Prediction of drainage chemistry for contact water passing through multiple rock units within a proposed panel cave mining operation.

Authors: [1]Jonathan Mackin, [1]David Flather, and [2]Harold Bent

[1]Lorax Environmental Services Ltd, 2289 Burrard Street, Vancouver, BC, Canada
[2]AuRico Metal Inc., 110 Yonge Street, Suite 601 Toronto, Ontario, Canada

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Introduction

- Overview:
  - Geologic Units (Geochemistry, Cross-Sectional View)
  - Project Description
  - Considerations
- Conceptual Design – Focus on operations phase (> Yr 1)
- Pre/feasibility stage modeling
- EA/Permitting stage conceptualized model
  - Source term development – experimental design
  - Kinetic test results (comparison of sequential testing with control)
- Closing

Overview

- Kemess Underground (KUG) Mine
- Location: Peace River Regional District in north-central BC
- 250 km north of Smithers / 6.5 km north of the past-producing Kemess South Mine

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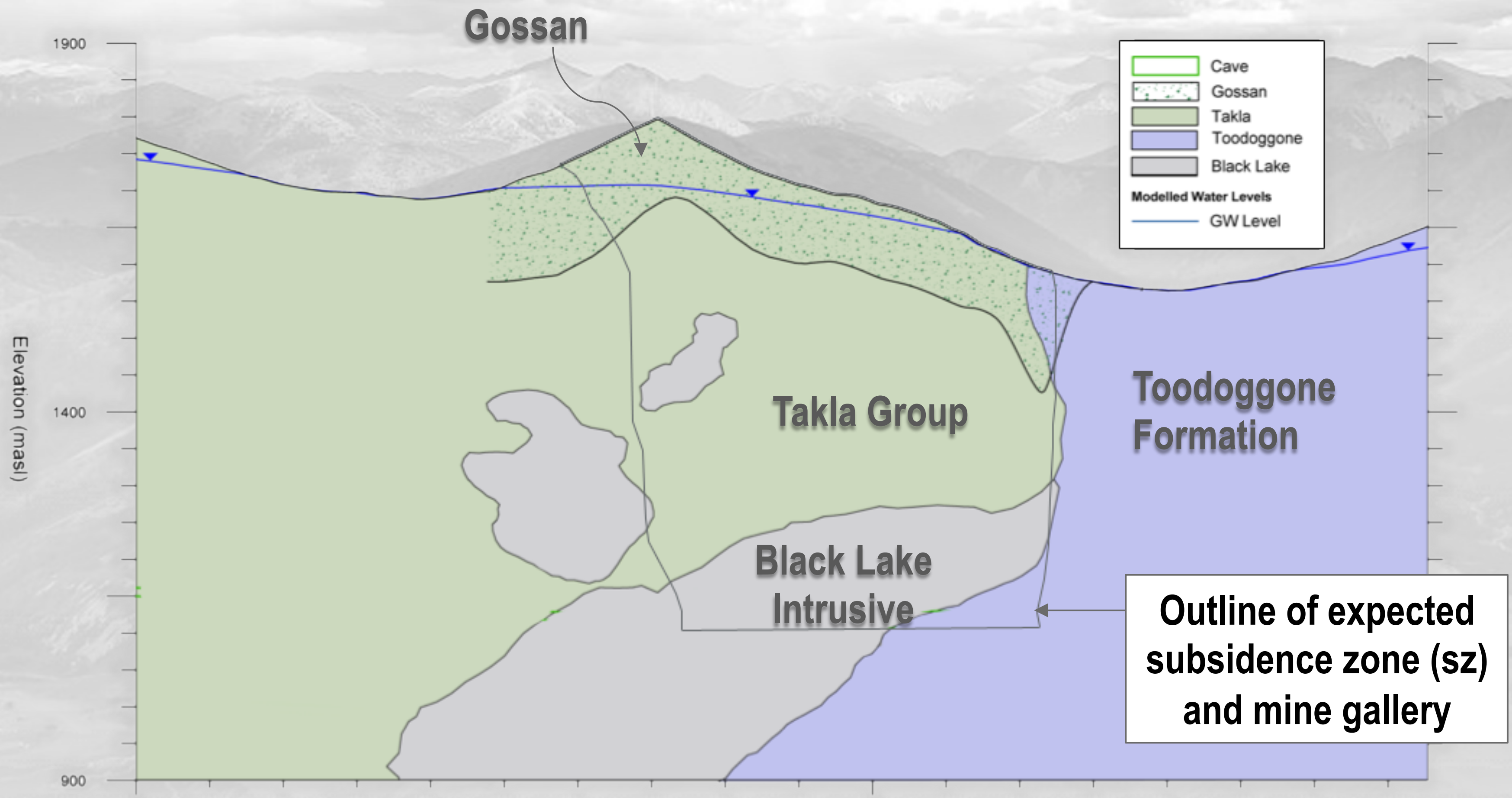
Overview – KUG Mine Area

- Ore zone is 150 to 600 m below the surface – underlying a glacial cirque: East Cirque
- Panel cave mining to occur at depth
- Subsidence zone (SZ) expected to form
- Rock units present in subsidence zone:
  - Gossan
  - Takla Group
  - Black Lake Intrusive (BLI) – Hypogene
- Rock units present around the subsidence zone:
  - Hazelton Group – Toodoggone Formation
- Mineable ore present in the BLI and Takla Group

Overview – Geologic Units



Overview – Geologic Units

- **Gossan**
  - Highly weathered and acidic unit
  - Solid Phase Geochemistry:
    - Low paste pH (3.0 to 8.5; median = 5.6)
    - S_2 from 0.030 to 15 %S, SO_4 from <0.010 to 0.37 %S
    - Low NP (< 40 kg $CaCO_3$/t)
    - NPR (< 0.5 and PAG)
    - Cu, Pb, Zn enriched
    - Considered an oxidation front into the Takla Group
  - Surface water quality and seepage water associated with the Gossan unit is low pH (pH 3.9 to 4.5) and high in Cu (0.050 to 0.30 mg/L) and Zn (0.040 to 0.28 mg/L)

Overview – Geologic Units

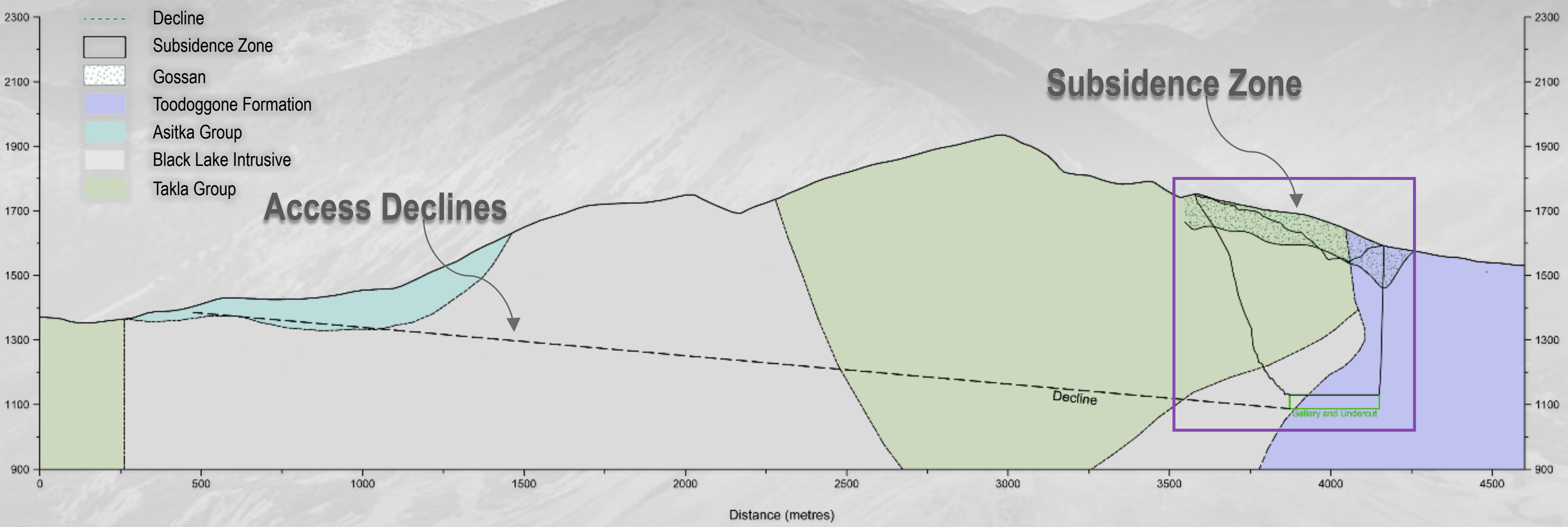
- **Takla Group**
  - Andesitic/basaltic flows, with the presence of a bladed feldspar porphyry
  - Partially hosts ore body
  - Solid Phase Geochemistry:
    - Circumneutral paste pH
    - S_2 from 0.080 to 15 %S, SO_4 from <0.010 to 7.6 %S
    - Moderate to Low NP (< 180 kg $CaCO_3$/t; P50 = 5.8 kg $CaCO_3$/t)
    - NPR – PAG (Generally < 2.0)
    - Cd, Cu, Mo, and Se enriched
  - Seepage water and groundwater associated with Takla: circumneutral pH, generally low trace element concentration (Se has been noted as relatively elevated)

Overview – Geologic Units

- **Black Lake Intrusive (BLI) - Hypogene**
  - Intrusive bodies
  - Intermediate composition (typically Quartz monzonite)
  - Mineralized with Au and Cu, ore bearing
  - Solid Phase Geochemistry:
    - Circumneutral paste pH
    - S_2 from 0.080 to 15 %S, SO_4 from <0.010 to 7.6 %S
    - Moderate to Low NP (< 180 kg CaCO3/t)
    - NPR – PAG (Generally < 2.0)
    - Cd, Cu, Mo, and Se enriched
  - Groundwater associated with the BLI unit: circumneutral pH, relatively low trace element concentration

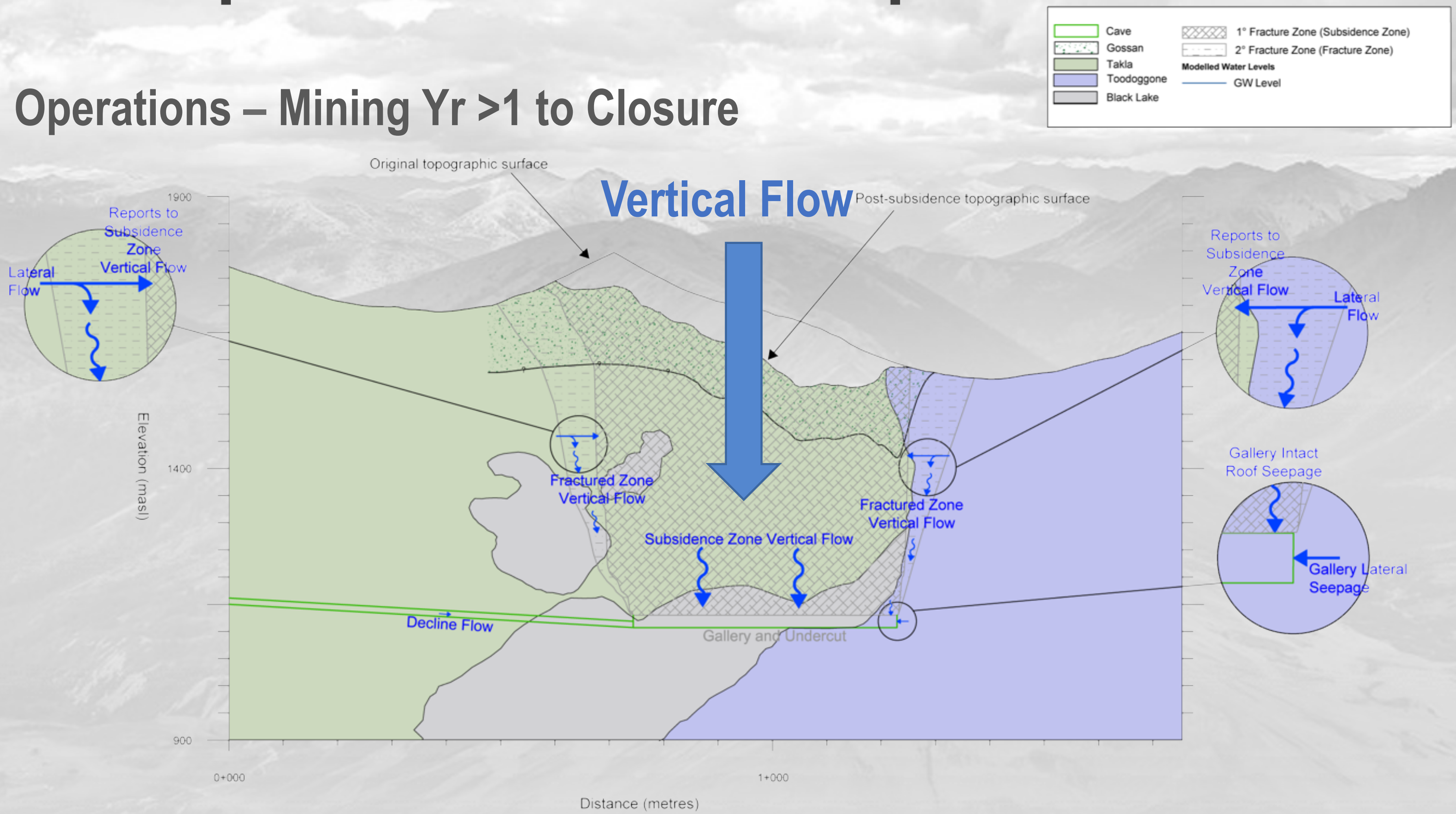
Overview – Geologic Units

- Overall underground operation – cross section



Conceptual Model - Development

Operations – Mining Yr >1 to Closure



Pre-/feasibility stage modeling

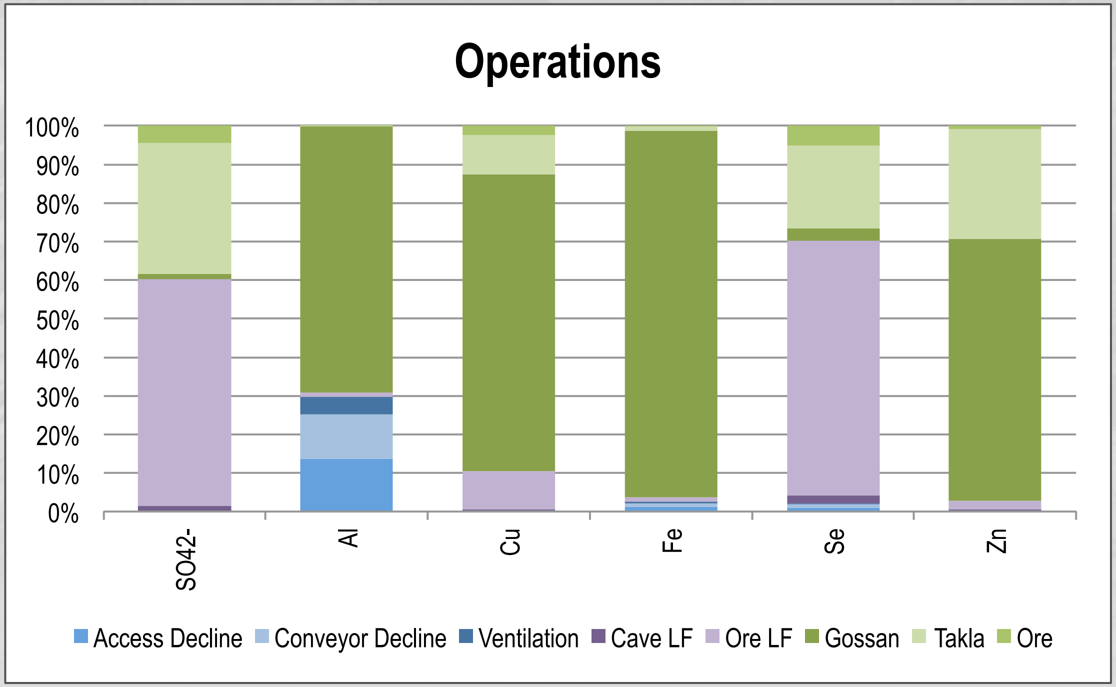
- Approach
  - Simply summed mass loadings
    - Gossan + Takla Group + Black Lake Intrusive = Combined mass loading (mg/mo)
  - Treated like a waste rock dump

- Results lacked:
  - Consideration of potential solubility constraints
  - Potential for acidic leachate from Gossan to affect the Takla and/or BLI was not understood at this stage
  - Kinetic tests used in modeling were not specifically from the area or materials to be disturbed

Pre-/feasibility stage modeling

- Outcome:
  - Results indicated the importance of understanding the chemistry of contact water passing from the surface through the subsidence zone (Gossan to Takla to BLI) into the underground

Parameter	Units	Pre/Feasibility	Pre/Feasibility SZ Source Term
Sulphate	mg/L	2188	2030
Aluminum	mg/L	2.1	1.4
Copper	mg/L	0.95	0.95
Iron	mg/L	0.76	0.72
Selenium	mg/L	0.077	0.055
Zinc	mg/L	1.0	1.0



Experimental Design

- Objective:
  - Determine influence or lack thereof for acidic influent water on geologic units below the Gossan? What is the effect on discharge water quality?
  - Determine if there is an additive effect on trace elements loadings to the discharge.
  - Are there natural solubility controls that could affect the discharge water quality?
- Need to have an experimental design for expected conditions
- How?

Experimental Design

- Sequential trickle leach columns
  - Use approximate proportion of material that is observed in subsidence zone (1 Gossan to 3 Takla to 2 BLI)
    - Gossan column: 5 kg (height of column ≅ 0.5 m)
    - Takla column: 15 kg (height of column ≅ 1.5 m)
    - BLI column: 10 kg (height of column ≅ 1.0 m)
  - Distilled water influent to Gossan; Gossan water influent to Takla; Gossan/Takla water influent to BLI
  - Sample collection at outlet port of Gossan, Takla, and BLI
  - Gossan was wetted and sampled initially, with the Takla being initiated the following week (week 2), and BLI in week 3.

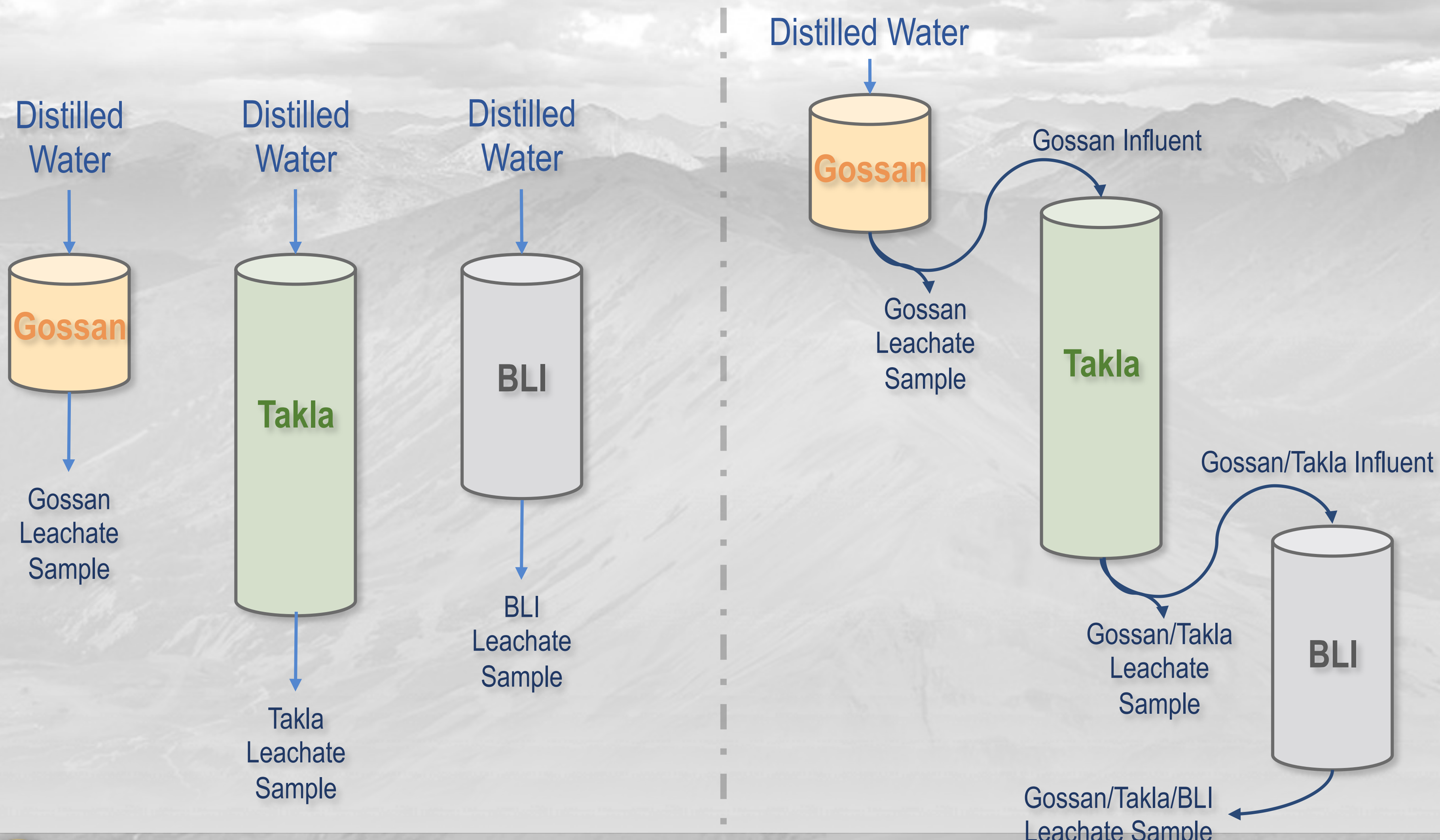
Experimental Design

- Control columns
  - Same setup up as Sequential Columns
    - Gossan column: 5 kg (height of column ≅ 0.5 m)
    - Takla column: 15 kg (height of column ≅ 1.5 m)
    - BLI column: 10 kg (height of column ≅ 1.0 m)
  - Columns set up as trickle leach columns
  - Each column used distilled water as influent
  - Separate sample collection at outlet ports of Gossan, Takla, and BLI

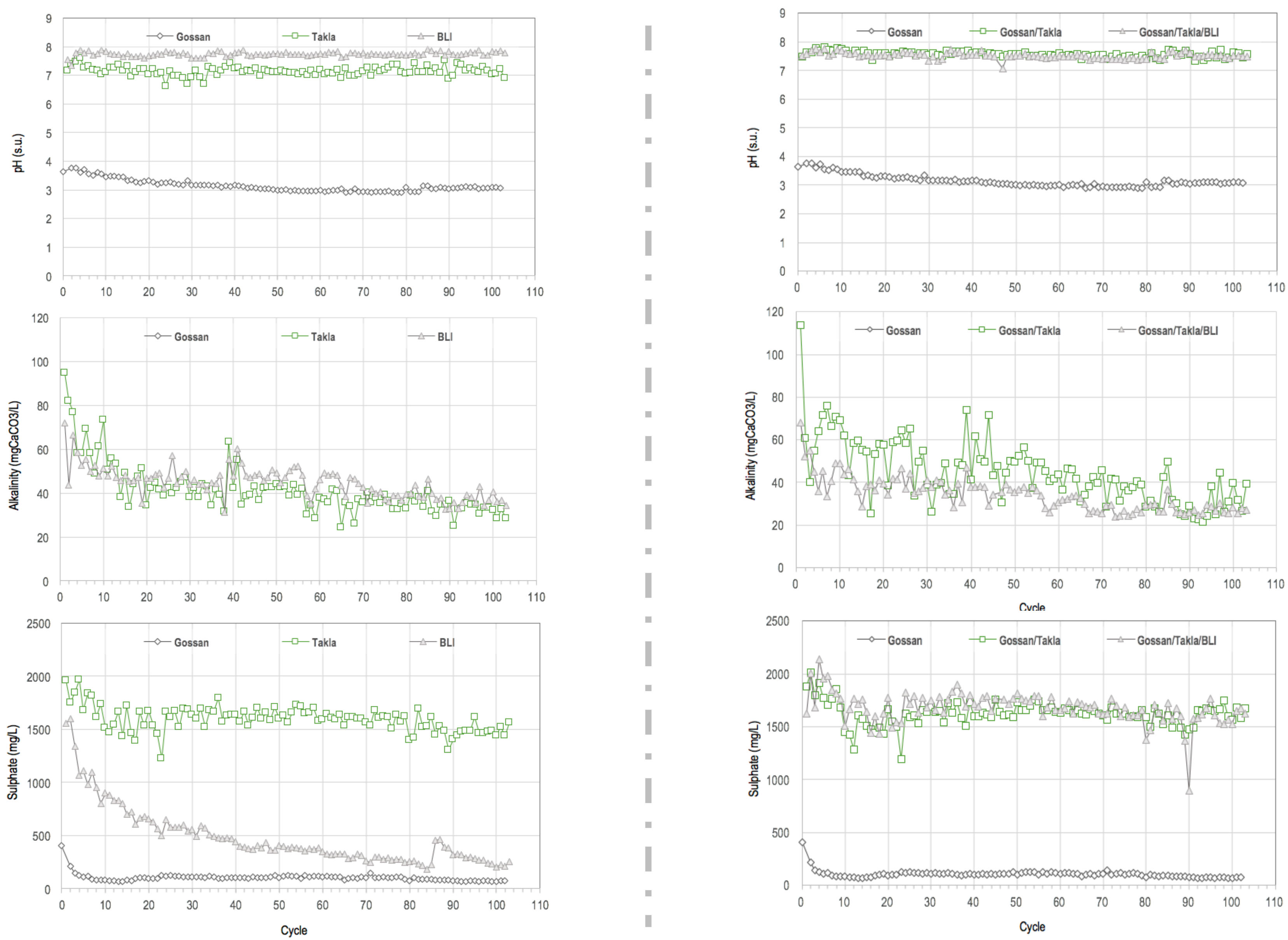
Experimental Design

Control Group

Sequential Leachate Group



Trickle Leach Results



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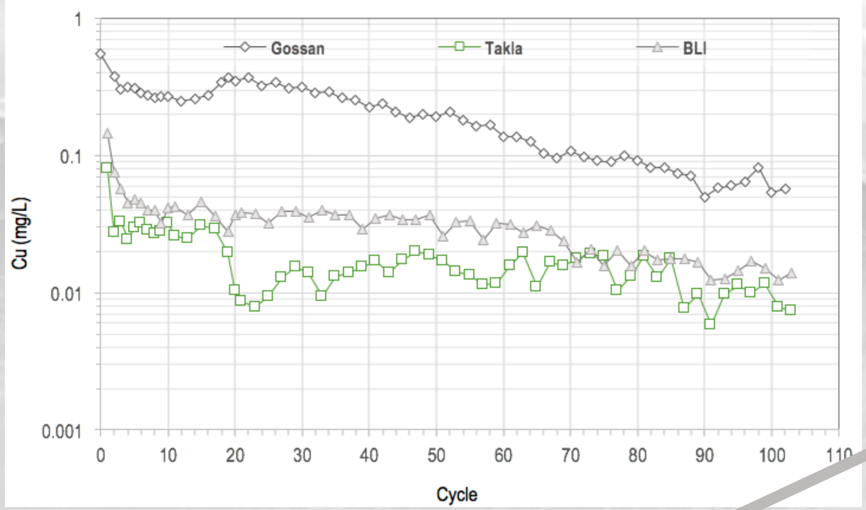
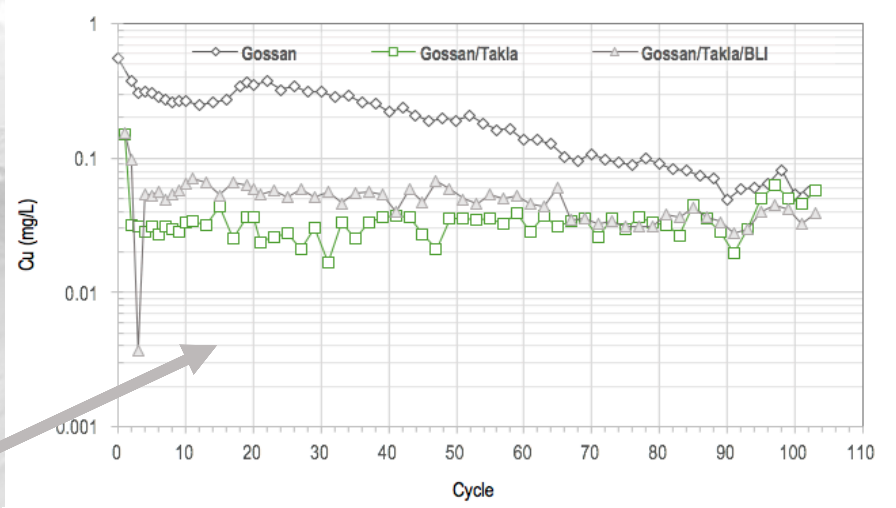
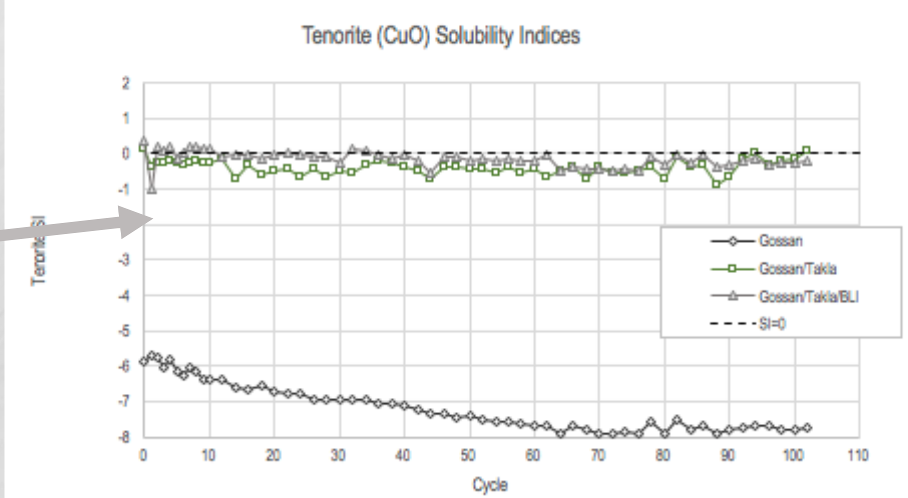
Trickle Leach Results

Control Group



Sequential Leachate Group

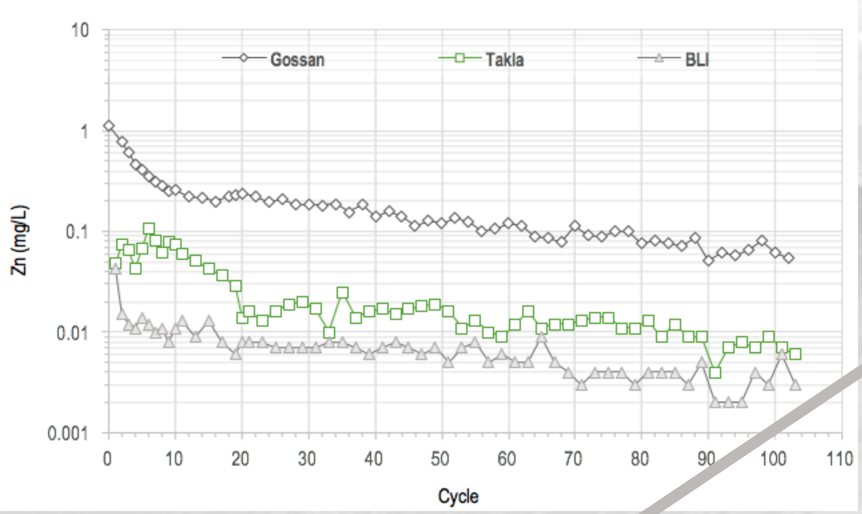




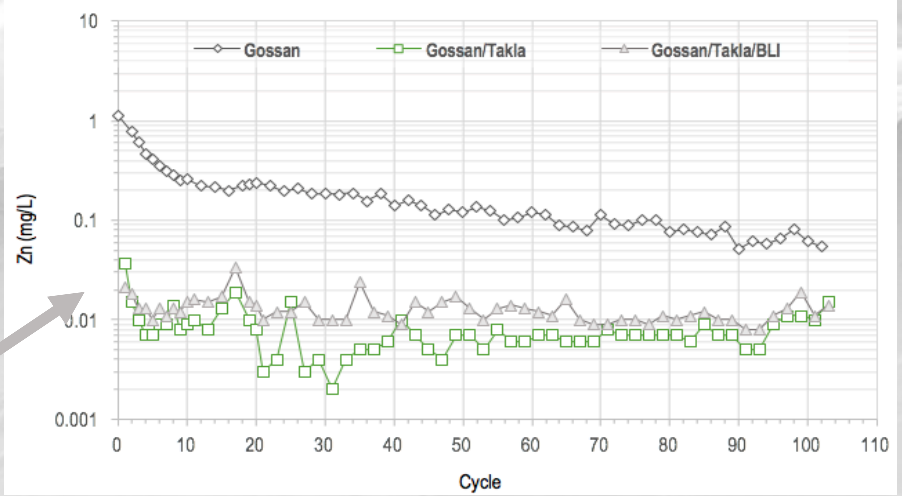
Cu Removal from
Gossan influent Within Takla
Tenorite Solubility Control

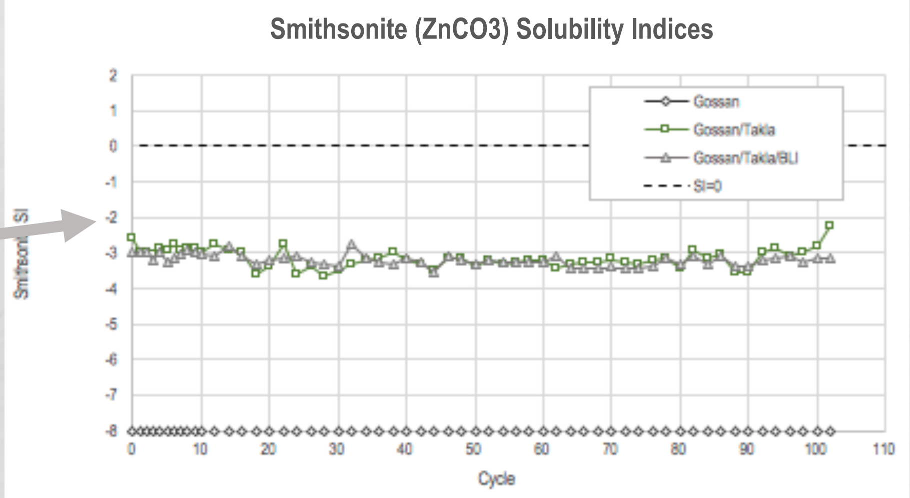
Trickle Leach Results

Control Group



Sequential Leachate Group





Zn Removal from
Gossan influent Within Takla
Smithsonite +/- pH sorption
Solubility Control

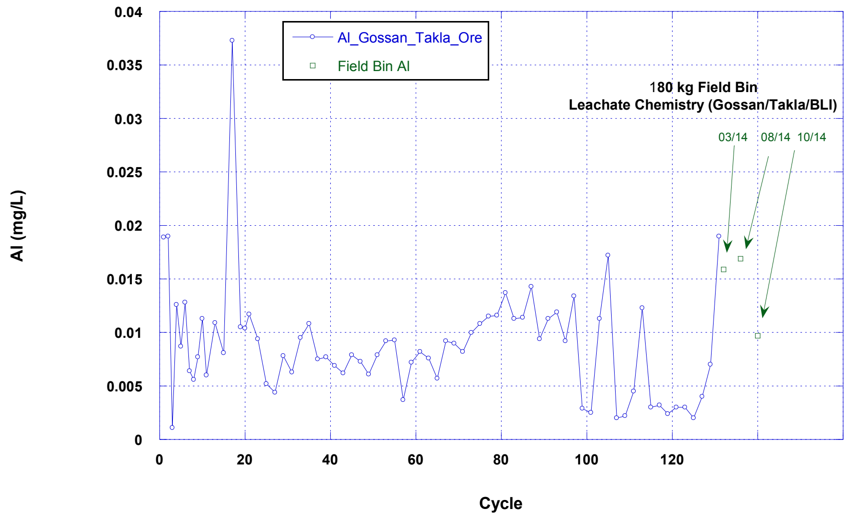
Trickle Leach Results

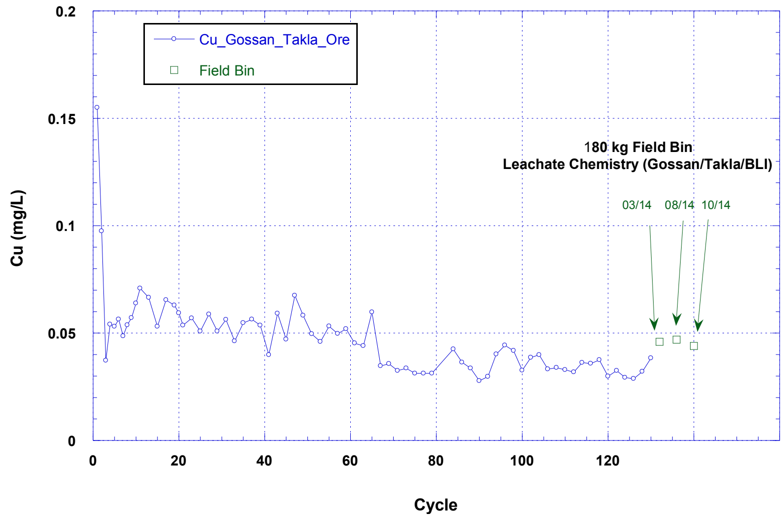
- Sequential Leachate trace element chemistry is slightly elevated over control leachate trace element chemistry
- Effect of acidic influent to the Takla unit is not substantially different than observed in the control over 70 pore volumes
- Trace element concentrations generally greater with acidic, metal rich influent, relative to DW influent
- For some parameters there is an increased metal concentration as leachate passes from Gossan to Takla to BLI
- Some parameters exhibited natural solubility controls (Cu and Zn) as leachate was passed from Gossan to Takla to BLI

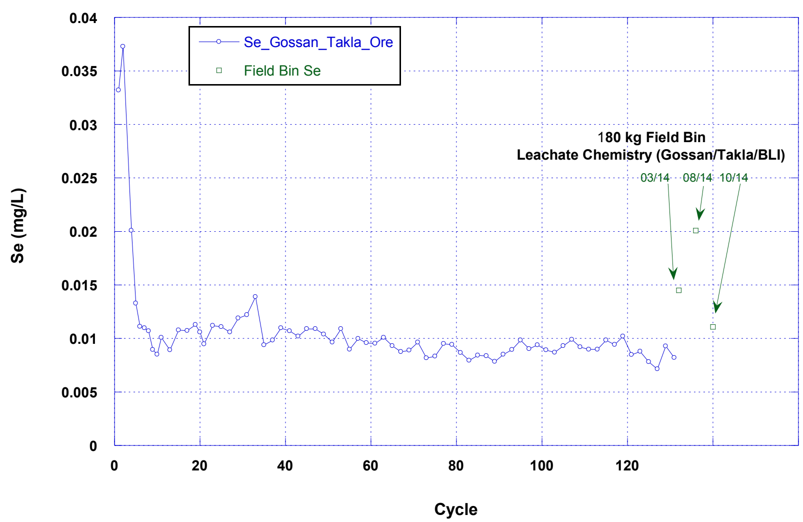
Trickle Leach vs Field Bin

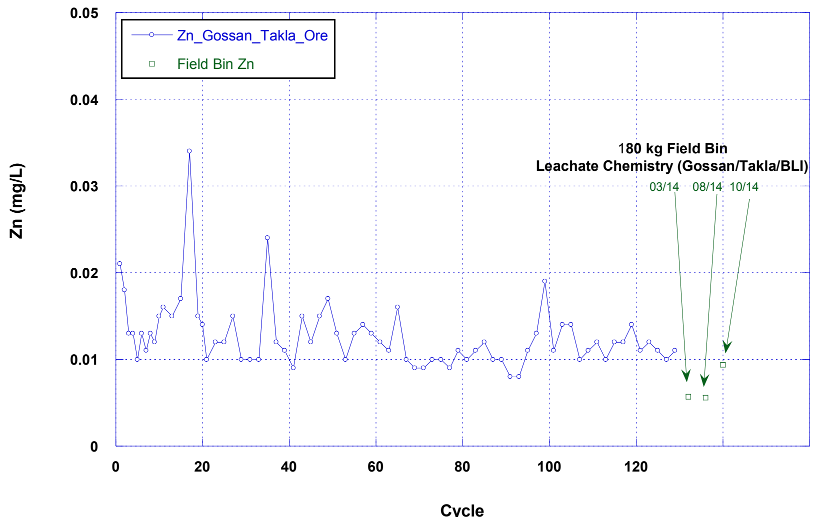
- Field bins set up to determine effect of scale
- Field bin 180 kg material vs Trickle leach (combined) 30kg
- 4 bins (Gossan, Takla, BLI, and Gossan/Takla/BLI)
- Compared results of leachate chemistry

Trickle Leach vs Field Bin









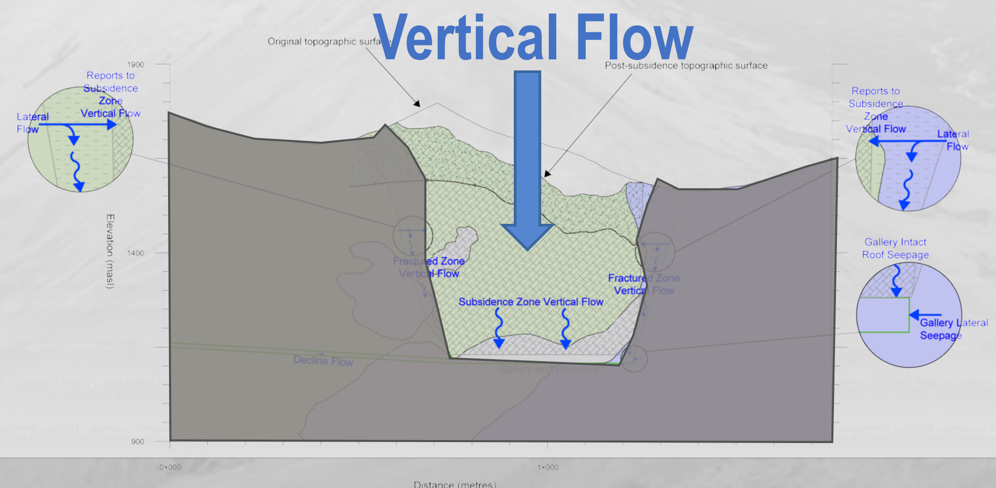
Trickle Leach vs Field Bin

- Combined Gossan/Takla/BLI bin:
  - Exhibited similar leachate chemistry to observed in lab scale tests
  - Regardless of:
    - Volume/mass of rock;
    - Volume of water in contact with rock material; and/or
    - Water:rock ratio.
  - Loading from various scale tests demonstrate similar loads for parameters of concern

Source Term Development

- Subsidence Zone (Contact water from Vertical flow)
  - Pre/feasibility source development – unknown of material interactions
  - Revised – focused kinetic testing provided insight into material interactions
  - Understanding contact leachate interaction provided less uncertainty
  - In general, lower parameter concentration than the summation approach used in the pre/feasibility stage

Parameter	Units	Pre/Feasibility SZ Source Term	Revised SZ Source Term
Sulphate	mg/L	2030	1954
Aluminum	mg/L	1.4	0.013
Copper	mg/L	0.95	0.054
Selenium	mg/L	0.055	0.020
Zinc	mg/L	1.0	0.013



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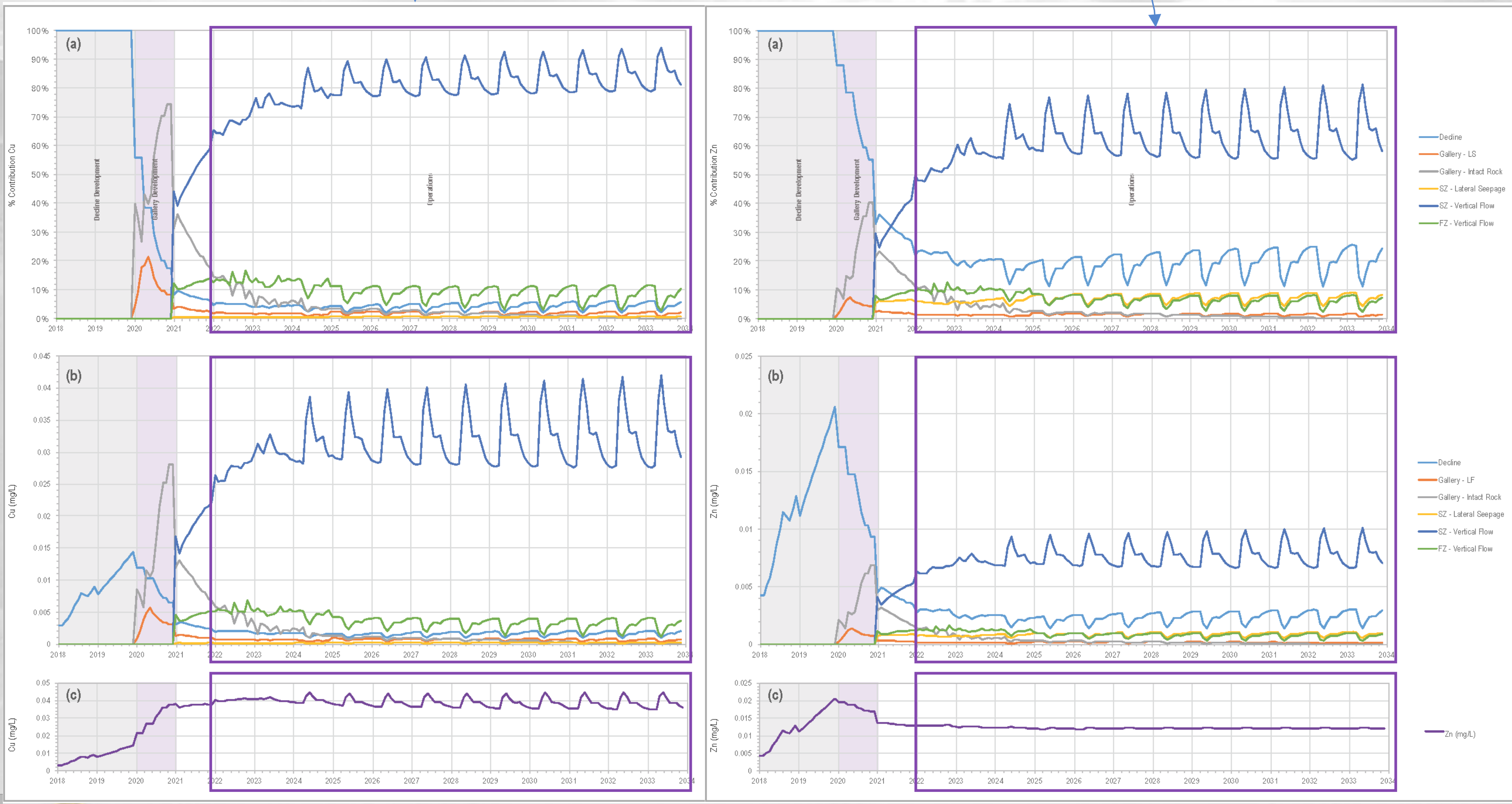
Model results - Overview

Subsidence zone is dominant provider of trace elements



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Closing

- Experimental design is very important:
  - Provides clarity where assumptions may have previously been employed
  - Decreases the amount of assumptions (i.e. assumptions around secondary mineral and minerals solubilities of contact water)
  - In this case provided clarity of solubility controls and potential buffering of acidic contact water by a unit that is considered PAG
  - Decreased the assumptions made by modeling and mixing of solutions in PHREEQC, or based on professional judgement
- Scaling is very important: How does the interaction look under larger scale conditions and with variations in water to rock conditions
- Important to understand the placement of waste materials, in this case left in-situ.
- It's key to understand the overall big picture of the project and its components and how they interact when developing experiments for the development of source terms