Life Cycle Impact Assessment of Metals in Mine Tailings

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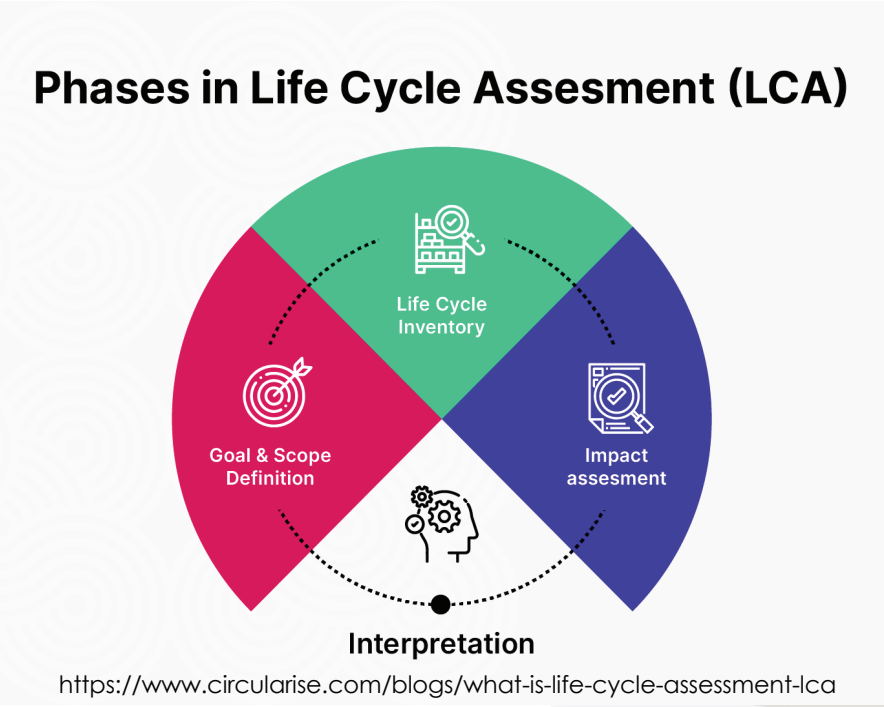
BC MEND ML-ARD Workshop
November 17, 2024
1600-1630

What is Life Cycle Assessment (LCA)?

- Method for evaluating environmental impacts of a product/process/service across its entire life cycle (extraction, production, use, and post-use)
- LCAs are being used in EU regulations for product selection (e.g. Product Environmental Footprint)
- Life Cycle Inventory (LCI): Compilation and quantification of inputs and outputs of a product throughout its life cycle
- Life Cycle Impact Assessment (LCIA): Evaluates the environmental impacts using LCI data and toxicity modeling



Why should the Mining World Care?

- Metals leaching estimates in LCA are unreliable for regulatory use due to poor underlying data in LCI
- LCA of metals are currently dominated by estimates of long-term metals release from mine tailings
- Partially due to many inaccurate assumptions made on mechanisms for metal(s) generation and transport within tailings storage facilities (TSFs)
- And due to the unrealistic time frames for assessment (*e.g. long term* = 60,000 years)

from O'Kane and Straker 2014

What do we Need To Do?

- A multi-faceted approach is needed:
  1) Compliant with LCA standard practice
  2) Includes mass-balancing
  3) Based on site-specific data and models
  4) Considers tailings as a resource
  5) Uses realistic and practical timeframes that are consistent across goals, scope, LCI models and LCIA methods

- Conceptual model - using foundational elements of TSFs and a workable number of archetypical scenarios: e.g. climate; geologic condition; hydrogeologic conditions

- Industry can support by creating relevant databases for the archetypes

from O'Kane and Straker 2014

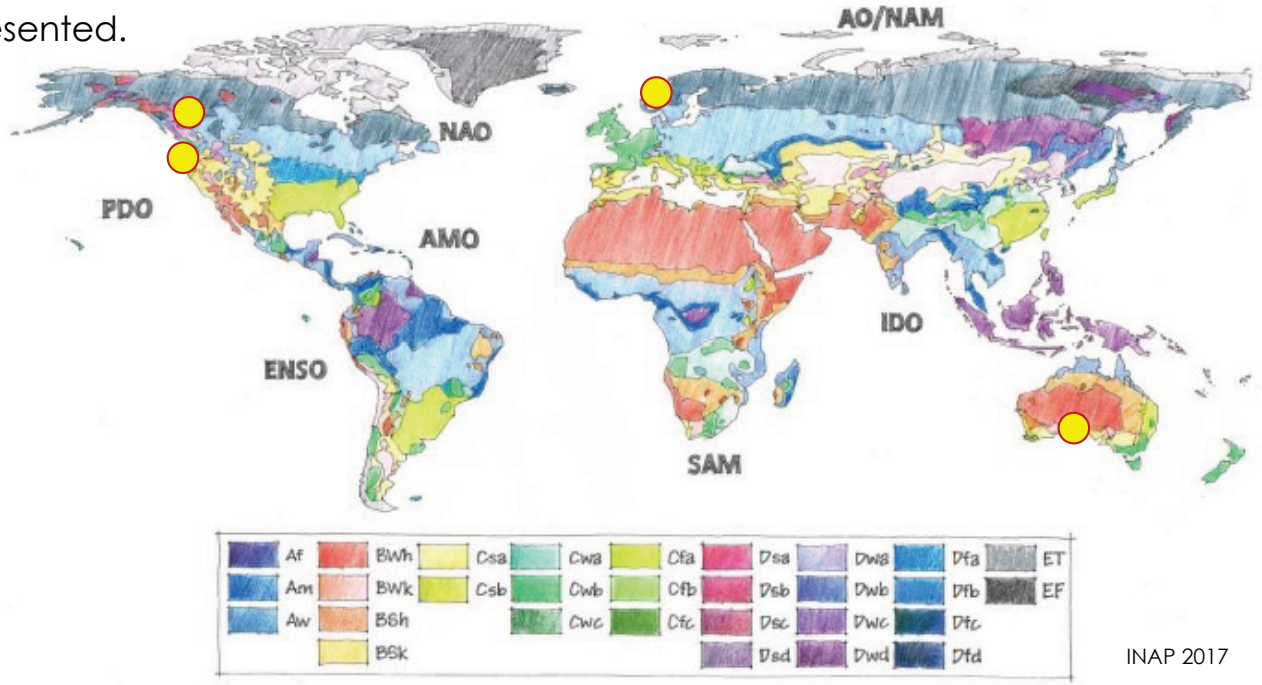
Focusing our Discussion for Today…

- Project: The Conceptual Model was applied to **Three Case Studies**
  - **Today's focus:** One Case Study is presented.

1) Faro Mine Remediation Project
   - Lead-Zinc-Silver
   - Sedimentary Exhalative (SEDEX)

2) Case Study #2
   - Copper-Gold-Silver
   - Porphyry Copper

3) Case Study #3
   - Iron-Sulphur (pyrite and pyrrhotite)
   - Pyritic Meta Sedimentary

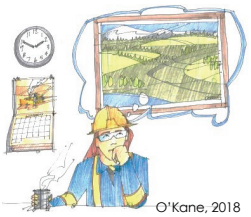


INAP 2017

…the *'destination'* before the *'journey'*

- **…from an LCA Perspective**

  "…there is a need to have confidence with tailings metal leaching rates (and extent), most likely aggregating characteristics from several different TSFs in different locations and climate…"



O'Kane, 2018

- **…from an ML-ARD Perspective**

  "…there is a need for robust (deep) conceptualization for TSF closure plans as they evolve from a 'closure plan' to 'a closure project' to be costed and/or executed …"

O'Kane, 2018

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the evolution of a closure plan to a project needs to occur with sufficient time to fully develop the project from concept through FS and detailed engineering prior to mining ceasing. This could be as much as 5 years prior. And this deep conceptualization needs to incorporate appropriate data, information and knowledge that must be collected, evaluated, understood and utilized, throughout the operating phase of the mining project

…the *'destination'* before the *'journey'*

- **…from an LCA Perspective**

  "…there is a need to have confidence with tailings metal leaching rates (and extent), most likely aggregating characteristics from several different TSFs in different locations and climate…"

- **…from an ML-ARD Perspective x 2**

  "…there is a need for robust understanding for material risk wrt to TSF design, to inform on investment decisions, such as PEAs and/or NI-43-101s, and likely Project Descriptions, before, perhaps a PFS (too late!) and for sure an FS…"

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that "first" model is, in the end, inevitably assumed to be 'the right' path to follow. It is extremely challenging to change.

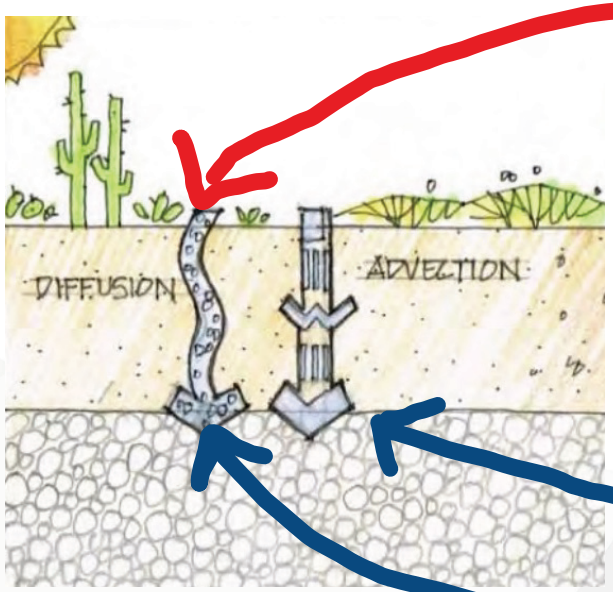
Hence, you better get it right.

Everything after that is more or less the "project development meat grinder"

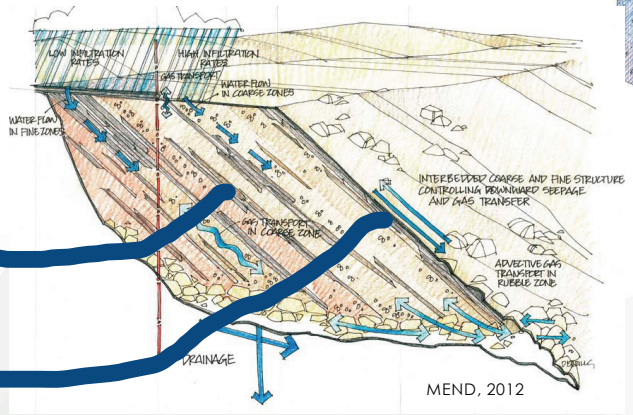
…now …before we go on our 'journey'

Tailings Storage Facilities (TSFs) vs Mine Rock Storage Facilities (MRSs)

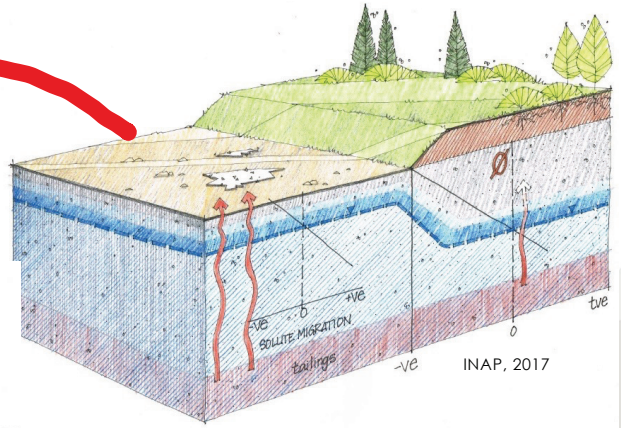
Understanding Gas Transport… Foundational Differences…



INAP, 2017



MEND, 2012

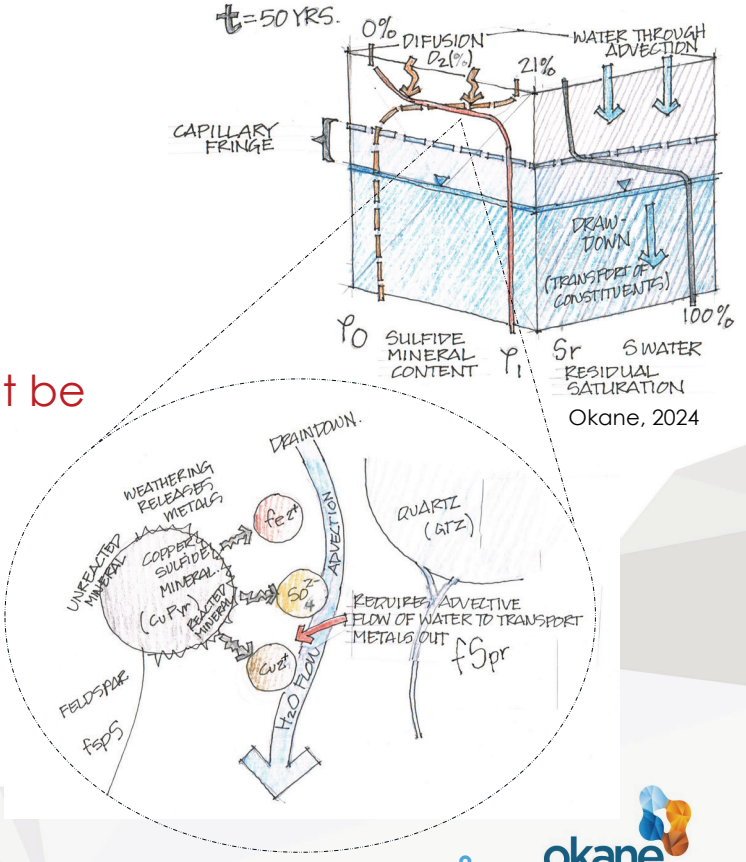


INAP, 2017

…now …before we go on our ‘journey’

- **Focus of the Project**
  - Evaluate three TSFs using the Conceptual Model
  - **Goal:** Show that a simple robust approach can demonstrate two key concepts:

1) Presence of metals in mineral form within tailings must not be taken as being definitive to mobilize within tailings, even when considering a timeframe of tens of thousands of years into the future



Okane, 2024

Focusing our Discussion for Today…

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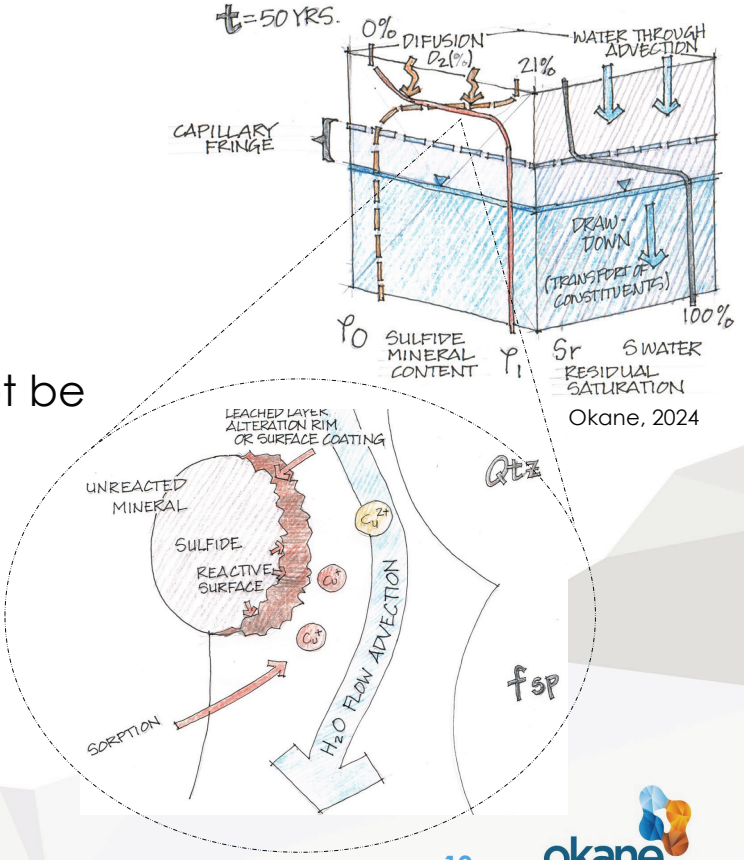
  - Evaluate three TSFs using the Conceptual Model
  - **Goal:** Show that a simple robust approach can demonstrate two key concepts:

1) Presence of metals in mineral form within tailings must not be taken as being definitive to mobilize within tailings, even when considering a timeframe of tens of thousands of years into the future
2) It is not definitive that metals released from their mineral form within tailings, will be released into the environment



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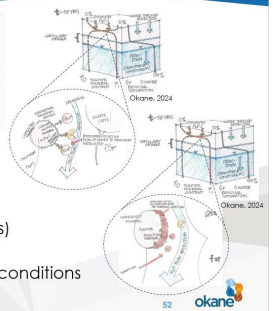
Implications for Considering these Two Concepts…

Implications for Considering these Two Concepts…

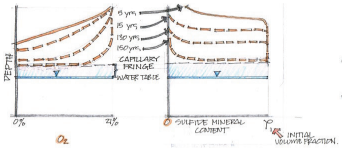
- ***…from an LCIA Perspective***

- Temporal Scale…
  i.e., long-term of 60,000 years and short-term 100 years
  vs.
  LT: >100 years and up to 200 years
  ST: focus on Ops and Closure Works (<50 years)
- Metal Leaching Estimates…
  Current approach not representative of field conditions and… is their a different, 'better', way…?

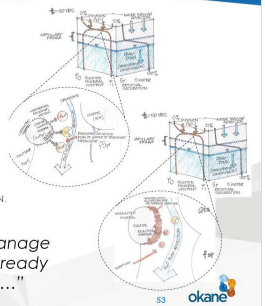


Implications for Incorporating these Two Concepts…

- ***…from an ML-ARD Perspective***



- …for me
  "…why would I construct a cover system to manage oxygen when the tailings themselves are already self-limiting with respect to oxygen ingress?…"



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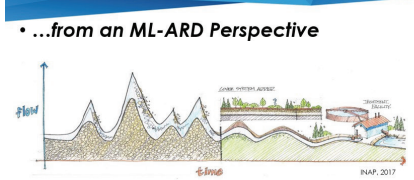
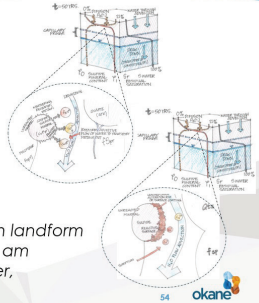


- …further
  "…perhaps I should be 'more' concerned with landform surface water quality, and consider that if I am concerned with longer-term seepage water, is there a better 'way'?…"



Implications for Incorporating these Two Concepts…

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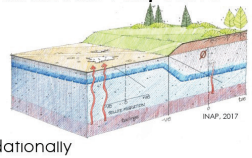
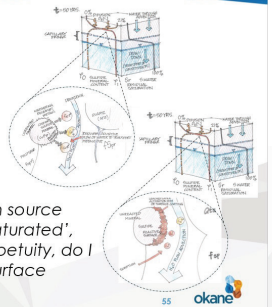


- …foundationally
  "…if I choose to manage ML-ARD risk through source control arising from 'keeping the tailings saturated', by maintaining a 'high' water table in perpetuity, do I appreciate I will be managing landform surface water in perpetuity?…"



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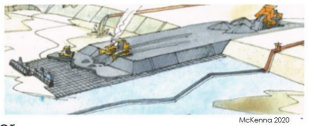
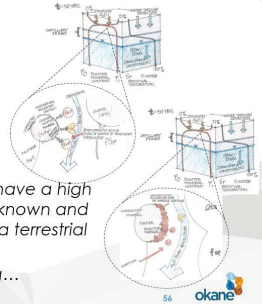


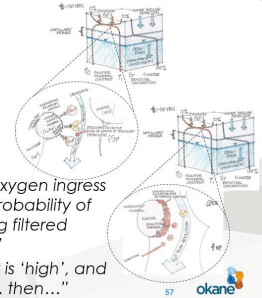
- …further
  "…have I considered that when I choose to have a high water table within my tailings landform, a known and 'should be expected' risk is placement of a terrestrial cover system on the landform?…"
  "…it is almost always much more challenging… … read: 'higher cost' than thought…"



Implications for Incorporating these Two Concepts…

- ***…from an ML-ARD Perspective***

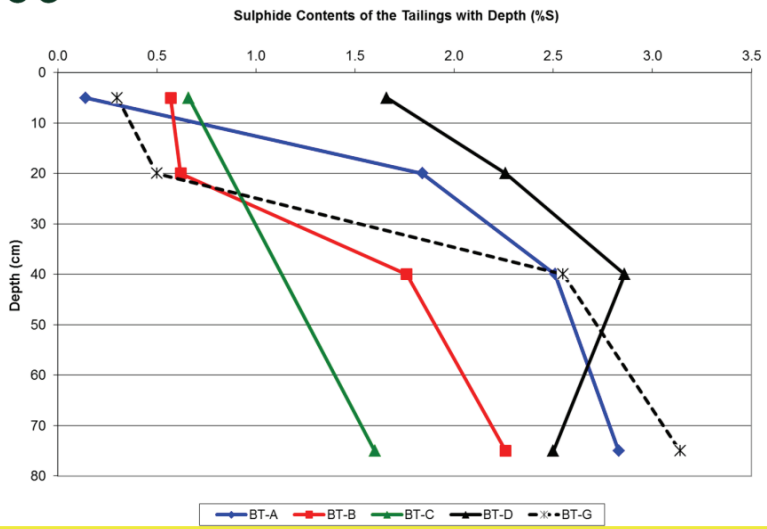
- …one more…
  "…if oxidation of tailings is self-limiting, and oxygen ingress is diffusion controlled, what really is the probability of the entire profile of a landform containing filtered tailings oxidizing throughout its profile?…"
  "…if it is my belief that the above probability is 'high', and the consequence effect(s) problematic… then…"



Oxidation of Sulphides in Tailings is Self-Limiting…

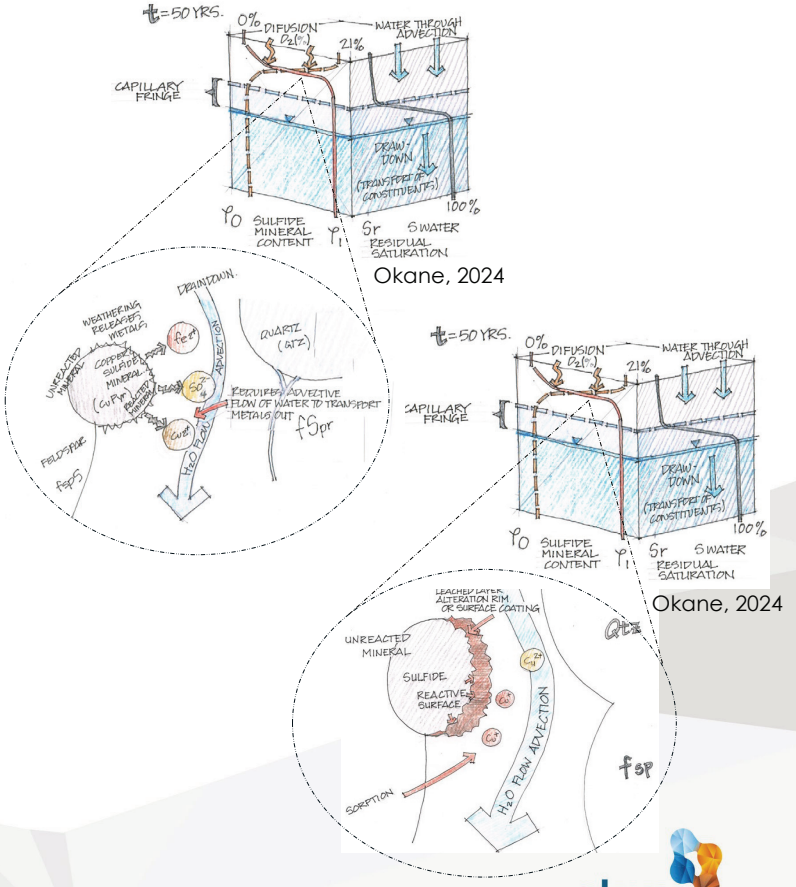
- ***…we can measure this***

Sulphide Depletion in Tailings 2009



Observed sulphide depletion much slower than predicted

Nicholson et., 2011



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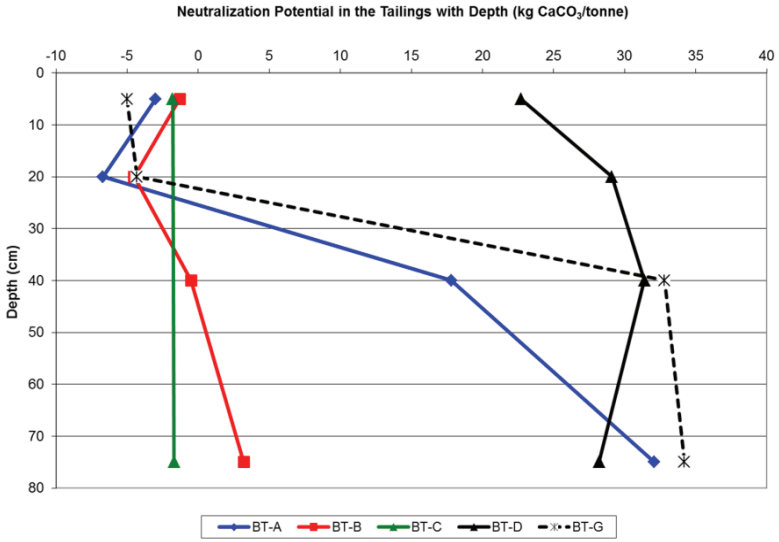
NP Depletion in Tailings 2009



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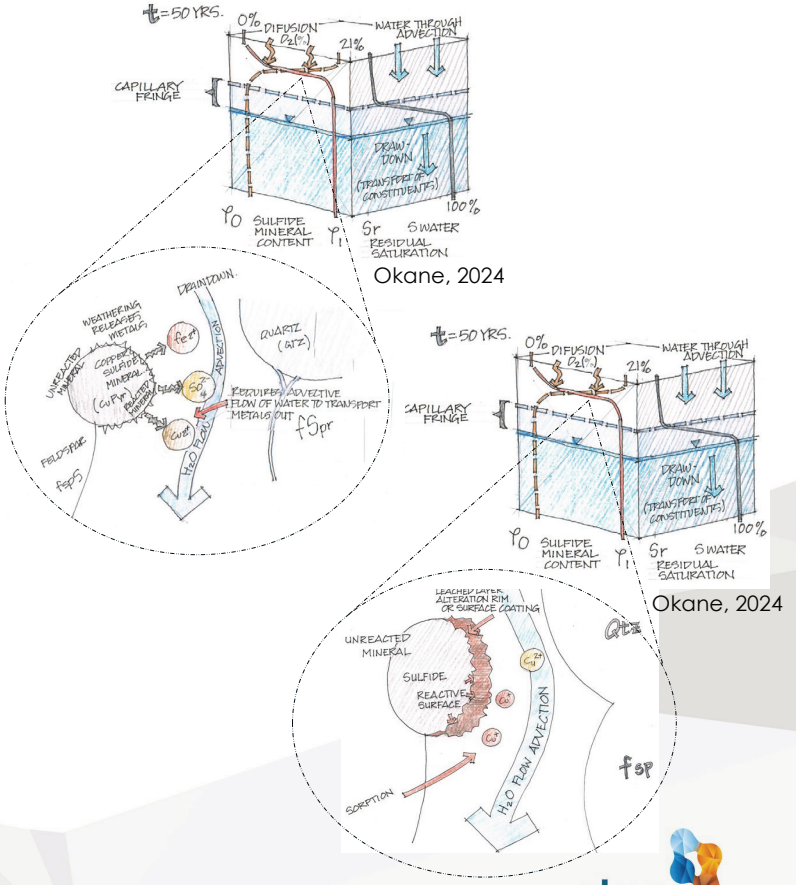

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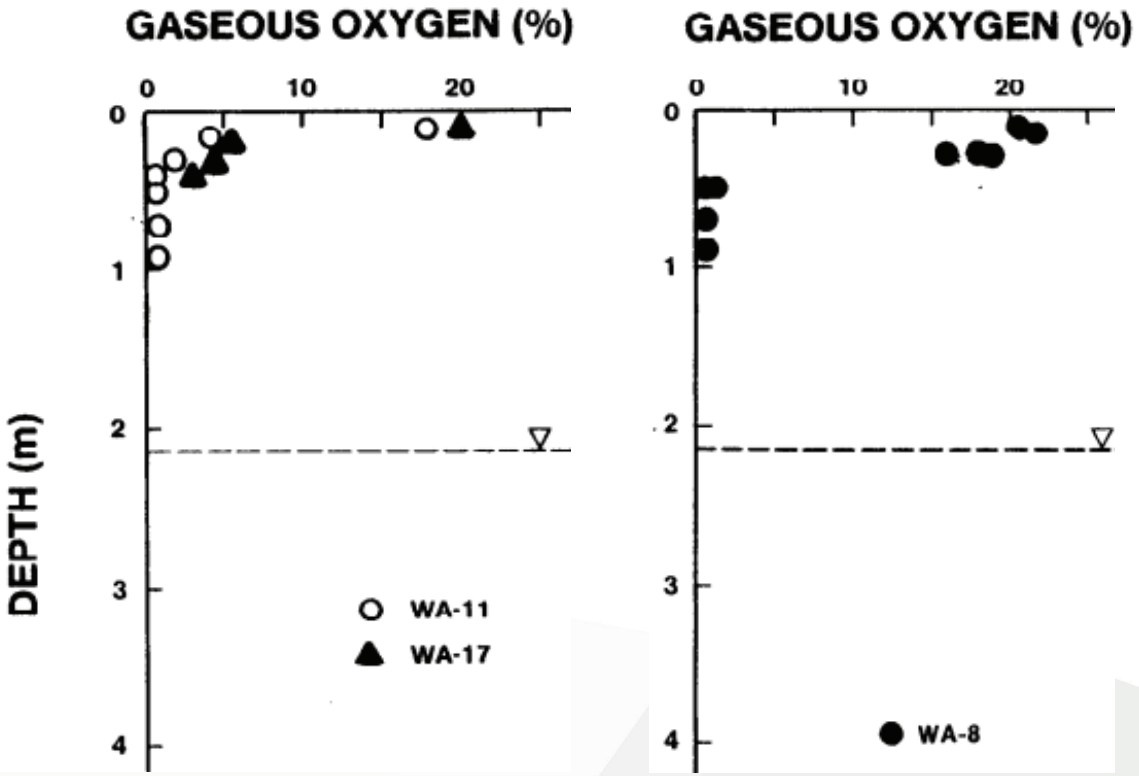
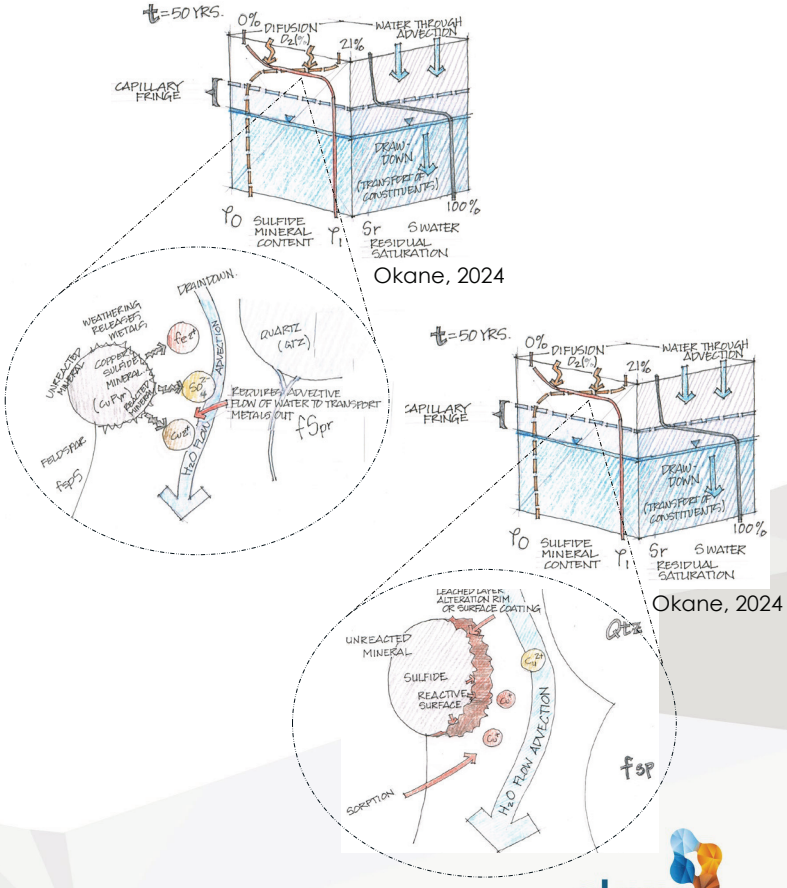


Blowes and Cherry, 1996



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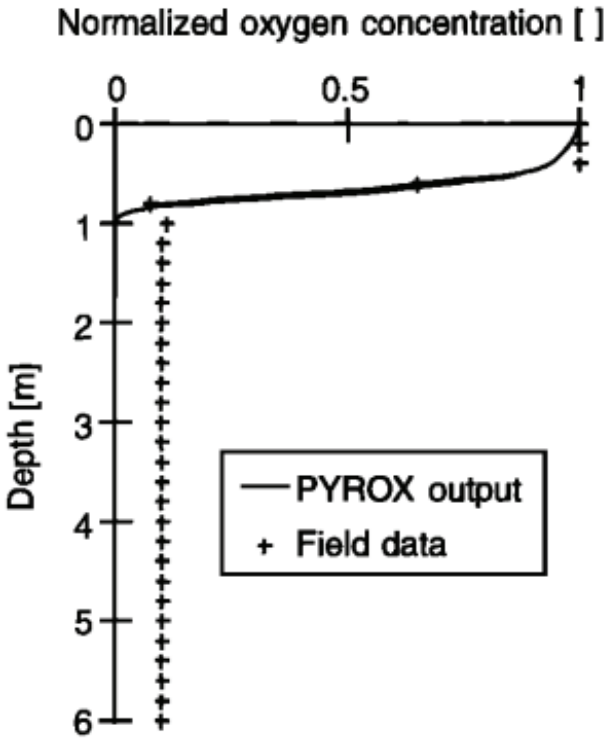
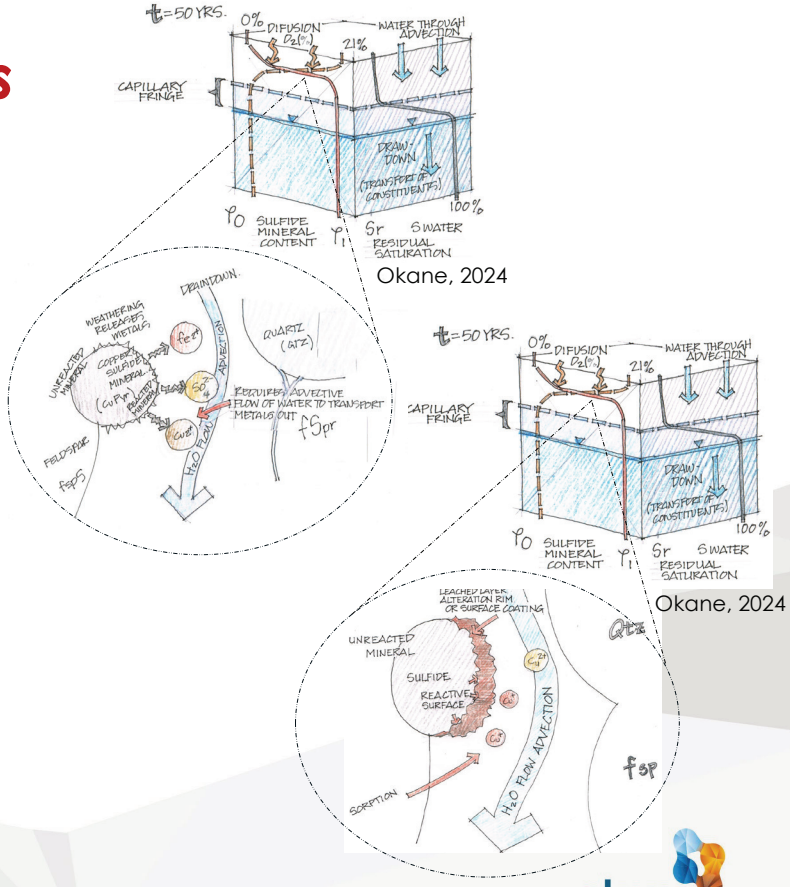
Oxidation of Sulphides in Tailings is Self-Limiting…

- ***…we can measure this*** ***…and model this***



Wunderly et., 1996



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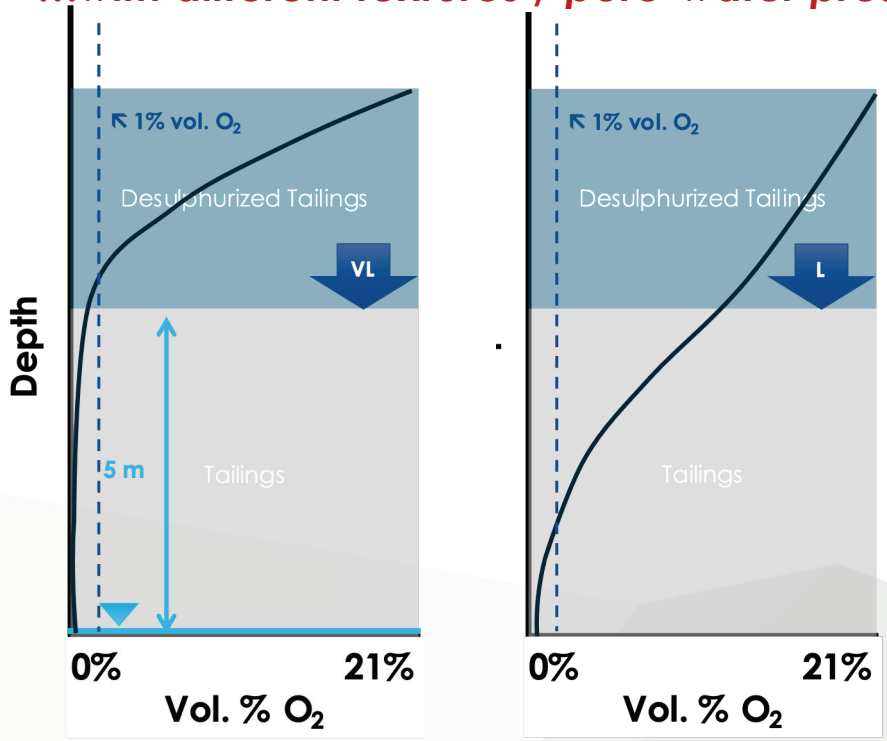
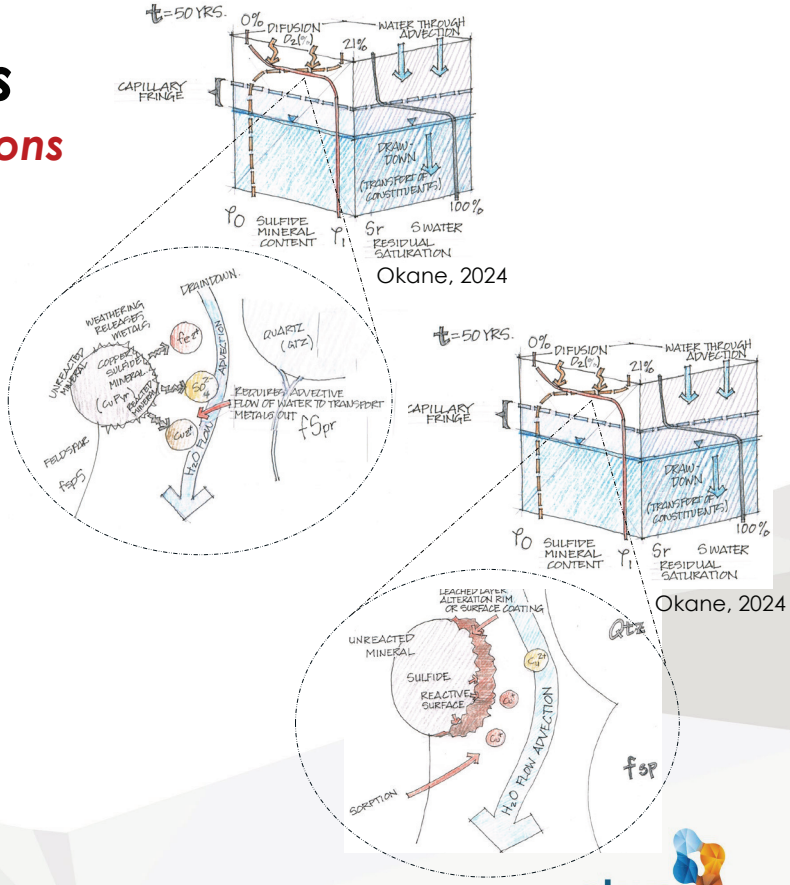
Oxidation of Sulphides in Tailings is Self-Limiting…

- *…we can measure …and model this*

…with different textures / pore-water pressure conditions

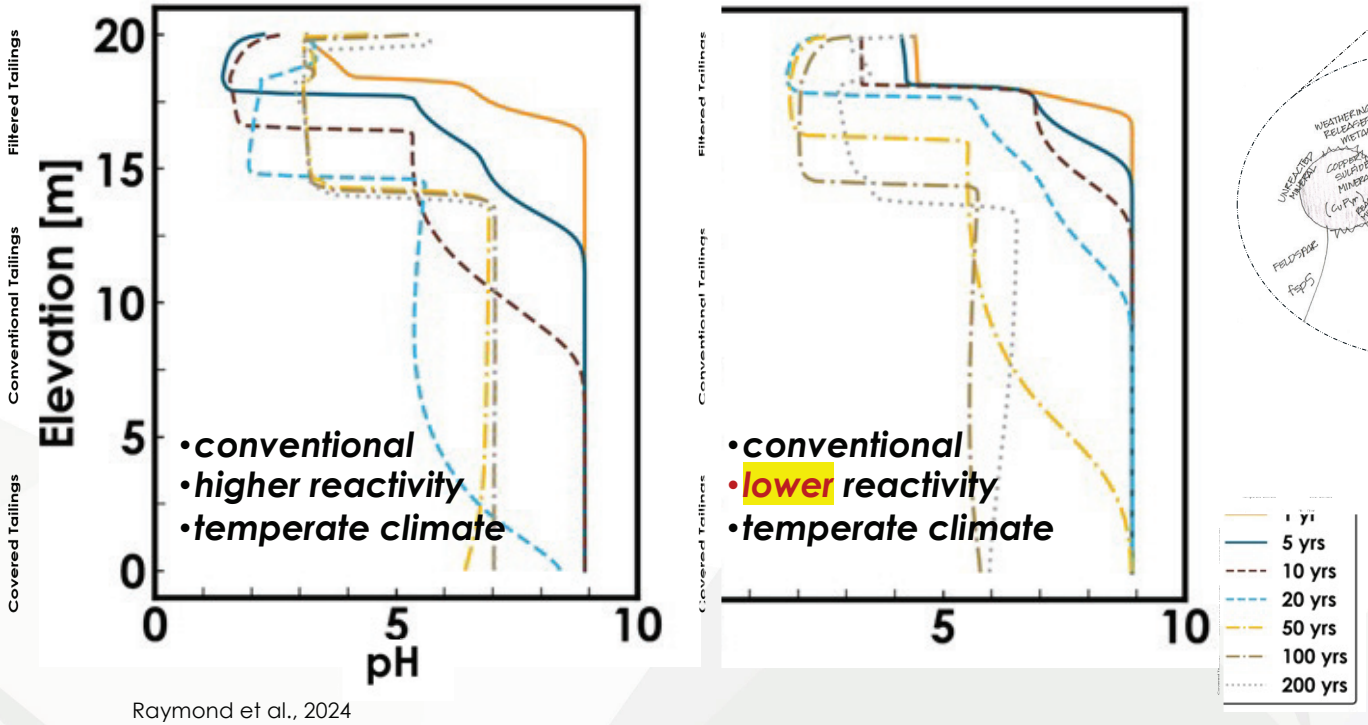


Okane, confidential client information

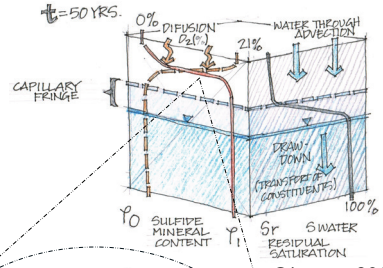


Oxidation of Sulphides in Tailings is Self-Limiting…

- ***…we can measure*** ***…and model this***
  - ***…with different S% / deposition method / climate, over time***



Raymond et al., 2024



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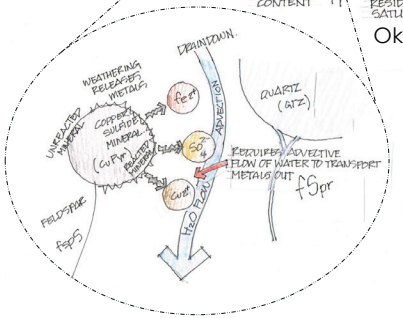

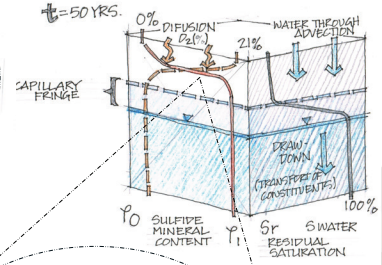

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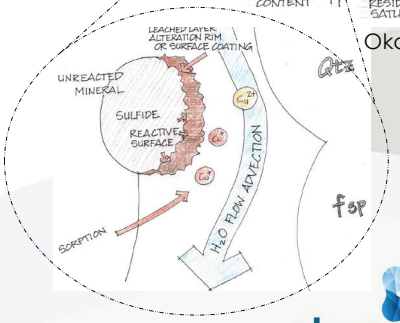

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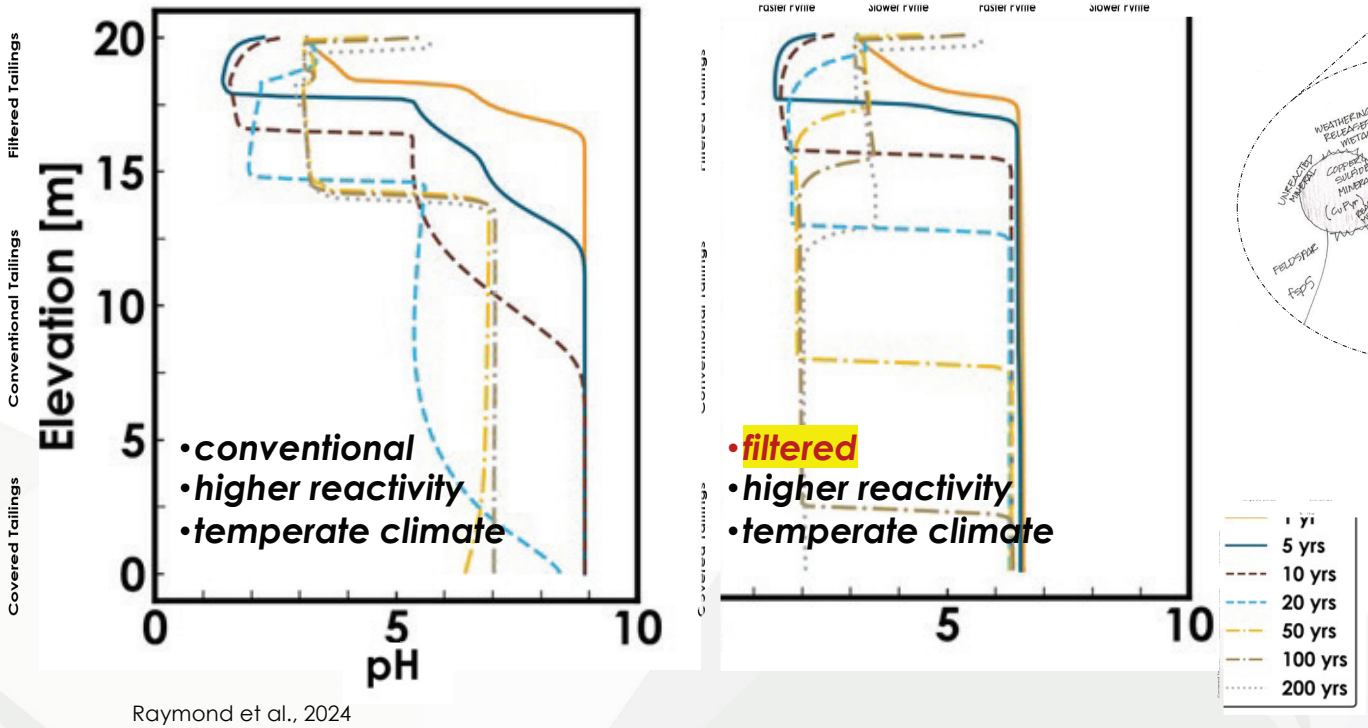

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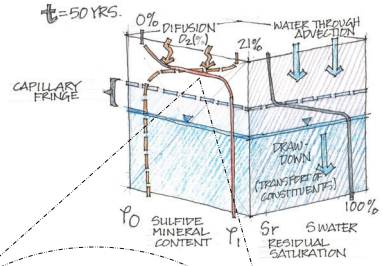

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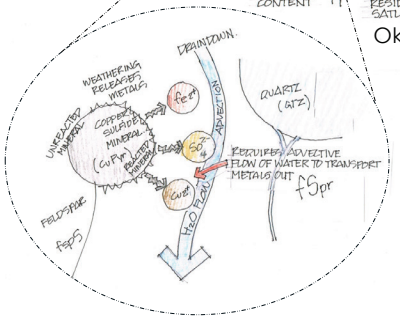

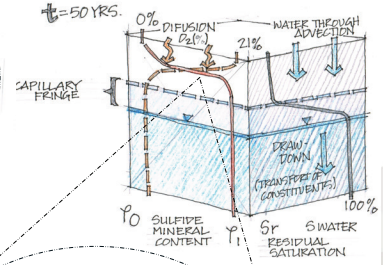

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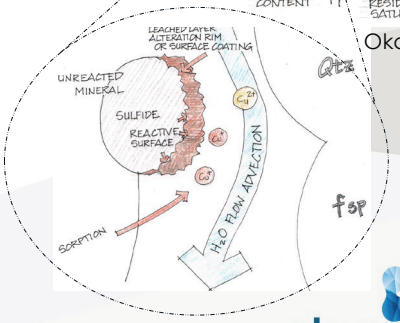

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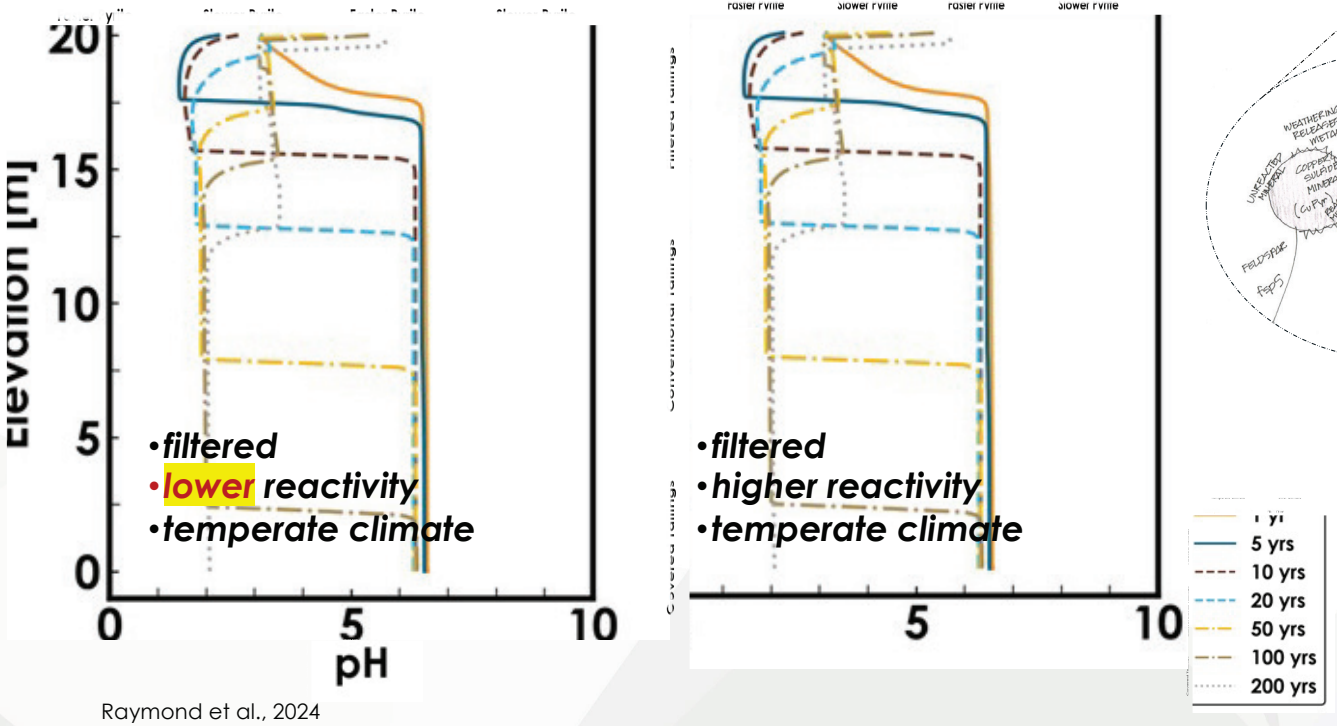

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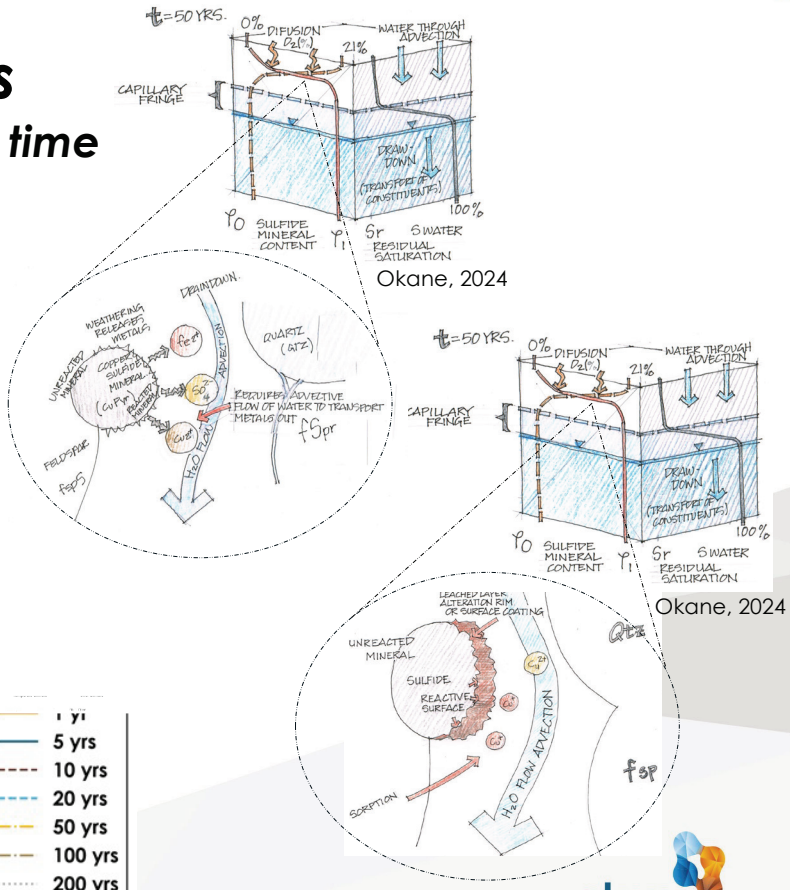

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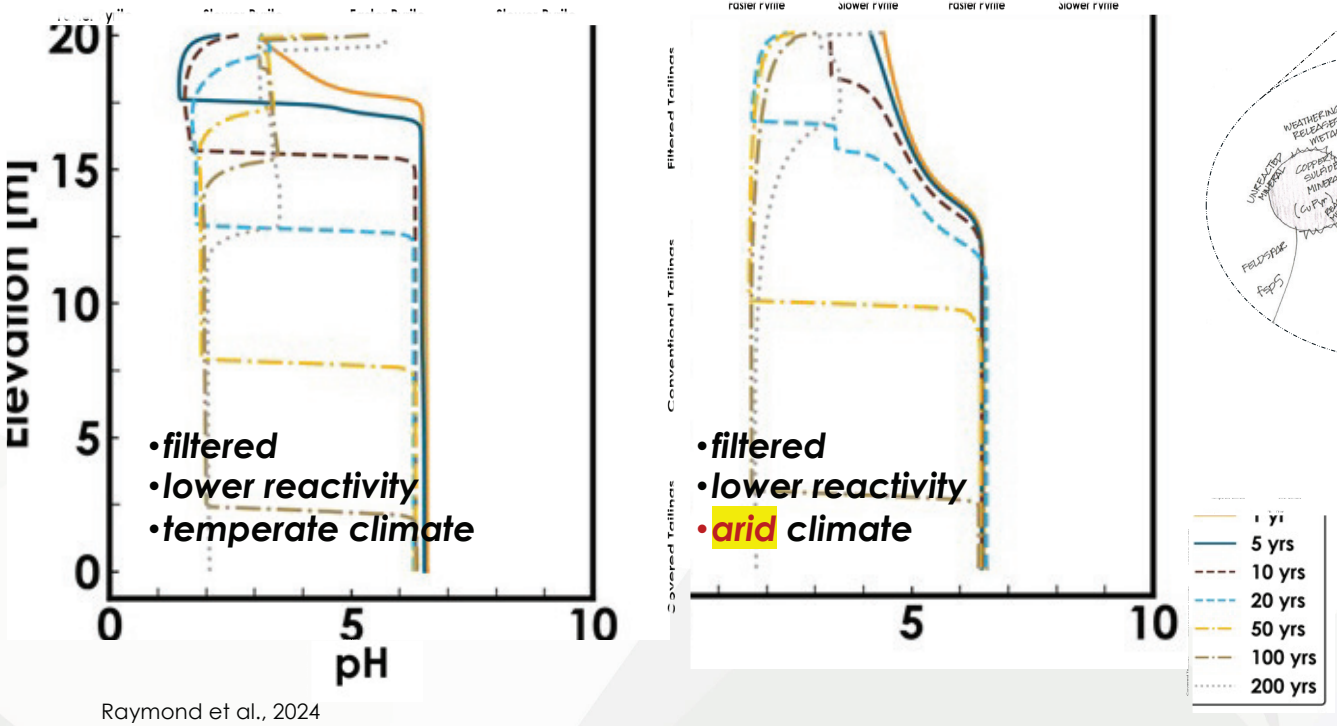

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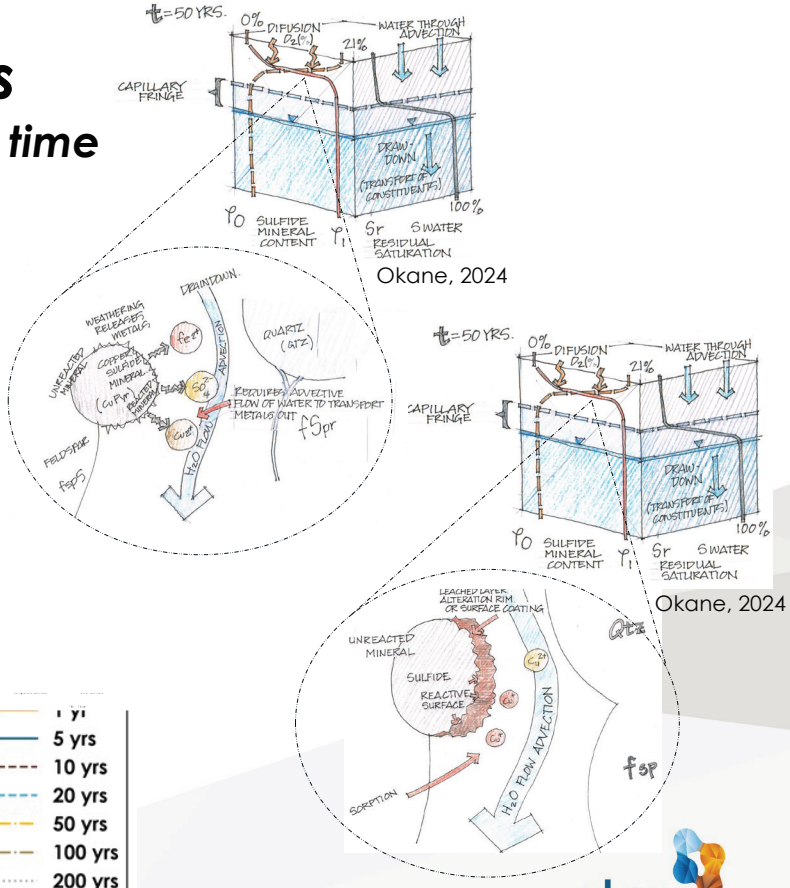

Okane, 2024

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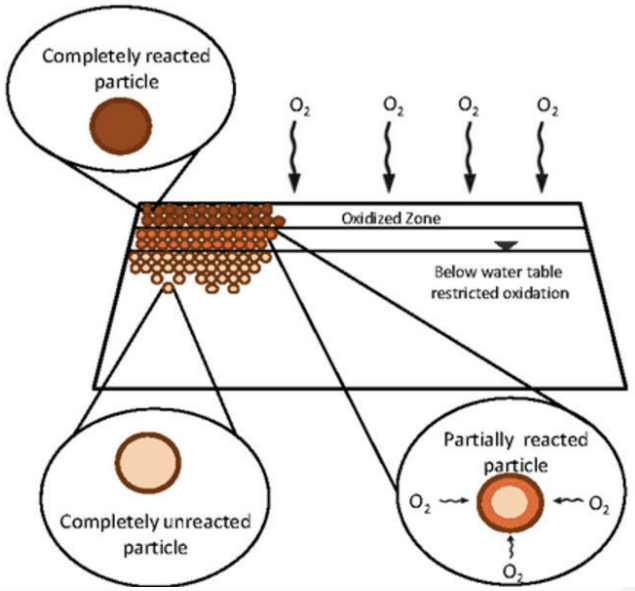
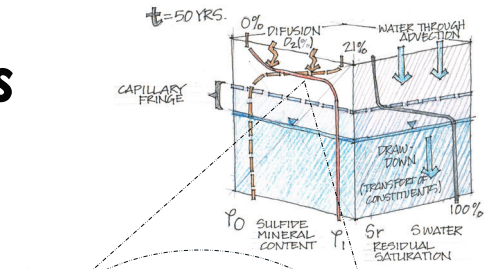
Oxidation of Sulphides in Tailings is Self-Limiting…

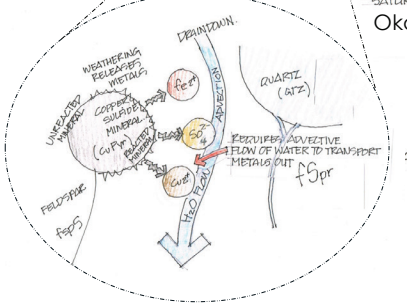
- ***…we can measure …and model this***
  - ***…it is in our guidance documents***

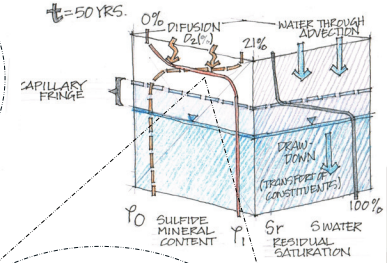


GARD Guide, www.inap.com.au, accessed Nov 15, 2024



Okane, 2024





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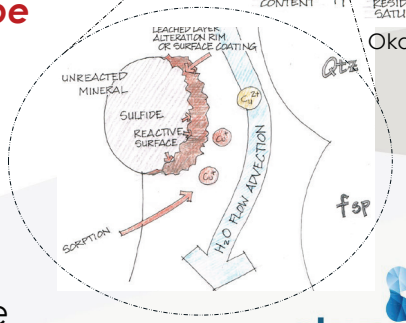
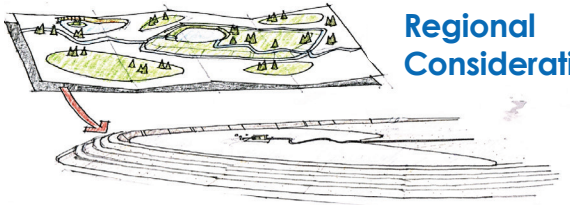


*"…at some point in time, **a steady state may be reached**, governed by the rate of oxygen consumption and by the rate of oxygen transport and replenishment…"*

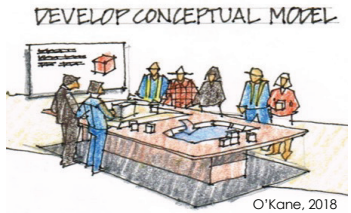
"…the shrinking core model has been successfully to simulate the observed advancement of an oxidation front in mine processing tailings…"

Conceptual Model Foundational Components

Define the TSF system (model inputs)



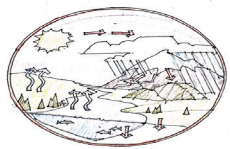
Regional Considerations



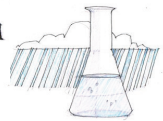
O'Kane, 2018

How is it Built?

Apply to the TSF System (model outcomes)



Water Balance



Geochemistry

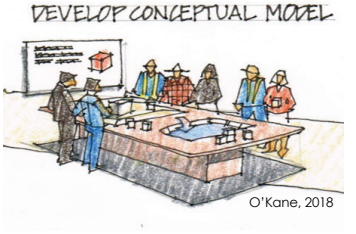
Climate first

How something is built (all materials going in, how they evolve, solids content, etc.)

Water balance

Chemistry

Conceptual Model Foundational Components



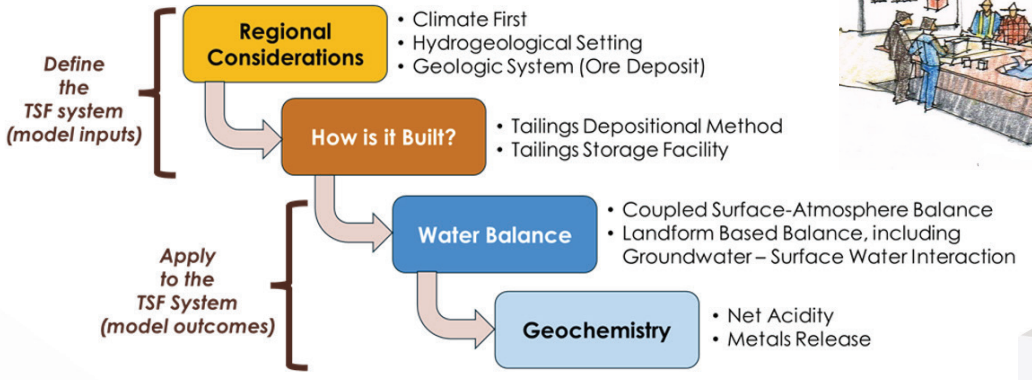


Figure 2.8: Flow diagram for processes captured in conceptual model.

okane

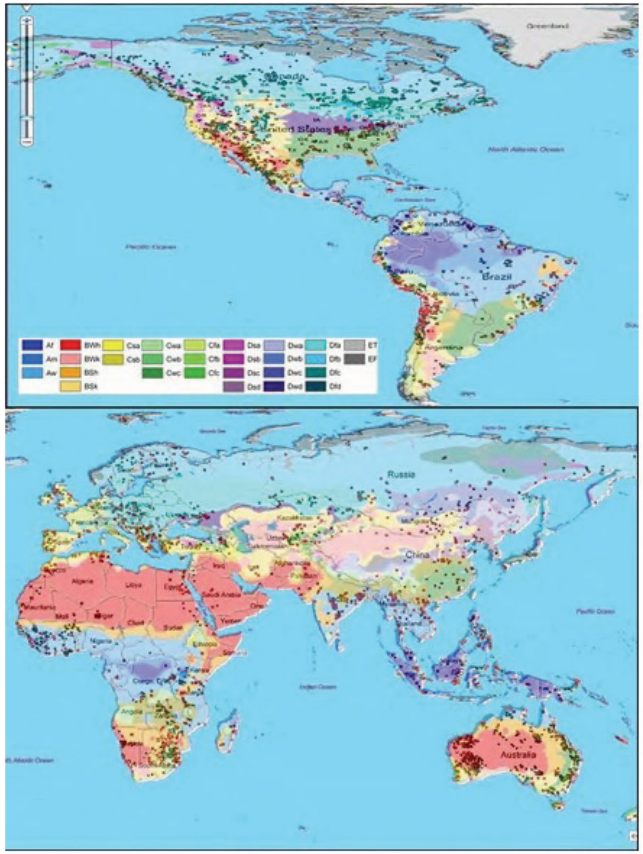
Climate first

How something is built (all materials going in, how they evolve, solids content, etc.)

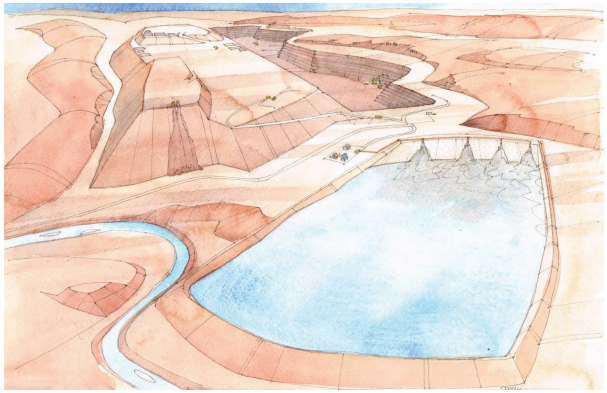
Water balance

Chemistry

Regional Considerations – *'archetypes'* Climate



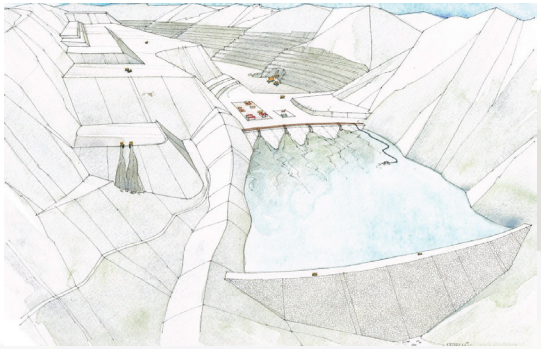
INAP, 2017



O'Kane, 2020

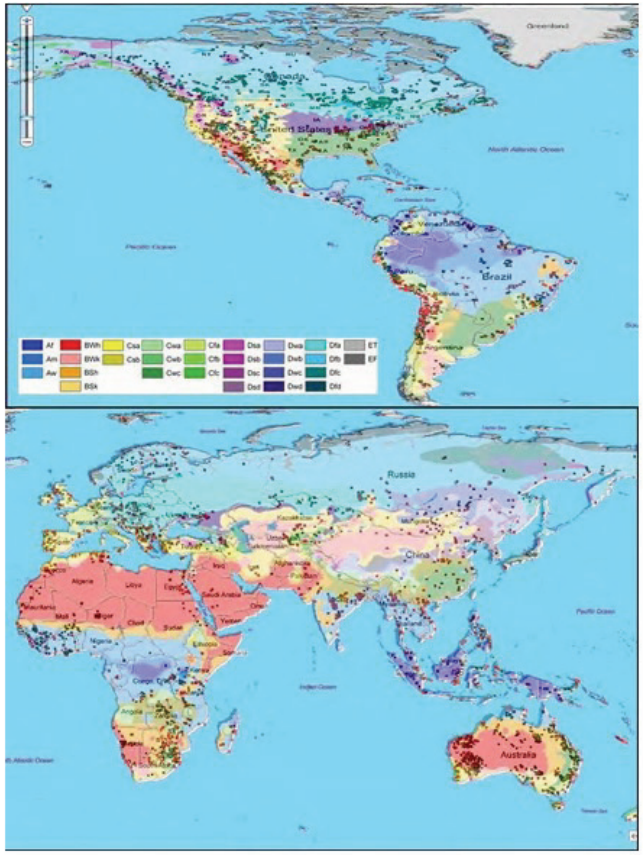
- Arid?
- Temperate?
- Tropical?
- Cold?

O'Kane, 2020

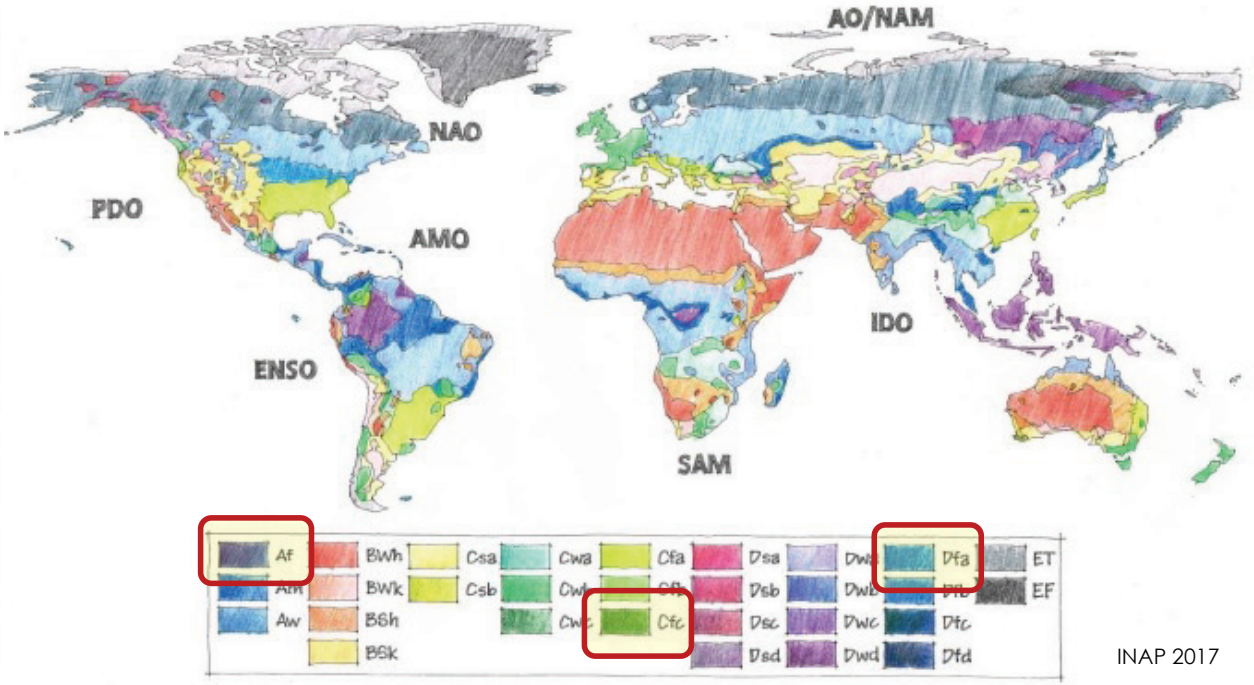


O'Kane, 2020

Regional Considerations – *'archetypes'* Climate



INAP, 2017



INAP 2017

- Seasonality of Temperature and Precipitation?
- ***Accuracy vs Precision***

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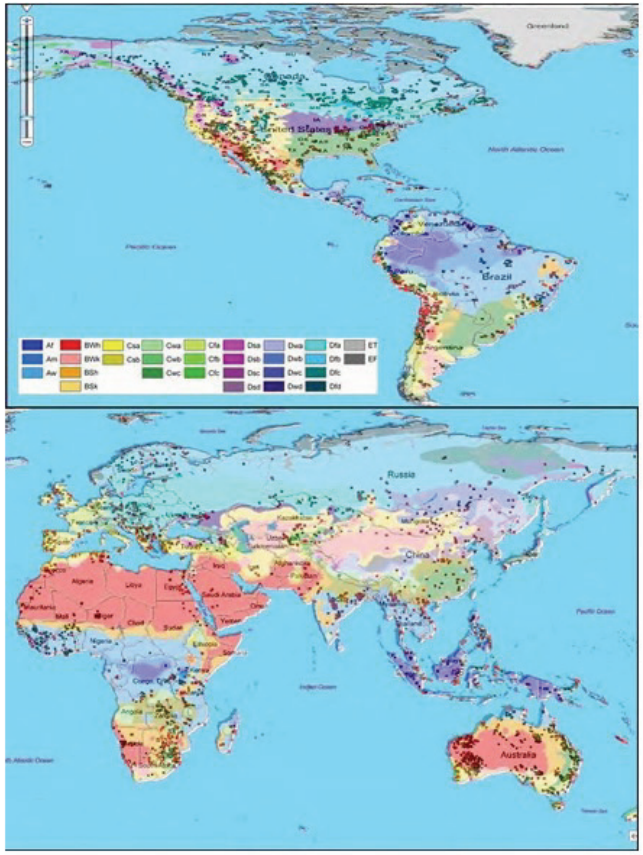
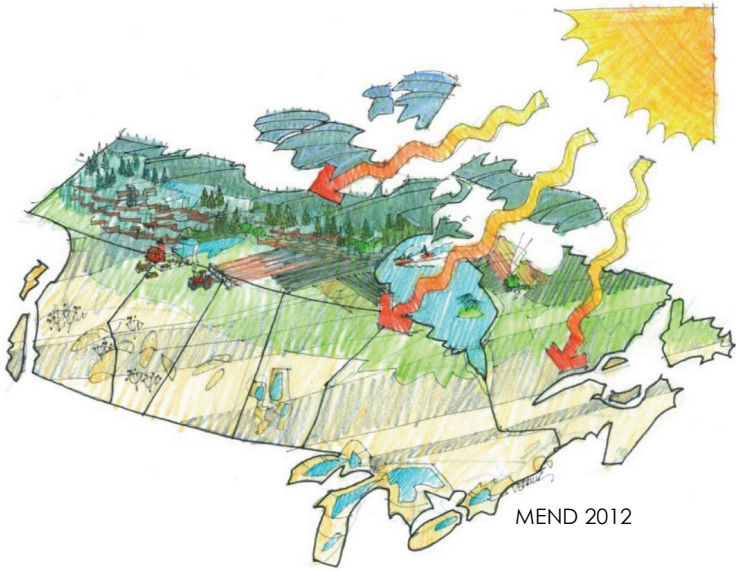
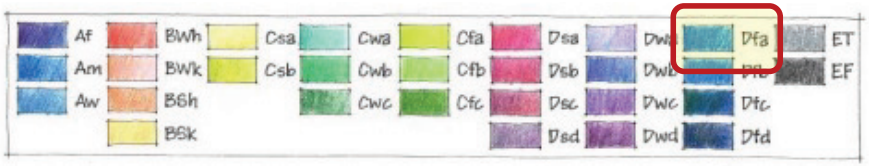
Regional Considerations – *'archetypes'* Climate



INAP, 2017

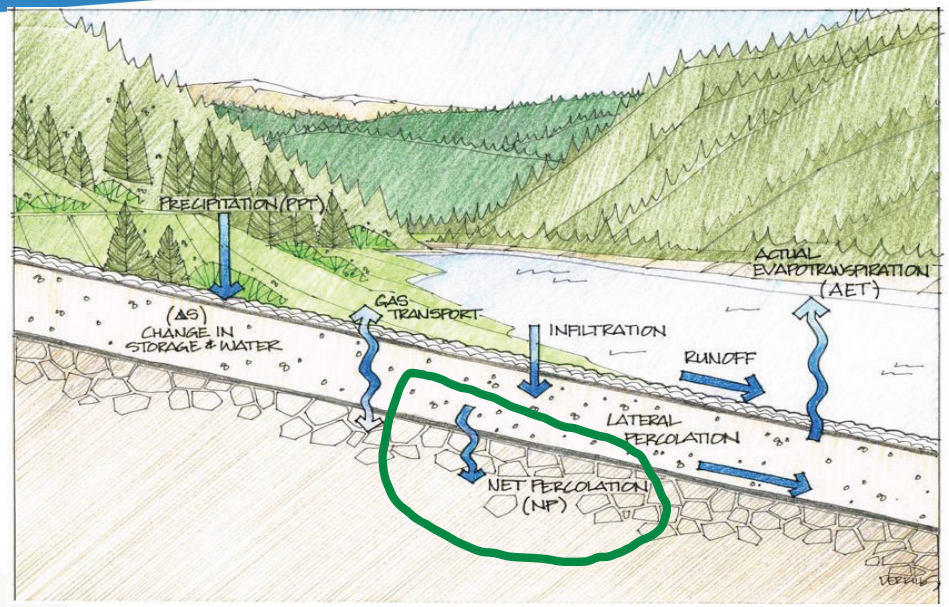


MEND 2012

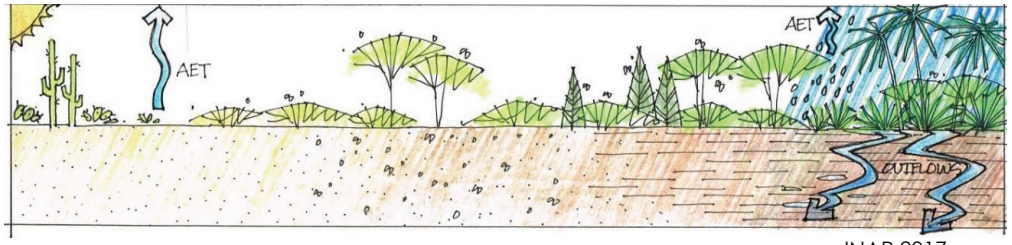


- Climate Change?

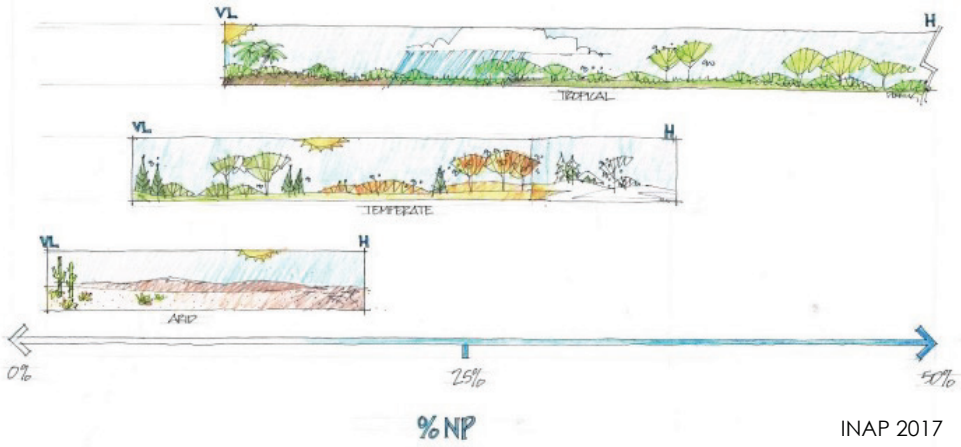
Regional Considerations – *'archetypes'* Water Balance



O'Kane 2018



INAP 2017



INAP 2017

- **Process vs Outcome**
- **Accuracy vs Precision**

VL L M H VH

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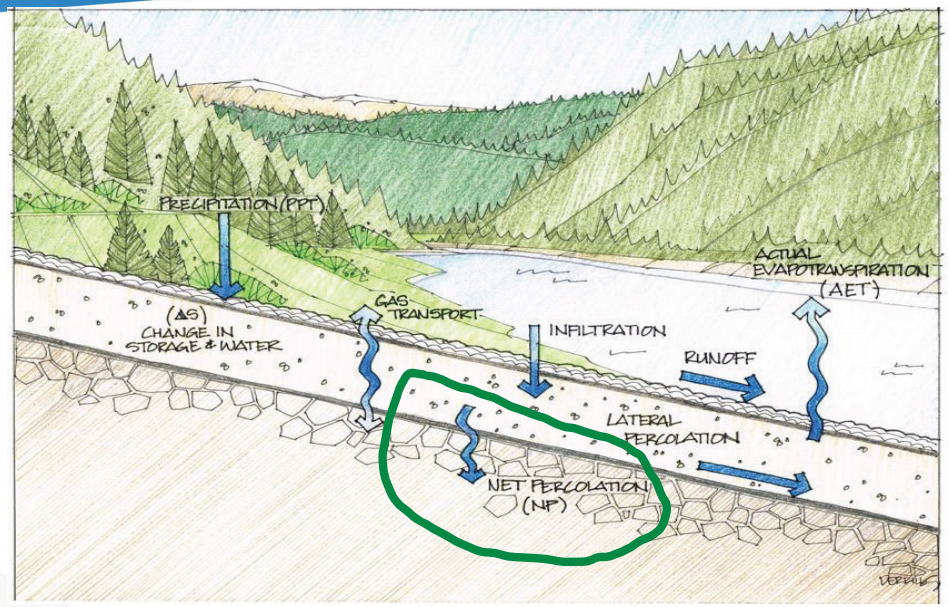
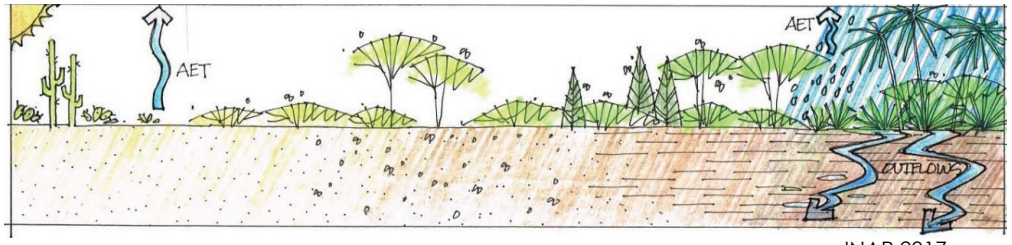
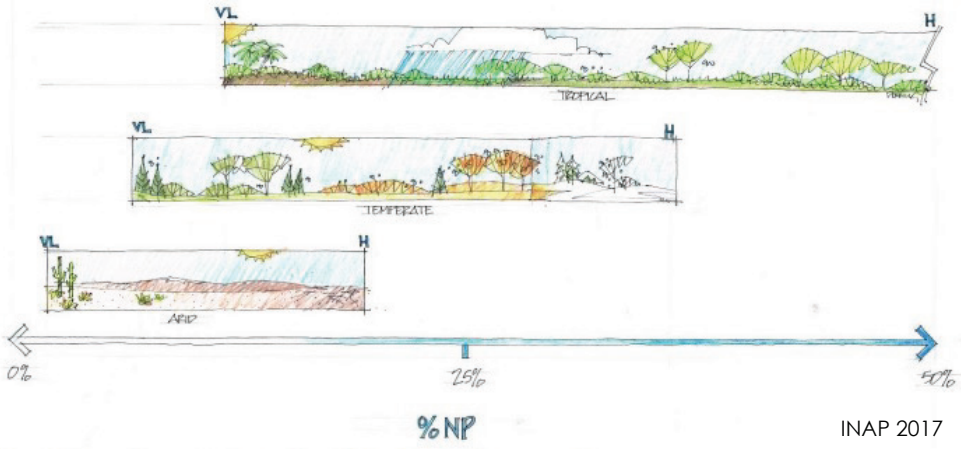
Regional Considerations – *'archetypes'* Water Balance



O'Kane 2018



INAP 2017



INAP 2017

- **Process vs Outcome**
- **Accuracy vs Precision**

VL L M H VH

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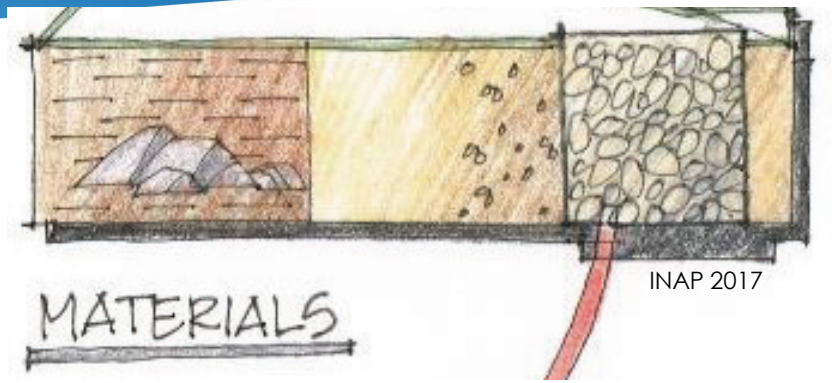
Regional Considerations – Geologic System



Ore deposits from in Igneous, Sedimentary, and Metamorphic Environments

- there are recognizable systematic origins and compositional ranges

Igneous

- Volcanogenic Massive Sulphides
- Magmatic Nickel
- Porphyry Cu - Mo - Au
- Epithermal Precious Metals

Sedimentary

- Banded Iron Formations
- Roll-Front Uranium
- Zambian Copperbelt
- Nickel Laterites

Metamorphic

- Homestake Gold
- Rossing Uranium
- Broken Hill Metamorphosed VMS

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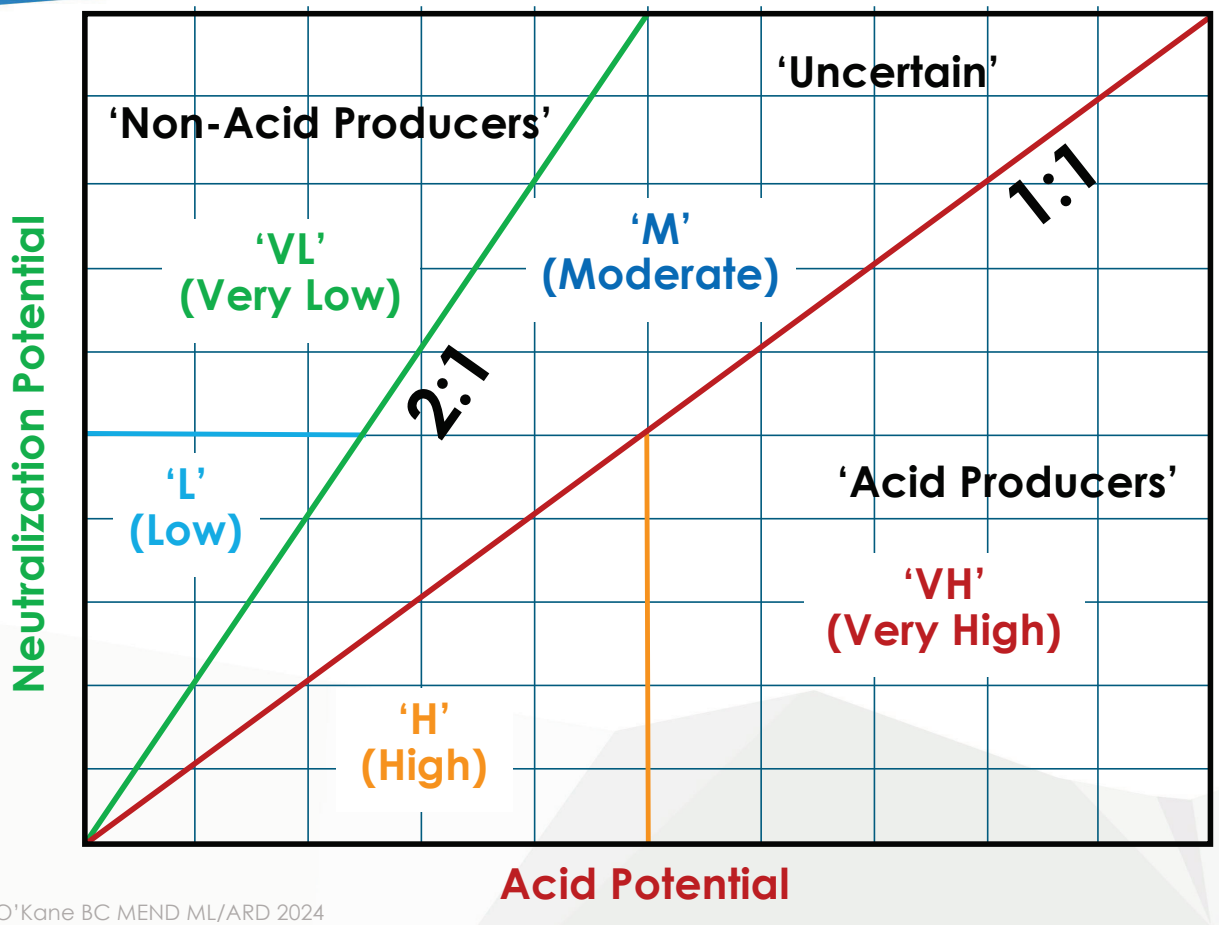
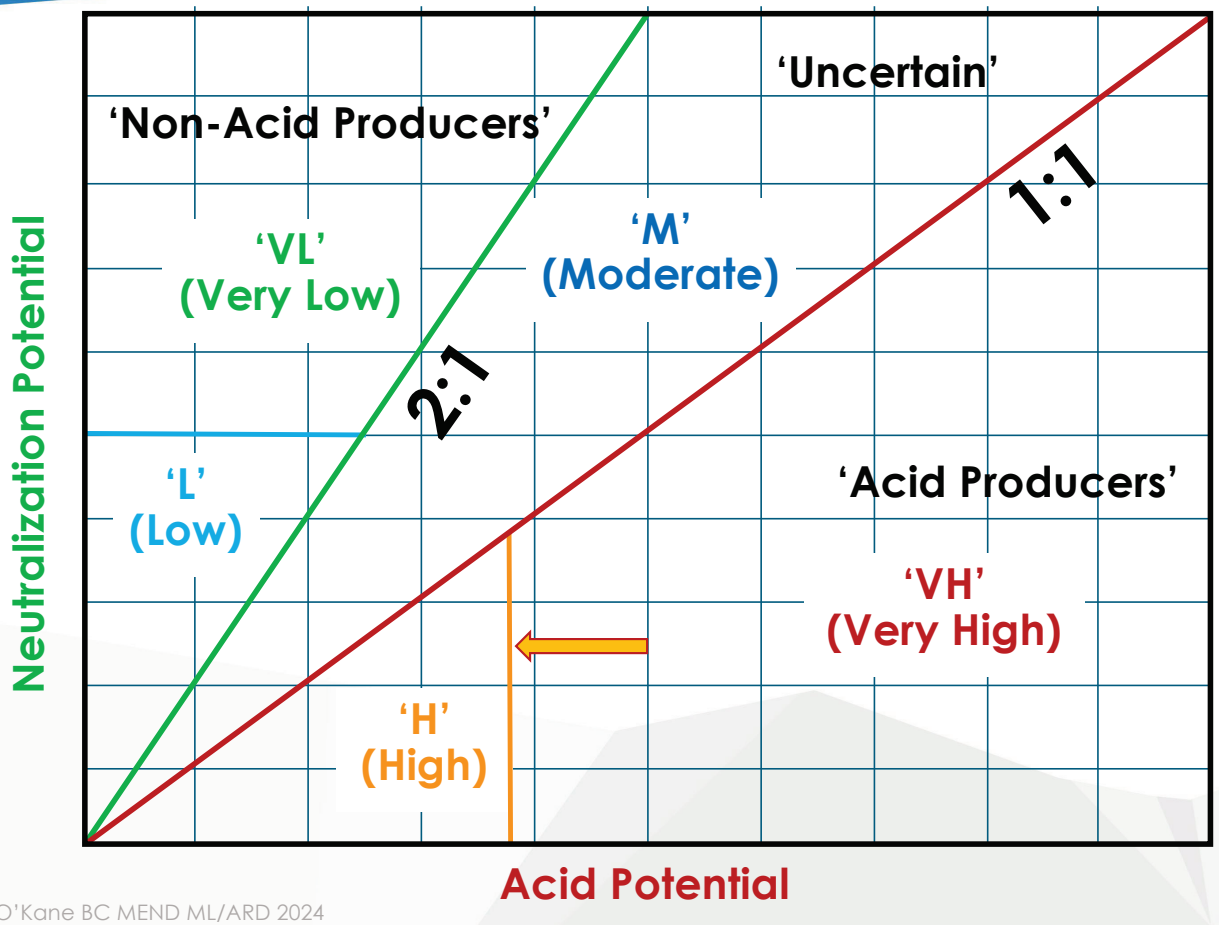
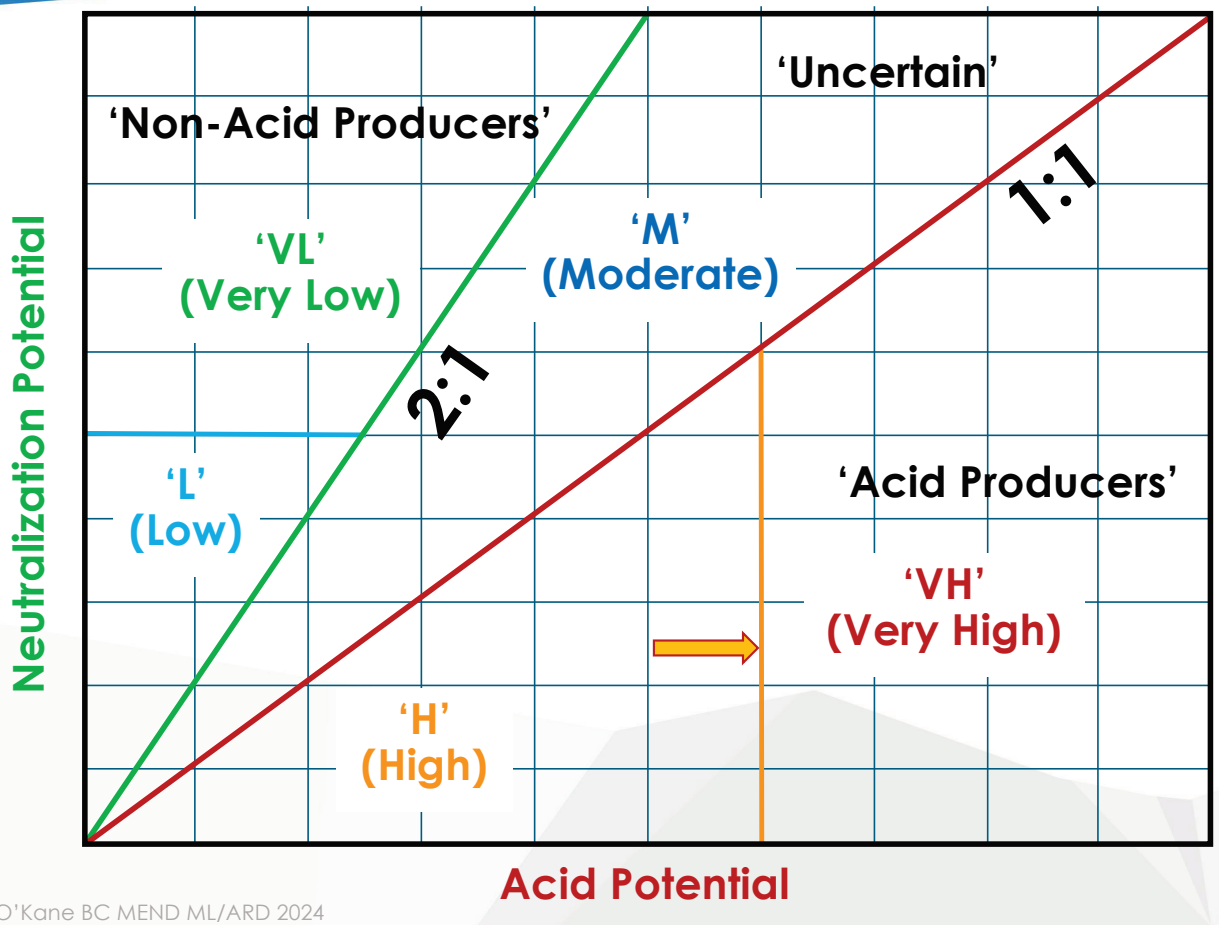
Regional Considerations – Geologic System



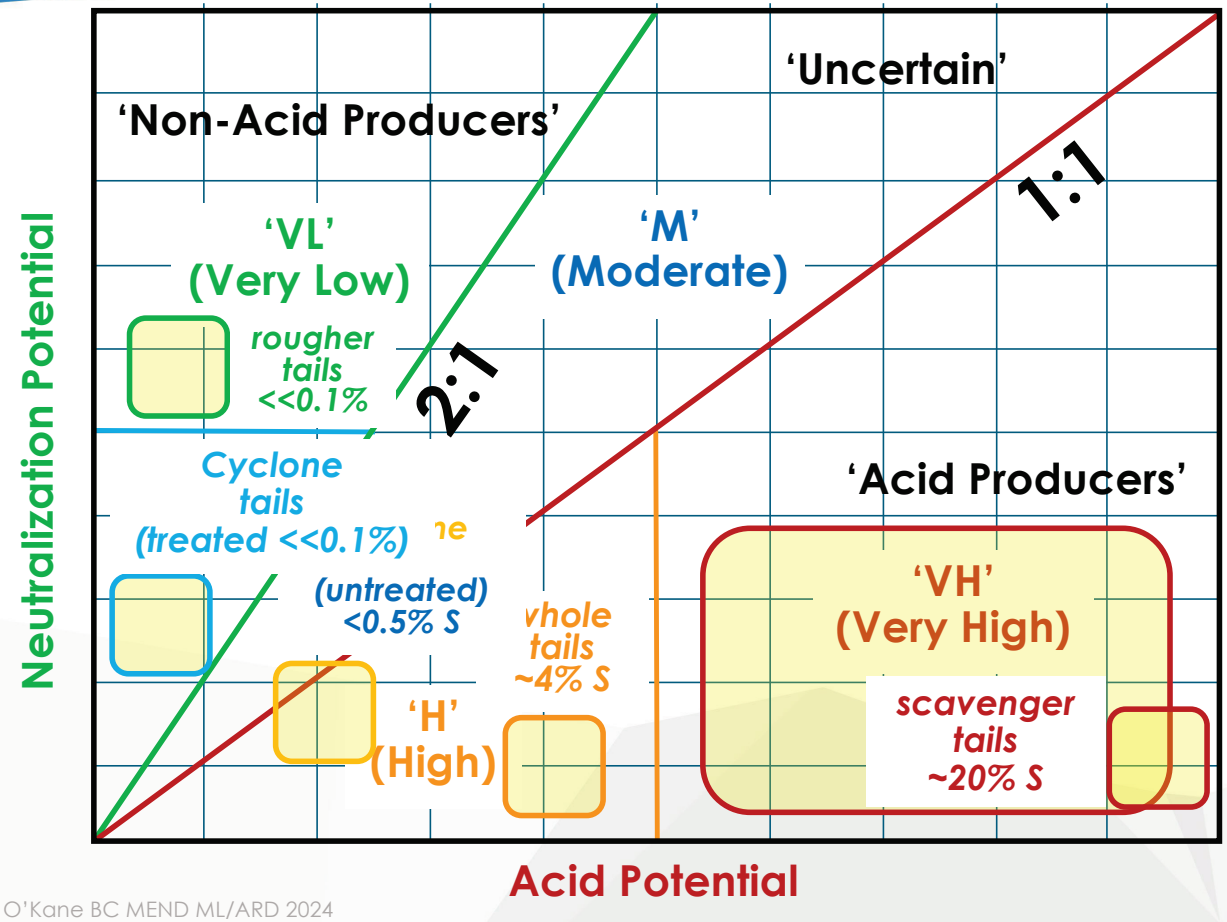
Regional Considerations – Geologic System



Regional Considerations – Geologic System

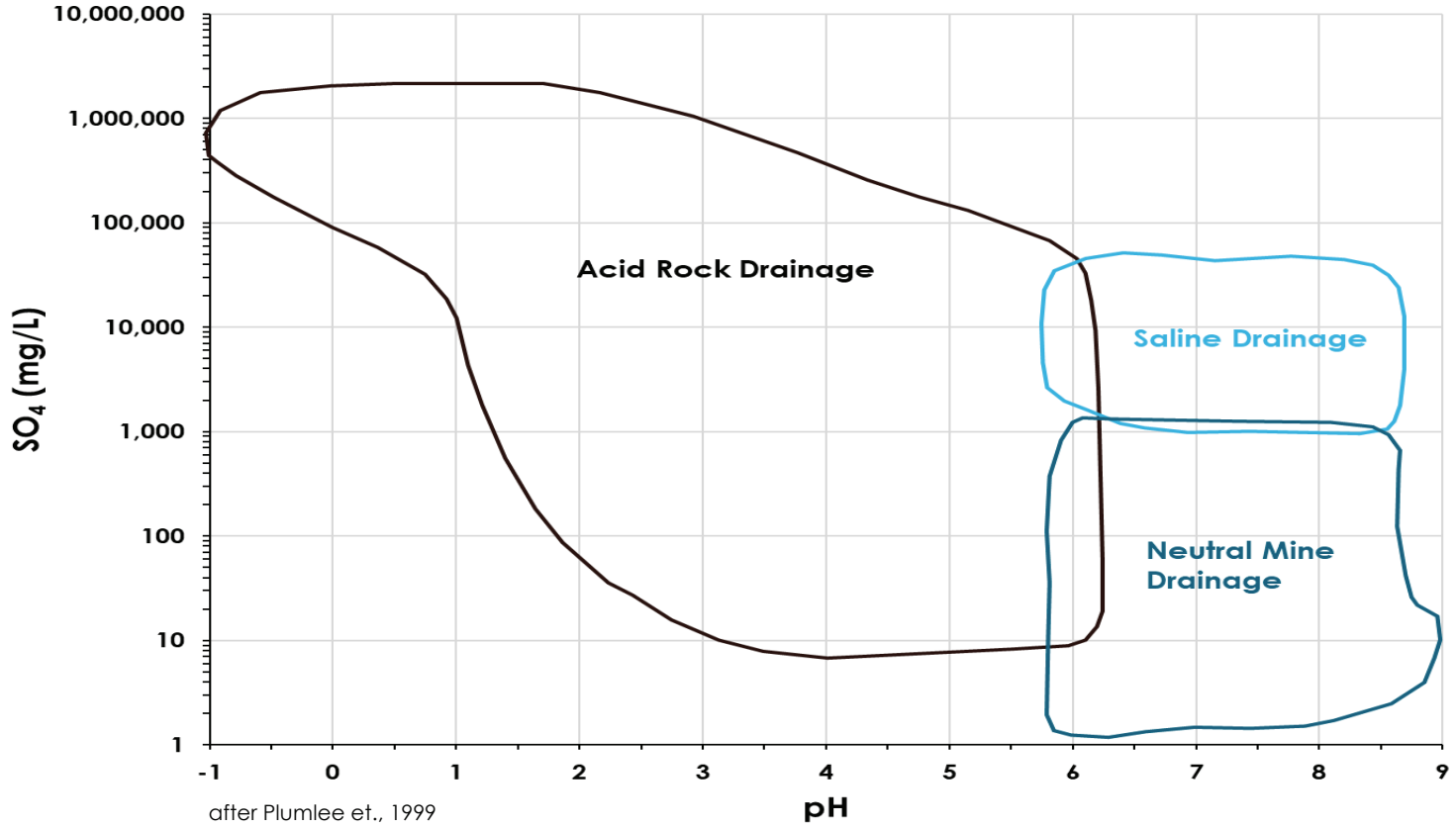


Regional Considerations – Geologic System



- For example:
  - SEDEX deposits
  - high probability Very High potential for acid generation
- However, consider:
  - a porphyry Au-Cu deposit
  - whole tailings vs. typical tailings processing

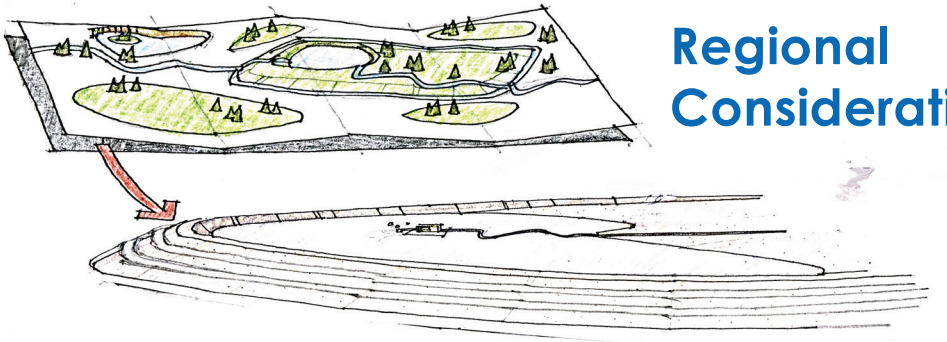
Regional Considerations – Geologic System



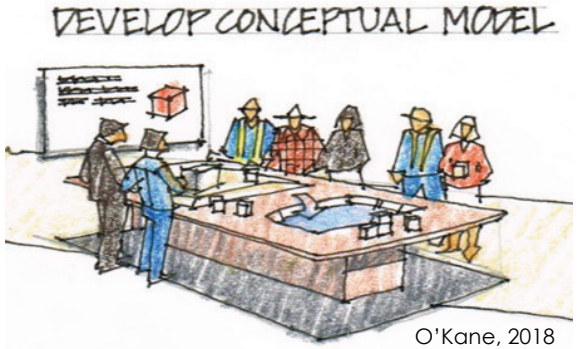
after Plumlee et., 1999

Conceptual Model Foundational Components

Define the TSF system (model inputs)



Regional Considerations

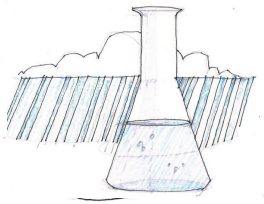


O'Kane, 2018

How is it Built?

Apply to the TSF System (model outcomes)

Water Balance



Geochemistry

Case Study #1 – Faro Mine Remediation Project

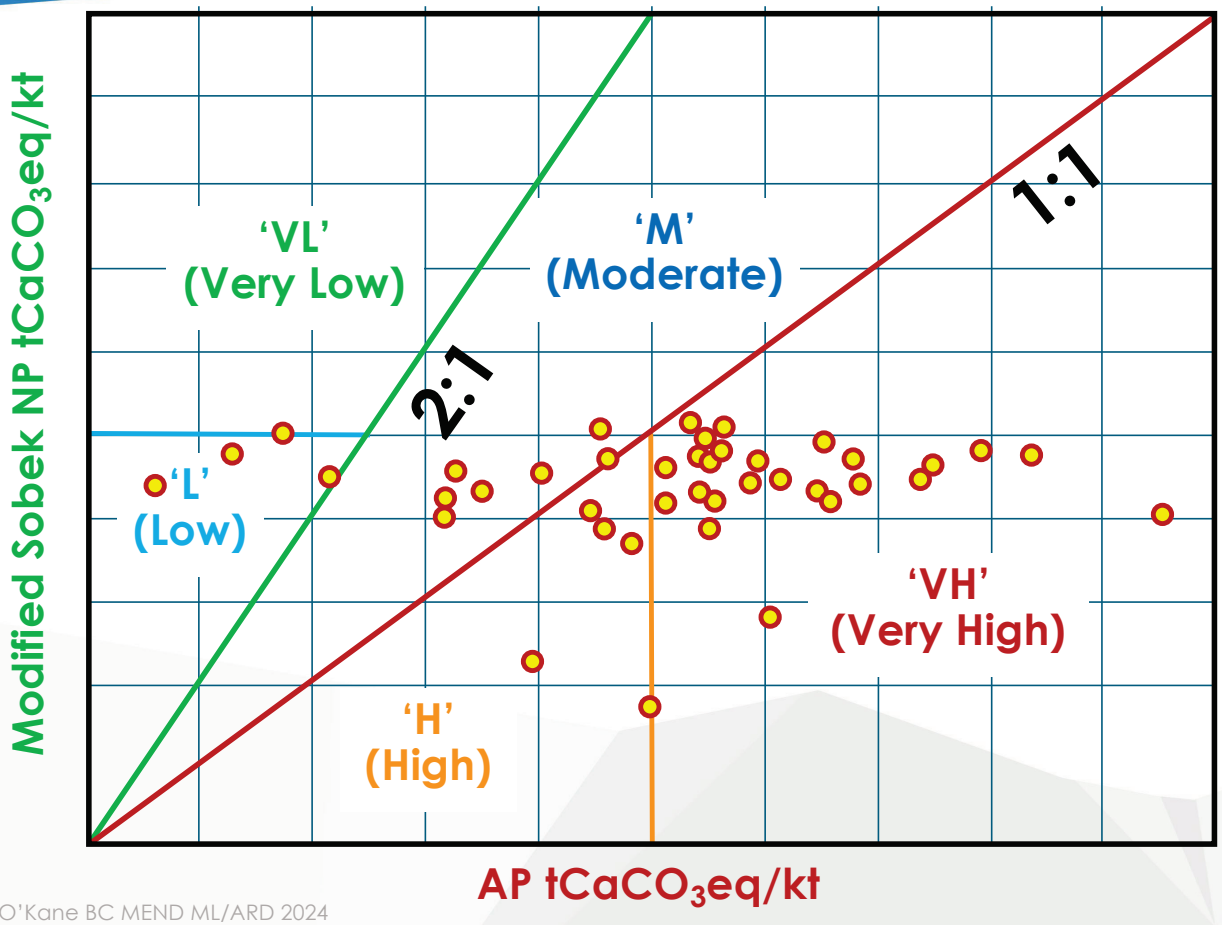
https://faromineproject.ca/about-fmrp/

- Faro Mine was once the largest open pit lead-zinc mine in the world
- Located in south-central Yukon, near the town of Faro, on the traditional territory of the Kaska Nations, and upstream from Selkirk First Nation
- Mine was abandoned in 1998
- 70 million tonnes of tailings

https://cbc.ca/

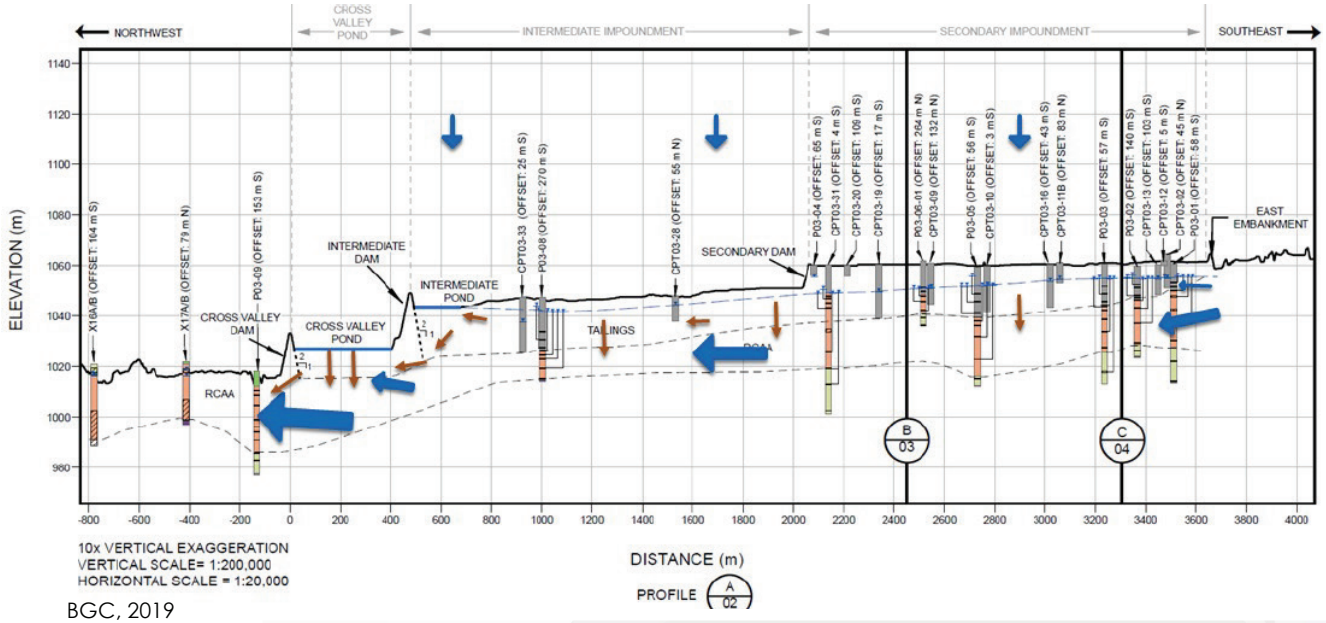
- ***Climate***
  - ***"Dsc" - Continental Subarctic Climate***
  - ***Dominated by winter season***
  - ***Long cold period with short, clear days***
  - ***Low precipitation mostly in the form of snow (320mm)***
  - ***Snow melt 'recharge'***
  - ***Relatively low humidity***

Case Study #1 – Faro Mine Remediation Project



- Geologic System
  - Sedimentary Exhalative (SEDEX)
  - SEDEX systems are particularly susceptible to acidity generation because of the abundance of sulfide minerals present
  - Relative to other geologic deposits SEDEX has a very high potential for acidity generation

Case Study #1 – Faro Mine Remediation Project



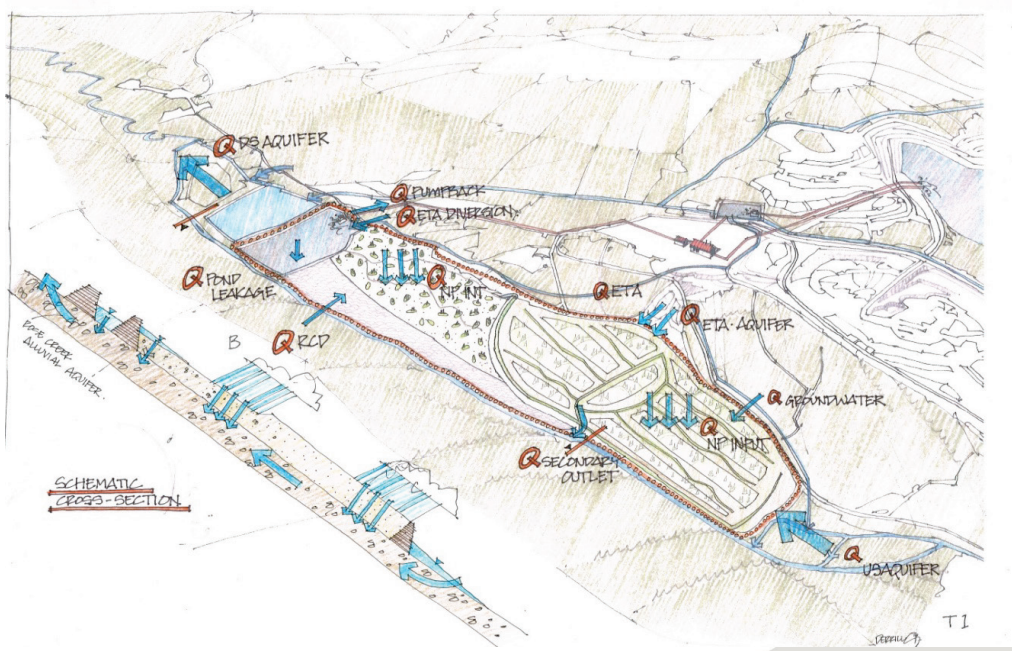
BGC, 2019

Faro Mine REMEDIATION PROJECT

Canada

https://faromineproject.ca/wp-content/uploads/2024/06/Re_-Faro-Mine-Remediation-Project_-Newsletter.pdf

Case Study #1 – Faro Mine Remediation Project



BGC, 2019

- ***Hydrogeologic Setting and Water Balance***
  - ***Moderate recharge (net surface infiltration)***
    "Moderate": 15% to 25% of average annual PPT
  - ***Water storage capacity in tailings material***
    "Low": conventional tailings deposition, low evaporation conditions
  - ***Pore-water velocity***
    "Low" to "Moderate": finer- and coarser-textured tailings
  - ***Recoverable – Unrecoverable seepage ratio***
    "Very Low": 40% - 60%

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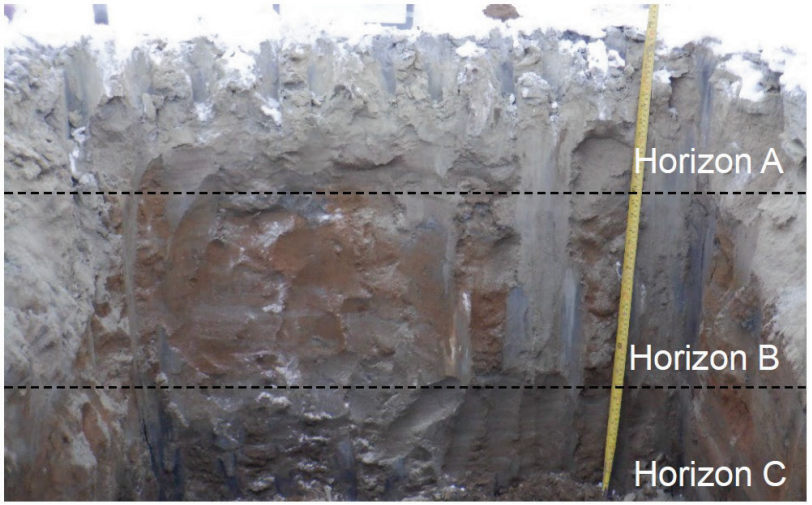
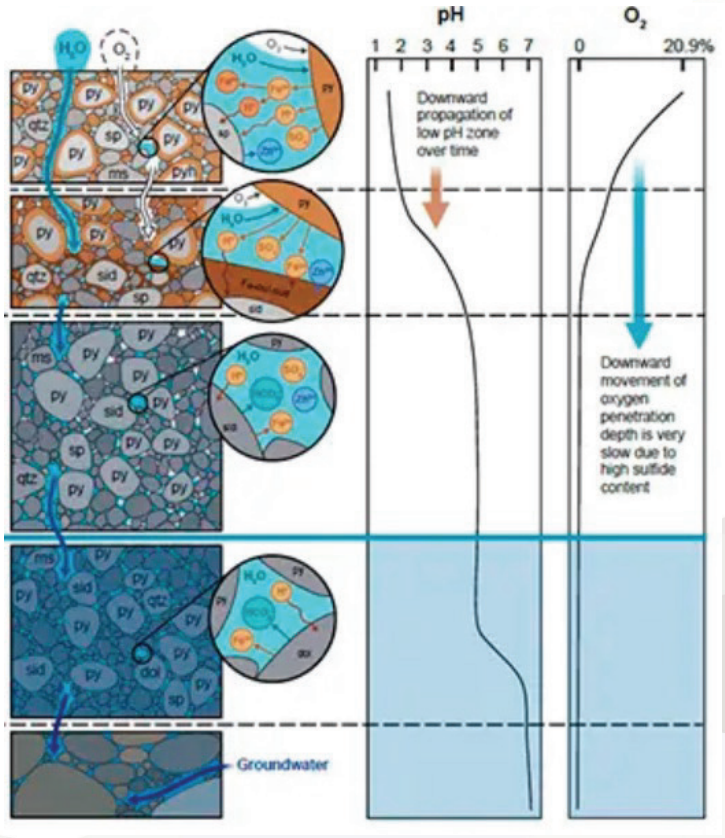
Case Study #1 – Faro Mine Remediation Project



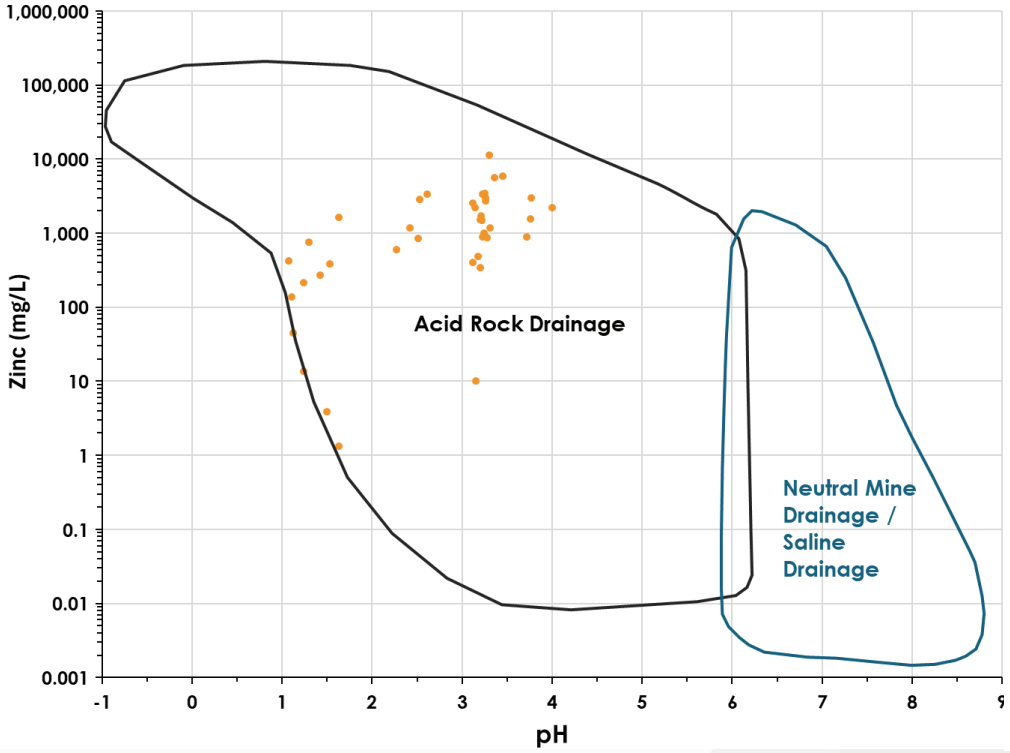
SRK 2020

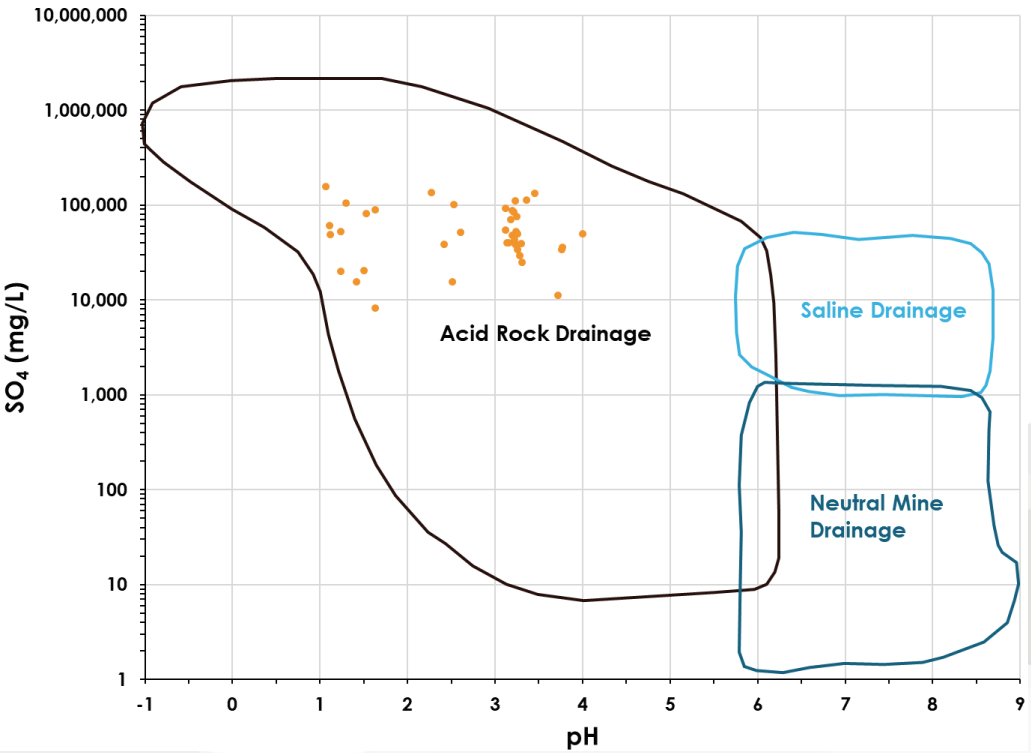


(Doherty and Sexsmith 2024)

- ***Geochemistry***
  - ***Depth of oxidation***
    "High": 0.75m to 1m
  - ***Attenuation capacity***
    "Moderate": neutralization capacity evident along tailings profile
  - ***Net Acidity and Metals***
    "Very High": Zinc: >50 t/yr
    Sulfate: >500 t/yr

Case Study #1 – Faro Mine Remediation Project





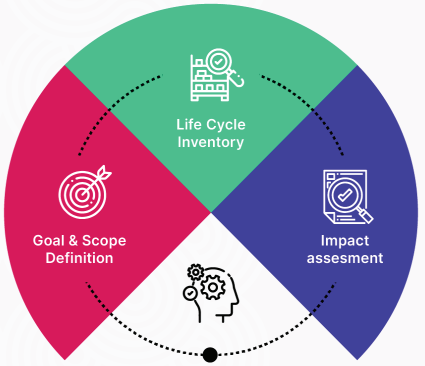
…the *'path forward'* to the *'destination'*

- A multi-faceted approach is needed:
  1) Compliant with LCA standard practice
  2) Includes mass-balancing
  3) Based on site-specific data and models
  4) Considers tailings as a resource
  5) Uses realistic and practical timeframes that are consistent across goals, scope, LCI models and LCIA methods

- ***Conceptual model - using foundational elements of TSFs and a workable number of archetypical scenarios: e.g. climate; geologic condition; hydrogeologic conditions***

- Industry can support by creating relevant databases for the archetypes

Phases in Life Cycle Assesment (LCA)



https://www.circularise.com/blogs/what-is-life-cycle-assessment-lca

…the *'path forward'* to the *'destination'*

- …evolution of a Closure Plan to an executable Project

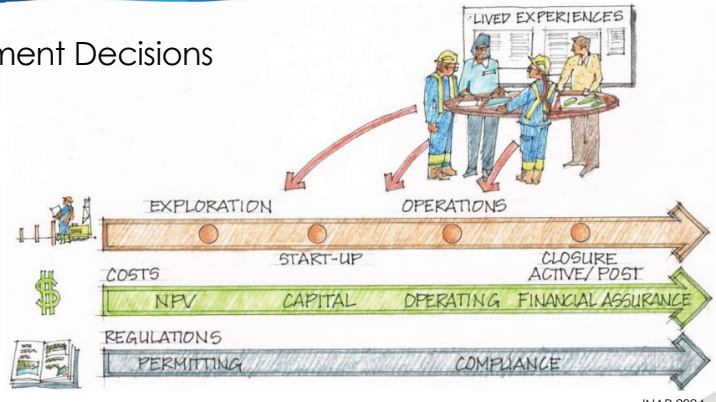
LDI 2023

"…there is a need for robust (deep) conceptualization for TSF closure plans as they evolve from a 'closure plan' to 'a closure project' to be costed and/or executed …"

the evolution of a closure plan to a project needs to occur with sufficient time to fully develop the project from concept through FS and detailed engineering prior to mining ceasing. This could be as much as 5 years prior. And this deep conceptualization needs to incorporate appropriate data, information and knowledge that must be collected, evaluated, understood and utilized, throughout the operating phase of the mining project

…the *'path forward'* to the *'destination'*

- …Informing on Investment Decisions



INAP 2024

"…there is a need for robust understanding for material risk wrt to TSF design, to inform on investment decisions, such as PEAs and/or NI-43-101s, and likely Project Descriptions, before, perhaps a PFS (too late!) and for sure an FS…"

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that "first" model is, in the end, inevitably assumed to be 'the right' path to follow. It is extremely challenging to change.

Hence, you better get it right.

Everything after that is more or less the "project development meat grinder"

Acknowledgements

- Thank you to…

BC MEND ML/ARD ANNUAL WORKSHOP

Cu International Copper Association

ICMM

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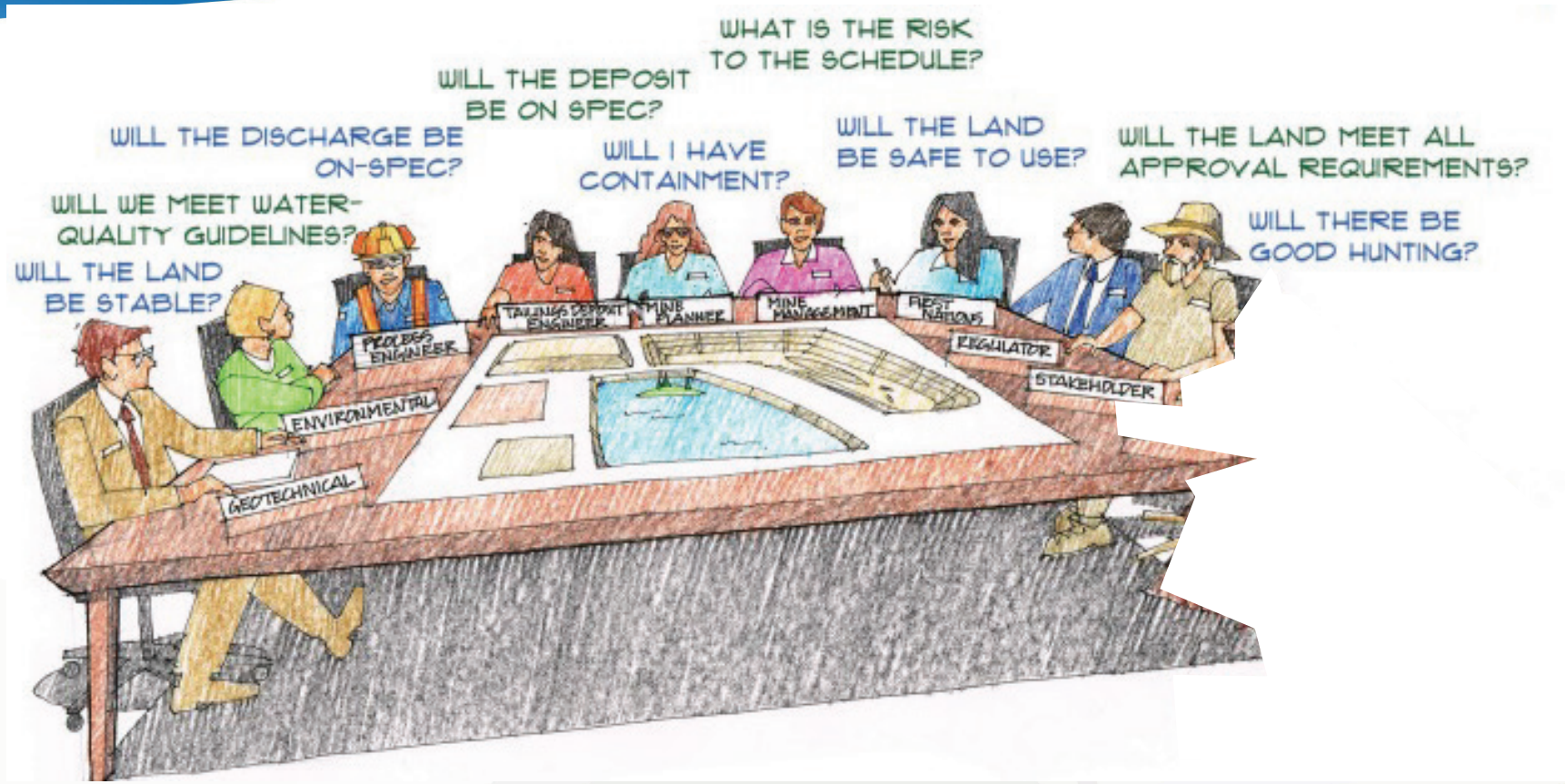
Faro Mine REMEDIATION PROJECT Canada

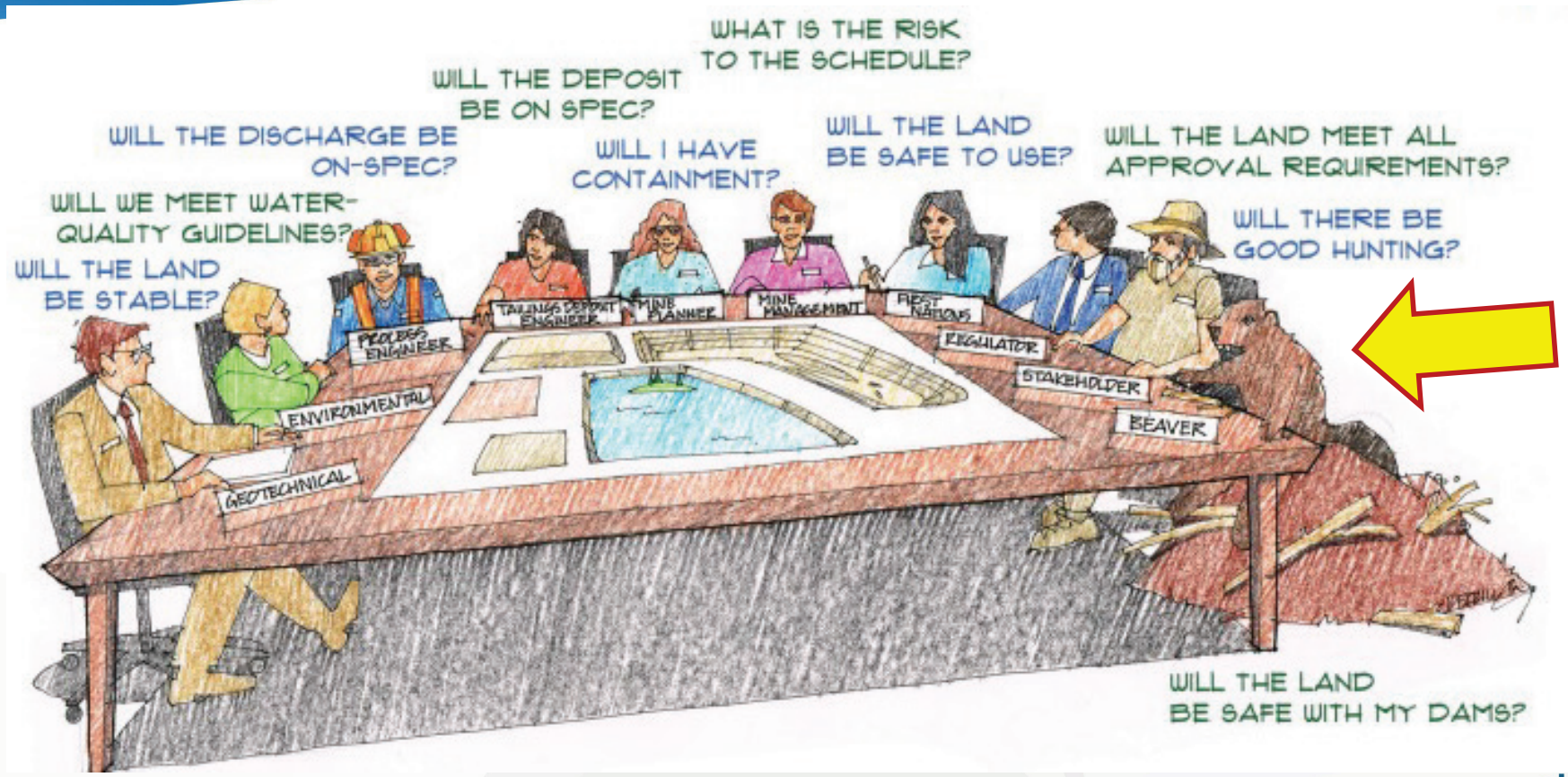
- ***Derrill Shuttleworth, Illustrator***
- ***Mark Logsdon, Geochemica***

Acknowledgements



LDI 2021

Acknowledgements



LDI 2021

Thank You!

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