Biogeochemistry of Saturated Rock Fill Facilities, Elk Valley BC

Presentation for BC MEND, 2025

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Acknowledgements

- Work on SRFs has spanned over 15 years, has involved a highly collaborative team across disciplines, consultancies, academic partners, and Elk Valley Resources staff (formerly Teck Coal)

- Contributors include:
  - **EVR/Teck Coal (including R&D, operations, regional water quality modelling, permitting, environmental compliance, engineering, etc.)**
  - **SRK (geochemistry, hydrogeology, engineering, permitting support)**
  - **Enviromin (microbiology)**
  - **USASK (geochemistry and hydrogeology)**
  - **MSU (microbiology)**
  - **Geosyntec (carbon characterization)**
  - **OKC (field support)**
  - **WSP/Golder (regional water quality modeling)**
  - **Wood and Tetra Tech (wellfield engineering)**
  - **Nupqu (sampling)**
  - And many more operators, site & field staff, analytical lab staff, coop students, etc.

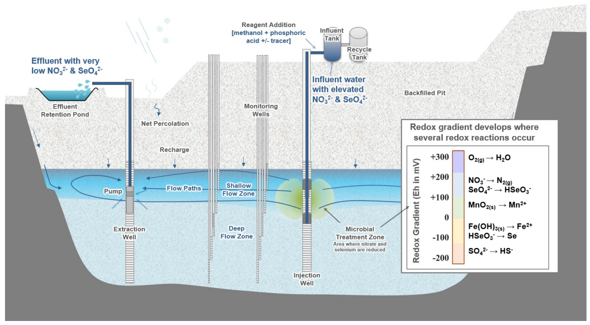
SRF expert advisory panel, subject matter experts, and technical team on a site tour at EVO SRF in 2018. From left to right: Steve Day, Marcie Schabert, Silvia Mancini, Shannon Shaw, Lisa Kirk, Len deVlaming, Seth D'Imperio, Rob Klein, Jim Hendry, Brent Peyton, Andrzej Prezpiora, Dan Mackie, Juris Harlamovs, Daryl Hockley, Lee Barbour

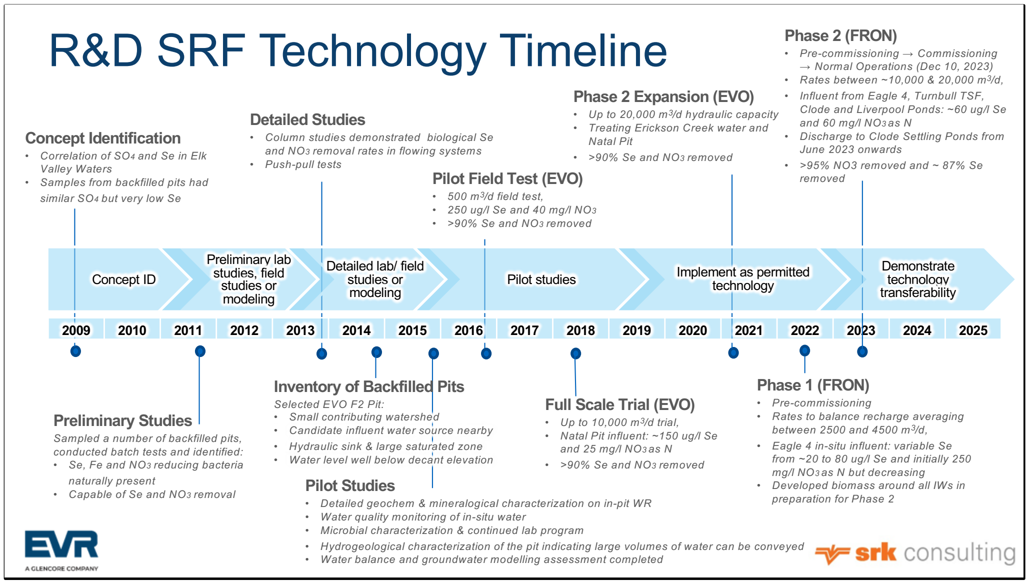
Outline

- Intro to SRFs
- Biogeochemical Conceptual Model
  - Biomass Zone
  - Re-equilibration Zone
- Overview of Active SRFs
  - EVO
  - FRO-N
- Findings for Key Constituents
  - Reagents (Carbon, Phosphorous)
  - Treatment Parameters (Nitrate, Selenium)
  - Redox Species (Manganese, Iron, Sulphate)
  - Trace Metals (Cadmium, Cobalt, Nickel, Zinc)
- Conclusions

Intro to SRF Biogeochemistry

- Previously mined pits are backfilled with waste rock and filled with water from precipitation
- Treatment utilizes microbially mediated reduction reactions or bioreduction
- These reactions transform nitrate and selenium (selenate) from soluble to non-aqueous forms
- Naturally occurring bioreduction is enhanced through the addition of carbon (as methanol) and nutrients (phosphoric acid) to support a larger community of reducing microbes
- Nitrate and selenium rich influent is injected into the saturated zone with reagents; the water travels through the SRF monitoring network to extraction, and then sent to a buffer pond




R&D SRF Technology Timeline
Concept Identification
• Correlation of SO_4 and Se in Elk Valley Waters
• Samples from backfilled pits had similar SO_4 but very low Se
Detailed Studies
• Column studies demonstrated biological Se and NO_3 removal rates in flowing systems
• Push-pull tests
Pilot Field Test (EVO)
• 500 m^3/d field test,
• 250 ug/l Se and 40 mg/l NO_3
• >90% Se and NO_3 removed
Phase 2 Expansion (EVO)
• Up to 20,000 m^3/d hydraulic capacity
• Treating Erickson Creek water and Natal Pit
• >90% Se and NO_3 removed
Phase 2 (FRON)
• Pre-commissioning → Commissioning → Normal Operations (Dec 10, 2023)
• Rates between ~10,000 & 20,000 m^3/d,
• Influent from Eagle 4, Turnbull TSF, Clode and Liverpool Ponds: ~60 ug/l Se and 60 mg/l NO_3 as N
• Discharge to Clode Settling Ponds from June 2023 onwards
• >95% NO3 removed and ~ 87% Se removed
Concept ID
Preliminary lab studies, field studies or modeling
Detailed lab/ field studies or modeling
Pilot studies
Implement as permitted technology
Demonstrate technology transferability
2009
2010
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2021
2022
2023
2024
2025
Preliminary Studies
Sampled a number of backfilled pits, conducted batch tests and identified:
• Se, Fe and NO_3 reducing bacteria naturally present
• Capable of Se and NO_3 removal
Inventory of Backfilled Pits
Selected EVO F2 Pit:
• Small contributing watershed
• Candidate influent water source nearby
• Hydraulic sink & large saturated zone
• Water level well below decant elevation
Pilot Studies
• Detailed geochem & mineralogical characterization on in-pit WR
• Water quality monitoring of in-situ water
• Microbial characterization & continued lab program
• Hydrogeological characterization of the pit indicating large volumes of water can be conveyed
• Water balance and groundwater modelling assessment completed
Full Scale Trial (EVO)
• Up to 10,000 m^3/d trial,
• Natal Pit influent: ~150 ug/l Se and 25 mg/l NO_3 as N
• >90% Se and NO_3 removed
Phase 1 (FRON)
• Pre-commissioning
• Rates to balance recharge averaging between 2500 and 4500 m^3/d,
• Eagle 4 in-situ influent: variable Se from ~20 to 80 ug/l Se and initially 250 mg/l NO_3 as N but decreasing
• Developed biomass around all IWs in preparation for Phase 2
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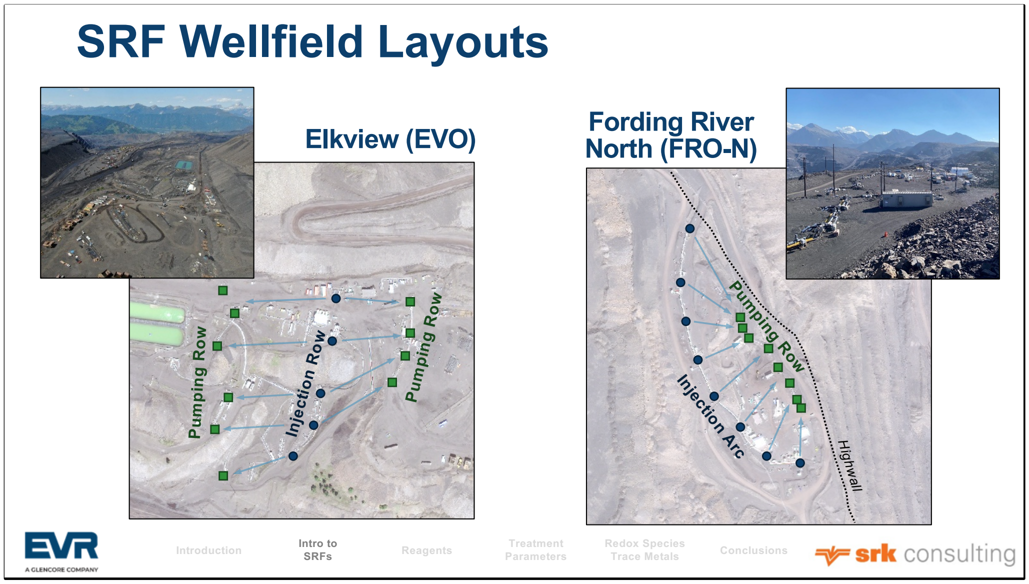
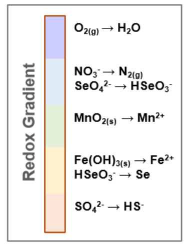
Key Aspects

	Elkview (EVO)	Fording River North (FRO-N)
		
Catchment Size	0.8 km^2	2.4 km^2
Waste Rock	18 million BCM, backfilling began in 1990s	300 million BCM, backfilling began in 2010s
Pit Geometry	Ovoid shape (~900 m x 700 m)	Long & narrow (~1.5 km x 200 m)
Total Volume of Saturated Zone	20.5 million m^3	7.3 million m^3
Pre Start-Up Nitrate Concentration	<1 mg/L as N	~200 mg/L as N
Pre Start-Up Selenium Concentration	~10 µg/L	~40 µg/L
Start-Up Date	January 2018	January 2022


SRF Wellfield Layouts
Elkview (EVO)
Pumping Row
Injection Row
Pumping Row
Fording River North (FRO-N)
Pumping Row
Injection Arc
Highwall
Introduction
Intro to SRFs
Reagents
Treatment Parameters
Redox Species Trace Metals
Conclusions

Data Presentation

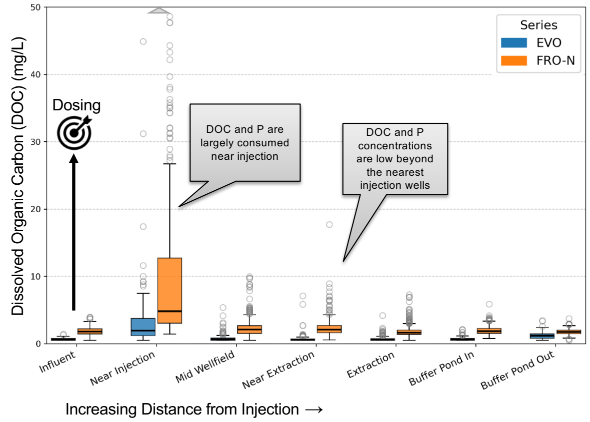
- Data presented is focused on the middle portion of each wellfield and water in the shallow flow zone
- Time period for data used is from the start of FRO-N P2 Operations (Dec 10, 2023) to Sept 10, 2025 (for both SRFs)
- Most slides use box & whisker plots to show the results for each SRF grouped by area:
  - Influent: injected water to be treated
  - Near Injection: nearest injection wells, within 20 m of injection
  - Mid Wellfield: at EVO ~ 35 m from injection and ~ 30-75 m for FRO-N
  - Near Extraction: ~ 75 m for EVO and ~ 100-110 m for FRO-N
  - Extraction: Pumping wells in the area of focus
  - Buffer Pond (In and Out): combined effluent in forward flow
  - Mean residence time through EVO is ~ 11-53 days and ~ 7-10 days through FRO-N



Monitoring Results

Carbon & Phosphorous

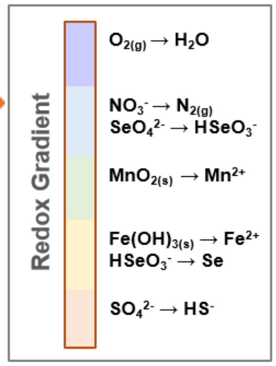
- Carbon (DOC) and Phosphorous (P) are dosed in influent water to support biomass growth and respiration
- Initial dosing was determined experimentally and adjusted operationally
- Dosing is based on the influent nitrate concentration (COD:N)
- Both reagents are pulsed
- DOC and/or P persisting beyond the near injection "biomass zone" is not beneficial after nitrate and selenium have been removed



Add notes on extensive database and

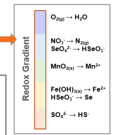
Redox Ladder

- Next group of slides will step down the redox ladder focusing on each electron acceptor
- Nitrate, selenium and sulphate are present in the influent water; manganese and iron are present in the backfilled waste rock mineral phases

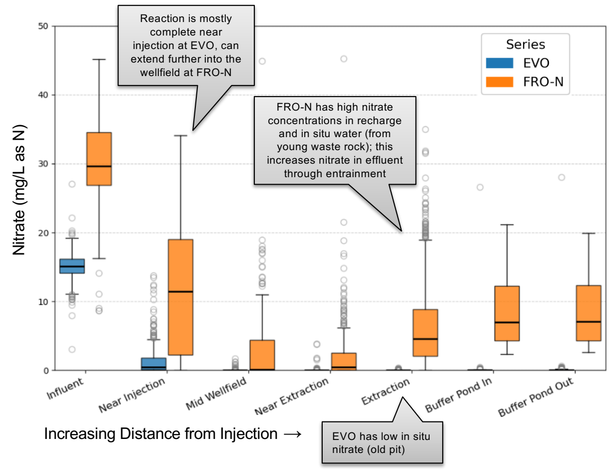


Nitrate

$6NO_3^- + 5CH_3OH \rightarrow 3N_2 + 5CO_2 + 7H_2O + 6OH^-$



- Influent nitrate is treated through denitrification
- Supported by isotopic data and literature
- Nitrate loads removed typically >300 kg/d
  - FRO-N at times is >500 kg/d



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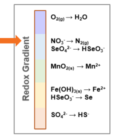
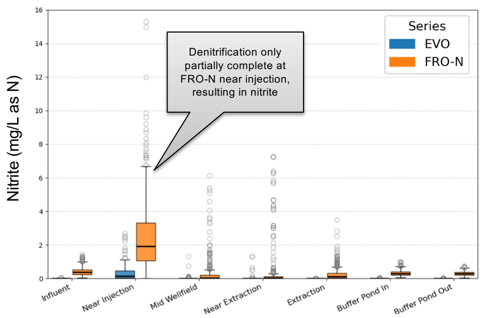
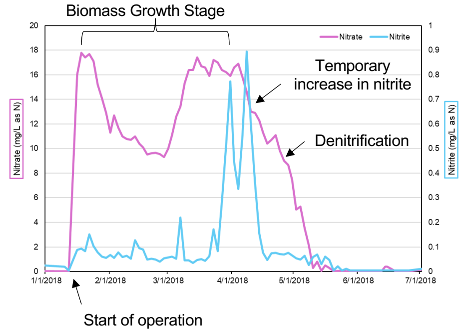
Nitrite

$NO_3^- \rightarrow NO_2^- \rightarrow NO \rightarrow N_2O \rightarrow N_2$



- Nitrite is a useful indicator of the onset of denitrification and can be elevated before denitrifying bacteria are fully established
- Also see nitrite when denitrification is incomplete e.g. if carbon is too low and can indicate system perturbations





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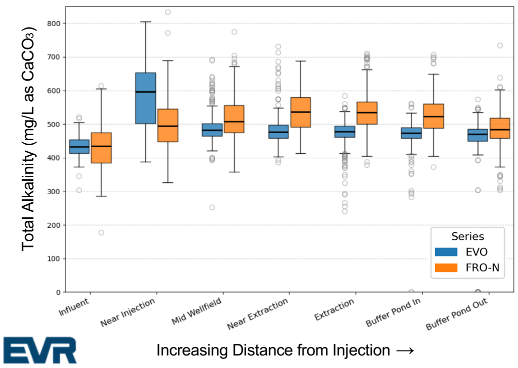
Alkalinity

$$6NO_3^- + 5CH_3OH \rightarrow 3N_2 + 5CO_2 + 7H_2O + 6OH^-$$

- Alkalinity in the backfilled pits is ~300 to 800 mg/L as $CaCO_3$
- Denitrification also adds alkalinity (3.57 mg as $CaCO_3$ per mg of NO_3^- (as N) reduced)
- Saturated conditions keep pCO_2 elevated, suppressing calcite precipitation until effluent can off-gas



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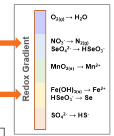
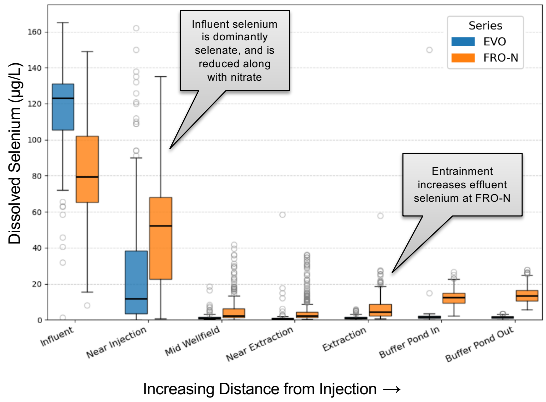
Selenium

$$1/8CH_3COO^- + 1/2SeO_4^{2-} + 1/2H^+ \rightarrow 1/8CO_2 + 1/2HSeO_3^- + 1/8HCO_3^- + 3/8H_2O$$

$$1/8CH_3COO^- + 1/4HSeO_3^- + 1/4H^+ \rightarrow 1/8CO_2 + 1/4Se^0 + 1/8HCO_3^- + 5/8H_2O$$

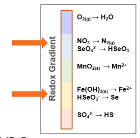


- Reduction from selenate to selenite (SeO_3^{2-}) occurs in similar REDOX conditions to denitrification
  - Selenite is more likely to adsorb to material in the SRF (e.g., ferrihydrite)
- At lower redox, selenite can be further reduced to:
  - Insoluble elemental selenium (Se^0) and selenide (Se^{2-})
- Selenium loads removed are typically >1 kg/d
  - EVO at times is >2.5 kg/d

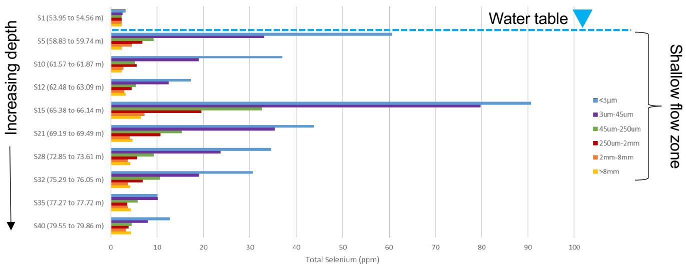


Selenium

$SeO_4^{2-} \rightarrow SeO_3^{2-} \rightarrow Se^0 \rightarrow Se^{2-}$



- Solid samples retrieved from ~5m lateral distance from injection at EVO indicated selenium attenuation occurs in the smallest size fractions within the shallow flow zone



- XANEs analyses on the smaller size fractions identified selenium attenuated as selenite adsorbed to ferrihydrite and zero-valent selenium best represented by the selenium sulfide (Se_nS_{8-n})

Introduction | Intro to SRFs | Reagents | **Treatment Parameters** | Redox Species Trace Metals | Conclusions

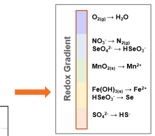
Selenium Species

$SeO_4^{2-} \rightarrow SeO_3^{2-} \rightarrow Se^0 \rightarrow Se^{2-}$

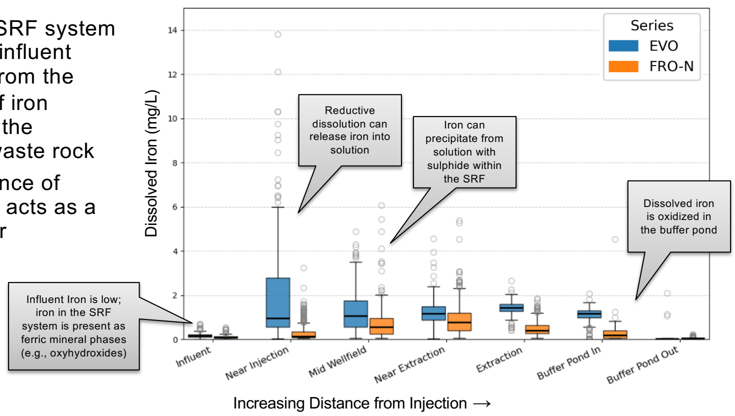
- Selenium in the influent is dominantly as selenate with minor selenite
- It's expected that some organo-selenium species are generated within the biomass and therefore organo-selenium species are occasionally detected in monitoring wells:
  - Concentrations of all organo-selenium species are generally low, often below DLs
  - Near injection, the occasional detection of methylseleninic acid (CH_3SeO_2H), selenocyanate (SeCN) and selenosulfate ($SeSO_3$) are seen.
  - As water moves away from the biomass, concentrations of the above organo-selenium species decrease; and occasional detection of dimethylseleneoxide ($(CH_3)_2SeO$) is observed.
  - In effluent, there is sometimes concentrations above detection for dimethylseleneoxide, methylseleninic acid and selenocyanate; concentrations in the SRF effluent are below values observed in similar tank-based systems.

Iron

$CH_2O + 2Fe(OH_3) + 4H^+ \rightarrow 2Fe^{2+} + CO_2 + 5H_2O$



- Iron in the SRF system is not from influent water, but from the presence of iron minerals in the backfilled waste rock
- In the absence of nitrate, iron acts as a redox buffer



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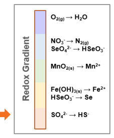
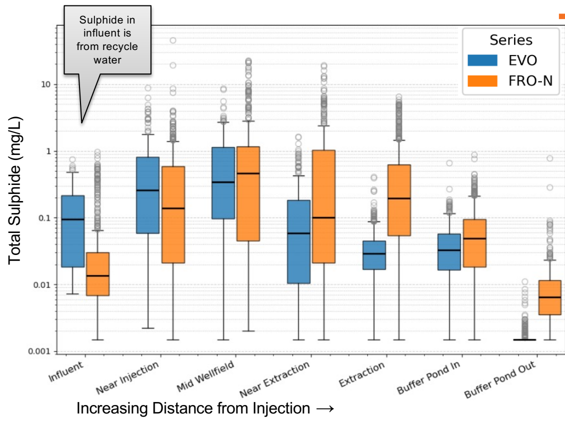
Sulphate/Sulphide

$4CH_3OH + 3SO_4^{2-} \rightarrow 4HCO_3^- + 3HS^- + 4H_2O + H^+$



- Influent has elevated sulphate but is generally low in sulphide except during times of recycling of sulphide-bearing effluent
- Sulphate reduction occurs in the biomass zone
- Sulphide is expected to largely precipitate out of solution, co-precipitating cations with it (e.g., Fe, Cd, Zn, Ni)



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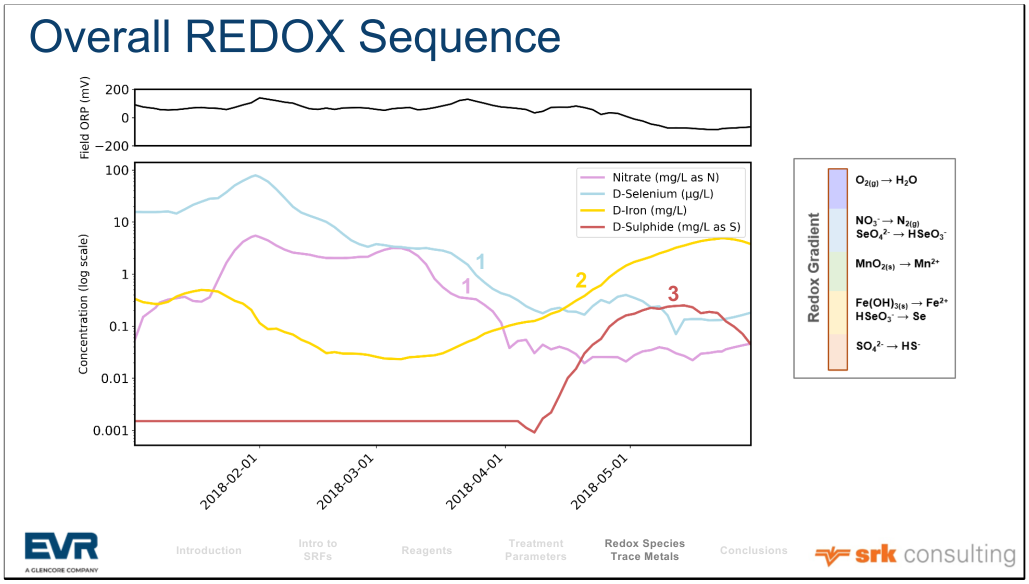
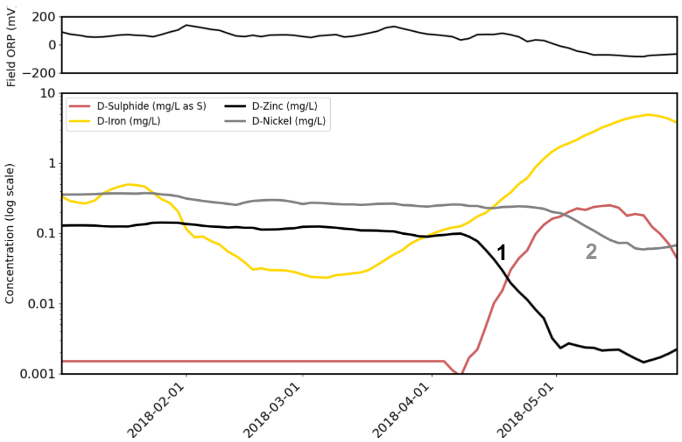


Initially, reductions in Selenium and Nitrate (and temporary increase in Nitrite)

After nitrate and selenium reduced to low concentrations, move further down the REDOX ladder

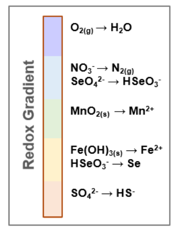
- Iron Reduction
- Sulphate Reduction

Overall REDOX Sequence & Trace Metals



- As sulphide increases, see a decrease in:

1. Cadmium & Zinc
2. Nickel & Cobalt



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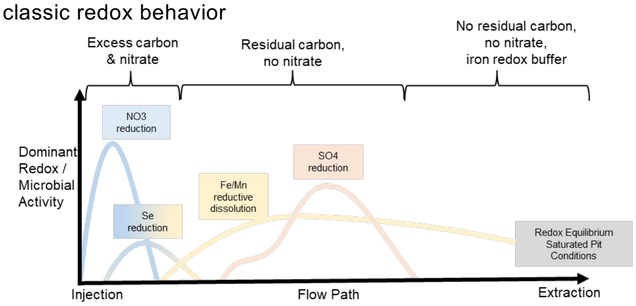
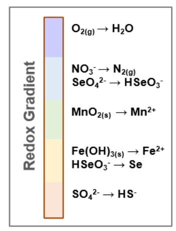
Conclusions

- The SRF technology has been demonstrated at two full scale facilities in the Elk Valley
- The two facilities have a number of differences, but the biogeochemical processes remain consistent
- The observed water chemistry, corroborated by mineralogical analyses, demonstrates classic redox behavior






Thank You