Forecasting Long-Term Water Quality After Closure: Boliden Aitik Cu mine

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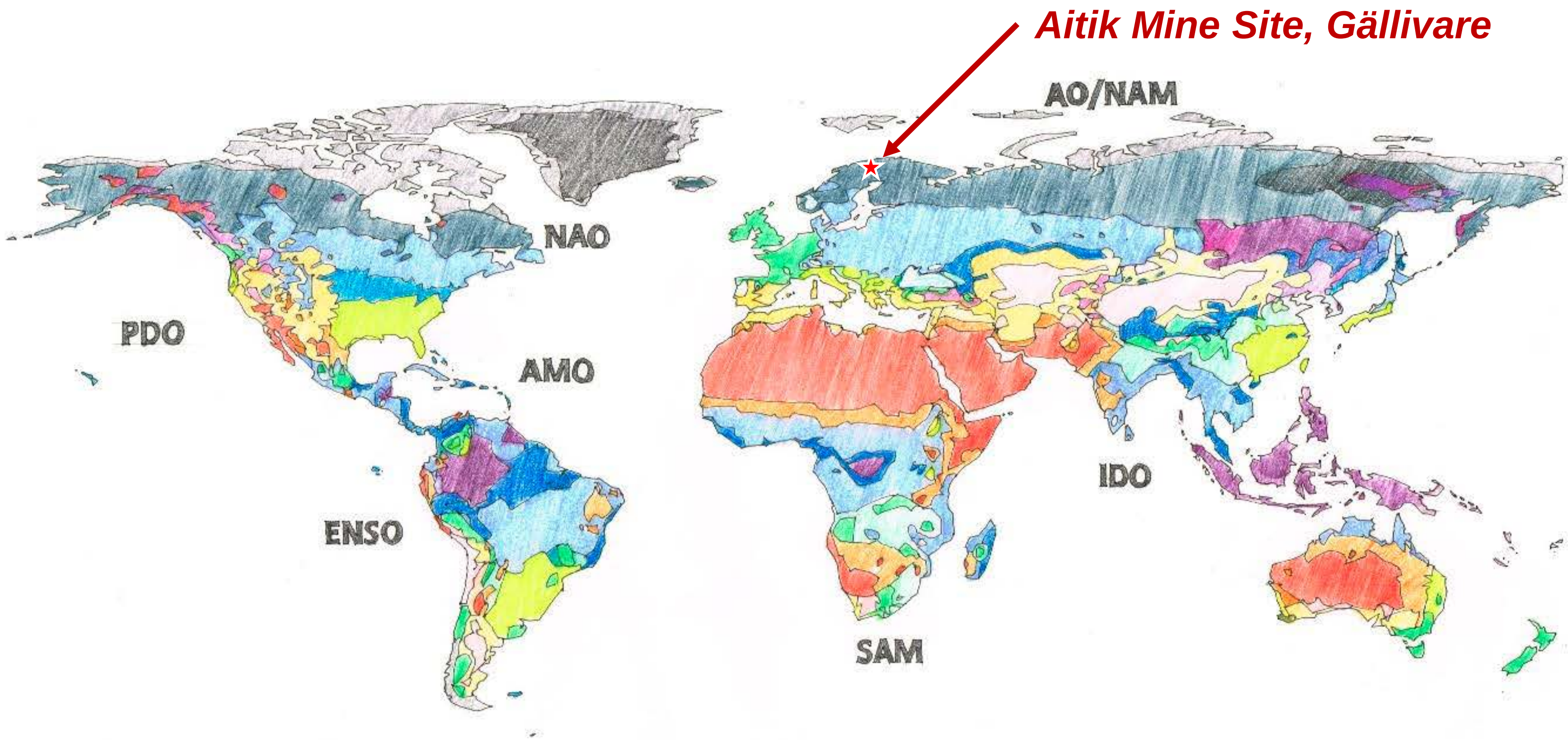
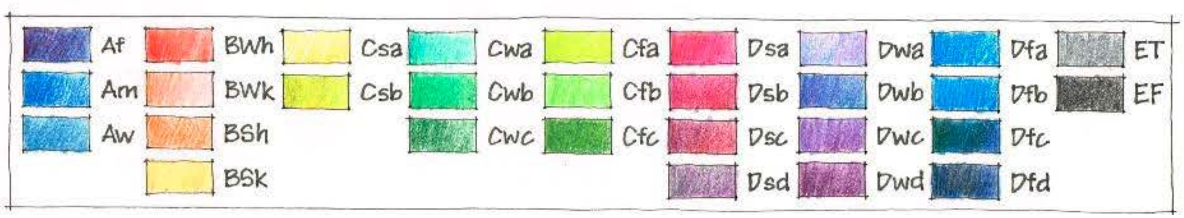
Aitik Boliden – Presentation Overview

The main objectives of the WRSF program were to understand the long-term water quality of WRSF seepage for the purpose of determining environmental risk at closure.

- **Develop a flow model for the WRSF area**
- **Determine PAF (potentially acid forming) WRSF basal seepage component – current water quality and flow rate**
- **Characterize the geochemistry of the PAF WRSF**
- **Derive other inputs for understanding long-term water quality**
- **Determine net percolation and oxygen flux into WRSFs**
- **Develop a long-term water quality model for the WRSFs**



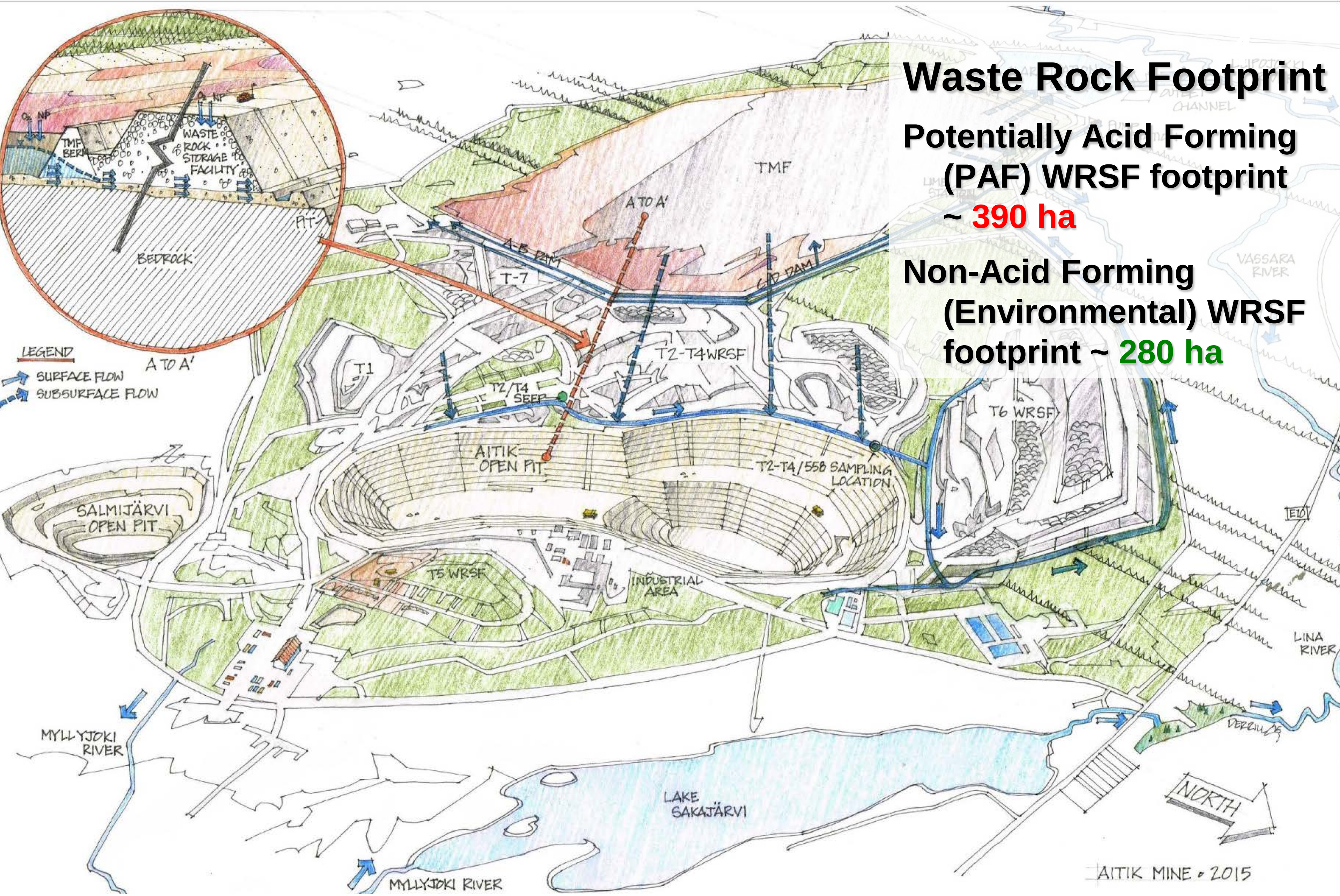
Köppen–Geiger climate classification system



Waste Rock Footprint

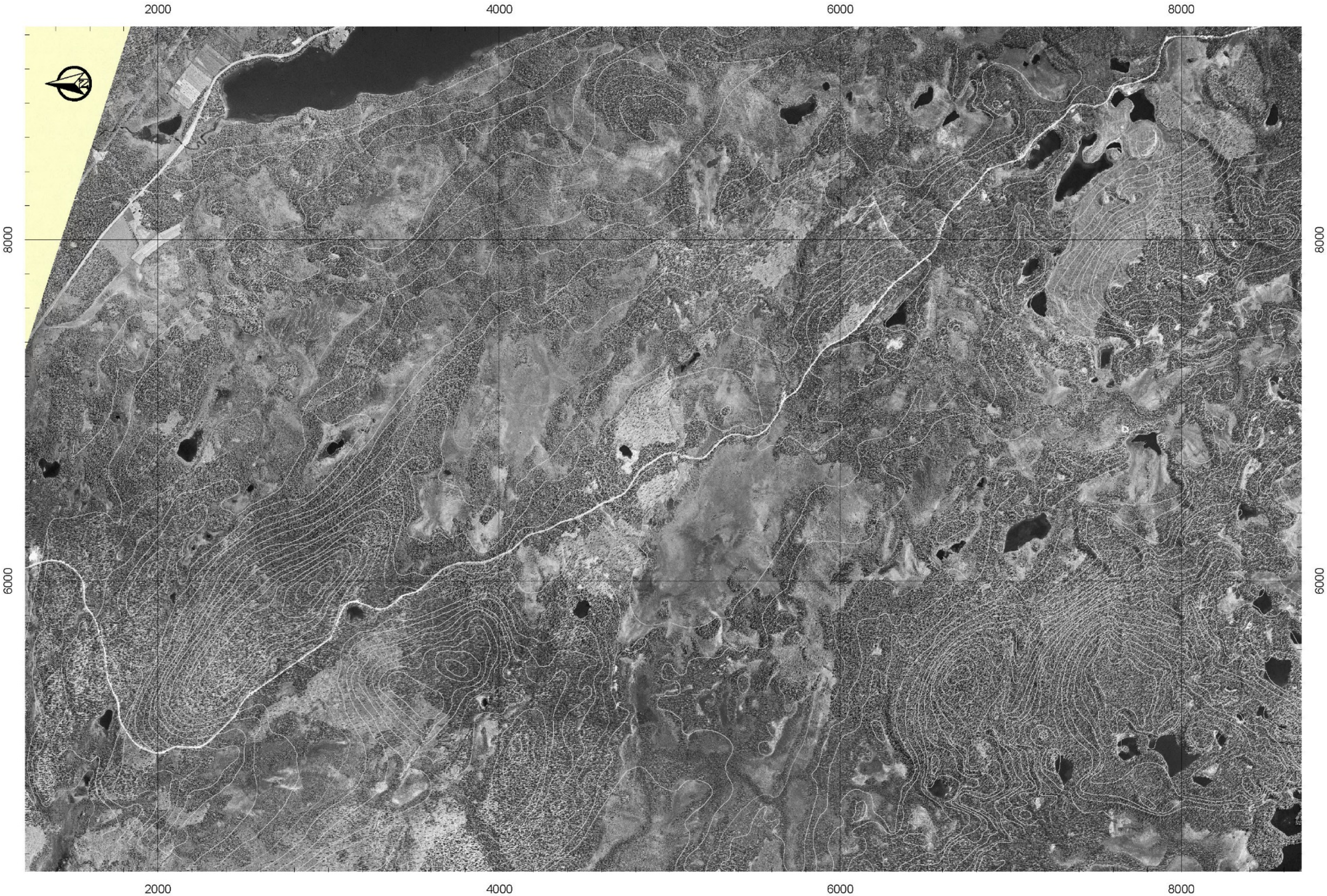
Potentially Acid Forming (PAF) WRSF footprint ~ 390 ha

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

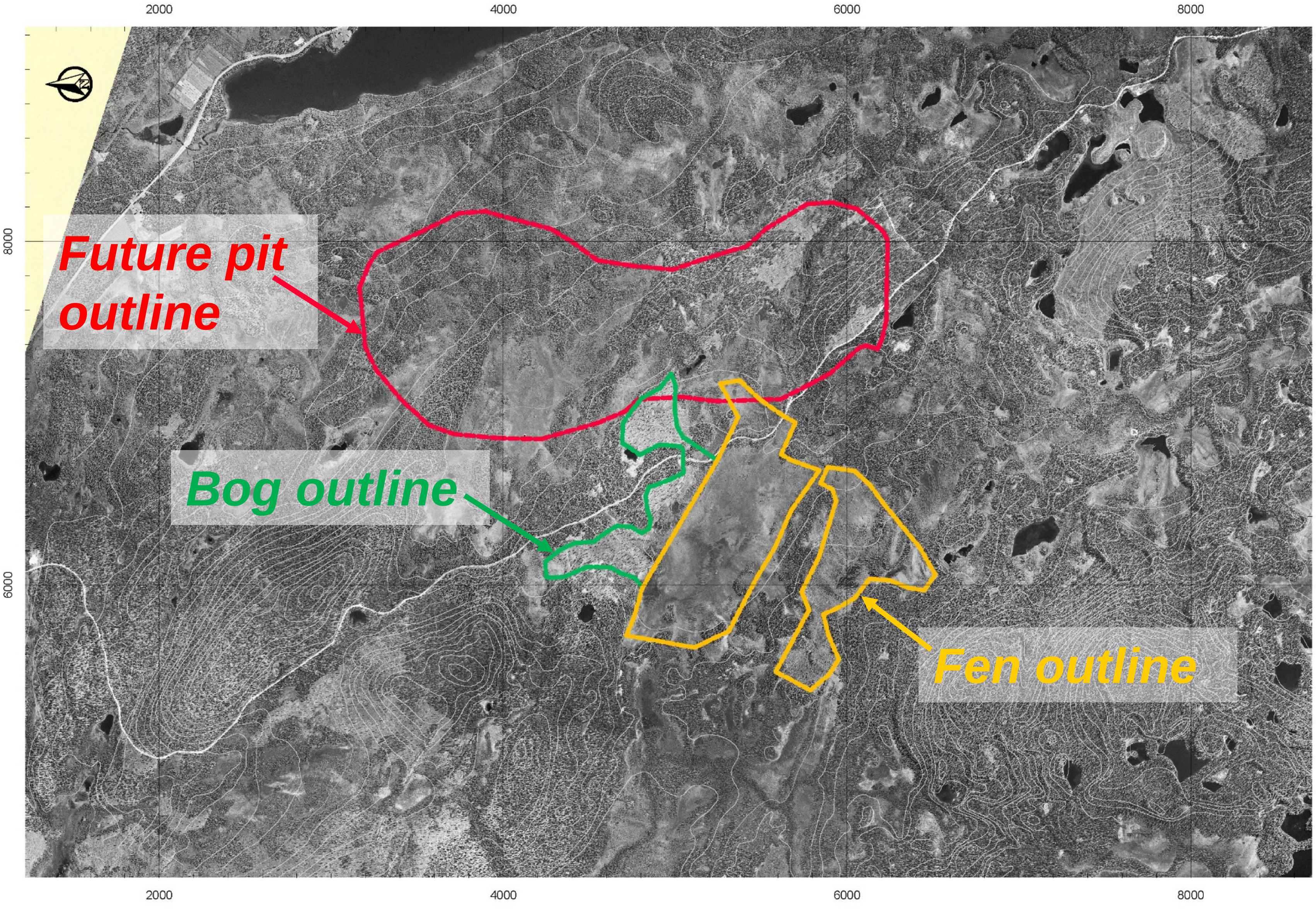


CONCEPTUAL SITE FLOW MODEL

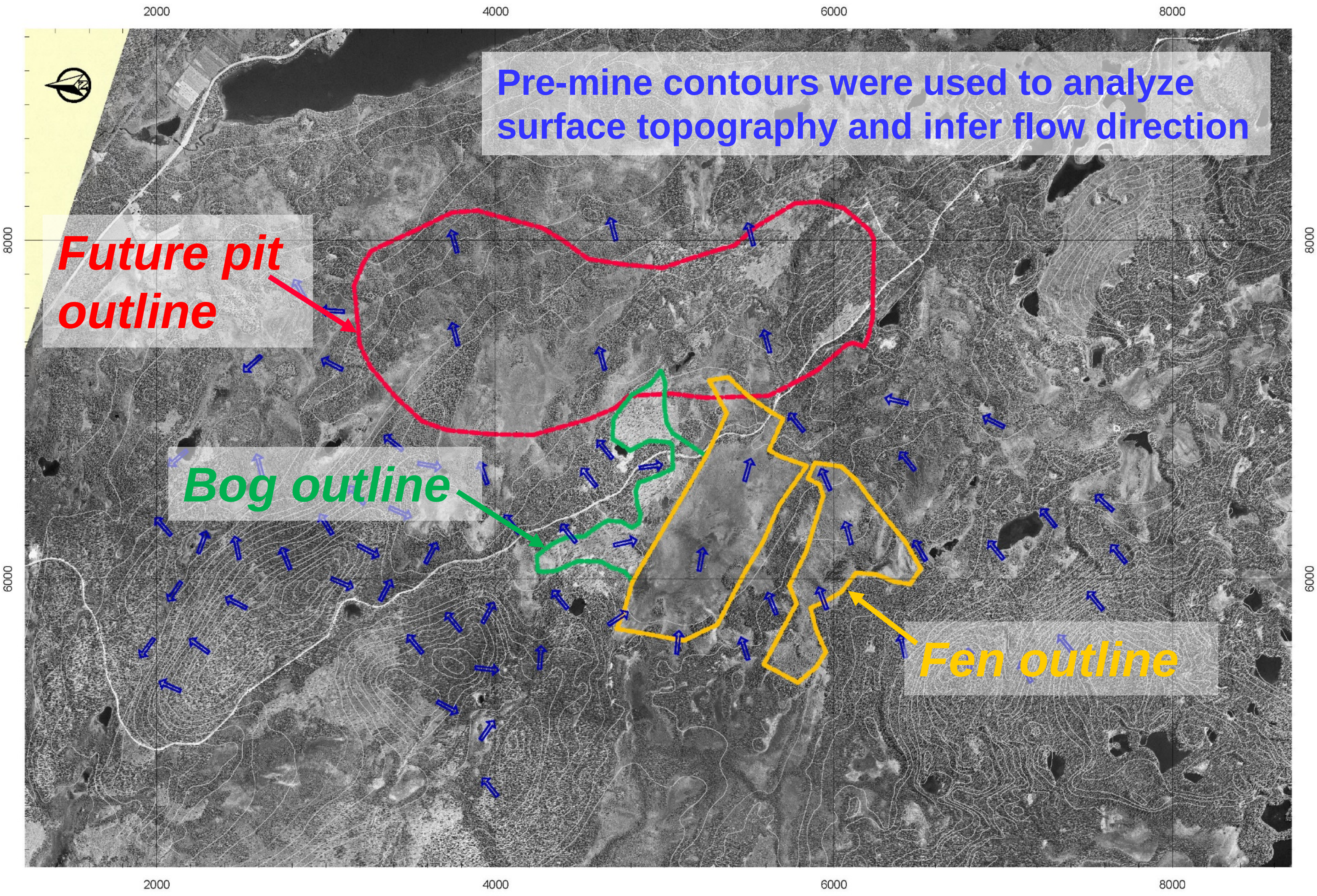
Site Topography – Pre-mining



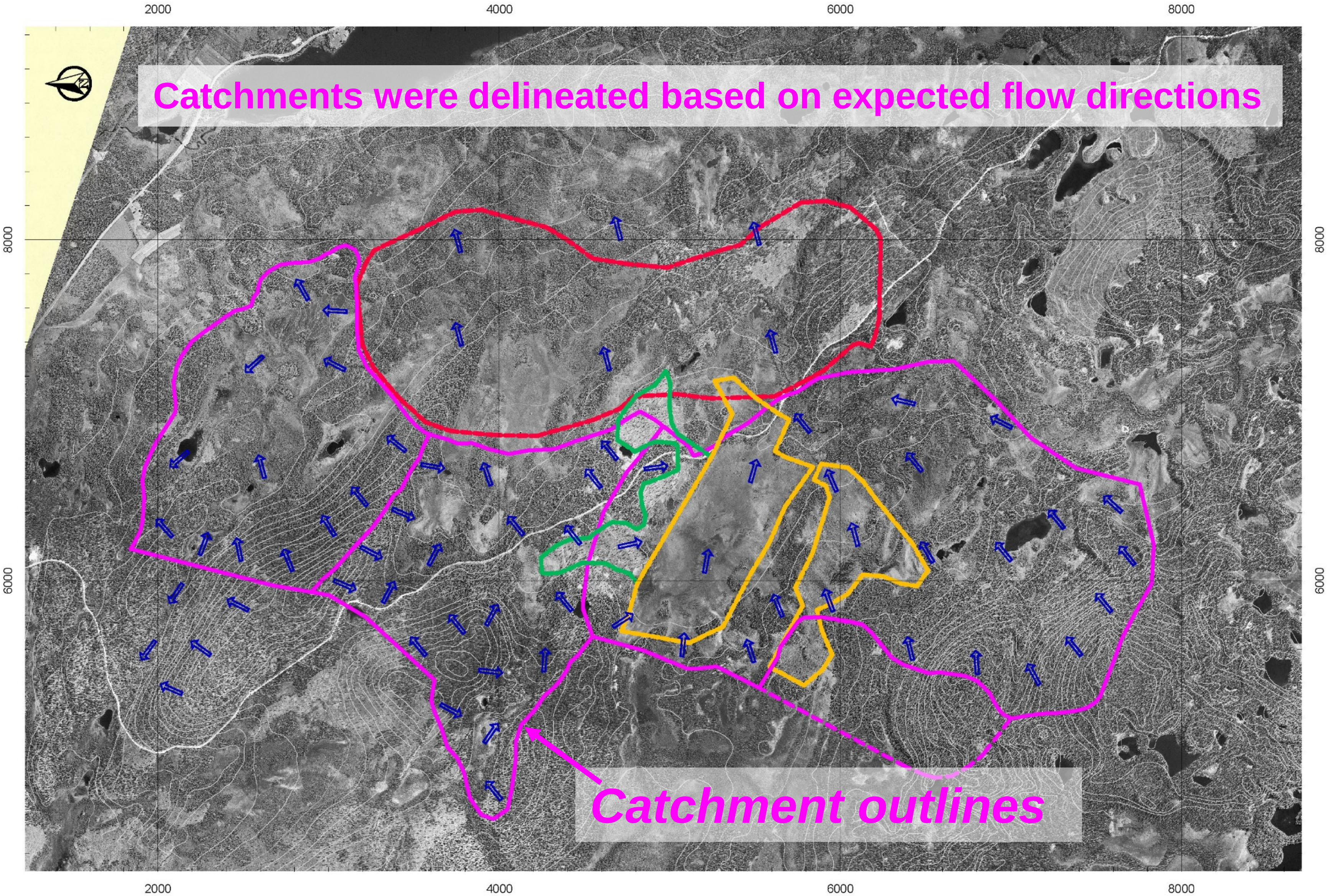
Site Topography – Pre-mining



Site Topography – Pre-mining

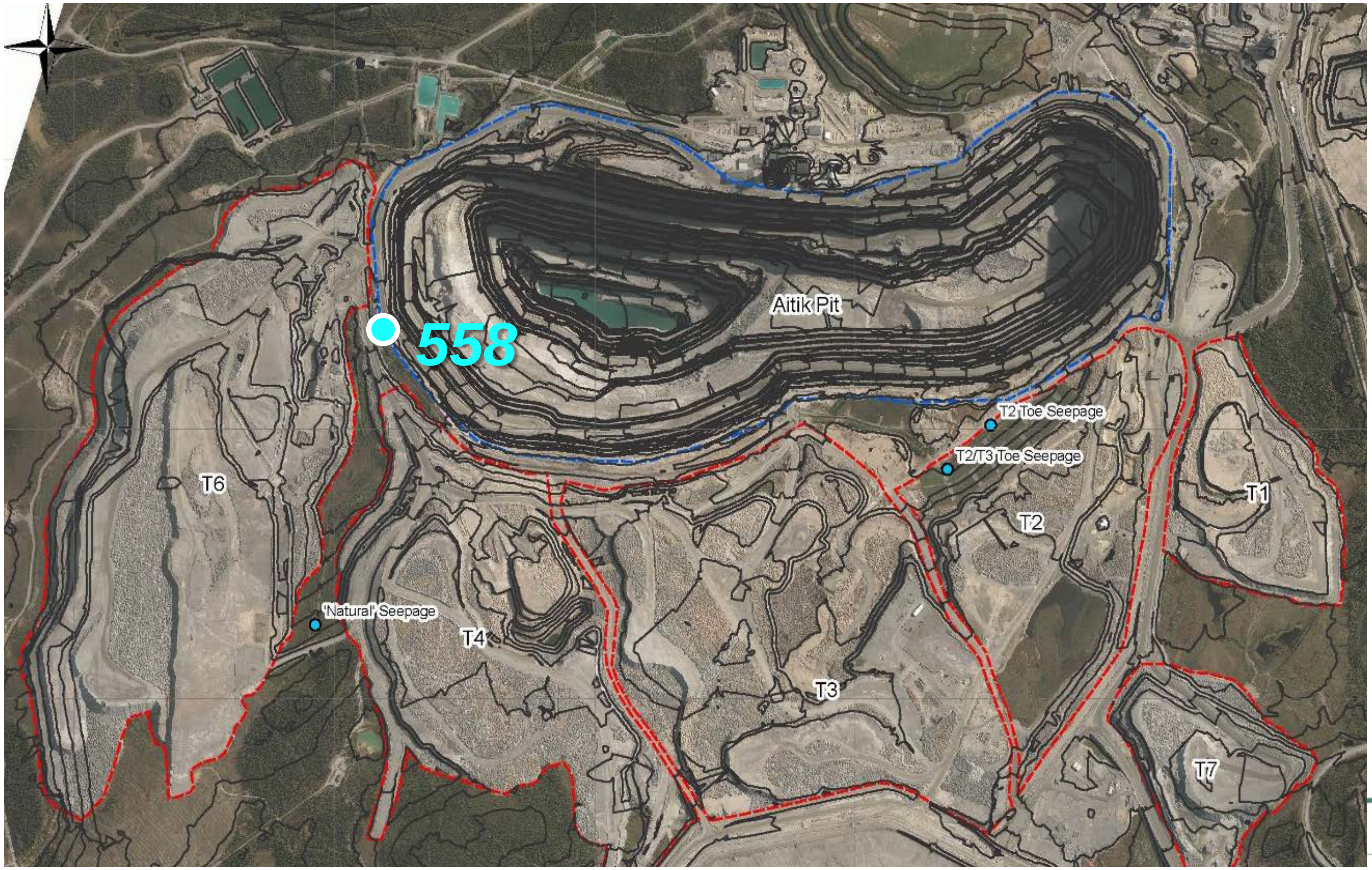


Site Topography – Pre-mining

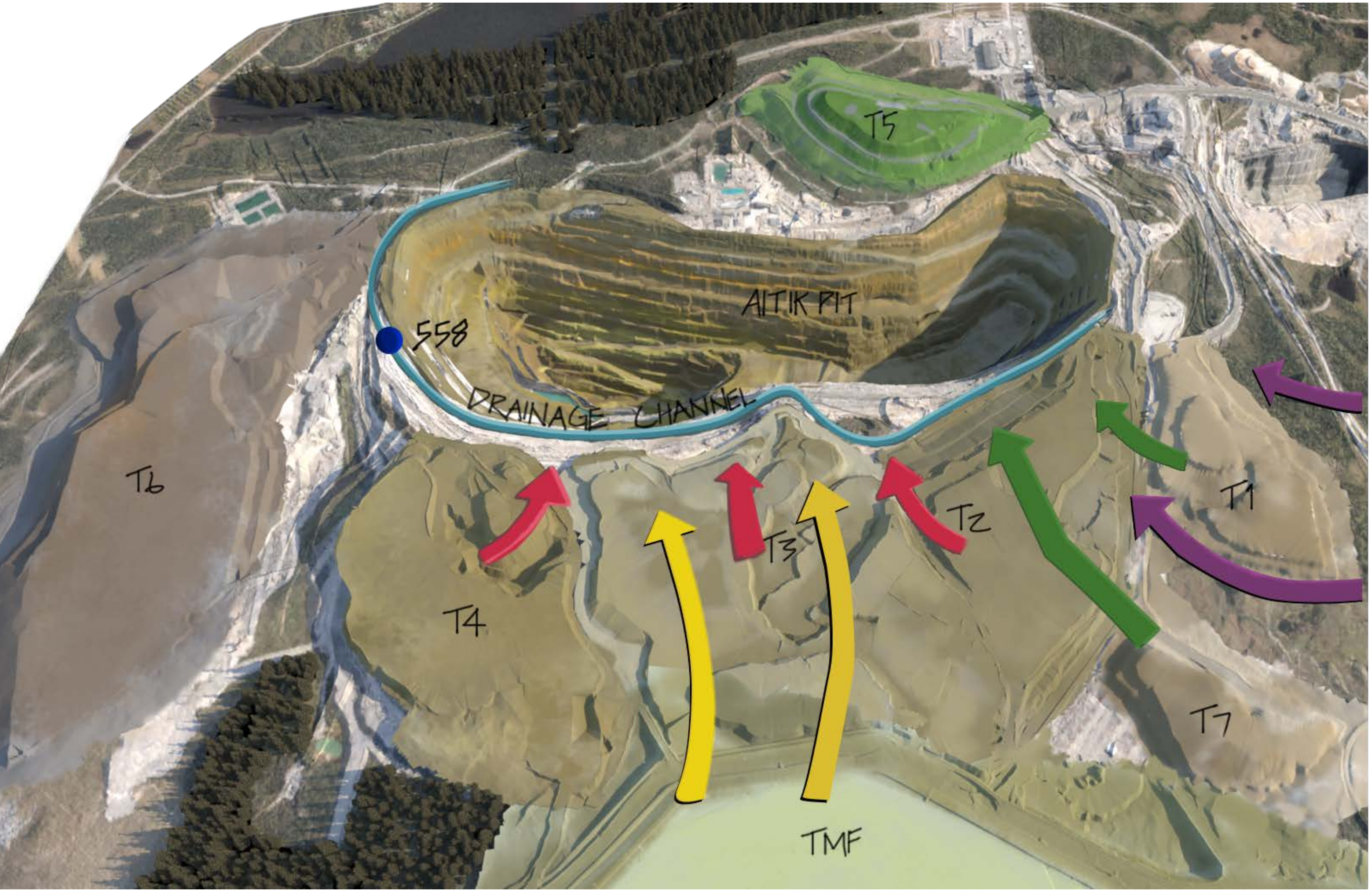


Water Quality Monitoring Location

- **Majority of surface and shallow groundwater flow reports to T2-T4 collection channel which is monitored at location 558.**
- **Flow rate measurements and water quality data are available**



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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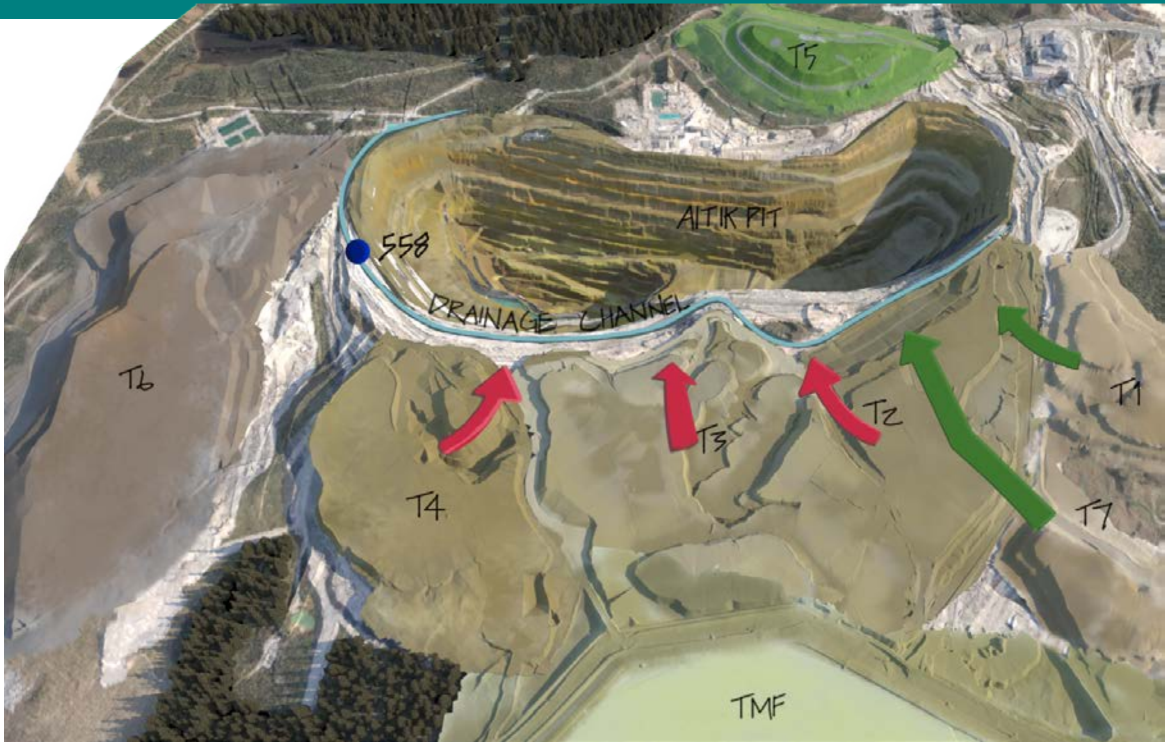
Specialists in Geochemistry and Unsaturated Zone Hydrology

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

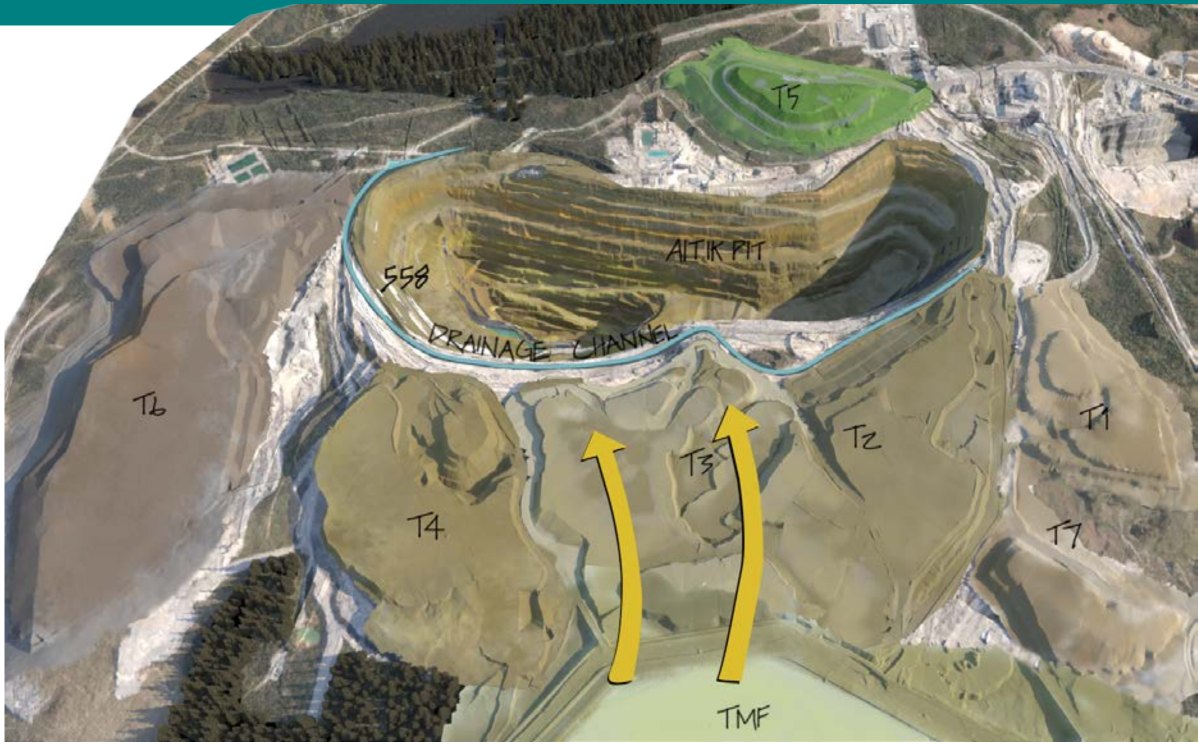
- **Flow occurs as basal seepage that reports to the surficial aquifer in underlying moraine layer**
- **<u>Need to determine this Water Quality</u>**

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

TMF Flow and Water Quality

- **TMF contributes substantial flow to collection channel**
- **Estimated contribution ranges from 43 to 90% 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

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FIELD BASED INVESTIGATIONS

Estimated PAF WRSF Mineralogy

Mineral	Key mineralogy used for PAF WRSF modelling(wt%)
Anorthite	6.0
Calcite	0.43
Pyrite	0.65
Chalcopyrite	0.12
Jarosite	0.41
Melanterite	0.02

Long term silicate neutralization source. Key mineral for neutralizing acidity in the long term from pyrite oxidation and jarosite dissolution

Rapid carbonate neutralization source

Potential acidity/metals, managed by limiting oxygen flux

Stored sparingly soluble acidity, kinetically controlled dissolution

Stored soluble acidity, reports as a function of net percolation

Derivation of Current PAF WRSF Source Term

GEOCHEMICAL MODELLING

Determination of PAF WRSF WQ

Environmental WRSF

- Flow Rate ~ 10 L/s
  - pH 6.9
  - Acidity 0.2 mg/L
  - Cu 0.007 mg/L
  - Al 0.01mg/L

TMF Flow

- Flow Rate ~ 157 L/s
  - pH 4.9
  - Acidity 79 mg/L
  - Cu 2.7 mg/L
  - Al 12 mg/L

Near Surface Water

- Flow Rate ~ 22 L/s
  - pH 6.8
  - Acidity 2.5 mg/L
  - Cu 0.002 mg/L
  - Al 0.02 mg/L

PAF WRSF Flow

- Flow Rate ~ 38 L/s
  - Water quality to be determined

T2-T4 Channel (Norra Dikka)

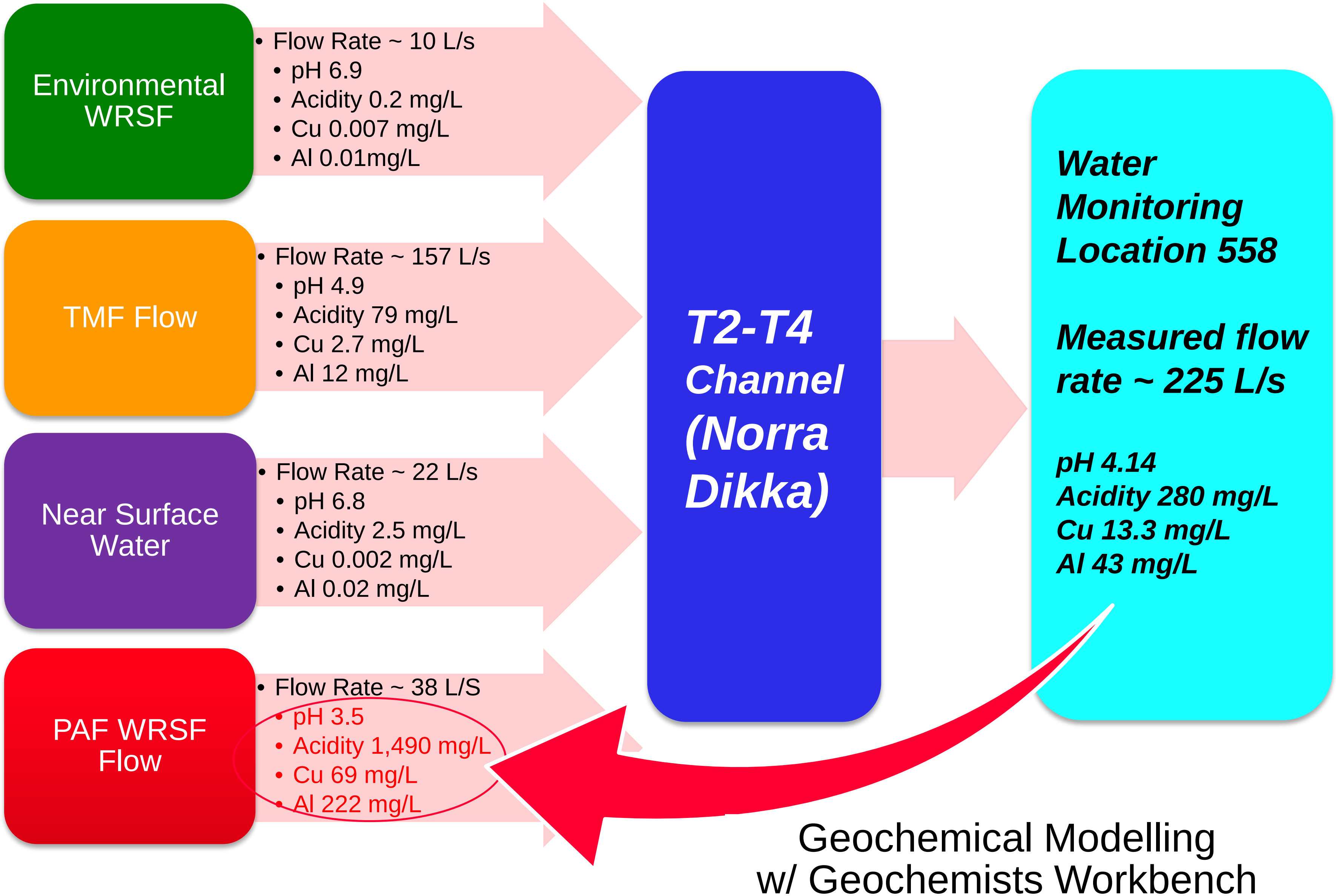
Monitoring Point 558

Measured flow rate ~ 225 L/s (Base flow)

pH 4.14
Acidity 280 mg/L
Cu 13.3 mg/L
Al 43 mg/L

Current PAF WRSF WQ requires determination to help understand long-term water quality evolution

Determination of PAF WRSF WQ



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

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 (being ~2,000 tonnes/year).

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

EVALUATION OF POST CLOSURE WATER QUALITY

Cover System Design Objectives

- The WRSF cover system design objective **is to integrate at source control of oxygen and water with the other elements of the closure plan such that the system as a whole meets recipient water quality criteria. This is achieved through:**
  - **Primarily a focus on managing oxygen ingress to very low levels to limit development of further stored acidity,**
  - **Understanding net percolation rates to inform on transport of stored acidity,**
  - **Utilizing site-specific climate conditions, and**
  - **Incorporating** locally available borrow materials.

Site Specific Inputs - Summary

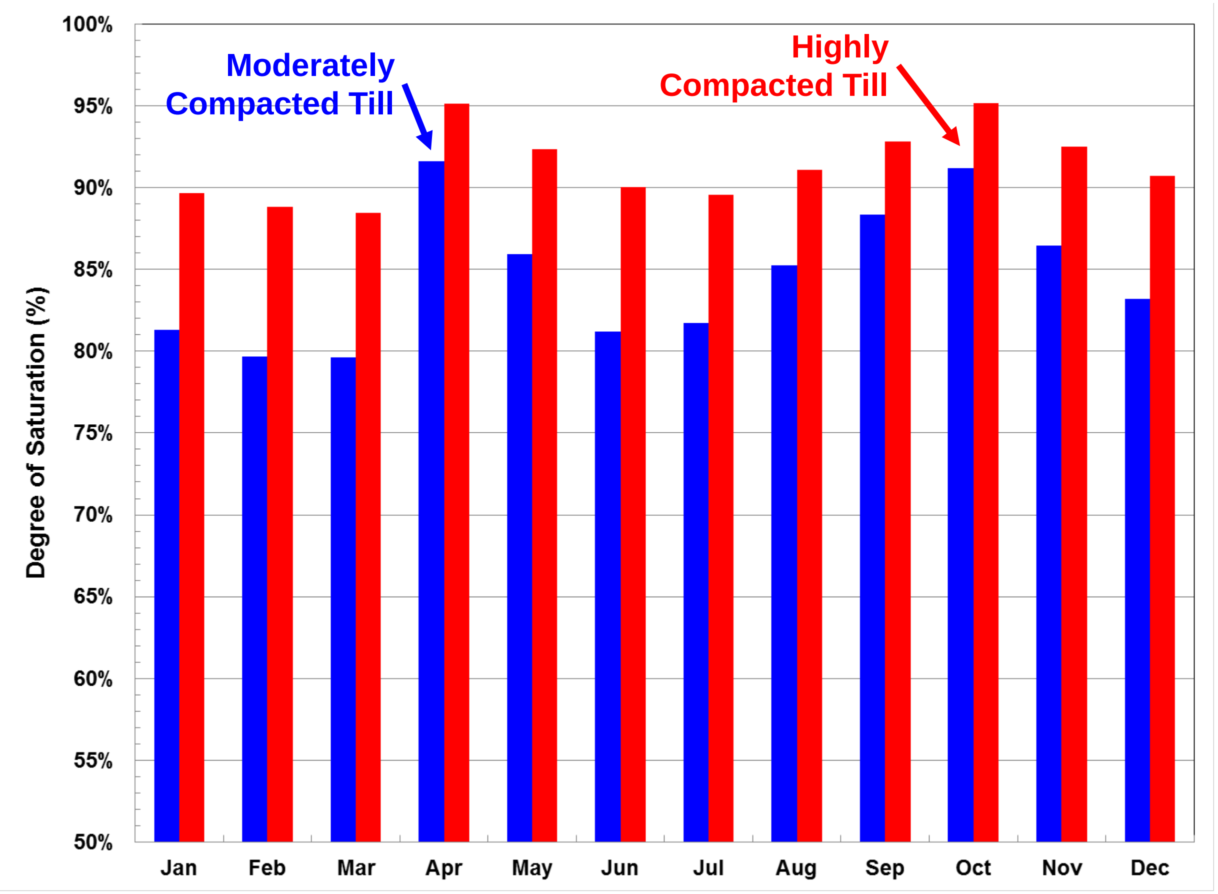
- Field investigation programs continued the previous cover design philosophy and focused on improving key areas
- Addition of highly compacted till layer enhanced its water retention characteristics and increased degree of saturation within the cover system leading to improved oxygen ingress management

- **Compaction trials determined achievable field k_{sat} and density using locally available materials**
- **Results of compaction trial study used to determine optimal compaction methodology**
- **Improved cover system alternatives built into cover system field trials to monitor *in situ* cover system performance over time**

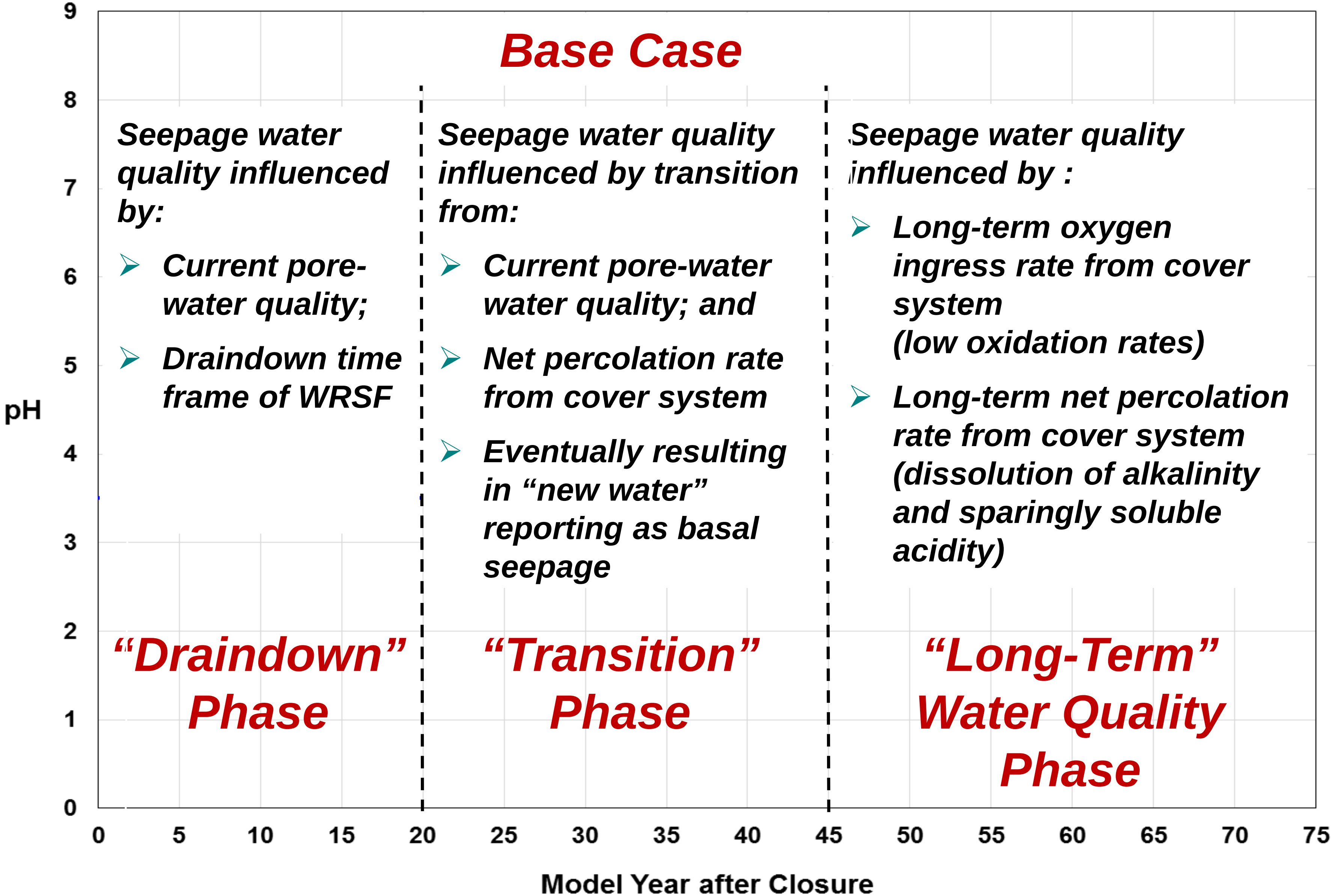
WRSF Cover System Program

- Predicted oxygen ingress by diffusion and dissolved oxygen in percolation reduced to a very low value
- Degree of saturation >85% is maintained during the simulation period in HCT layer
- Oxygen moving through the cover system was consumed in the upper 5 m of PAF profile

Predicted Average Monthly Degree of Saturation
(Averaged all measurements by month 2015 to 2200)



Evaluation of Long-Term Water Quality



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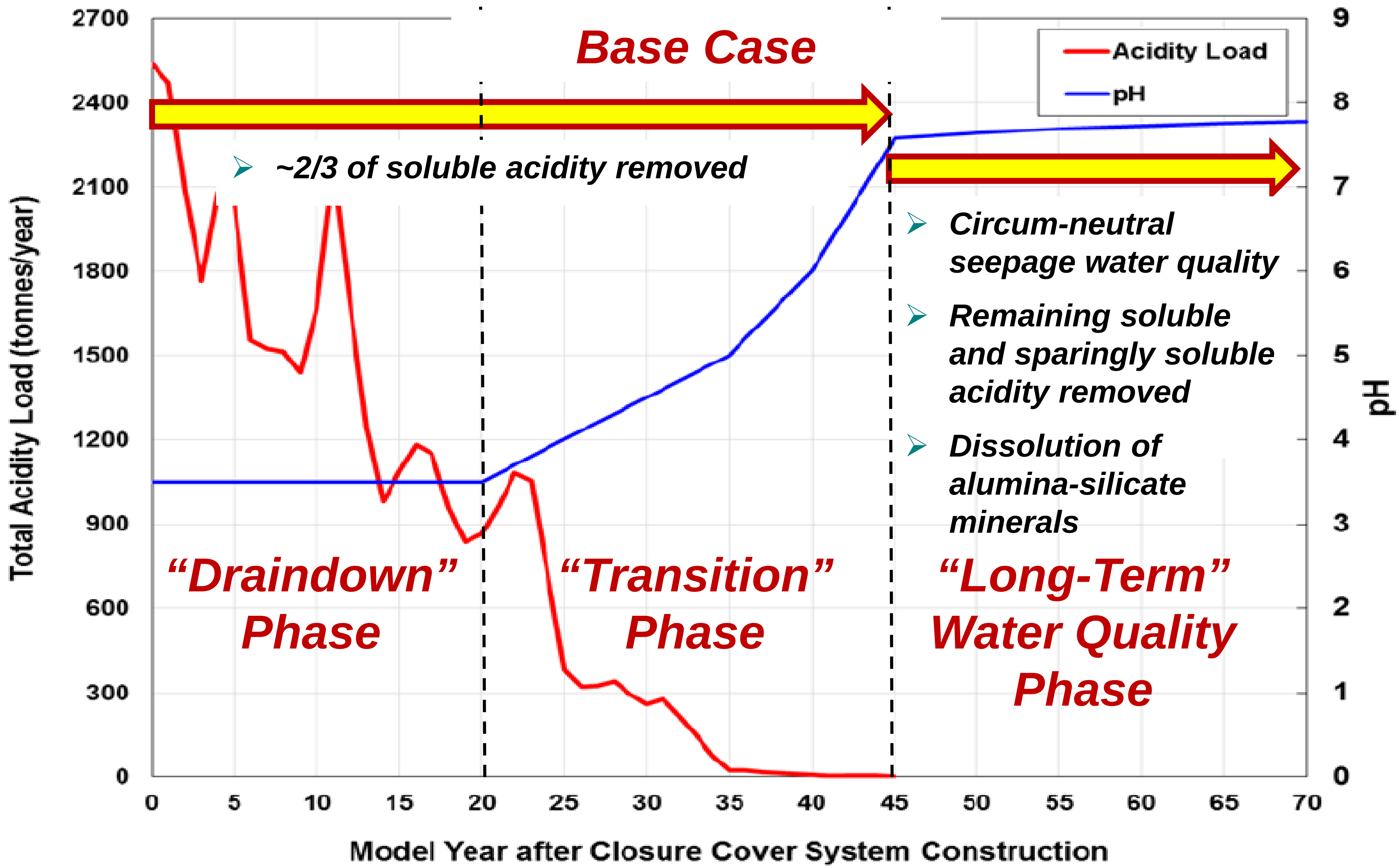

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Thank You!

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