Geochemical Evaluation of the Copper Flat Project, New Mexico

Ruth Griffiths, *EurGeol, CGeol, PhD*
Rob Bowell, *EurGeol, CChem, CGeol, PhD*
Amy Prestia, *PG, MSc*

SRK Consulting

September, 2018

Overview

- Introduction of Technical Experts
- Objectives of Copper Flat Geochemical Evaluation
  - Fundamentals of Acid Rock Drainage and/or Metal Leaching
  - Copper Rule Requirements
- Geochemical Characterization Program
  - Methods and QA
  - Results
  - Comparison of Copper Flat to Analogue Deposits
- Water Quality Predictions
  - Waste Rock Stockpile
  - Tailings Storage Facility
  - Pit lake
- Summary

Dr. Ruth Griffiths, EurGeol, CGeol, PhD

- Senior Geochemist, SRK Consulting (UK)
- Education:
  - BSc Environmental Earth Science (2004)
  - MSc Environmental Monitoring and Analysis (2005)
  - PhD Environmental Geochemistry (2009)
- Certifications:
  - Chartered Geologist (2013)
  - Certified European Geologist (2016)
- 8 years' experience in the mining industry, specializing in:
  - Geochemical characterization of mine waste, waters and soils
  - Geochemical modeling of mining environments
- Worked on over 35 geochemical characterization and modeling projects in North America, South America, Africa, Asia and Europe
- 20+ peer-reviewed mining and geochemistry-related publications and conference papers

Dr. Rob Bowell, EurGeol, CChem, CGeol, PhD

- Corporate Geochemist, SRK Consulting (UK)
- Education:
  - BSc Chemistry and Geology (1987)
  - PhD Geochemistry (1991)
- Certifications:
  - Chartered Chemist (1997)
  - Chartered Geologist (2001)
  - Certified European Geologist (2002)
  - Accreditation Auditor, Cyanide Code (2005)
  - Adjunct Professor, Queen’s University, Kingston, Ontario (2018)

- 30 years’ experience in the mining industry, specializing in:
  - Environmental geochemistry and engineering
  - Mineralogy and process chemistry

- Worked on 177 environmental geochemical characterization and modeling projects in North America, South America, Africa, Asia, Europe and Australasia

- 170 peer-reviewed mining and geochemistry-related publications and conference papers including books on Arsenic, Uranium and Vanadium and an Elsevier text book on Mine Water Geochemistry to be published by Elsevier in 2019

Amy Prestia, PG, MSc

- Principal Geochemist, SRK Consulting (US)

- Education:
  - BSc Geology with minor in chemistry (1996)
  - MSc Geology (1999)

- Certifications:
  - Professional Geologist, Washington (#29940)

- 17 years' experience in the mining industry, specializing in:
  - Geochemical characterization of mine waste, waters and soils for mine permitting and closure
  - Field and laboratory-based analytical chemistry
  - Development of Waste Rock Management Plans designed to address acid rock drainage and metal leaching from mine waste.

- Contributed to over 20 mine permitting projects in Nevada, Idaho, California and Oregon
- Several peer-reviewed mining and geochemistry-related publications and conference papers

Introduction

- Primary objective
  - Develop geochemistry data required for permitting the Copper Flat Project

- Geochemical characterization of waste rock, tailings and pit walls is required to:
  - Predict potential geochemical reactivity and stability of extracted material
  - Assess impacts to receptors (humans, animals and the wider environment)
  - Identify options for management and closure of mine facilities
    - Tailings and waste rock facilities, pit lake

- Geochemistry program builds on previous work carried out by SRK in 1996-1999

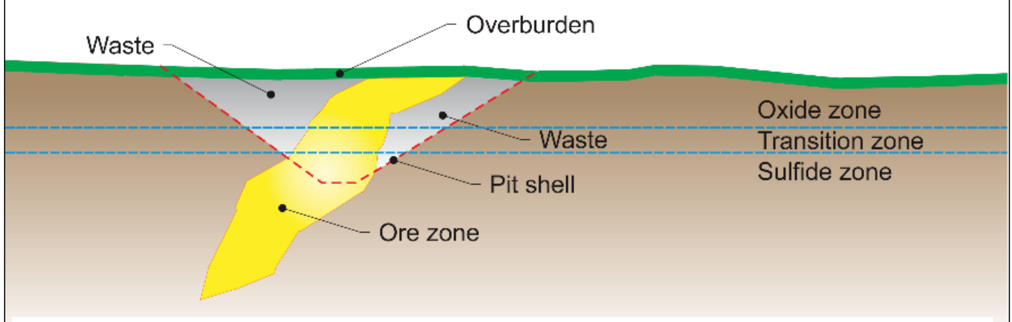
Objectives

- Key questions :
  - What is the potential for development of acid rock drainage and metal leaching (ARDML) from material generated by the project?
  - Does the geochemistry change due to mining?
  - Is there an increased risk to impact groundwater and surface water from mine facilities?
  - What sort of management or closure actions can be implemented to mitigate this risk?

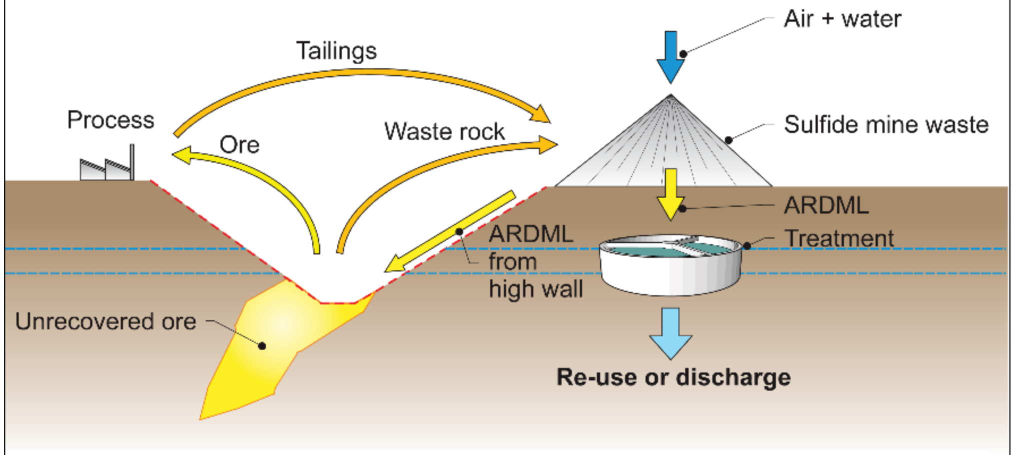
Fundamentals of Acid Rock Drainage and Metal Leaching

- Mining can result in exposure and weathering of sulfide minerals (e.g. pyrite), potentially resulting in
    - Acid Rock Drainage (ARD)
    - Metal Leaching (ML)

- Geochemical characterization required for:
    - Waste rock
    - Tailings
    - Pit wall rock
    - Low grade ore

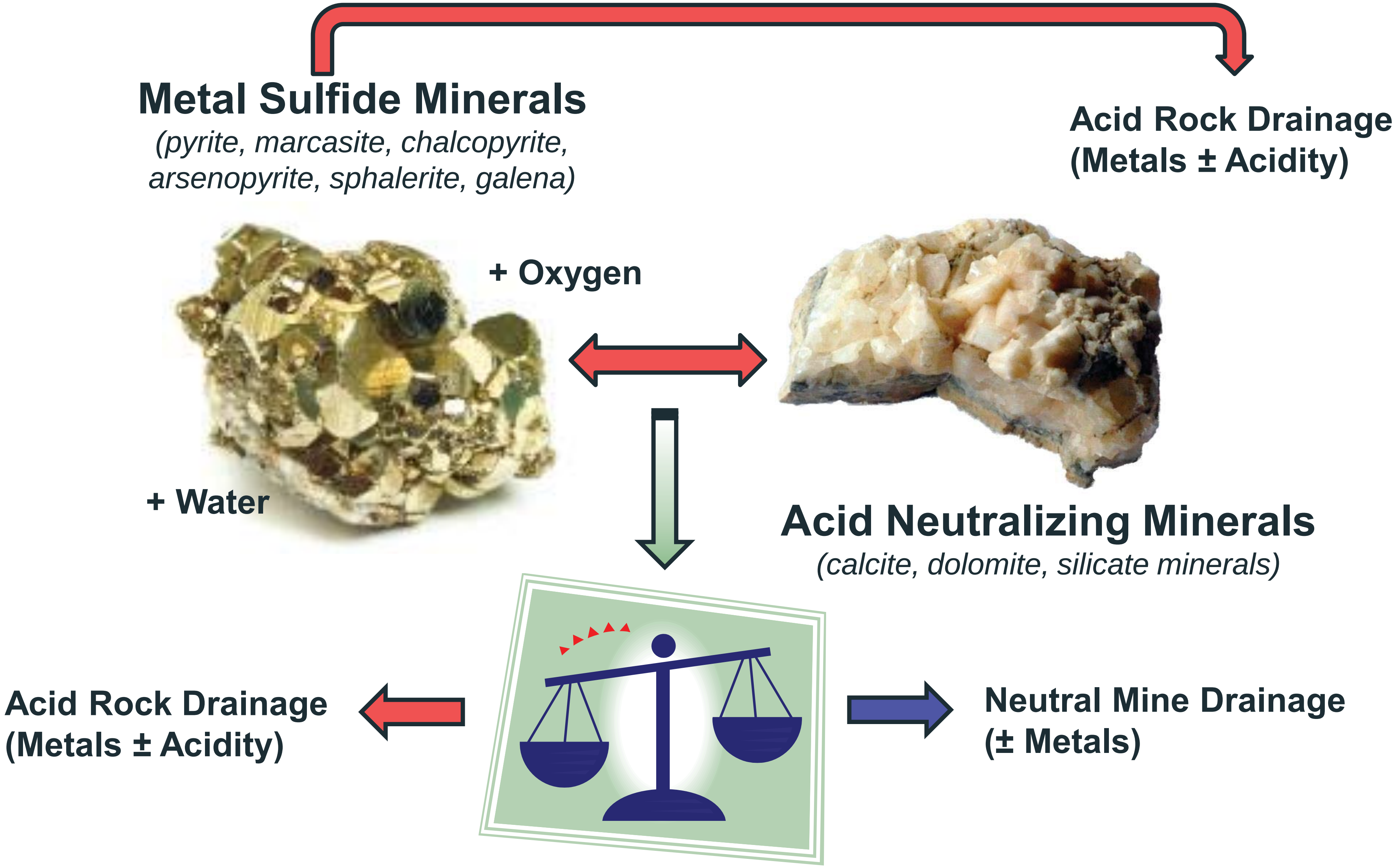


Pre-Mining System



Mining System

Fundamentals of Acid Rock Drainage and Metal Leaching



Metal Sulfide Minerals
(pyrite, marcasite, chalcopyrite, arsenopyrite, sphalerite, galena)

Acid Rock Drainage (Metals ± Acidity)

+ Oxygen

+ Water

Acid Neutralizing Minerals
(calcite, dolomite, silicate minerals)

Acid Rock Drainage (Metals ± Acidity)

Neutral Mine Drainage (± Metals)

The potential for acid rock drainage may also be affected by mineral textures. For example acid generation may be inhibited by encapsulation of sulfide minerals in non-reactive silicates

Copper Rule Requirements

20.6.7.21 REQUIREMENTS FOR COPPER MINE WASTE ROCK STOCKPILES

A. Material characterization requirements.

(1) Material characterization and acid mine drainage prediction

- All waste rock stored, deposited or disposed of at a copper mine facility shall be evaluated for its potential to generate acid and to release water contaminants at levels in excess of the standards of 20.6.2.3103 NMAC.
- A plan for determining the potential of the material to release water contaminants, and the method for such evaluations shall be submitted to the department for approval in a material characterization plan that includes the following:
  a. The geologic, mineralogical, physical and geochemical characteristics of the material stored, deposited or disposed.
  b. A sampling and analysis plan to provide representative samples of the entire range of material stored, deposited or disposed. The plan should consider the following factors in collecting and establishing representative samples:
    i. Lithological variations
    ii. Particle size distribution of each lithology
    iii. Hydraulic conductivity, water content and matric suction relationship for each lithology
    iv. Mineralogical and textural variations
    v. The nature and extent of sulfide mineralization
    vi. Color variation
    vii. Degree and nature of fracturing
    viii. Variations in oxidation and reducing conditions; and
    ix. The nature and extent of secondary mineralization

Copper Rule Requirements (continued)

20.6.7.21 REQUIREMENTS FOR COPPER MINE WASTE ROCK STOCKPILES

A. Material characterization requirements.

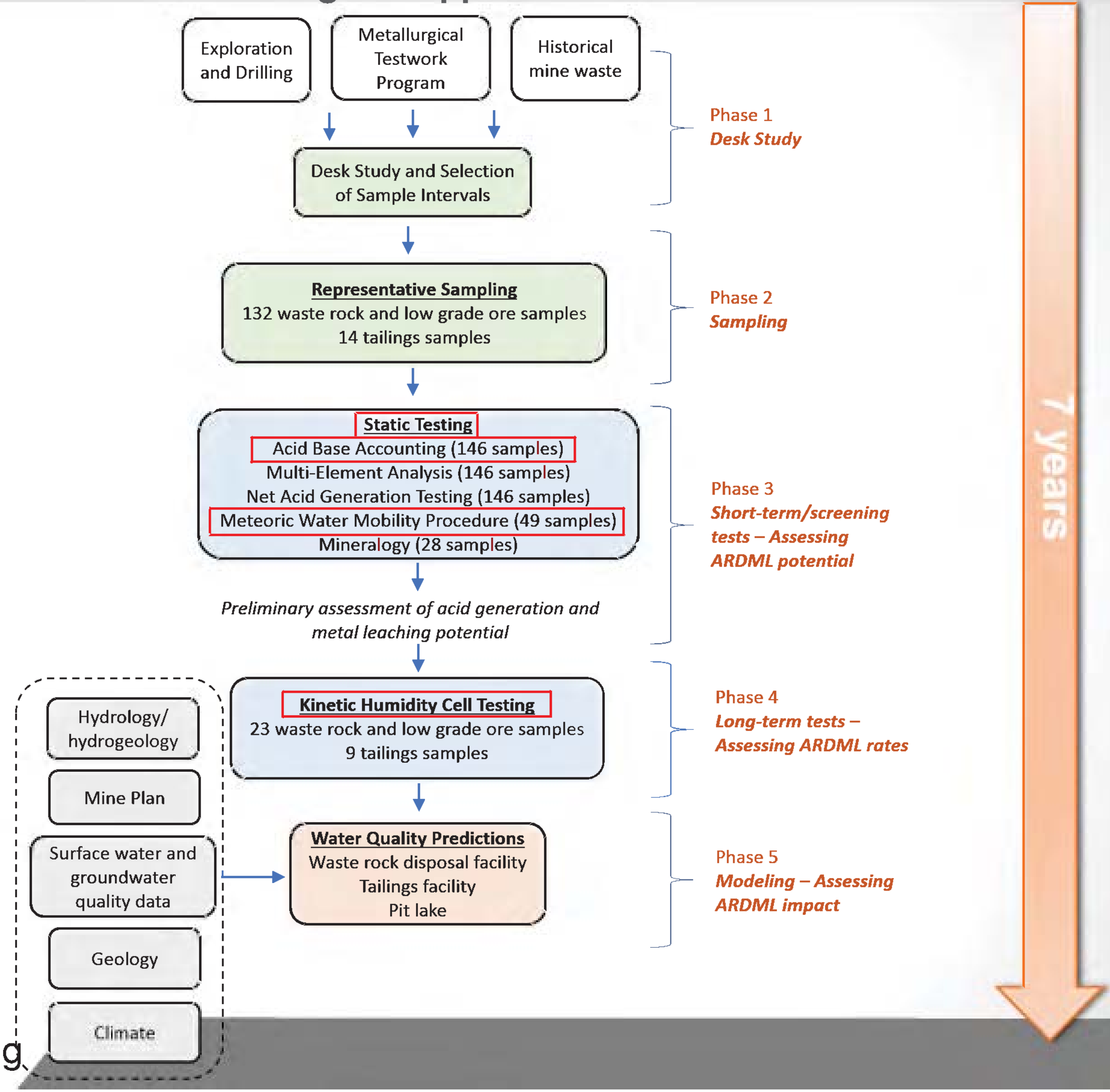
(1) Material characterization and acid mine drainage prediction

c. A static testing program using, at a minimum, acid/base accounting to evaluate the acid generation and neutralization potential of the material; and meteoric water mobility procedure to determine water contaminant leaching potential.

d. If the results of the static testing indicate that a material may be acid generating or may generate a leachate containing water contaminants, a kinetic testing program shall be proposed to evaluate reaction rates, provide data to estimate drainage quality, the lag time to acidification of the material and primary weathering and secondary mineral precipitation/dissolution as it may affect acidification, neutralization and drainage quality. The length and means of determining when kinetic tests will be discontinued shall be approved by the department prior to implementation of the kinetic testing program.

c. If the results of the static testing or kinetic testing indicate that the material will be acid generating or generate water contaminants, and the materials will be placed outside of an open pit surface drainage area, a plan shall be submitted to the department to evaluate whether discharges of leachate from the stockpile may cause an exceedance of applicable standards.

Copper Flat Characterization Program Approach



Exploration and Drilling

Metallurgical Testwork Program

Historical mine waste

Desk Study and Selection of Sample Intervals

Phase 1
Desk Study

Representative Sampling
132 waste rock and low grade ore samples
14 tailings samples

Phase 2
Sampling

Static Testing
Acid Base Accounting (146 samples)
Multi-Element Analysis (146 samples)
Net Acid Generation Testing (146 samples)
Meteoric Water Mobility Procedure (49 samples)
Mineralogy (28 samples)

Preliminary assessment of acid generation and metal leaching potential

Phase 3
Short-term/screening tests – Assessing ARDML potential

Hydrology/ hydrogeology

Mine Plan

Surface water and groundwater quality data

Geology

Climate

Kinetic Humidity Cell Testing
23 waste rock and low grade ore samples
9 tailings samples

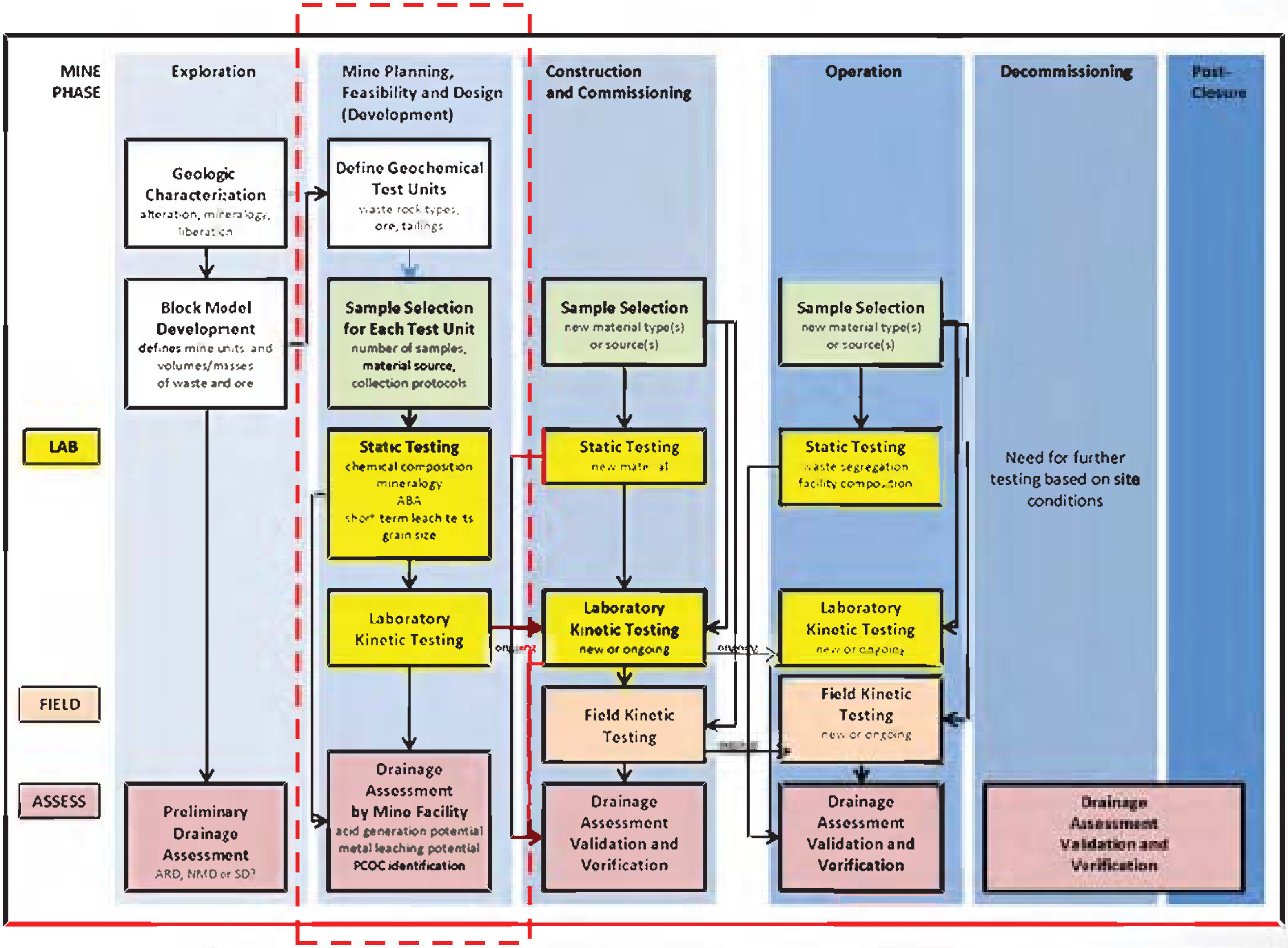
Phase 4
Long-term tests – Assessing ARDML rates

Water Quality Predictions
Waste rock disposal facility
Tailings facility
Pit lake

Phase 5
Modeling – Assessing ARDML impact

Global Acid Rock Drainage (GARD) Guide

- Characterization program carried out in accordance with Global Acid Rock Drainage (GARD) Guide (INAP, 2014)- International Best Practice



Desk Study and Selection of Sample Intervals

- Review of drill core logs and identification of primary material types
- Materials defined by:
  - **Primary rock type**
    - Quartz monzonite (78%)
    - Coarse crystalline porphyry (15%)
    - Breccia (6%)
    - Andesite (1%)
  - **Oxidation**
    - Sulfide (96%)
    - Oxide
    - Transitional

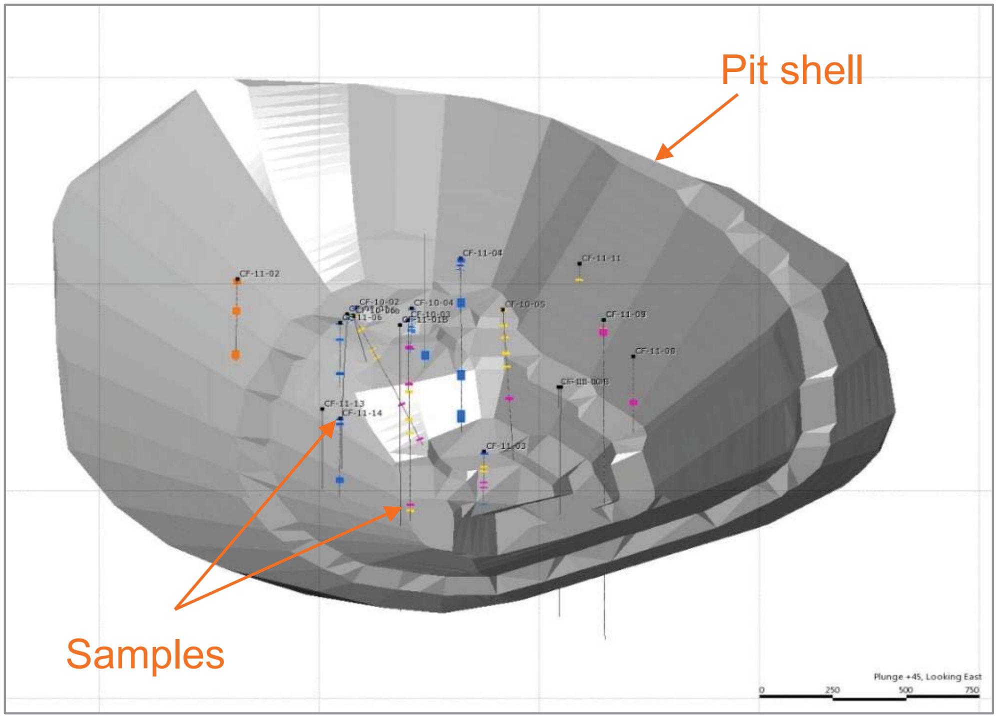
    $\left.\begin{array}{l}\text{Oxide}\\ \text{Transitional}\end{array}\right\}$ 4%
  - **Copper grade**
    - Ore >0.164% Cu
    - Waste <0.164% Cu

Sample Collection

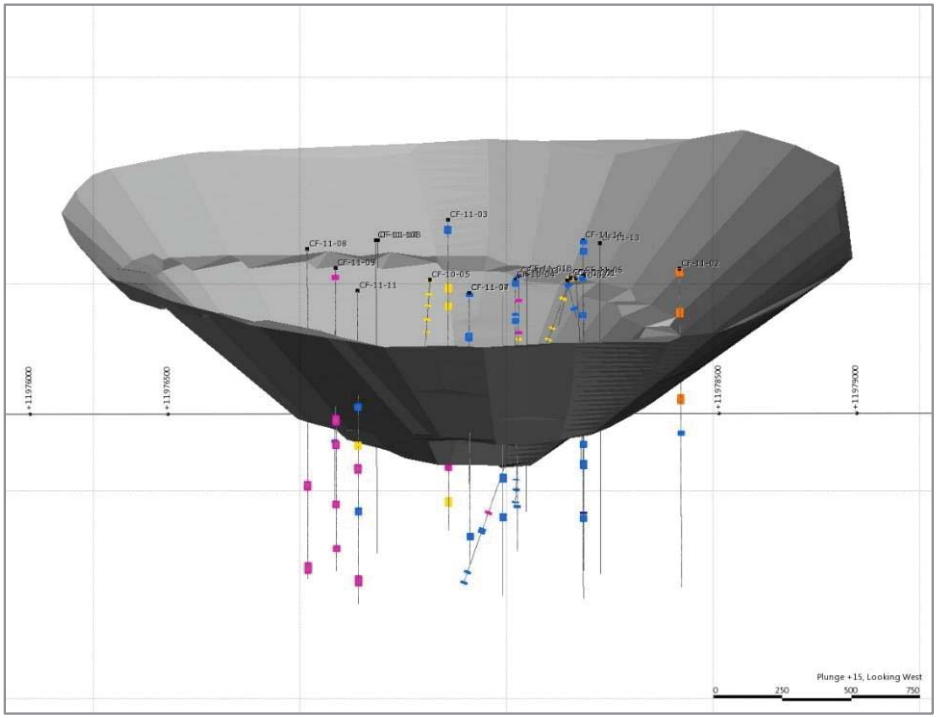
- Two phases of sample collection (April 2010 and December 2011)
- 146 samples collected representative of waste rock, ore and tailings
  - 112 core samples
  - 22 grab samples from existing waste rock dump surfaces, pit walls and tailings facility
  - 12 tailings samples from metallurgical testwork program
- Samples are spatially and lithologically representative to the extent possible

Core Sample Collection

- Leapfrog 3D geological modeling software used to query mine model
- Sample intervals representative of waste within PFS pit shell
- Includes samples inside and outside proposed pit shell

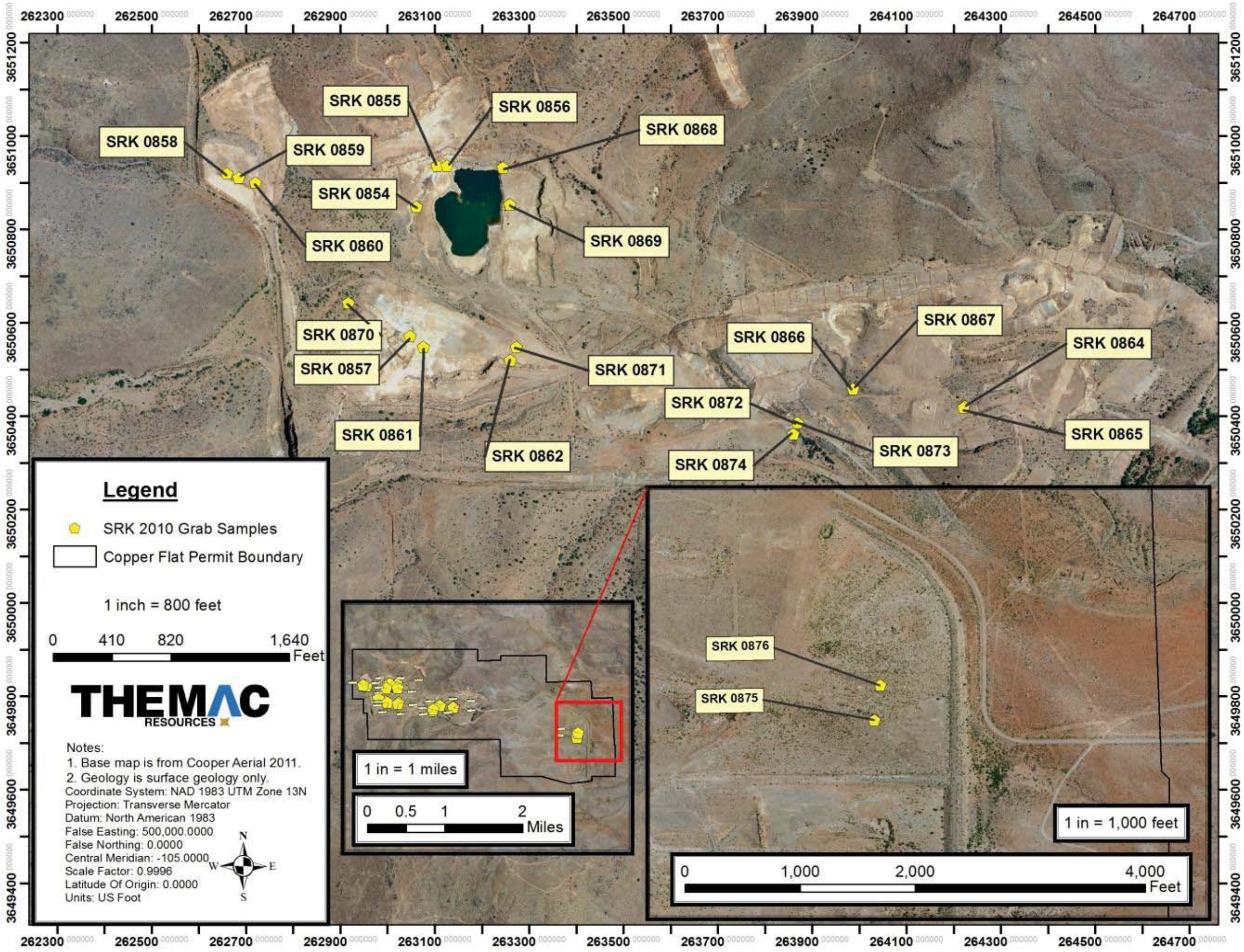

Pit shell

Samples



Grab Sample Collection

- Grab samples collected from existing waste rock piles and tailings facility
- Samples are spatially representative
- Representative of waste rock, ore and tailings material that has been exposed to weathering for 30+ years



Sample Matrix – By Lithology

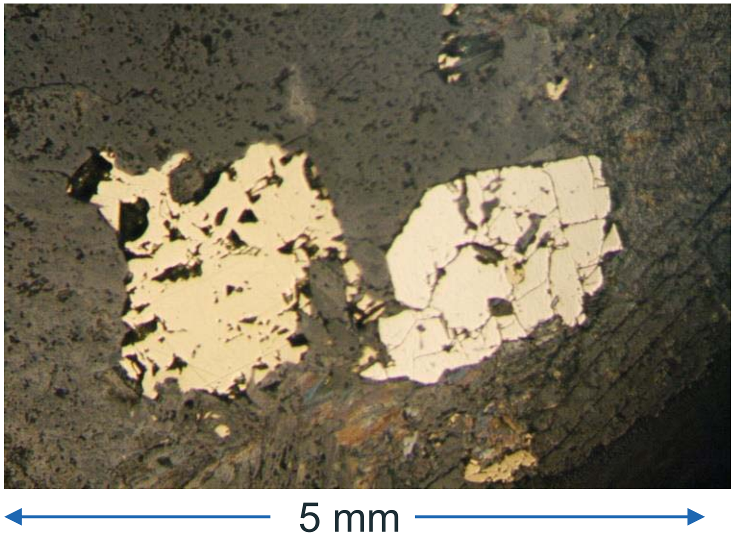
Material Type	Percentage of waste	Number of waste samples	Percentage of ore	Number of ore samples
Andesite / diabase	1.1%	5	0%	1
Biotite breccia – oxide/transitional	0.1%	1	0.1%	4
Biotite breccia – sulfide	1.1%	7	14%	17
Quartz feldspar breccia – oxide/transitional	0.1%	0	0.1%	1
Quartz feldspar breccia – sulfide	4.5%	16	8.4%	7
Quartz monzonite – oxide/transitional	2.8%	8	0.8%	13
Quartz monzonite – sulfide	75%	22	72%	24
Coarse crystalline porphyry – oxide/transitional	0.9%	1	0.03%	0
Coarse crystalline porphyry – sulfide	14%	3	4.8%	0
Undefined	0.1%	2	0.01%	0
TOTAL	**100%**	**65**	**100%**	**67**

Geochemical Characterization Testwork - Methods used for Copper Flat

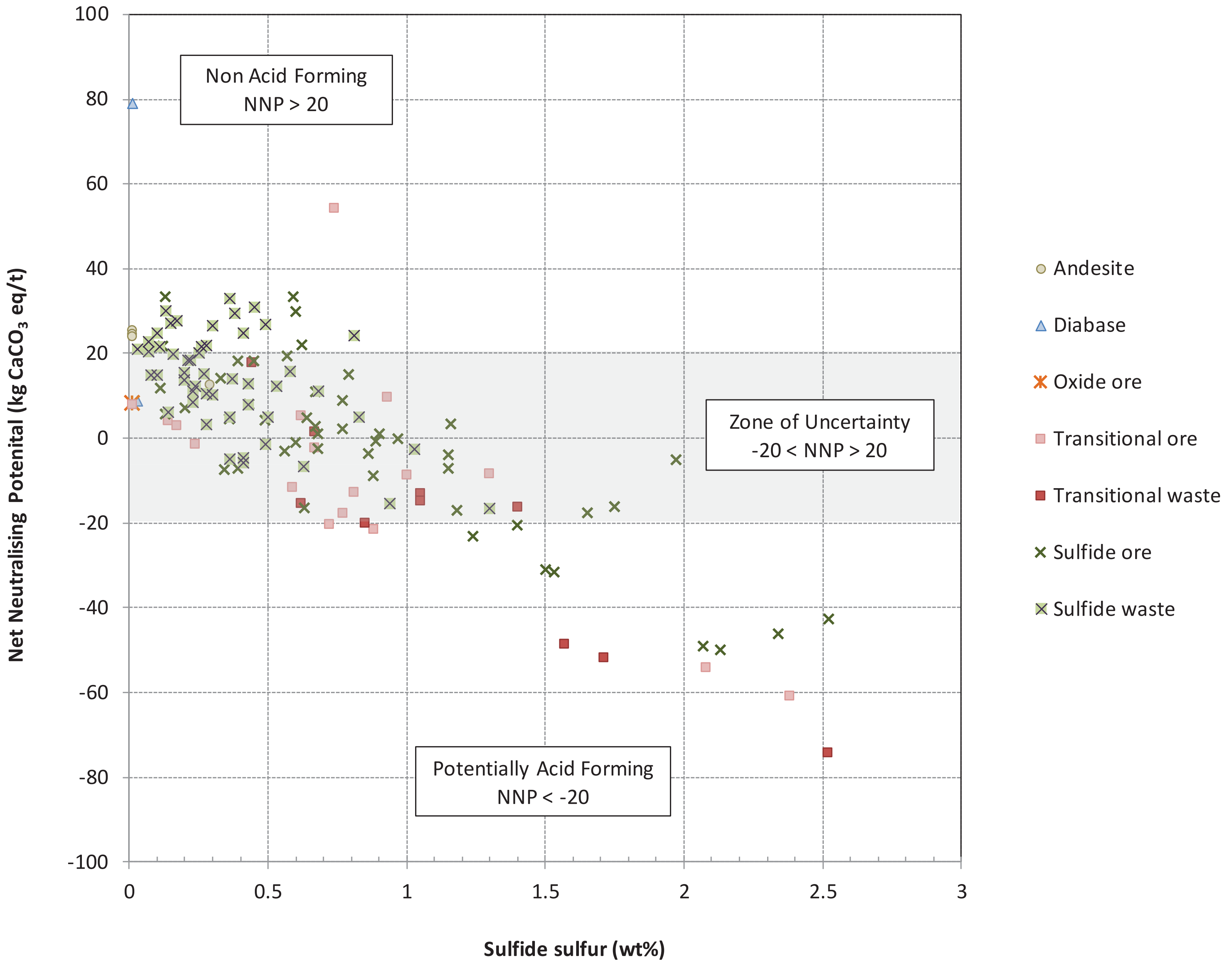
Test Type	Test Method	Purpose	Number of Tests
Static	Acid Base Accounting (ABA)	To assess balance of acid generating sulfide minerals and acid neutralizing carbonate minerals	146
	Net Acid Generation (NAG) test		
	Multi Element Analysis	To identify constituents present at potentially elevated concentrations that may be released in contact waters	146
	Mineralogical Assessment	To assess mineral textures and controls on acid generation / metal release	28
	Meteoric Water Mobility Procedure (MWMP) – waste rock	A 24-hour water leach test to assess short-term metal mobility and potential for metal leaching	49
	Synthetic Precipitation Leaching Procedure (SPLP) – tailings		
Kinetic	Humidity Cell Test (HCT)	To assess long-term kinetics of acid generation and metal release – involves weekly leaching over 20+ weeks	32

Static Testwork Results – Waste Rock and Ore

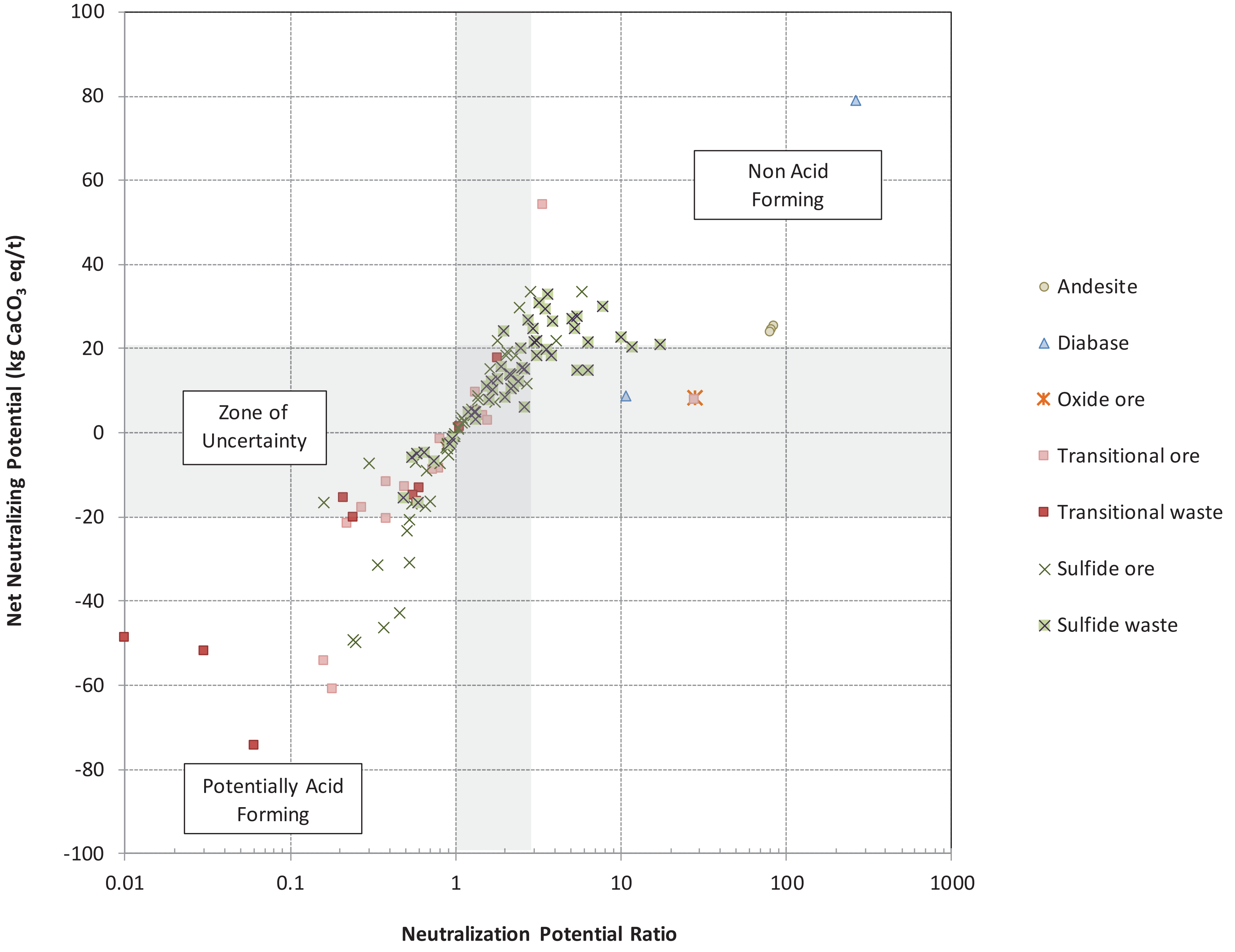
- Acid Generation Potential
  - Dependent on sulfide content (i.e., limited neutralizing minerals)
  - Majority of samples (72%) show low or uncertain potential for acid generation based on ABA
  - Potentially acid generating material limited to transitional waste, transitional ore and sulfide ore
  - Longer-term kinetic testing required to confirm long-term acid generating potential of waste/ore
- Metal Leaching Potential
  - Waste rock and ore enriched in copper, molybdenum, sulfur, selenium and silver
  - Neutral leachates with low metal concentrations
  - Higher metal mobility for transitional material collected from historic waste dumps
    - Comprises a small proportion of material



Acid Base Accounting Results – Waste Rock and Ore



Acid Base Accounting Results – Waste Rock and Ore

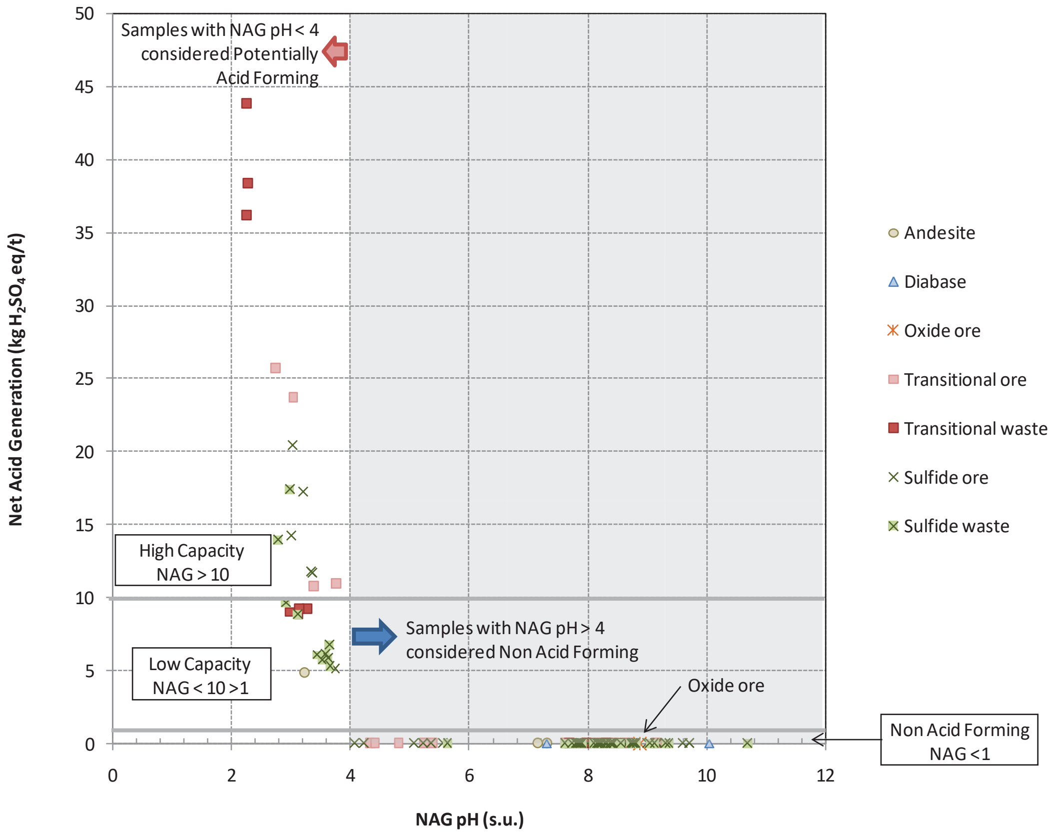


Net Acid Generation Tests

- Measure of reactivity by reaction of sulfide minerals with a strong oxidizing agent (hydrogen peroxide) it provides an estimate of maximum acid generation.
- Influenced by exposure of sulfide minerals to the reacting solution and by crystalline stability of sulfides as a reaction barrier to oxidation

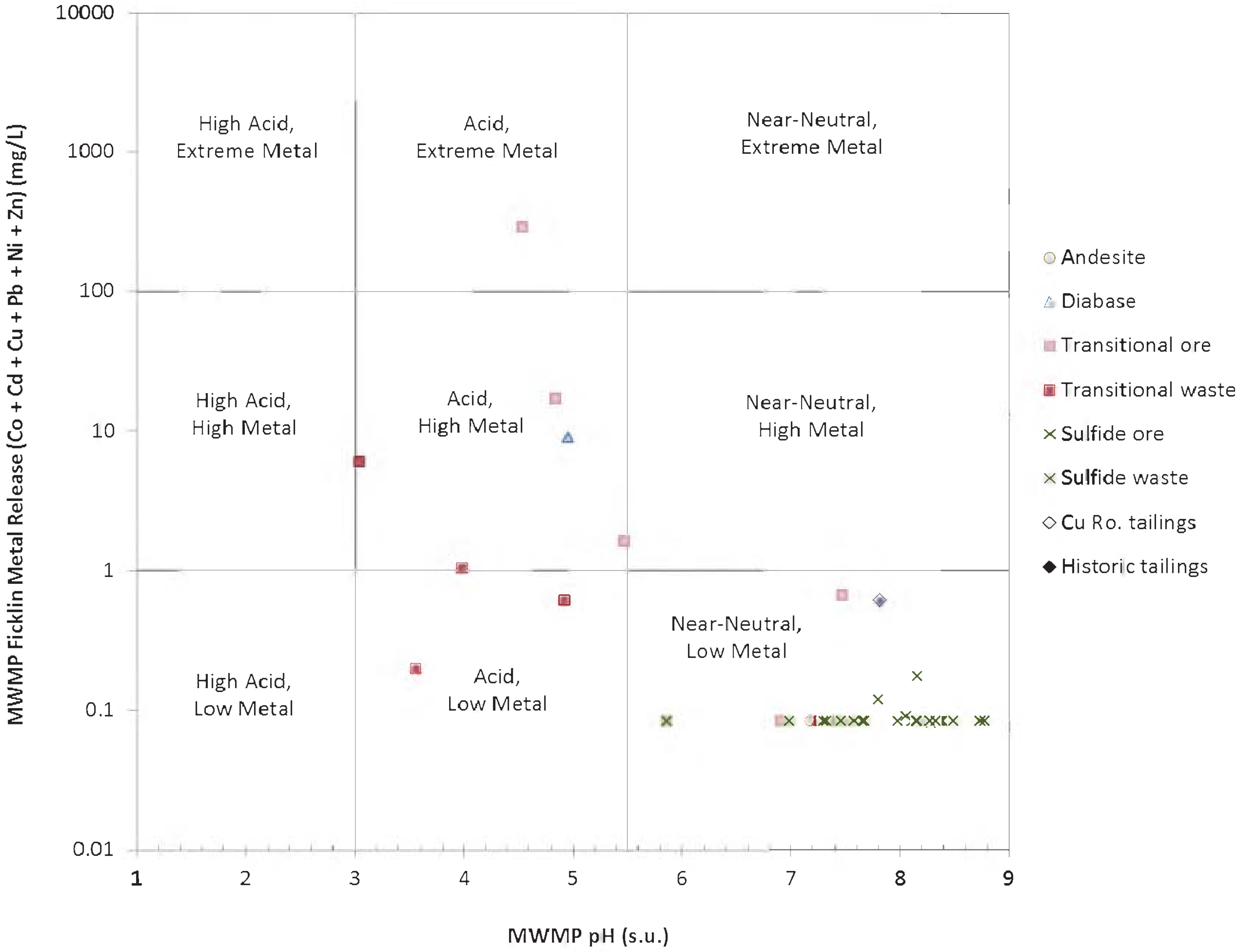
Material Type	#	NAG pH (s.u.)		NAG (kg H_2SO_4 eq/t)	
		Mean	S.D.	Mean	S.D.
Andesite	4	6.50	2.23	1.23	2.45
Diabase	2	8.69	1.94	0	0
Sulfide waste	50	7.33	2.12	1.71	3.88
Transitional waste	10	4.34	2.57	15.5	17.1
Sulfide ore	48	7.38	2.02	1.68	4.81
Transitional ore	17	6.17	2.34	4.20	8.54
Oxide ore	1	8.88	-	0	-

#	Number of samples representing material type
🟥	Potentially acid forming (PAF)
🟨	Potentially acid forming (PAF) lower capacity
⬜	Non Acid Forming (NAF)



Meteoric Water Mobility Procedure Results

- Metal leaching generally low with the exception of transitional waste and ore



Static Testwork Results - Tailings

- Tailings material shows either non-acid forming or uncertain characteristics based on Acid Base Accounting
  - Acid generating potential controlled by sulfide content

- Tailings produced during year 0 – 5 of mine life:
  - Characterized by higher sulfide content (0.39 to 0.53%)
  - Uncertain potential for acid generation based on static testwork

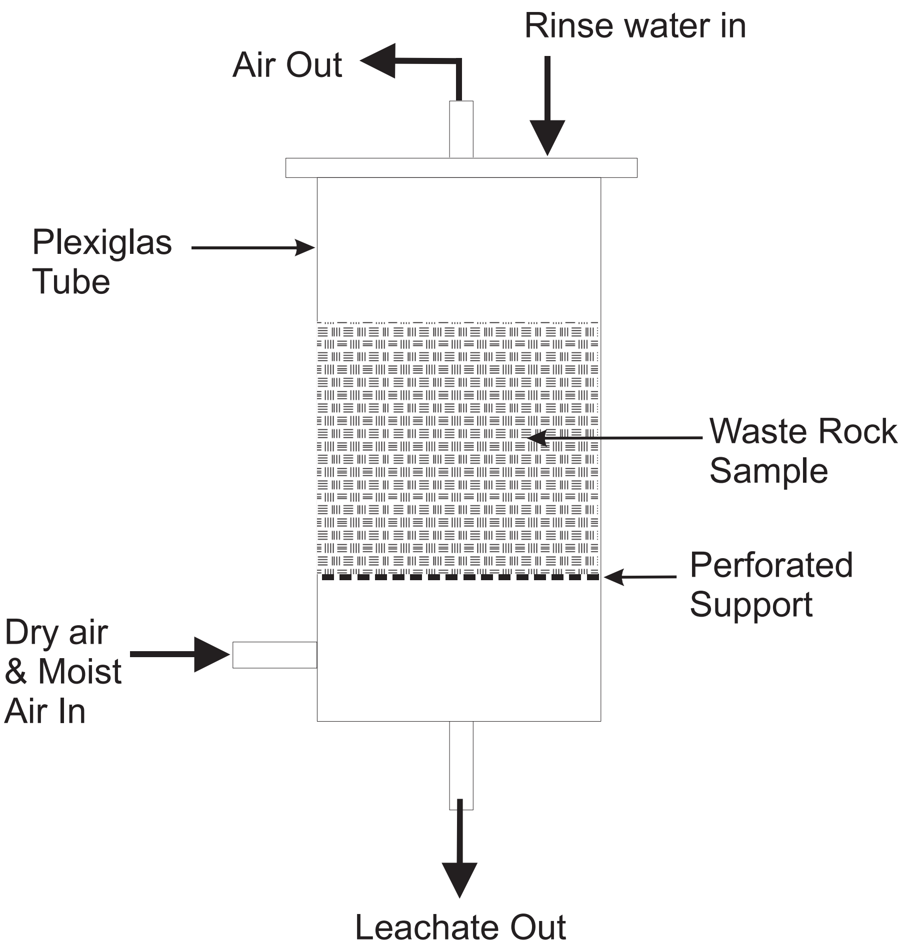
- Tailings produced during year 5+ of mine life:
  - Characterized by lower sulfide content (<0.2%)
  - Non-acid generating

Kinetic Humidity Cell Testwork (HCT) Program Objectives

- Humidity cell testing carried out to:
  - Address the uncertainties of the static tests
  - Provide source term chemistry for:
    - Waste rock
    - Final pit walls
  - Data used as input to water quality predictions

- Accelerated weathering test designed to simulate long-term acid generation and metal leaching rates
- Testing carried out according to American Society for Testing and Materials (ASTM) standard D5744-13e1

Kinetic Humidity Cell Testwork (HCT) Program Method

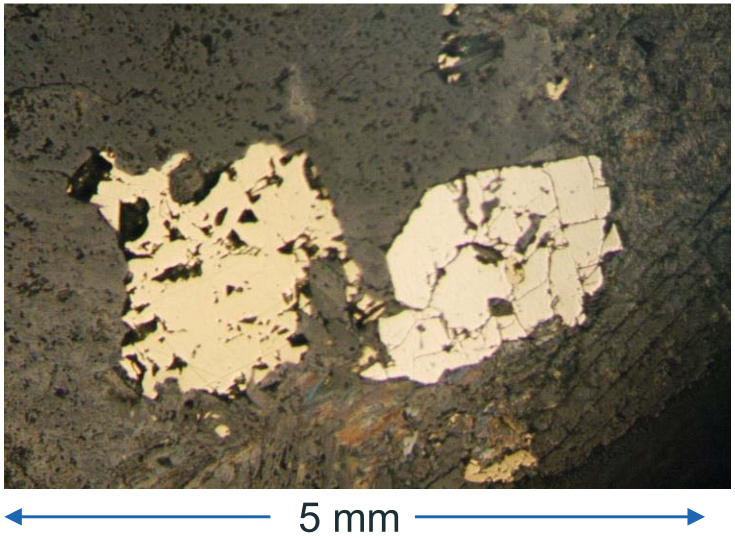


Kinetic Humidity Cell Testwork (HCT) Program Methodology

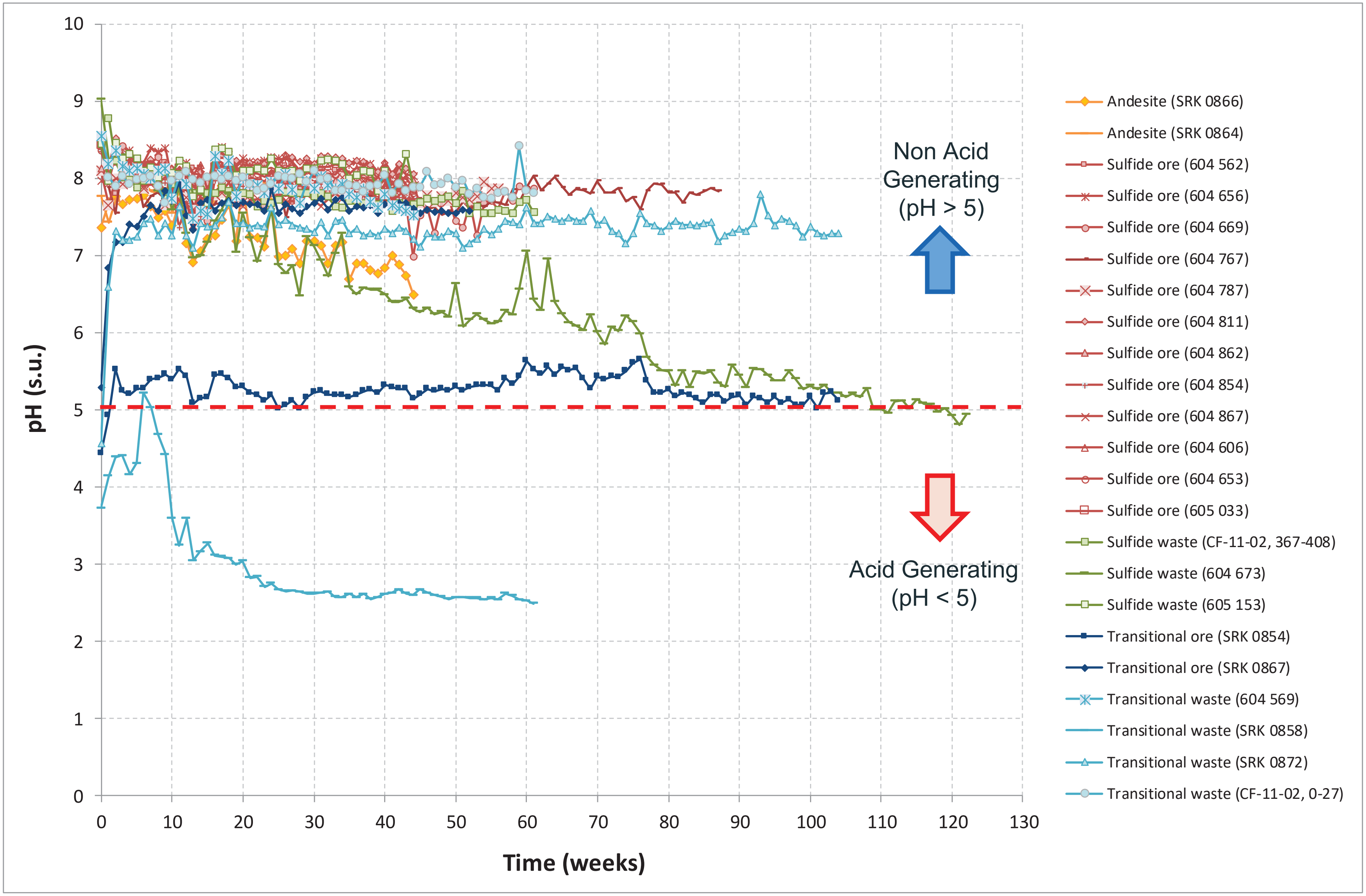
- Representative humidity cell dataset:
  - 32 tests started in 2010
  - Testing focused on more abundant material types as defined by geologic model
  - Aimed at characterizing the range in behavior for the main material types
  - ASTM standard calls for a minimum testing period of 20 weeks
    - Copper Flat humidity cells run for a minimum of 28 weeks and a maximum of 122 weeks
  - Termination of the test is determined by attainment of steady state or equilibrium leaching (i.e., no significant change in last 10 weeks)

Kinetic Test Results

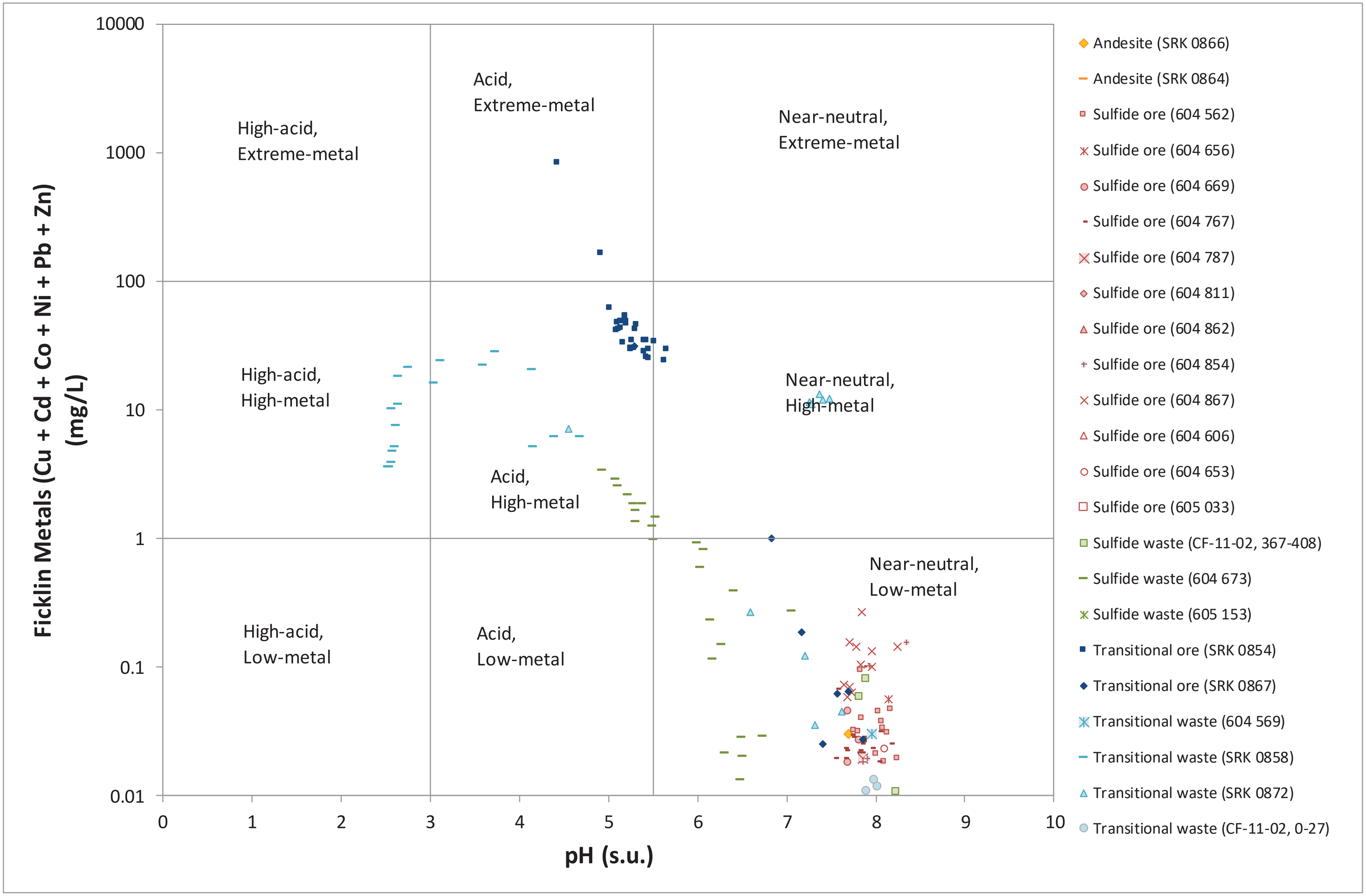
- Acid Generation Potential:
  - Dependent on sulfide content and mineral habit and silicate buffering
  - 20 out of 23 HCTs generated neutral to alkaline leachate throughout the duration of the test
  - Greater reactivity seen for material with partially oxidized/weathered sulfides (transitional ore and waste)
  - Only one sample of unoxidized sulfide showed limited late-stage acid generation potential
    - pH around 5 after 80 weeks of testing
  - Kinetic tests not consistent with static tests
    - ABA and NAG tests over-predict acid generation
- Metal Leaching Potential
  - Consistent with static tests
  - Waste rock and ore enriched in copper, molybdenum, sulfur, selenium and silver
  - Neutral leachates with low metal concentrations
  - Higher metal mobility for transitional material (comprises a small proportion of material)



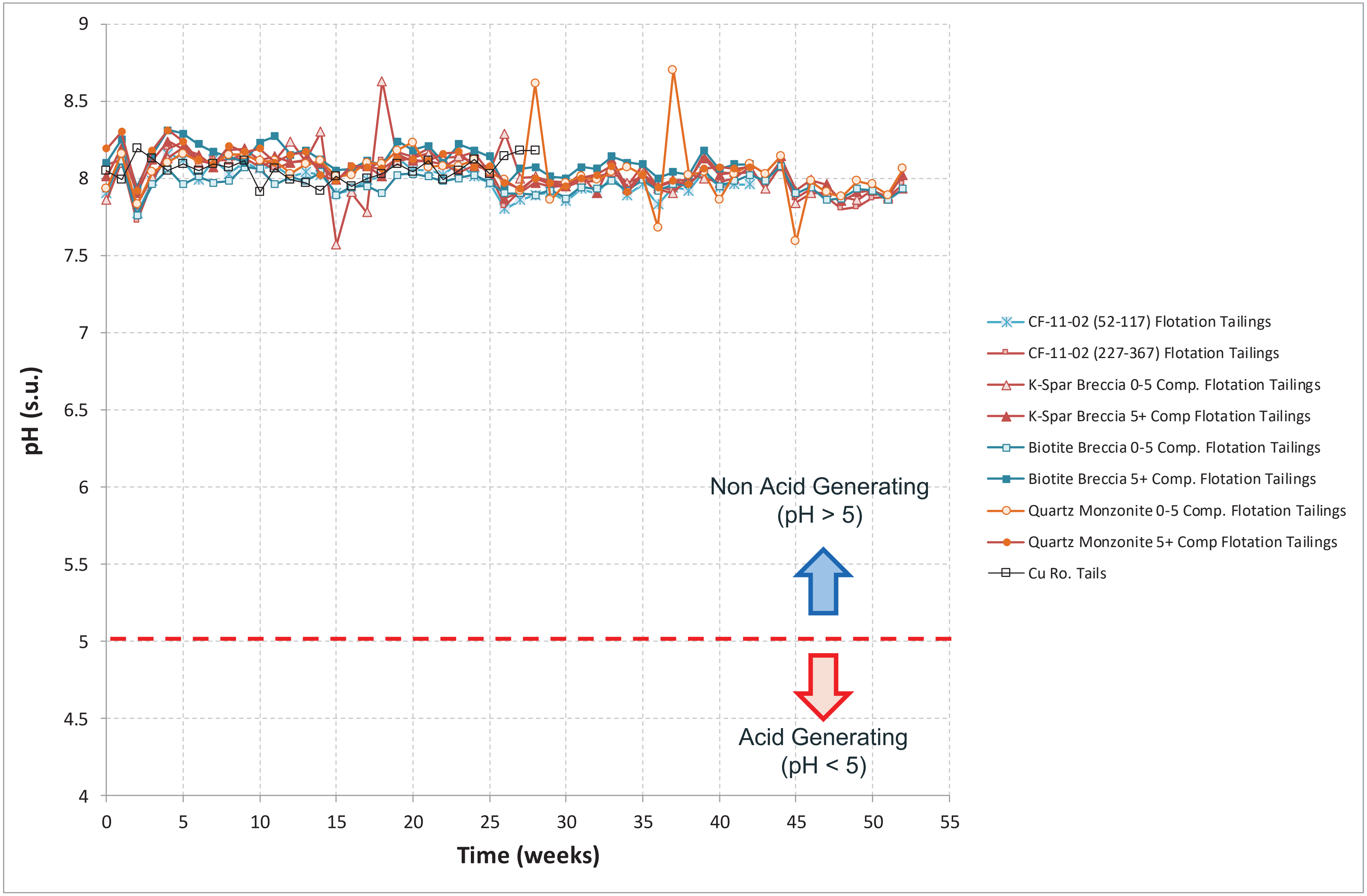
Waste Rock Humidity Cell pH



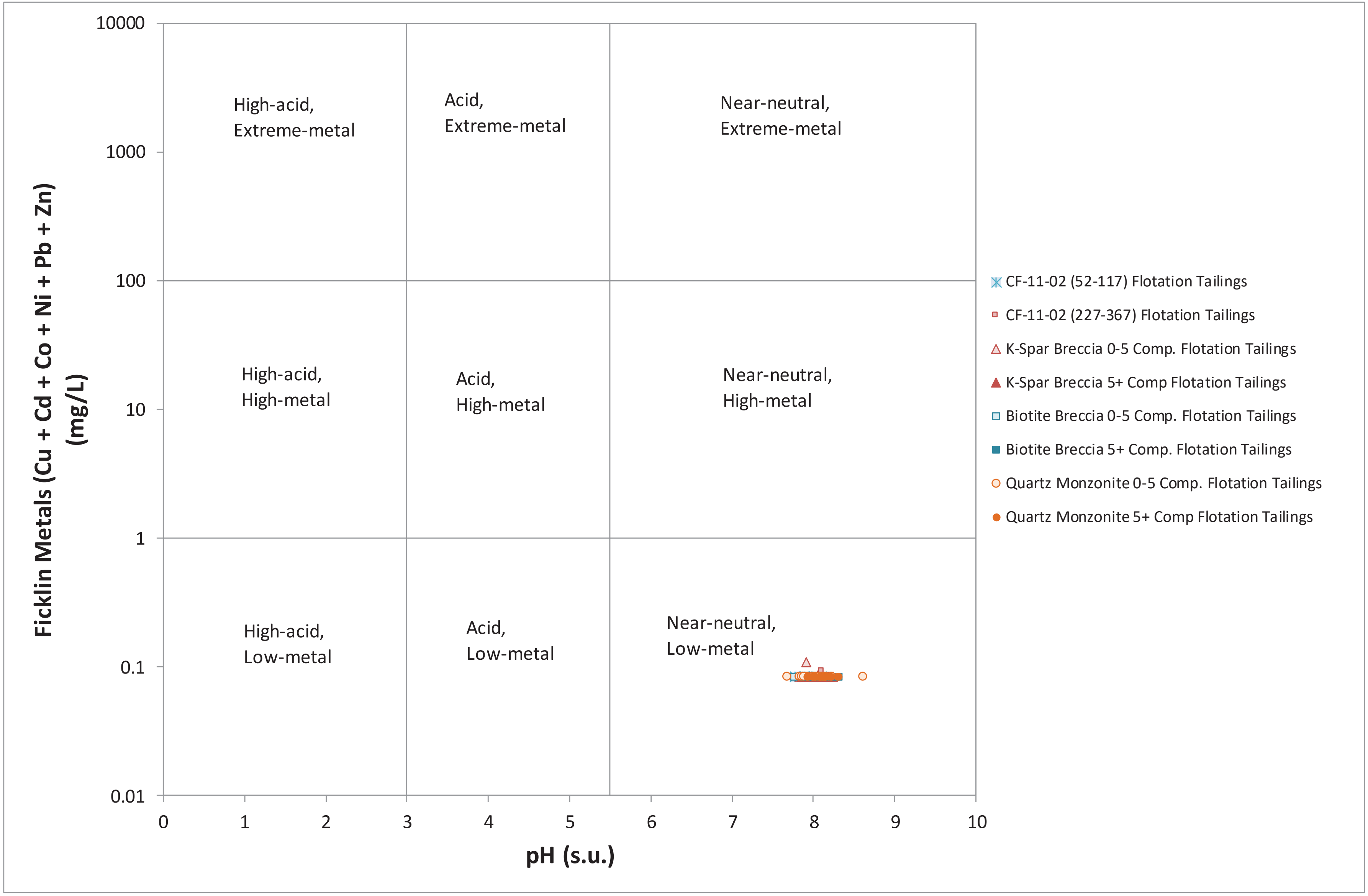
Waste Rock Humidity Cell Metals



Tailings Humidity Cell pH

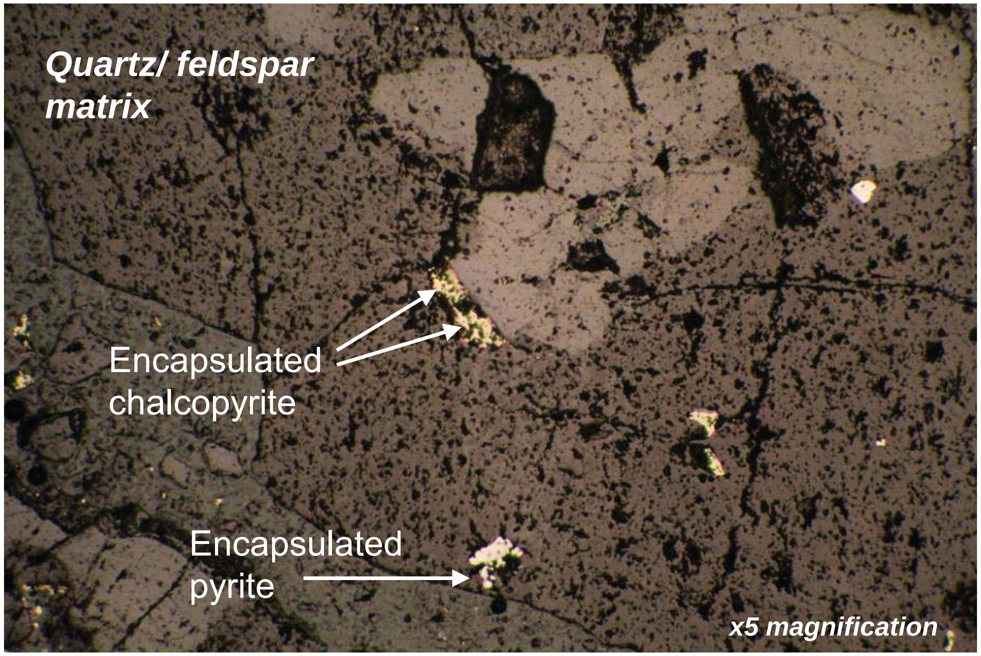


Tailings Humidity Cell Metals



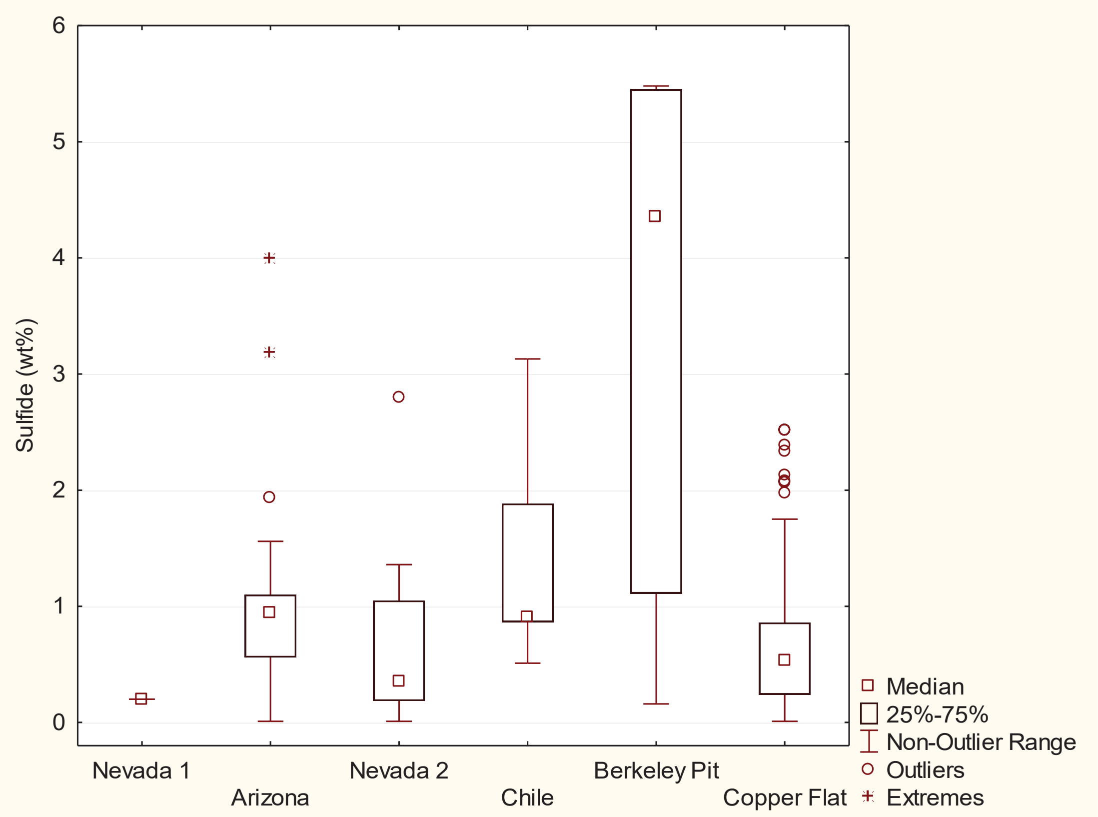
Mineralogy

- Mineralogy was conducted on 28 samples of waste rock/ore
  - Included 7 humidity cell samples to understand why acid conditions did not develop despite elevated sulfide content and prolonged testing
- Lack of acid generation can be attributed to:
  - Encapsulation of sulfides in non-reactive silicate minerals
  - Sulfides are medium to coarse-grained and well-crystallized – means they are more stable and resistant to oxidation
  - Presence of acid buffering silicate minerals (e.g. chlorite)

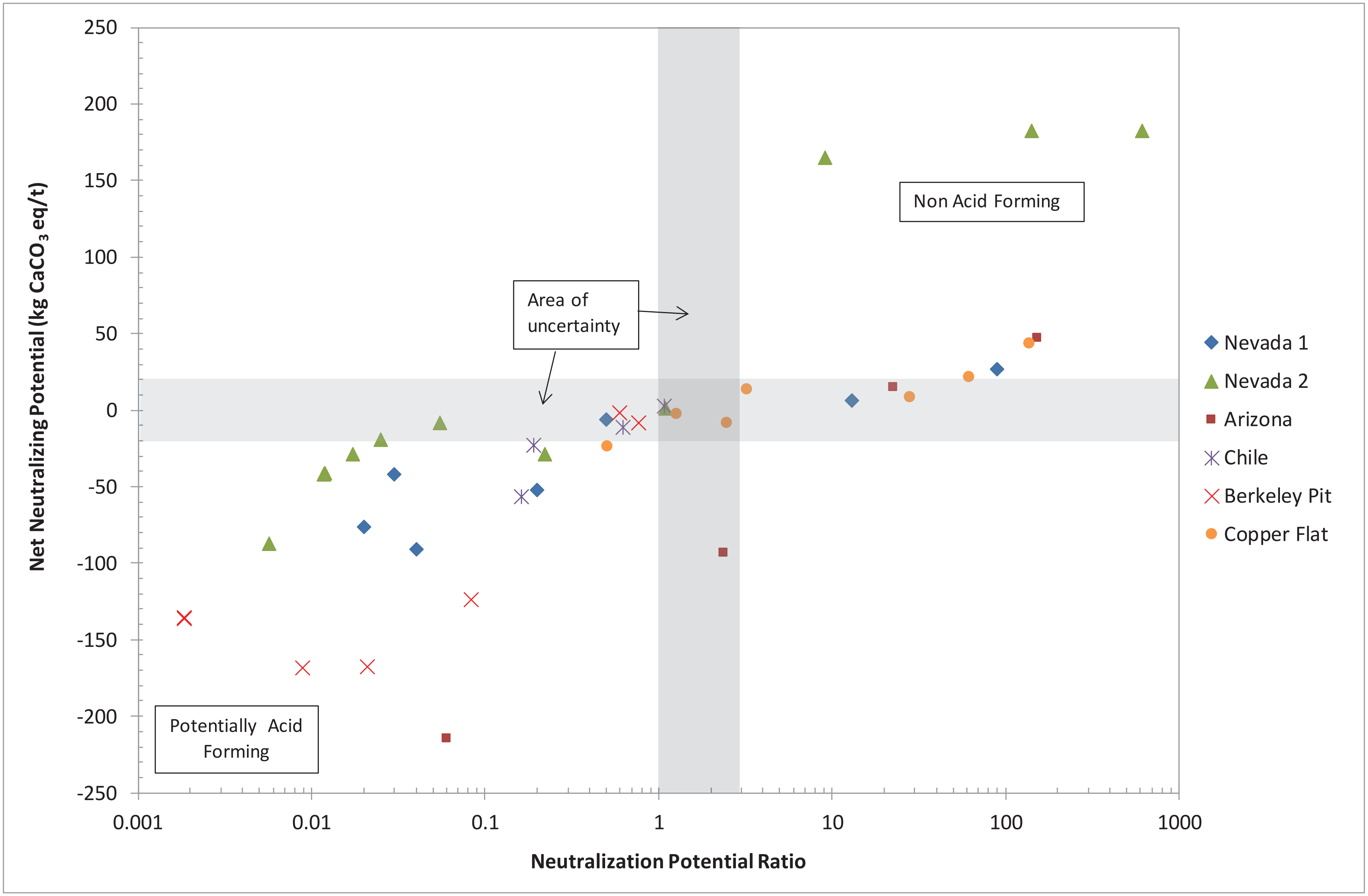


Comparison with Analogue Sites

- The geochemistry of the Copper Flat deposit has been compared to 5 analog sites
    - Similar geological characteristics (oxidized calc-alkaline porphyry systems in volcanic terrains)
    - Similar climate (arid)
- The sulfide content and acid generating potential of Copper Flat waste rock/ore is towards the lower end of the observed range



Comparison with Analogue Sites

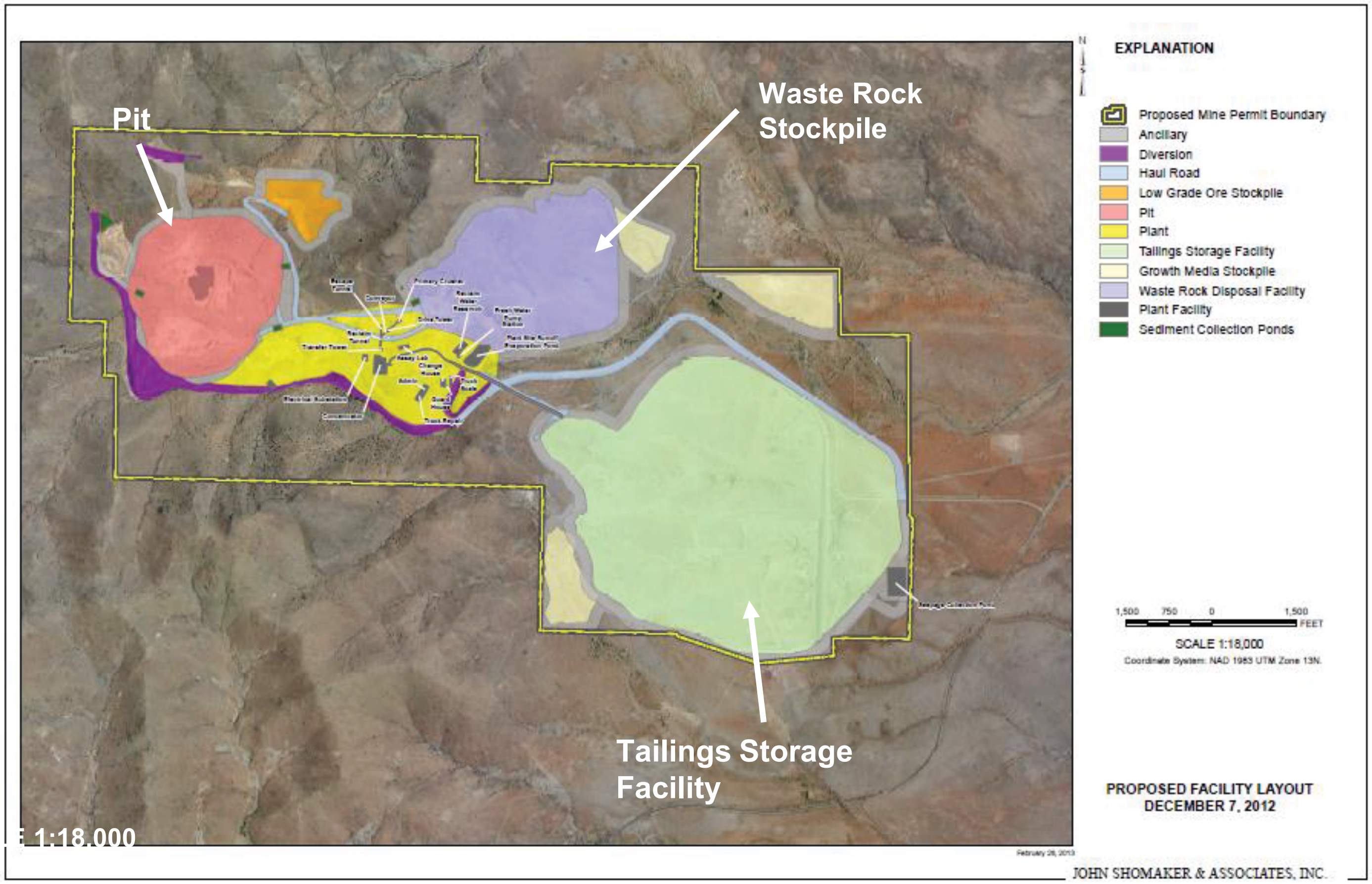


Characterization Summary

- The majority of waste rock (96%) shows a low potential for acid generation and metal release
- Weathering reactions are slow due to the coarse crystalline nature of sulfide minerals and encapsulation in slow-reacting silicates
- Acid Base Accounting and Net Acid Generation methods generally over-predict acid generation
- 20 out of 23 waste rock cells showed neutral conditions in the humidity cell test, even after 100+ weeks of testing
- Transitional material shows a greater potential for acid generation and metal leaching
    - Only comprises 4% of waste rock and none of the final pit wall surfaces
    - Will be managed by encapsulation within the waste rock stockpile
    - Low risk to groundwater and surface water

Water Quality Predictions

- Geochemical characterization testwork results used to develop water quality predictions for the mine facilities, including:
  - Waste Rock Stockpile
  - Tailings Storage Facility
  - Pit lake- calibration on the current pit as well as estimation of future water quality



Water Quality Predictions – Data Inputs

1. Mass-balanced results from humidity cell testwork – scaled to field conditions (SRK)
2. Site-specific climate data (THEMAC)
3. Hydrological and hydrogeological water balance (JSAI)
4. Representative groundwater chemistry data (THEMAC)
5. Rainwater chemistry data (NADP)
6. Tailings supernatant chemistry (Quintana)
7. Mine plan information (THEMAC), including:
   - Waste rock and tailings tonnages
   - Facility design and footprints
   - Pit wall composition

Geochemical predictions undertaken using U.S. Geological Survey software PHREEQC

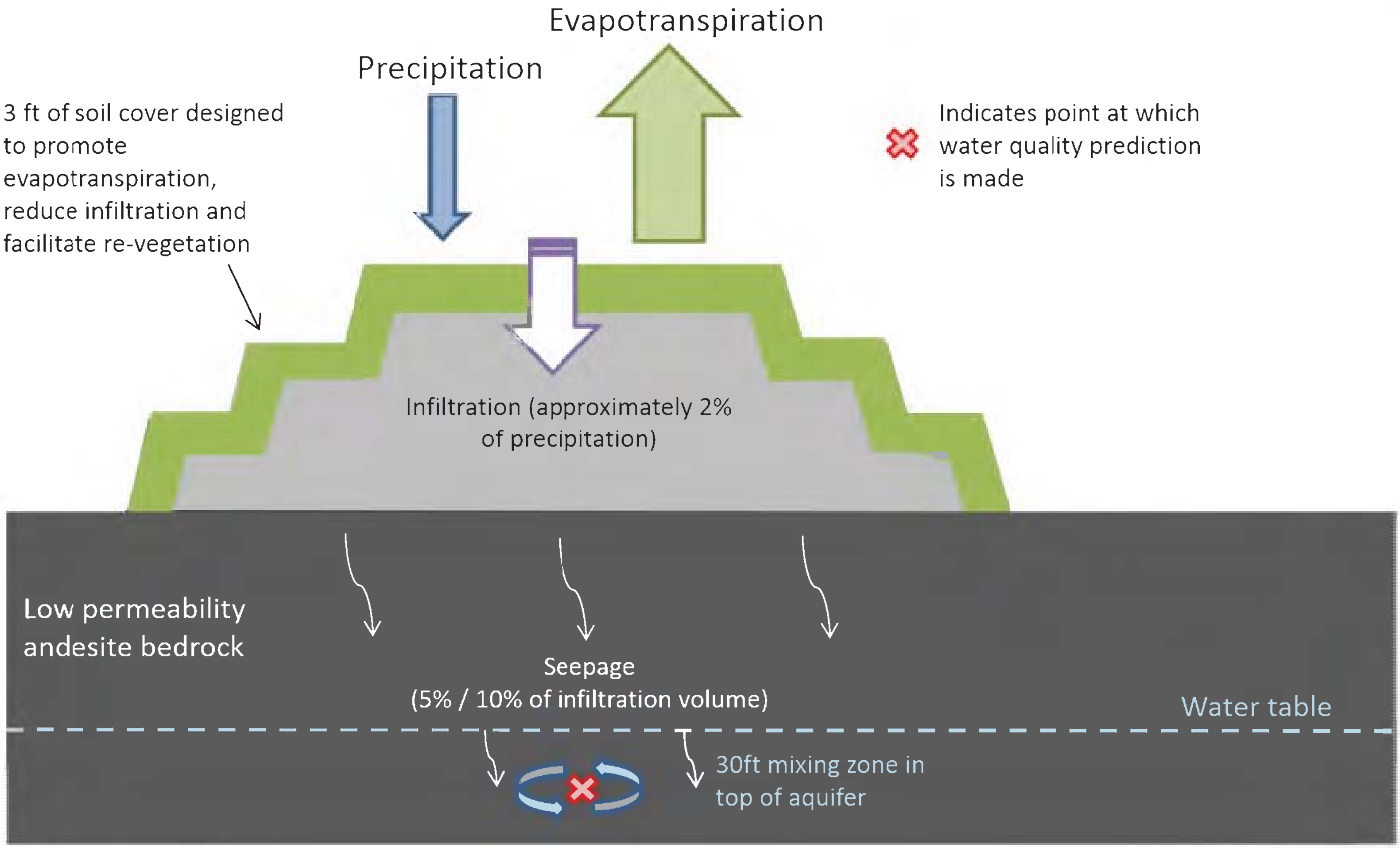
Water Quality Predictions – Waste Rock Stockpile

- Objectives:
  - To assess potential for groundwater impacts from Waste Rock Stockpile
- Assumptions:
  - The final facility (year 11) will contain 60 Mt waste rock – mostly comprising Quartz Monzonite (~75%)
  - The final facility surface area will be 180 acres
  - A re-vegetated 36-inch store-and-release soil cover will be placed after closure to enhance evapotranspiration
  - Long-term infiltration to the facility will be ~2% of mean annual precipitation (MAP)
  - 20% of the total rock mass in the facility will be available for geochemical weathering reactions
  - Low permeability (10^{-6} cm/s) andesite underlying the facility
  - A small proportion of water infiltrating the facility (5-10%) may seep to groundwater (equating to 0.1 – 0.2% of MAP)

Waste Rock Stockpile – Conceptual Model

Final surface area = ~180 acres

Final capacity = 60 Mt



Waste Rock Stockpile – Results

- Pore water within the waste rock stockpile is predicted to be moderately alkaline (pH ~8.2)
- Covering the facility with a re-vegetated store-and-release cover will reduce exposure to air and water → sulfide oxidation will be limited
- No impact to groundwater is predicted should any seepage occur
    - Predicted groundwater chemistry similar to current groundwater chemistry
- All parameters predicted to be below New Mexico WQCC groundwater standards
    - Exception is fluoride, which is naturally elevated in the existing groundwater

Waste Rock Stockpile – Results

Parameter		Units	*NMWQCC numeric standard*	*Average groundwater chemistry in andesite*	**Predicted groundwater chemistry under WRDF assuming 5% seepage from facility**	**Predicted groundwater chemistry under WRDF assuming 10% seepage from facility**
pH	**pH**	s.u.	*6 - 9†*	*6.40*	8.51	8.51
Alkalinity	**Alkalinity as $CaCO_3$**	mg/L	*-*	*-*	183.6	183.4
Ag	**Silver**	mg/L	*0.05**	*0.002*	0.018	0.018
Al	**Aluminium**	mg/L	*5‡*	*0.03*	0.0015	0.0015
As	**Arsenic**	mg/L	*0.1**	*0.005*	2.85E-07	2.86E-07
B	**Boron**	mg/L	*0.75‡*	*0.19*	0.19	0.19
Ba	**Barium**	mg/L	*1**	*0.15*	0.027	0.027
Ca	**Calcium**	mg/L	*-*	*59.1*	9.43	9.45
Cd	**Cadmium**	mg/L	*0.01**	*0.003*	0.0003	0.0003
Co	**Cobalt**	mg/L	*0.05‡*	*0.03*	0.005	0.005
Cr	**Chromium**	mg/L	*0.05**	*0.014*	0.00003	0.00003
Cu	**Copper**	mg/L	*1†*	*0.024*	0.005	0.005
F	**Fluoride**	mg/L	*1.6**	*1.93*	1.93	1.93
Fe	**Iron**	mg/L	*1†*	*1.6*	0.00004	0.00004
Hg	**Mercury**	mg/L	*0.002**	*0.0007*	0.0007	0.0007
K	**Potassium**	mg/L	*-*	*3.23*	3.25	3.26
Mg	**Magnesium**	mg/L	*-*	*7.34*	6.38	6.38
Mn	**Manganese**	mg/L	*0.2†*	*0.65*	0.03	0.03
Mo	**Molybdenum**	mg/L	*1‡*	*0.031*	0.03	0.03
Na	**Sodium**	mg/L	*-*	*127*	118	118
Ni	**Nickel**	mg/L	*0.2‡*	*0.027*	0.002	0.002
Pb	**Lead**	mg/L	*0.05**	*0.009*	0.0002	0.0002
Sb	**Antimony**	mg/L	*-*	*0.002*	0.002	0.002
Se	**Selenium**	mg/L	*0.05**	*0.004*	0.0002	0.0002
Tl	**Thallium**	mg/L	*-*	*0.001*	0.001	0.001
U	**Uranium**	mg/L	*0.03**	*0.001*	0.001	0.001
V	**Vanadium**	mg/L	*-*	*0.05*	0.000003	0.000003
Zn	**Zinc**	mg/L	*10†*	*0.03*	0.001	0.001
SO_4	**Sulfate**	mg/L	*600†*	*115*	115	115
Cl	**Chloride**	mg/L	*250†*	*64.5*	64.5	64.5
N	**Nitrogen as N**	mg/L	*10**	*1.23*	1.24	1.24
TDS¤	**Total Dissolved Solids**	mg/L	*1000†*	*614*	428	428

*	Human health groundwater standard
†	Domestic water supply standard
‡	Irrigation standard
¤	TDS has been calculated as the sum of total ions from the PHREEQC model output and cannot be considered a true representation

- All constituents in groundwater below the WRSP are predicted to be either:
  - Below the NMWQCC numeric standard; or
  - Equal to or below baseline groundwater concentrations in the andesite

Water Quality Predictions – Tailings Storage Facility

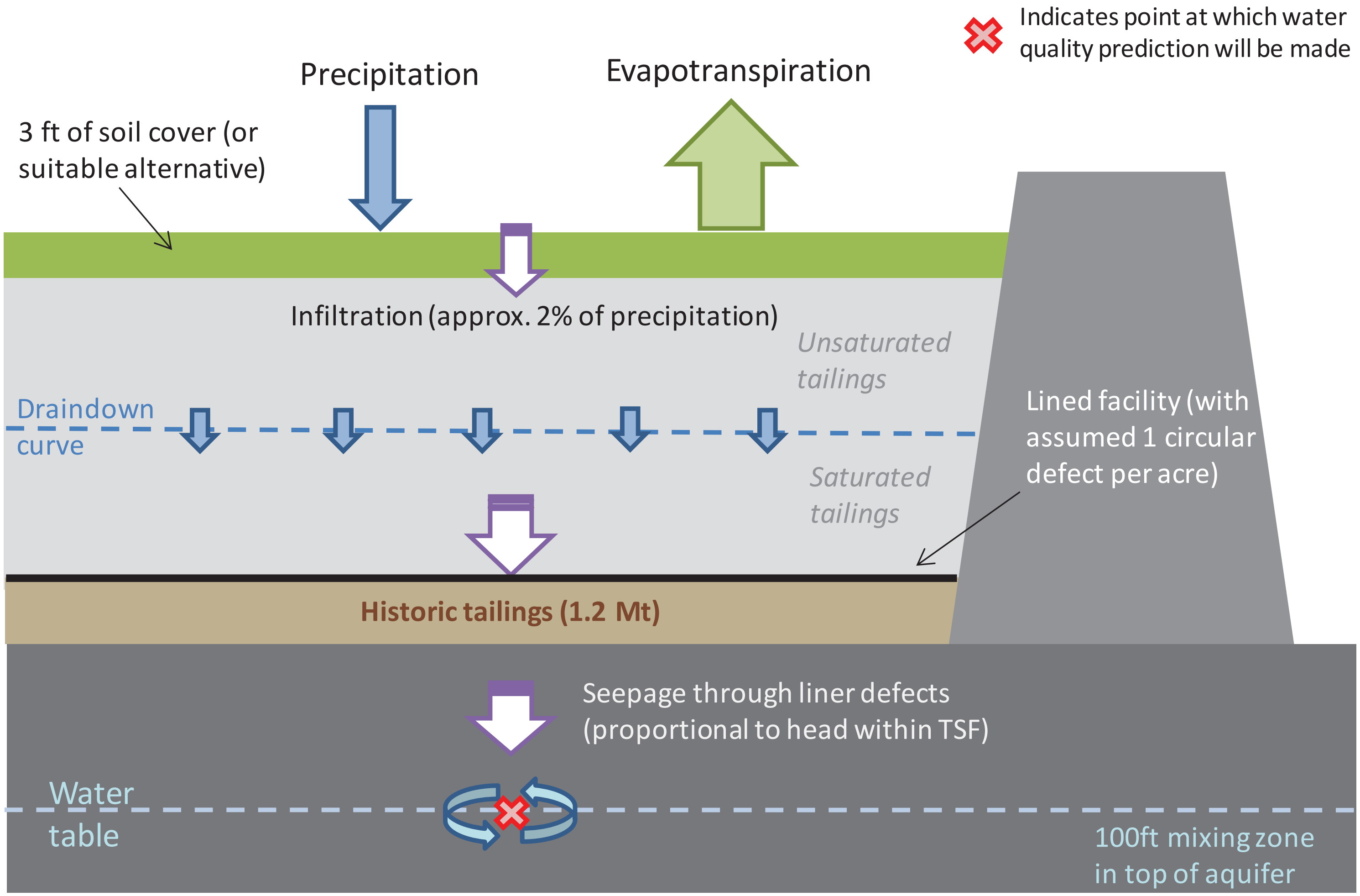
- Objectives:
  - To assess potential for groundwater impacts from Tailings Storage Facility
- Assumptions:
  - The final facility (year 11) will contain 100 Mt of tailings
  - The facility surface area will be 530 acres
  - Tailings will be deposited in a lined facility that will be constructed on the site of the existing (historic) tailings facility
  - Historic tailings (1.2 Mt) will be placed below the new, lined facility
  - Closure of the facility will include:
    - Grading of the embankment slopes
    - Placement of a 36-inch store-and-release cover
    - Management of underdrainage
  - Approximately 2% of mean annual precipitation may infiltrate the facility
  - 70% of the total mass of tailings in the facility will be available for chemical weathering reactions

Water Quality Predictions – Tailings Storage Facility

- Assumptions:
  - Seepage from the facility will be small, however there may be minor seepage through manufacturing defects in the liner
  - It is assumed there will be one circular defect (1 cm^2) per acre in the liner (JSAI, 2012; Giroud and Bonaparte, 1989)
  - This will result in minor seepage (<0.25 gallons/day/acre) from the facility
  - Seepage will consist of a mixture of process water and precipitation

Tailings Storage Facility – Conceptual Model

Final TSF surface area = ~530 acres
Final TSF capacity = 100 Mt



Tailings Storage Facility – Results

- Solution chemistry will be dominated by moderately alkaline process water during the draindown period (pH ~8.2)
- Seepage through liner defects will be so low that impacts to groundwater underlying the TSF will be negligible
- Predicted groundwater chemistry is similar to existing groundwater chemistry
- **No parameters are predicted to exceed New Mexico WQCC groundwater standards**
- Containment of the historic tailings below the lined facility is likely to improve groundwater quality (particularly sulfate)
- Particle tracking (JSAI, 2012) indicates that any seepage from the facility would remain in immediate area for several hundred years with no migration or plume generation

Tailings Storage Facility – Results

			NMWQCC standard	Baseline groundwater under TSF (wells GWQ94-16, NP-2, NP-4 and NP5)	Predicted groundwater chemistry at 25% draindown	Predicted groundwater chemistry at 50% draindown	Predicted groundwater chemistry at 75% draindown	Predicted groundwater chemistry at 90% draindown	Predicted groundwater chemistry at 95% draindown
pH	**pH**	s.u.	6 - 9[†]	7.76	8.05	8.05	8.05	8.05	8.05
pe	**pe**	s.u.	-	-	4.72	4.72	4.72	4.72	4.72
Alk	**Alkalinity as CaCO$_3$**	mg/L	-	178	65.6	65.6	65.6	65.6	65.6
HCO$_3$	**Bicarbonate**	mg/L	-	178	39.4	39.4	39.4	39.4	39.4
Ag	**Silver**	mg/L	0.05*	0.005	0.005	0.005	0.005	0.005	0.005
Al	**Aluminium**	mg/L	5[‡]	0.02	0.0005	0.0005	0.0005	0.0005	0.0005
As	**Arsenic**	mg/L	0.1*	0.002	0.002	0.002	0.002	0.002	0.002
B	**Boron**	mg/L	0.75[†]	0.044	0.044	0.044	0.044	0.044	0.044
Ba	**Barium**	mg/L	1*	0.036	1.79E-09	1.19E-09	5.96E-10	2.35E-10	6.63E-11
Ca	**Calcium**	mg/L	-	137	91.7	91.7	91.7	91.7	91.7
Cd	**Cadmium**	mg/L	0.01*	0.002	0.002	0.002	0.002	0.002	0.002
Co	**Cobalt**	mg/L	0.05[‡]	0.006	0.006	0.006	0.006	0.006	0.006
Cr	**Chromium**	mg/L	0.05*	0.006	0.00005	0.00005	0.00005	0.00005	0.00005
Cu	**Copper**	mg/L	1[†]	0.006	0.005	0.005	0.005	0.005	0.005
F	**Fluoride**	mg/L	1.6*	0.57	0.57	0.57	0.57	0.57	0.57
Fe	**Iron**	mg/L	1[†]	0.03	0.00005	0.00005	0.00005	0.00005	0.00005
Hg	**Mercury**	mg/L	0.002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002
K	**Potassium**	mg/L	-	2.70	2.73	2.72	2.71	2.71	2.71
Mg	**Magnesium**	mg/L	-	35.2	35.2	35.2	35.2	35.2	35.2
Mn	**Manganese**	mg/L	0.2[†]	0.02	0.02	0.02	0.02	0.02	0.02
Mo	**Molybdenum**	mg/L	1[‡]	0.008	0.01	0.01	0.01	0.01	0.01
Na	**Sodium**	mg/L	-	65.6	55.8	55.8	55.8	55.8	55.8
Ni	**Nickel**	mg/L	0.2[‡]	0.01	0.01	0.01	0.01	0.01	0.01
Pb	**Lead**	mg/L	0.05*	0.005	0.004	0.004	0.004	0.004	0.004
Sb	**Antimony**	mg/L	-	0.001	0.001	0.001	0.001	0.001	0.001
Se	**Selenium**	mg/L	0.05*	0.01	0.01	0.01	0.01	0.01	0.01
Tl	**Thallium**	mg/L	-	0.001	0.001	0.001	0.001	0.001	0.001
U	**Uranium**	mg/L	0.03*	0.002	0.001	0.001	0.001	0.001	0.001
V	**Vanadium**	mg/L	-	0.05	0.05	0.05	0.05	0.05	0.05
Zn	**Zinc**	mg/L	10[†]	0.43	0.43	0.43	0.43	0.43	0.43
SO$_4$	**Sulfate**	mg/L	600[†]	269	269	269	269	269	269
Cl	**Chloride**	mg/L	250[†]	120	120	120	120	120	120
N	**Nitrogen as N**	mg/L	10	4.37	4.35	4.35	4.35	4.35	4.35
TDS[¤]	**Total Dissolved Solids**	mg/L	1000[†]	825 (measured)	620	620	620	620	620

▨	Indicates exceedance of NMWQCC standard
*	Human health groundwater standard
†	Domestic water supply standard
‡	Irrigation standard
¤	TDS has been calculated as the sum of total ions from the PHREEQC model output and cannot be considered a true representation of TDS from a chemical analysis

Pit Lake Water Quality Predictions

- Objectives of pit lake geochemical predictions:
  - Assess future pit lake chemistry for the Copper Flat Project
  - Compare predicted pit lake chemistry to the existing pit lake
  - Assess effects of proposed reclamation actions on predicted pit lake chemistry
  - Demonstrate compliance with New Mexico Mining Act regulations, specifically:
    - The operations must be planned and conducted to minimize change in the hydrologic balance in the permit and potentially affected areas
    - Reclamation must result in a hydrologic balance similar to existing conditions
    - Post-mining water quality must be similar to baseline pre-mining water quality

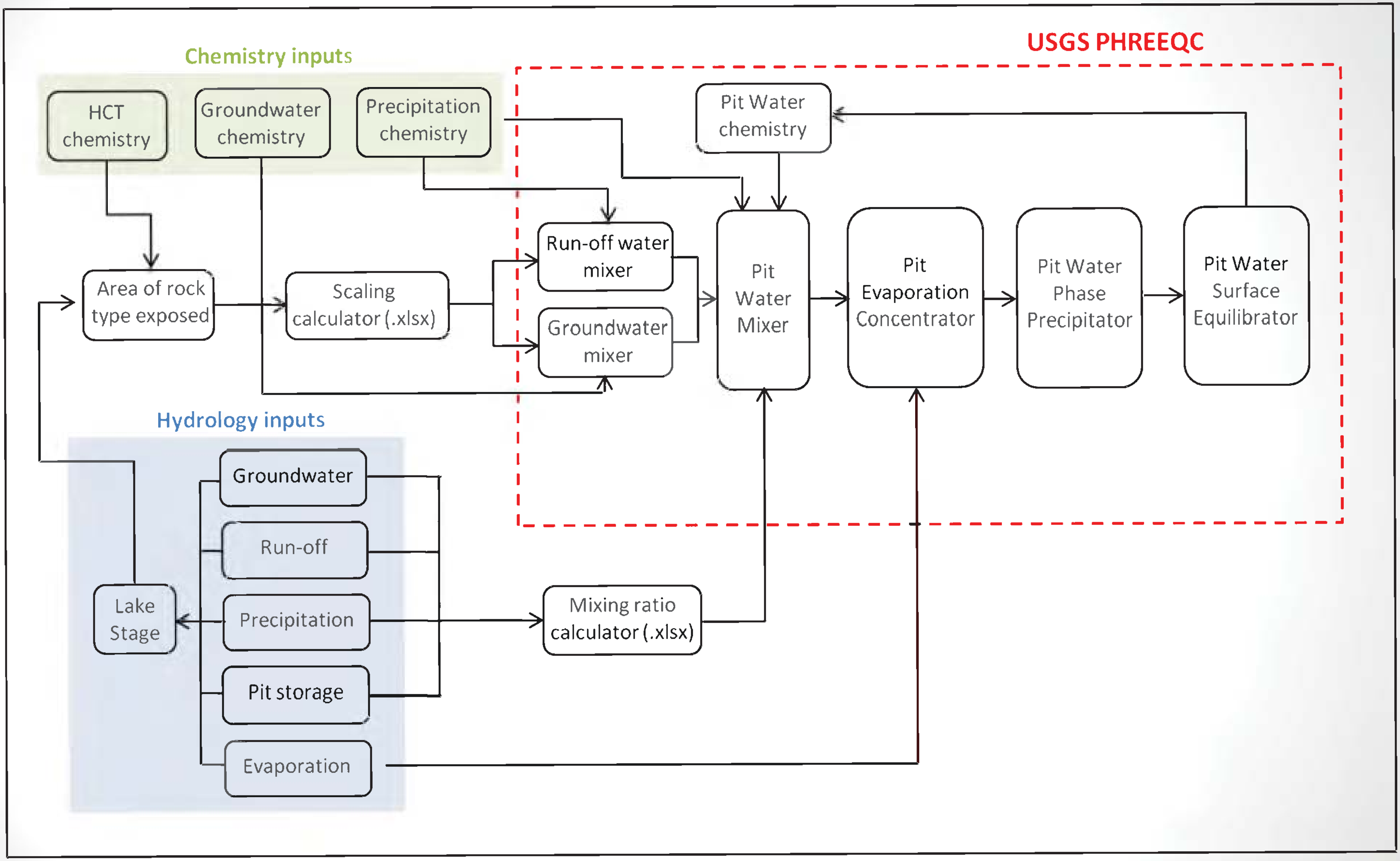
Pit Lake Water Quality Predictions - Introduction

- Pit lake predictions completed for three scenarios:
  - Existing conditions – to calibrate model and refine modeling approach
  - Future conditions
    - Unreclaimed pit with natural fill
    - Reclaimed pit with rapid fill
- Predictions made using the USGS code PHREEQC (Parkhurst and Appelo, 2010)
- Predictions made for 0.5, 1, 2, 5, 10, 25, 50, 75 and 100 years after the start of pit lake formation

Pit Lake Water Quality Predictions - Model Inputs and Assumptions

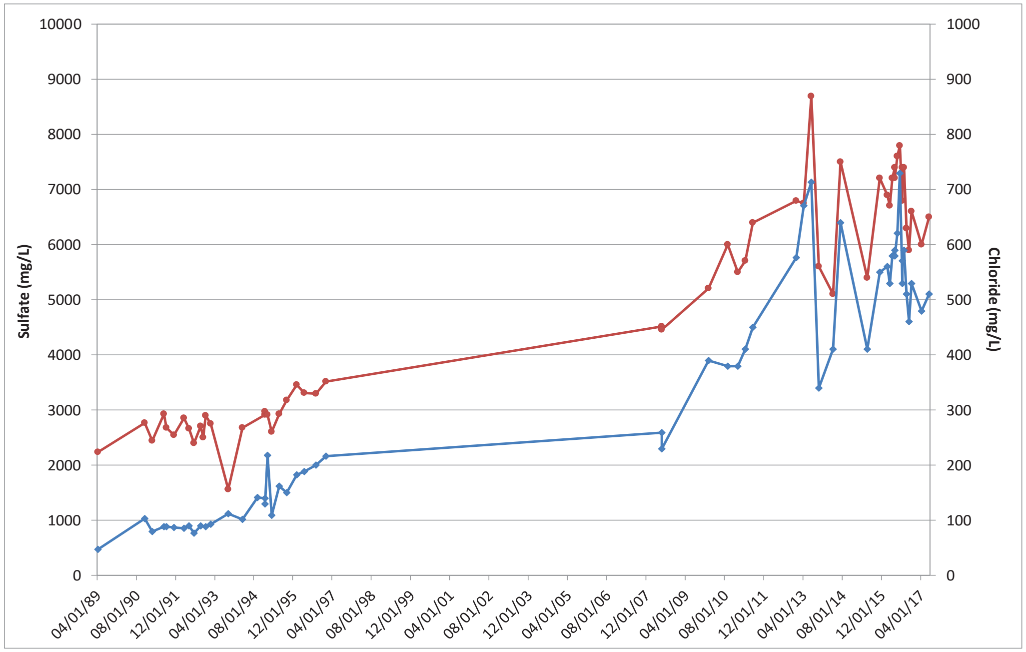
Component	Source
Pit wall geology and surface areas	2017 MORP pit shell and FS geologic block model with expanded 4900 catch bench
Water balances	JSAI (2017) provided separate water balances for: • Existing pit • Natural fill model • Rapid fill model
Groundwater chemistry	Baseline groundwater chemistry data from the ongoing monitoring program (INTERA, 2012, JSAI, 2017)
Water supply well chemistry (rapid fill model)	Groundwater quality data from wells PW-1 and PW-3 (JSAI, 2017)
Pit wall source term chemistry	Humidity cell testing conducted as part of SRK geochemical characterization program (SRK, 2012)
Precipitation chemistry	Precipitation chemistry data from Gila Cliff Dwelling National Monument Meteorological Station (1985-2011) (NADP, 2012)
Thermodynamic data	Minteq.v4 database supplied with USGS PHREEQC (Parkhurst and Appelo, 1999). Modified to include sorption data for arsenic and manganese.

Pit Lake Water Quality Predictions - General Modeling Approach



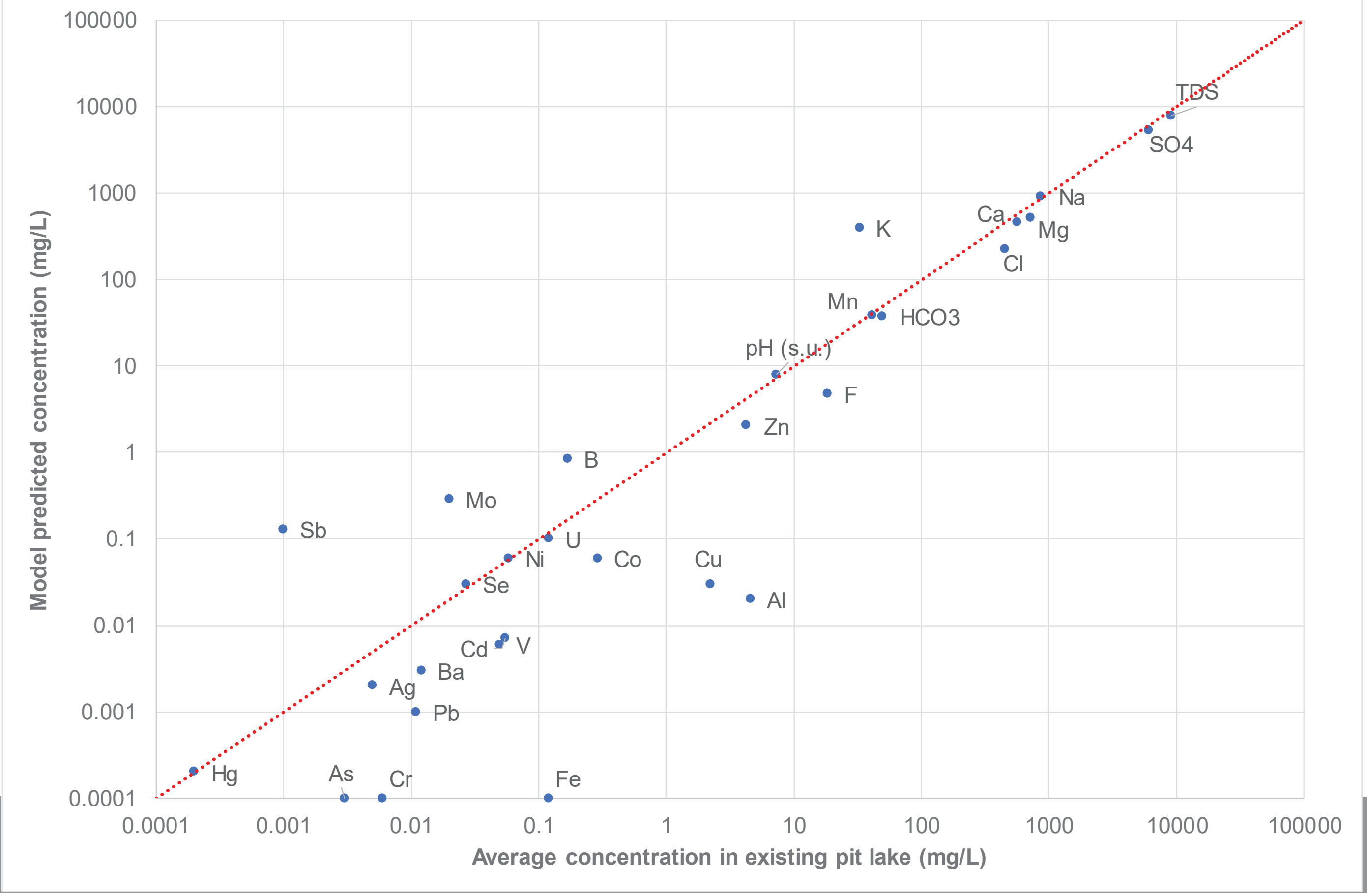
Existing Pit Lake

- Developed during the early 1980s
- Circum-neutral (pH ~6.5)
- Occasional acid wall seep (AWS) events
- Evapoconcentration of sulfate, chloride, TDS, manganese, fluoride, sodium and potassium over time
- Provides understanding of processes that control pit lake chemistry
- Used to verify model assumptions/approach



Pit Lake Water Quality Predictions - Model Calibration

- Numerical predictions undertaken to model existing pit lake chemistry to calibrate and verify future pit lake geochemical predictions
- Water balance developed for existing pit by JSAI
  - Used to develop geochemical model to predict current water chemistry
- Model results show good calibration for most parameters
  - Constituent concentrations are within range of measured concentrations in existing pit lake
  - Verifies modeling approach



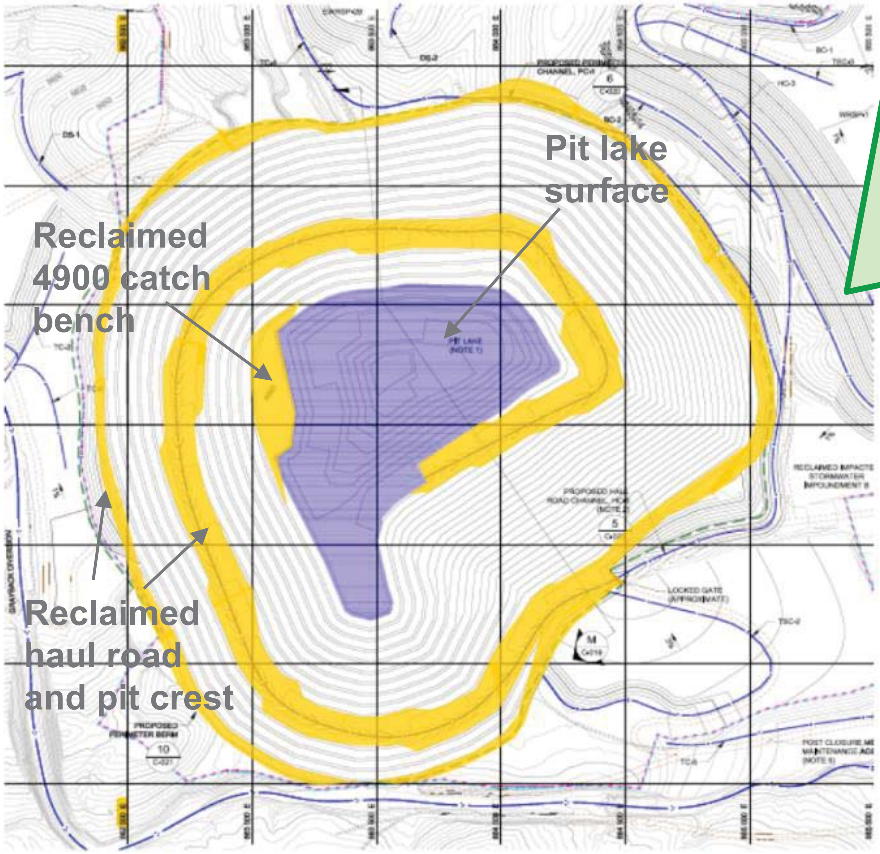
Pit Lake Water Quality Predictions – Model Scenarios

1. Unreclaimed Pit with Natural Fill

- Assumes no reclamation measures
- Pit will be allowed to fill naturally

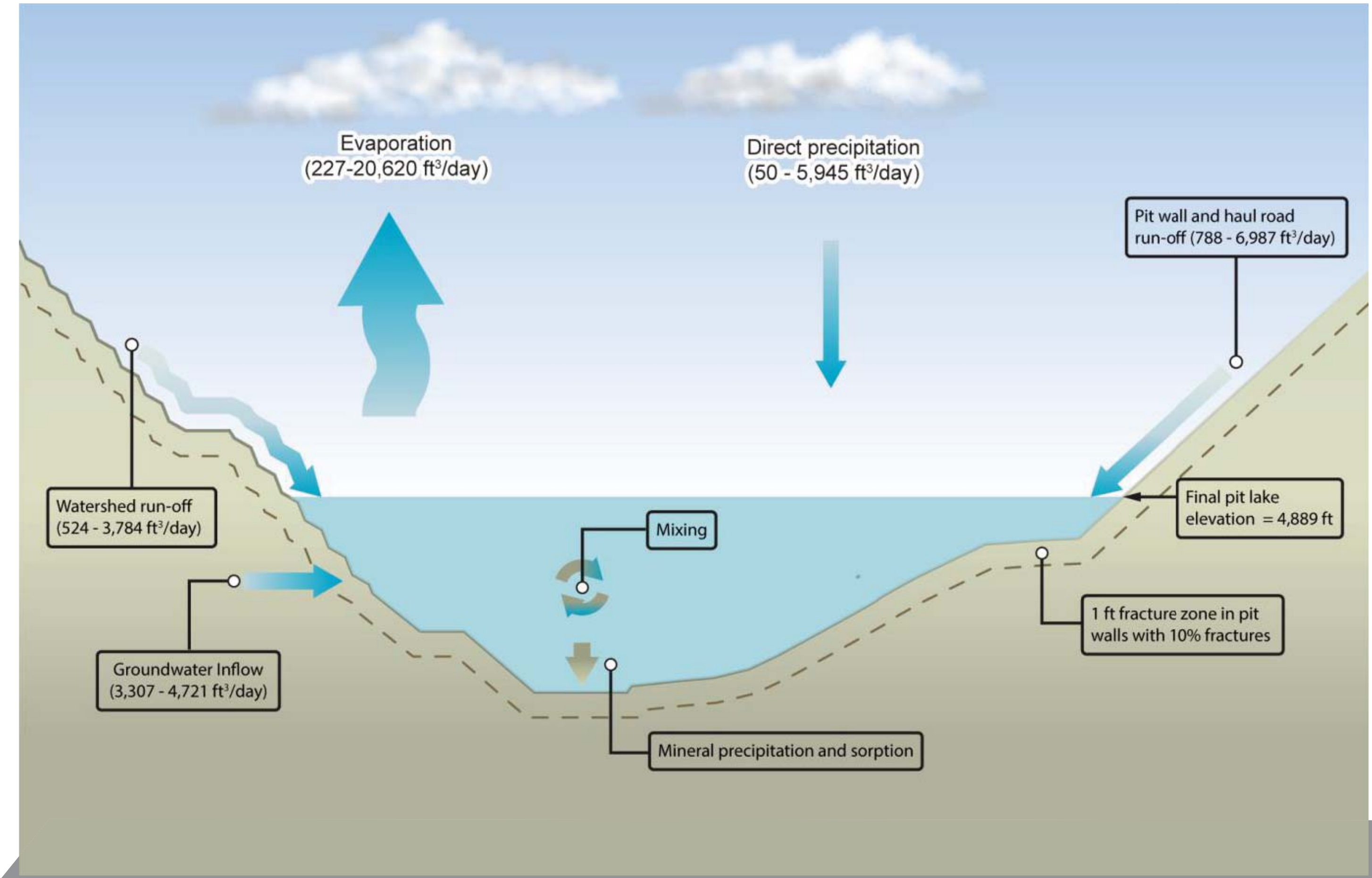
2. Reclaimed Pit with Rapid Fill

- Incorporates reclamation from NMCC's Mine Reclamation Plan, including:
  - Reclamation of the pit haul road
  - Reclamation of the expanded section of the 4900 catch bench
  - Reclamation of benches at the crest of the pit
  - Rapid fill of the pit with fresh water from the production supply wells

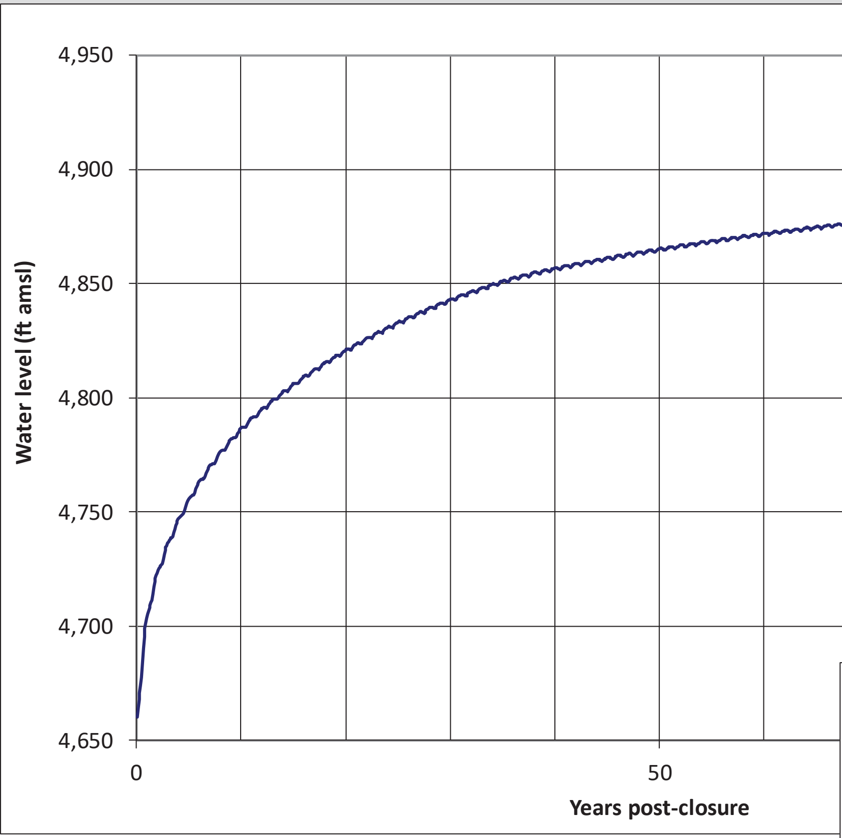


Conceptual Model - Future Unreclaimed Pit

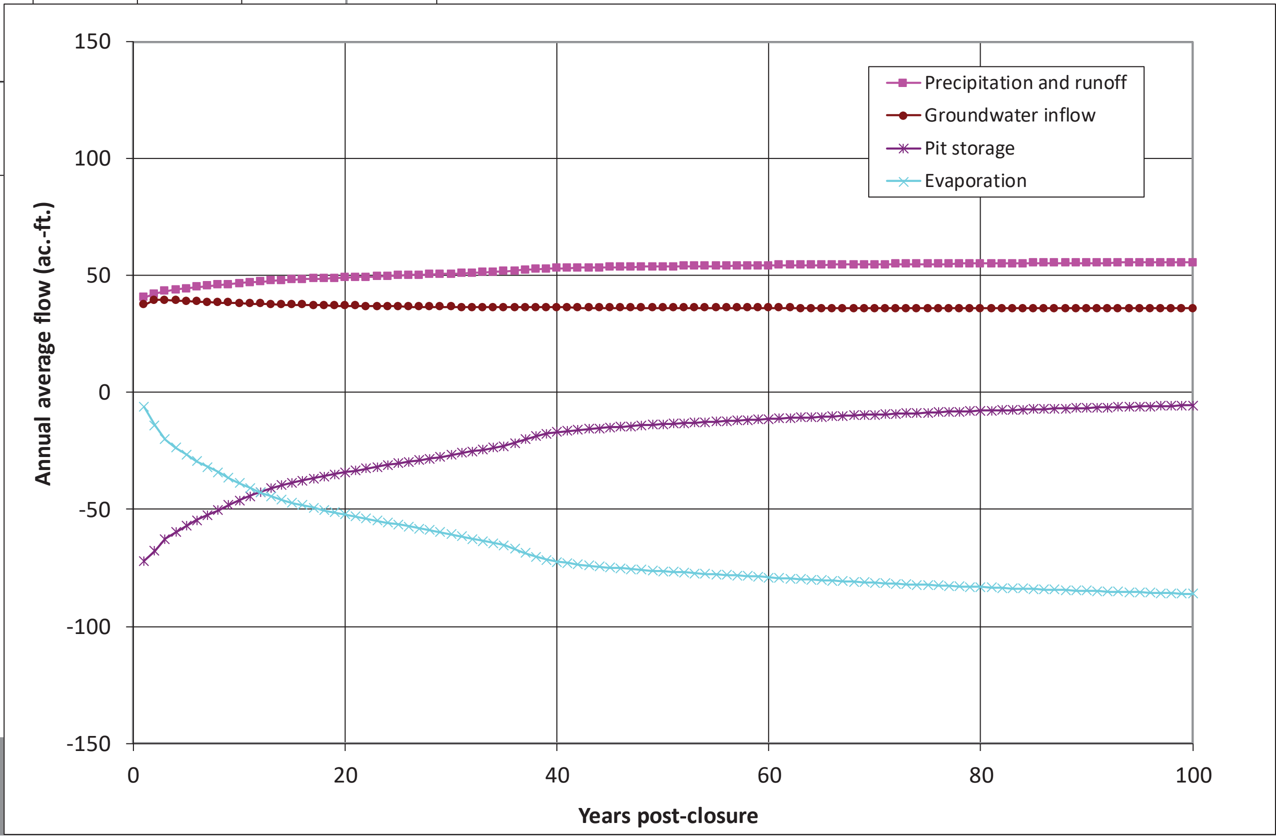
- Assumes a pit lake will form post-closure by natural refill as a result of:
  - Groundwater inflow to pit
  - Direct precipitation onto pit lake surface
  - Run-off from the pit walls
  - Run-off from the open pit surface drainage area
- Resulting pit lake will be a hydraulic sink



Pit Lake Water Balance – Future Unreclaimed Pit

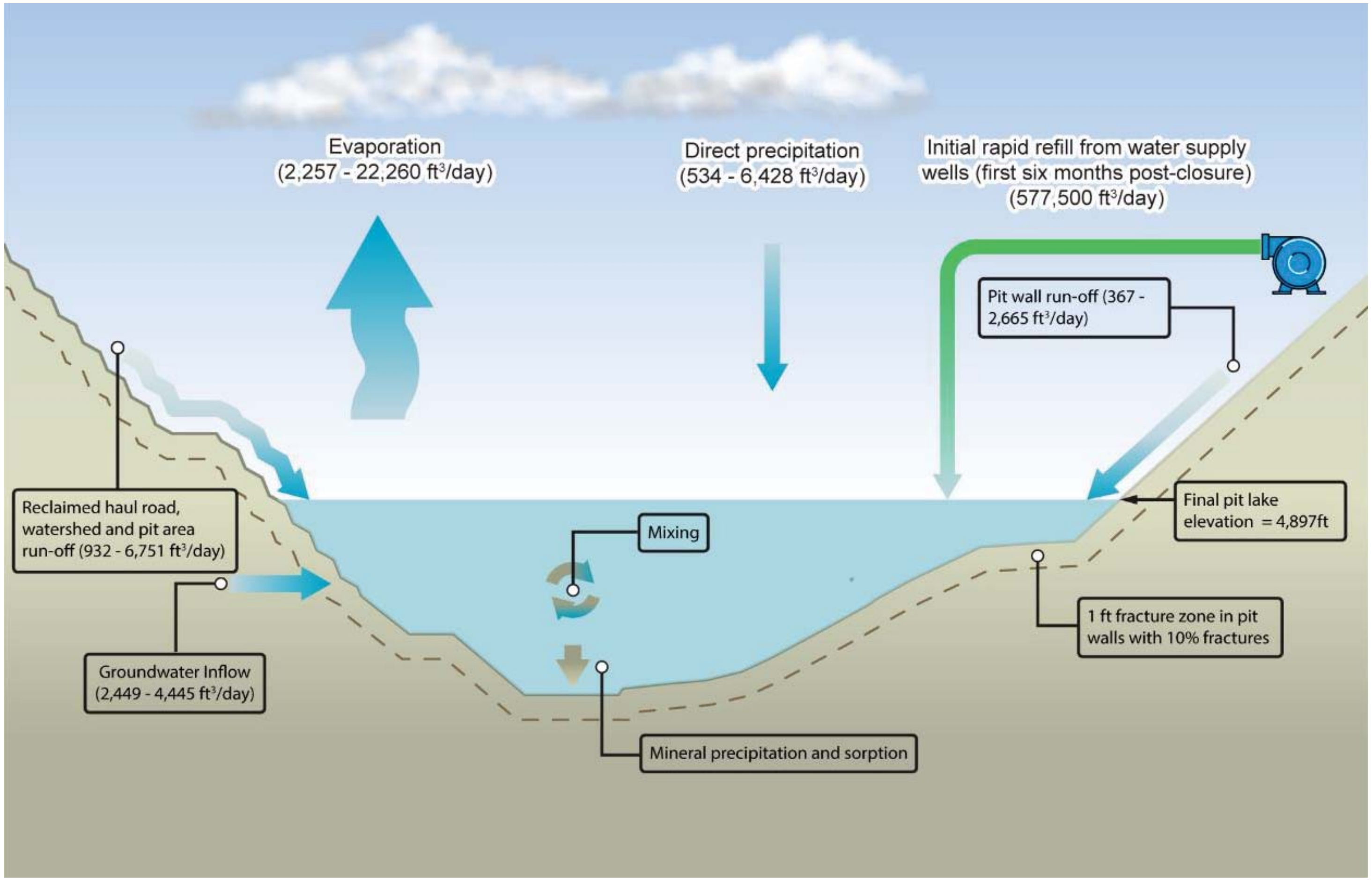


- The lake will cover an area of approximately 20.7 acres with a depth of ~247 ft



Pit Lake Conceptual Model – Future Reclaimed Pit with Rapid Fill

- During the first 6 months post-closure, the pit will be filled with 2,200 acre-feet of water from water supply wells
  - Pit walls and benches will be rapidly submerged
  - Limits exposure of sulfide minerals to oxygen
  - Reduces effects of evapoconcentration



Evaporation (2,257 - 22,260 ft^3/day)

Direct precipitation (534 - 6,428 ft^3/day)

Initial rapid refill from water supply wells (first six months post-closure) (577,500 ft^3/day)

Pit wall run-off (367 - 2,665 ft^3/day)

Reclaimed haul road, watershed and pit area run-off (932 - 6,751 ft^3/day)

Mixing

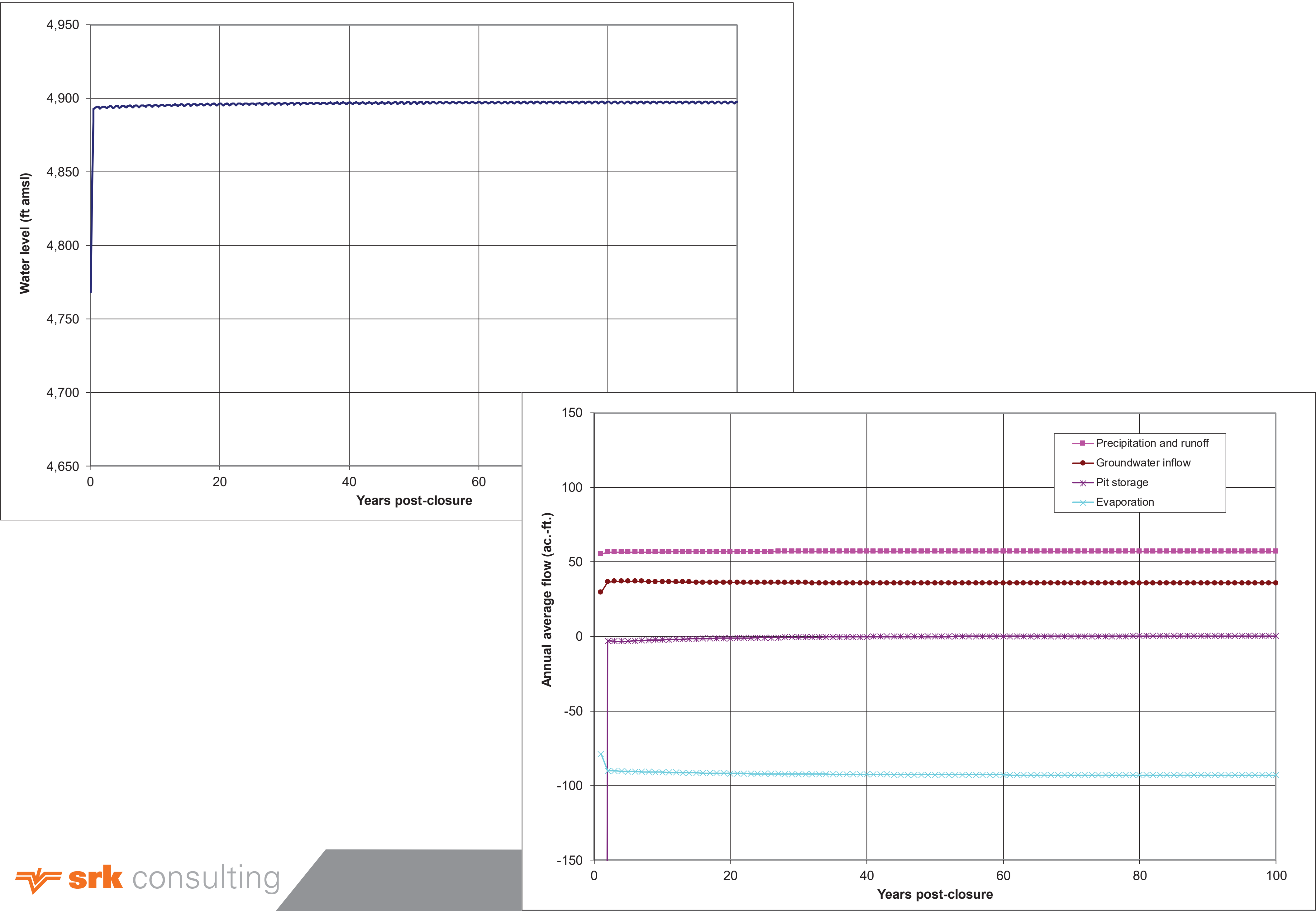
Final pit lake elevation = 4,897ft

1 ft fracture zone in pit walls with 10% fractures

Groundwater Inflow (2,449 - 4,445 ft^3/day)

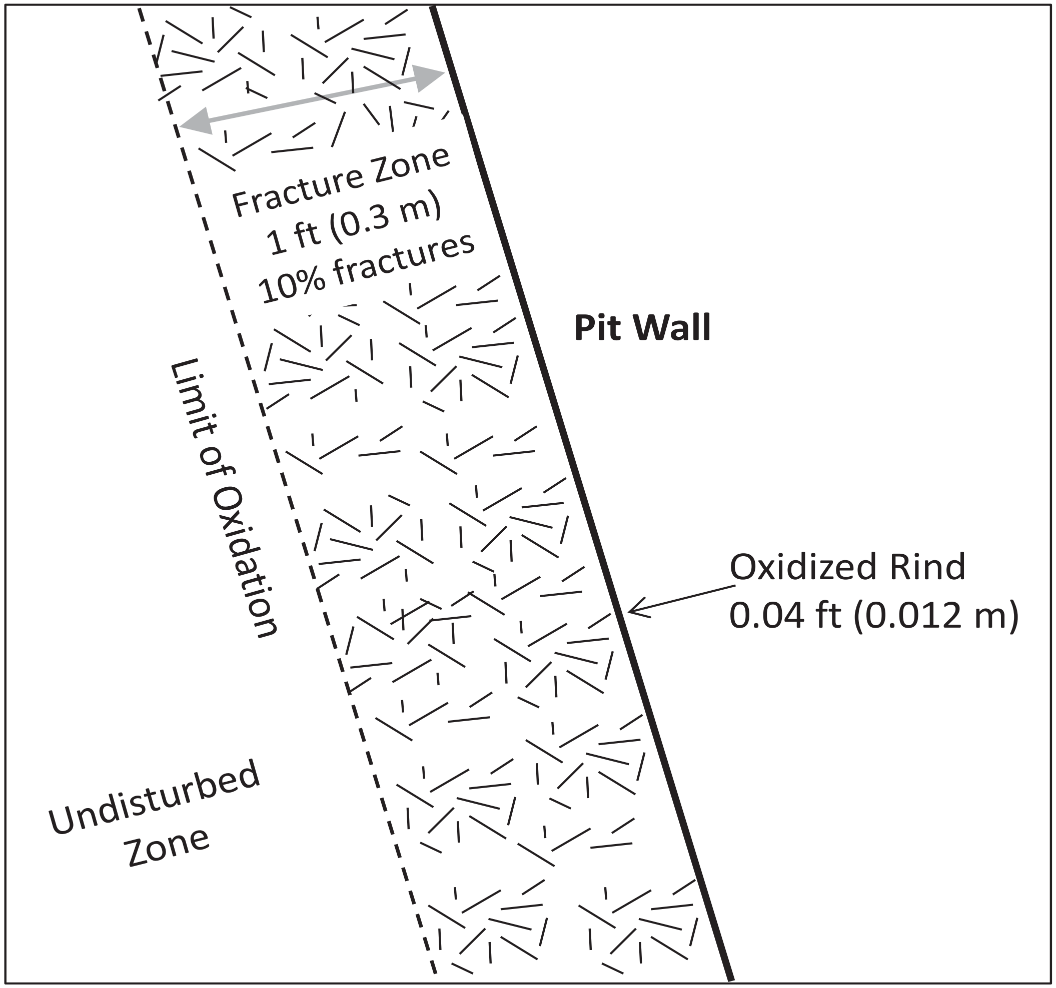
Mineral precipitation and sorption

Pit Lake Water Balance – Future Reclaimed Pit with Rapid Fill



Pit Wall Rock Leaching

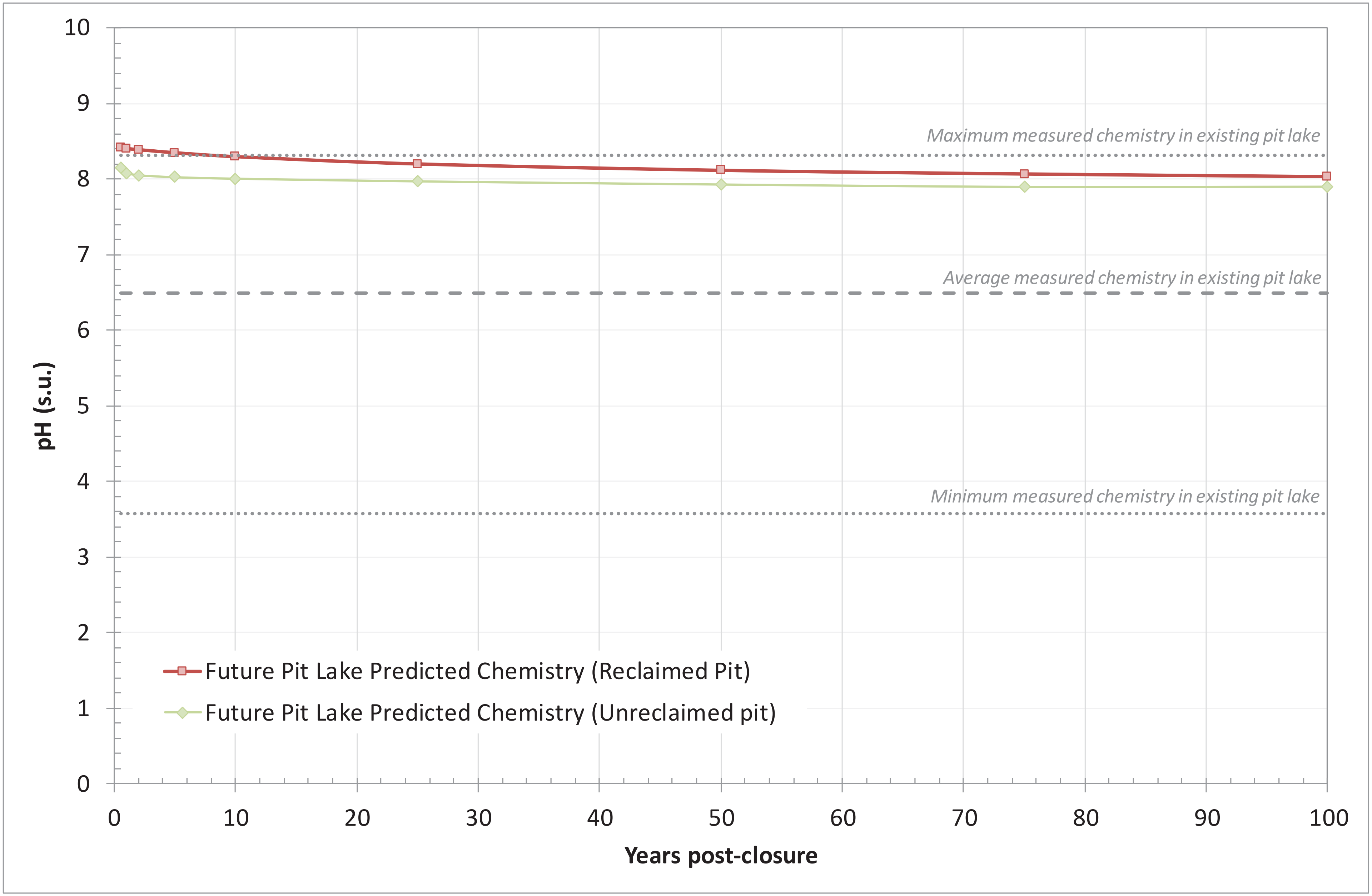
- Laboratory HCT data scaled to field conditions based on:
  - Mass of material available for leaching in pit walls
  - Volume of inflowing run-off/groundwater defined by water balance
- Assume fractures extend to a depth of 1ft, with a fracture density of 10%



Pit Lake Water Quality Predictions - Results

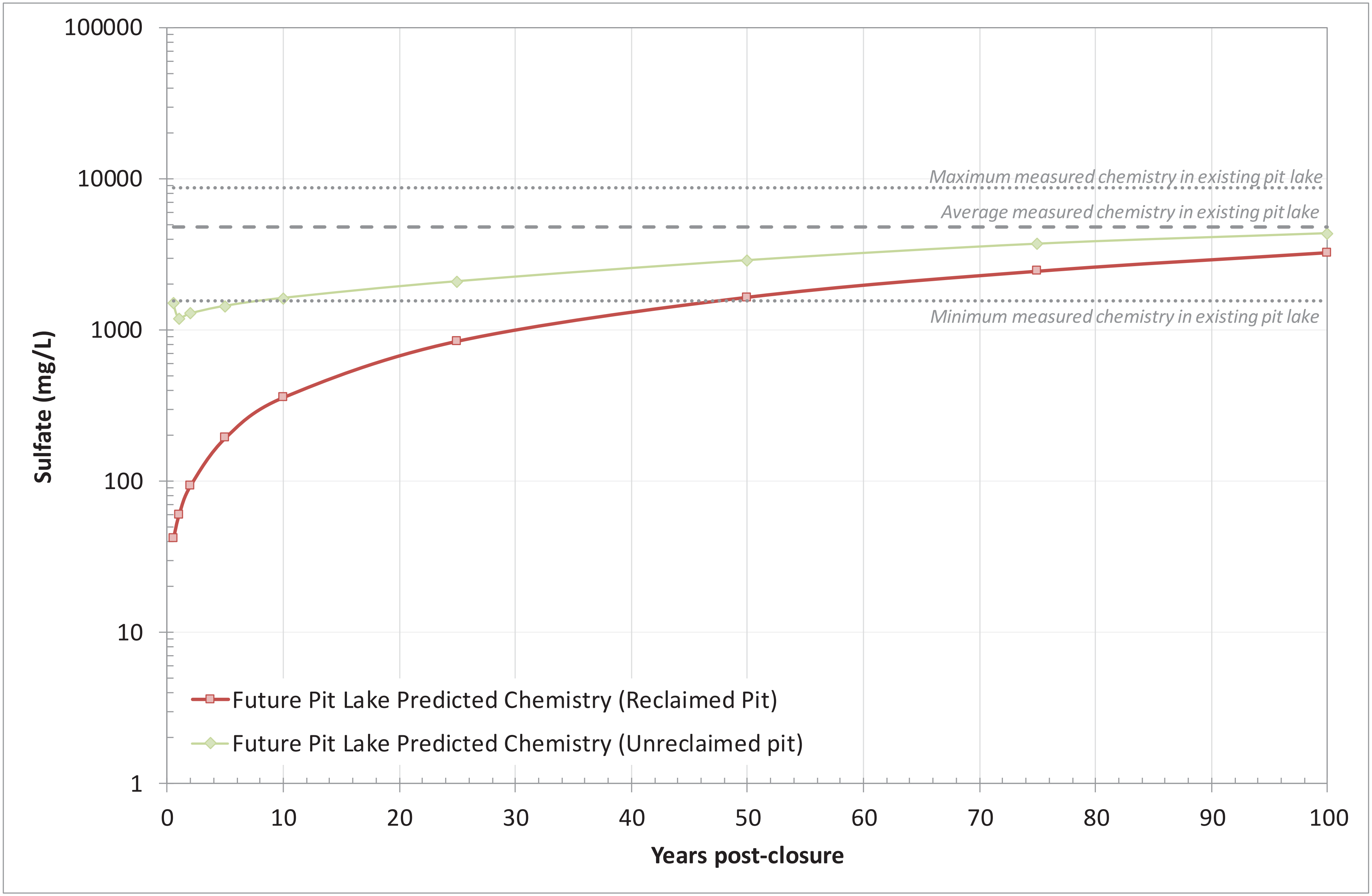
- Pit lake predicted to be moderately alkaline (pH 7.9 – 8.2)
  - Buffered by inflowing groundwater
  - Non-acid generating wall rock
- Initial flush of trace elements during first six months
- Increase in TDS over time due to evapoconcentration
  - Similar to trends in existing pit lake
- In comparison to existing pit lake
  - Predicted major element chemistry within the same range as existing pit lake
  - Acid wall seep events are not predicted for the future pit (removal of transitional material), resulting in lower sulfate and metals concentrations
- Rapidly refilling the pit results in better initial water quality
  - Long-term effects of evapoconcentration are reduced
  - Predicted constituent concentrations are lower

Pit Lake Water Quality Predictions - pH

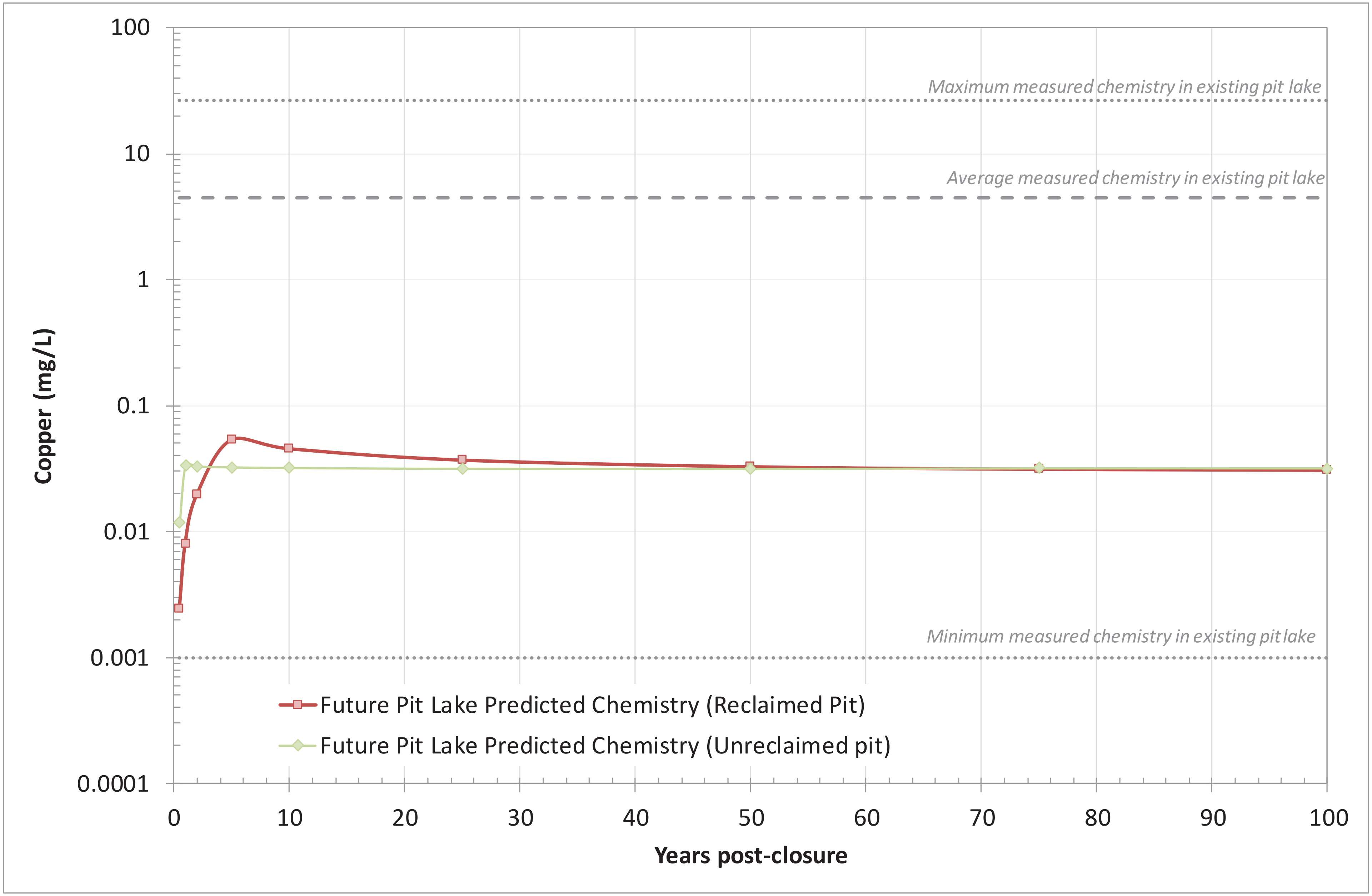


Average/maximum/minimum value – based on measured chemistry in existing pit lake between 1989 and 2017

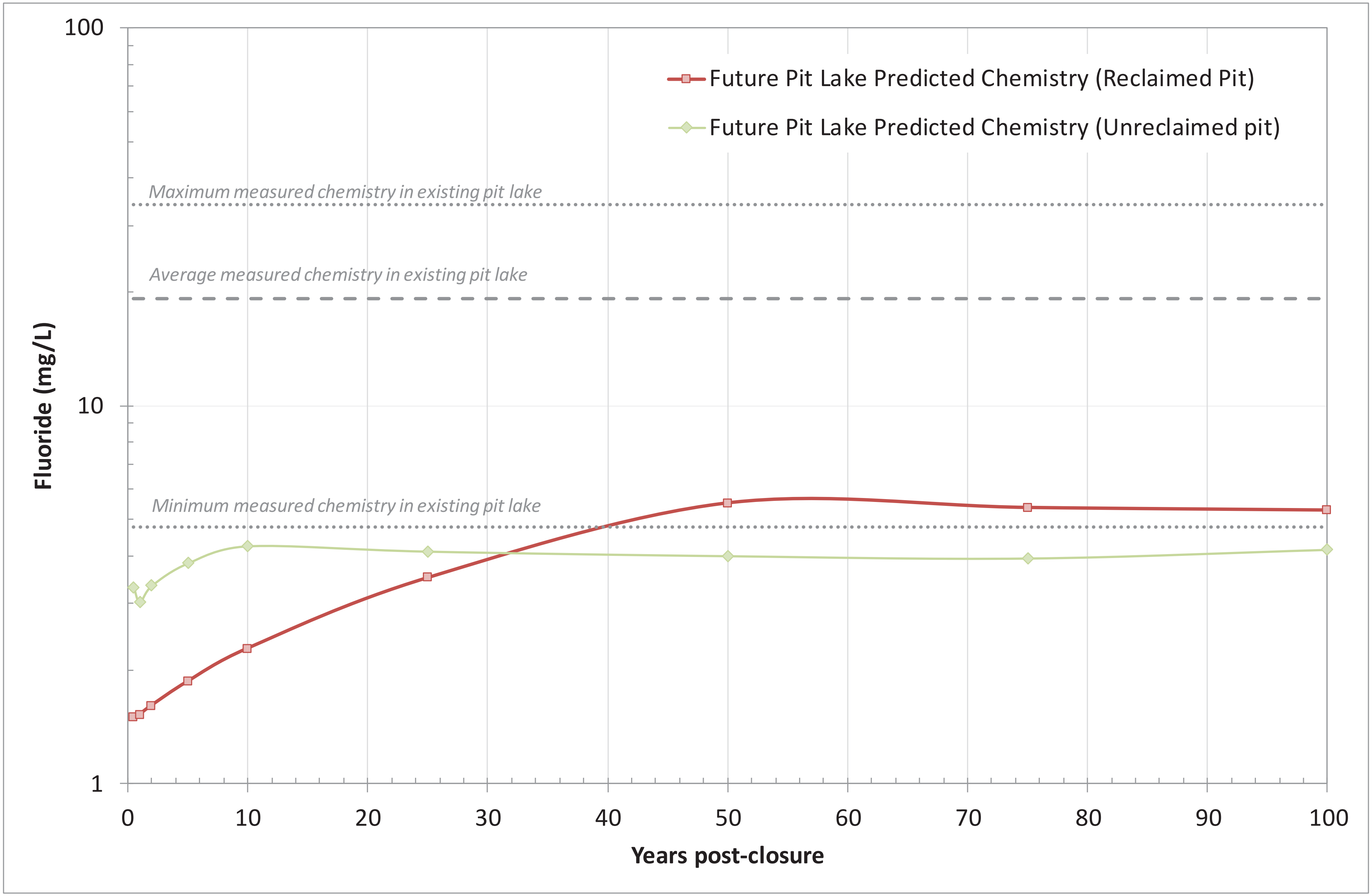
Pit Lake Water Quality Predictions - Sulfate



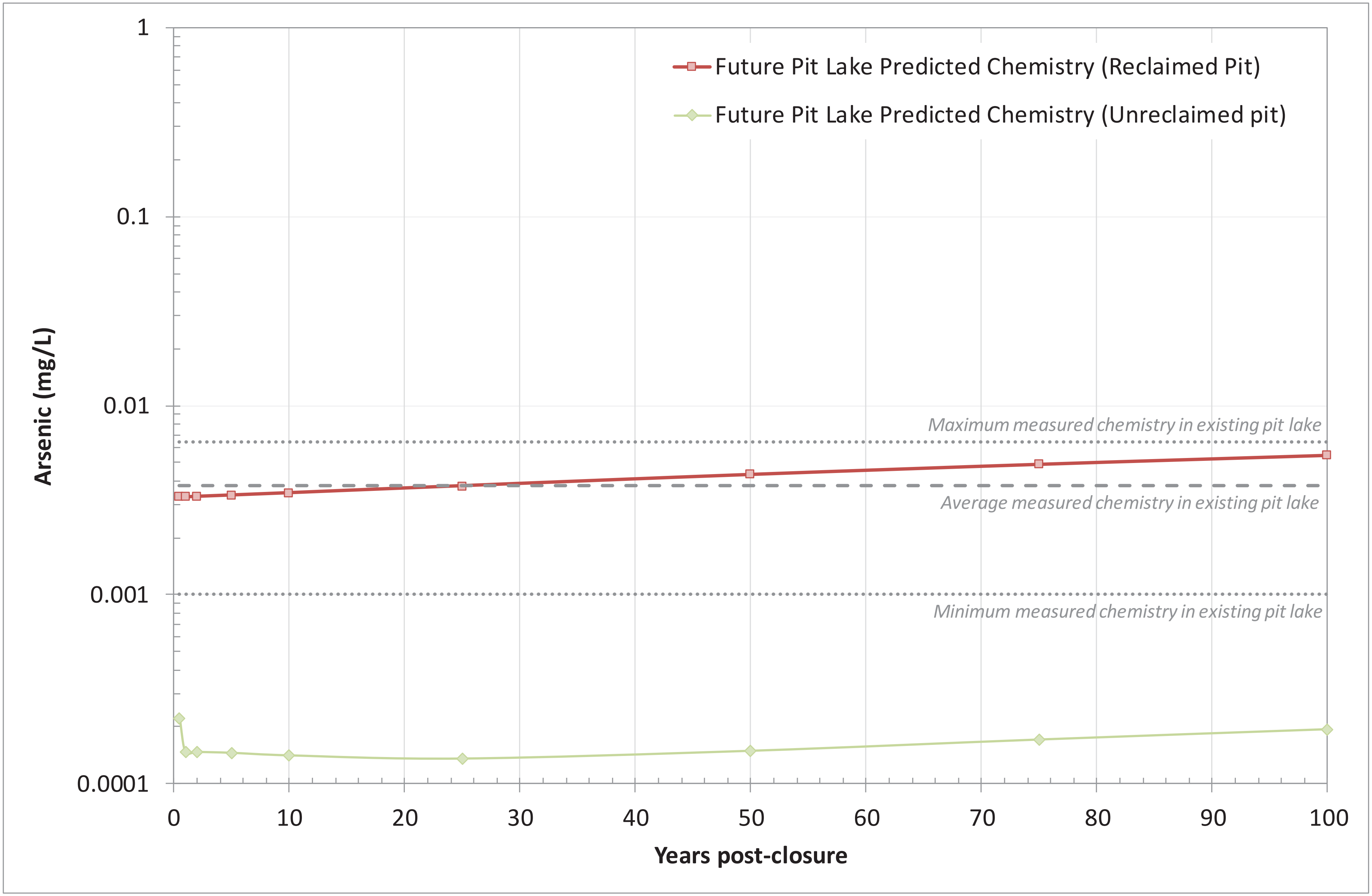
Pit Lake Water Quality Predictions - Copper



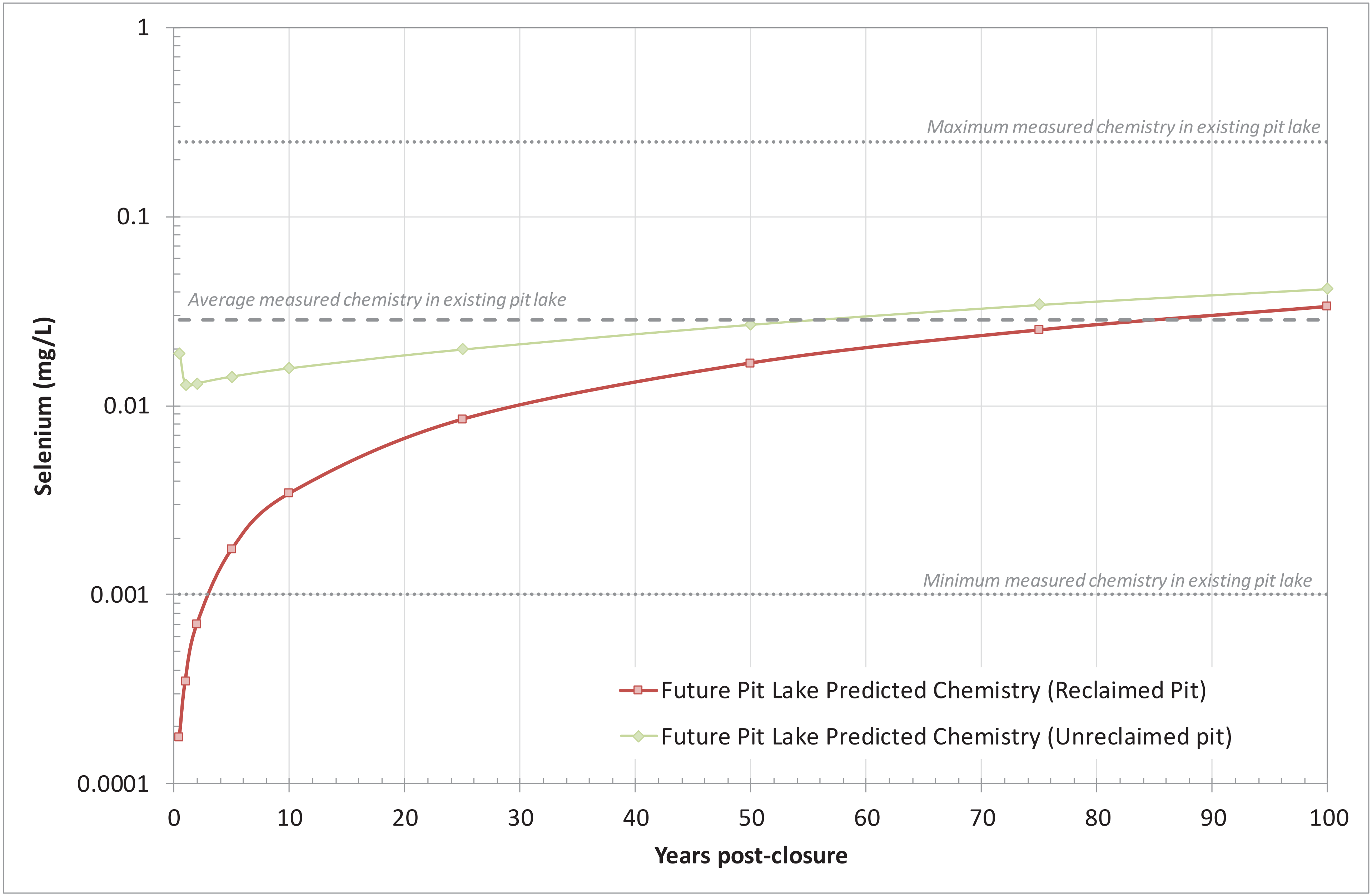
Pit Lake Water Quality Predictions - Fluoride



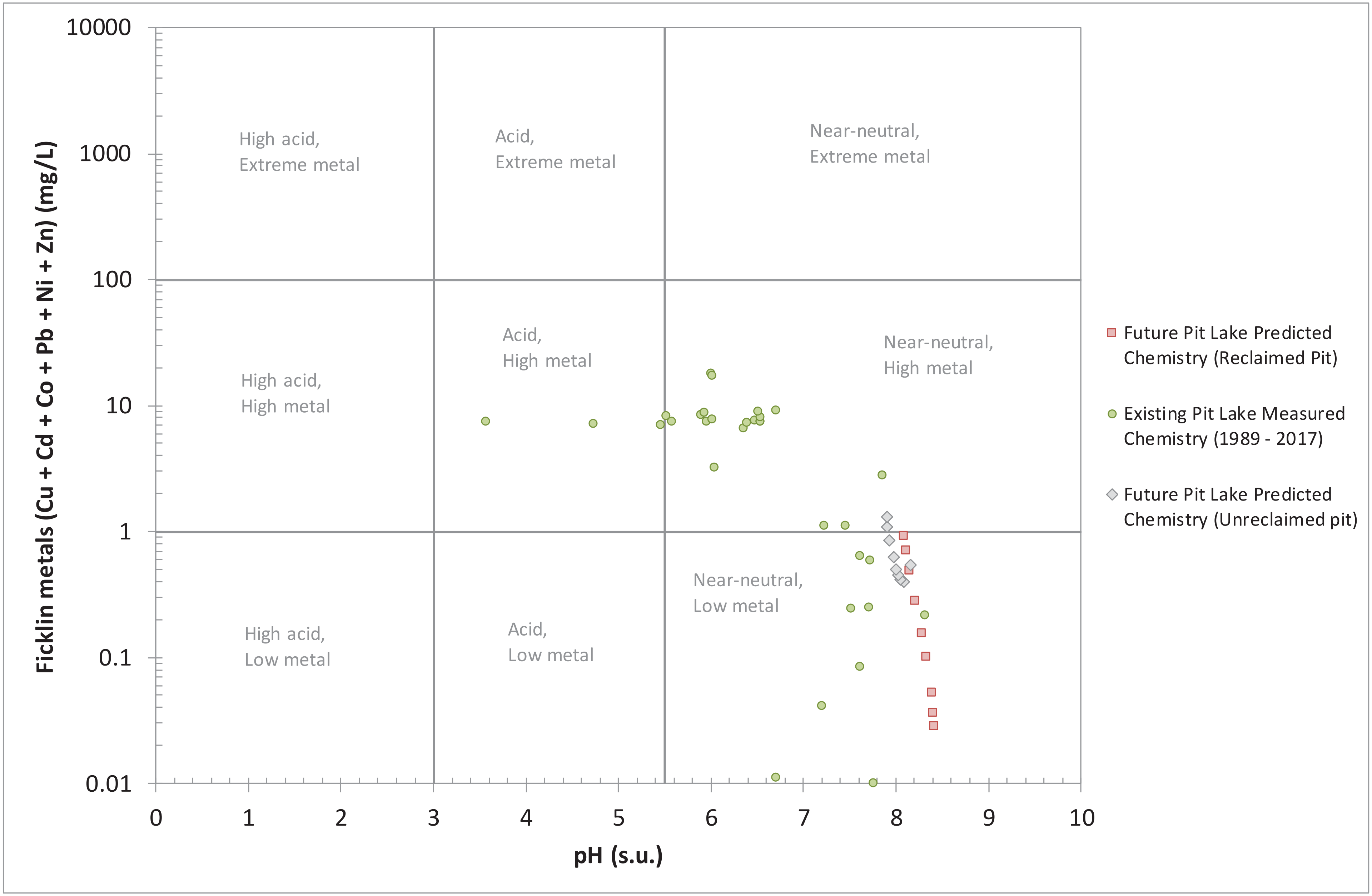
Pit Lake Water Quality Predictions - Arsenic



Pit Lake Water Quality Predictions - Selenium



Pit Lake Water Quality Predictions – Ficklin Metals



Pit Lake Water Quality Predictions - Summary

- Future pit lake predicted to be moderately alkaline (pH 7.9 – 8.2)
- Constituent concentrations within the range of variation seen for existing pit lake
- Increase in TDS over time due to evapoconcentration
  - Similar to trends in existing pit lake
- Acid wall seep events are not anticipated for future pit lake and water quality is predicted to be better than existing pit lake
- Results demonstrate
  - Changes to the hydrologic balance of the future pit will be nil or minimal, i.e., similar to existing conditions
  - Future water quality will be similar or better than existing pit lake
  - Rapid refilling of the pit results in further improvement of water quality

Summary

- The majority of waste rock (96%) shows a low potential for acid generation and metal release
- Weathering reactions are slow due to the coarse **crystalline** nature of sulfide minerals and encapsulation in slow-reacting silicates
- Acid Base Accounting generally over-predicts acid generation – no assessment of reactivity
- MWMP tests indicate low potential for generation of metal-rich solutions
- Transitional material shows a greater potential for acid generation and metal leaching
  - Only comprises 4% of waste rock
  - Will be managed by encapsulation within the waste rock stockpile
  - Low risk to site surface water or groundwater
- Groundwater impacts from the Waste Rock Stockpile and Tailings Storage Facility are not predicted to occur
- Pit waters are predicted to be neutral to moderately alkaline with constituent concentrations similar to or less than existing pit lake


COPPER FLAT