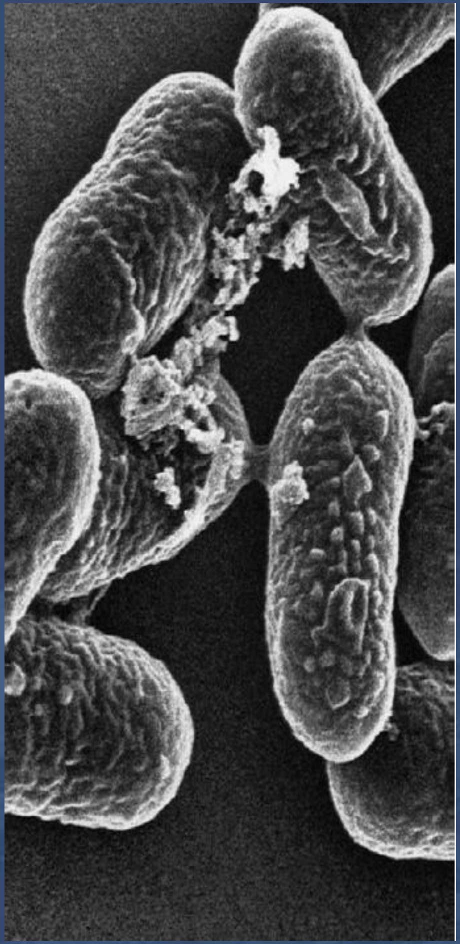
Outline

- Selenium bioremediation overview
- Flooded pits
- Flooded backfill
- Design for closure

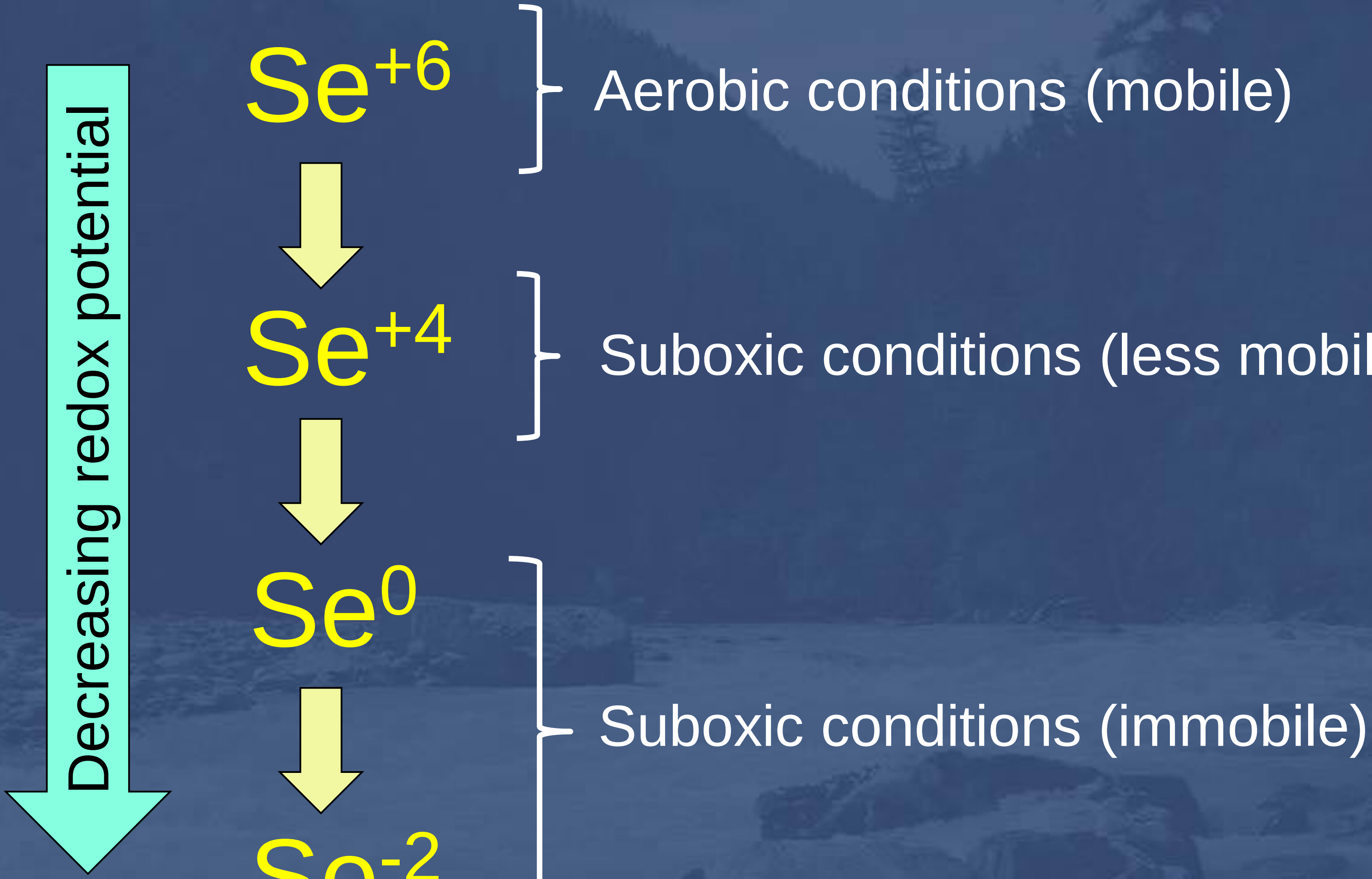
Selenium Bioremediation Overview

Selenium Biogeochemistry

- Selenium exists in multiple oxidation states (geochemical analogue to sulfur).
- Selenium speciation and removal strongly dependent on redox conditions.
- Selenium reduction is microbially mediated.
- Suboxia is required for effective removal.



Selenium Bioremediation Overview



Decreasing redox potential

Se^{+6} Aerobic conditions (mobile)

Se^{+4} Suboxic conditions (less mobile)

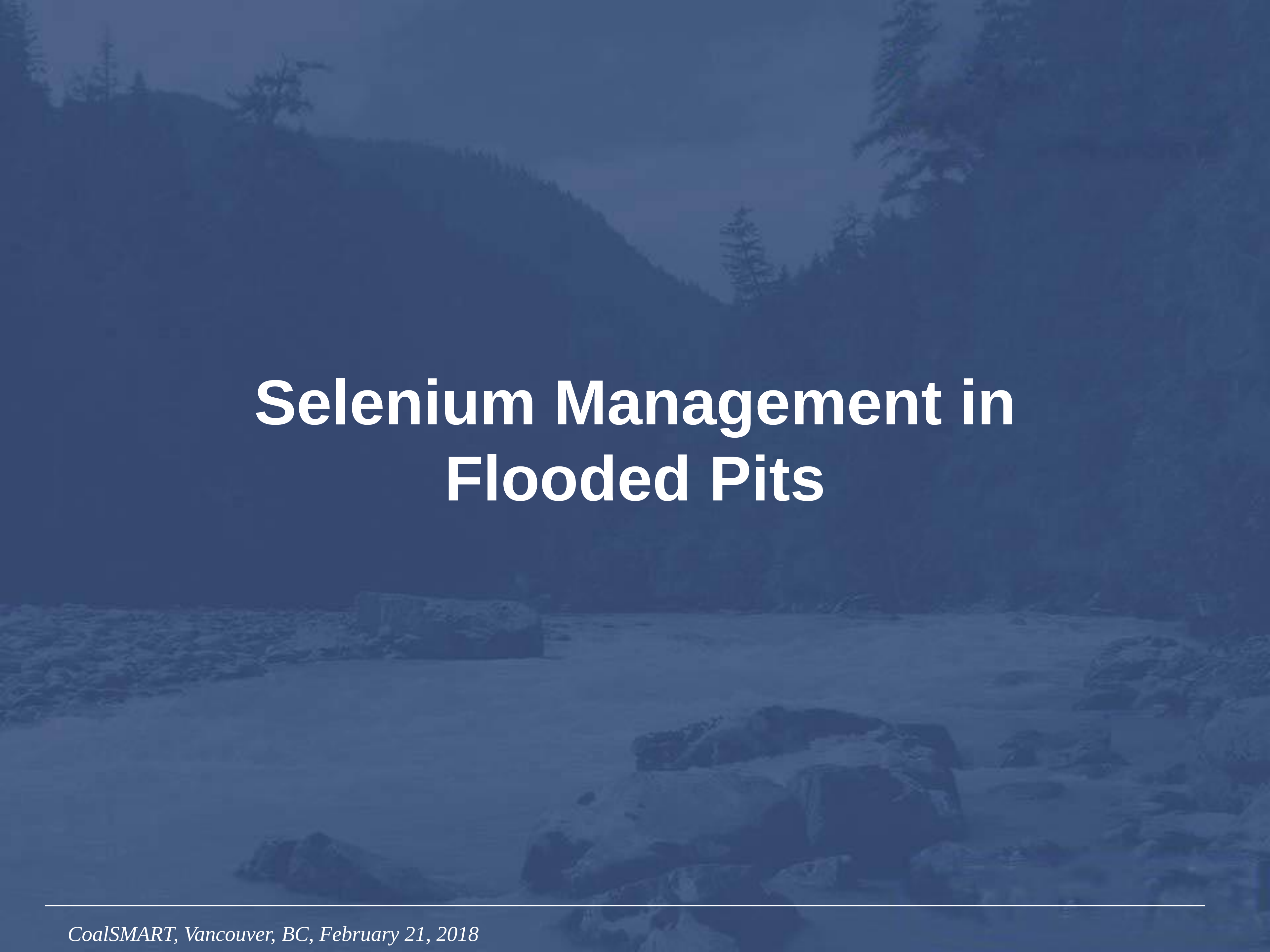
Se^{0}

Se^{-2}

Suboxic conditions (immobile)

Se Behaviour in Mine Environments

- Se typically associated with sulfur (e.g., pyrite) in waste materials (waste rock, plant rejects, etc.)
- Primary driver governing Se loadings is weathering associated with unsaturated spoils.
- Once remobilized, Se is very mobile and behaves conservatively along aerobic pathways.

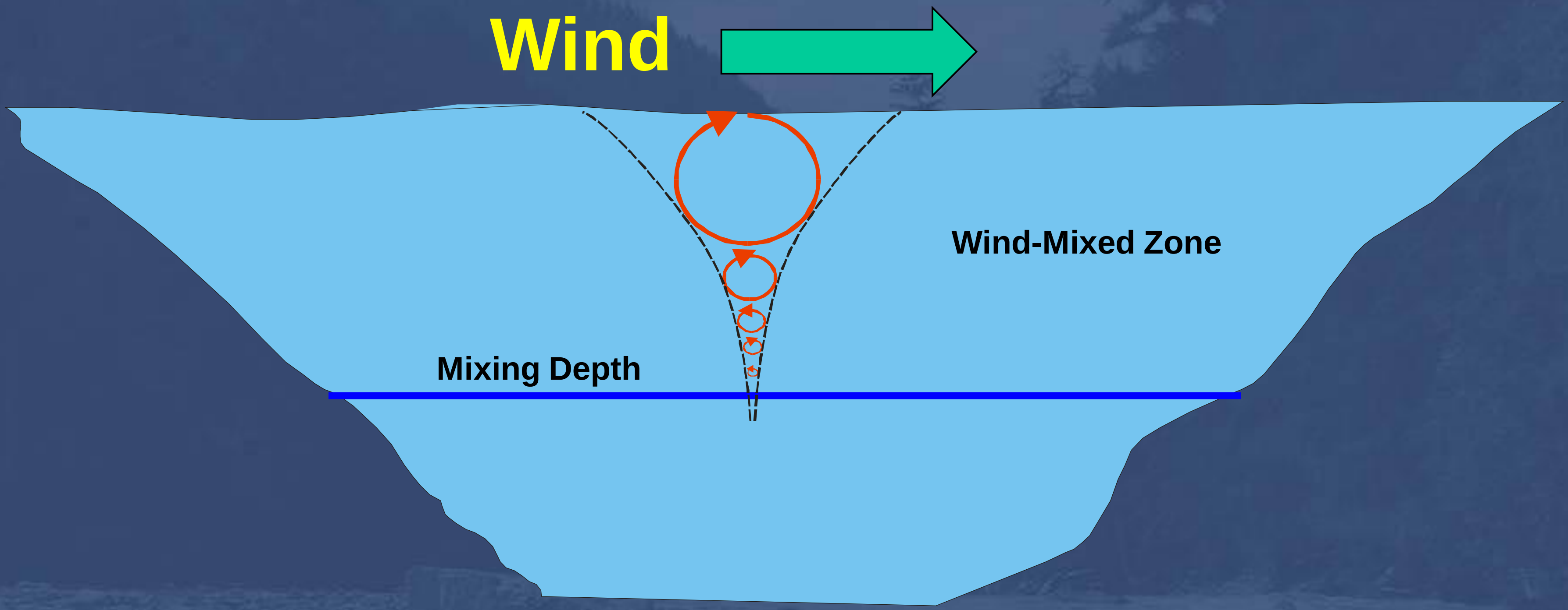


Selenium Management in Flooded Pits

Flooded Pits – General Features

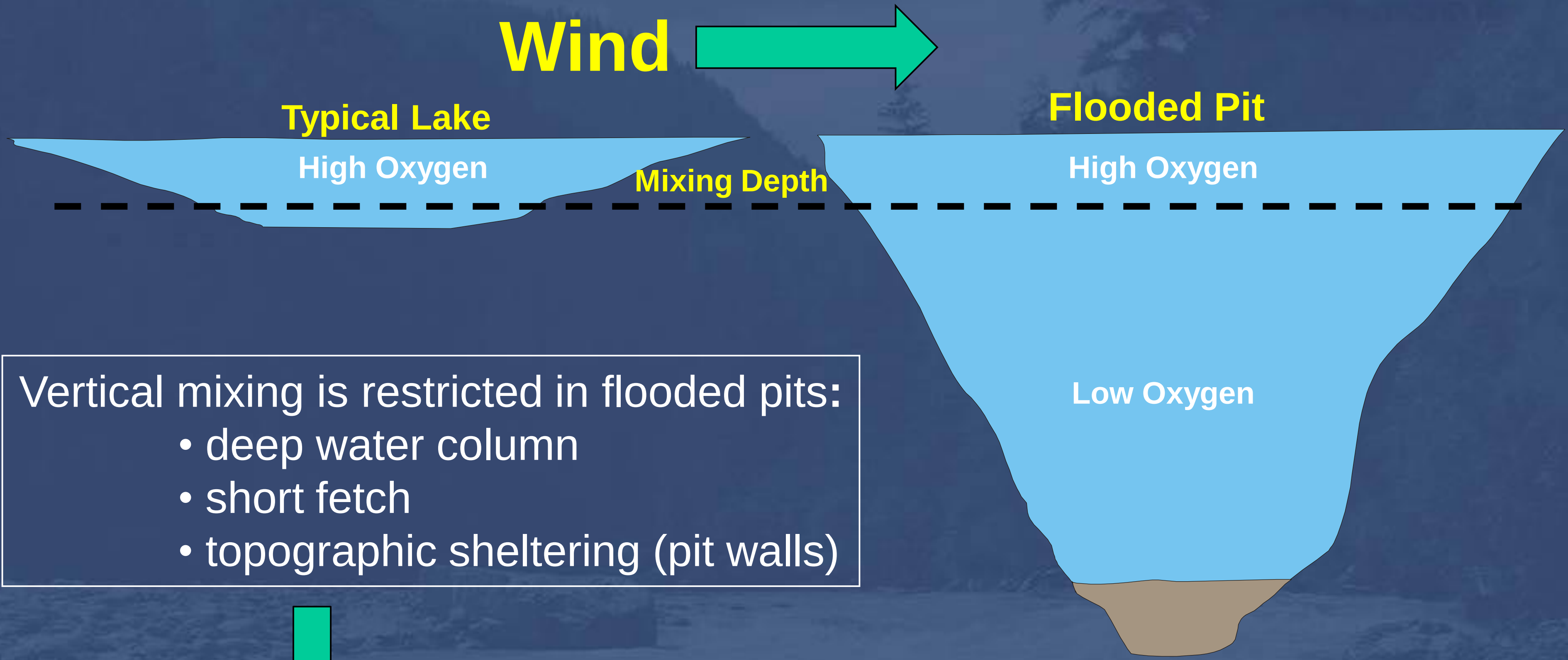
- Pit lakes are common features of the post-closure landscape at coal mine operations.
- Large repositories for mine-influenced water.
- Tendency for water column stratification and development of suboxic bottom waters.

Mixing Features of Natural Lakes



- Aspect Ratio: shallow and wide
- Lake overturn common typically in spring and fall (i.e., dimictic)
- Generally well-mixed and oxygenated

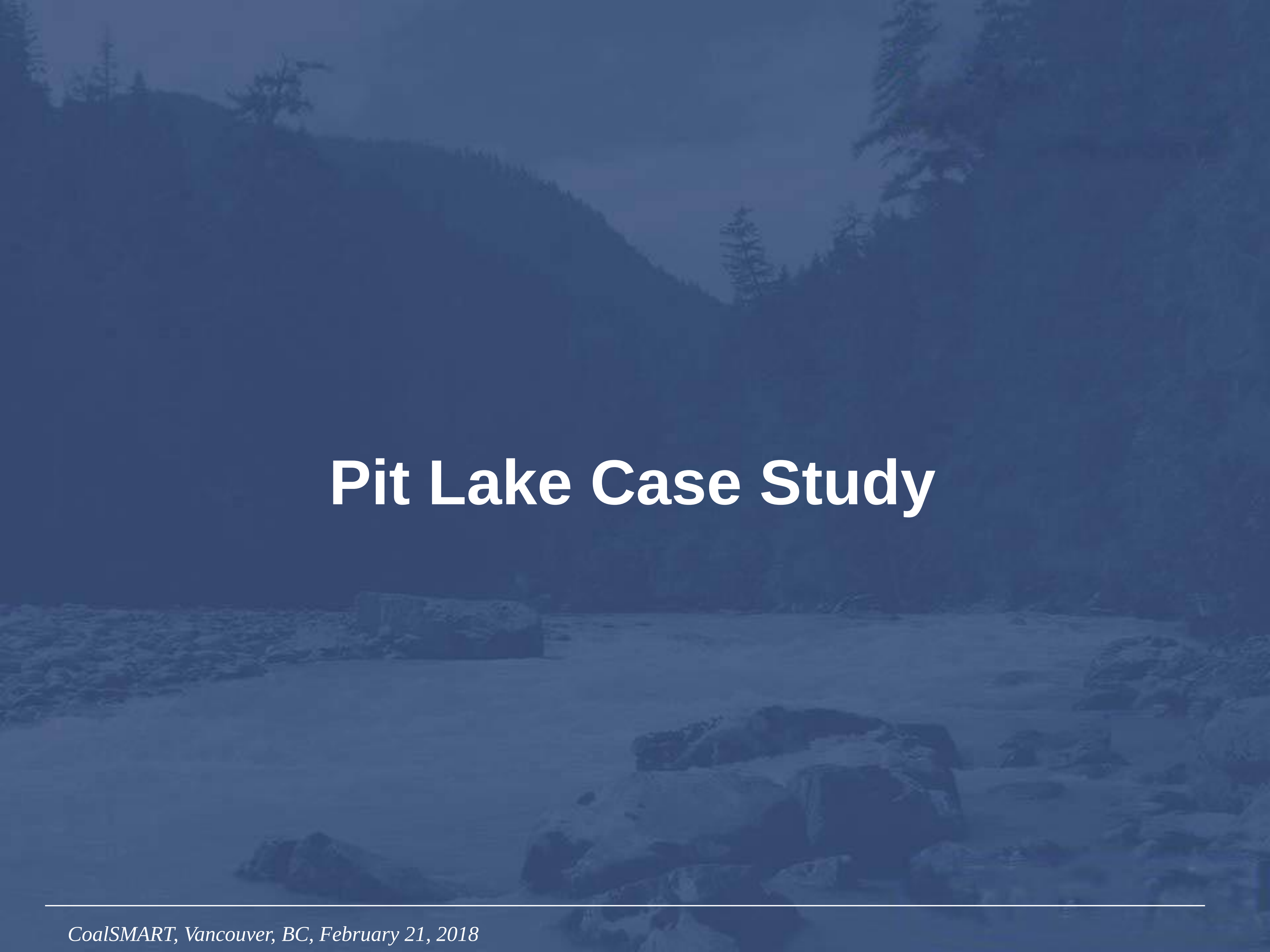
Mixing Features of Flooded Pits



Vertical mixing is restricted in flooded pits:

- deep water column
- short fetch
- topographic sheltering (pit walls)

- Tendency for seasonal and/or permanent stratification
- Natural tendency to develop suboxic bottom waters

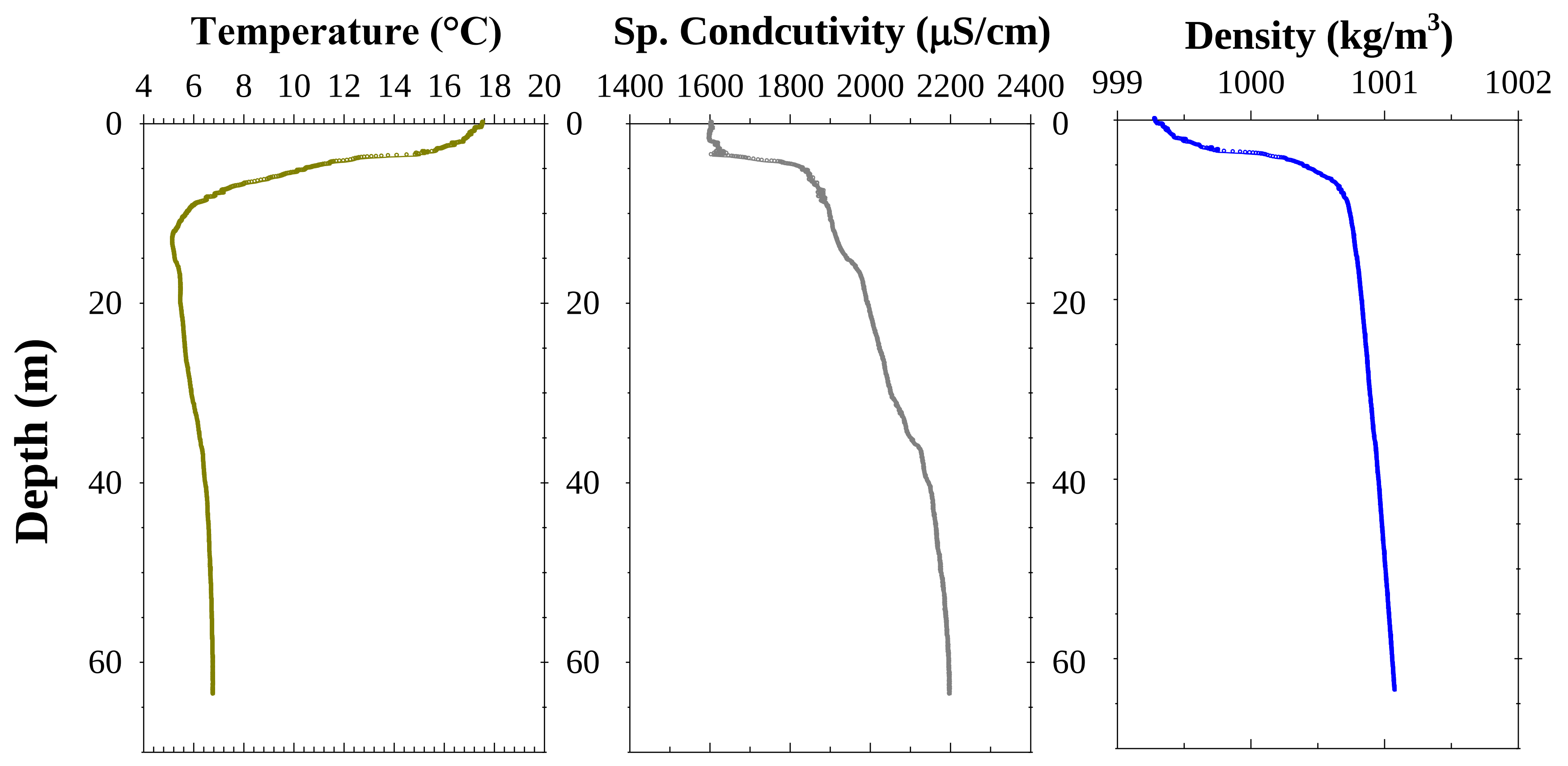


Pit Lake Case Study

Case Study – General Features

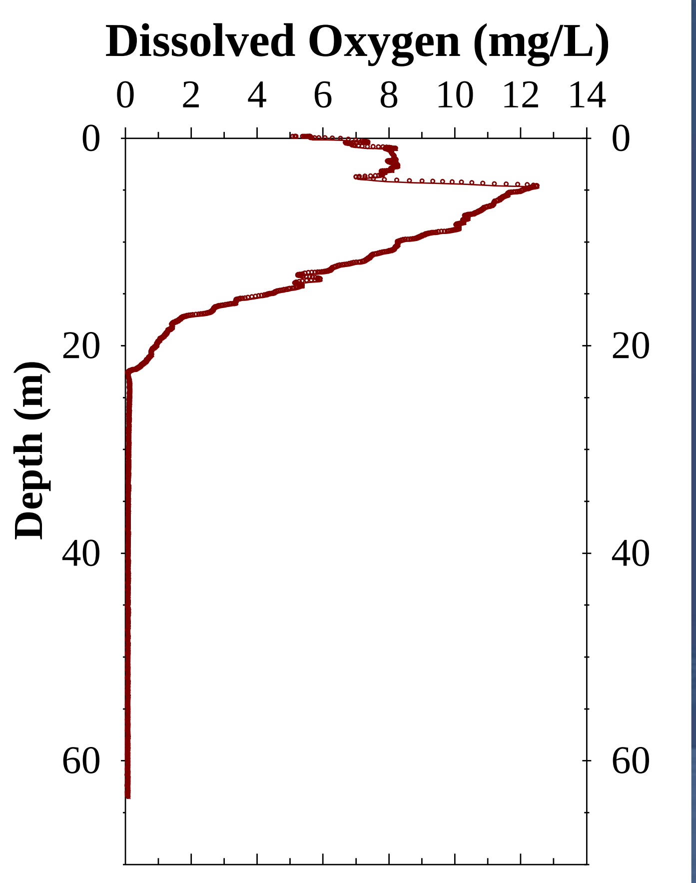
- Coal mine in western Canada
- Open pit developed between ~1987 and ~1995
- Pit partially backfilled with spoils from ~1995 to ~1998
- Pit flooded passively from ~1998 to 2002
- Maximum water depth: 70 m
- Water volume: 2.35 million m^3

Case Study – Water Column Structure



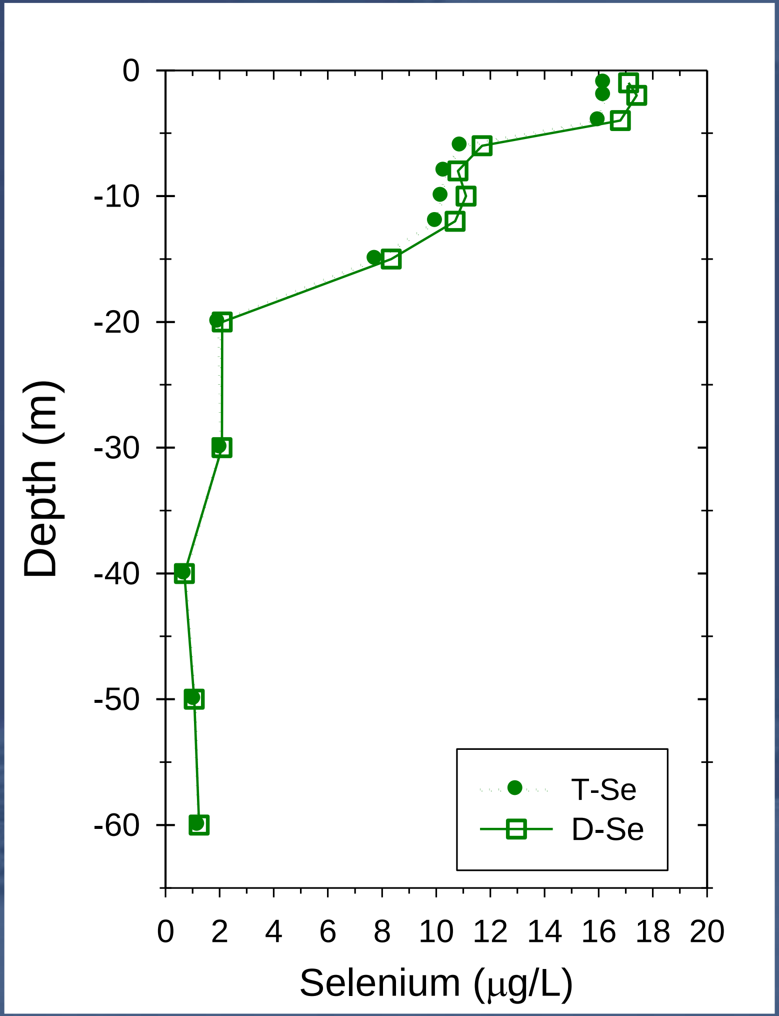
- Water column stratified with respect to temperature and conductivity.
- Strong density gradient (pycnocline) between 3 and 6 m.
- Stratification likely a permanent feature.

Case Study – Dissolved Oxygen



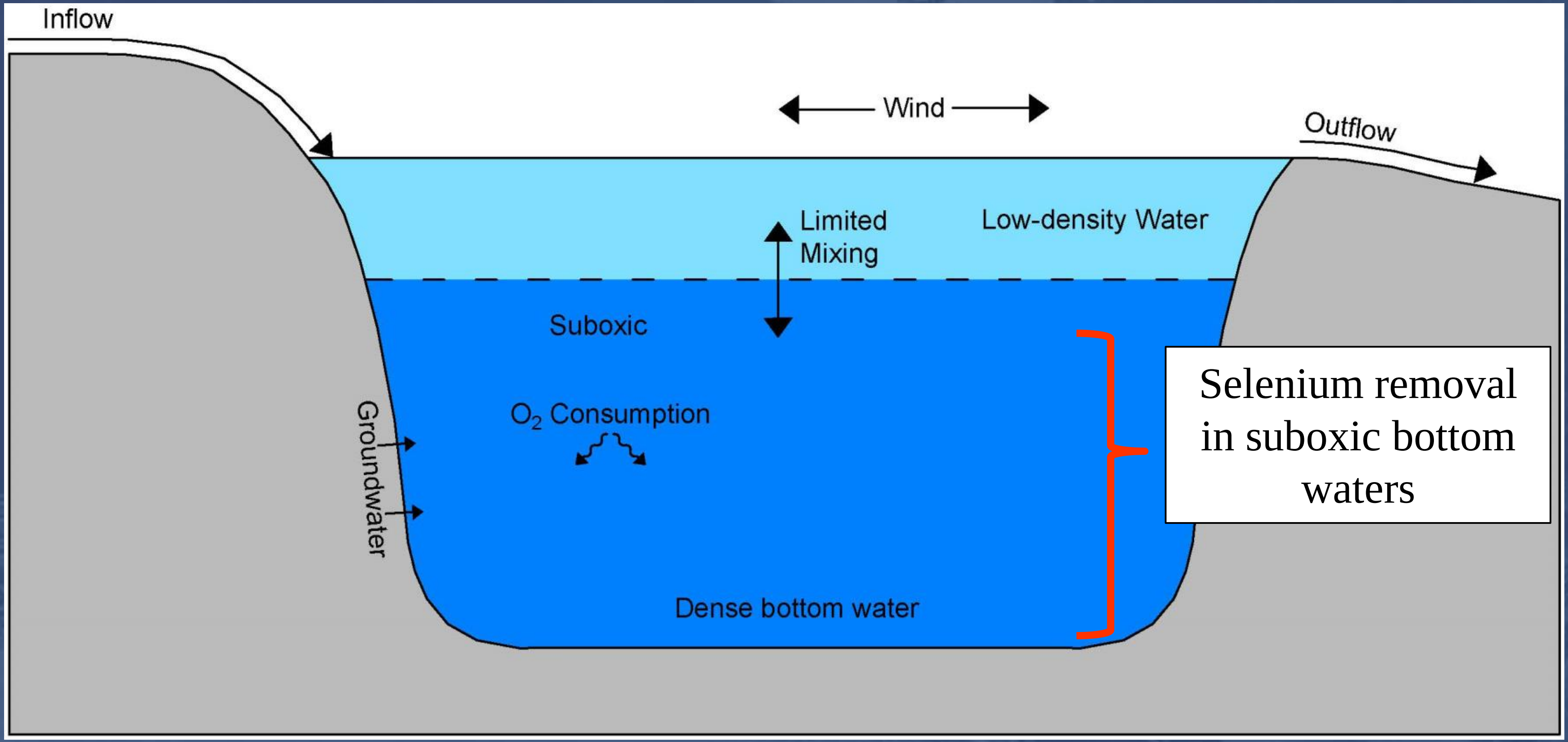
- Suboxic conditions below 20 m.
- Presence of stratification limits replenishment of oxygen to deep waters.
- Bacterial respiration of dissolved oxygen represents the primary oxygen sink.

Case Study – Selenium



- Total-Se in surface layer = 10 to 20 ppb.
- Values decrease below 20 m to concentrations ≤ 2 ppb.
- Data suggest that Se is being removed passively via microbially-mediated reduction reactions in suboxic bottom water.
- Approximately 1.5 million m^3 of water with [Se] ≤ 5 ppb.

Pit Lakes:
Conceptual Model for Se Removal



Selenium removal in suboxic bottom waters

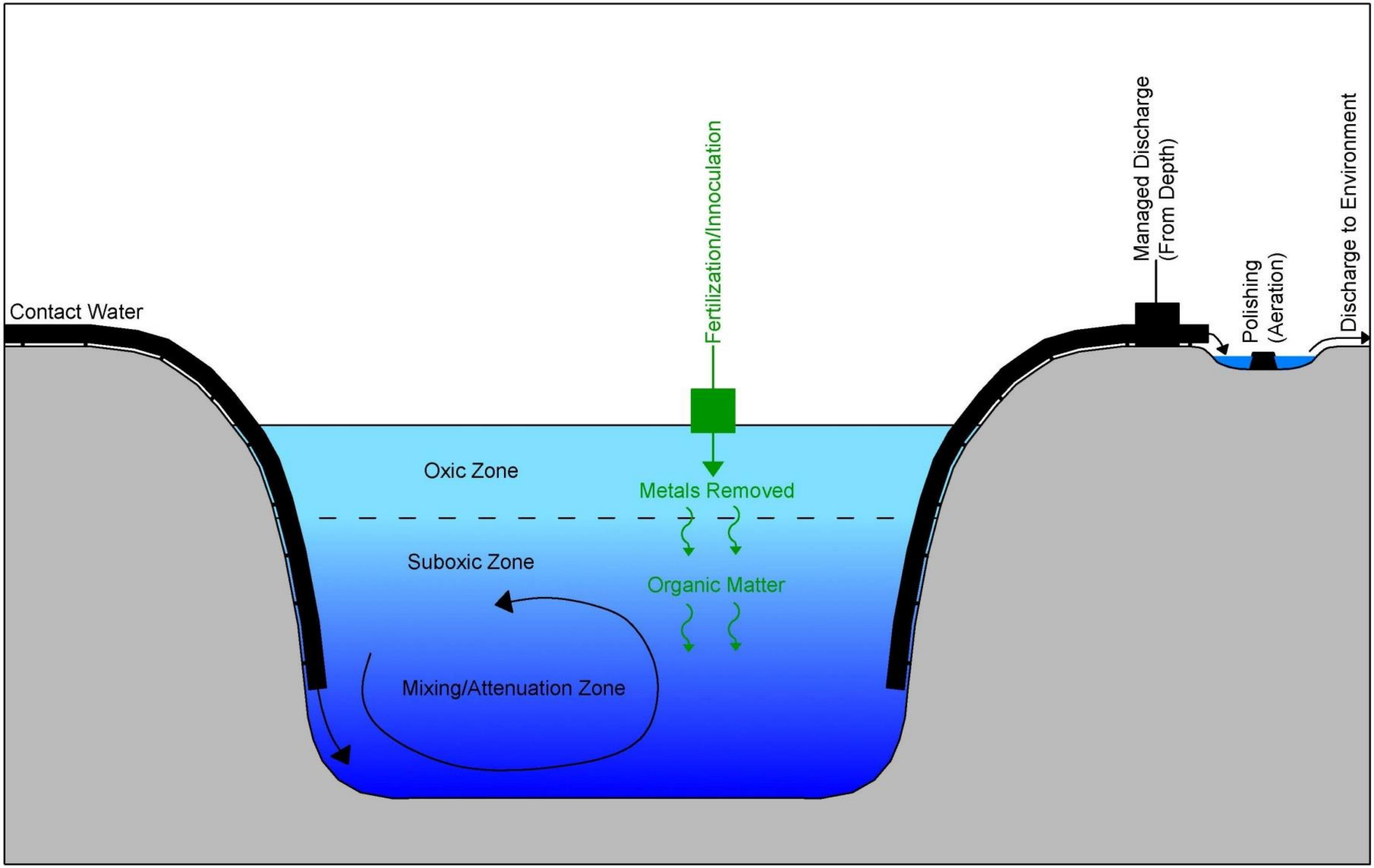
Pit Lakes – Se Management

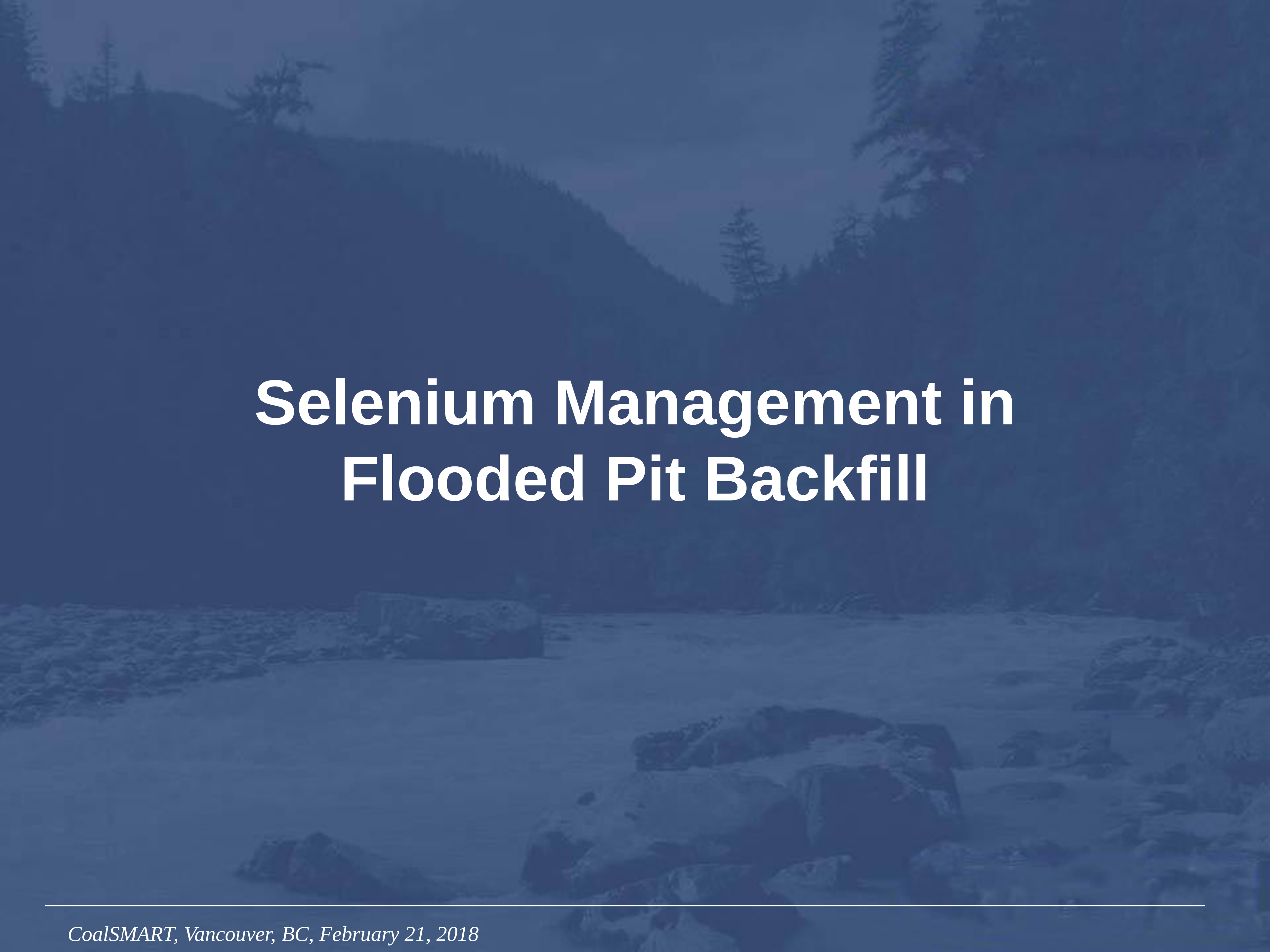
- Stratified flooded pits offer potential to treat large volumes of water at relatively low cost.
- Advantages:
  - Natural tendency for development of suboxic bottom waters
  - Large volume of suboxic water
  - Long hydraulic residence times
  - Control over water release
  - Geotechnical stability (no engineered impoundments)
  - Potential to integrate other site contact flows

Pit Lakes: Enhanced Bioremediation

- Conditions conducive to Se removal in stratified flooded pits can be enhanced at low cost through bioengineering methods (e.g., fertilization).
- Organic matter is the fuel that drives oxygen demand and rates of microbially-mediated redox reactions.
- Organic matter production can be greatly enhanced via nutrient addition.

Pit Lake Bioengineering

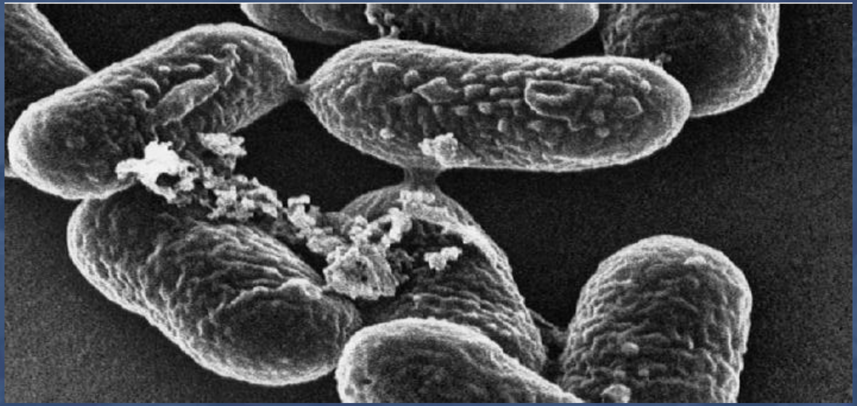




Selenium Management in Flooded Pit Backfill

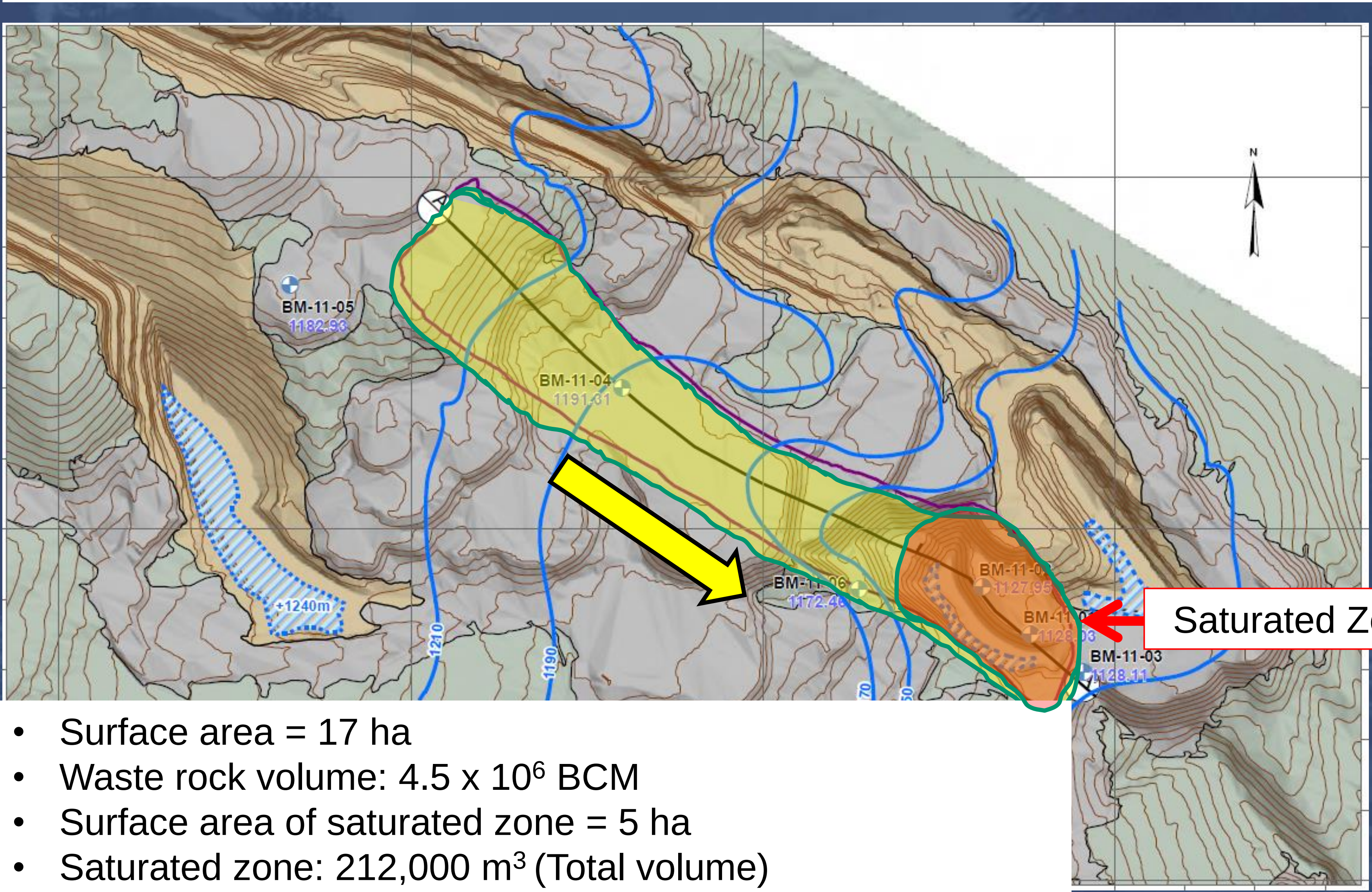
Overview

- The saturated zones of backfilled pits can provide optimum environments for the attenuation of Se.
- The oxygen demand imposed by residual carbon (e.g., coal), in conjunction with relatively-long water residence times, can promote the development of suboxic conditions.
- Under conditions of suboxia, Se is host to a suite of microbially-mediated processes that favour the removal of dissolved Se from solution.



Saturated Fill Case Study

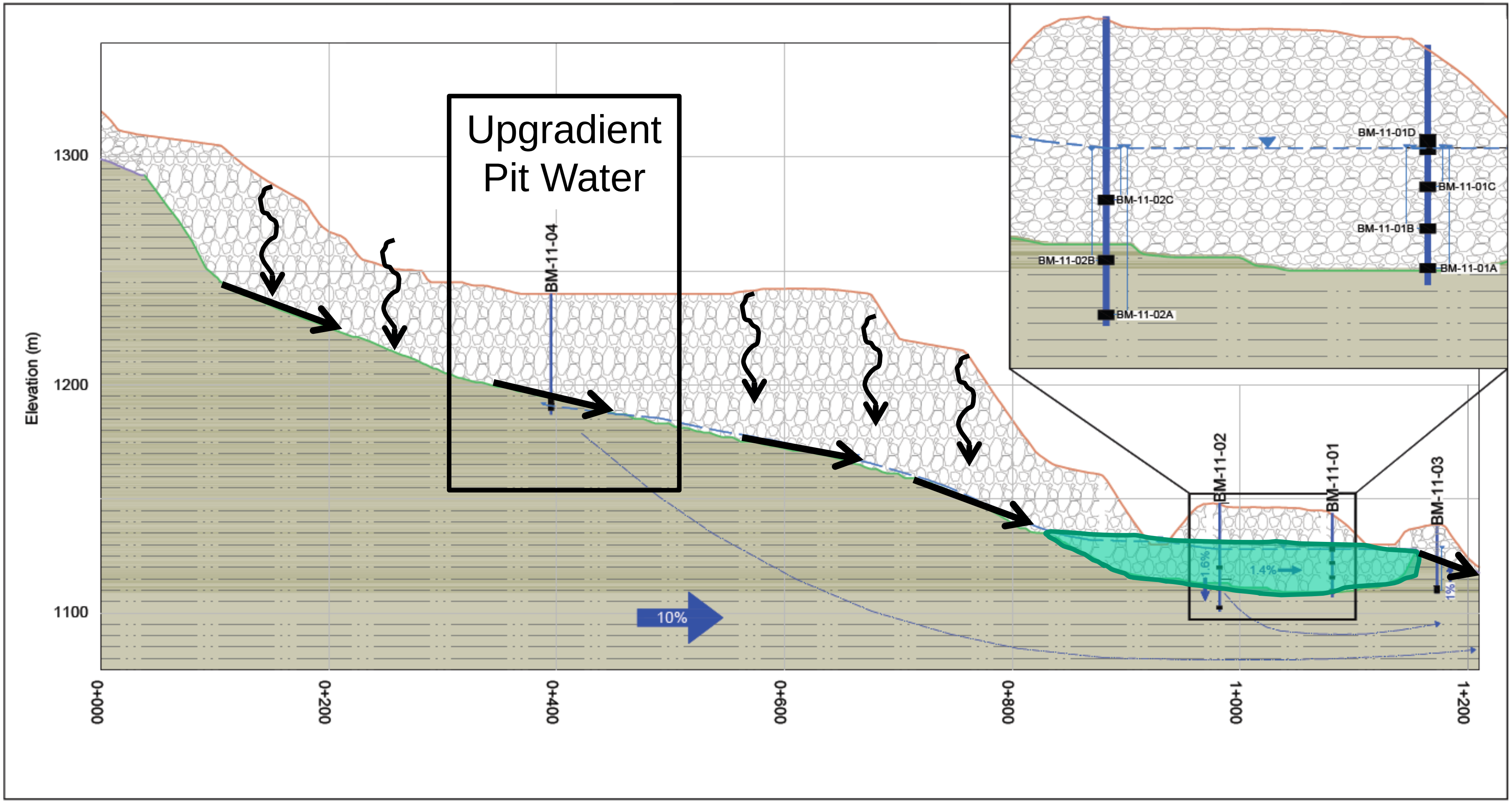
Case Study – Pit Features



Saturated Zone

- Surface area = 17 ha
- Waste rock volume: 4.5 x 10^6 BCM
- Surface area of saturated zone = 5 ha
- Saturated zone: 212,000 m^3 (Total volume)
- Small pit lake at downstream end: 0.3 ha

Case Study – Pit Cross Section



Case Study – Physical Features of Saturated Fill

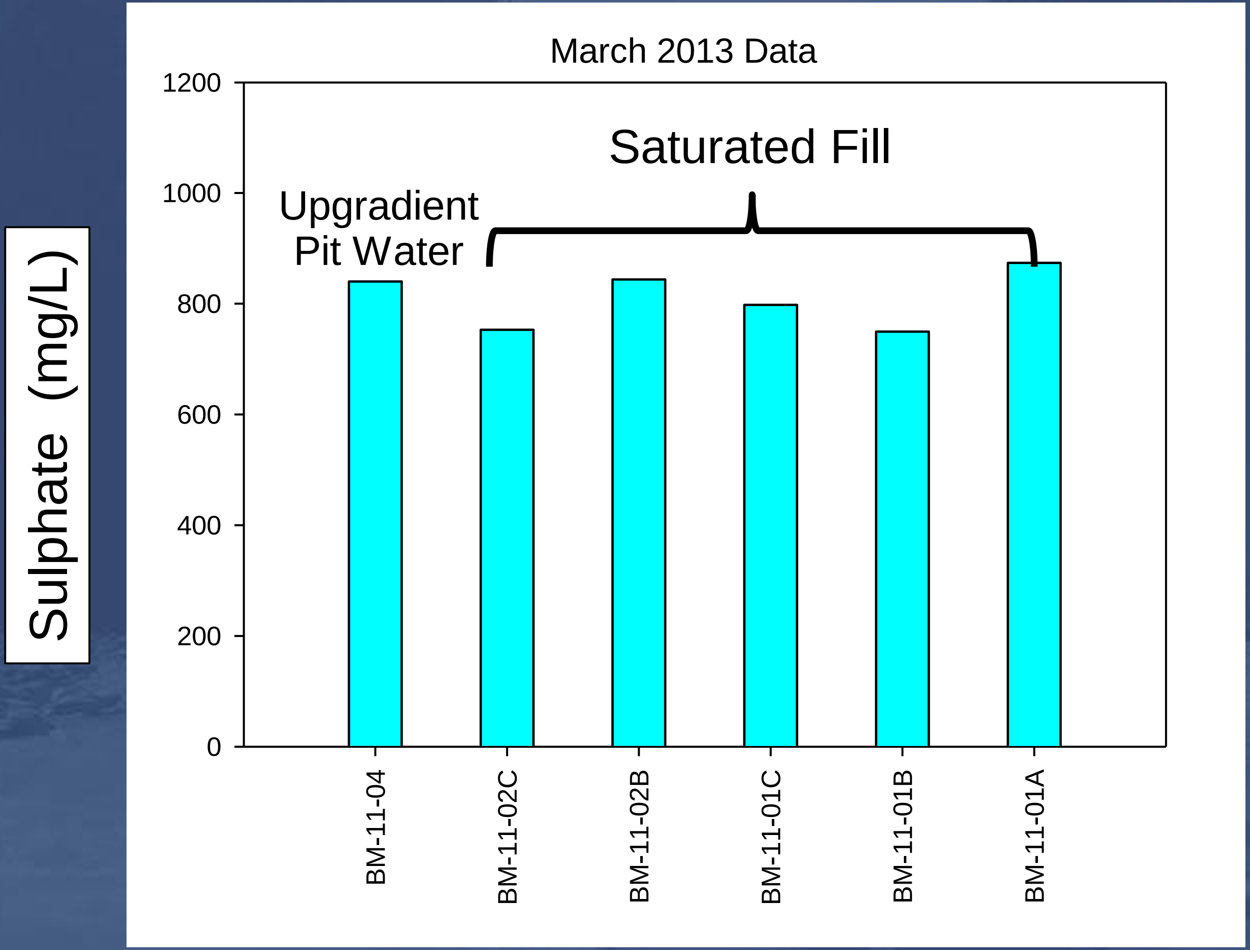
- Total Saturated Volume: 212,000 m^3
- Porosity: 0.25
- Porewater volume: 53,000 m^3
- Flow: 133,000 m^3/year (~4 L/s)
- Average Hydraulic Residence Time: 145 days (varies from 90 to 368 days on a monthly basis)

Case Study – WQ Features of Saturated Fill

Saturated backfill characterized by mildly reducing (suboxic) conditions:

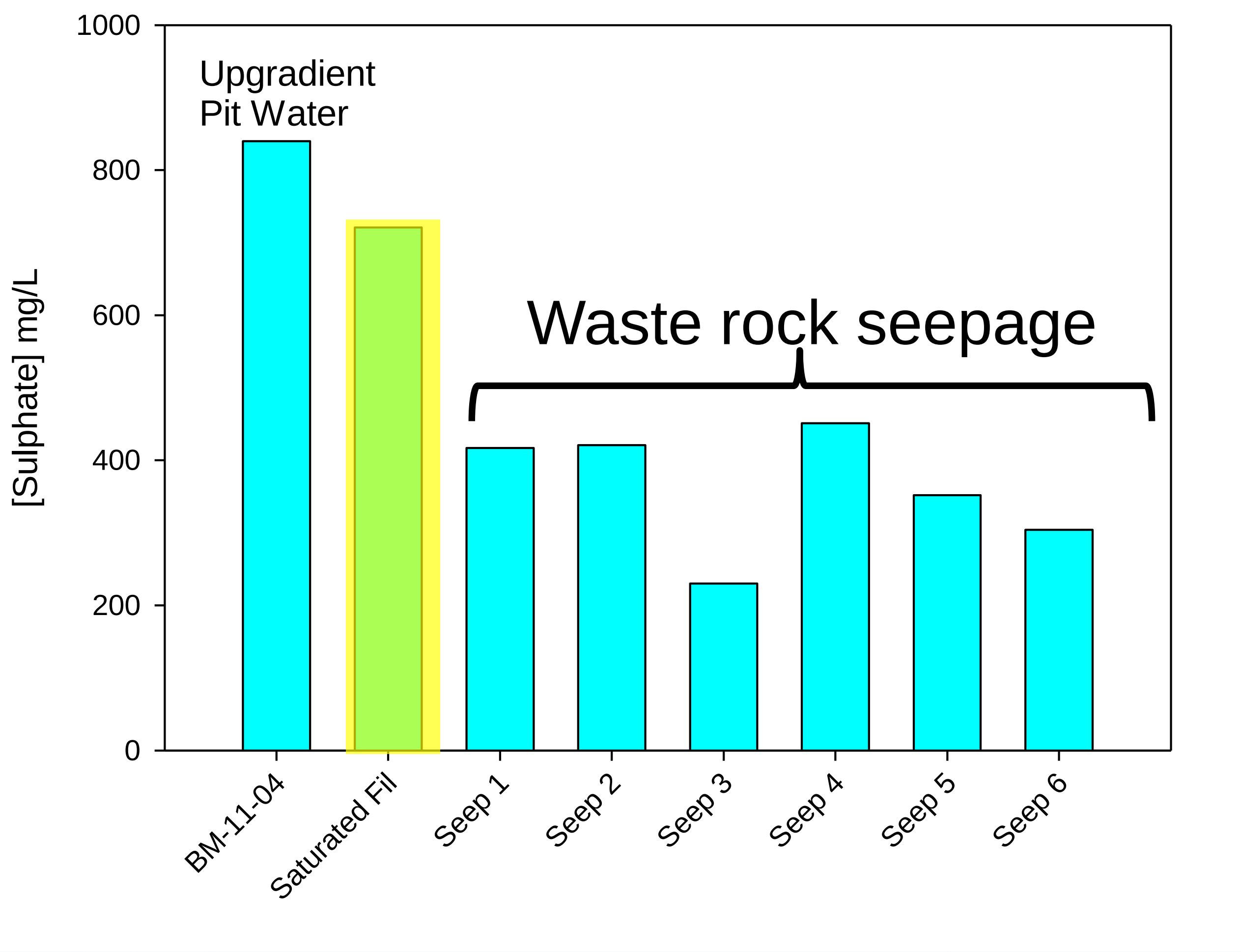
- ≤ 0.5 mg/L Dissolved O_2
- 0.3 to 1.3 mg/L D-Fe
- Low nitrate (<0.05 to 0.12 mg/L)
- Predominance of selenite (Se^{+4})

Case Study Results: Sulphate



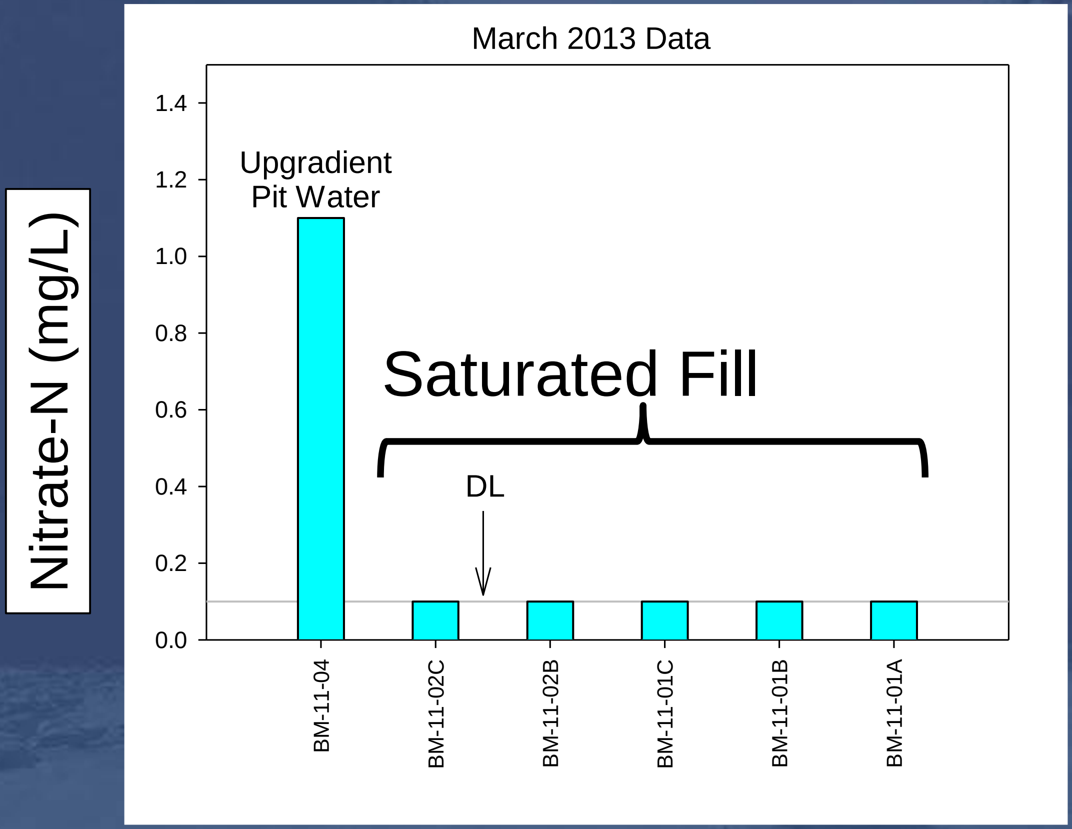
- Elevated sulphate in saturated porewaters

Case Study Results: Sulphate cont.



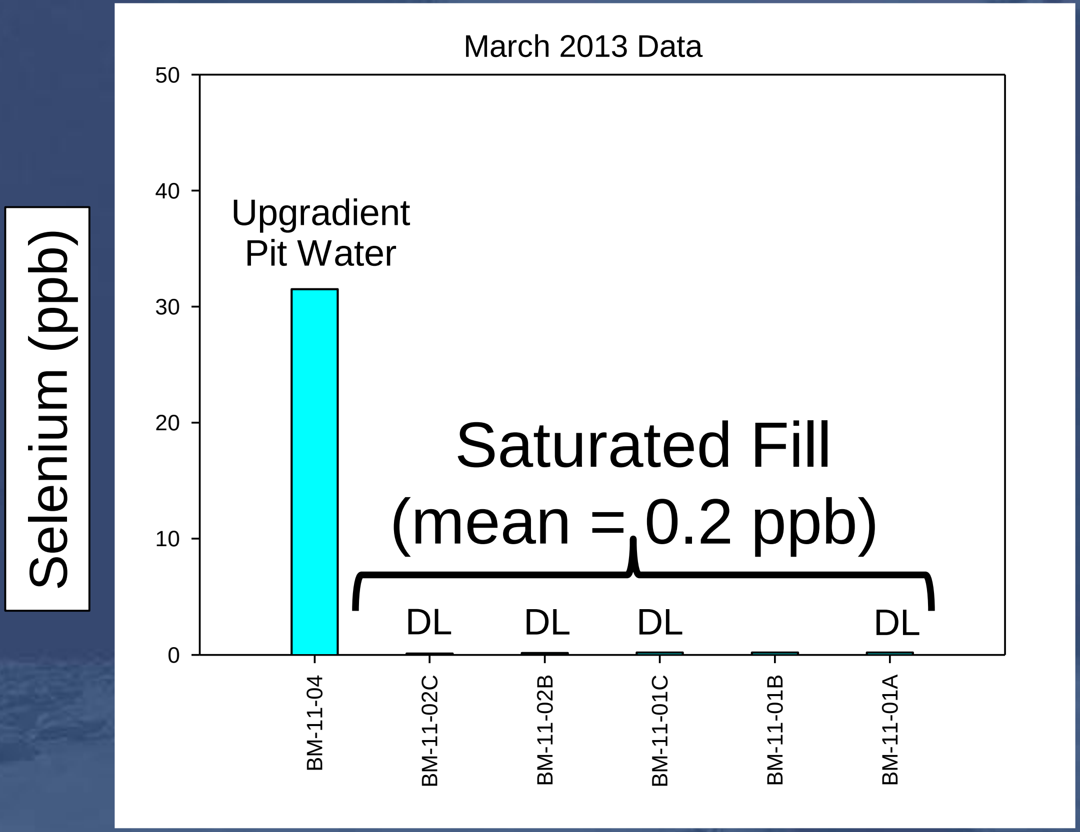
- Sulphate levels in saturated zone comparable or higher than waste rock seepage values.

Case Study Results: Nitrate



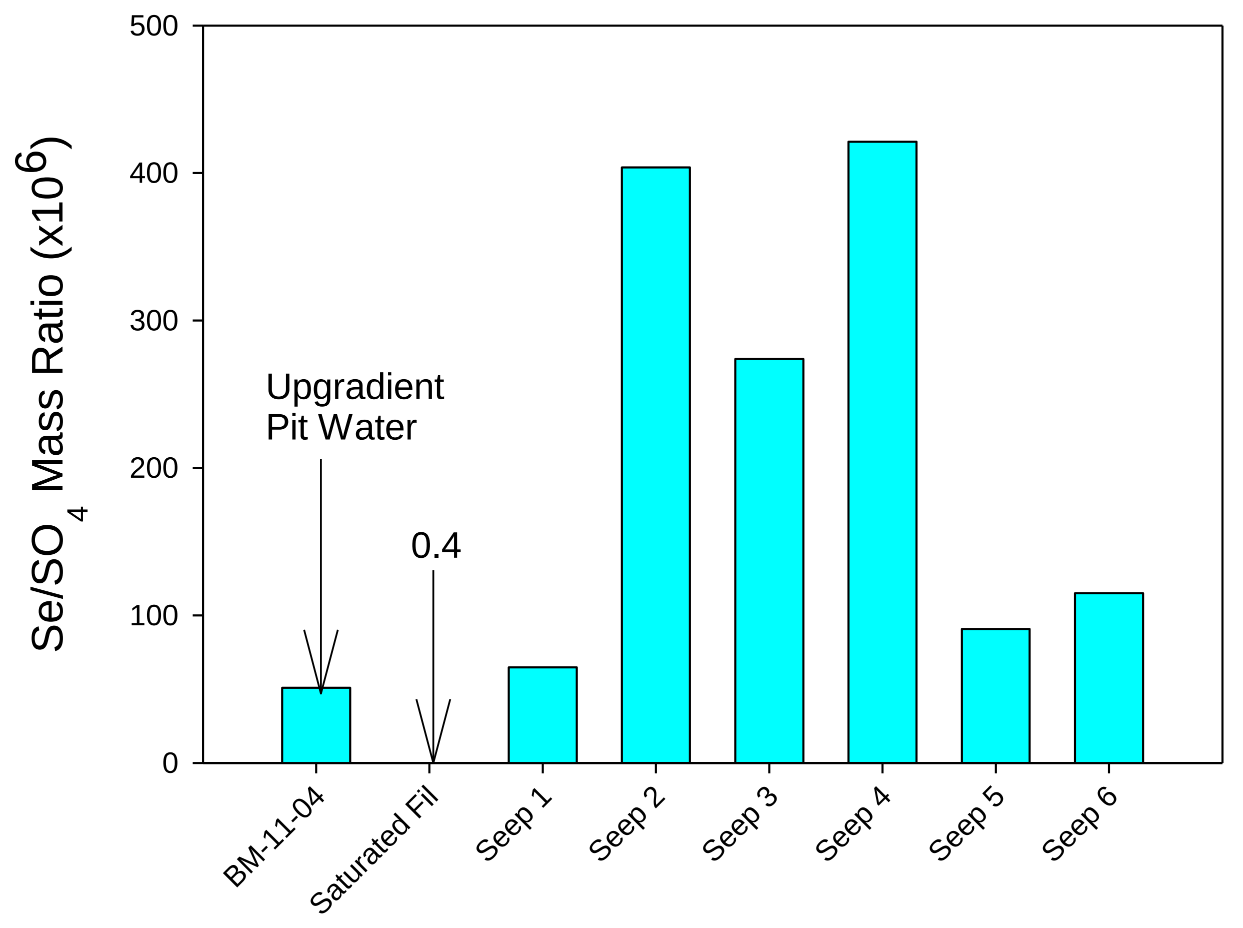
- Nitrate-N values in saturated zone below DL
- Low nitrate values indicative of denitrification (nitrate reduction) in suboxic porewaters.

Case Study Results: Selenium



- Most Se values in saturated zone below DL (<0.3 ppb)
- Low Se values indicative of Se reduction and immobilization in suboxic porewaters.

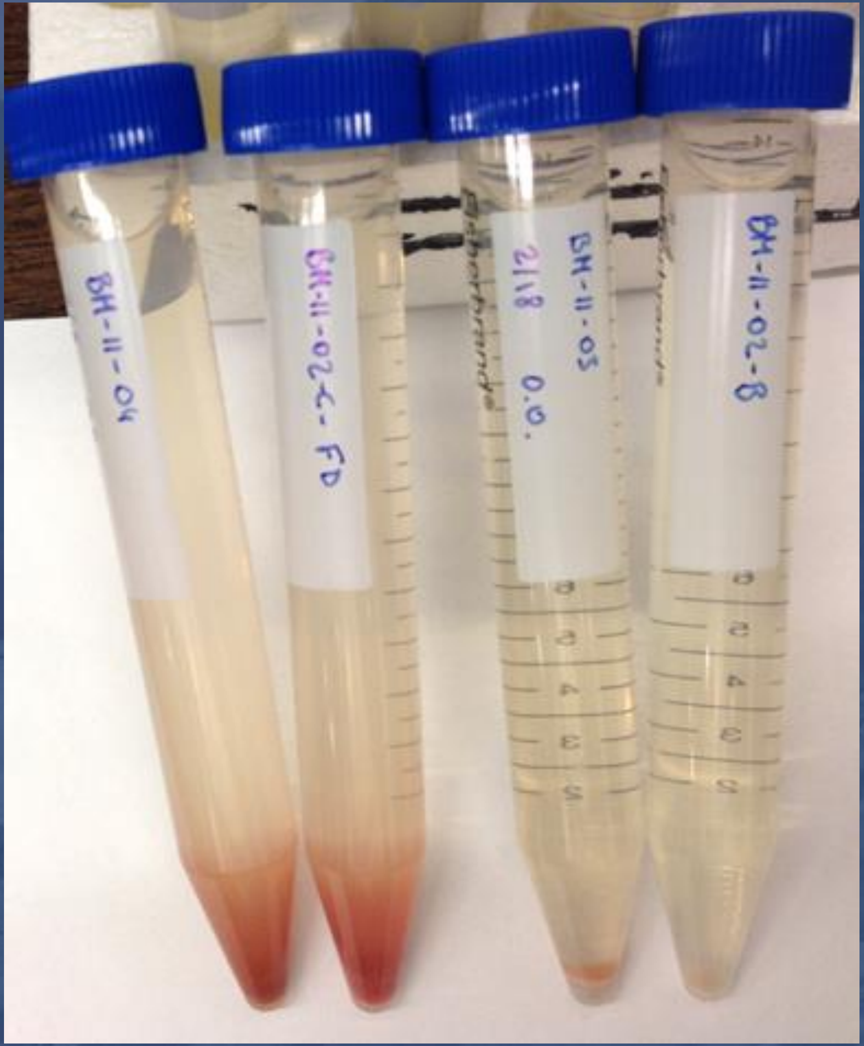
Case Study Results:
Selenium to Sulphate Ratio



- $Se/S0_4$ ratio in saturated zone is 2-3 orders of magnitude lower in comparison to waste rock seepages.

Case Study Results: Microbial Assessment

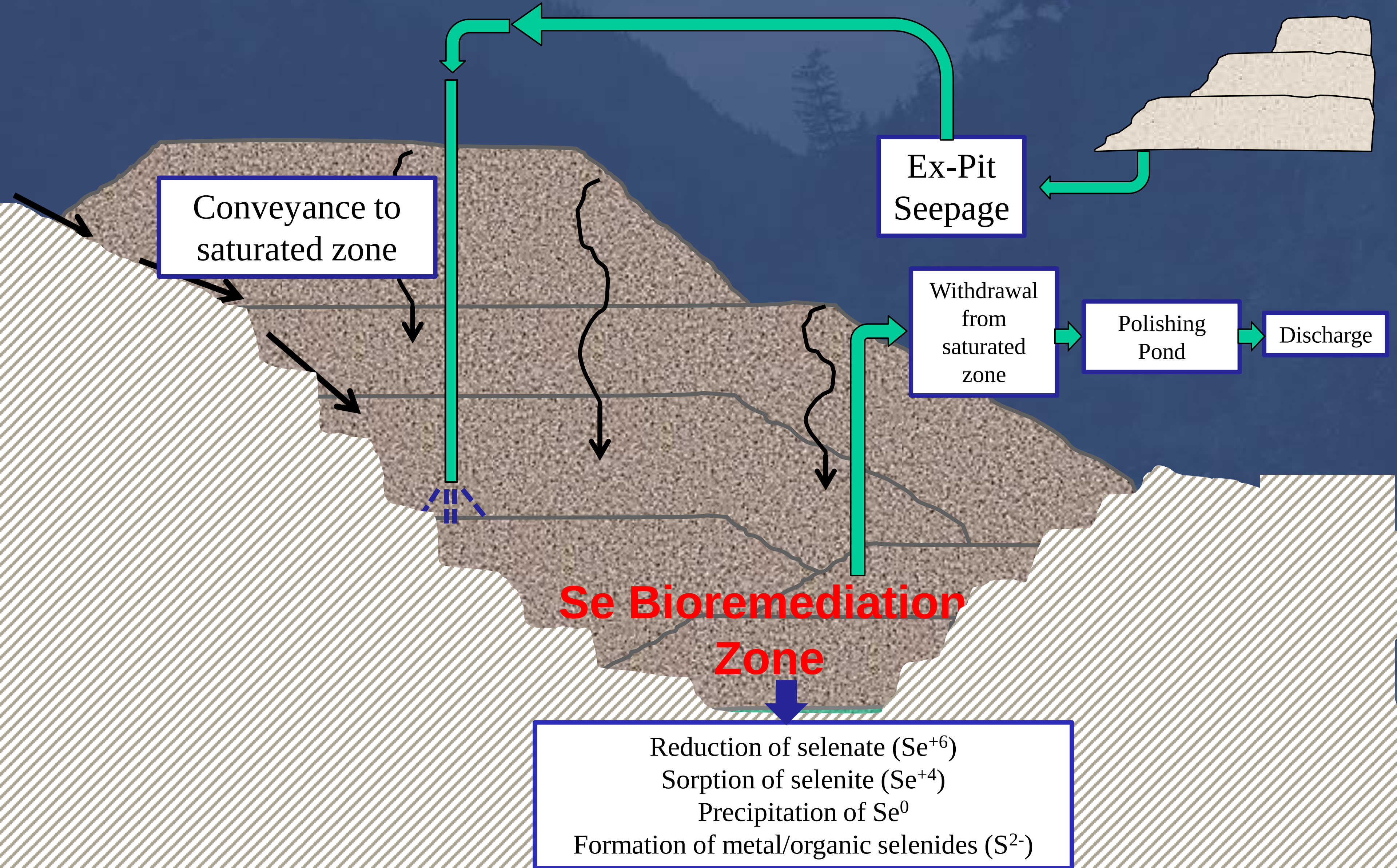
- Microbial analysis revealed active bacterial assemblages in all samples from saturated fill.
- Presence of low levels of Se reducing bacteria confirmed in some samples.
- Precipitation of elemental Se evident in some samples after longer culturing periods.



Saturated Backfill – Se Management

- Saturated backfill offers potential to treat large volumes of water at relatively low cost.
- Advantages:
  - Natural tendency for development of suboxic pore waters
  - Large volume of suboxic water
  - Long hydraulic residence times
  - Hydrologic control
  - Geotechnical stability (no engineered impoundments)
  - Potential to integrate into site-wide water management plan

Saturated Fill



Conveyance to saturated zone

Ex-Pit Seepage

Withdrawal from saturated zone

Polishing Pond

Discharge

Se Bioremediation Zone

Reduction of selenate (Se^{+6})
Sorption of selenite (Se^{+4})
Precipitation of Se^{0}
Formation of metal/organic selenides (S^{2-})

Saturated Backfill - Summary

- Data highlight potential for using backfilled pits as *in situ* bioremediation cells.
- Near-quantitative removal of Se is observed for hydraulic residence times on order of 1 year.
- Se bioremediation will be site specific, depending on:
    - Pit shell morphometry
    - Permeability
    - Climate & water balance
    - Dump size and construction methods
    - Waste rock properties: grain size distribution, mineralogy, and organic content.

Design for Closure

Considerations – Mine Planning

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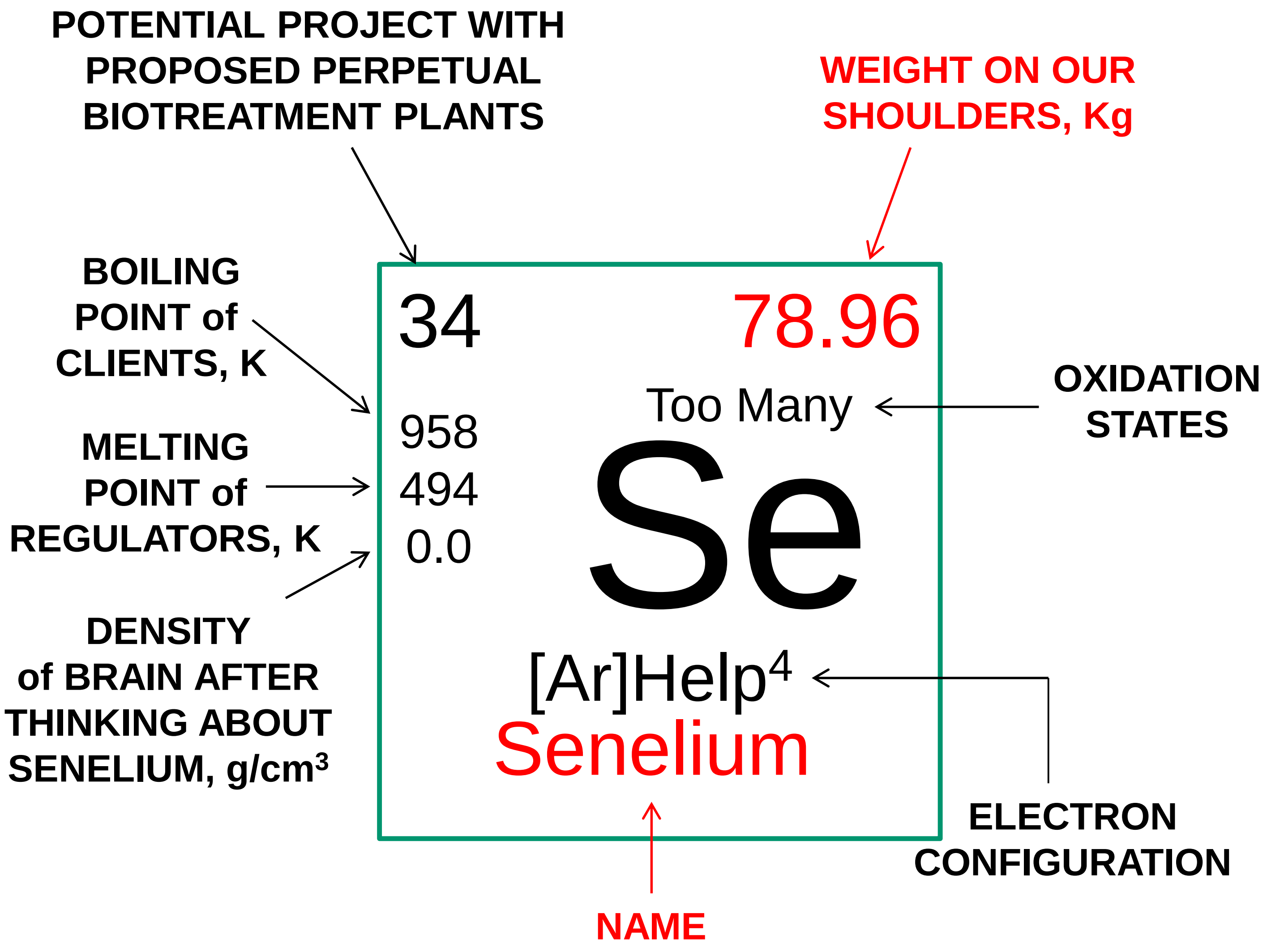
Bioremediation System

Design for Closure - Considerations

Potential to increase utility of pits for Se management through:

- Maximize saturated storage volume (pit design)
- Maximize pit backfill (reduce footprint of ex-pit dumps)
- Maximize passive drainage of contact flows reporting to saturated zones (waste placement, water management, pit design)
- Timing of availability of in-pit storage (design of pits, mine sequencing)
- Collection and conveyance of ex-pit seepage to pit (seepage collection, water management)

Thank You!



POTENTIAL PROJECT WITH PROPOSED PERPETUAL BIOTREATMENT PLANTS

WEIGHT ON OUR SHOULDERS, Kg

BOILING POINT of CLIENTS, K

MELTING POINT of REGULATORS, K

DENSITY of BRAIN AFTER THINKING ABOUT SENELIUM, g/cm^3

34

78.96

958

494

0.0

Too Many

Se

[Ar]Help^4

Senelium

OXIDATION STATES

ELECTRON CONFIGURATION

NAME