Removing Selenium and Nitrate using Saturated Rock Fills: From Concept to Full-Scale Operation

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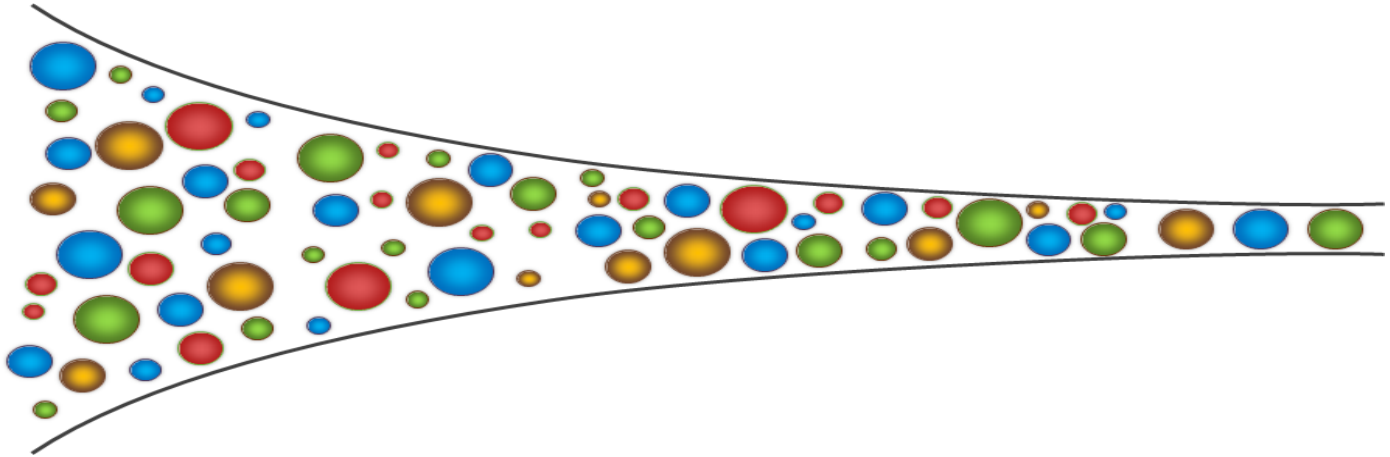
Overview of Teck R&D Stage Gate Process

Resolve technical uncertainty at the smallest scale possible to manage cost and risk, and advance the most promising technologies in a timely manner



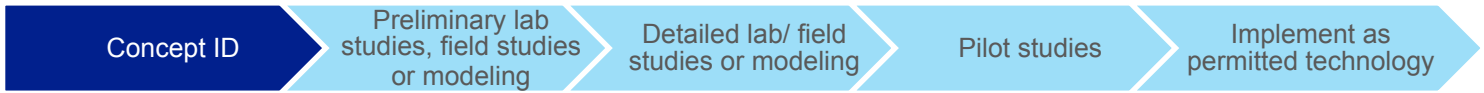
Concept ID → Preliminary lab studies, field studies or modeling → Detailed lab/ field studies or modeling → Pilot studies → Implement as permitted technology

Selenium Management Approaches

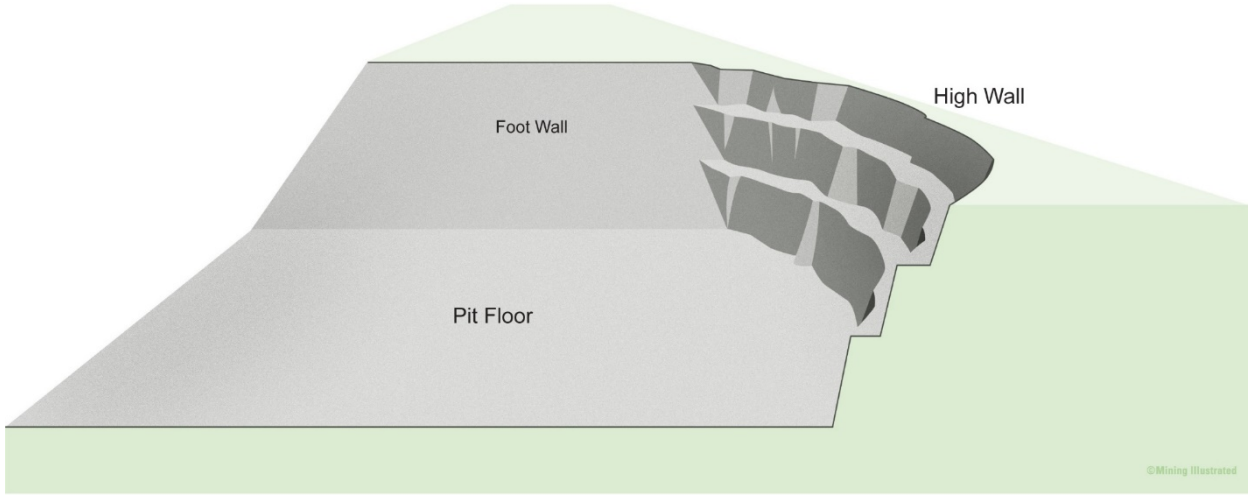
Numerous potential technologies were identified by internal and external groups that could be used to manage water quality in the Elk Valley

- Source control
- Tank-based water treatment
- *In situ* water treatment
- Fundamental studies

SRFs were identified as a candidate for further study.

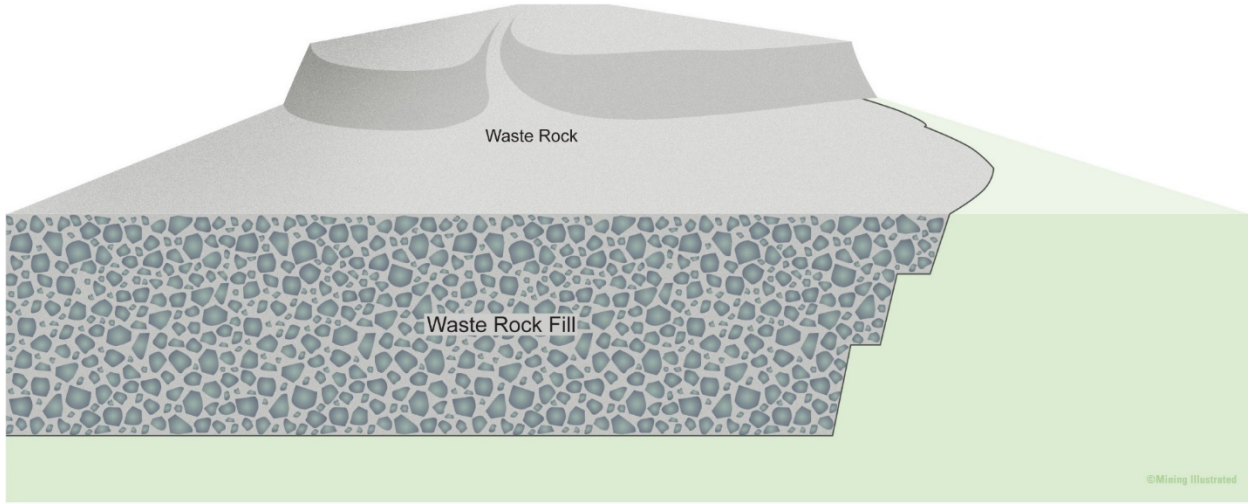


What is a Saturated Rock Fill?
Start with a fully contained pit



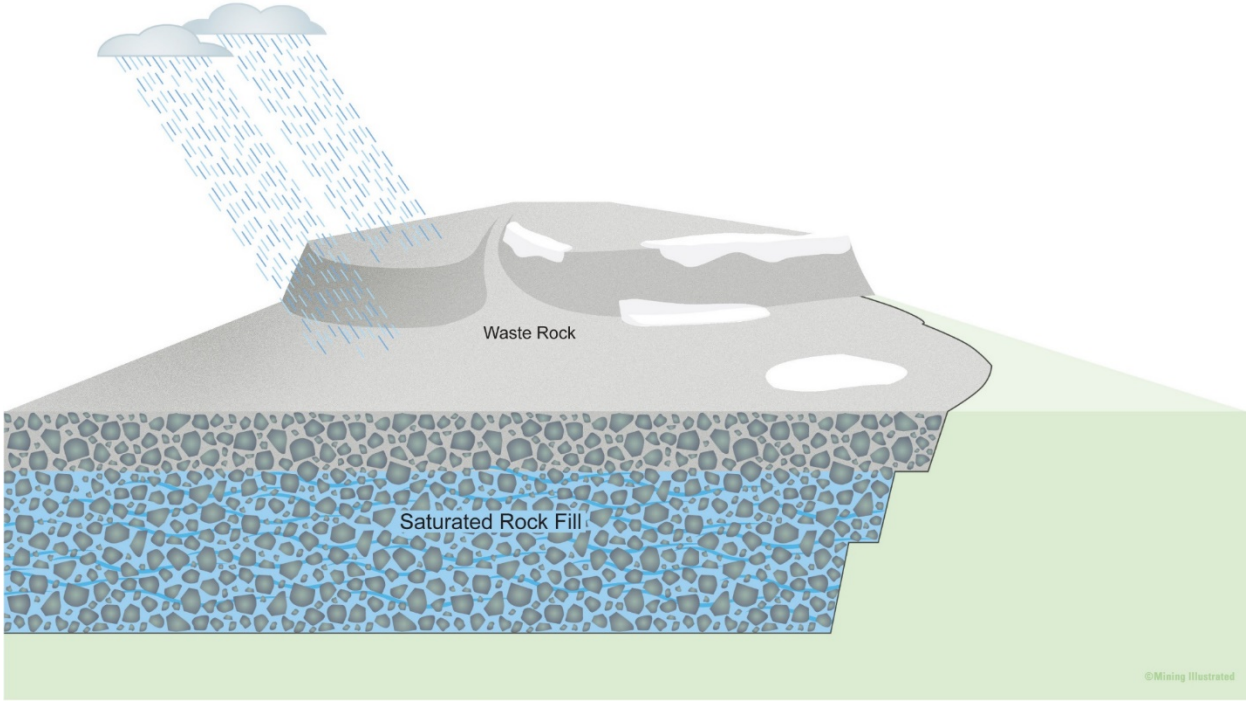
What is a Saturated Rock Fill?

Fill that pit with waste rock



What is a Saturated Rock Fill?

The pit then holds water from precipitation



What is a Saturated Rock Fill?

Partially Backfill Pit

What is a Saturated Rock Fill?

Fully Backfilled

How do they work?

The saturated portion supports a microbial community capable of nitrate and selenate reduction.

Occurs through anaerobic respiration where microbes use nitrate and selenate instead of oxygen as electron acceptors to gain energy from carbon oxidation.

When they are reduced, they are removed from the water

1. Concept Identification

2009-2011

Mode of Se release is oxidative dissolution of pyrite.

- Strong correlation between sulphate and selenium

Early SRF sampling results had similar sulphate concentrations to surface waters around the Elk Valley, but with lower selenium

Why do backfilled pits have lower selenium?

2. Preliminary Studies

2011-2012

Key question:

- What causes lower selenium in SRFs and do we have a suitable number of SRFs?

Approach:

- Inventory and sampling of existing SRFs

Risk management:

- Lab and desktop work only

Concept ID | **Preliminary lab studies, field studies or modeling** | Detailed lab/ field studies or modeling | Pilot studies | Implement as permitted technology

2. Preliminary Studies - Results

2011-2012

What causes lower selenium in SRFs?

- Microbiology capable of Se and NO_3 removal present

Do we have a suitable number of SRFs?

- Several locations in the Elk Valley where this technology would be applicable and could be studied
- Lower Se and NO_3 in numerous SRFs

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3. Detailed Studies

2012 - 2014

Key question:

- How fast does Se removal occur and what mechanisms are at work?

Approach:

- Detailed lab studies replicating field conditions
- Push-pull tests at multiple wells

Risk management:

- Small tests (<10 m^3) paired with lab testing

3. Detailed Studies - Results
2012 - 2014

How fast?

- Biological Se and NO_3 removal rates are meaningful

What mechanisms are at work?

- Selenium removal is likely to occur via:
  - biological reduction of Se(VI) to Se(IV),
  - abiotic adsorption, and
  - further reduction to elemental Se(Se(0))

4. Pilot Studies

2015

Key question:

- How much water can be conveyed and how permanent is removal?

Approach:

- Dedicated SRF drilling with material collection for lab studies
- Geophysics and hydraulic testing

Risk management:

- All remobilization testing done in the lab

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4. Pilot Studies - Results

2015

How much water can be conveyed?

- SRFs have hydraulic conductivities capable of conveying mine-scale volumes of water (10's of thousands m^3/d)

How permanent is removal?

- Management of dissolved oxygen in SRFs is important as it can remobilize attenuated selenium

- Overly reducing conditions did not remobilize selenium and trace element release is unlikely

5. Pilot Studies

2016

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5. Pilot Studies - Results

2016

Can SRFs remove Se and NO_3 in the field?

- Yes, >90% Se and NO_3 removed
- No unexpected water chemistry

Results indicated that it should be possible to treat mine scale volumes of water – recommended trialing at a full scale

6. Full Scale Trial
2017-2018

Key Question

- Can SRFs reliably treat mine-scale quantities of water?

Approach

- 10,000 m^3/d capacity
- Predicted Influent:
  - ~30 mg/l Nitrate
  - ~100 ug/l Se

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6. Full Scale Trial
Risk Management - Operations

Buffer pond with 24 hour capacity as well as an onsite laboratory

Storage capacity onsite for off-spec effluent

Experienced operations team

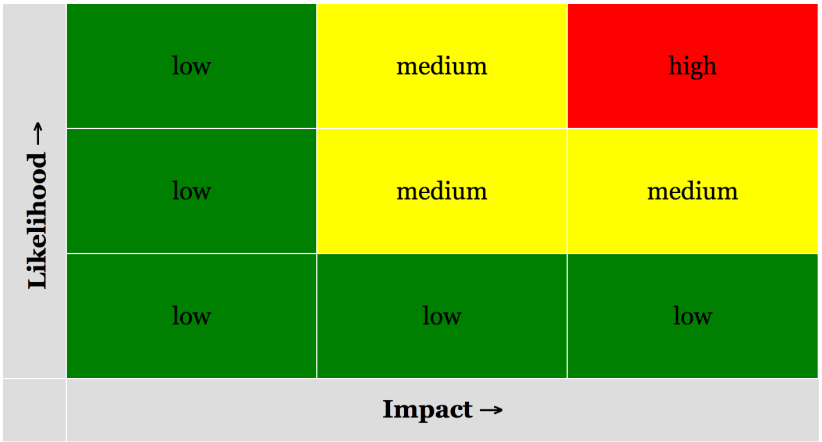
Extensive monitoring (55 locations, 13,000 water samples, >1 million data points)

6. Full Scale Trial
Risk Management - Risk Register

Assessed risks of

- Full Scale Trial specifically
- Technology in general

- Involved all the key technical specialists and stakeholders



6. Full Scale Trial

Risk Management – External Oversight

Expert Advisory Panel

- 8 person team of experts provide technical oversight
  - Enviromin Consulting
  - Geosyntec Consulting
  - Montana State University
  - O'Kane Consultants
  - SRK Consulting (Canada) Inc.
  - Teck Applied R&D team
  - University of Saskatchewan

6. Full Scale Trial

Risk Management – External Oversight

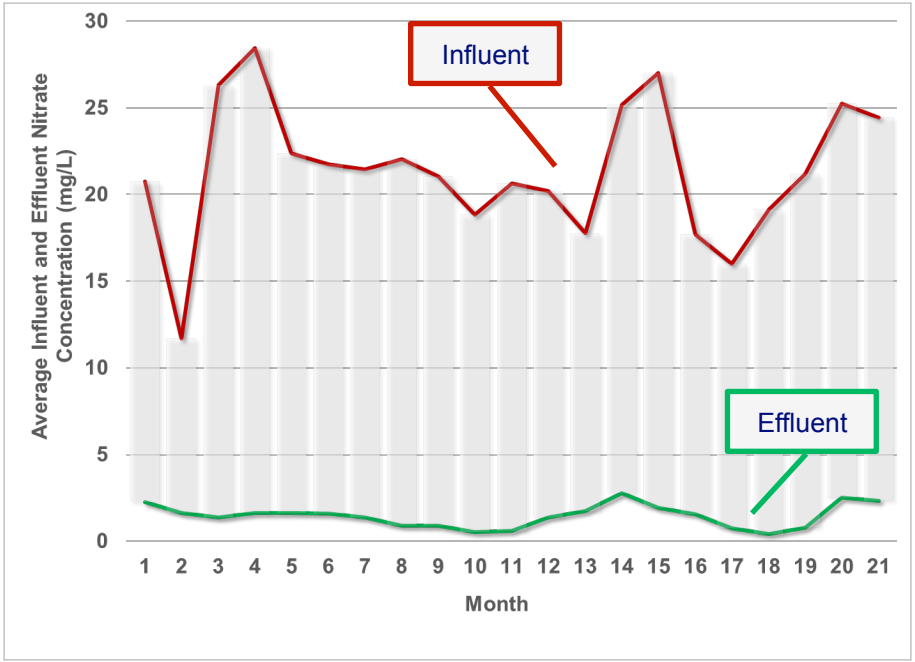
Independent Peer Review

- Week-long review of results by 4 independent experts after trial conclusion

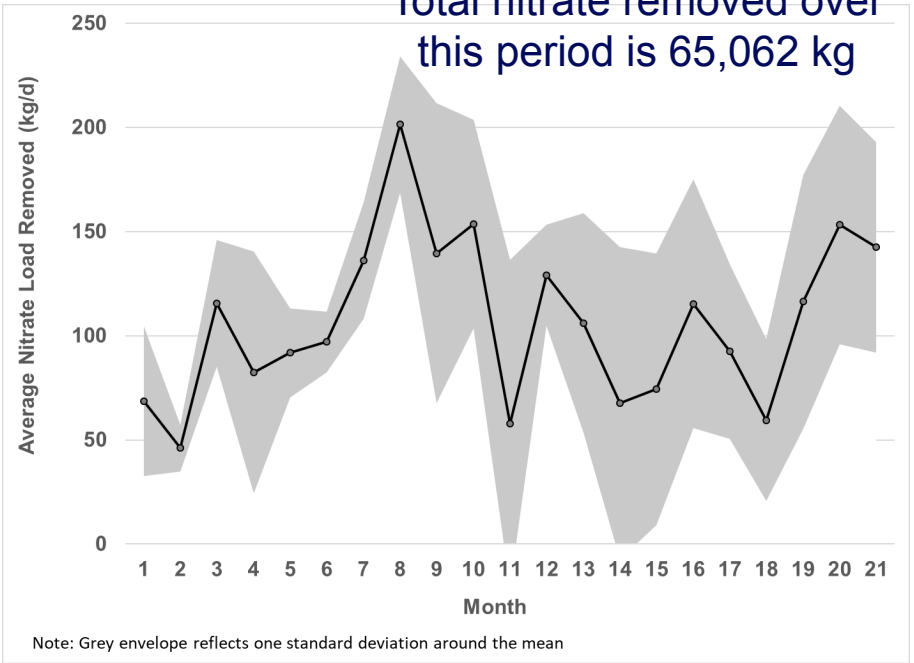
Regulatory Engagement

- Early and often

6. Full Scale Trial Results - Nitrate removal



Total nitrate removed over this period is 65,062 kg



Note: Grey envelope reflects one standard deviation around the mean

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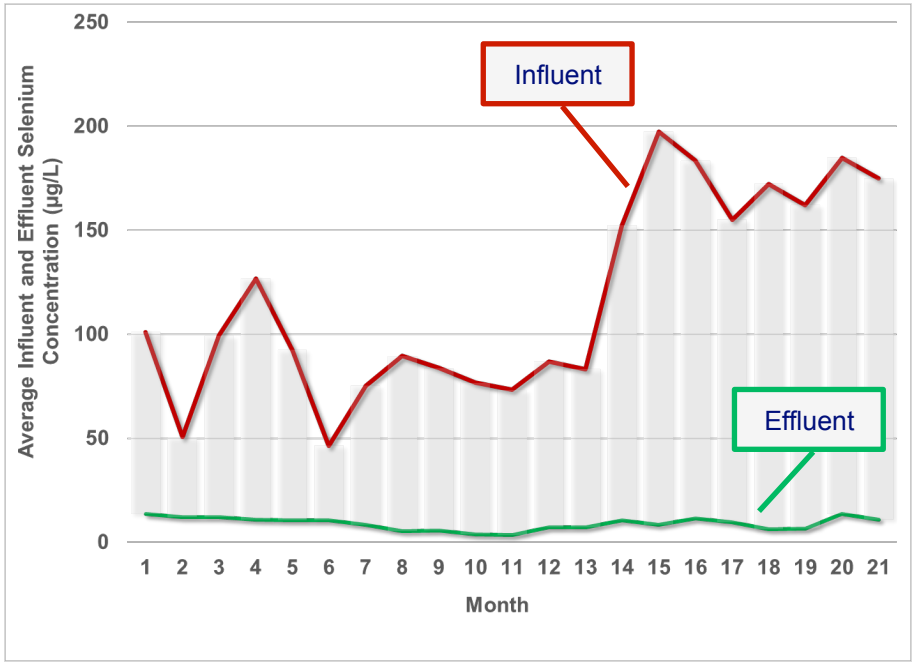
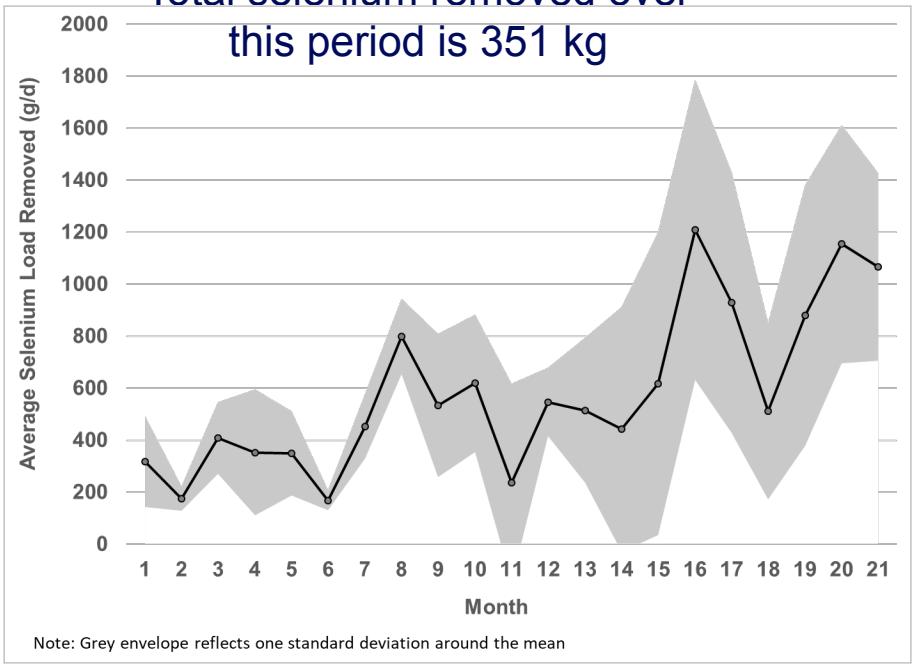
6. Full Scale Trial Results – Selenium removal



Total selenium removed over this period is 351 kg



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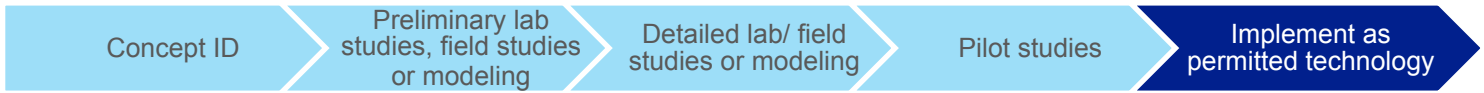
Conclusions and Next Steps

R&D stage gating of development allowed Teck to manage risk.

After 2 years and almost 4 million m^3 of water, Teck has demonstrated that SRF technology can safely remove Se and NO_3 at a meaningful scale.

Next Steps

- Expansion to 20,000 m^3/d capacity
- Continued R&D on remaining uncertainties
- Use of Adaptive Management Process to adapt to low velocity risks
- Trigger Action Response Plans embedded in operational management
- Peer Reviewed Publications



Questions?