Boliden Aitik Mine Closure Planning

WRSF Closure Planning Support Studies

25th BC MEND ML-ARD Workshop

Vancouver, BC

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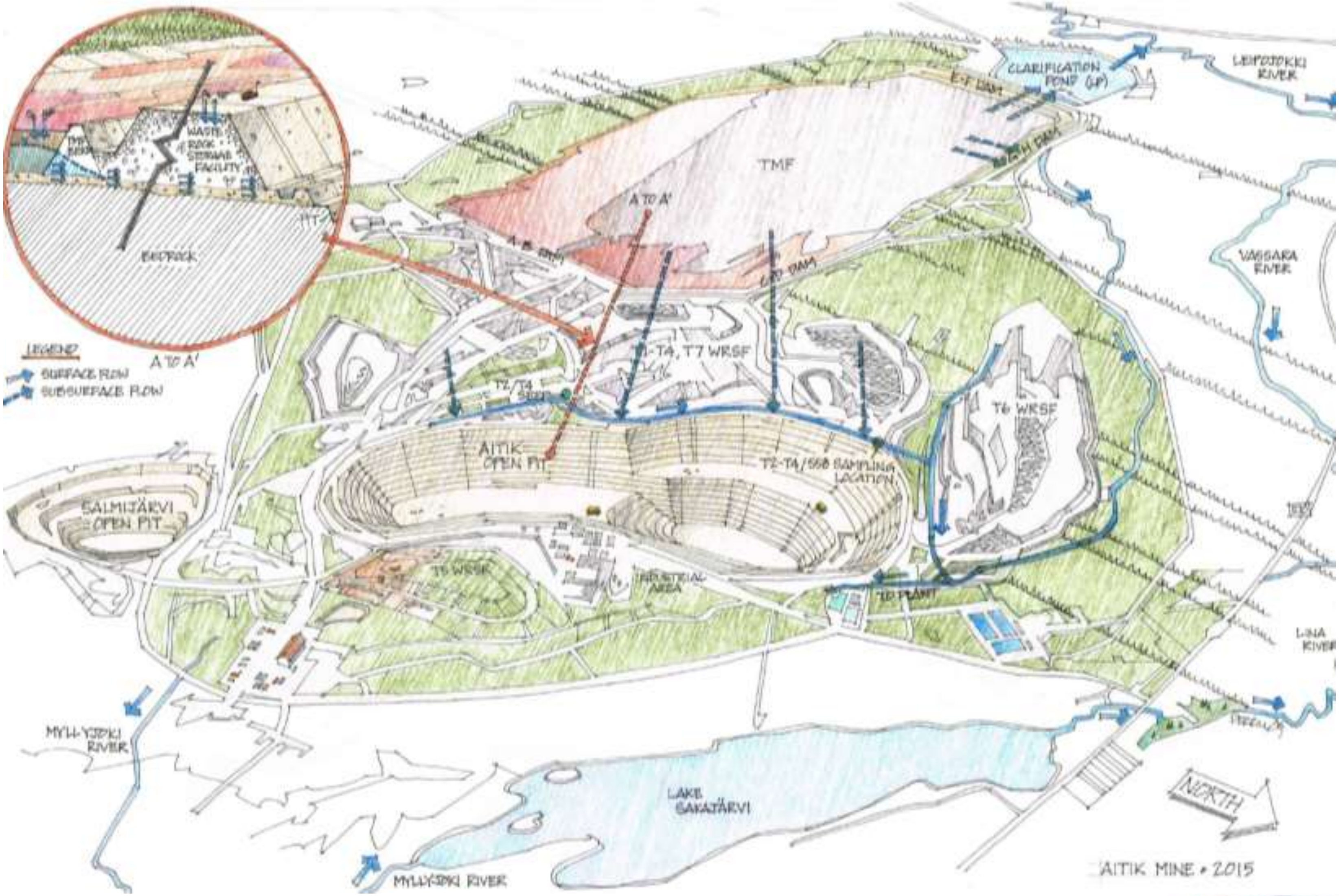
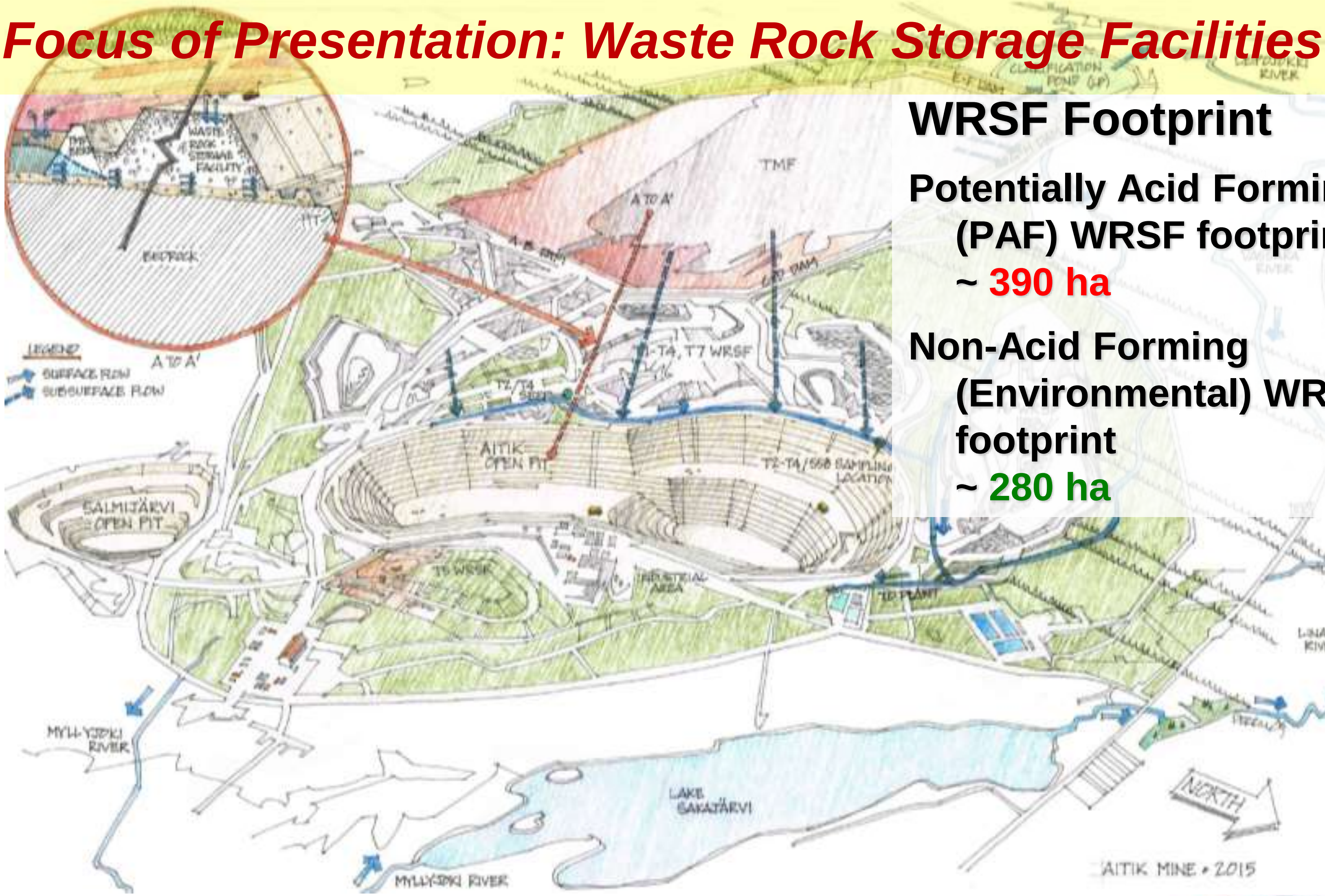
O'Kane Consultants

Boliden - Aitik



Boliden - Aitik

Focus of Presentation: Waste Rock Storage Facilities



WRSF Footprint

Potentially Acid Forming (PAF) WRSF footprint ~ 390 ha

Non-Acid Forming (Environmental) WRSF footprint ~ 280 ha

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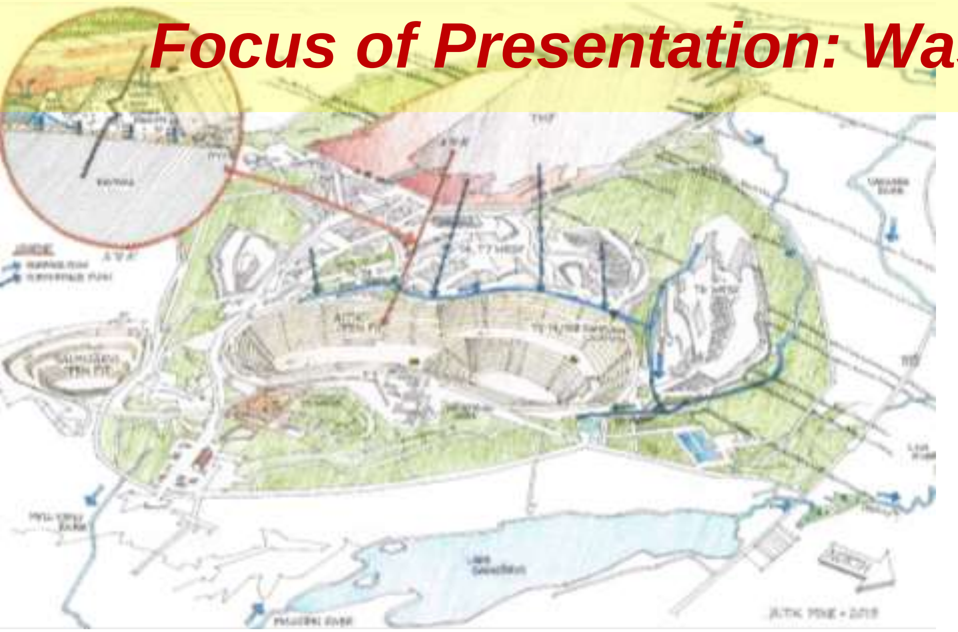

Include all Mine Site Elements (Domains):

- ***Waste Rock Storage Facilities (WRSFs)***
- ***Tailings Management Facility (TMF)***
- ***Pit Lakes***

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Focus of Presentation: Waste Rock Storage Facilities

Risk Management and Opportunities:

Evaluate water quality at closure for aquatic receptors downstream to Aitik

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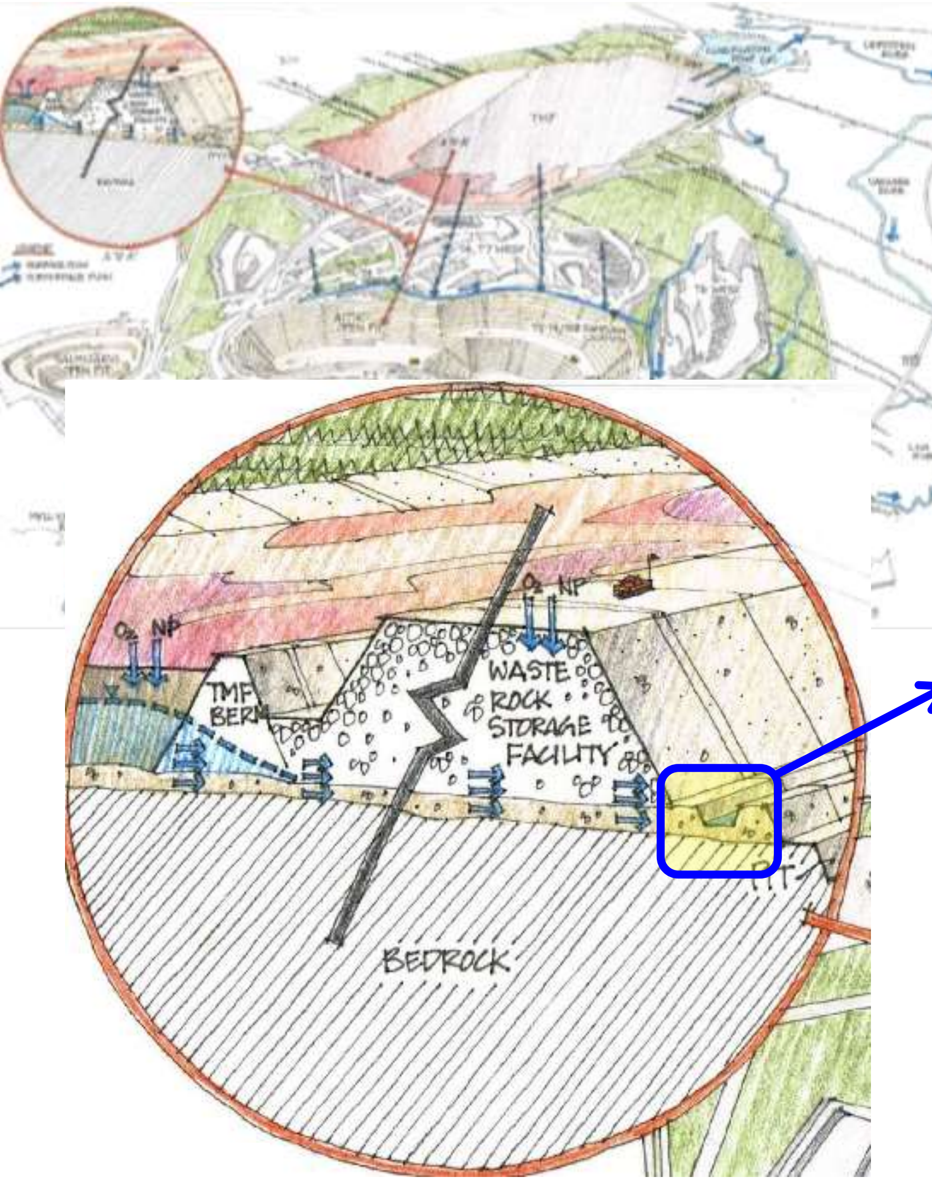
- *Tailings Management Facility (TMF)*
- *Pit Lakes*

Overarching Summary



- ***WRSF Seepage Flow and Water Quality Over Time?***
- ***Why…?***
  - ***Input to Pit Lake Assessment and Downstream Recipient Modelling***

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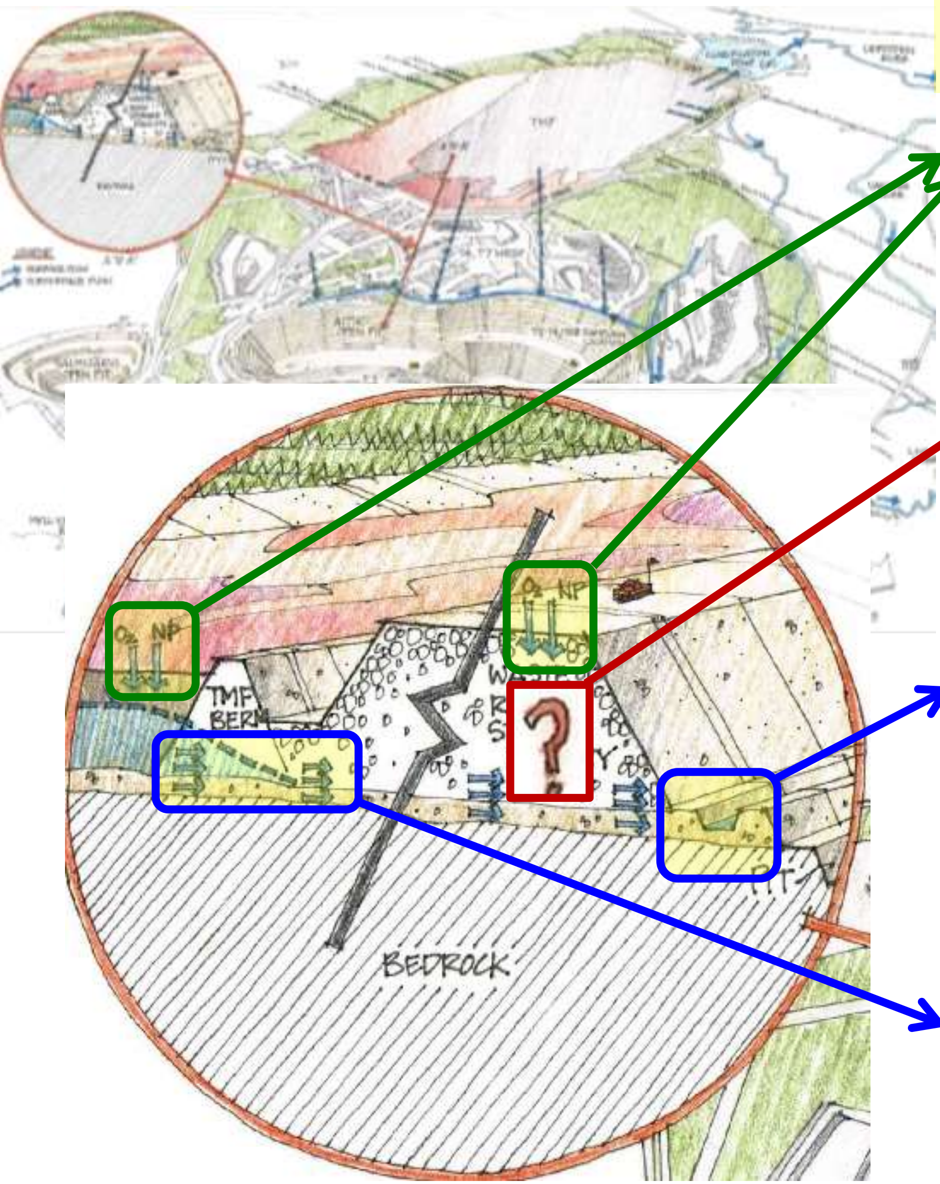
Overarching Summary - Methodology



Waste Rock Pore-Water Quality?

- ***Cover System Field Trials and Modelling***
  - ***Model Result: Waste Rock Pore-Water Quality***
  - ***Waste rock characteristics***
- ***WRSF Seepage Flow and Water Quality***
  Now?: Monitoring
  Over Time?: Modelling
- ***TMF Seepage Monitoring and Modelling***

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Overarching Summary - Methodology

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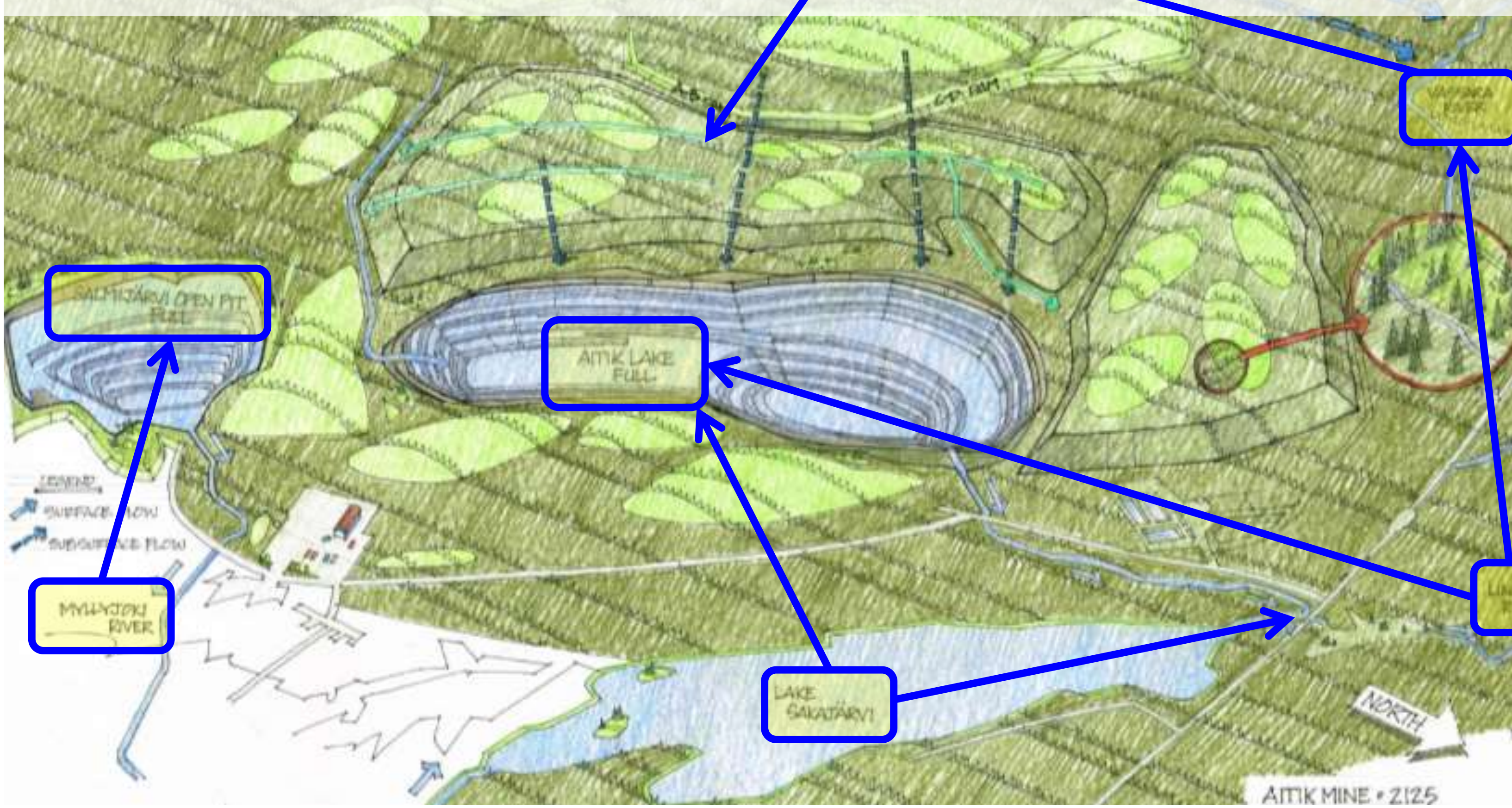

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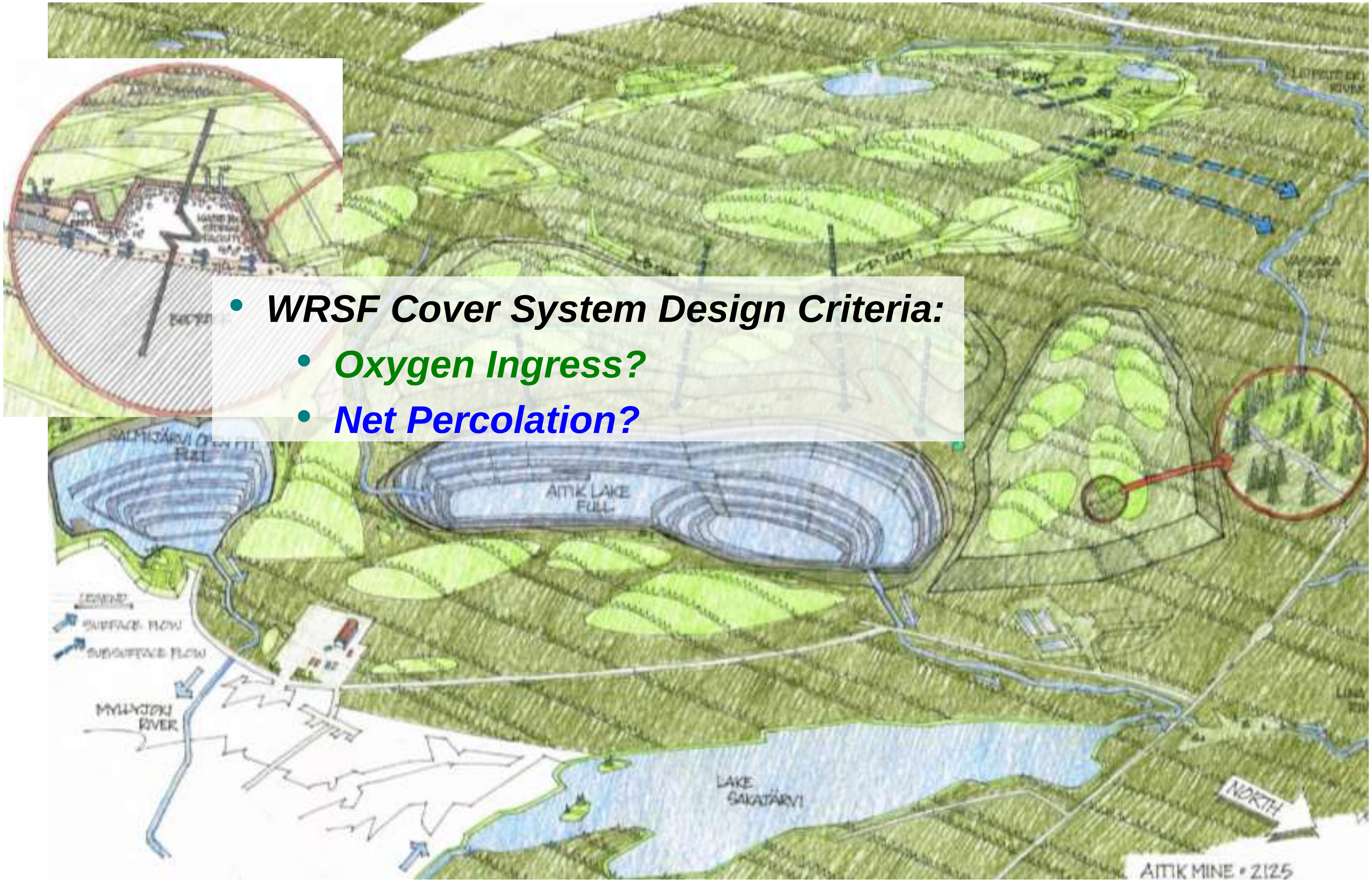
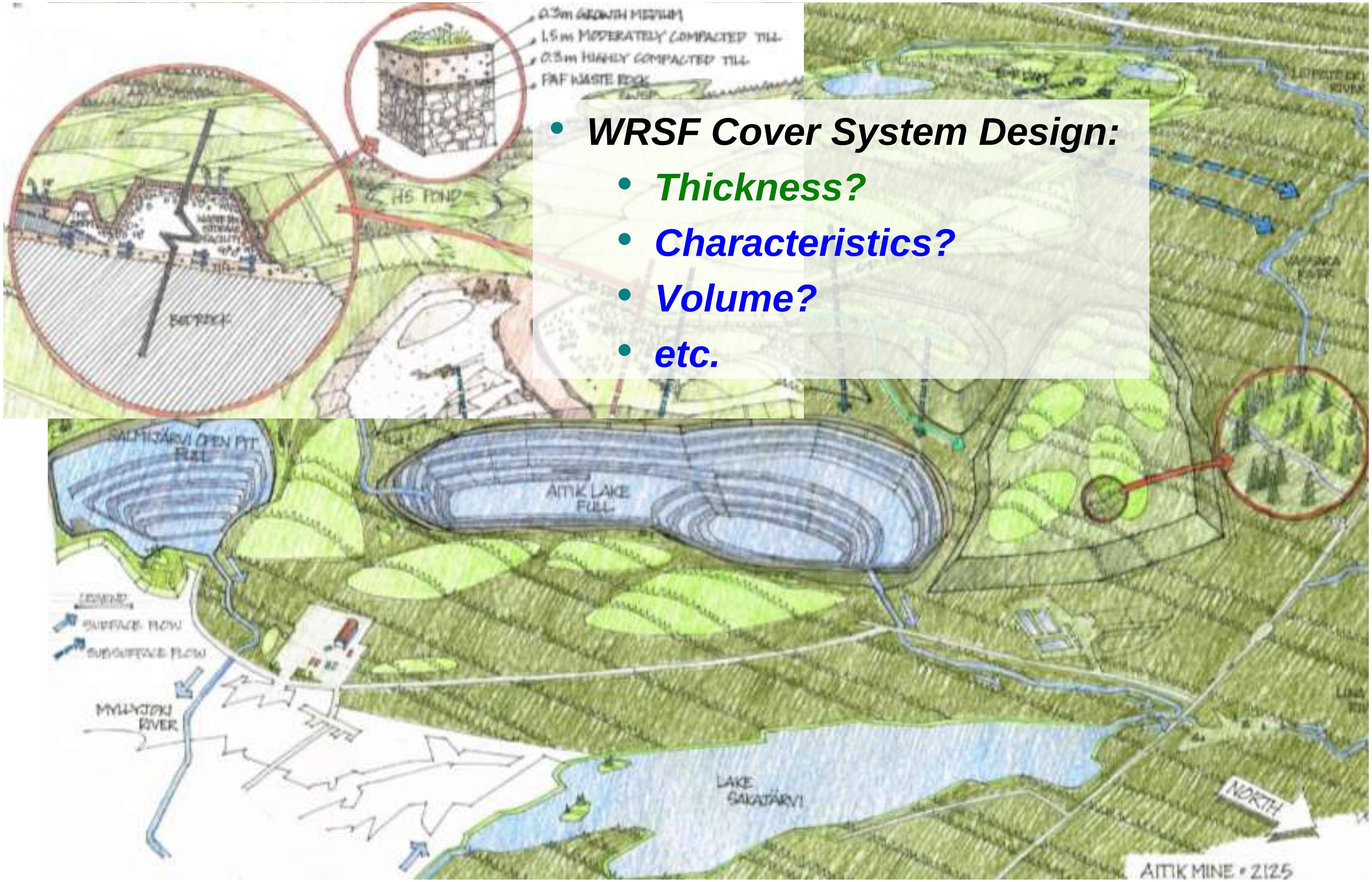
Overarching Summary - Methodology



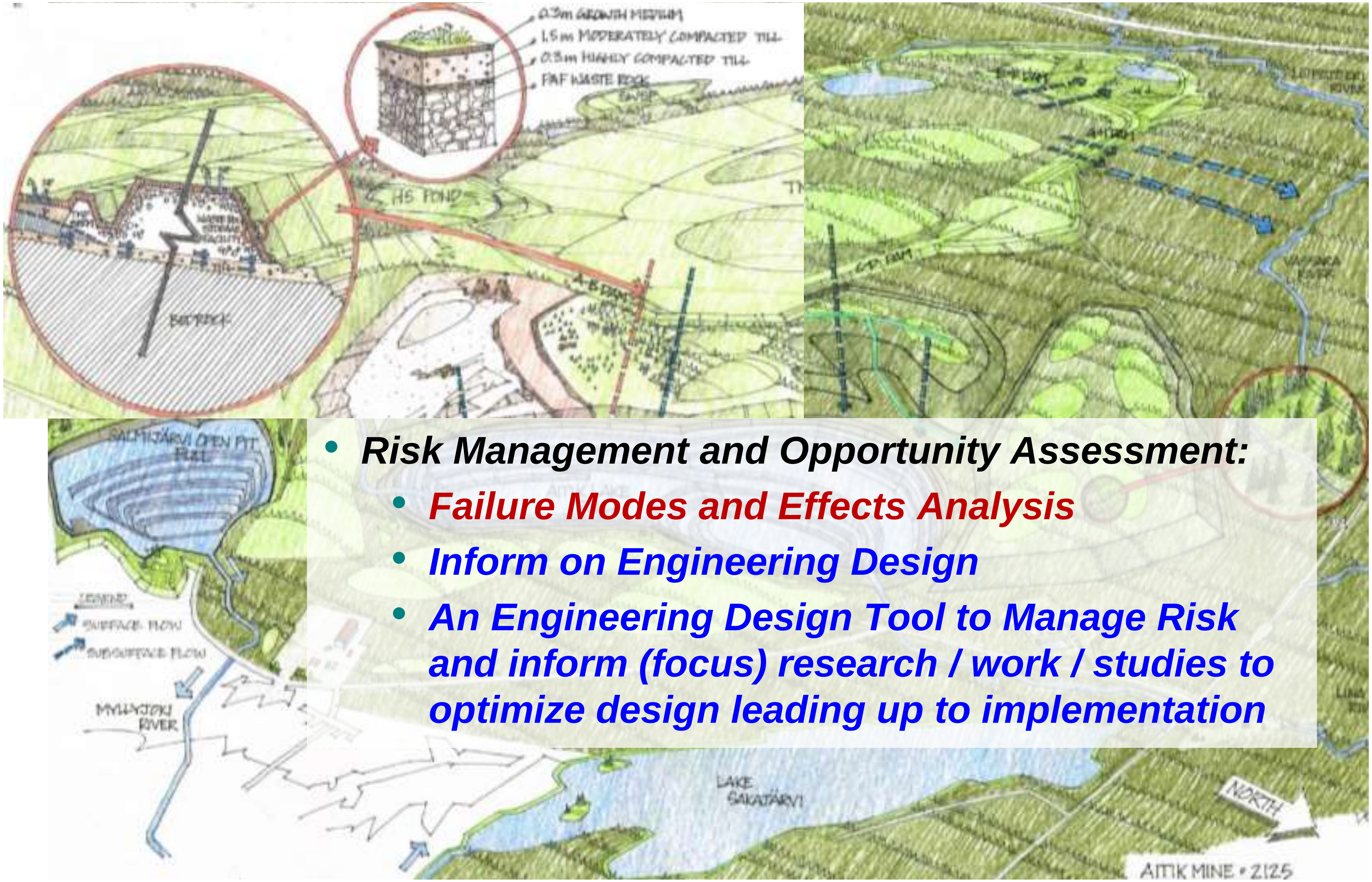
- ***WRSF Cover System Design Criteria:***
  - ***Oxygen Ingress?***
  - ***Net Percolation?***

Overarching Summary - Result



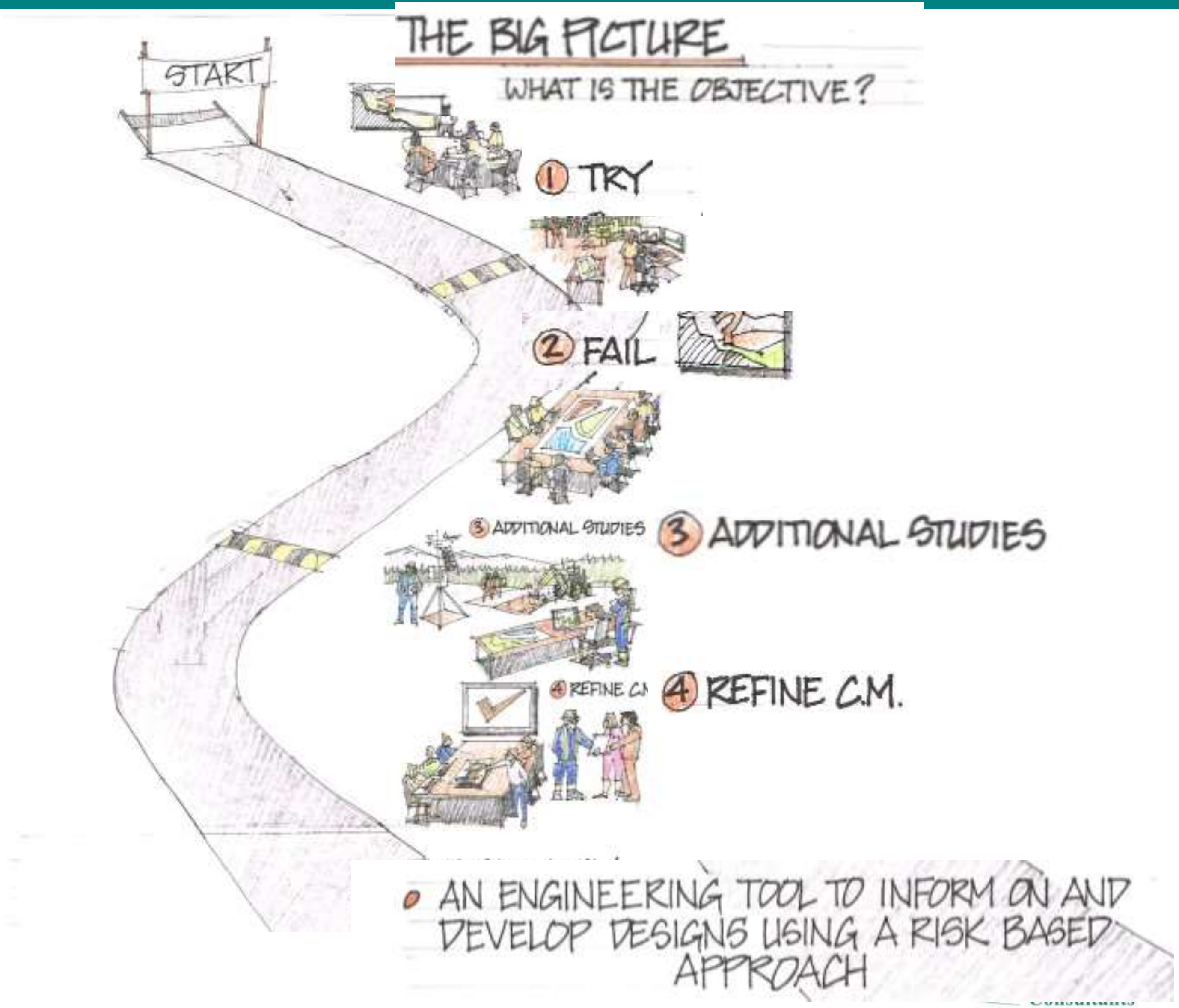
- ***WRSF Cover System Design:***
  - ***Thickness?***
  - ***Characteristics?***
  - ***Volume?***
  - ***etc.***

Overarching Summary - Evaluation

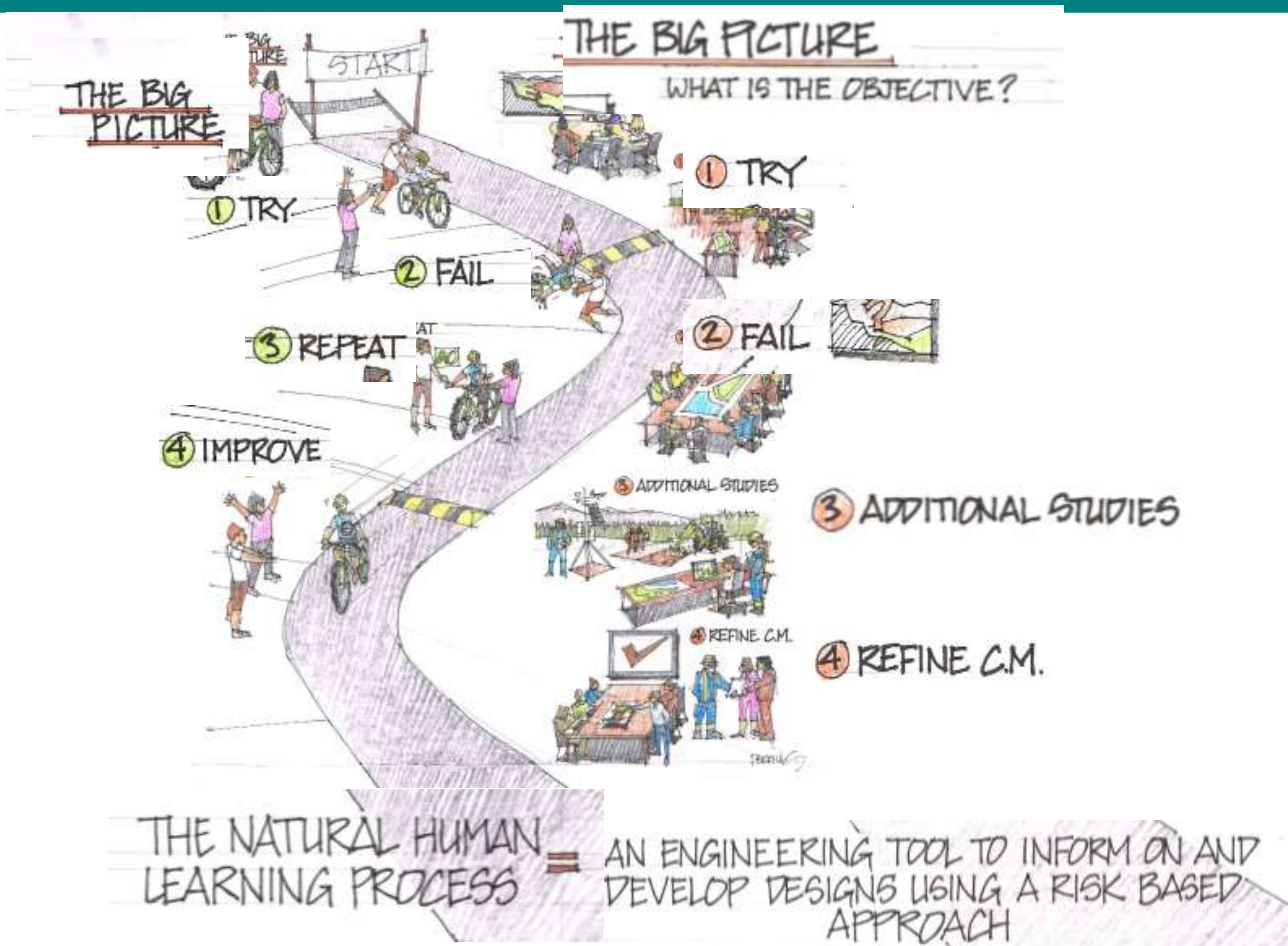


- ***Risk Management and Opportunity Assessment:***
  - ***Failure Modes and Effects Analysis***
  - ***Inform on Engineering Design***
  - ***An Engineering Design Tool to Manage Risk and inform (focus) research / work / studies to optimize design leading up to implementation***

Overarching Summary - Evaluation



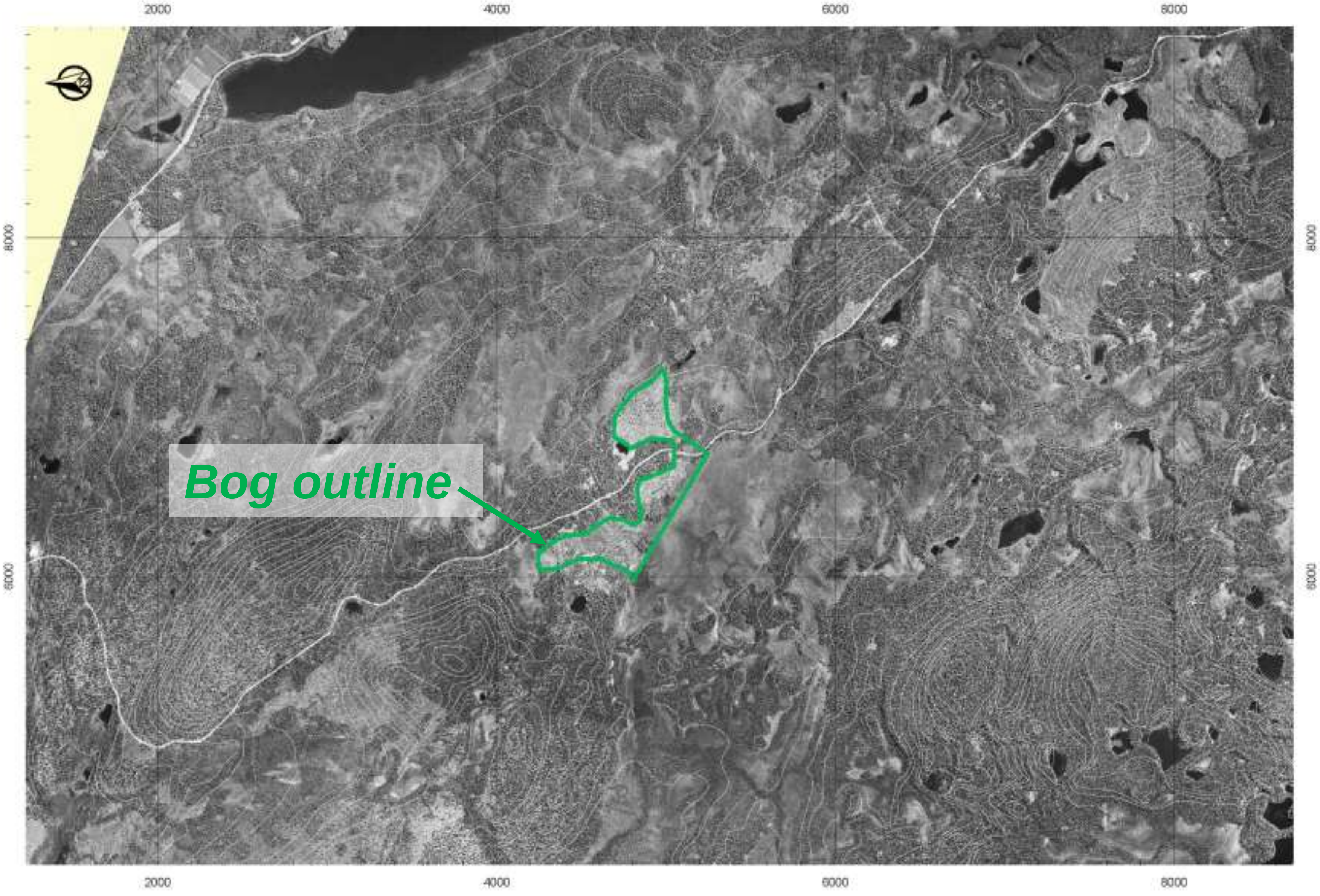
Overarching Summary - Evaluation



Derivation of flow rates for the 558 water quality monitoring location (key monitoring location below the PAF WRSFs)

CONCEPTUAL SITE FLOW MODEL

Site Topography – Pre-mining



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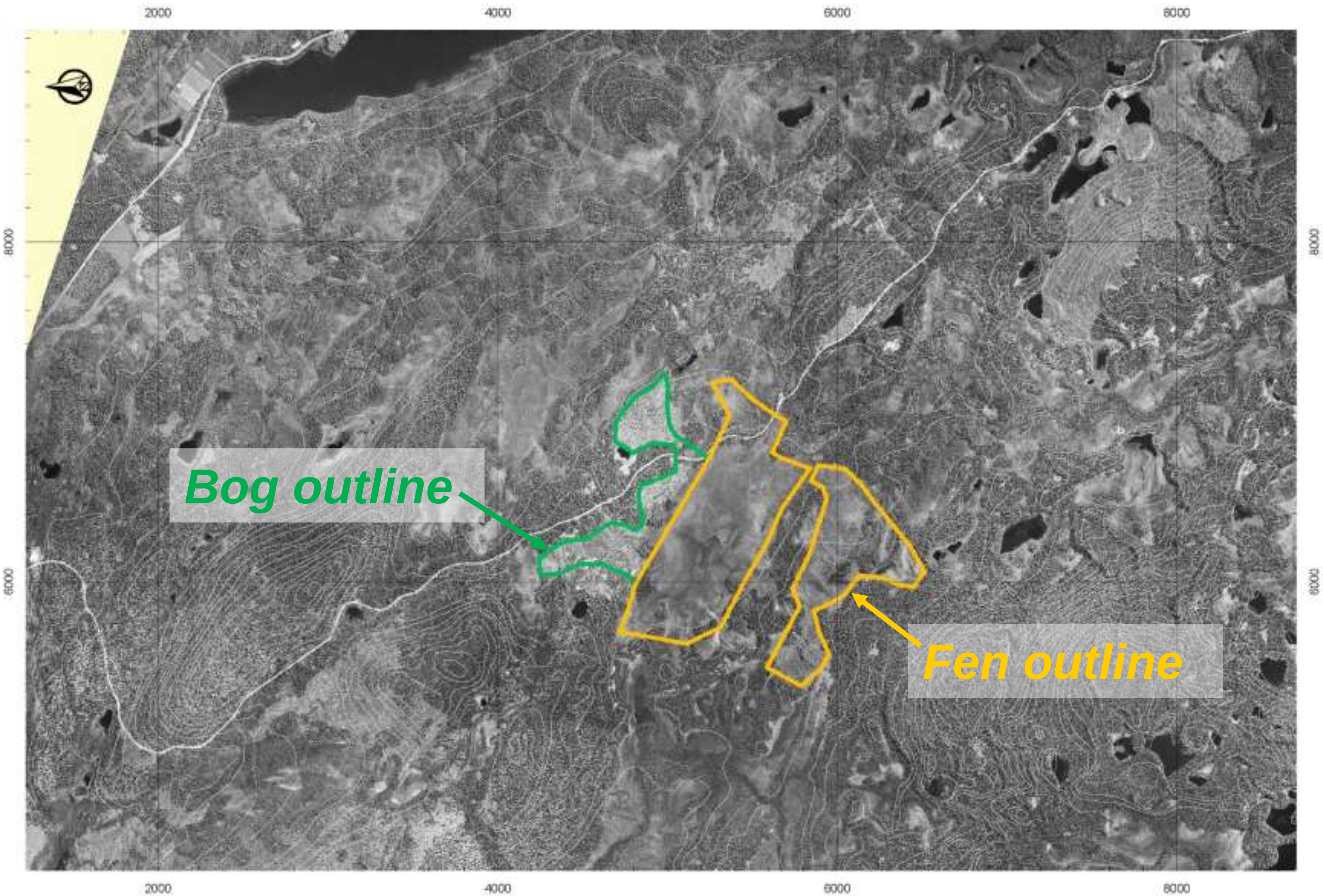

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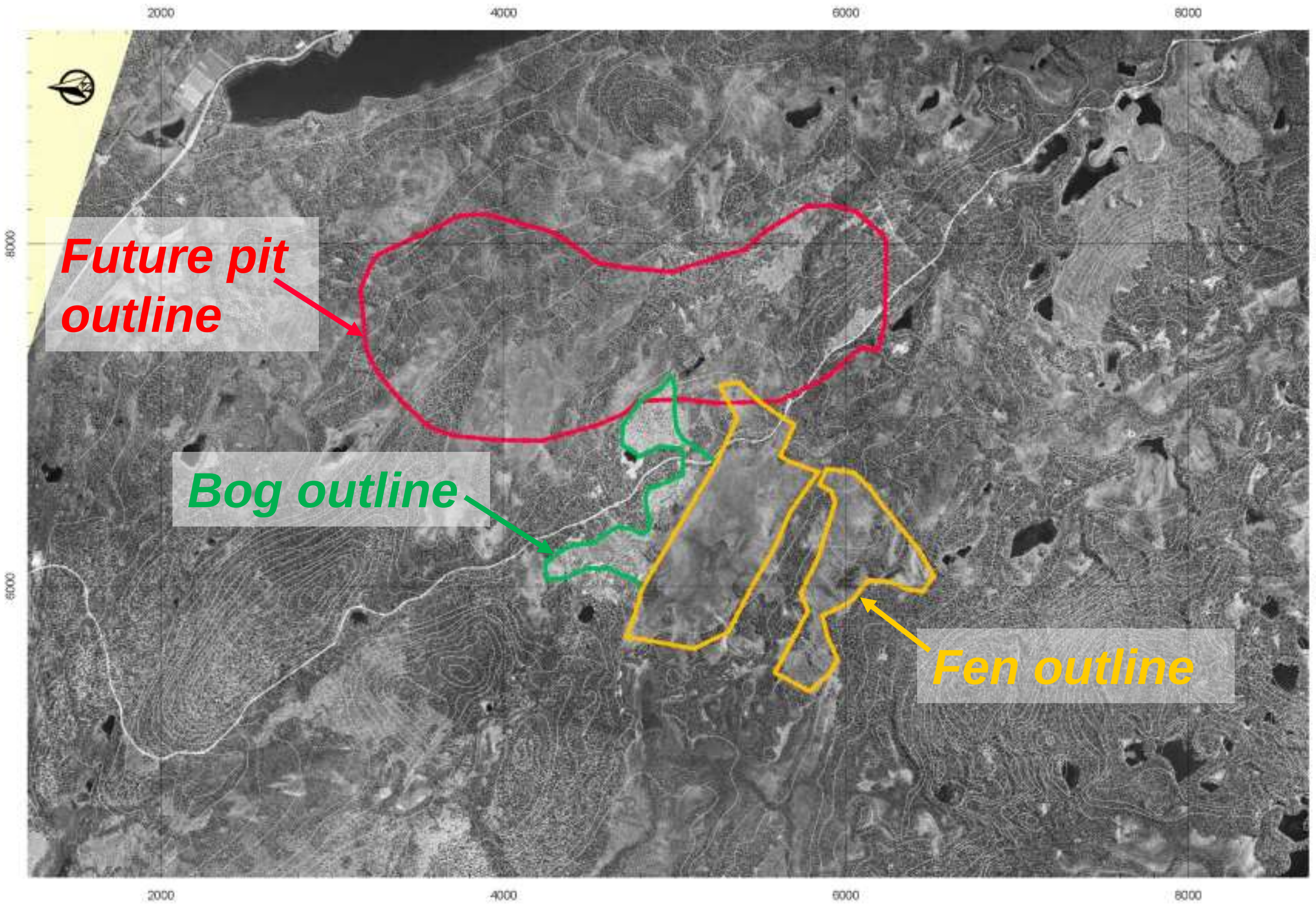

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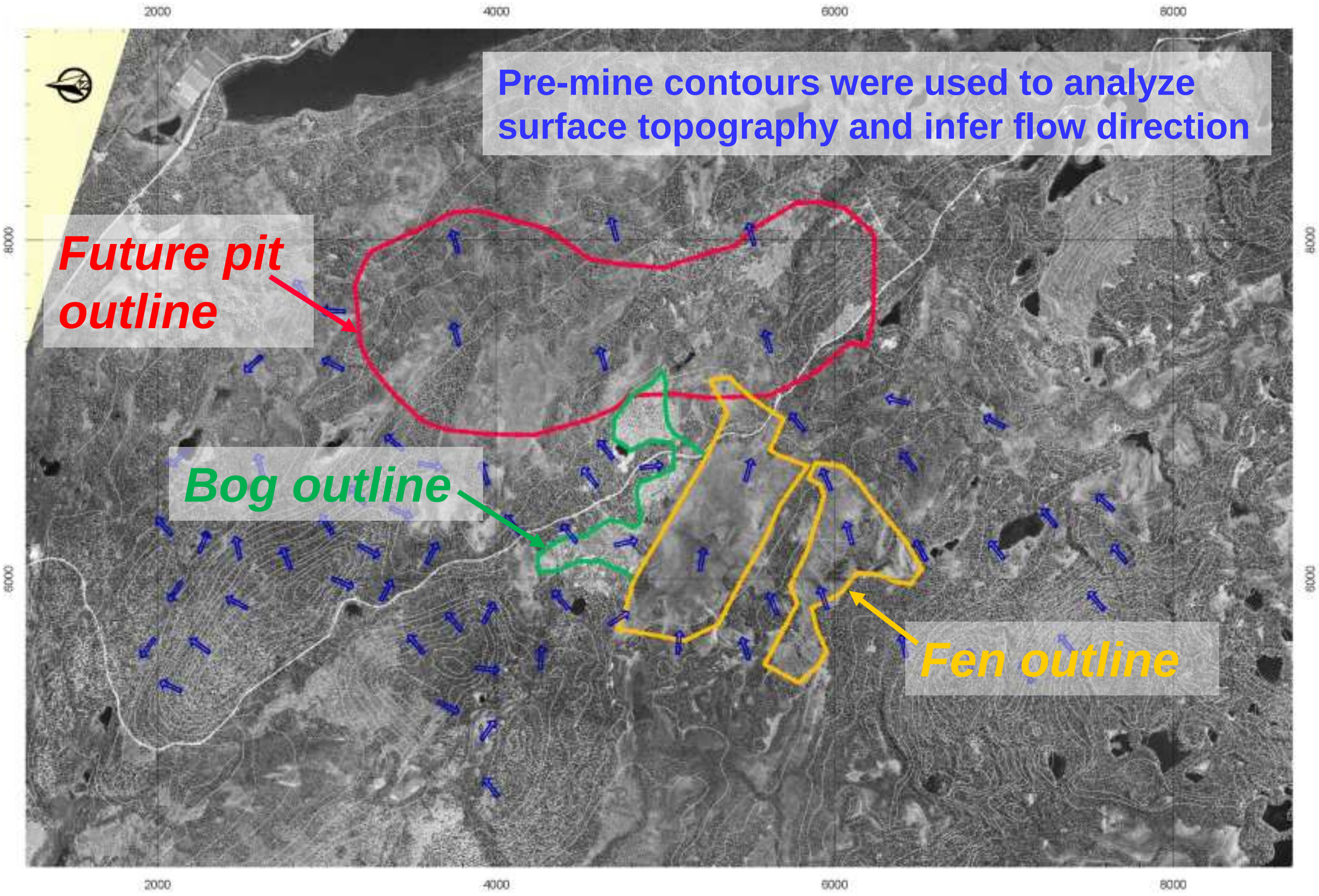

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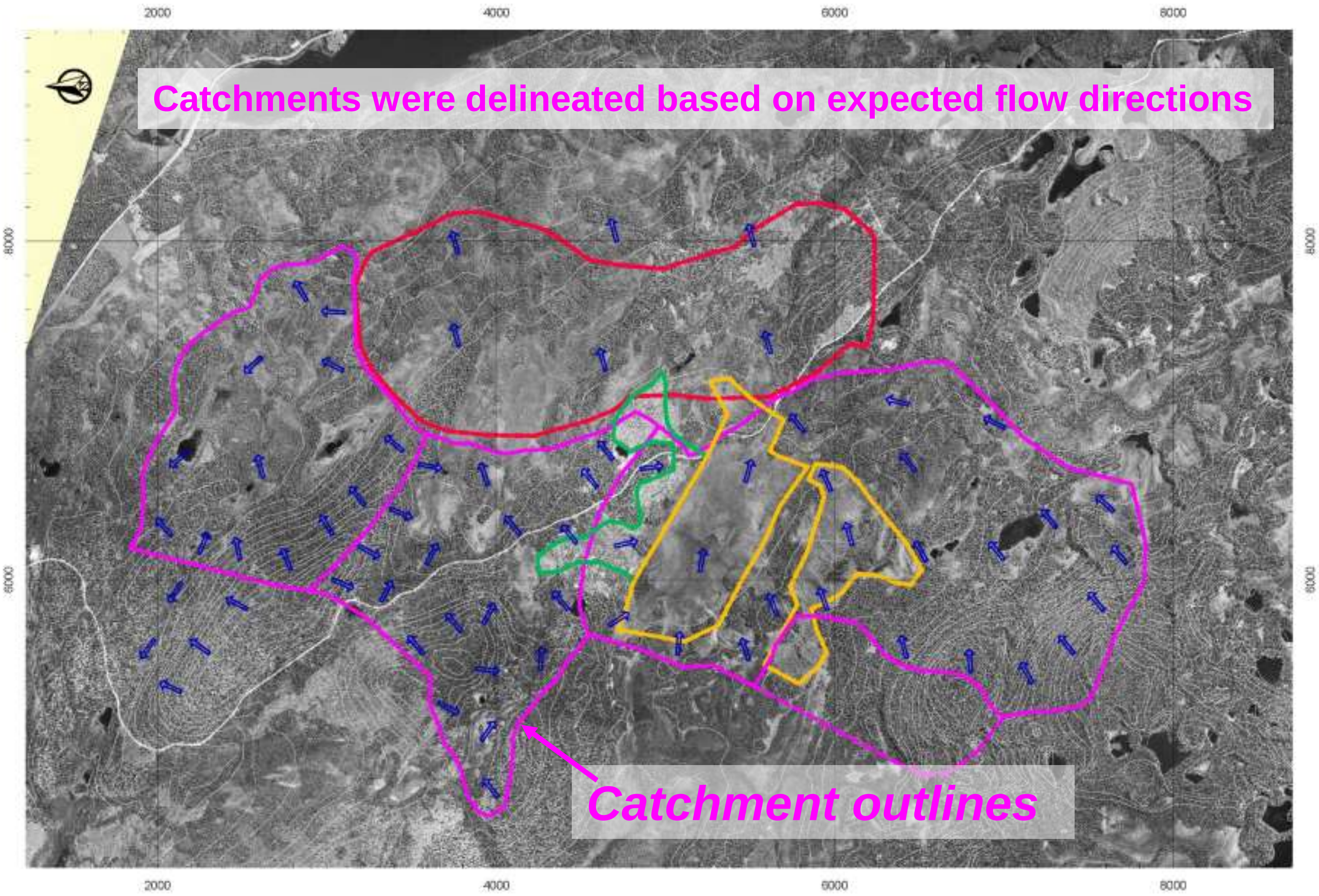

Water Monitoring Location 558

- **Majority of surface and shallow groundwater flow reports to water monitoring location 558, along T2-T4 collection channel**
- **Flow rate measurements and water quality data are available**
- **To understand Long-Term water quality, requires characterizing each flow component individually to understand current water quality**

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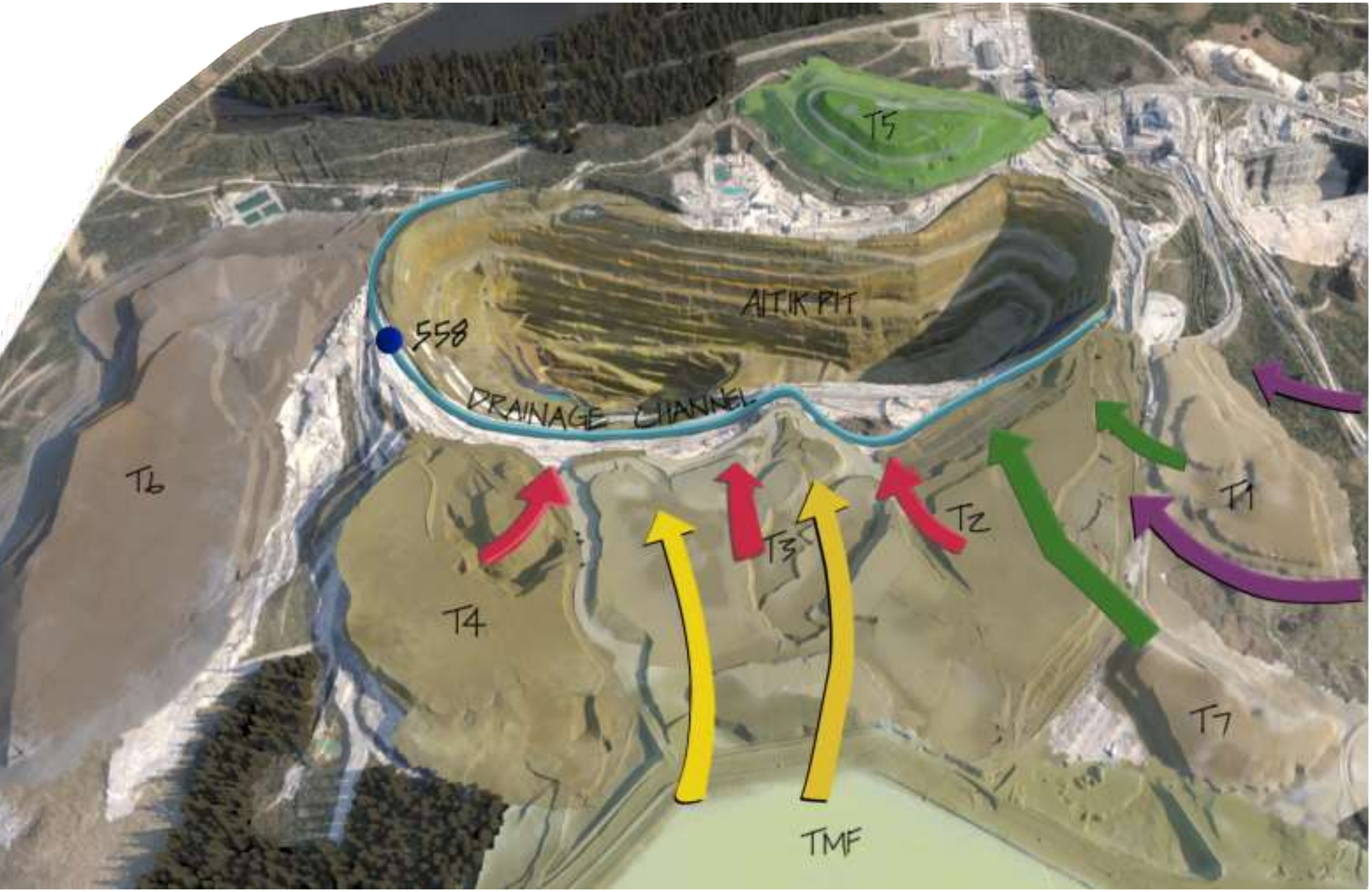
Monitoring Location 558 Flow Regime



- Infiltration and percolation through PAF WRSFs (T2, T3, T4) produces poor water quality
- Percolation through Environmental WRSFs (T1, T7) produces acceptable water quality
- TMF contributes a substantial flow volume
- Near surface natural ground flow contributes clean water

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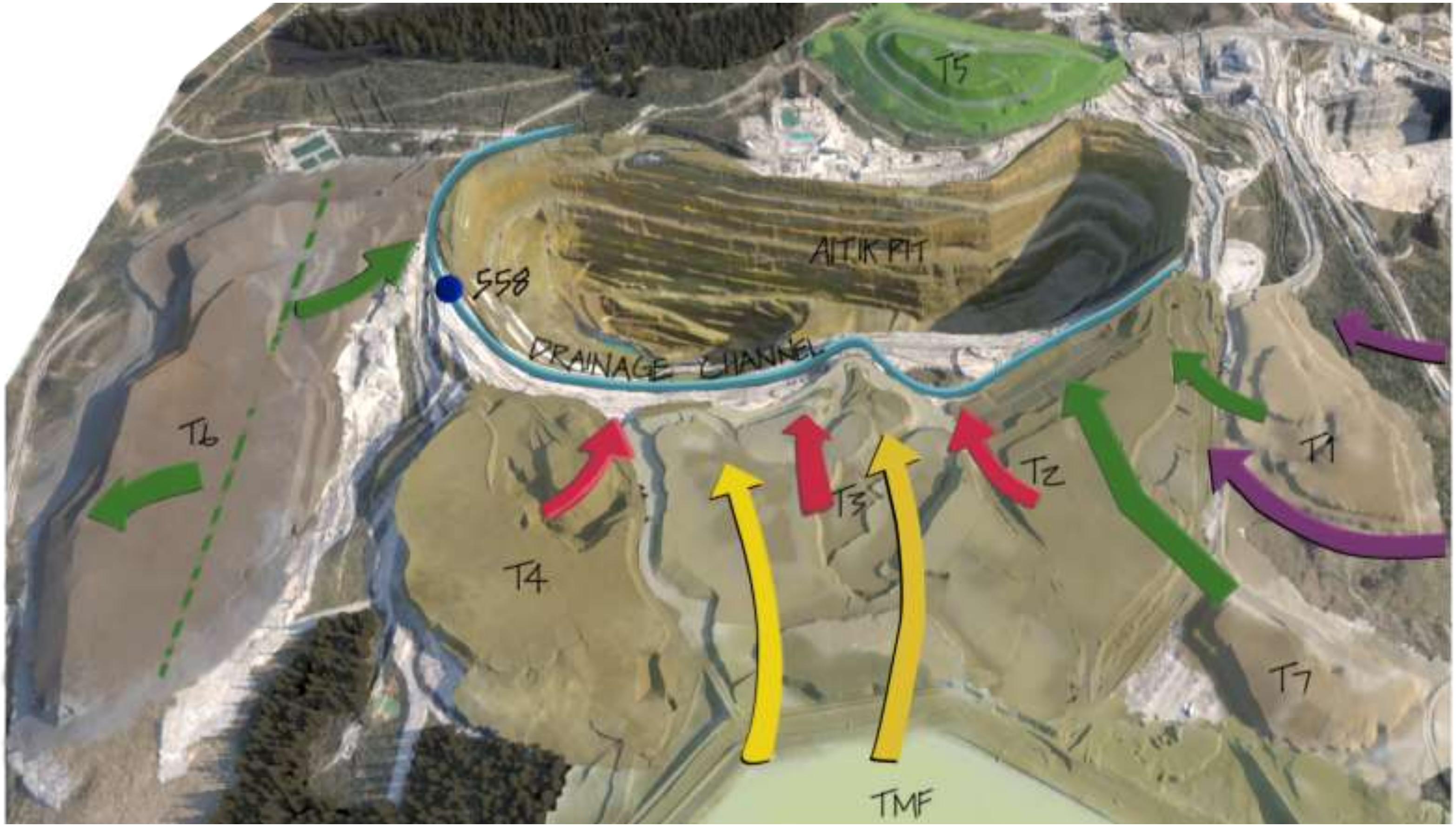
Site 558 Flow Regime

- **Seepage collected in T2-T4 drainage channel, which then reports to water monitoring location 558**
- **Majority of groundwater reports to open pit**



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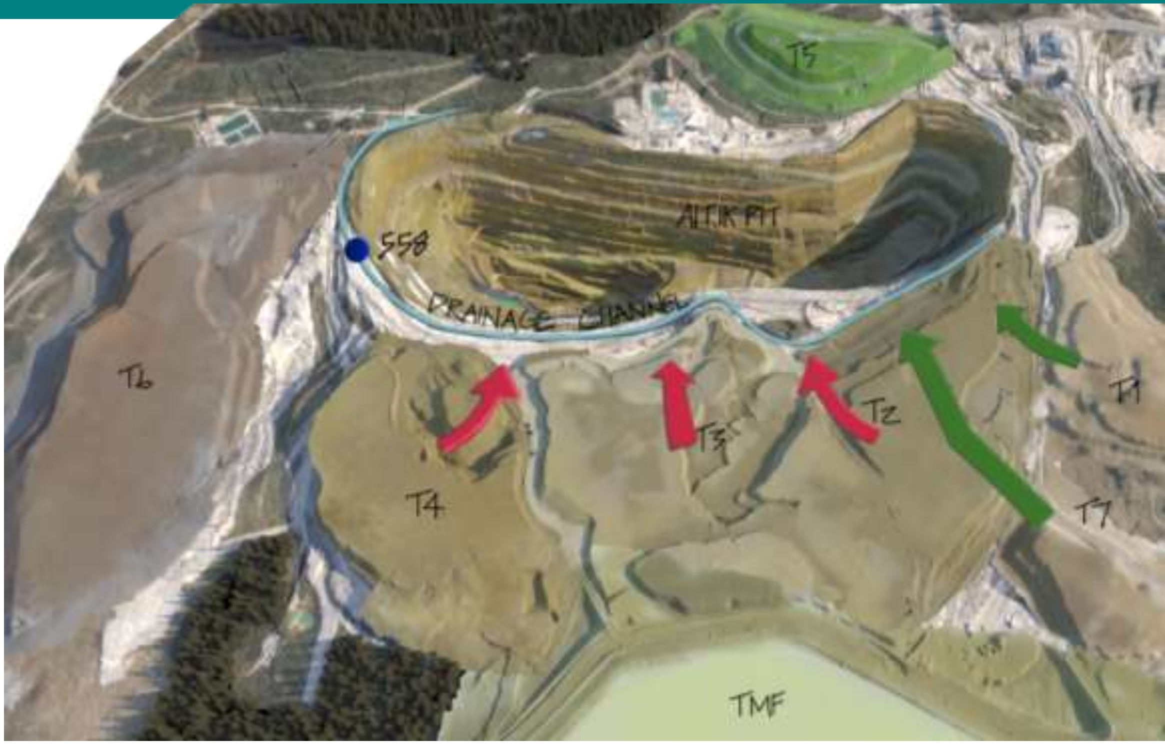
Water Model Characteristics

- **Estimation of WRSF basal seepage flow rates based on net percolation ~ 330 mm/yr**
  - **~55% of average annual precipitation calculated based on bare waste rock conditions**
- **WRSF flow rates based on annual net percolation x footprint area**



- **PAF WRSFs ~38 L/s**
  - **Flow occurs as basal seepage that reports to the surficial aquifer in underlying moraine layer**
  - **Need: Determine Water Quality**
- **Env. WRSFs ~10 L/s**
  - **Flow occurs as basal seepage that reports to the surficial aquifer in underlying moraine layer**
  - **Water quality based on weighted mean from T6, representative of T1 and T7**
    - pH ~ 6.9
    - Acidity ~0.2 mg/L
    - Cu ~ 0.007 mg/L
    - Al ~ 0.01 mg/L

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TMF Flow and Water Quality

- **TMF contributes substantial flow to collection channel**
- **Estimated contribution ranges from 43 to 100% of flow in T2-T4 channel from previous research studies at site**
- **~157 L/s**
  (70% of flow in T2-T4 channel)
  based on Dupuit analysis of anticipated phreatic surface in TMF and head gradient of flow path through PAF WRSF

- **Water quality from samples (mean of two representative data sources)**
  - pH ~ 4.9
  - Acidity ~ 79 mg/L
  - Cu ~ 2.7 mg/L
  - Al ~ 12 mg/L

Near Surface Flow and Water Quality

- **Flow rate ~22 L/s based on difference between measured flow at water monitoring location 558 and other flow component estimates (base flow)**
- **Water Quality from near surface water quality provided by Lorax (2015), based on water quality monitoring location 522 (close to Myllyjoki Creek)**
  - pH ~ 6.8
  - Acidity ~ 2.5 mg/L
  - Cu ~ 0.002 mg/L
  - Al ~ 0.02 mg/L

Derivation of WRSF Waste Rock Characteristics
Mineralogy and Acid Base Accounting

FIELD BASED INVESTIGATIONS

Determine Current PAF WRSF Source Term (pore-water quality)

GEOCHEMICAL MODELLING

PAF WRSF Source Term

Summary of Key Parameters

Component	Concentration (mg/L)
pH	3.5
Acidity (as $CaCO_3$)	1,490
HCO_3^-	1.2
NH_4^+	0.37
NO_3^-	19.3
NO_2^-	0.01
Cu^{2+}	69
Zn^{2+}	9.5
Ni^{2+}	0.79
Na^+	91
K^+	59
Ca^{2+}	729
Mg^{2+}	192
Sr^{2+}	3.3
Al^{3+}	222
Fe^{3+}	14
Mn^{2+}	40
SO_4^{2-}	3,830

Contaminant Load = Flow Rate x Water Quality

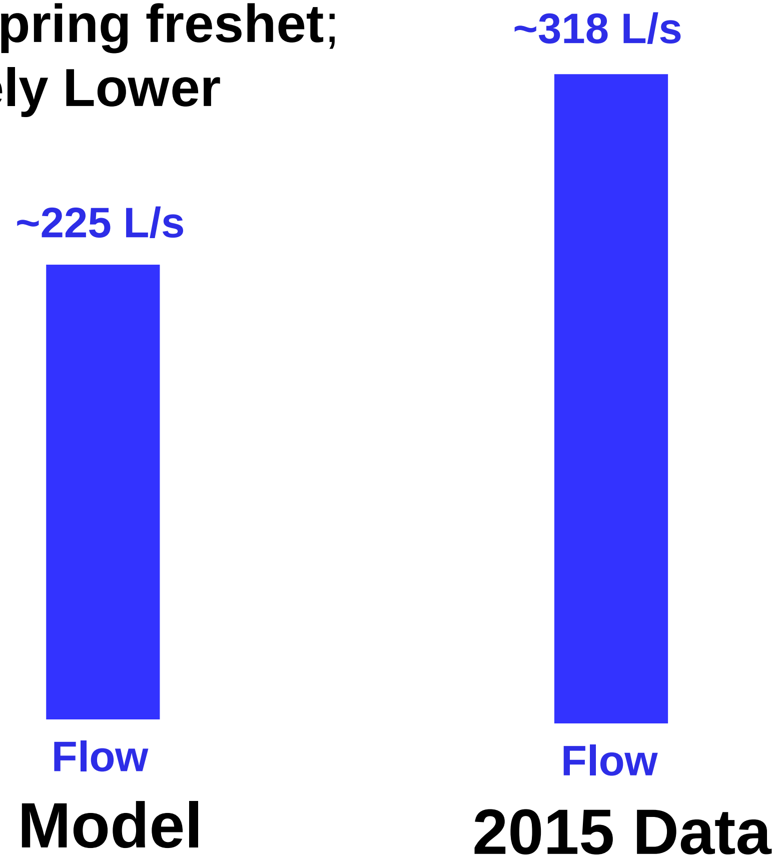
1,490 mg/L Acidity x 37.5 L/s ~ 56,000 mg/s
or ~1,760 tonnes acidity/year

PAF WRSF contributes dominant source of acidity to water monitoring location 558 (558: ~2,000 tonnes/year).

Reducing load from the PAF WRSF will significantly reduce overall catchment load.

2015 Flow Measurements

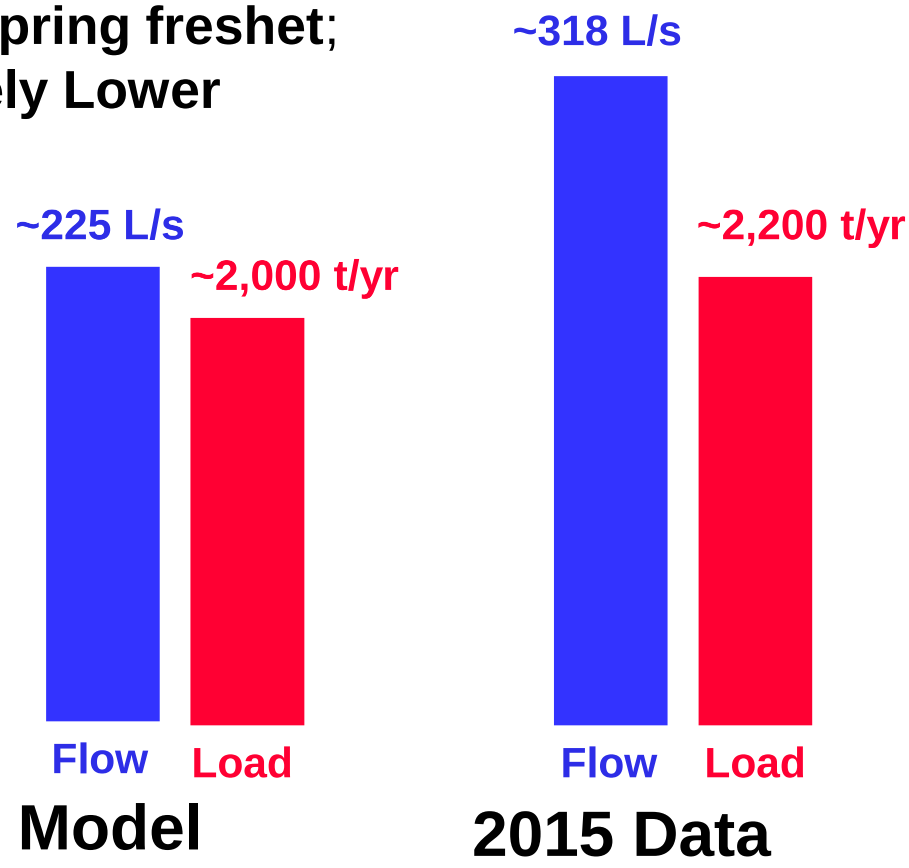
- **Additional flow modelling conducted in 2015.**
  - **Total average flow measurement at location 558 between February and May 2015 was 318 L/s, higher than 225 L/s used in model**
  - **2015 flow rate influenced by spring freshet; Therefore Ave. Flow Rate Likely Lower**



2015 Flow Measurements

- **Additional flow modelling conducted in 2015.**
  - **Total average flow measurement at location 558 between February and May 2015 was 318 L/s, higher than 225 L/s used in model**
  - **2015 flow rate influenced by spring freshet; Therefore Ave. Flow Rate Likely Lower**
- **However, Load is a critical parameter in understanding effects**
- **Total acidity used in model ~2,000 tonnes/year**
- **Total acidity associated with 2015 measurements is ~10% higher**

Confirms model is reasonable

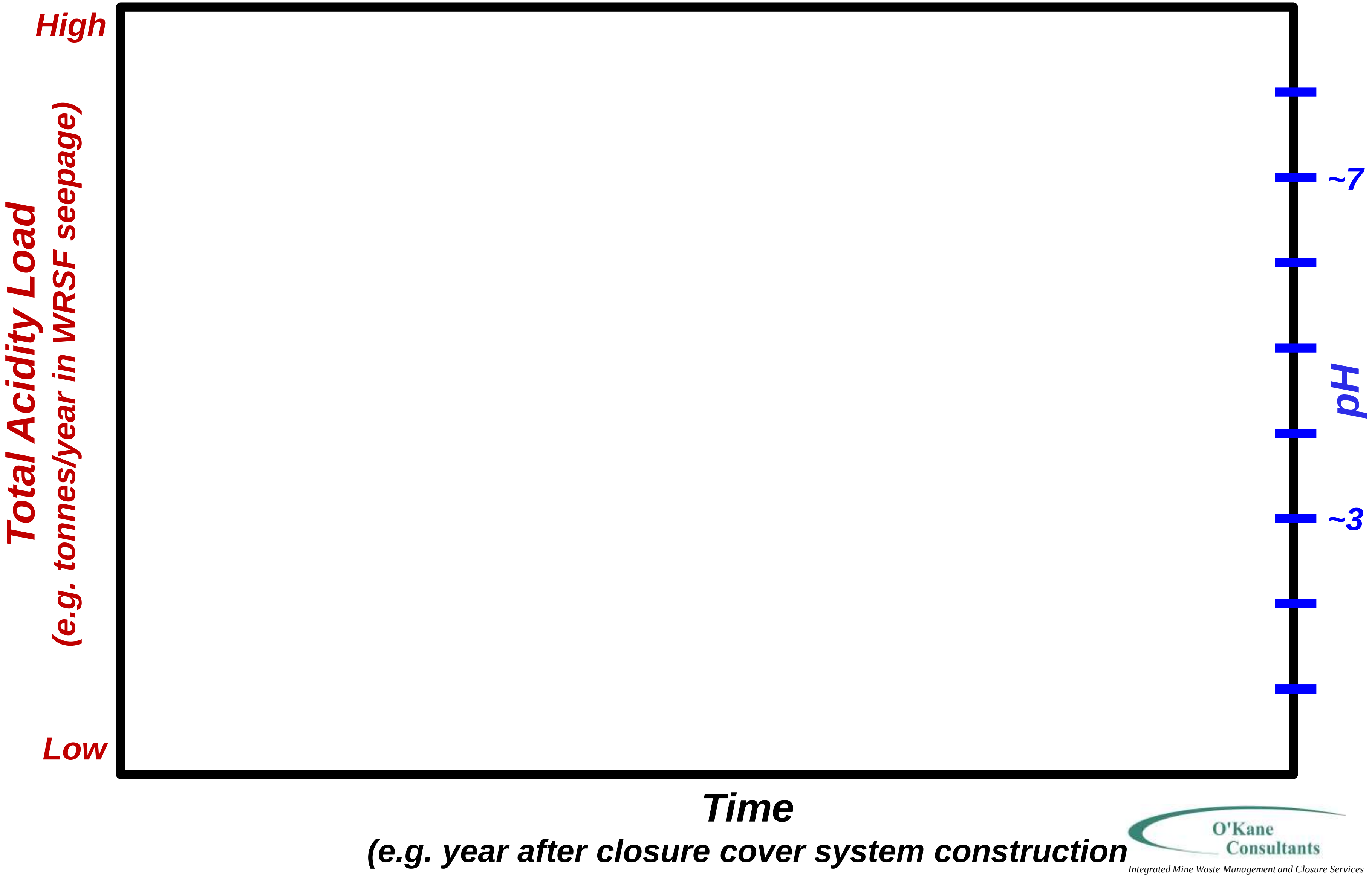


EVALUATION OF POST CLOSURE WRSF SEEPAGE WATER QUALITY

Three key components of long-term water quality model:

1. **Current water quality of the PAF WRSF**
2. **Long term water quality (geochemical maturity)**
3. **Transition water quality (during flushing of stored oxidation products)**

Long-Term WRSF Seepage Water Quality Methodology



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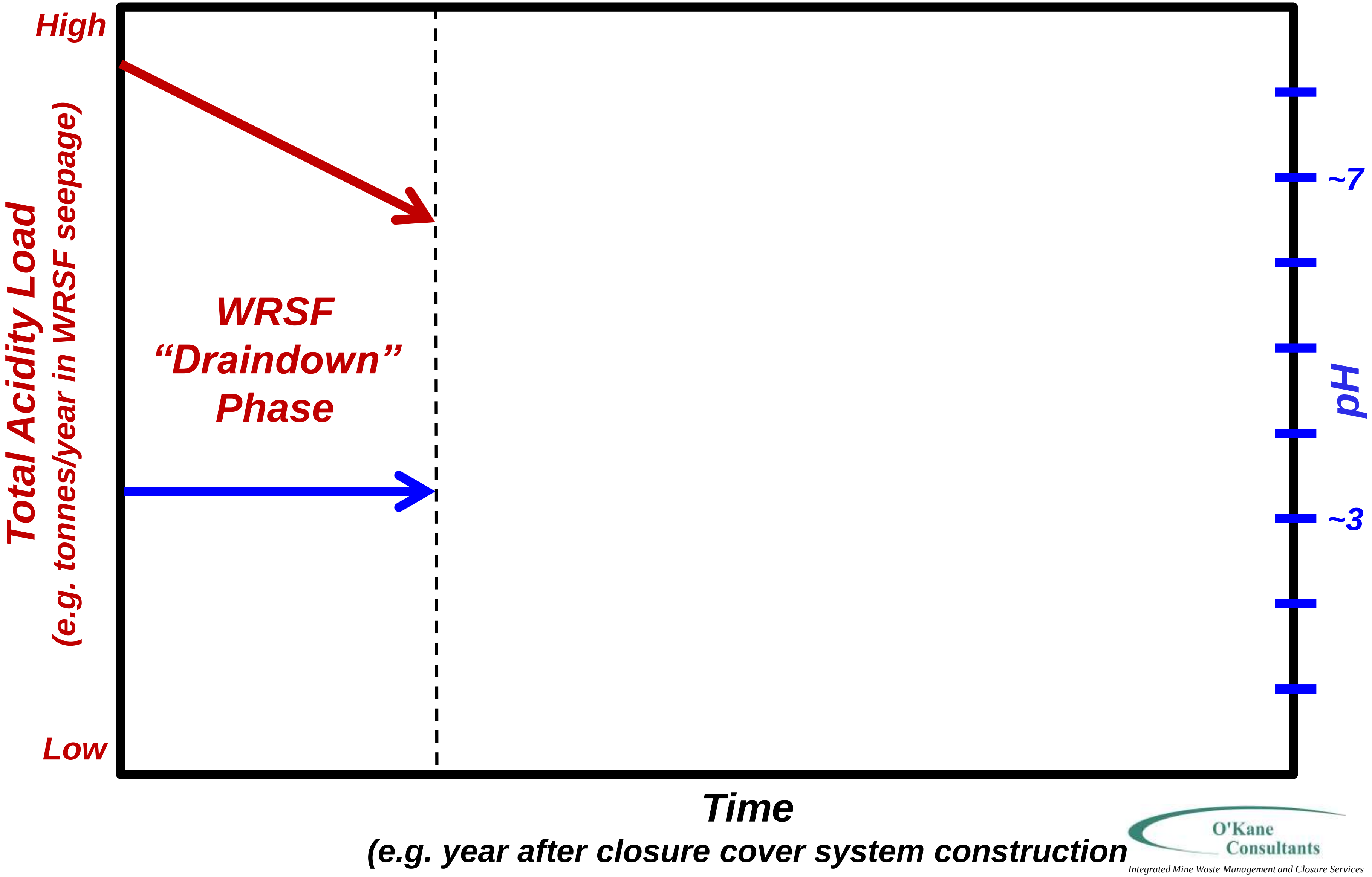
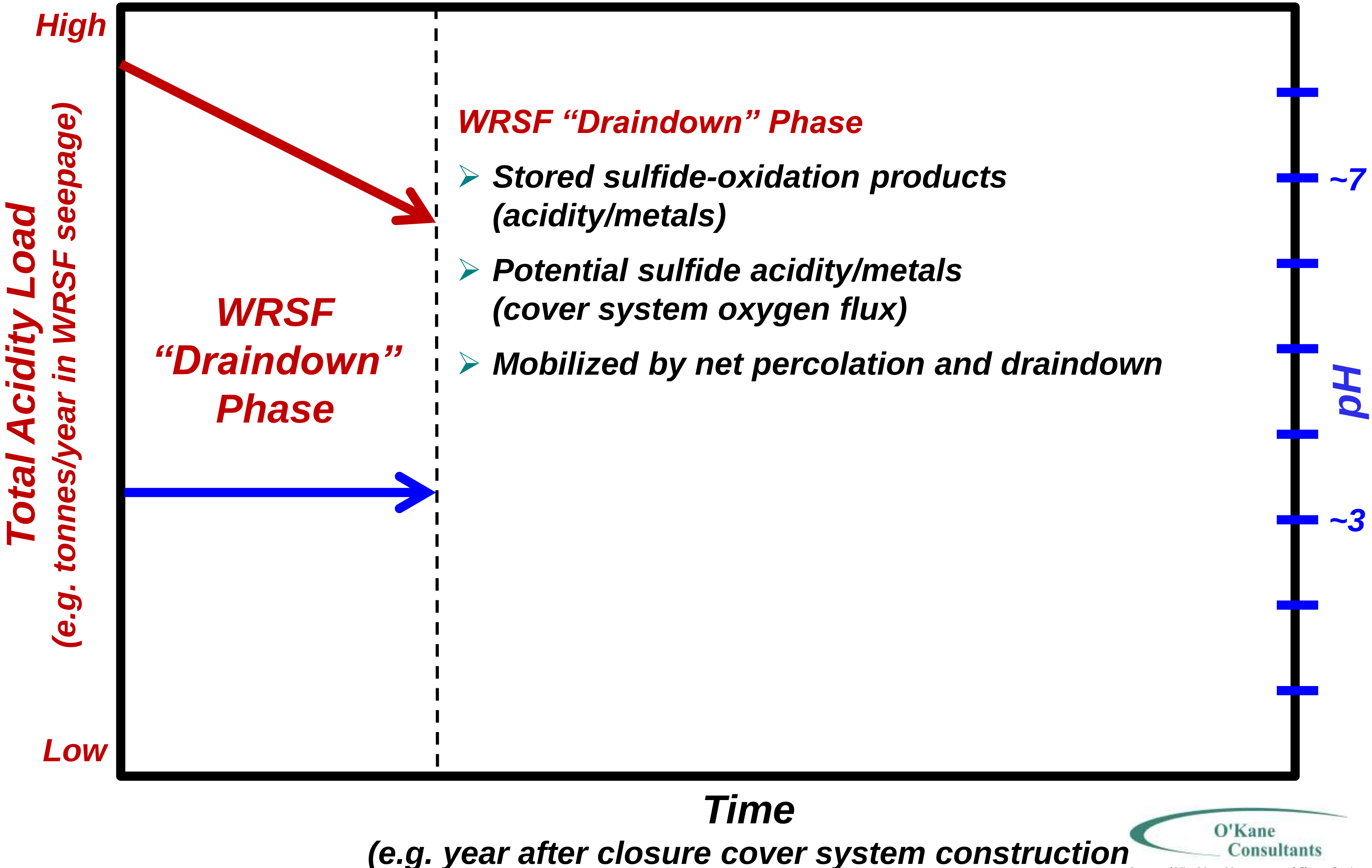


Long-Term WRSF Seepage Water Quality Methodology



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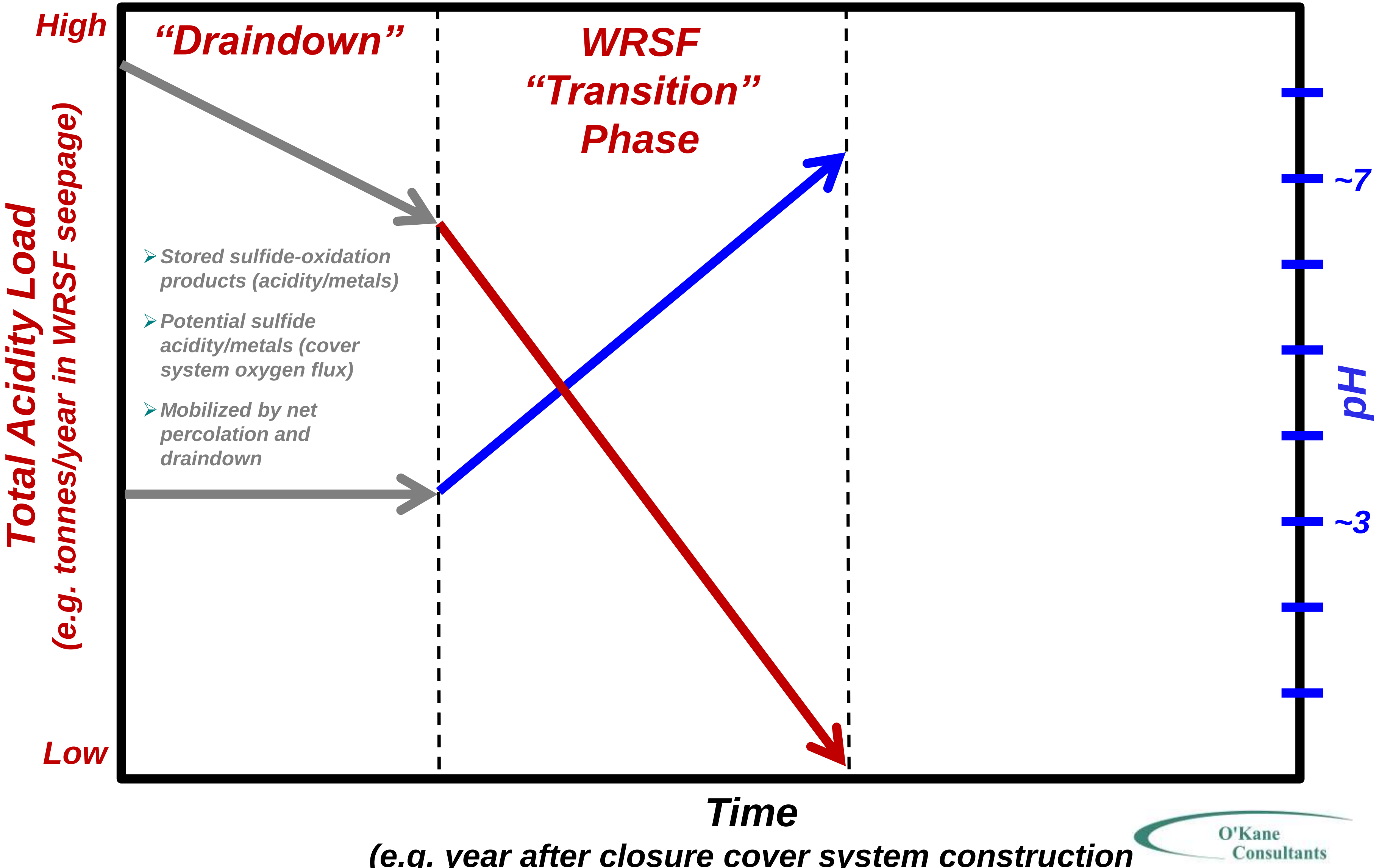

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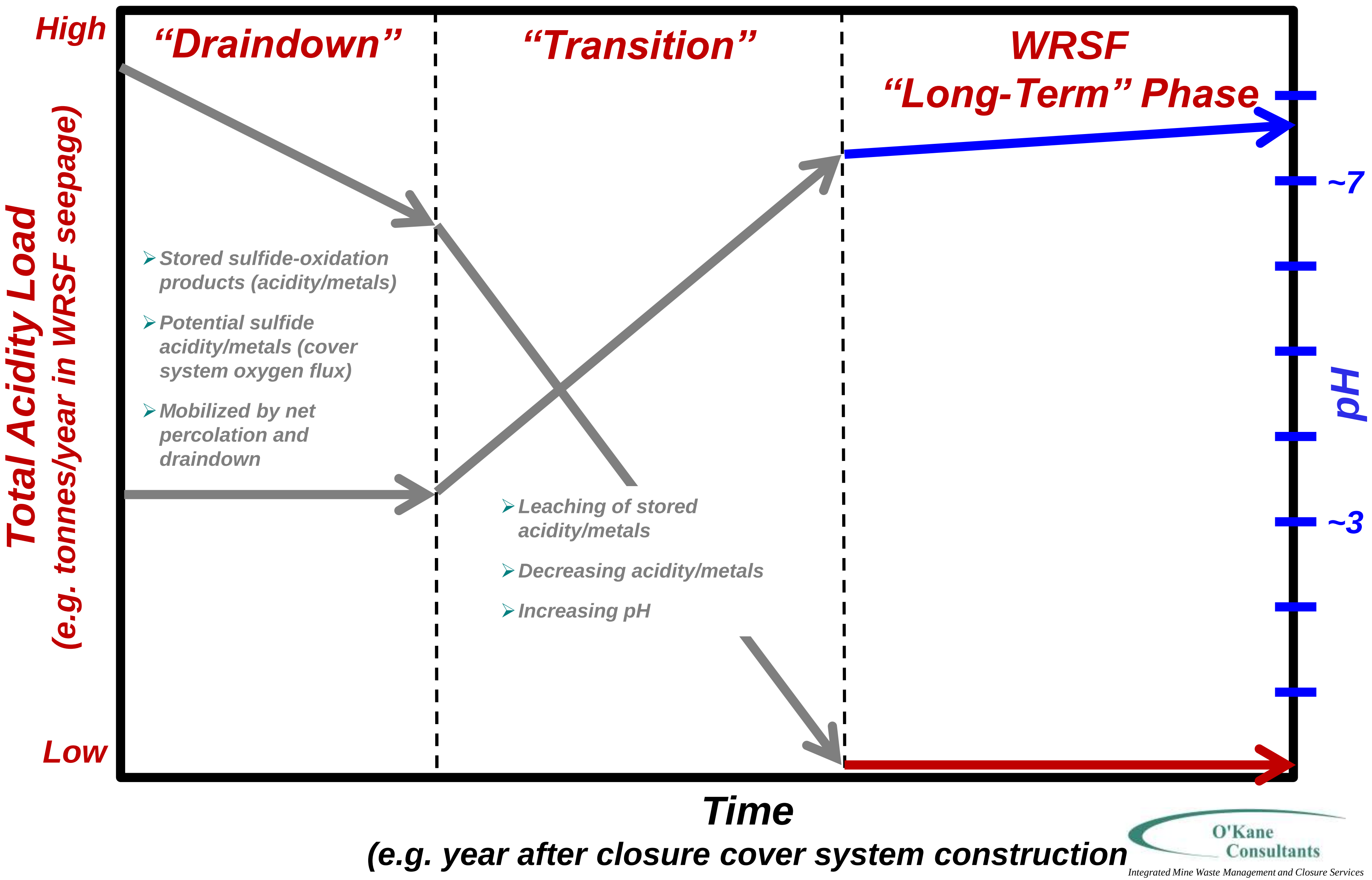

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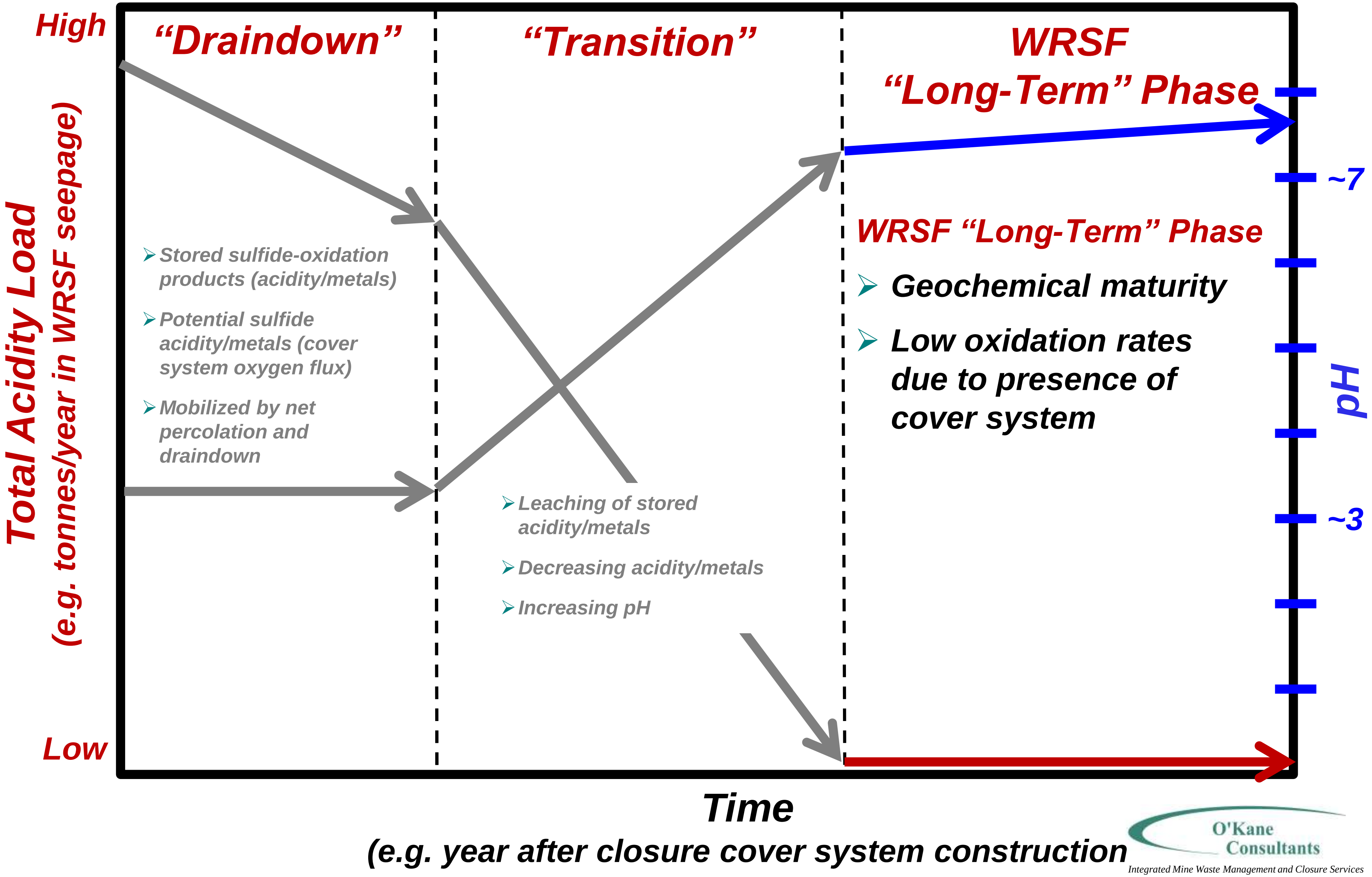

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Long-Term WRSF Seepage Water Quality Methodology

High

Low

Degree of Saturation
(of Waste Rock Material)

“Draindown”	“Transition”	“Long-Term”
➢ *But the waste rock **does not** “wet up” to the point where S = 100%* ➢ *Then, due to surface infiltration, the waste rock “wets up”* ➢ ***Initially**, waste rock, when placed, has a **low** water content (degree of saturation (**S%**)*		

Time
(e.g. year after closure cover system construction

Long-Term WRSF Seepage Water Quality Methodology

High

"Draindown" | ***"Transition"*** | ***"Long-Term"***

- ***When the cover system is placed, the waste rock "drains down"***
- ***Due to the net percolation rate being lower than initial surface infiltration rate***

Degree of Saturation
(of Waste Rock Material)

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Time

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Long-Term WRSF Seepage Water Quality Methodology

High

"Draindown" | "Transition" | "Long-Term"

- When the cover system is placed, the waste rock ***"drains down"***
- Due to the net percolation rate being lower than initial surface infiltration rate

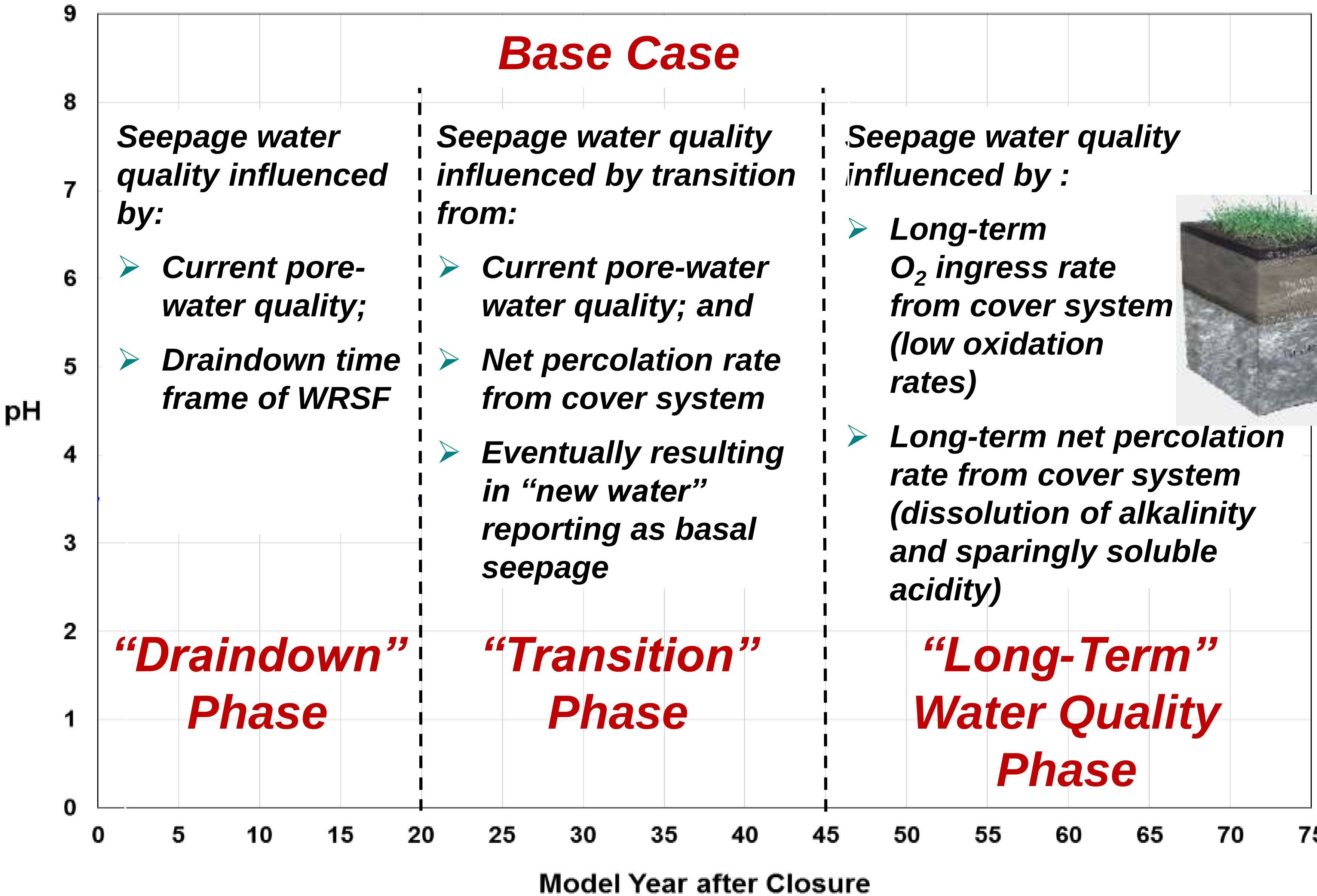
Degree of Saturation
(of Waste Rock Material)

- And, the system reaches a new quasi steady-state (lower S%) where WRSF seepage flow is a function of the cover system

Low

Time
(e.g. year after closure cover system construction

Long-Term WRSF Seepage Water Quality Results



Base Case

"Draindown" Phase

Seepage water quality influenced by:

- *Current pore-water quality;*
- *Draindown time frame of WRSF*

"Transition" Phase

Seepage water quality influenced by transition from:

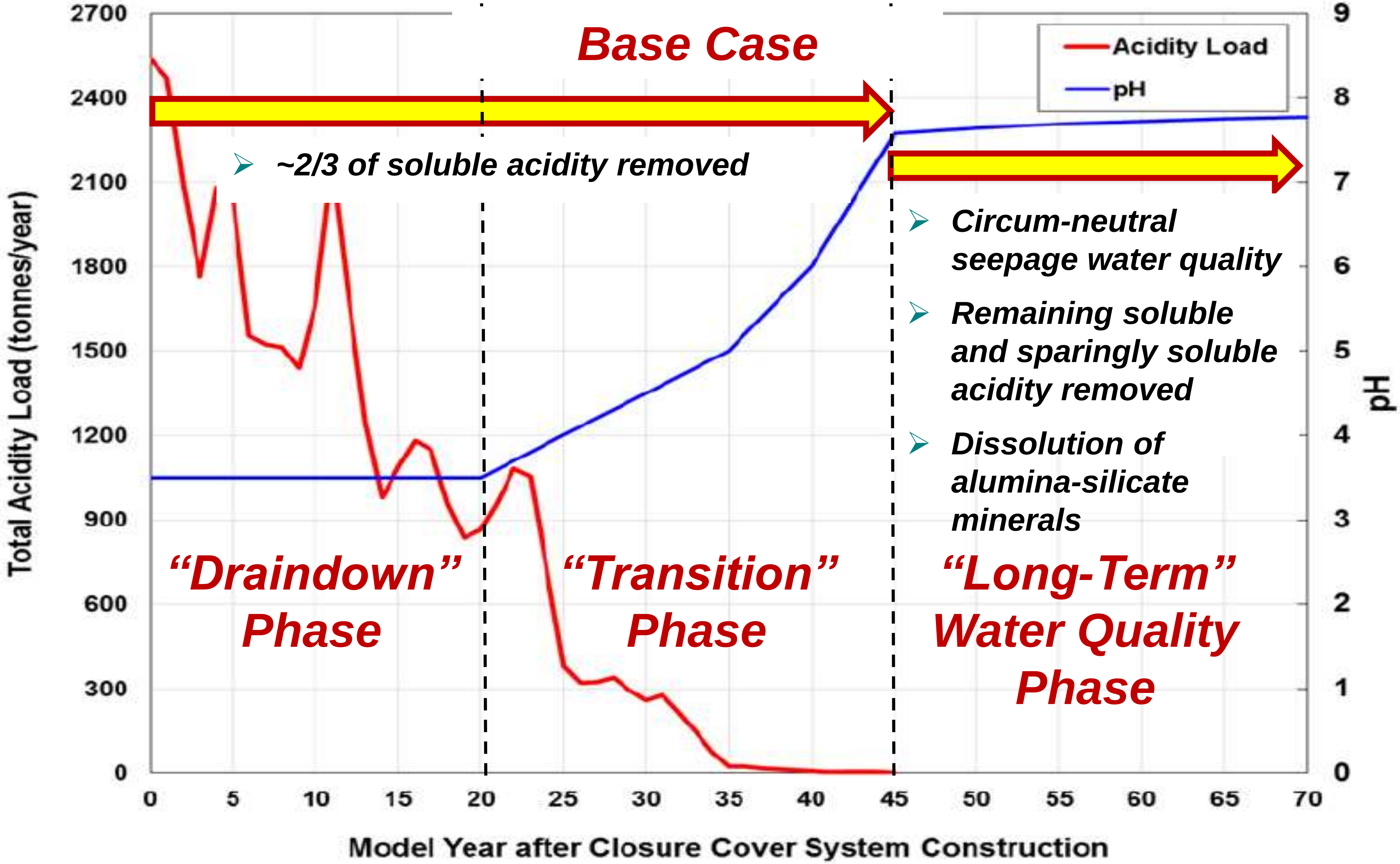
- *Current pore-water water quality; and*
- *Net percolation rate from cover system*
- *Eventually resulting in "new water" reporting as basal seepage*

"Long-Term" Water Quality Phase

Seepage water quality influenced by :

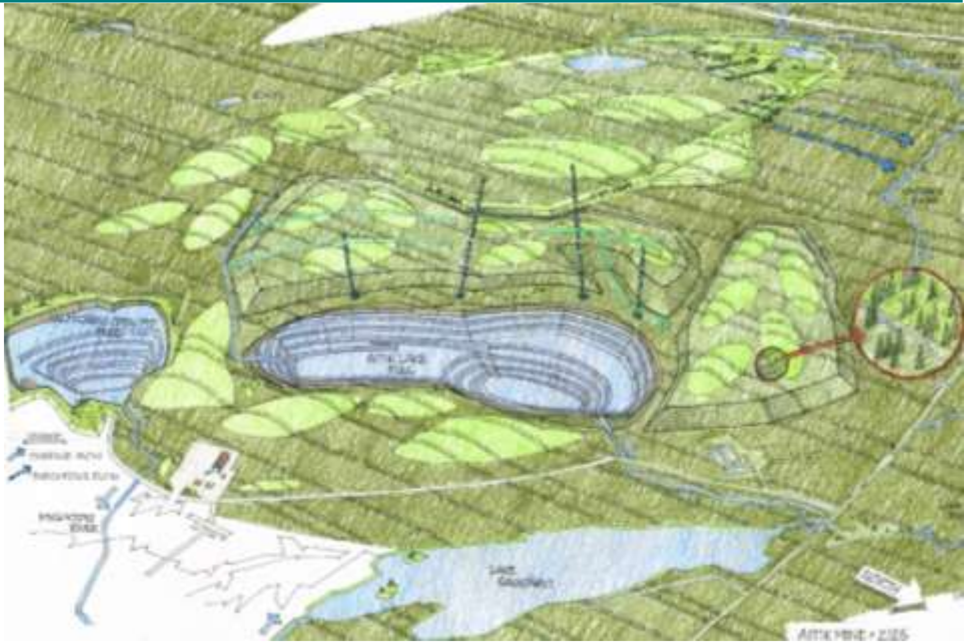
- *Long-term O_2 ingress rate from cover system (low oxidation rates)*
- *Long-term net percolation rate from cover system (dissolution of alkalinity and sparingly soluble acidity)*

Long-Term WRSF Seepage Water Quality Results



Long-Term WRSF Seepage Water Quality Results

- ***Base Case:***
  - ➢ ***Long-term WRSF seepage meets requirements for Pit Lake performance and Recipient water quality***



- ***Risk Management / Opportunities:***
  - ➢ ***Prior to Implementation***
  - ➢ ***FMEA informs on managing risk and assessing opportunities to optimize design through additional study, work, and research***

Thank You!

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