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Troilus Gold Project -

Predicted Maximum Aqueous Concentrations and Geochemical Source Terms

prepared for:

Troilus Gold Corp.
334, 3ième Rue
Chibougamau (Québec) G8P 1N5
Attention : Jacqueline Leroux, ing. VP environnement et permis

prepared by:

Kevin A. Morin, Ph.D., P.Geo., L.Hydrogeo.
Minesite Drainage Assessment Group
www.MDAG.com
contact@MDAG.com

and

Ann Lamontagne, ing., Ph.D.
Lamont inc.
2200 chemin de la Sagamité,
Québec, QC, G2N 0B7

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Report Summary

This document contains predictions and modelling of future water chemistry, also called "geochemical source terms", from full-scale minesite components at the Troilus Gold Project. These minesite components include pit walls, waste-rock piles, and ore stockpiles.

This document contains a numerical model for calculating maximum dissolved concentrations depending on the selected scale and pH. This model contains a series of logarithmic equations relating pH, sulphate, and the concentrations of many other water-quality elements and parameters, based on laboratory-scale testwork and on-site monitoring including first flushes and highest measured aqueous concentrations. These lead to the predicted maximum dissolved concentrations at Troilus, as shown in Table A below, typically reflecting the presence of many primary and secondary minerals that are dissolving or precipitating to equilibrium solubility.

These maximum equilibrium concentrations can then be adjusted where appropriate at Troilus to lower values reflecting (1) smaller piles of waste rock and ore, (2) shorter flowpaths through minesite components, (3) shorter residence times of water, and (4) slower rates of oxidation and leaching.

Table A. Maximum dissolved water-chemistry model for the Troilus Gold Project under relatively oxidizing conditions; see Appendix A for details; Troilus reaction rates are relatively slow so that maximum values may not be attained; nitrogen species from explosive residues are predicted separately

Dissolved Parameter (mg/L)	Equation
Alkalinity	log10(Alk) = +0.35*pH - 0.70 not including groundwater or log10(Alk) = +0.30*log10(SO4) + 1.30 not including groundwater
Acidity	if pH < 4.5, log10(Acid) = -0.60*pH + 4.65 if pH => 4.5, log10(Acid) = -0.19*pH + 2.80 Also, acidity proportionally decreases against sulphate with increasing scale
Sulphate	for full-scale monitoring, log10(SO4) = -0.20*pH + 4.50 for large-scale on-site columns, log10(SO4) = -0.10*pH + 3.40 for small-scale lab tests, log10(SO4) = -0.04*pH + 1.95
Conductivity (in uS/cm)	log10(Cond) = +0.65*log10(SO4) + 1.40
Chloride	log10(Cl) = +1.602 or Cl = 40 mg/L
Fluoride	log10(F) = +0.000 or F = 1 mg/L
Bromide	log10(Br) = -0.301 or Br = 0.5 mg/L
Dissolved Organic Carbon	log10(DOC) = -0.20*pH + 2.25 not including groundwater

Dissolved Parameter (mg/L)	Equation
Aluminum	if $pH<5.3$, $\log10(Al) = -0.80*pH + 4.65$ if $pH =>5.3$, $\log10(Al) = -0.30*pH + 2.00$
Antimony	$\log10(Sb) = +0.35*pH - 5.10$
Arsenic	$\log10(As) = +0.60*\log10(SO4) - 3.20$
Boron	$\log10(B) = +0.60*\log10(SO4) - 2.30$
Barium	$\log10(Ba) = +0.05*\log10(SO4) - 1.40$
Beryllium	$\log10(Be) = -0.50*pH - 0.40$
Bismuth	$\log10(Bi) = -3.000$ or $Bi = 0.001$ mg/L
Cadmium	$\log10(Cd) = -0.18*pH - 1.30$
Calcium	$\log10(Ca) = +0.65*\log10(SO4) + 0.70$
Chromium	$\log10(Cr) = +0.40*\log10(SO4) - 3.00$
Cobalt	$\log10(Co) = -0.50*pH + 1.90$
Copper	$\log10(Cu) = -0.35*pH + 1.55$
Iron	if $pH<8.0$, $\log10(Fe) = -0.35*pH + 2.90$ if $pH =>8.0$, $\log10(Fe) = -4.00*pH + 32.10$
Lead	$\log10(Pb) = -0.30*pH - 0.20$
Lithium	$\log10(Li) = -0.25*pH + 0.55$
Magnesium	$\log10(Mg) = +0.85*\log10(SO4) - 0.80$
Manganese	$\log10(Mn) = -0.30*pH + 1.80$ not including groundwater
Mercury	$\log10(Hg) = -3.000$ or $Hg = 0.001$ mg/L
Molybdenum	$\log10(Mo) = +0.30*pH - 3.70$
Nickel	$\log10(Ni) = -0.50*pH + 2.70$
Phosphorus	$\log10(P) = -0.10*pH + 1.40$
Potassium	$\log10(K) = +0.50*\log10(SO4) + 0.25$
Scandium	$\log10(Sc) = +0.60*\log10(SO4) - 3.50$
Selenium	$\log10(Se) = -0.15*pH -1.20$
Silicon	$\log10(Si) = +0.60*\log10(SO4) - 0.20$ not including groundwater; on-site waters generally between the solubilities of quartz and amorphous $SiO2$ and smaller-scale testwork at and below the solubility of quartz
Silver	$\log10(Ag) = +0.25*pH - 5.00$
Sodium	$\log10(Na) = +1.3980$ or $Na = 25$ mg/L not including groundwater
Strontium	$\log10(Sr) = +0.70*\log10(SO4) - 2.10$

Dissolved Parameter (mg/L)	Equation
Tellurium	log10(Te) = -4.000 or Te = 0.0001 mg/L
Thallium	log10(Tl) = -0.20*pH - 2.40
Thorium	log10(Th) = -5.000 or Th = 0.00001 mg/L
Tin	log10(Sn) = -0.20*log10(SO4) - 1.10
Titanium	log10(Ti) = -2.000 or Ti = 0.01 mg/L
Uranium	if pH<5.3, log10(U) = -1.00*pH + 2.50 if pH =>5.3, log10(U) = +1.00*pH - 8.10 (the maximum near-neutral uranium concentrations have been traced to granites and pegmatites in Troilus Rock Unit I1 (Felsic Intrusives)
Vanadium	log10(V) = +0.25*log10(SO4) - 2.95
Zinc	log10(Zn) = -0.30*pH + 1.55

1. Introduction

This document contains predictions and modelling of future water chemistry, also called "geochemical source terms", from full-scale minesite components at the Troilus Gold Project. These minesite components include pit walls, waste-rock piles, and ore stockpiles.

This document contains a numerical model for calculating maximum dissolved concentrations depending on the selected scale and pH. The model contains a series of logarithmic equations relating pH, sulphate, and concentrations of many other water-quality elements and parameters. It is based on laboratory-scale testwork and on-site monitoring including first flushes and highest measured aqueous concentrations. These lead to the predicted maximum dissolved concentrations at Troilus, typically reflecting equilibrium mineral solubilities based on Minteq calculations.

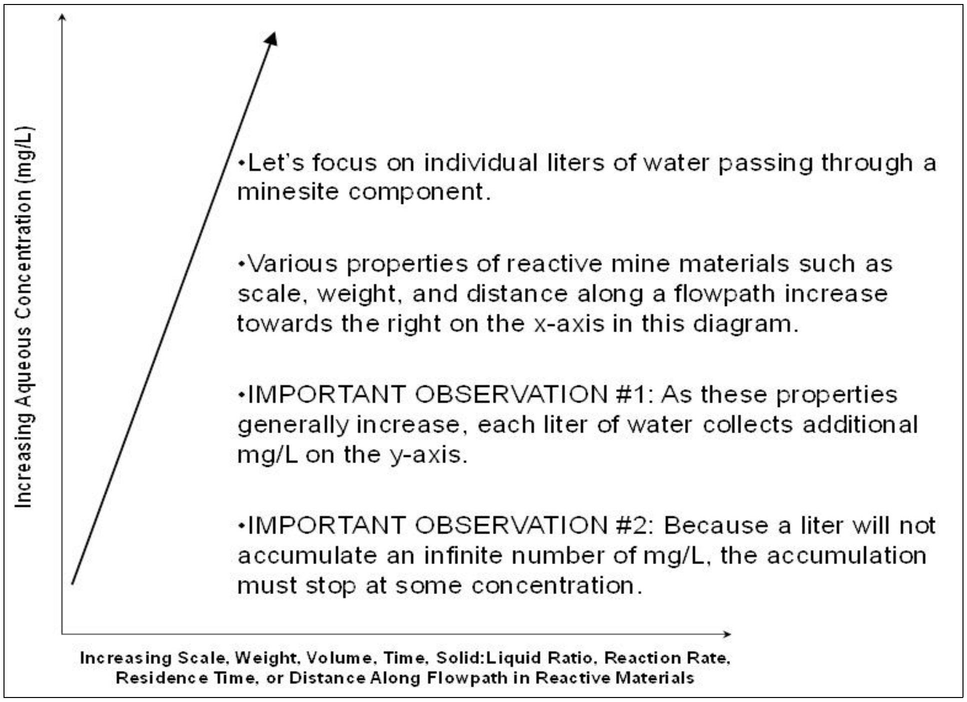
These maximum equilibrium concentrations can then be adjusted where appropriate at Troilus to lower values reflecting (1) smaller piles of waste rock and ore, (2) shorter flowpaths through minesite components, (3) shorter residence times of water, and (4) slower rates of oxidation and leaching.

2. Rationale for the Full-scale Empirical Maximum Water-Chemistry Model

Because laboratory tests are relatively small scale, they can require adjustments to larger scales ("scale up"). For example, near-neutral leaching rates for copper in the International Kinetic Database (currently containing 707 cells and 93 columns from 91 sites around the world) show that vertical heights as low as 2 cm, and as high as 20 m, for rock or tailings can produce "maximum" equilibrium concentrations that cannot go higher (Morin and Hutt, 2007; www.MDAG.com/IKD.html). These maximum equilibrium concentrations are the same as full-scale maximum predictions for dissolved elements, as explained next.

The rationale used here to scale up Troilus Project laboratory-based and on-site concentrations (in mg/L) to full-scale conditions is based on two simple observations illustrated in Figures 2-1 to 2-3. They are based on considering an individual liter of water in contact with, or flowing through, a full-scale minesite component.

Therefore, the approach used here for the full-scale maximum water-quality model for the Troilus Project is to search for any full-scale maximum concentrations (in mg/L) already detected in laboratory testwork and by on-site monitoring (Chapter 3).



- Let's focus on individual liters of water passing through a minesite component.
- Various properties of reactive mine materials such as scale, weight, and distance along a flowpath increase towards the right on the x-axis in this diagram.
- IMPORTANT OBSERVATION #1: As these properties generally increase, each liter of water collects additional mg/L on the y-axis.
- IMPORTANT OBSERVATION #2: Because a liter will not accumulate an infinite number of mg/L, the accumulation must stop at some concentration.

Figure 2-1. The two important observations used to adjust Troilus laboratory tests to full-scale conditions, with these two observations leading to the scaling trend in Figure 2-2.

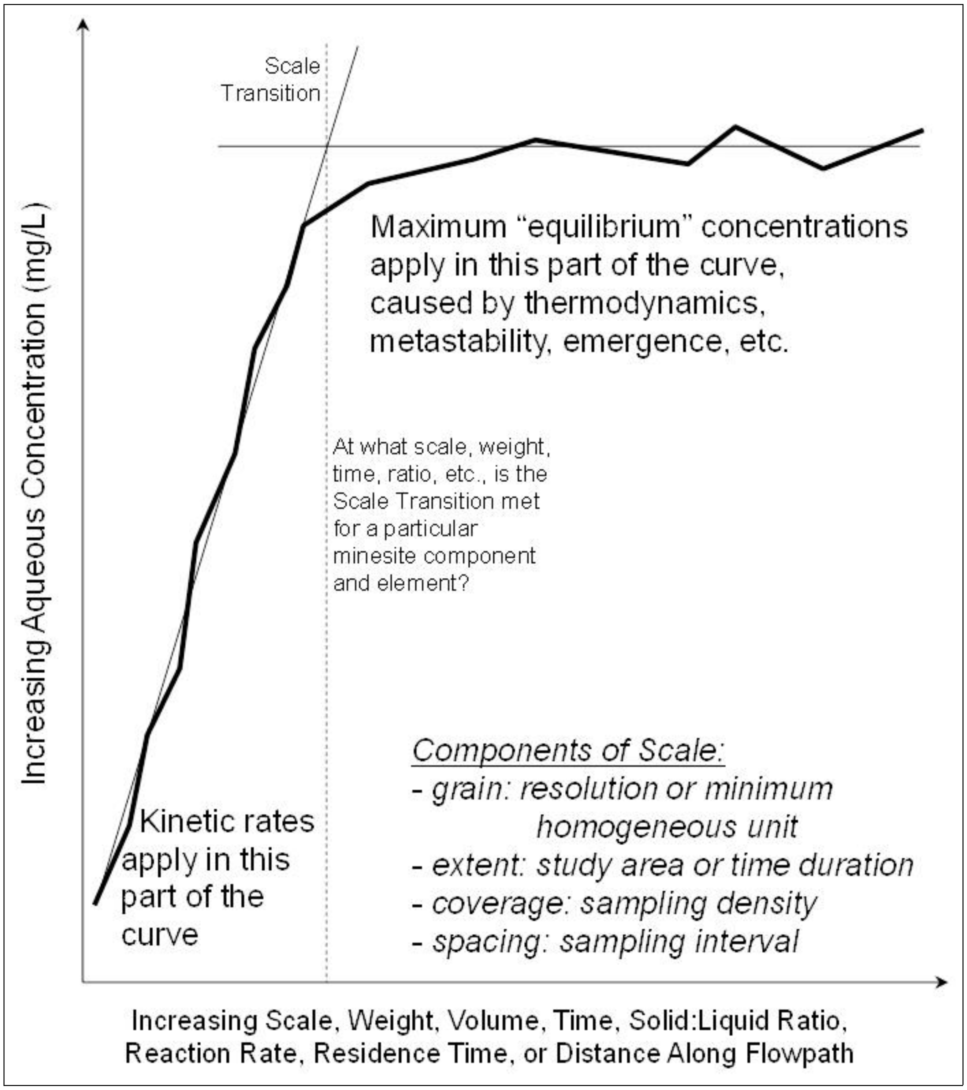


Figure 2-2. The two important observations in Figure 2-1 lead to this trend, where aqueous concentrations (in mg/L) generally level off at maximum "equilibrium" concentrations above the "Scale Transition" and do not increase significantly more as scale (x-axis) increases further. For full-scale water-chemistry predictions at Troilus, the equilibrium concentrations above the Scale Transition have been identified based on the information below.

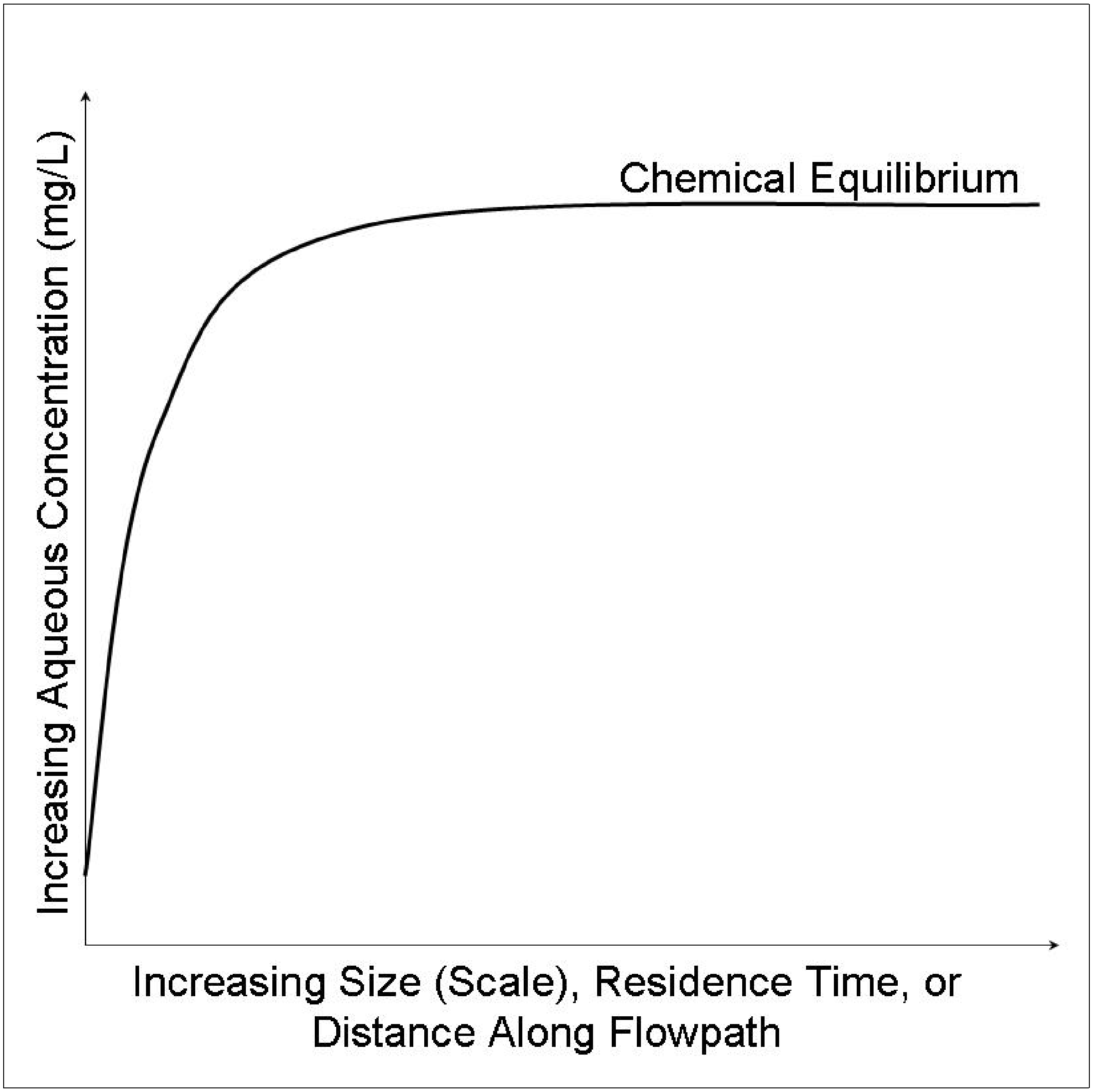


Figure 2-3. A common, but overly simplified, version of Figure 2-2.

In this document, the assessments of full-scale maximum equilibrium concentrations were based on two approaches to determine whether they would represent full-scale concentrations.

First, scatterplots of aqueous concentrations with pH were created, looking for correlations similar to those shown in Figures 2-4 and 2-5 that depict full-scale concentrations as Empirical Drainage-Chemistry Models (EDCM). This is discussed further in Morin and Lamontagne (2023). Such correlations are seen in many scatterplots for Troilus laboratory-based testwork and on-site monitoring (see Appendix A of this report below). For each element, many of the highest concentrations across each range of pH were then used to create pH-dependent equations for maximum, full-scale concentrations (Chapter 4). In some cases, predictions correlated better with sulphate, where sulphate can then be calculated from pH. It is important to note that the highest concentrations of some elements were purposely ignored due to effects like (1) total concentrations sometimes having to substitute for dissolved concentrations and (2) sporadic analytical and transcription errors.

Second, aqueous concentrations from Troilus testwork, considered maximum, full-scale concentrations, were evaluated for mineral solubility and equilibrium using a geochemical speciation model. Minteq, originally from the U.S. EPA, was the model used for speciation and solubility calculations here (see Chapter 5 below).

This approach used for Troilus maximum concentrations and geochemical source terms is similar to the Leaching Environmental Assessment Framework (LEAF) from the U.S. Environmental Protection Agency (2019). This can be seen by comparing U.S. EPA LEAF pH-dependent trends (Figures 2-6 and 2-7 below) to Figures 2-4 and 2-5 and to Troilus plots in Appendix A.

However, LEAF methods are more limited here than the EDCM due to LEAF test conditions such as (1) single-scale methods providing fewer datapoints than used here, (2) air-tight vessels that may limit oxidation reactions, and (3) the assumption that maximum equilibrium is reached based on specified generic contact times for specific particles sizes (e.g., 24-hour contact time to 85-wt-% passing 0.3 mm). Nevertheless, the objectives and interpretations here for pH-dependent and sulphate-dependent maximum aqueous concentrations and geochemical source terms for Troilus are similar to those of the U.S. EPA LEAF.

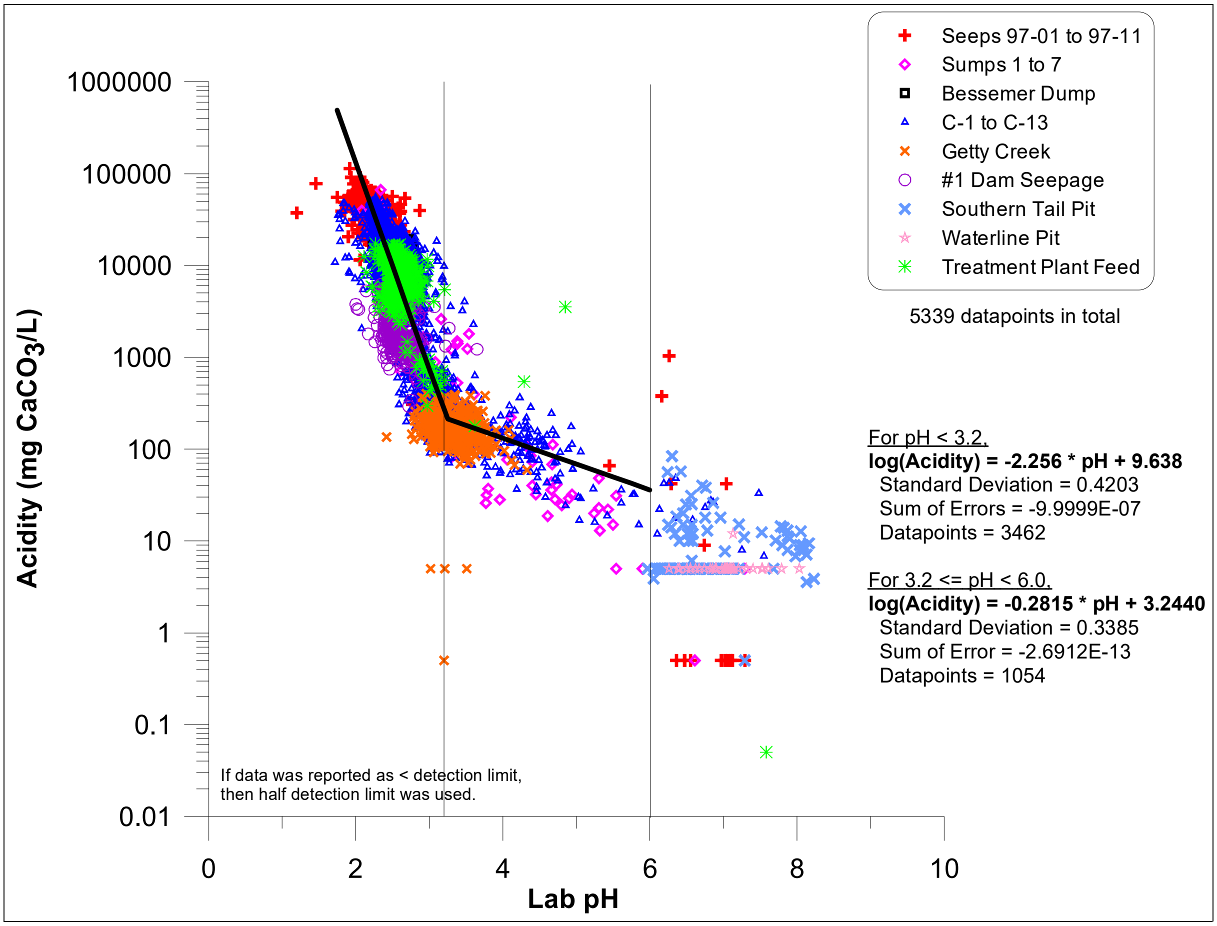
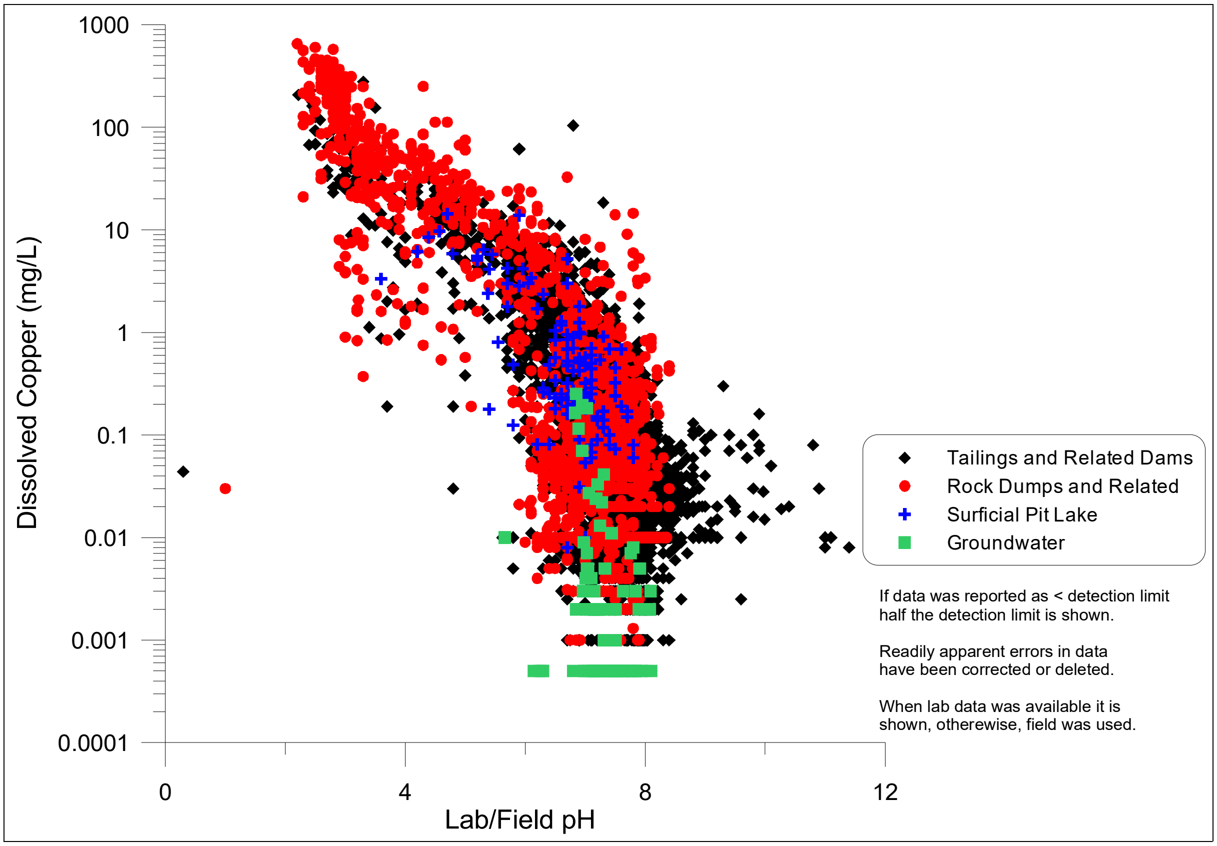


Figure 2-4. A full-scale example of pH-dependent trends in aqueous concentrations of acidity, based on 5339 analyses (from Morin et al., 2010 and 2012); also called an Empirical Drainage-Chemistry Model (EDCM).



If data was reported as < detection limit half the detection limit is shown.

Readily apparent errors in data have been corrected or deleted.

When lab data was available it is shown, otherwise, field was used.

Figure 2-5. A full-scale example of pH-dependent trends in aqueous concentrations of copper, based on approximately 640 analyses (from Morin and Hutt, 2010); also called an Empirical Drainage-Chemistry Model (EDCM).

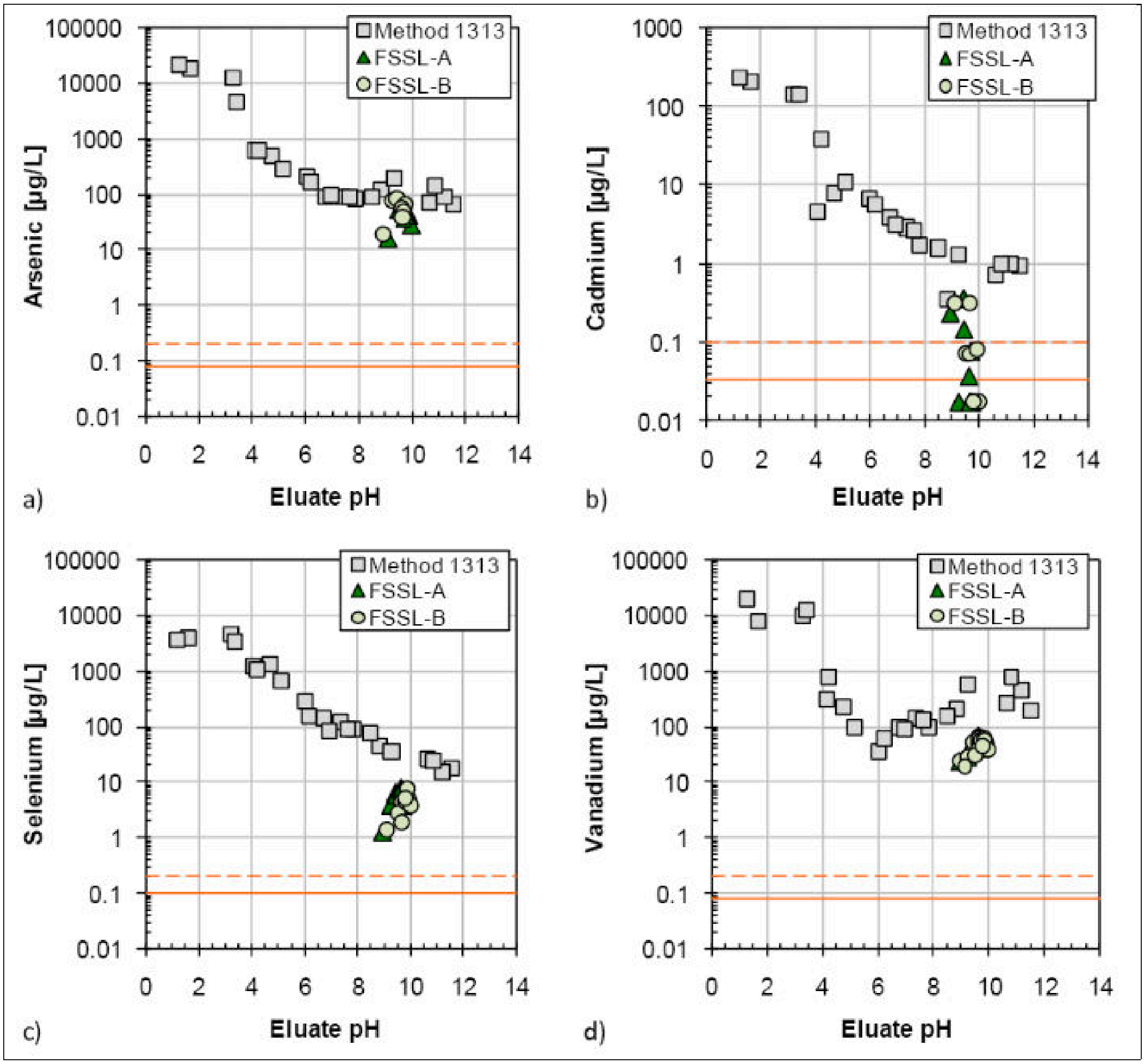


Figure 2-6. A laboratory-scale example of pH-dependent maximum-solubility trends for four aqueous elements (from U.S. EPA, 2019; compare to Figures 2-4 and 2-5).

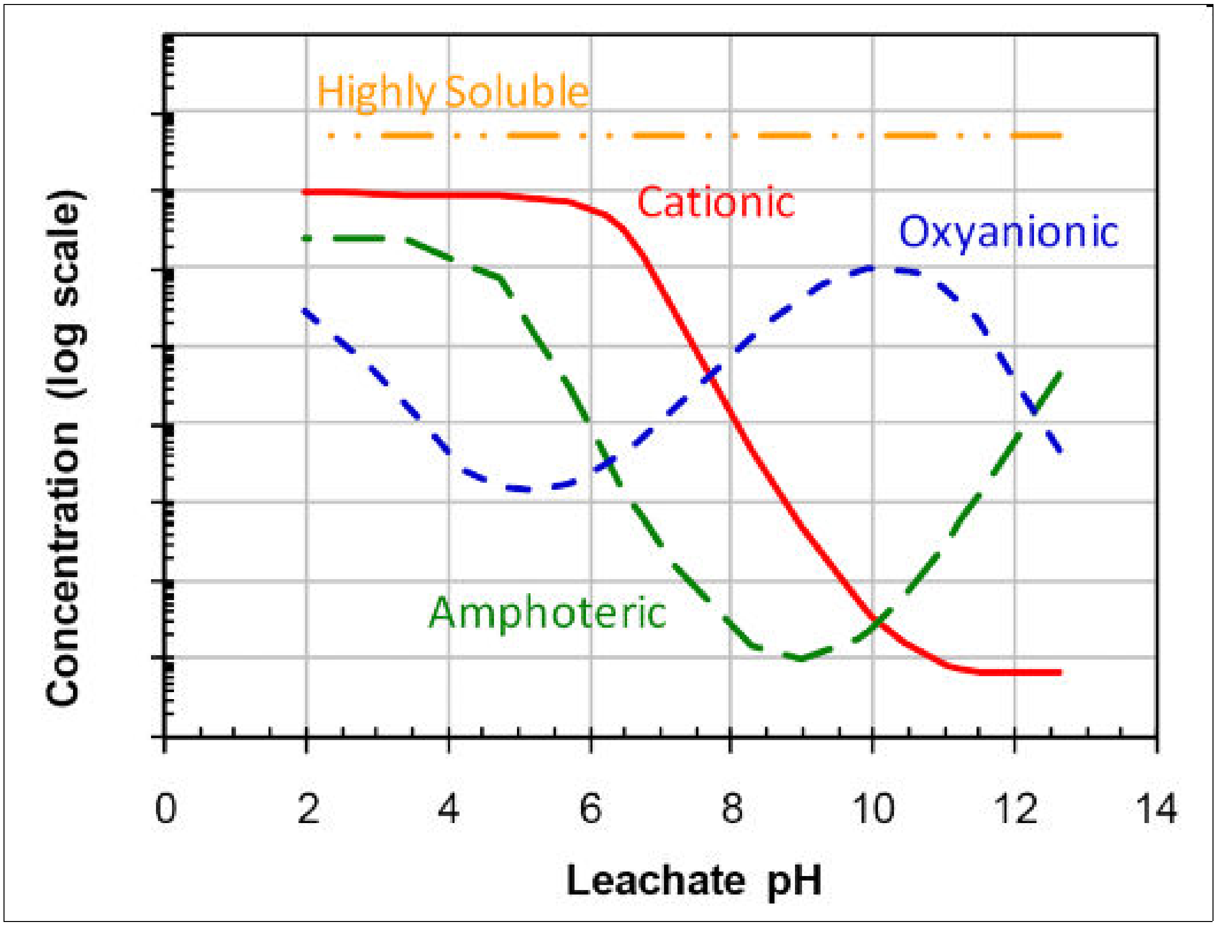


Figure 2-7. Generic pH-dependent trends in aqueous concentrations (from U.S. EPA, 2019; compare to Appendix A).

3. Troilus Datasets and Procedures Used for Predicting Full-Scale Maximum Dissolved Concentrations

In order to identify maximum concentrations and to predict full-scale aqueous dissolved concentrations at Troilus, several datasets of laboratory-based and on-site information were used, providing approximately 1,700 water-chemistry analyses. Emphasis was placed on correlations with pH. However, as seen in Appendix A below, many elements correlated better with sulphate, which could still be correlated with pH since pH and sulphate correlate with each other depending on the scale (see Figure A3 in Appendix A).

The datasets used here included long-term full-scale on-site monitoring at STP-9 (drainage from the existing J4 waste-rock pile), J4 Pit, 87 Pit, tailings seepage, and miscellaneous groundwater around Troilus. These datasets also included laboratory-based humidity cells containing ~1 kg and on-site field columns containing up to ~300 kg.

It is important to note, as explained in other Troilus reports, that the rates of oxidation and leaching are relatively low in Troilus rock. Therefore, the maximum concentrations predicted here are not expected most of the time at most locations around the current Troilus site.

Additionally, spurious and unrepresentatively high concentrations are sometimes encountered in the Troilus datasets. This is due to two major reasons. First, to maximize the number of datapoints here, total concentrations that can far exceed dissolved concentrations are included when dissolved concentrations were not available. Second, analytical analyses are not 100% accurate and precise, and thus occasionally anomalous values appear. Also, transcription errors, such as during conversion from ug/L to mg/L, can lead to anomalous values. Therefore, it is important not to consider every datapoint in the figures of Appendix A to be important and valid.

Because these Troilus datasets span scales from ~1 kg to the full site scale with up to many tens of millions of rock, they reveal some important scale-dependent trends. These scale-dependent trends are included in this maximum-concentration model, and examples can be seen in the following figures and in Appendix A below.

For example, Figure 3-1 of acidity vs. sulphate shows that increasing scale (the groups of coloured datapoints from left to right) leads to an increasing proportion of acidity neutralization. Figure 3-2 of alkalinity vs. sulphate shows that alkalinity increases as scale and sulphate increase. Figure 3-3 is not explained in detail here, but shows that at constant pH (1) calcium increases as scale increases, and (2) the molar ratio of calcium:sulphate (and thus the Net Potential Ratio for predicting ARD) decreases as scale and sulphate increase. Figure 3-4 shows that silicate minerals in smaller-scale testwork were not sufficiently reactive to reach quartz solubility (below the lower dashed line), whereas full-scale surface waters and groundwaters reached levels between the solubilities of quartz and amorphous SiO_2 between the two dashed lines.

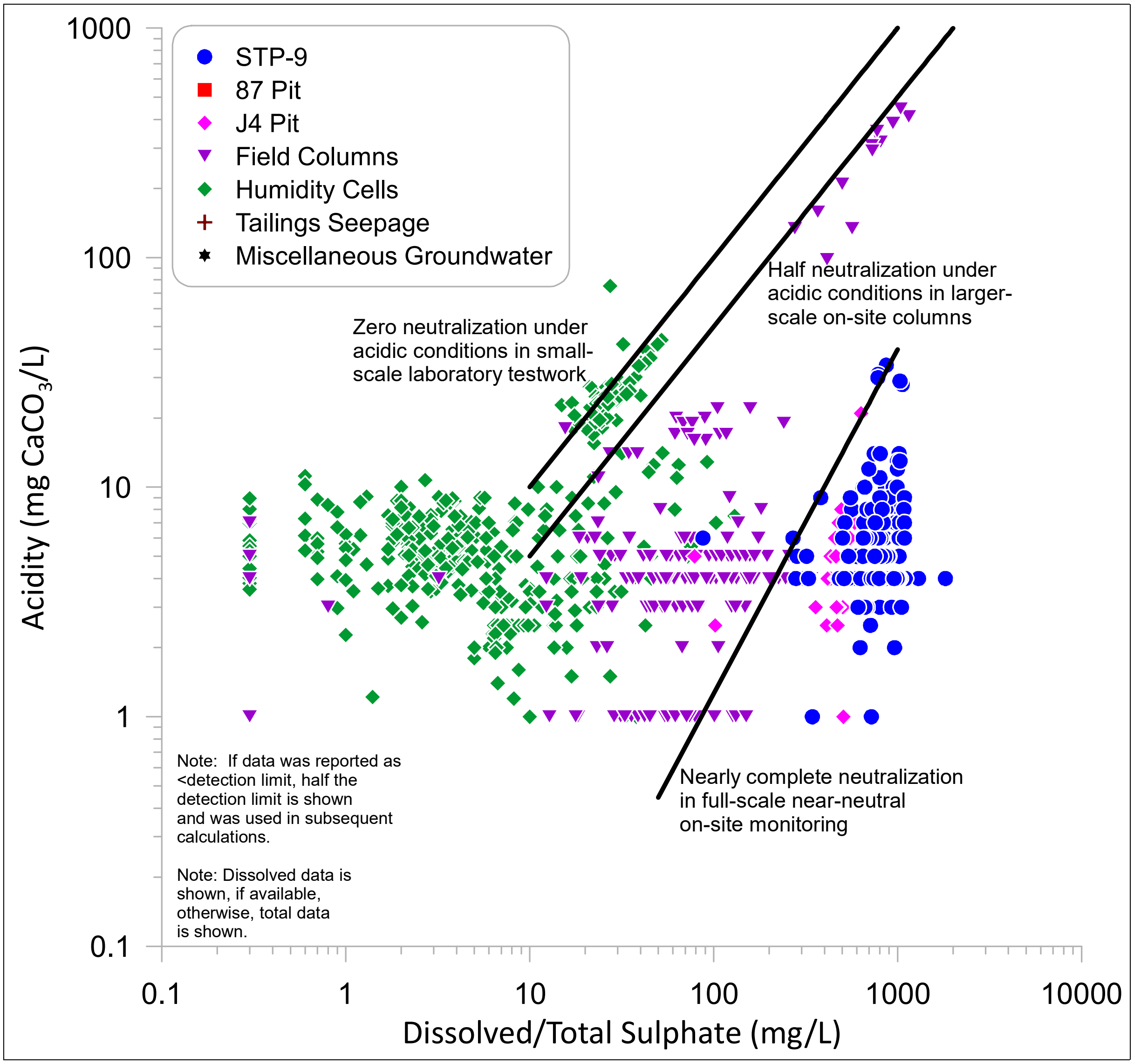
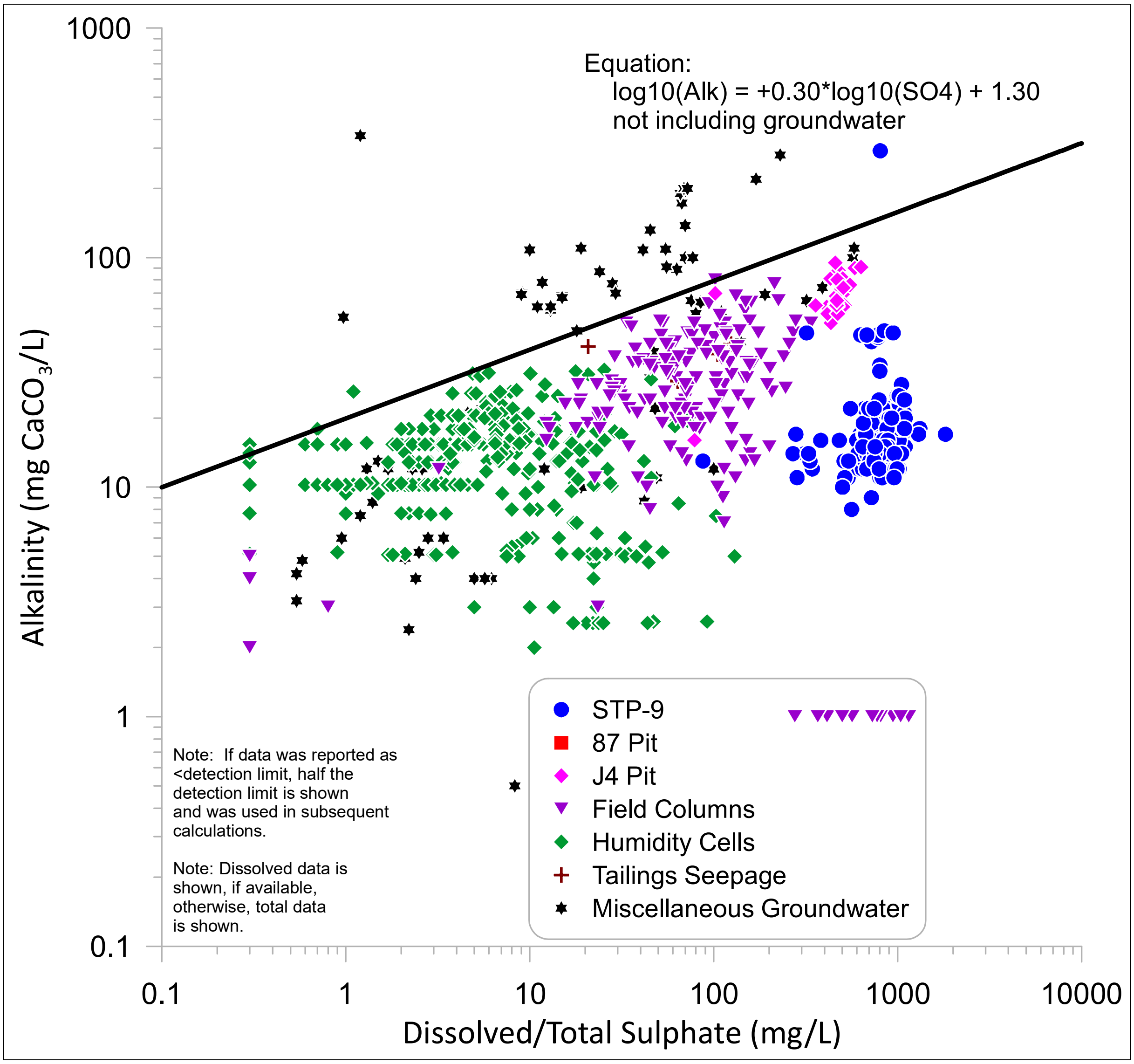


Figure 3-1. Acidity vs. sulphate in water at the Troilus Gold Project, showing that increasing scale (coloured groups of datapoints from left to right) increases the proportion of neutralization of acidity.



Note: If data was reported as <detection limit, half the detection limit is shown and was used in subsequent calculations.

Note: Dissolved data is shown, if available, otherwise, total data is shown.

Figure 3-2. Alkalinity vs. sulphate in water at the Troilus Gold Project, showing that alkalinity increases as scale (coloured groups of datapoints from left to right) and sulphate increase from left to right.

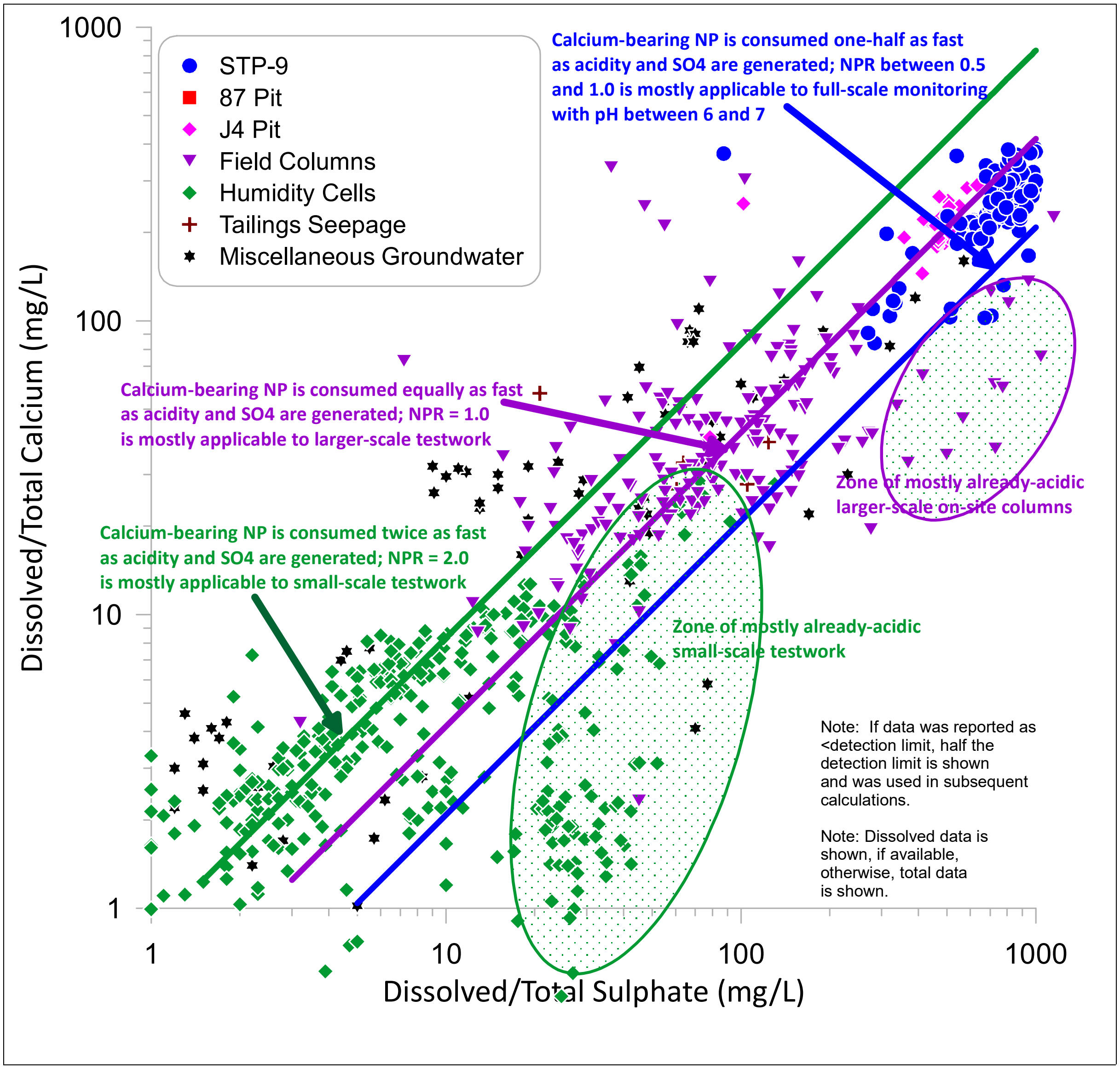
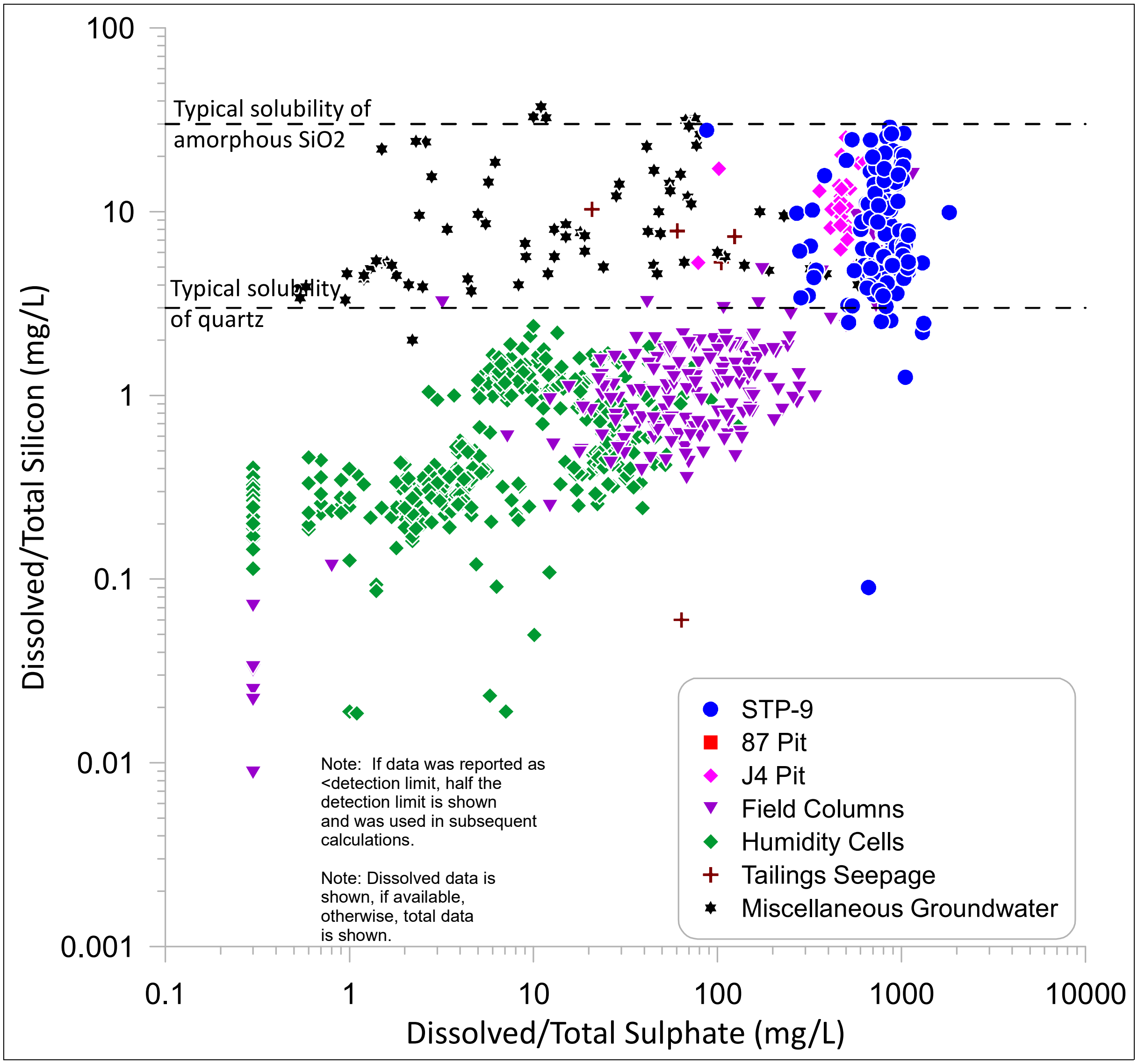


Figure 3-3. Calcium vs. sulphate in water at the Troilus Gold Project, showing complex trends including the molar ratio of calcium:sulphate (and thus the Net Potential Ratio for predicting ARD) decreases as scale and sulphate increase from left to right.



Note: If data was reported as <detection limit, half the detection limit is shown and was used in subsequent calculations.

Note: Dissolved data is shown, if available, otherwise, total data is shown.

Figure 3-4. Silicon vs. sulphate in water at the Troilus Gold Project, showing that silicate minerals in smaller-scale testwork were not sufficiently reactive to reach quartz solubility (below the lower dashed line), whereas full-scale surface waters and groundwaters reach levels between the solubilities of quartz and amorphous SiO_2 (between the two dashed lines).

4. Summary of the Troilus Full-scale Water-Chemistry Model for Maximum Dissolved Concentrations

For the Troilus laboratory-based testwork and on-site monitoring, scatterplots with pH and sulphate are compiled in Appendix A of this document. Based on correlations in these scatterplots, the Troilus Gold Project pH-dependent empirical maximum water-chemistry model for full-scale minesite components is compiled in Table 4-1.

Table 4-1. Maximum dissolved water-chemistry model for the Troilus Gold Project under relatively oxidizing conditions; see Appendix A for details; Troilus reaction rates are relatively slow so that maximum values may not be attained; nitrogen species from explosive residues are predicted separately

Dissolved Parameter (mg/L)	Equation
Alkalinity	log10(Alk) = +0.35*pH - 0.70 not including groundwater or log10(Alk) = +0.30*log10(SO4) + 1.30 not including groundwater
Acidity	if pH < 4.5, log10(Acid) = -0.60*pH + 4.65 if pH => 4.5, log10(Acid) = -0.19*pH + 2.80 Also, acidity proportionally decreases against sulphate with increasing scale
Sulphate	for full-scale monitoring, log10(SO4) = -0.20*pH + 4.50 for large-scale on-site columns, log10(SO4) = -0.10*pH + 3.40 for small-scale lab tests, log10(SO4) = -0.04*pH + 1.95
Conductivity (in uS/cm)	log10(Cond) = +0.65*log10(SO4) + 1.40
Chloride	log10(Cl) = +1.602 or Cl = 40 mg/L
Fluoride	log10(F) = +0.000 or F = 1 mg/L
Bromide	log10(Br) = -0.301 or Br = 0.5 mg/L
Dissolved Organic Carbon	log10(DOC) = -0.20*pH + 2.25 not including groundwater
Aluminum	if pH<5.3, log10(Al) = -0.80*pH + 4.65 if pH =>5.3, log10(Al) = -0.30*pH + 2.00
Antimony	log10(Sb) = +0.35*pH - 5.10
Arsenic	log10(As) = +0.60*log10(SO4) - 3.20
Boron	log10(B) = +0.60*log10(SO4) - 2.30
Barium	log10(Ba) = +0.05*log10(SO4) - 1.40
Beryllium	log10(Be) = -0.50*pH - 0.40
Bismuth	log10(Bi) = -3.000 or Bi = 0.001 mg/L
Cadmium	log10(Cd) = -0.18*pH - 1.30

Dissolved Parameter (mg/L)	Equation
Calcium	log10(Ca) = +0.65*log10(SO4) + 0.70
Chromium	log10(Cr) = +0.40*log10(SO4) - 3.00
Cobalt	log10(Co) = -0.50*pH + 1.90
Copper	log10(Cu) = -0.35*pH + 1.55
Iron	if pH<8.0, log10(Fe) = -0.35*pH + 2.90 if pH =>8.0, log10(Fe) = -4.00*pH + 32.10
Lead	log10(Pb) = -0.30*pH - 0.20
Lithium	log10(Li) = -0.25*pH + 0.55
Magnesium	log10(Mg) = +0.85*log10(SO4) - 0.80
Manganese	log10(Mn) = -0.30*pH + 1.80 not including groundwater
Mercury	log10(Hg) = -3.000 or Hg = 0.001 mg/L
Molybdenum	log10(Mo) = +0.30*pH - 3.70
Nickel	log10(Ni) = -0.50*pH + 2.70
Phosphorus	log10(P) = -0.10*pH + 1.40
Potassium	log10(K) = +0.50*log10(SO4) + 0.25
Scandium	log10(Sc) = +0.60*log10(SO4) - 3.50
Selenium	log10(Se) = -0.15*pH -1.20
Silicon	log10(Si) = +0.60*log10(SO4) - 0.20 not including groundwater; on-site waters generally between the solubilities of quartz and amorphous SiO2 and smaller-scale testwork at and below the solubility of quartz
Silver	log10(Ag) = +0.25*pH - 5.00
Sodium	log10(Na) = +1.3980 or Na = 25 mg/L not including groundwater
Strontium	log10(Sr) = +0.70*log10(SO4) - 2.10
Tellurium	log10(Te) = -4.000 or Te = 0.0001 mg/L
Thallium	log10(Tl) = -0.20*pH - 2.40
Thorium	log10(Th) = -5.000 or Th = 0.00001 mg/L
Tin	log10(Sn) = -0.20*log10(SO4) - 1.10
Titanium	log10(Ti) = -2.000 or Ti = 0.01 mg/L
Uranium	if pH<5.3, log10(U) = -1.00*pH + 2.50 if pH =>5.3, log10(U) = +1.00*pH - 8.10 (the maximum near-neutral uranium concentrations have been traced to granites and pegmatites in Troilus Rock Unit I1 (Felsic Intrusives)

Dissolved Parameter (mg/L)	Equation
Vanadium	log10(V) = +0.25*log10(SO4) - 2.95
Zinc	log10(Zn) = -0.30*pH + 1.55

5. Solubility Calculations Using Minteq

An important aspect to predicting and understanding maximum concentrations more accurately is the identification of minerals that may be dissolving or precipitating to equilibrium solubility levels (illustrated in Figure 2-2). These minerals may be dissolving or precipitating to equilibrium in some Troilus laboratory kinetic tests, on-site field columns, and/or on-site waters (Appendix A).

Maximum dissolved concentrations were calculated from Table 4-1 using pH 6.5 typical of silicate-mineral neutralization at Troilus and using pH 8.0 typical of carbonate neutralization. These maximum concentrations were then entered into the geochemical speciation-solubility model called Minteq (Visual MINTEQ Version 3.1, February 2019). Minteq was originally developed by the U.S. Environmental Protection Agency, and provides similar results and information as other models like the U.S. Geological Survey PHREEQC.

These geochemical models calculate solubility products based on minerals that are either ideal or specific to one site. In reality, each minesite can produce similar minerals, but with distinctly different solubilities than those in these models due to site-specific differences in mineral compositions, crystal distortions, impurities, solid solutions, etc. (e.g., Morin and Hutt, 2000). As a result, Minteq results were used here as general guides to identify minerals close to theoretical and ideal solubility saturation. Thus, these are the minerals most likely dissolving or forming in Troilus waters, and in turn accounting for the maximum concentrations in Table 4-1 and Appendix A.

Table 5-1 lists the minerals close to ideal solubility based on maximum concentrations at pH 6.5 and 8.0 using Table 4-1. This shows that many minerals can be dissolving or forming to their maximum solubility levels to create the observed maximum concentrations at Troilus. In effect, this confirms the maximum levels as likely established by mineral solubility.

At pH 8.0 in Table 5-1, many more carbonate minerals are likely present than at pH 6.5. This is because pH ~8 is typical of carbonate-mineral dissolution and precipitation, whereas pH 6.5 is typical of water not in contact with common carbonate minerals like calcite and dolomite.

Table 5-1. Minerals identified by Minteq as being generally close to solubility and thus accounting for maximum aqueous concentrations at pH 6.5 and 8.0[1]

Parameter	pH 6.5	pH 8.0
Alkalinity	malachite, calcite	calcite, dolomite, aragonite, malachite, vaterite, rhodocrosite, azurite, smithsonite, ZnCO3, magnesite, NiCO3, ZnCO3·H2O, cerrusite, strontianite, CuCO3, otavite, CoCO3
Sulphate	gypsum, AlOHSO4, celestite, barite	barite, Na-jarosite, gypsum, celestite
Chloride	BiOCl	cerargyrite
Fluoride	fluorite	fluorite
Bromide	bromyrite	bromyrite
Aluminum	Al(OH)3(am), AlOHSO4, Al2O3	variscite, AlPO4·1.5H2O, Al2O3, Zn2Al(OH)6(CO3)0.5
Antimony		
Arsenic	BaHAsO4·H2O	BaHAsO4·H2O
Boron		
Barium	barite, BaHAsO4·H2O	barite, BaHAsO4·H2O
Bismuth	BiOCl	
Cadmium	CdMoO4	CdMoO4, otavite
Calcium	Ca3(PO4)2(beta), gypsum, CaHPO4, calcite, Ca3(PO4)2(am), Ca4H(PO4)3·3H2O, calcite, fluorite	calcite, dolomite, aragonite, CaHPO4, CaHPO4·2H2O, vaterite, gypsum, fluorite, Ca3(PO4)2(am), CaMoO4
Chromium	Cr2O3, Cr(OH)3(am)	Cr2O3, Cr(OH)3(am)
Cobalt		CoCO3
Copper	CuMoO4, tenorite, malachite	malachite, tenorite, azurite, CuMoO4, CuCO3, Cu(OH)2
Iron[2]	Fe3(OH)8, Fe2(OH)4SeO3, pQ = 35.2	Na-jarosite, pQ = 35.2
Lead	PbMoO4	PbMoO4, cerrusite, Pb2V2O7
Lithium		
Magnesium		dolomite, sepiolite, magnesite, chrysotile
Manganese	manganite	rhodocrosite, MnCO3(am)
Molybdenum	PbMoO4, CuMoO4, CdMoO4	PbMoO4, CdMoO4, CuMoO4, CaMoO4

Parameter	pH 6.5	pH 8.0
Nickel		NiCO3, Ni(OH)2
Phosphorus	Ca3(PO4)2(beta), CaHPO4, Ca3(PO4)2(am), Ca4H(PO4)3·3H2O, K-autunite	variscite, CaHPO4, CaHPO4·2H2O, Ca3(PO4)2(am), AlPO4·1.5H2O, Zn3(PO4)2·4H2O
Potassium	K-autunite	
Selenium	Fe2(OH)4SeO3	
Silicon	cristobalite, amorphous SiO2, quartz, chalcedony	chalcedony, cristobalite, sepiolite, amorphous SiO2, quartz, chrysotile
Silver	bromyrite	bromyrite, cerargyrite
Sodium		Na-jarosite
Strontium	celestite	celestite, strontianite
Tin		H2Sn(OH)6, Sn(OH)4
Uranium	K-autunite	
Vanadium		Pb2V2O7
Zinc		smithsonite, ZnCO3, Zn2Al(OH)6(CO3)0.5, Zn3(PO4)2·4H2O, ZnCO3·H2O

[1] Minteq and other mineral-solubility software cannot reliably identify minerals controlling aqueous concentrations of all elements due to site-specific variations in mineral composition, crystallinity, solubility, imperfections, solid solutions, etc.

[2] pQ = -log10[Fe^{3+}] - 3*log10[OH^-]; pQ values around 36 indicate ferric iron is likely dissolving, and pQ values around 34 indicate ferric iron is likely precipitating.

6. References

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APPENDIX A. Compiled Scatterplots from Troilus Humidity Cells, On-Site Field Columns, and On-Site Monitoring of STP-9 (J4 waste-rock drainage), J4 Pit, 87 Pit, Tailings Seepage, and Miscellaneous Groundwater

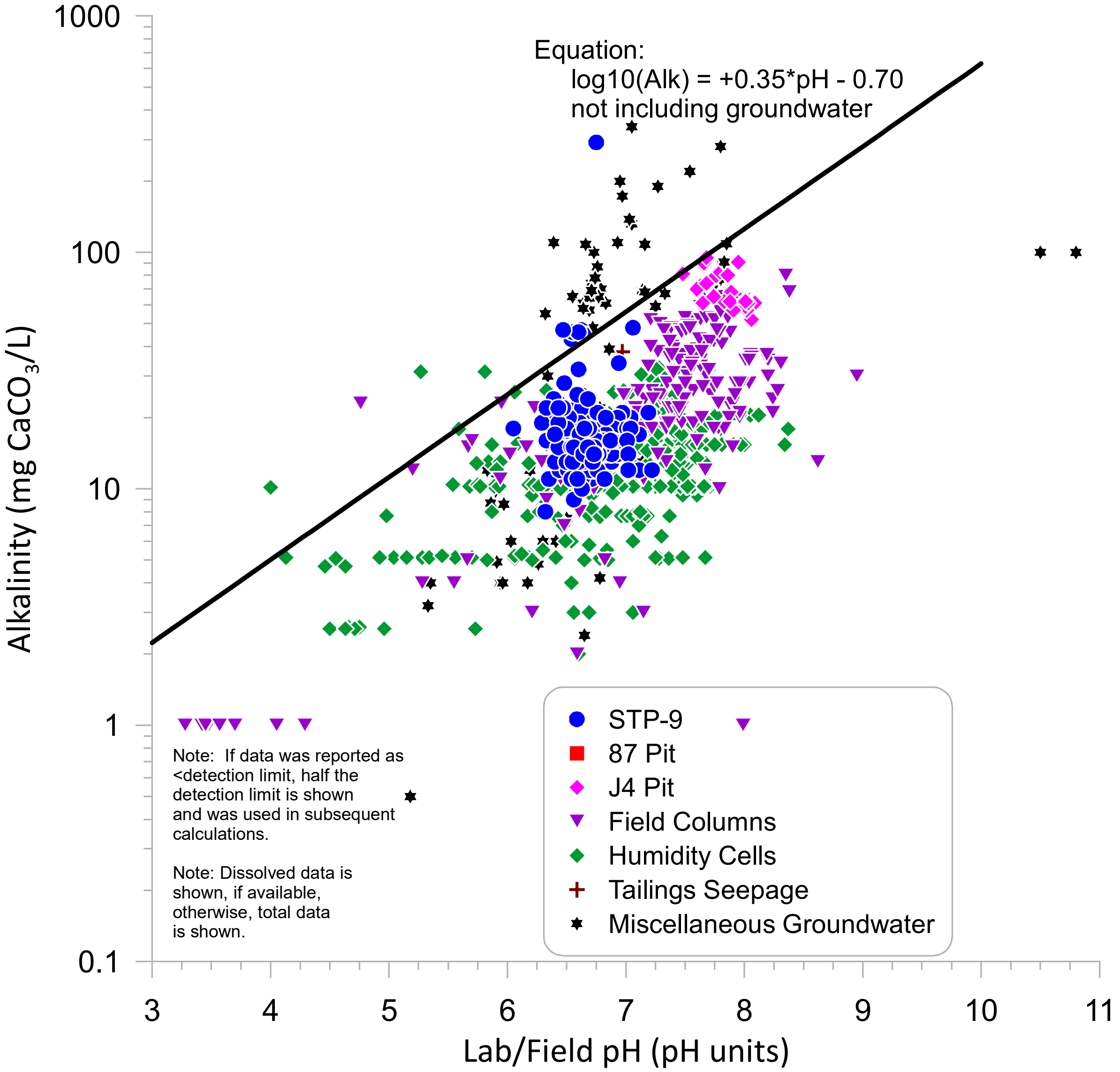


Figure A1a. Alkalinity vs. pH at the Troilus Gold Project, showing the pH-dependent maximum equation.

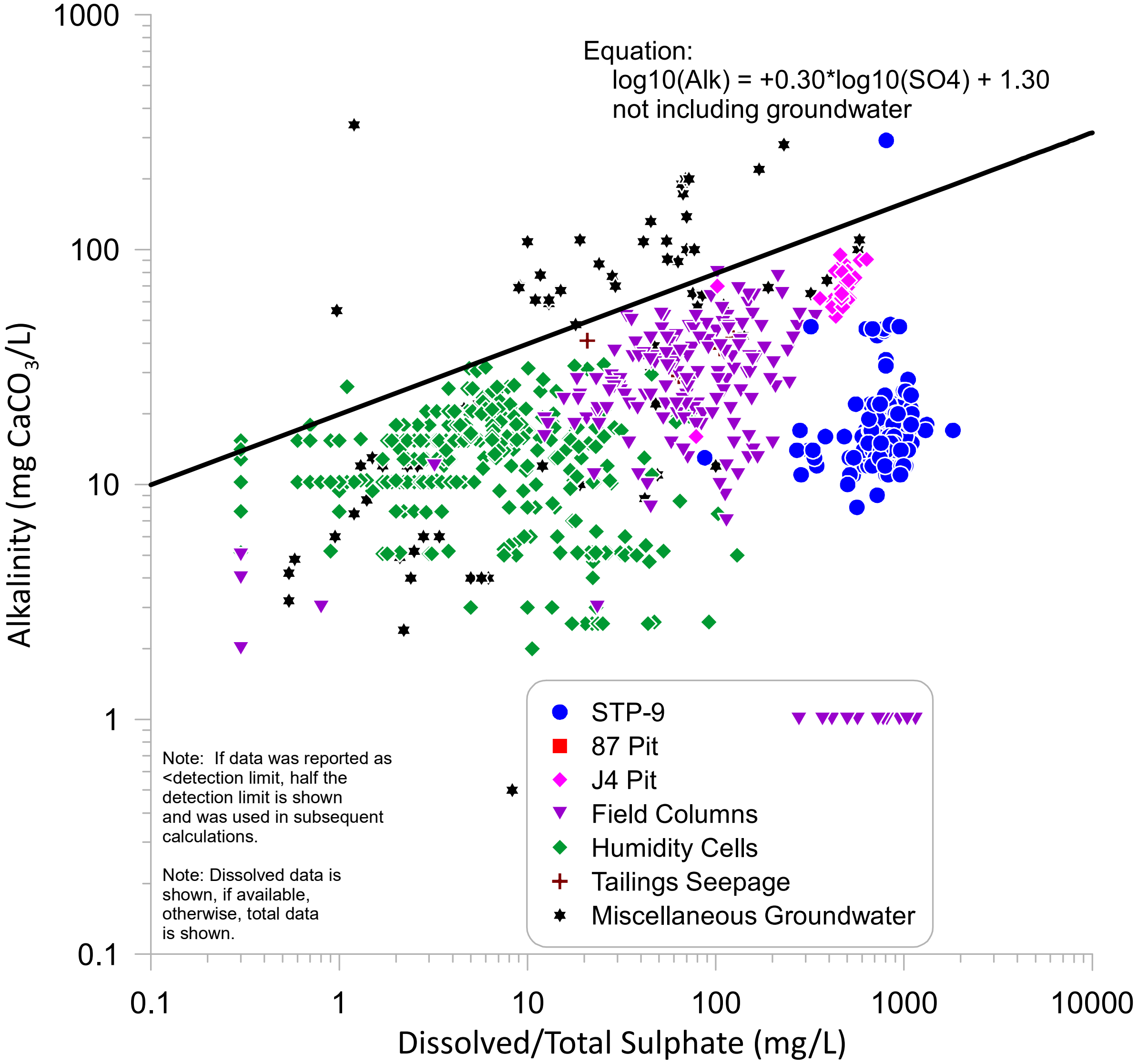


Figure A1b. Alkalinity vs. sulphate at the Troilus Gold Project, showing the sulphate-dependent maximum equation.

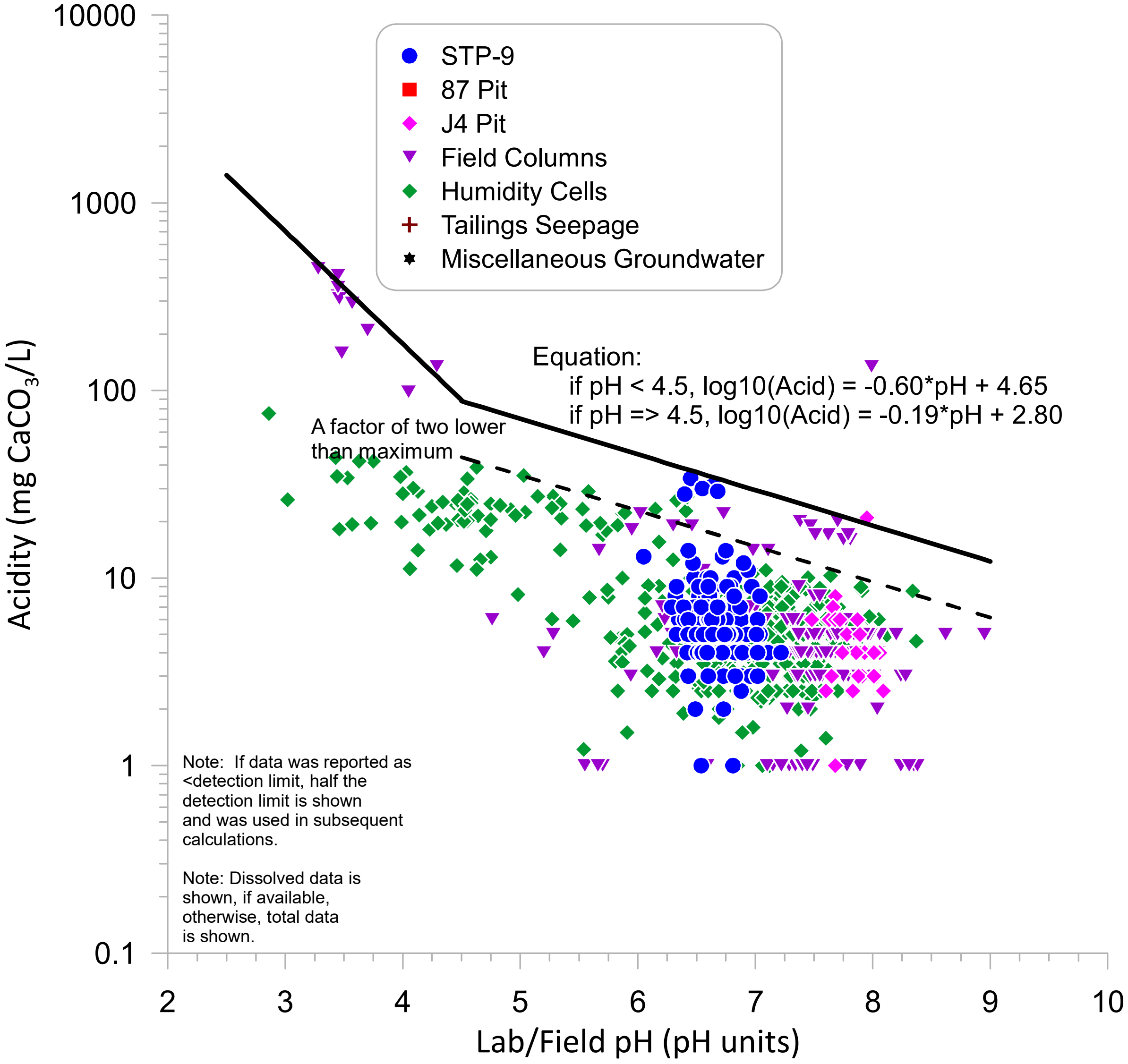


Figure A2a. Acidity vs. pH at the Troilus Gold Project, showing the pH-dependent maximum equation.

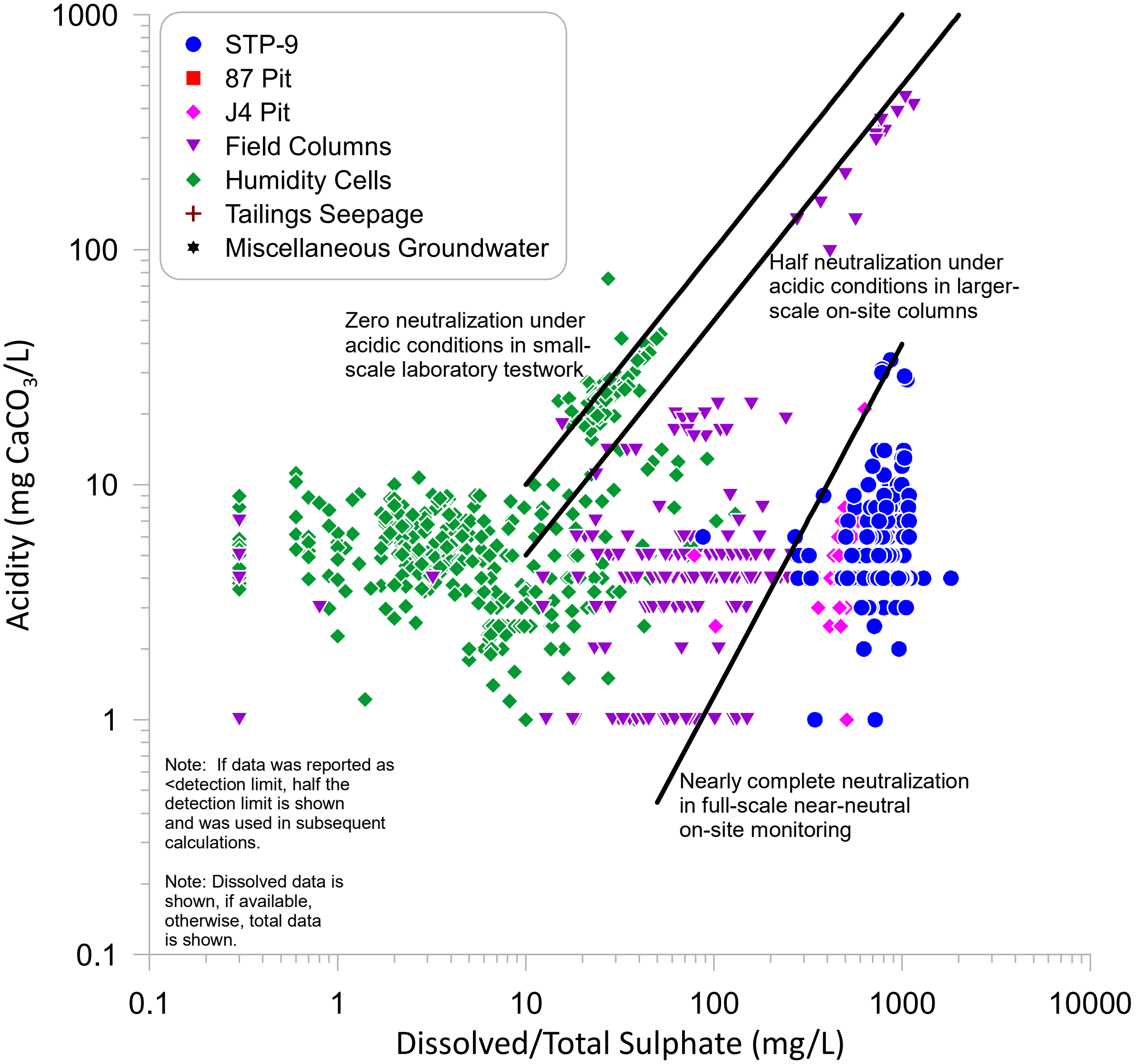


Figure A2b. Acidity vs. sulphate at the Troilus Gold Project, showing the sulphate-dependent maximum equation.

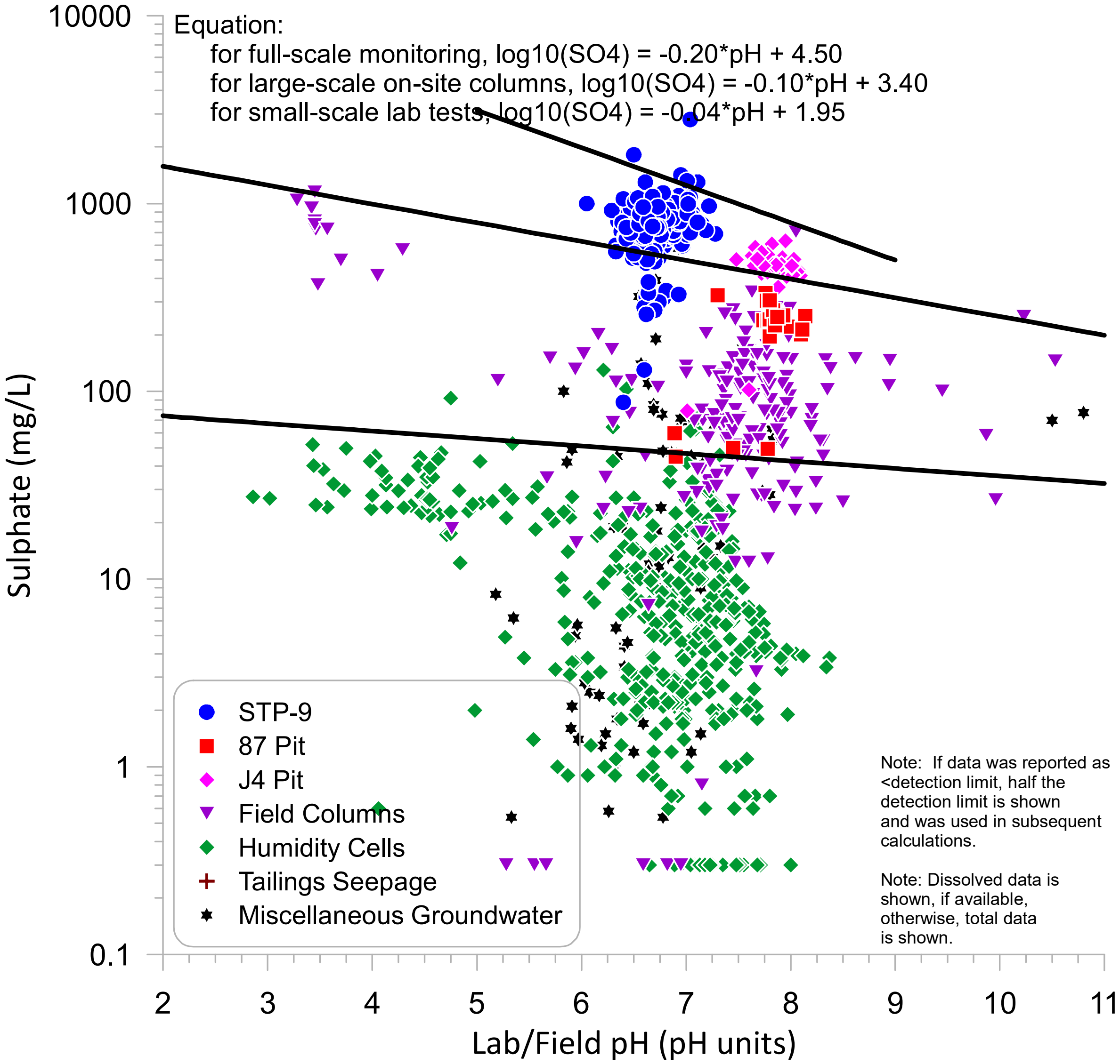


Figure A3. Sulphate vs. pH at the Troilus Gold Project, showing the pH-dependent maximum equation.

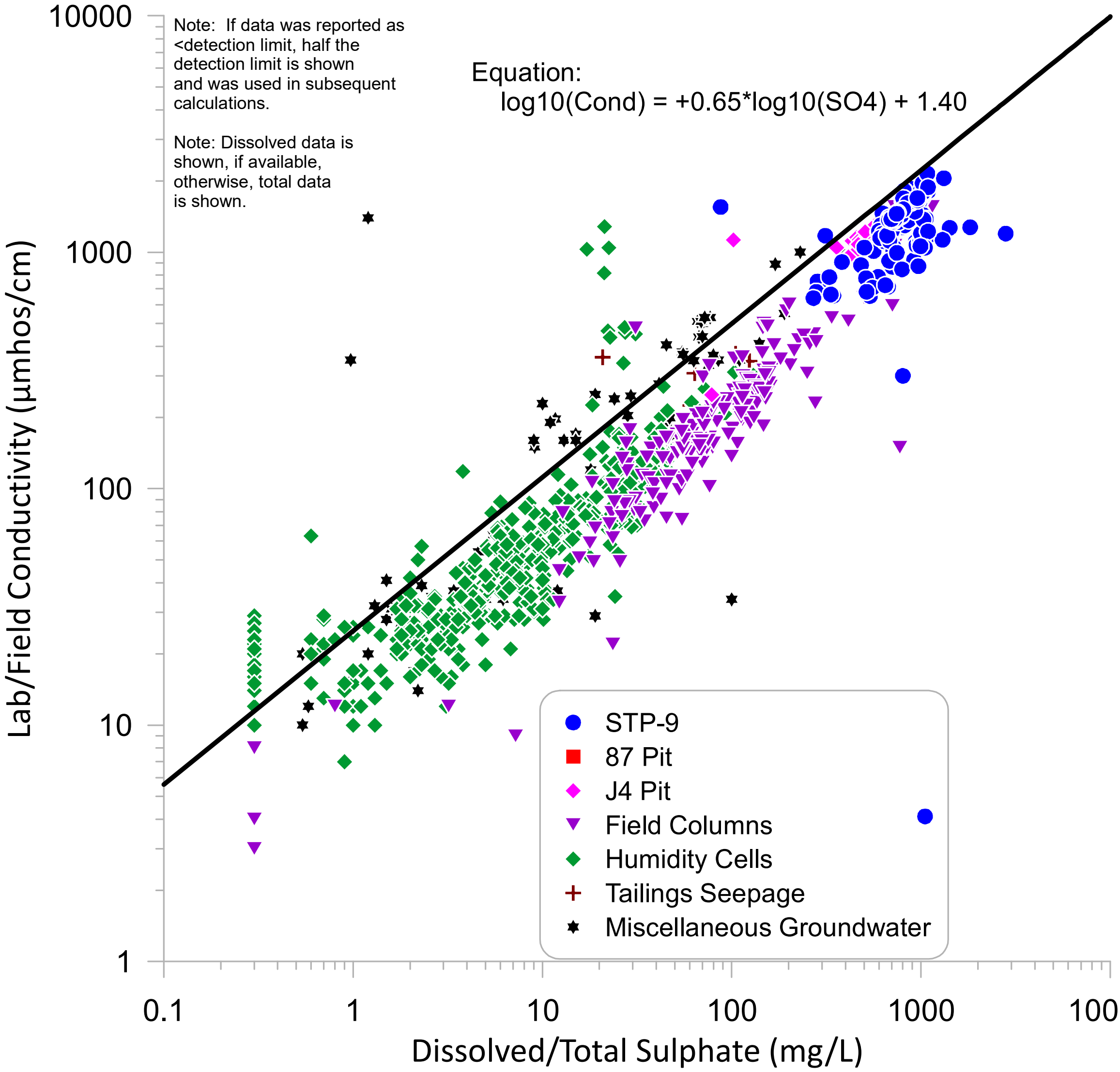
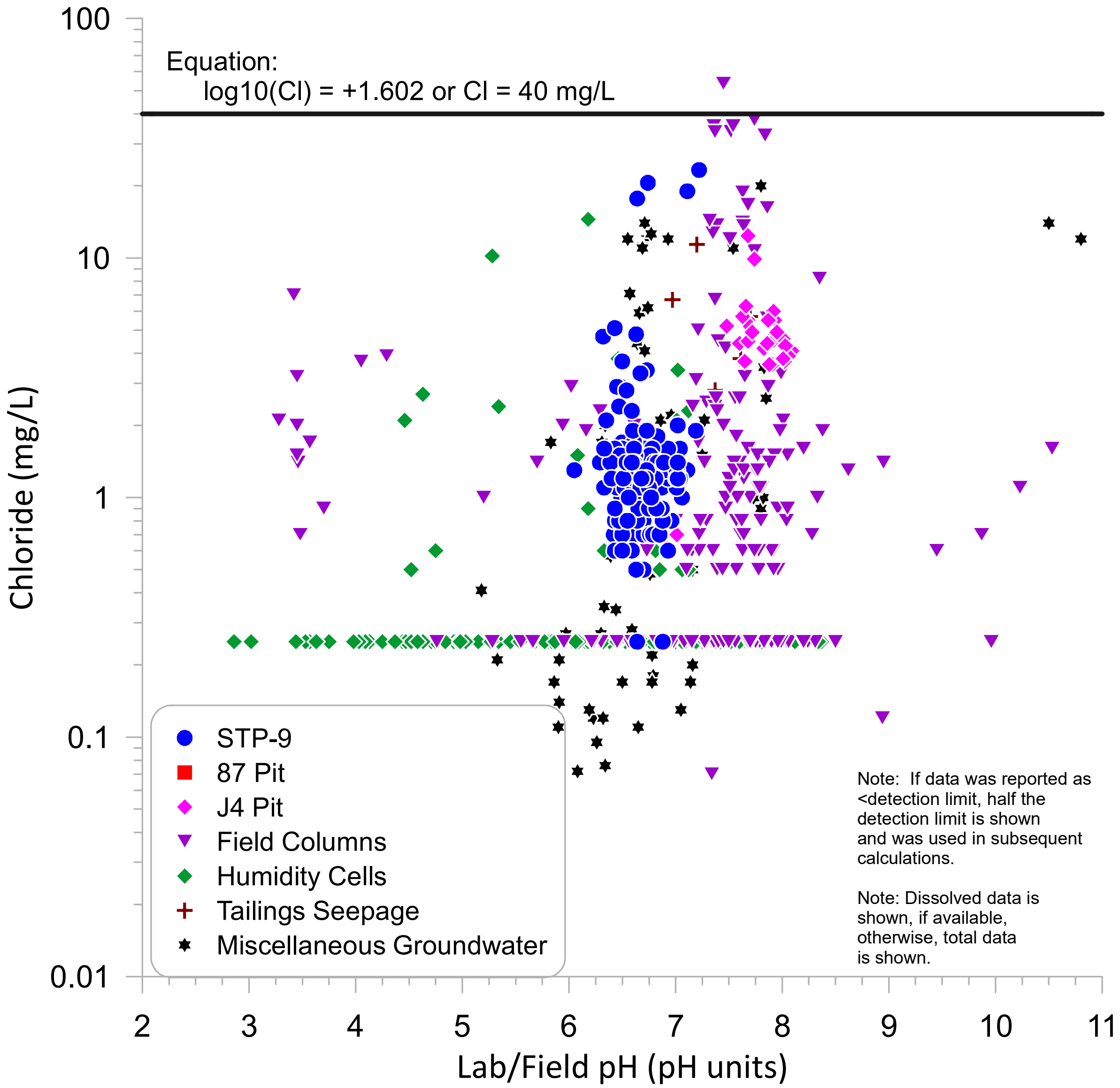


Figure A4. Electrical conductivity vs. sulphate at the Troilus Gold Project, showing the sulphate-dependent maximum equation.



Note: If data was reported as <detection limit, half the detection limit is shown and was used in subsequent calculations.

Note: Dissolved data is shown, if available, otherwise, total data is shown.

Figure A5. Chloride vs. pH at the Troilus Gold Project, showing the pH-dependent maximum equation

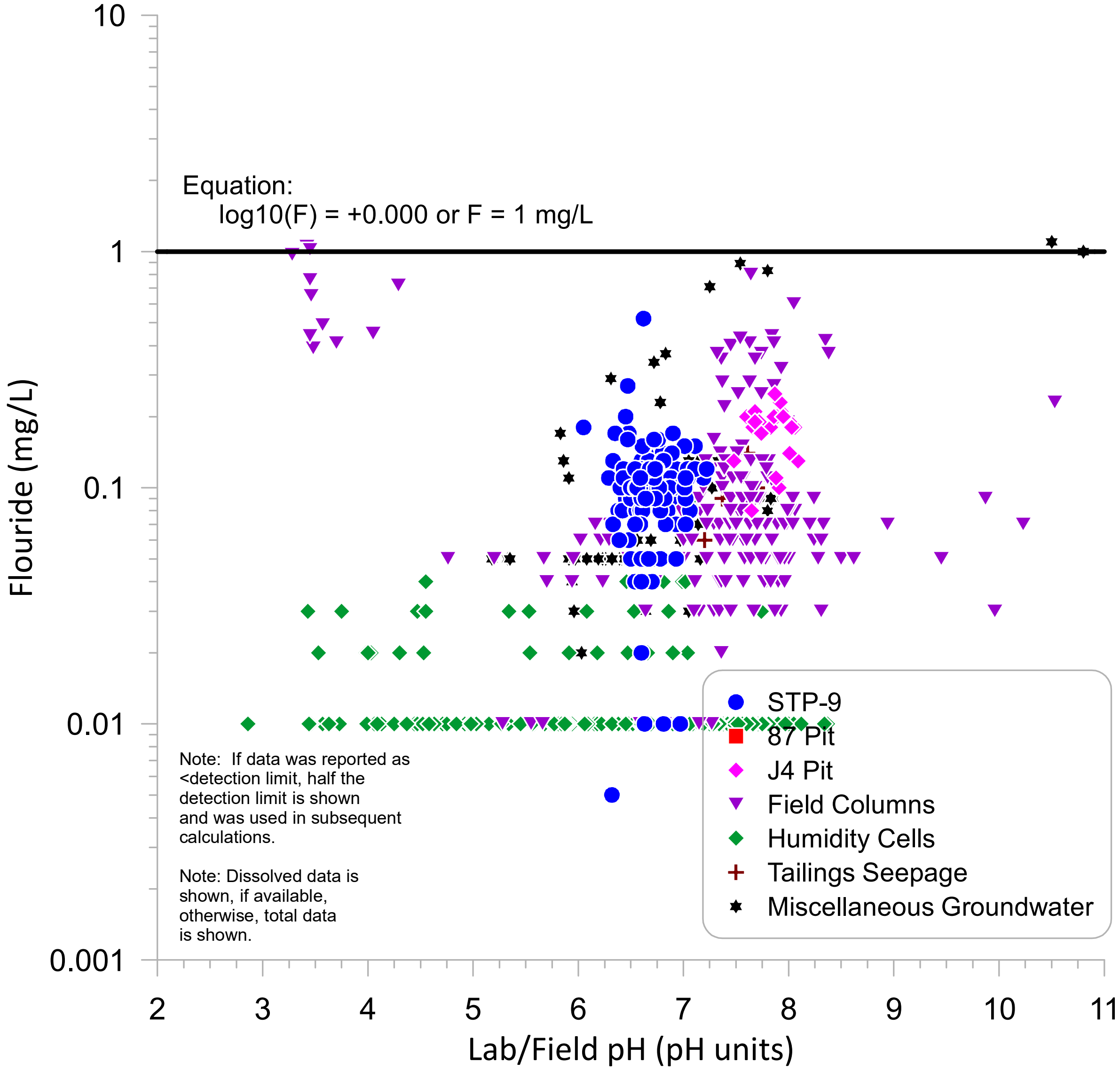
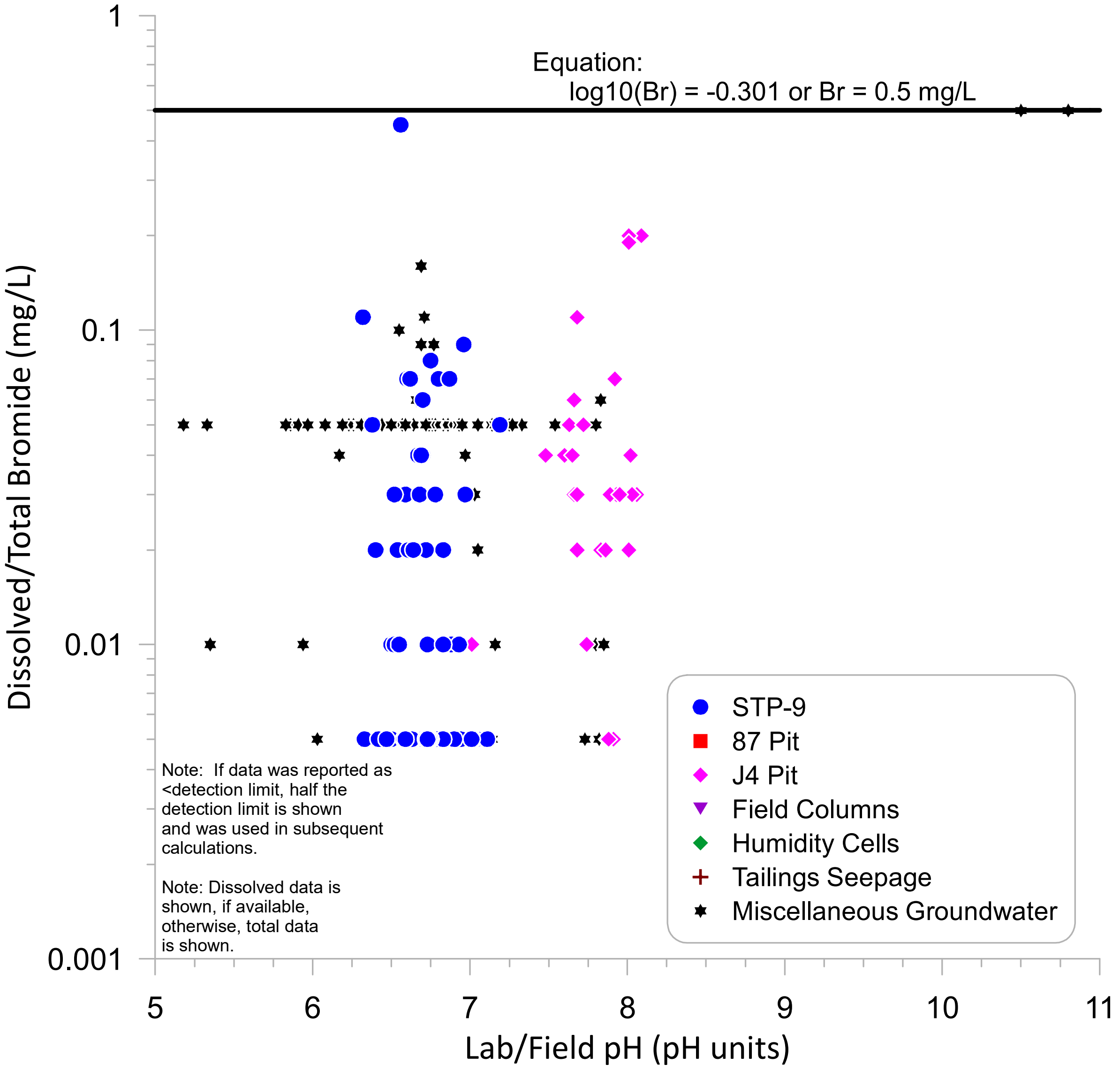


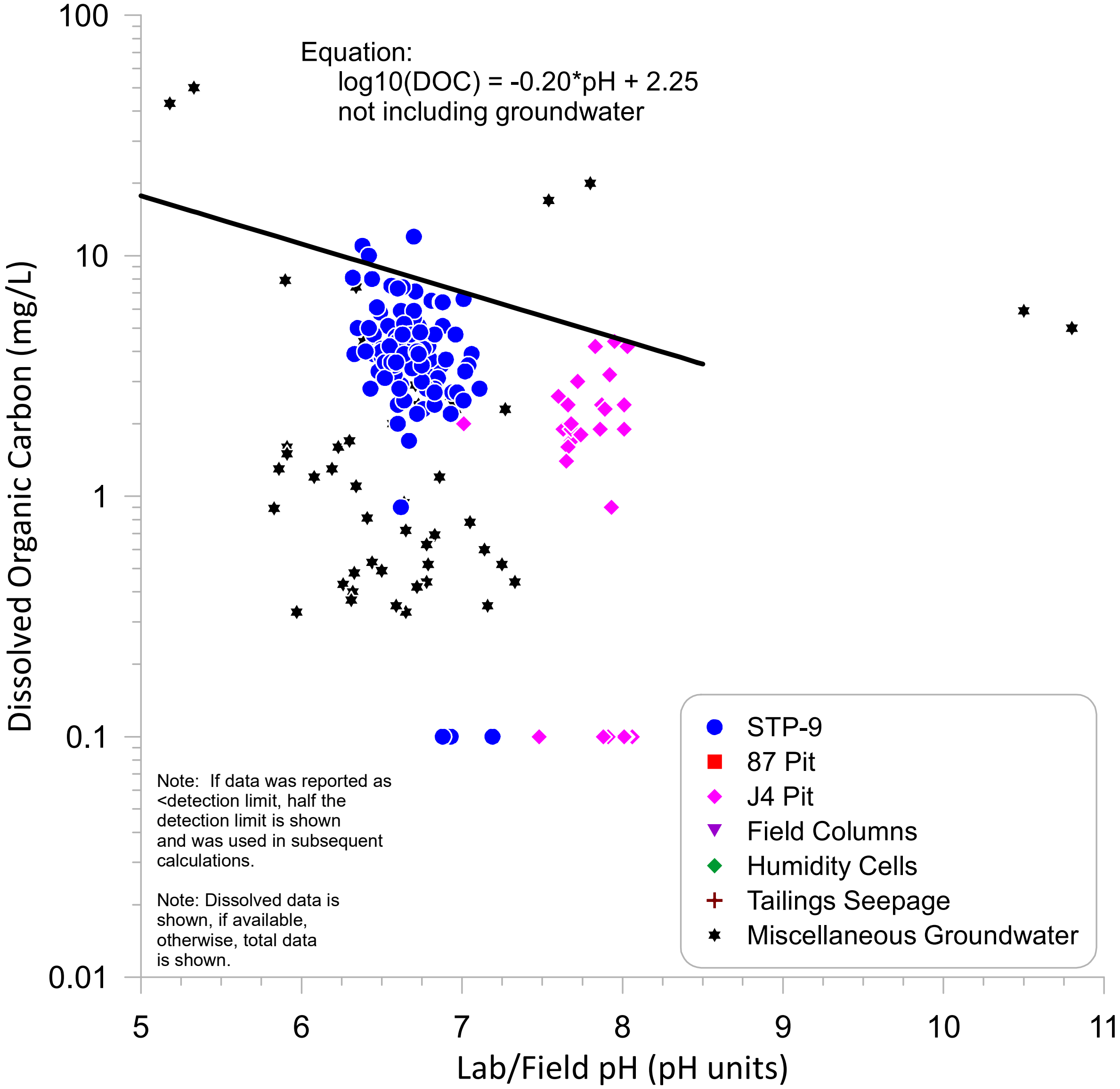
Figure A6. Fluoride vs. pH at the Troilus Gold Project, showing the pH-dependent maximum equation.



Note: If data was reported as <detection limit, half the detection limit is shown and was used in subsequent calculations.

Note: Dissolved data is shown, if available, otherwise, total data is shown.

Figure A7. Bromide vs. pH at the Troilus Gold Project, showing the pH-dependent maximum equation.



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Note: Dissolved data is shown, if available, otherwise, total data is shown.

Figure A8. Dissolved Organic Carbon vs. pH at the Troilus Gold Project, showing the pH-dependent maximum equation.

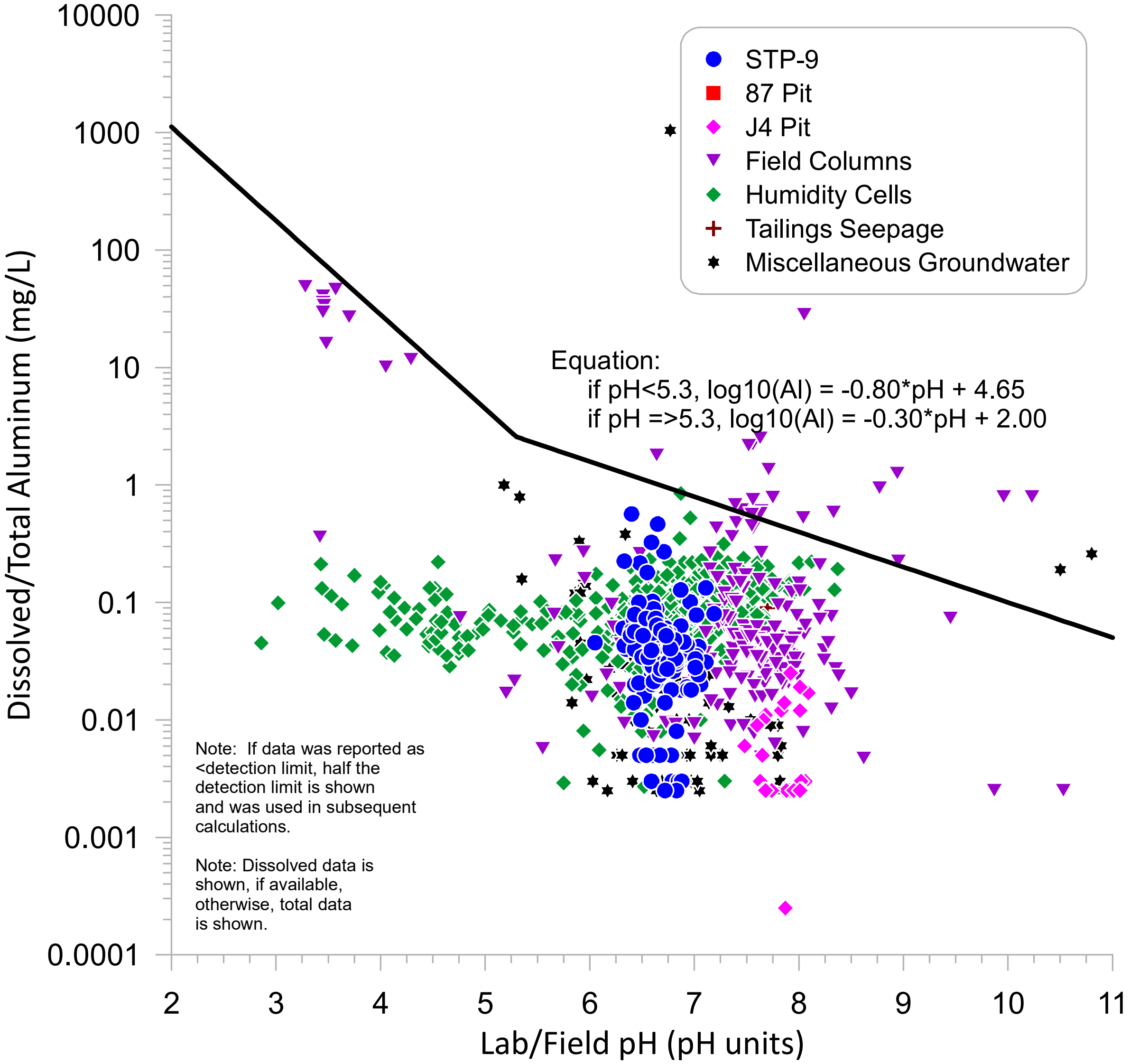
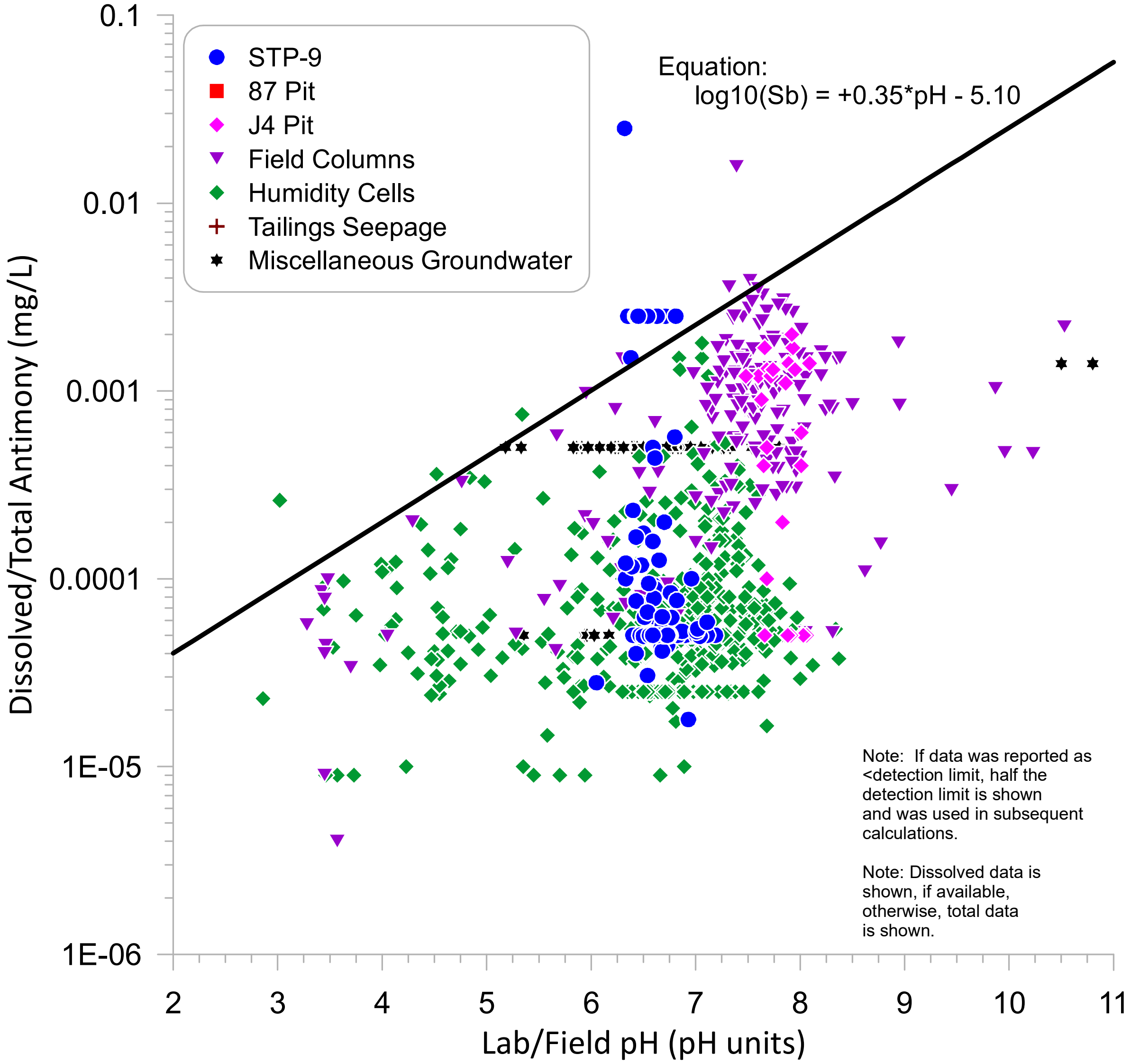


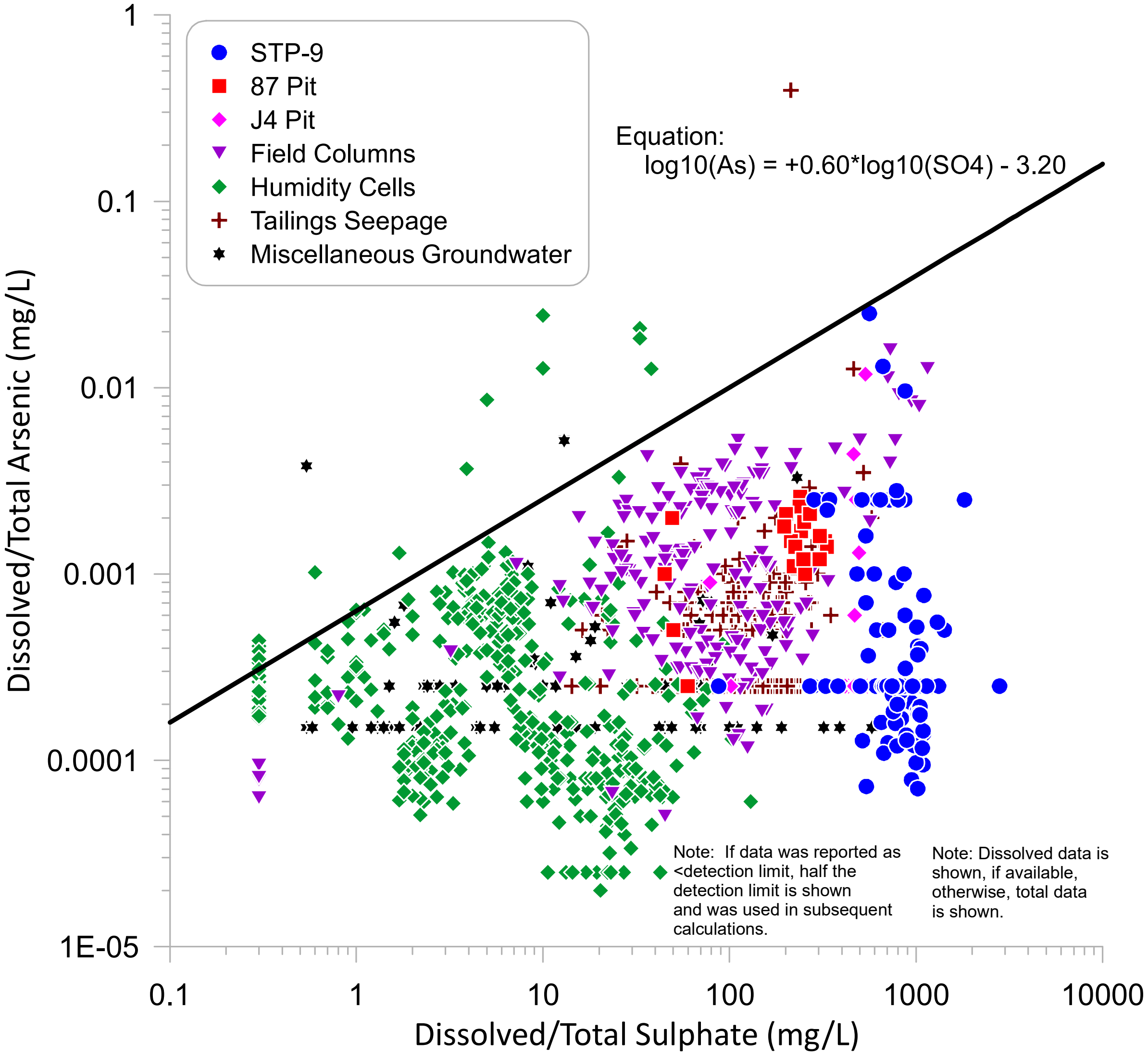
Figure A9. Aluminum vs. pH at the Troilus Gold Project, showing the pH-dependent maximum equation.



Note: If data was reported as <detection limit, half the detection limit is shown and was used in subsequent calculations.

Note: Dissolved data is shown, if available, otherwise, total data is shown.

Figure A10. Antimony vs. pH at the Troilus Gold Project, showing the pH-dependent maximum equation.



Note: If data was reported as <detection limit, half the detection limit is shown and was used in subsequent calculations.

Note: Dissolved data is shown, if available, otherwise, total data is shown.

Figure A11. Arsenic vs. sulphate at the Troilus Gold Project, showing the sulphate-dependent maximum equation.

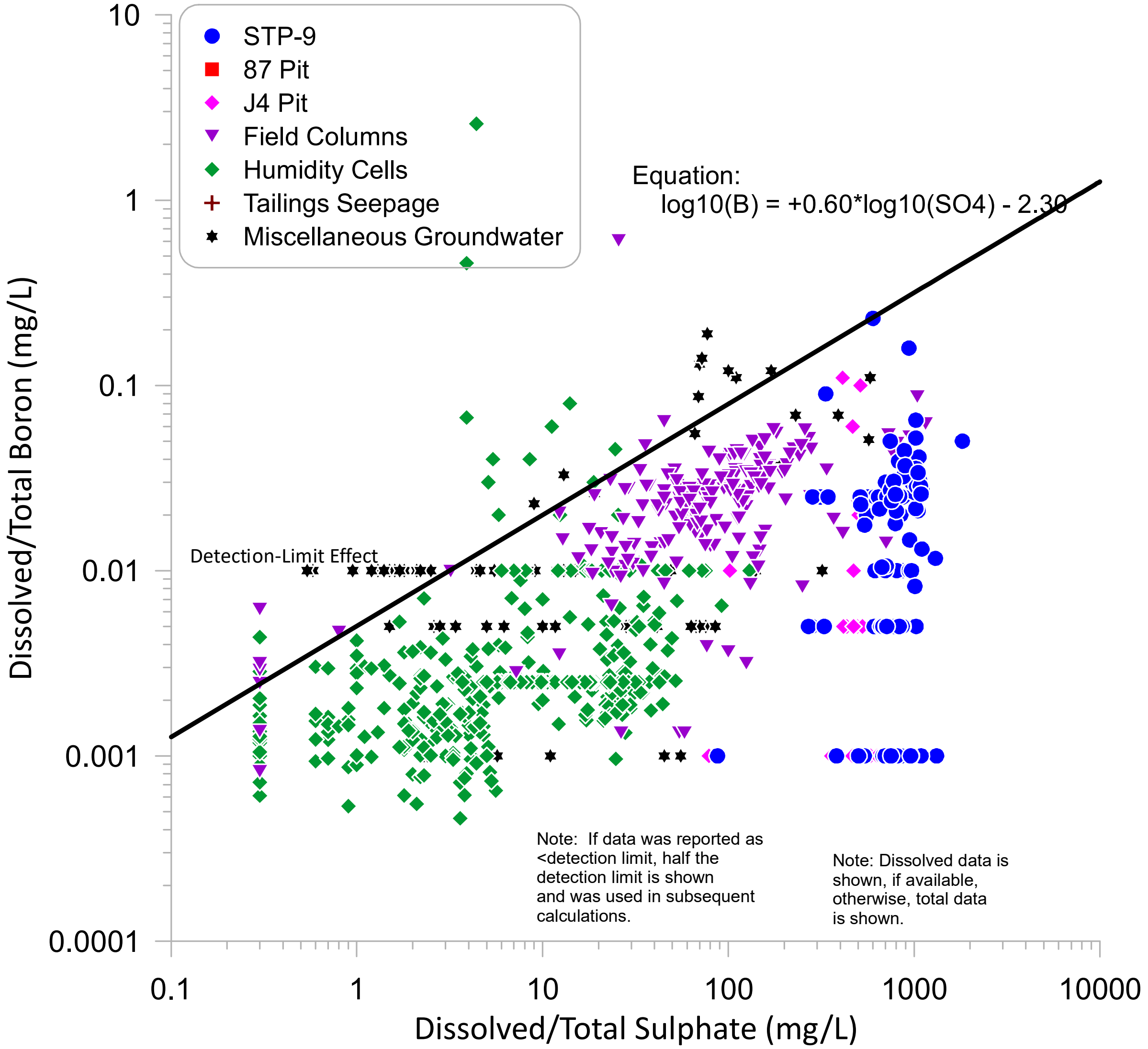
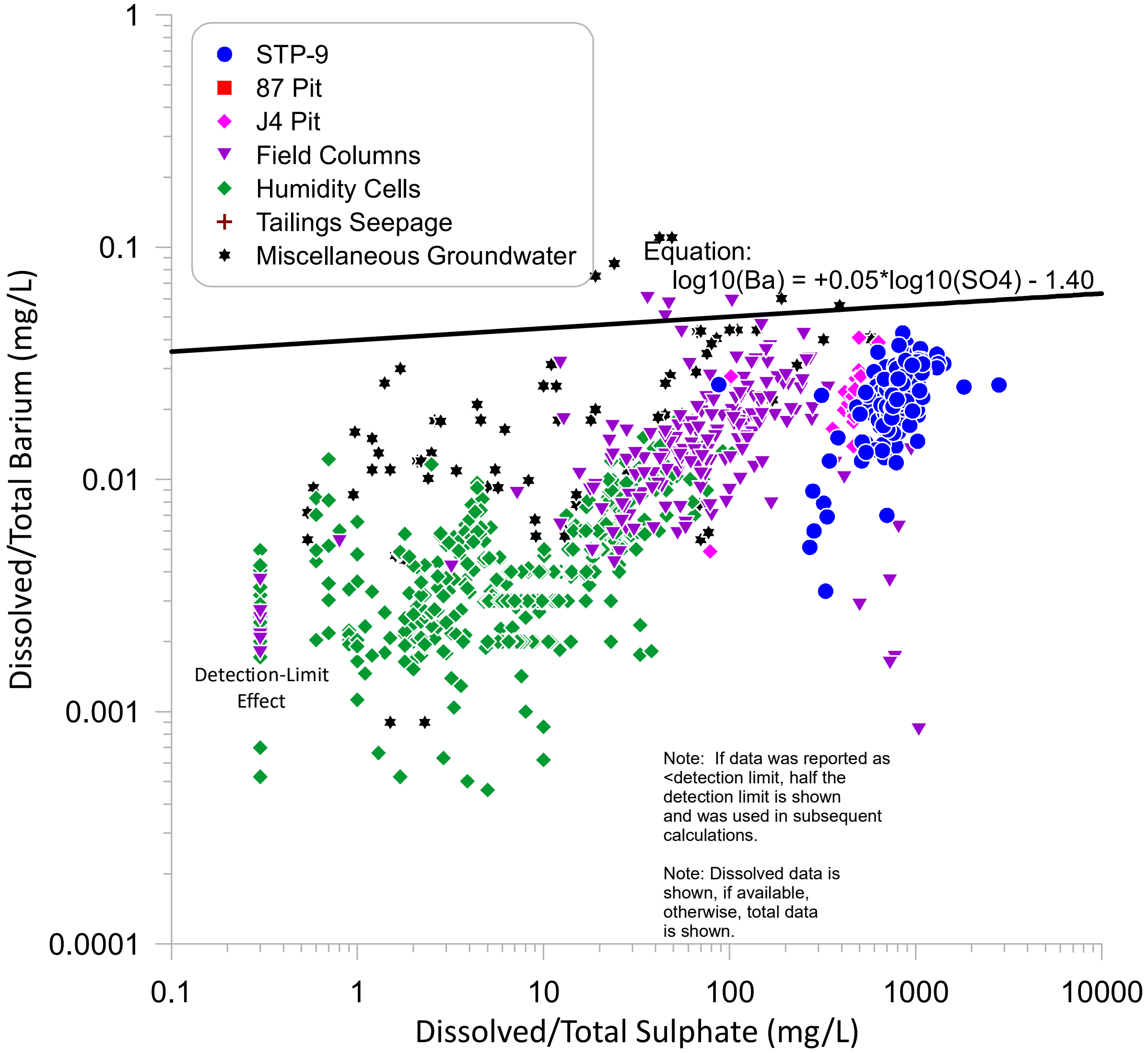


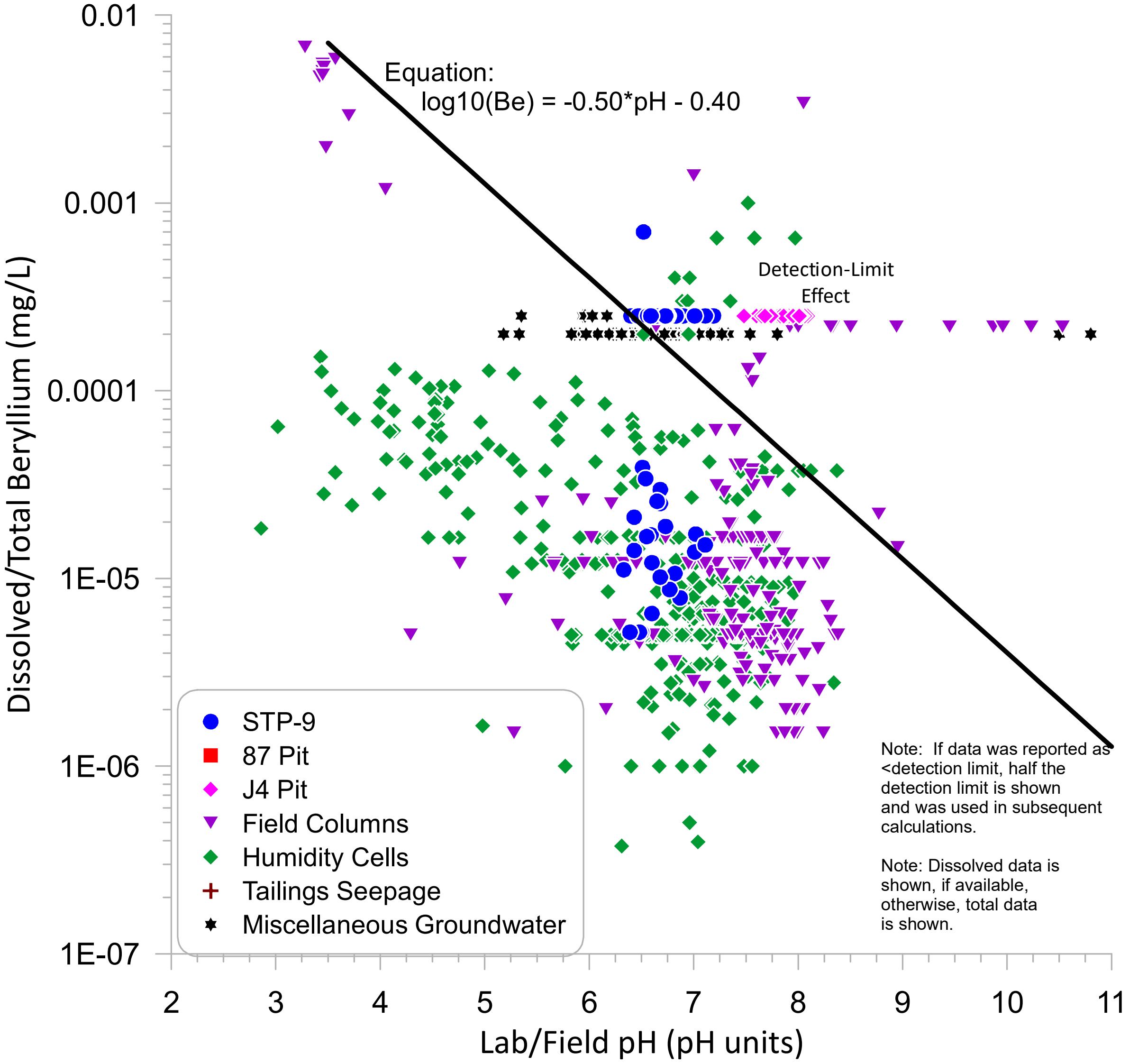
Figure A12. Boron vs. sulphate at the Troilus Gold Project, showing the sulphate-dependent maximum equation.



Note: If data was reported as <detection limit, half the detection limit is shown and was used in subsequent calculations.

Note: Dissolved data is shown, if available, otherwise, total data is shown.

Figure A13. Barium vs. sulphate at the Troilus Gold Project, showing the sulphate-dependent maximum equation.



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Note: Dissolved data is shown, if available, otherwise, total data is shown.

Figure A14. Beryllium vs. pH at the Troilus Gold Project, showing the pH-dependent maximum equation.

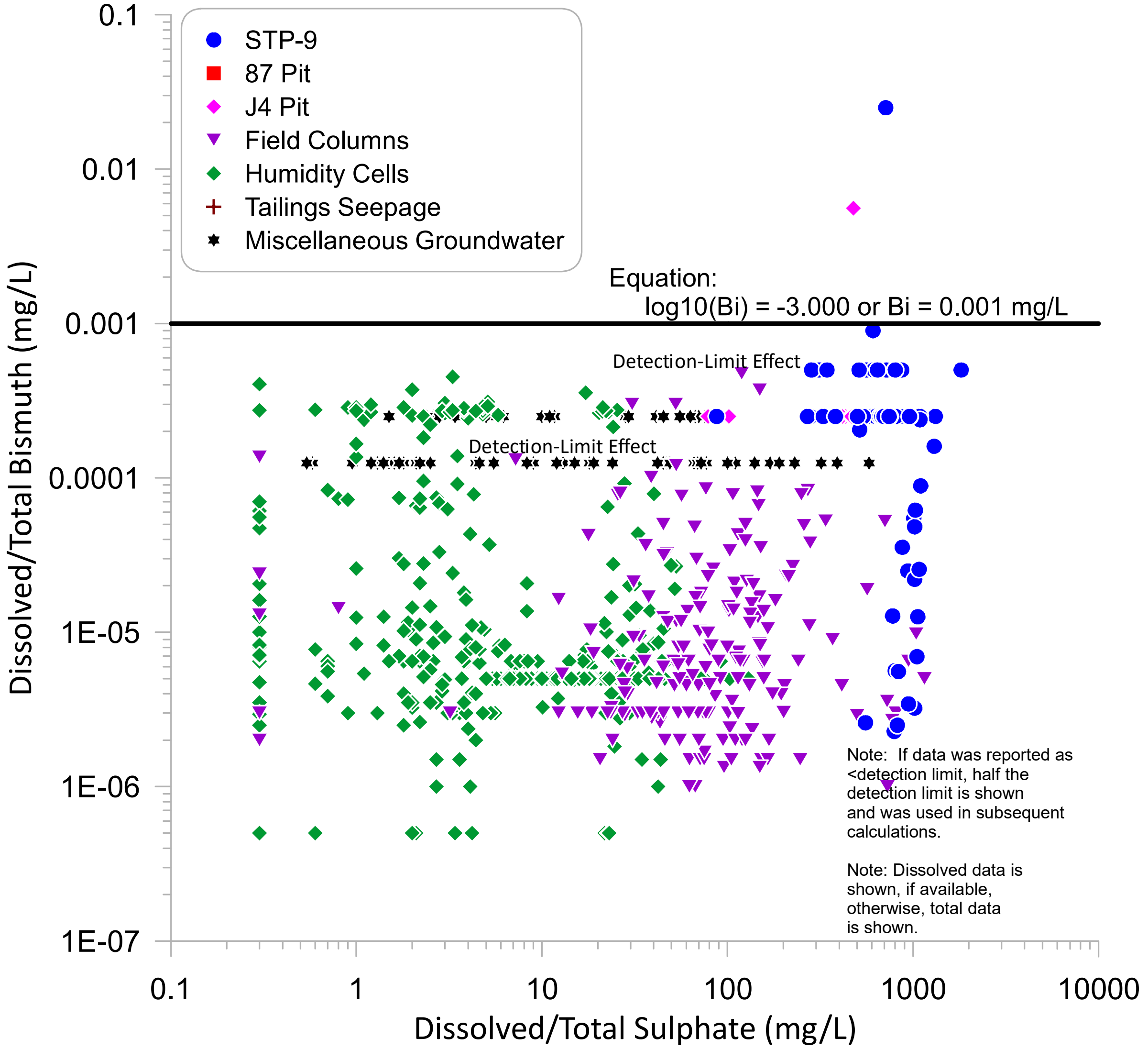


Figure A15. Bismuth vs. sulphate at the Troilus Gold Project, showing the sulphate-dependent maximum equation.

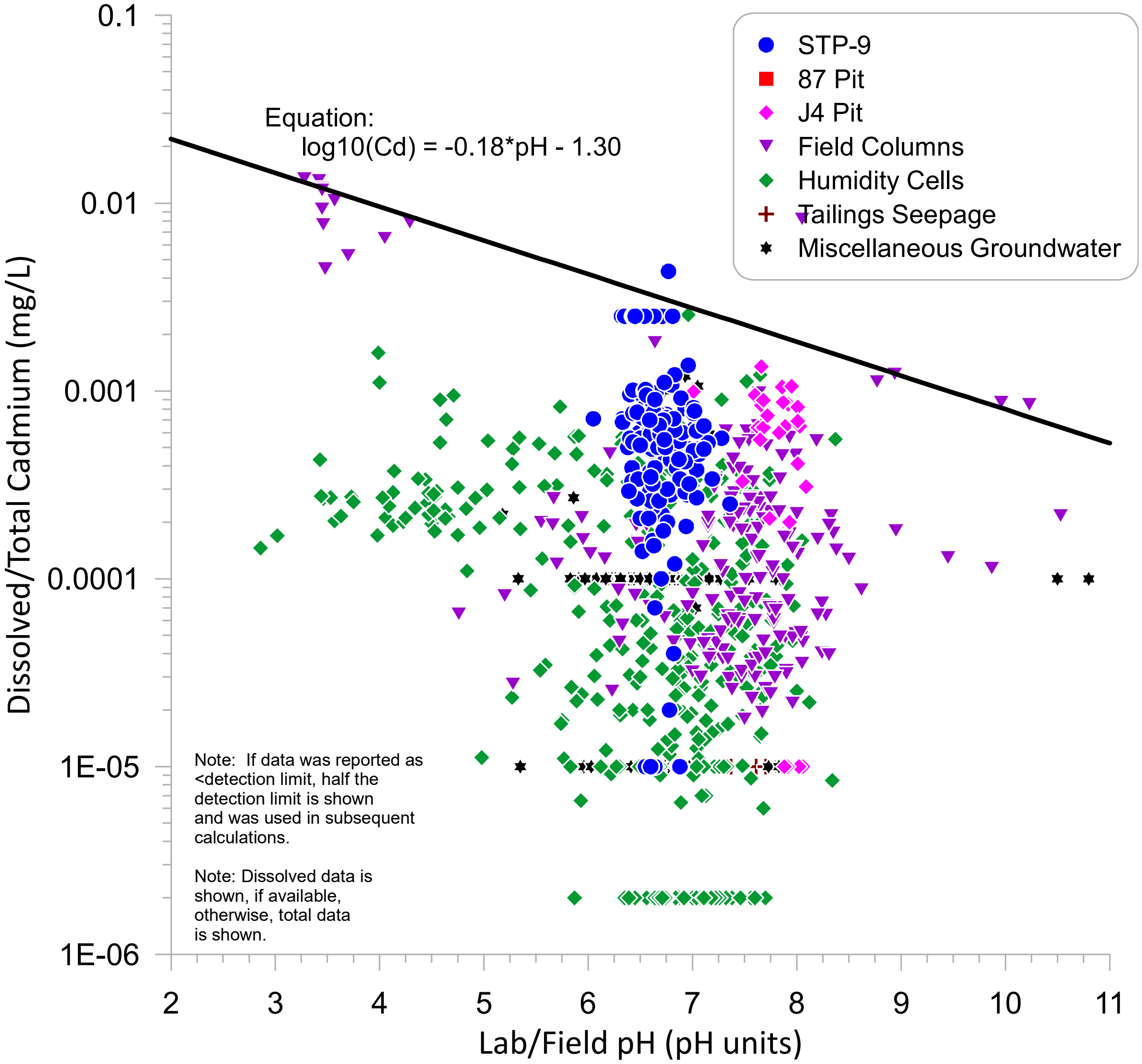


Figure A16. Cadmium vs. pH at the Troilus Gold Project, showing the pH-dependent maximum equation.

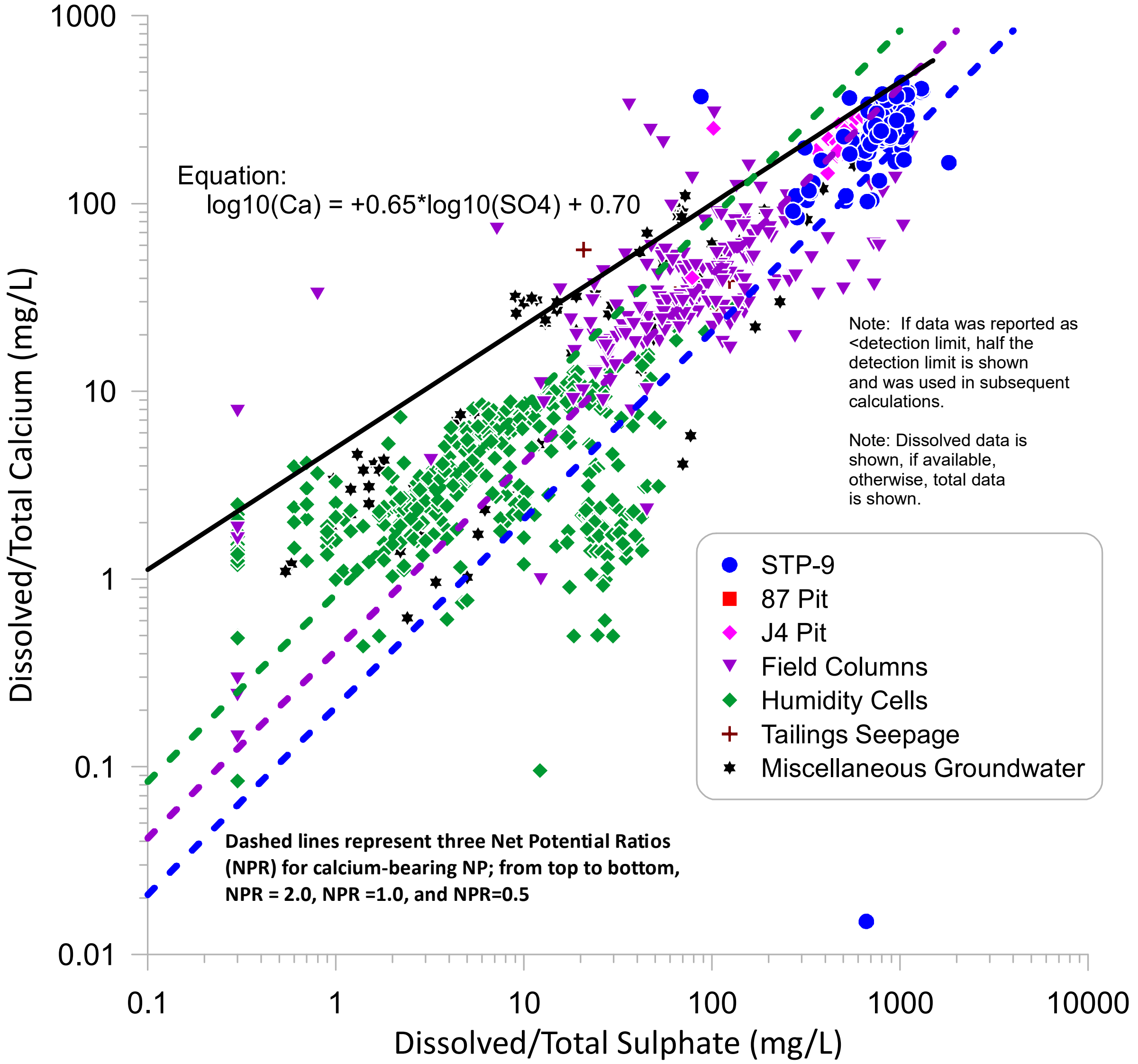
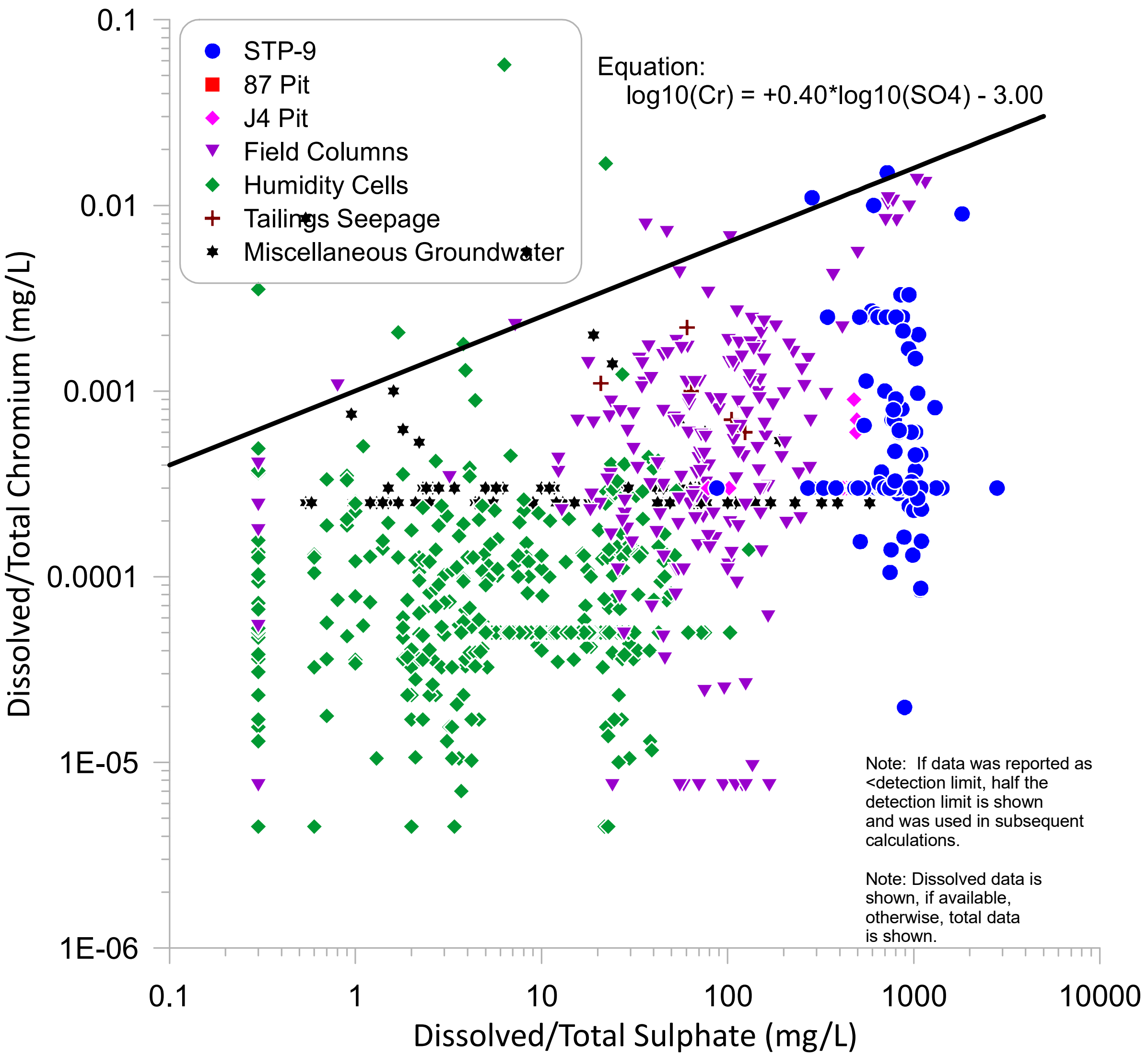


Figure A17. Calcium vs. sulphate at the Troilus Gold Project, showing the sulphate-dependent maximum equation.



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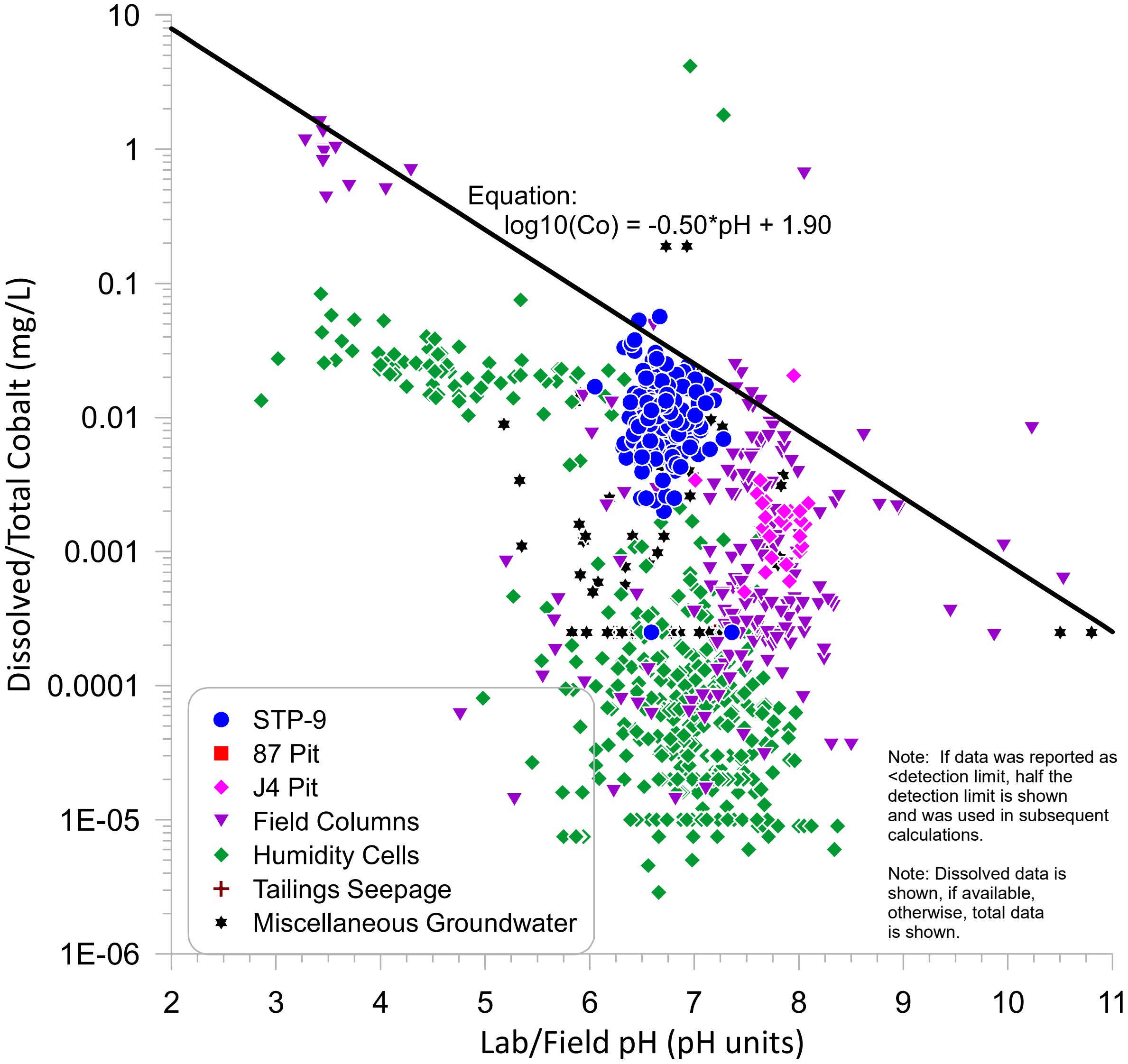
Note: Dissolved data is shown, if available, otherwise, total data is shown.

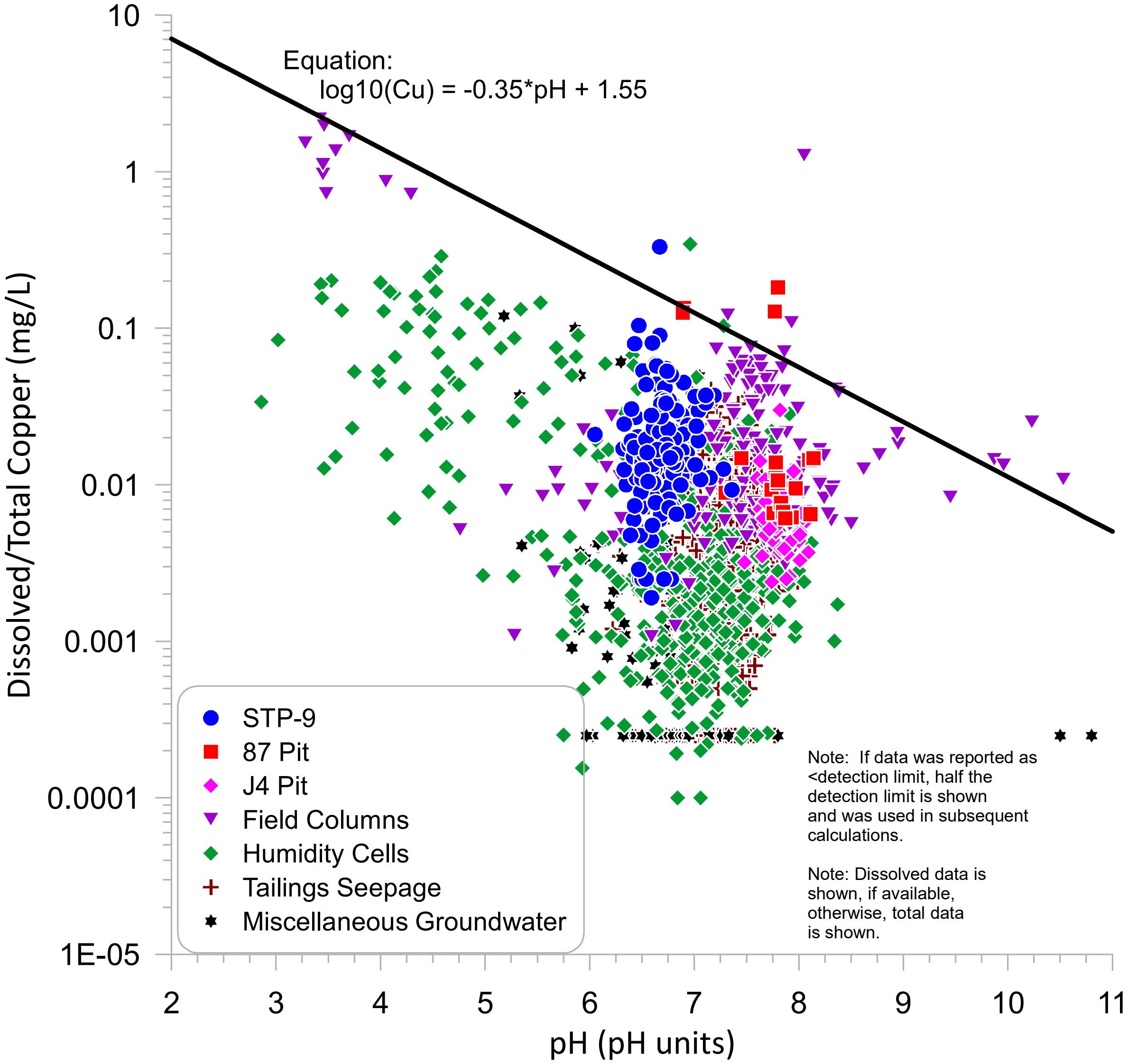
Figure A18. Chromium vs. sulphate at the Troilus Gold Project, showing the sulphate-dependent maximum equation.



Note: If data was reported as <detection limit, half the detection limit is shown and was used in subsequent calculations.

Note: Dissolved data is shown, if available, otherwise, total data is shown.

Figure A19. Cobalt vs. pH at the Troilus Gold Project, showing the pH-dependent maximum equation.



Note: If data was reported as <detection limit, half the detection limit is shown and was used in subsequent calculations.

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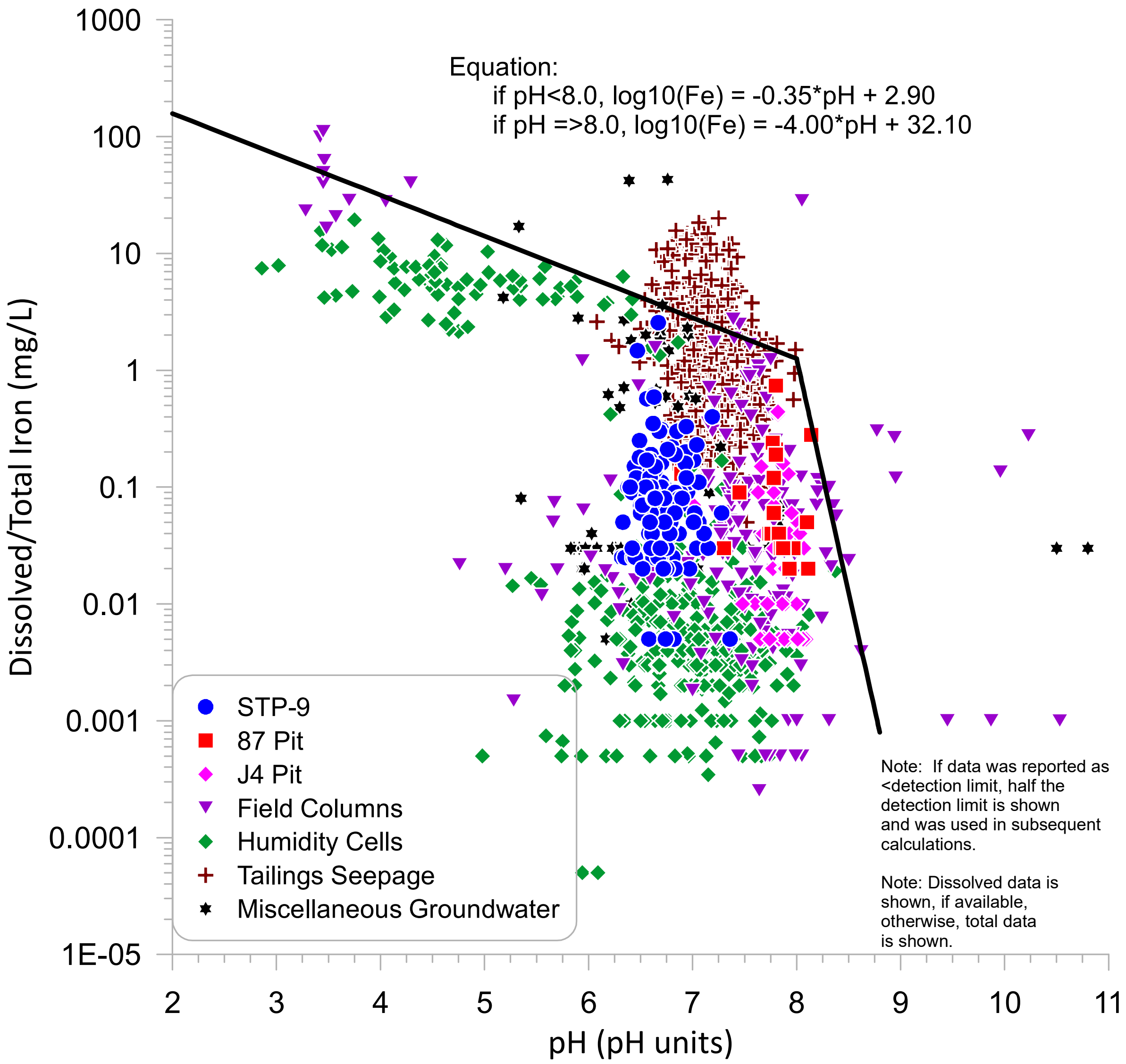
Figure A20. Copper vs. pH at the Troilus Gold Project, showing the pH-dependent maximum equation.



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Note: Dissolved data is shown, if available, otherwise, total data is shown.

Figure A21. Iron vs. pH at the Troilus Gold Project, showing the pH-dependent maximum equation.

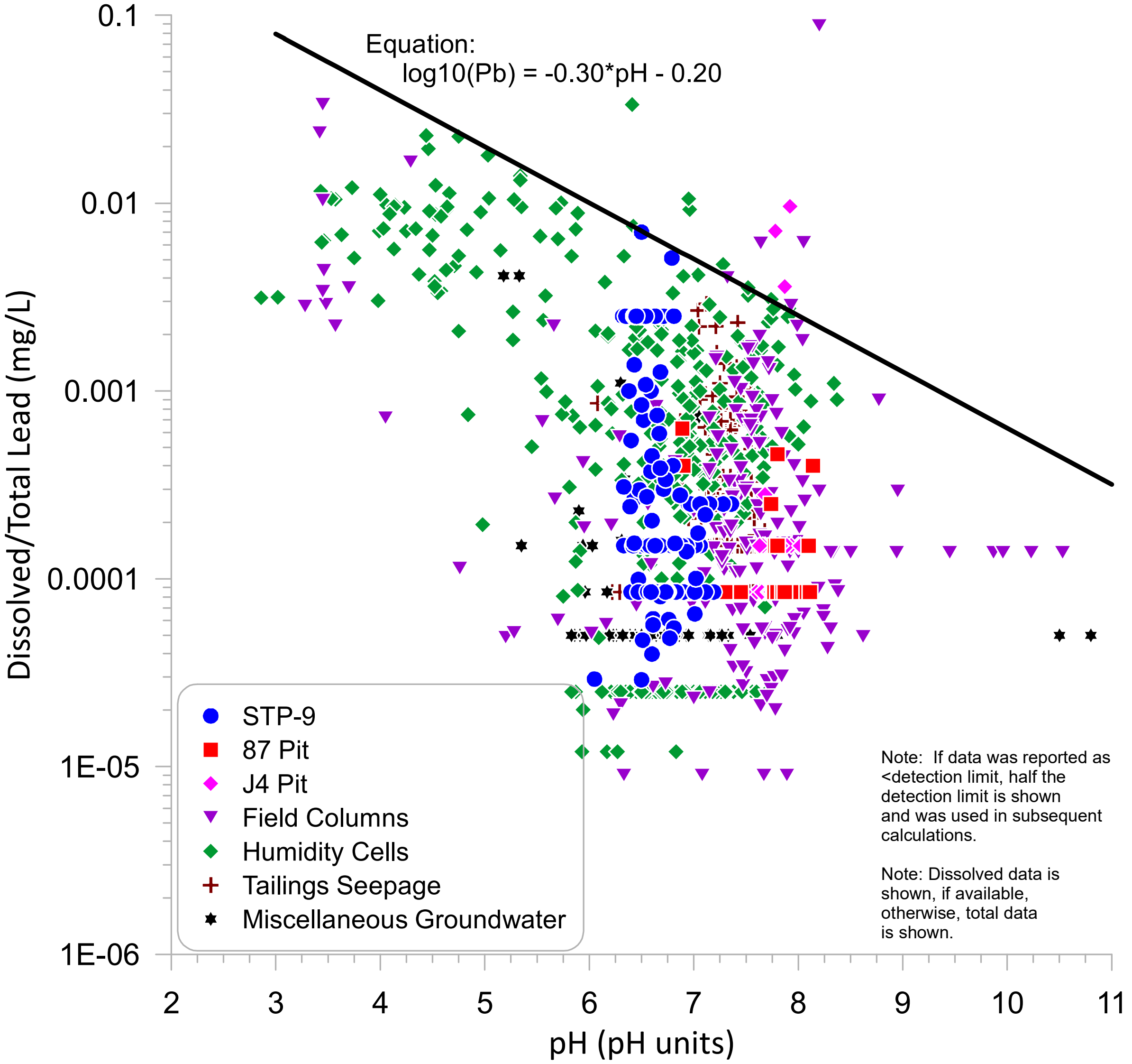

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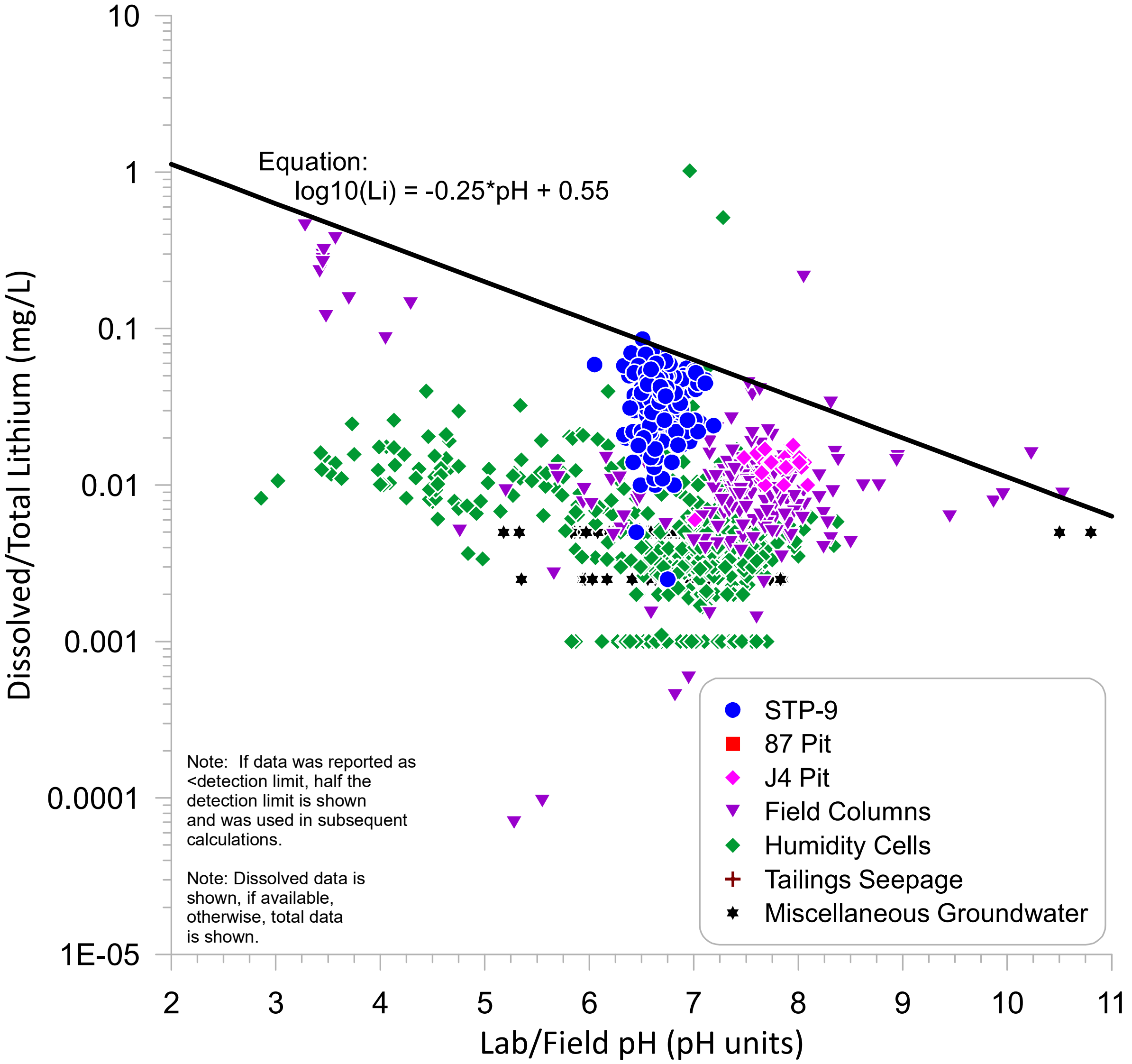
Figure A22. Lead vs. pH at the Troilus Gold Project, showing the pH-dependent maximum equation.



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Note: Dissolved data is shown, if available, otherwise, total data is shown.

Figure A23. Lithium vs. pH at the Troilus Gold Project, showing the pH-dependent maximum equation.

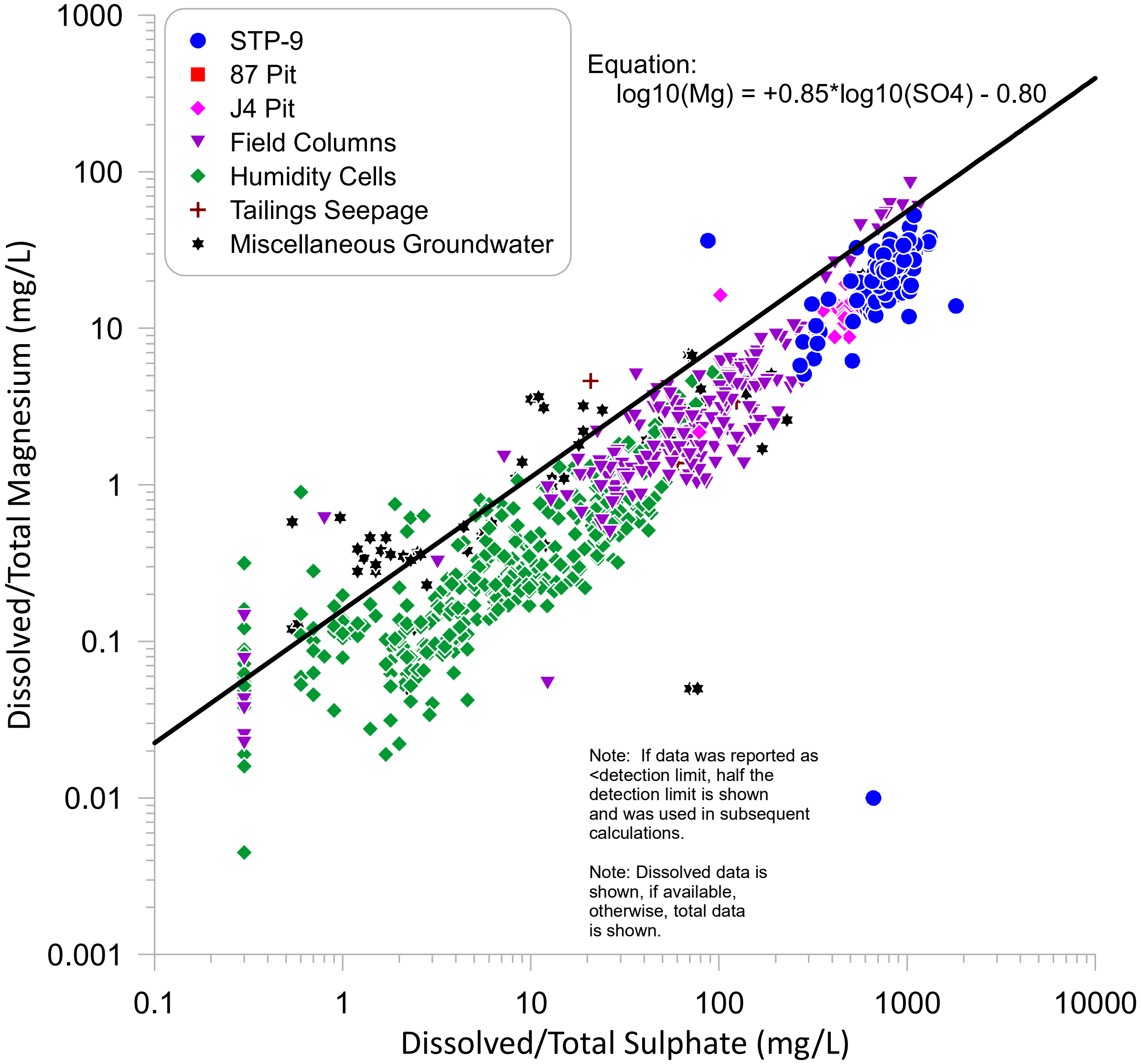

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Figure A24. Magnesium vs. sulphate at the Troilus Gold Project, showing the sulphate-dependent maximum equation.

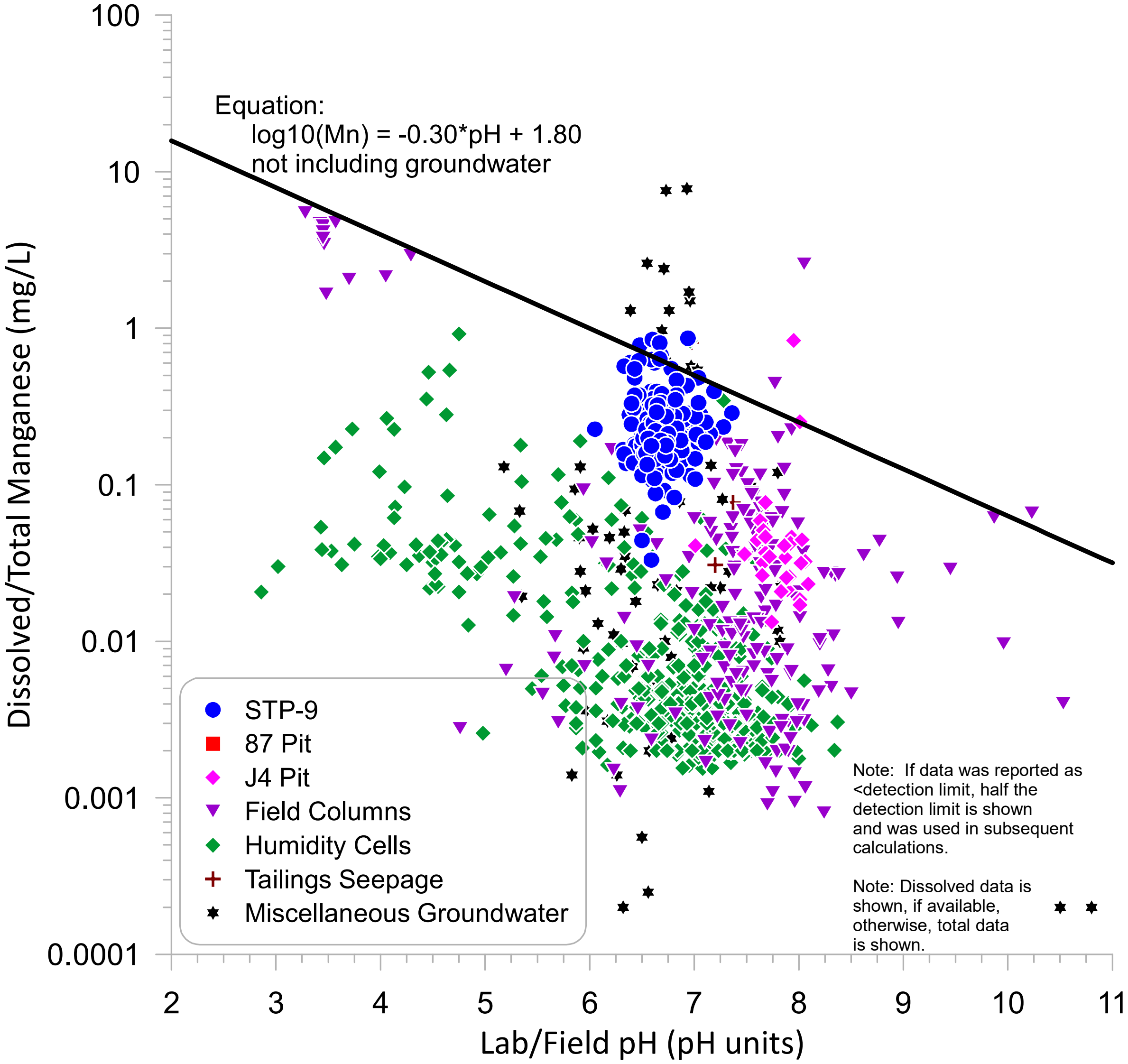

Figure A25. Manganese vs. pH at the Troilus Gold Project, showing the pH-dependent maximum equation.

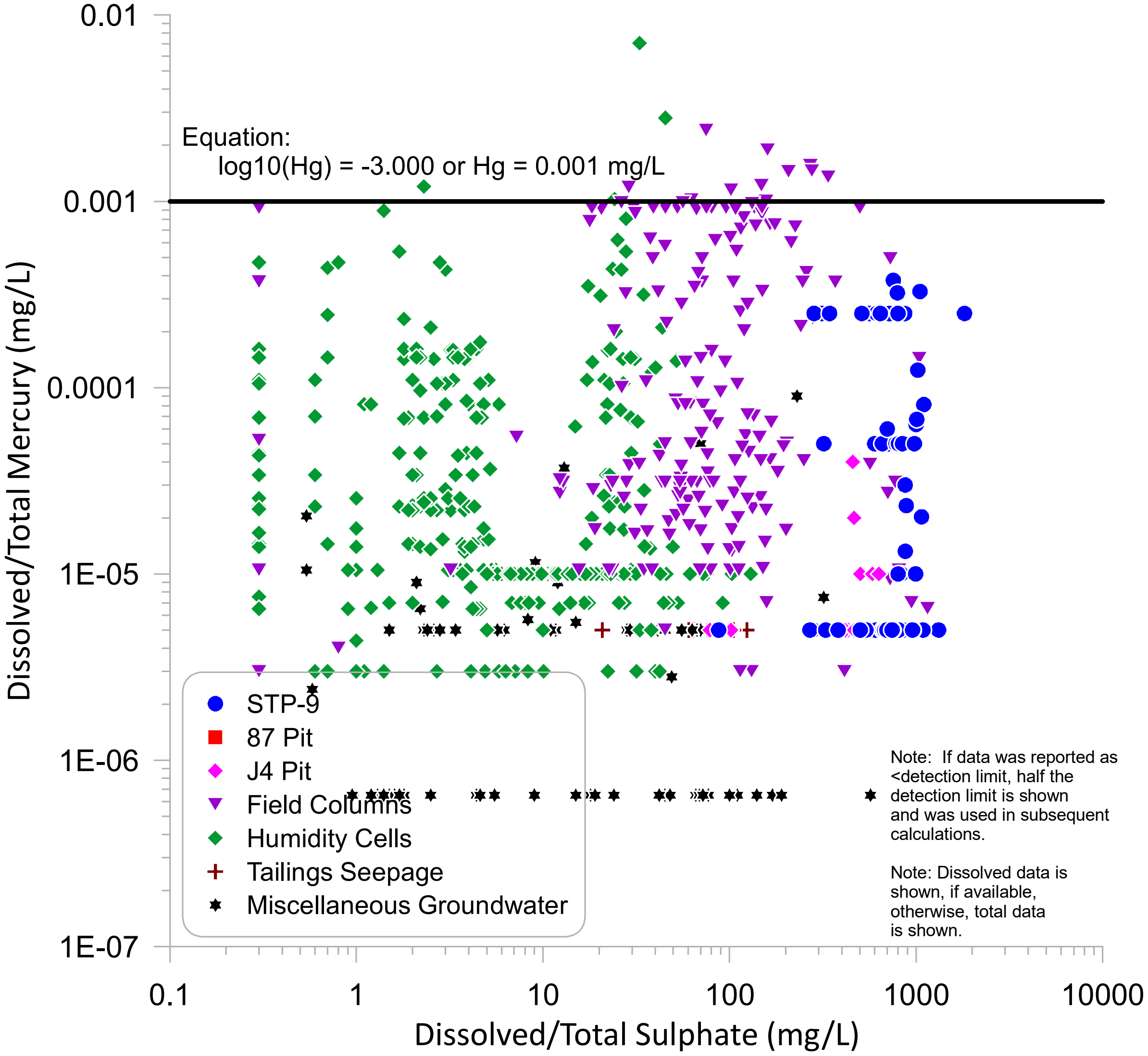

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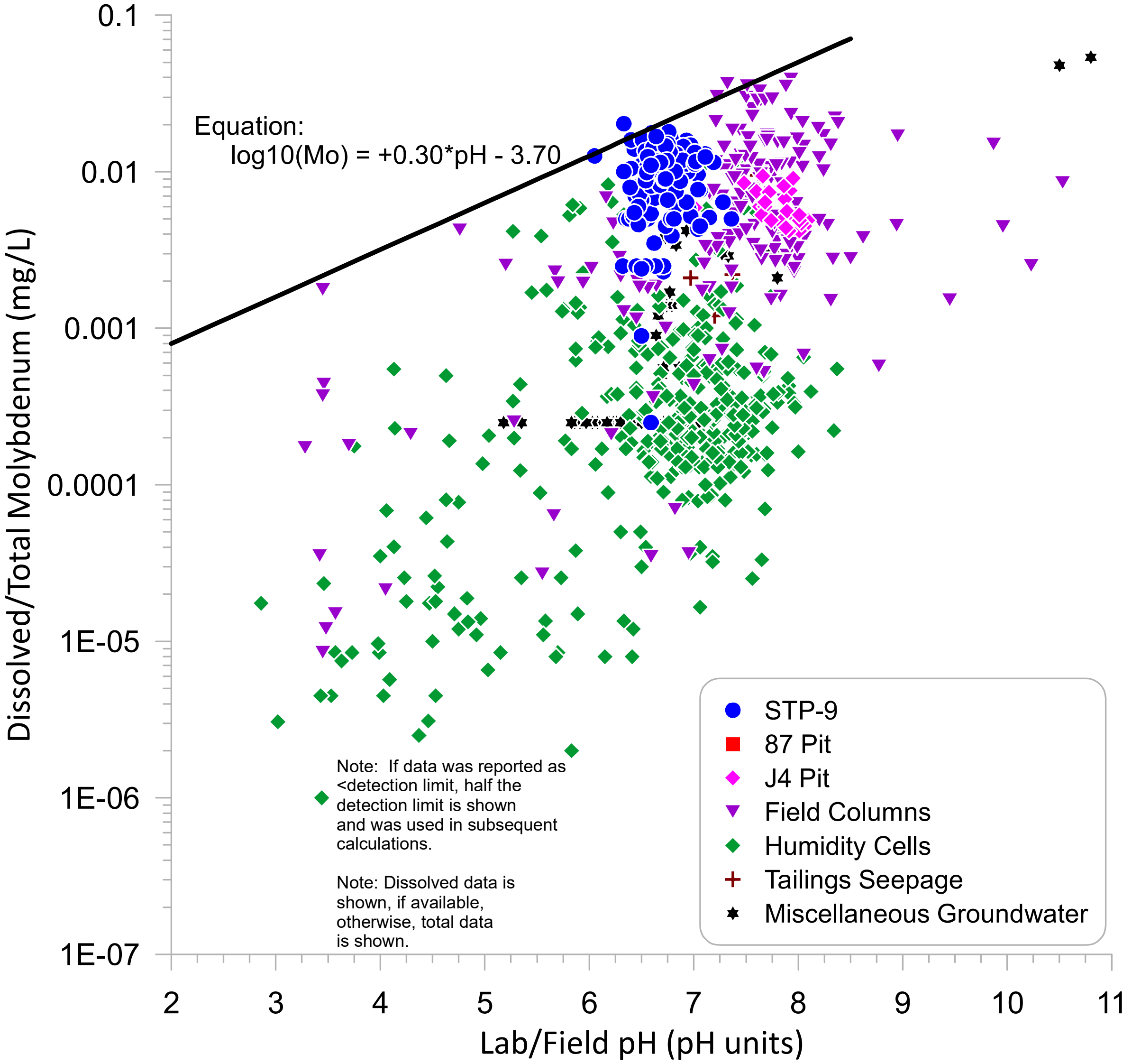
Figure A26. Mercury vs. sulphate at the Troilus Gold Project, showing the sulphate-dependent maximum equation.



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Note: Dissolved data is shown, if available, otherwise, total data is shown.

Figure A27. Molybdenum vs. pH at the Troilus Gold Project, showing the pH-dependent maximum equation.

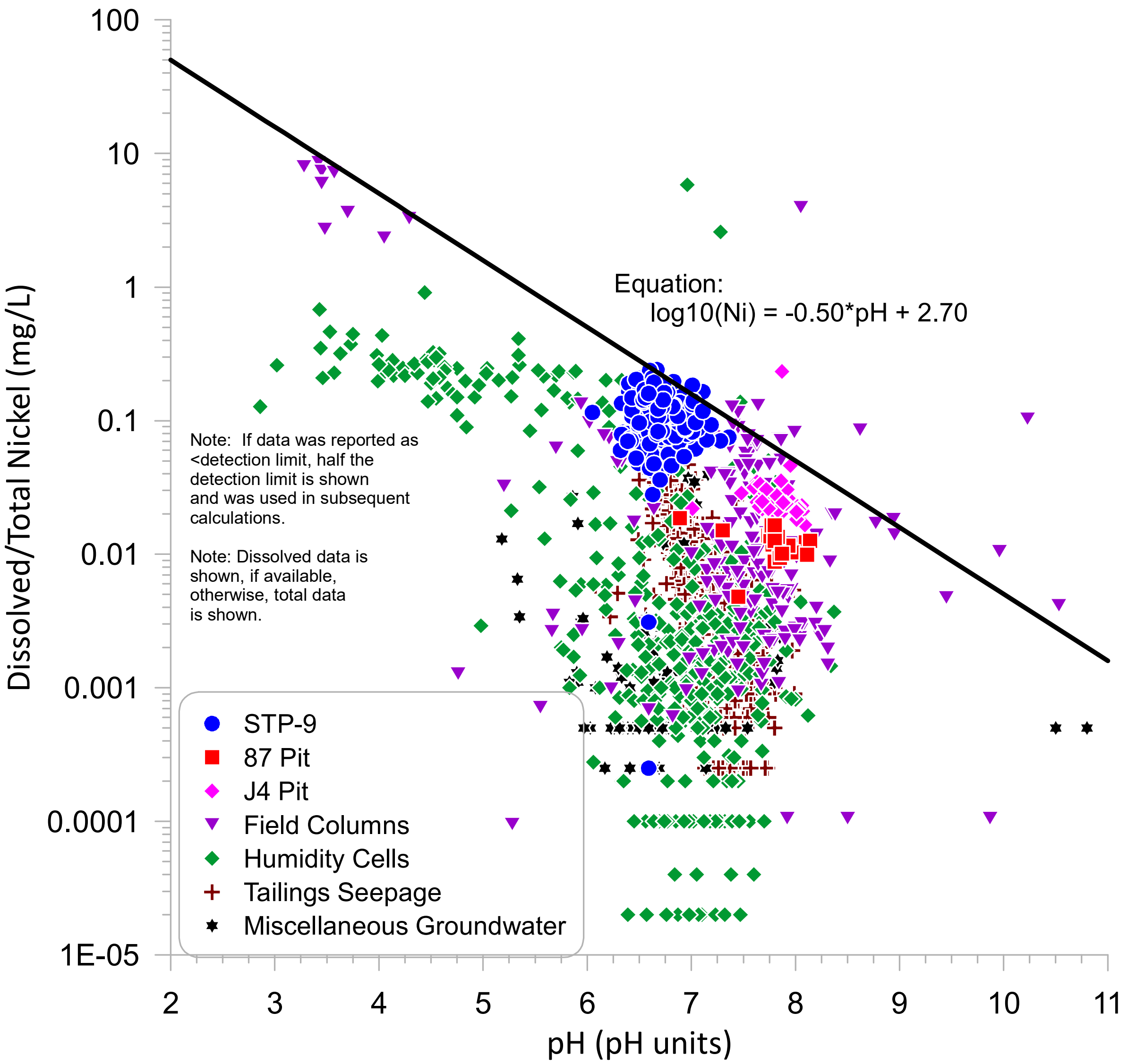


Figure A28. Nickel vs. pH at the Troilus Gold Project, showing the pH-dependent maximum equation.

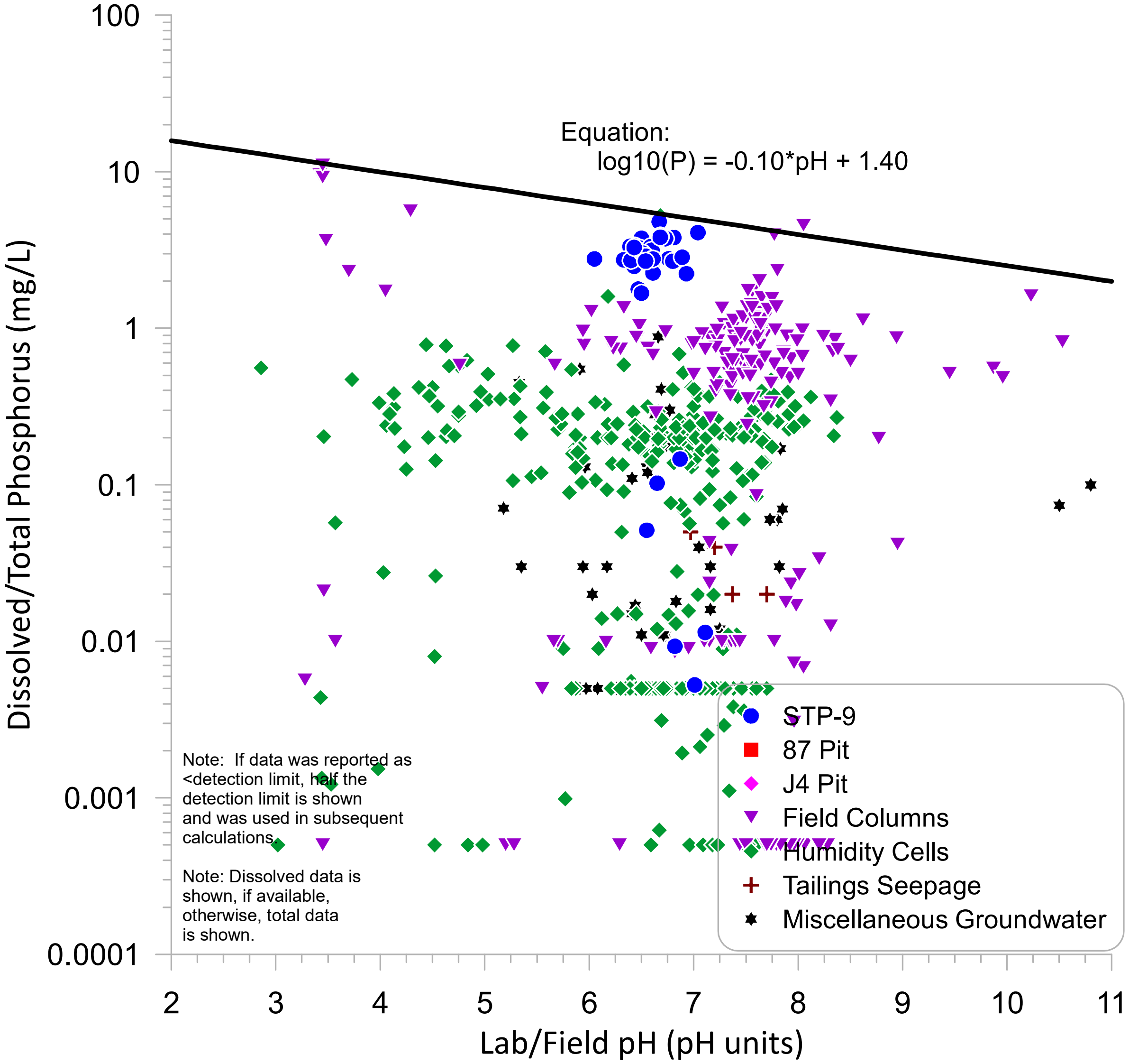


Figure A29. Phosphorus vs. pH at the Troilus Gold Project, showing the pH-dependent maximum equation.

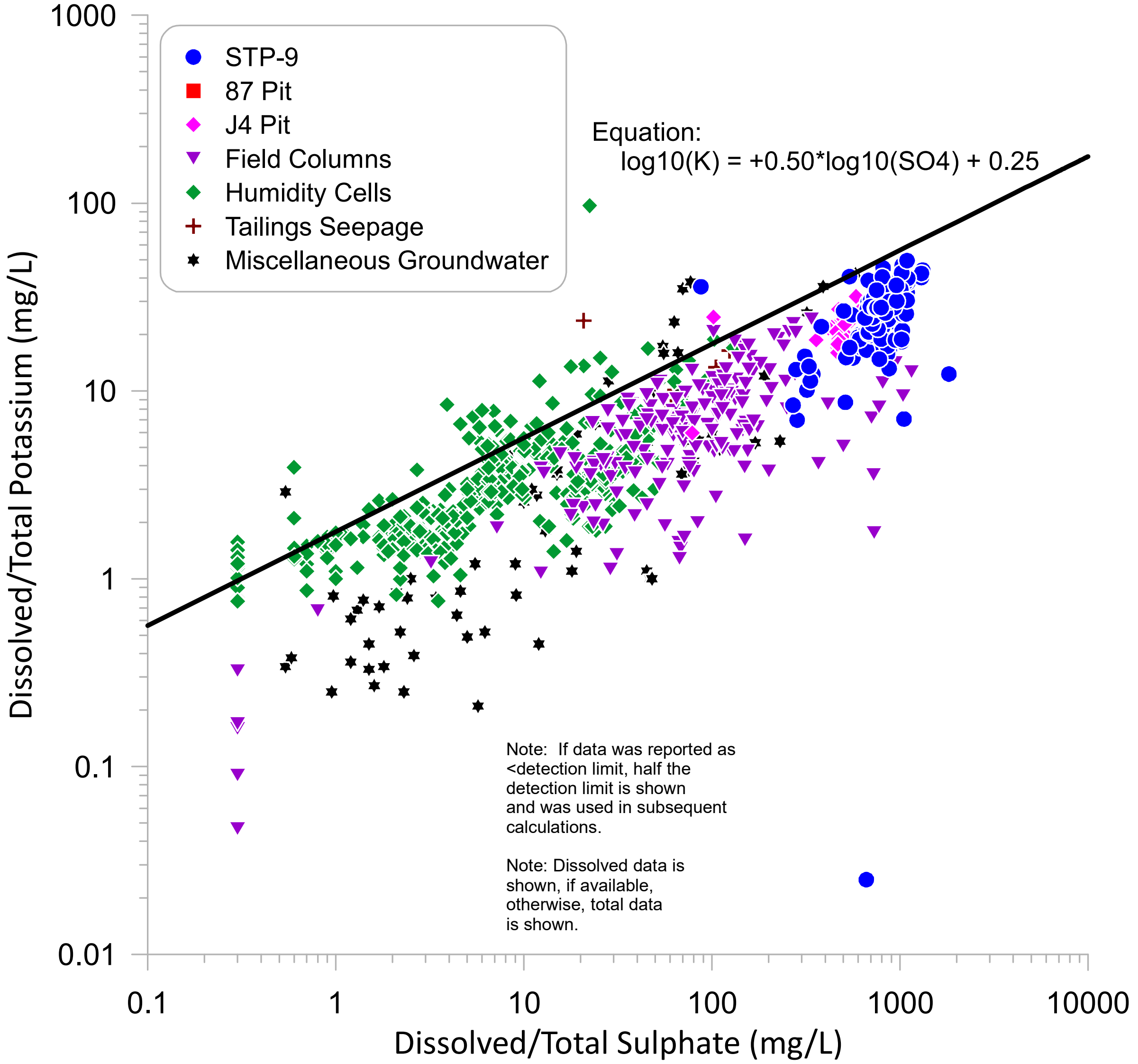
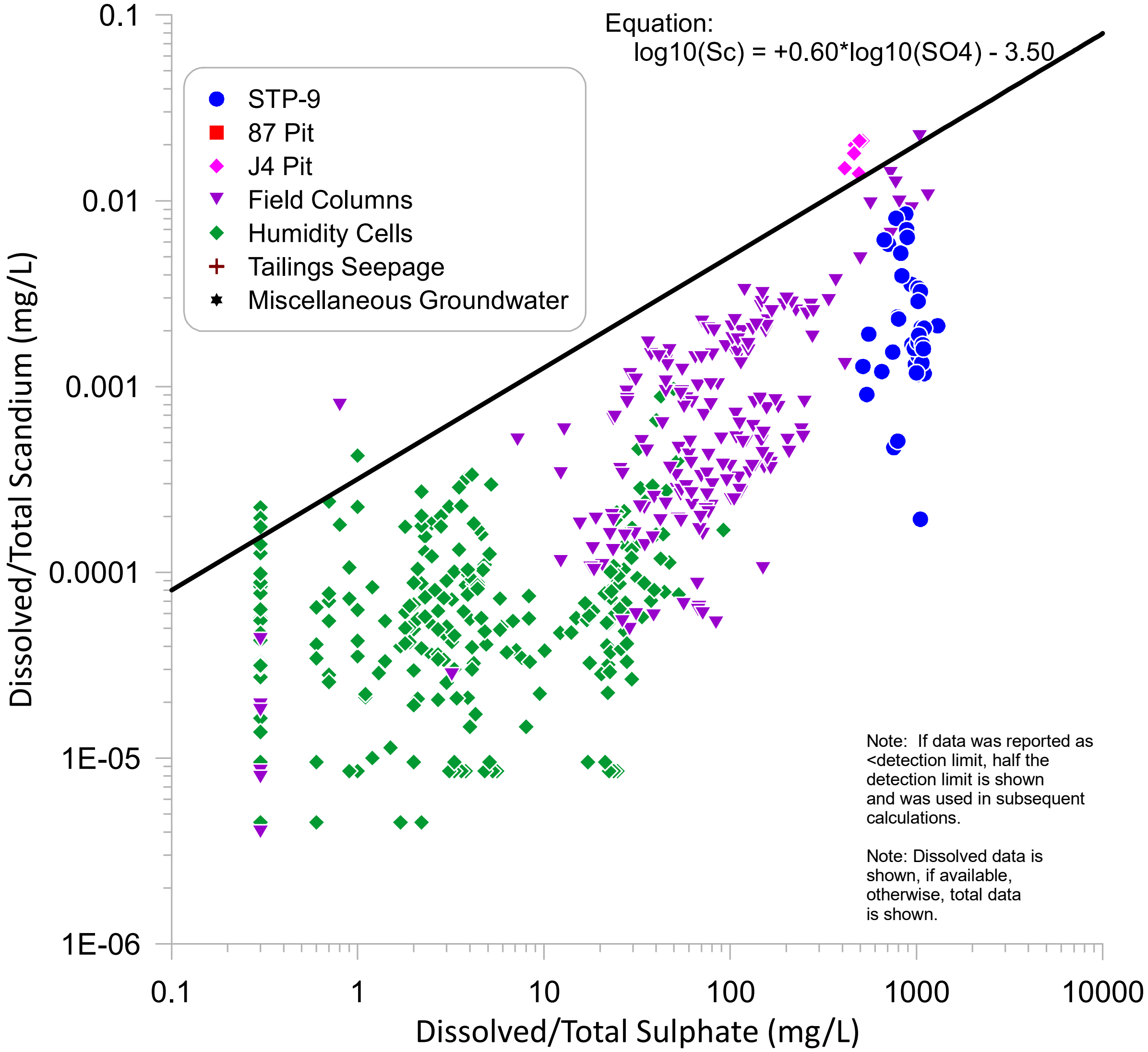


Figure A30. Potassium vs. sulphate at the Troilus Gold Project, showing the sulphate-dependent maximum equation.



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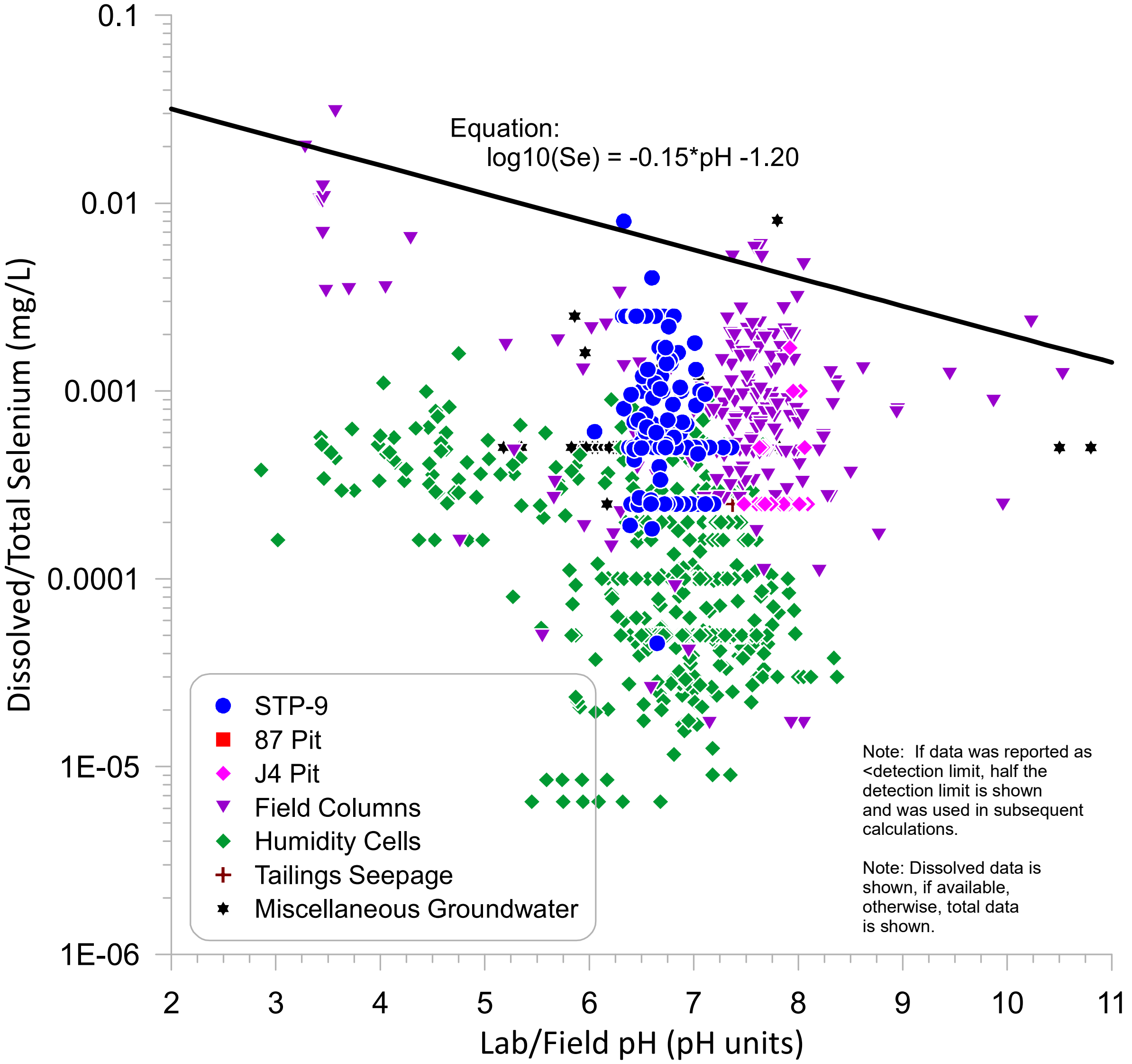
Note: Dissolved data is shown, if available, otherwise, total data is shown.

Figure A31. Scandium vs. sulphate at the Troilus Gold Project, showing the sulphate-dependent maximum equation.



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Note: Dissolved data is shown, if available, otherwise, total data is shown.

Figure A32. Selenium vs. pH at the Troilus Gold Project, showing the pH-dependent maximum equation.

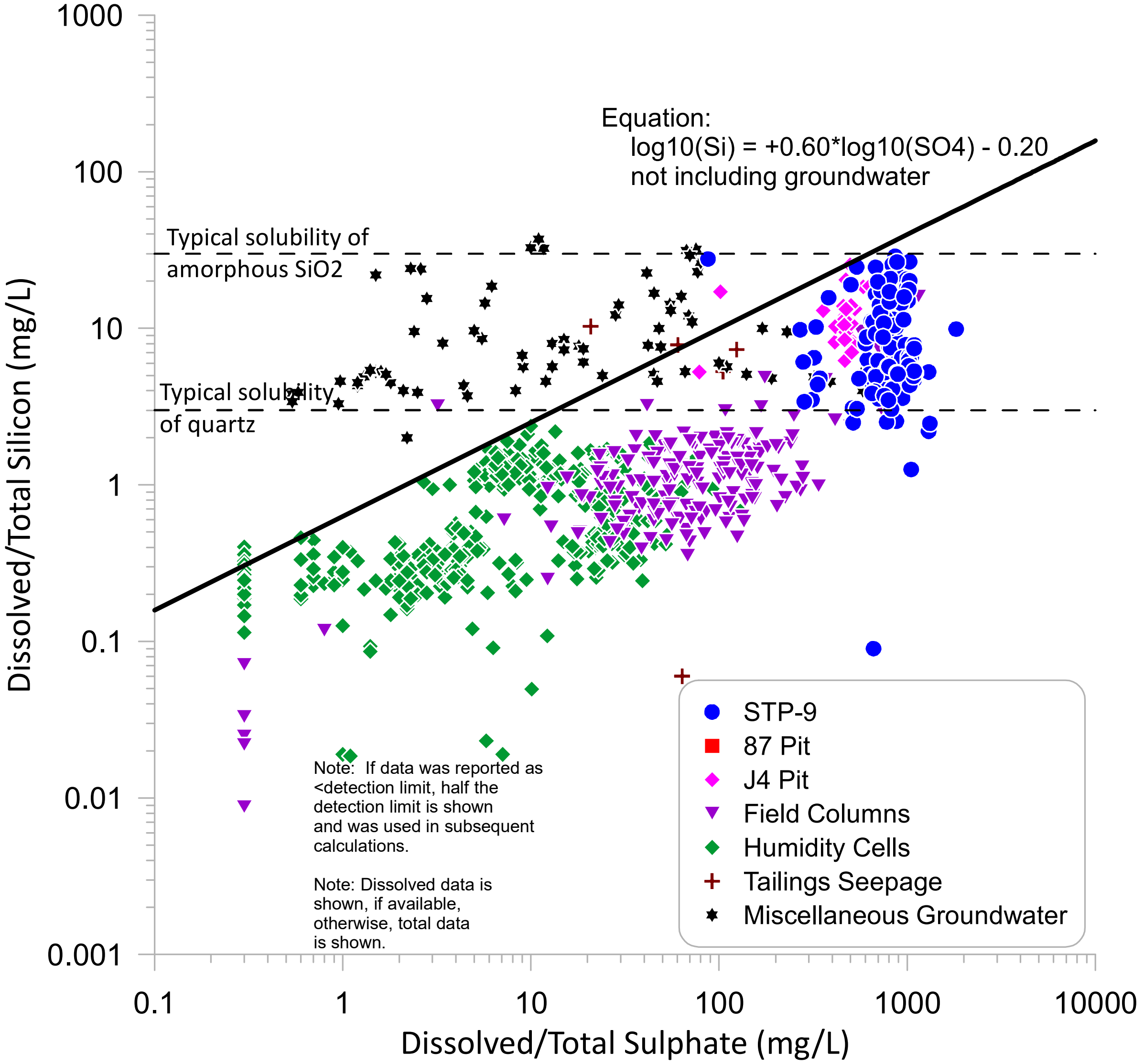
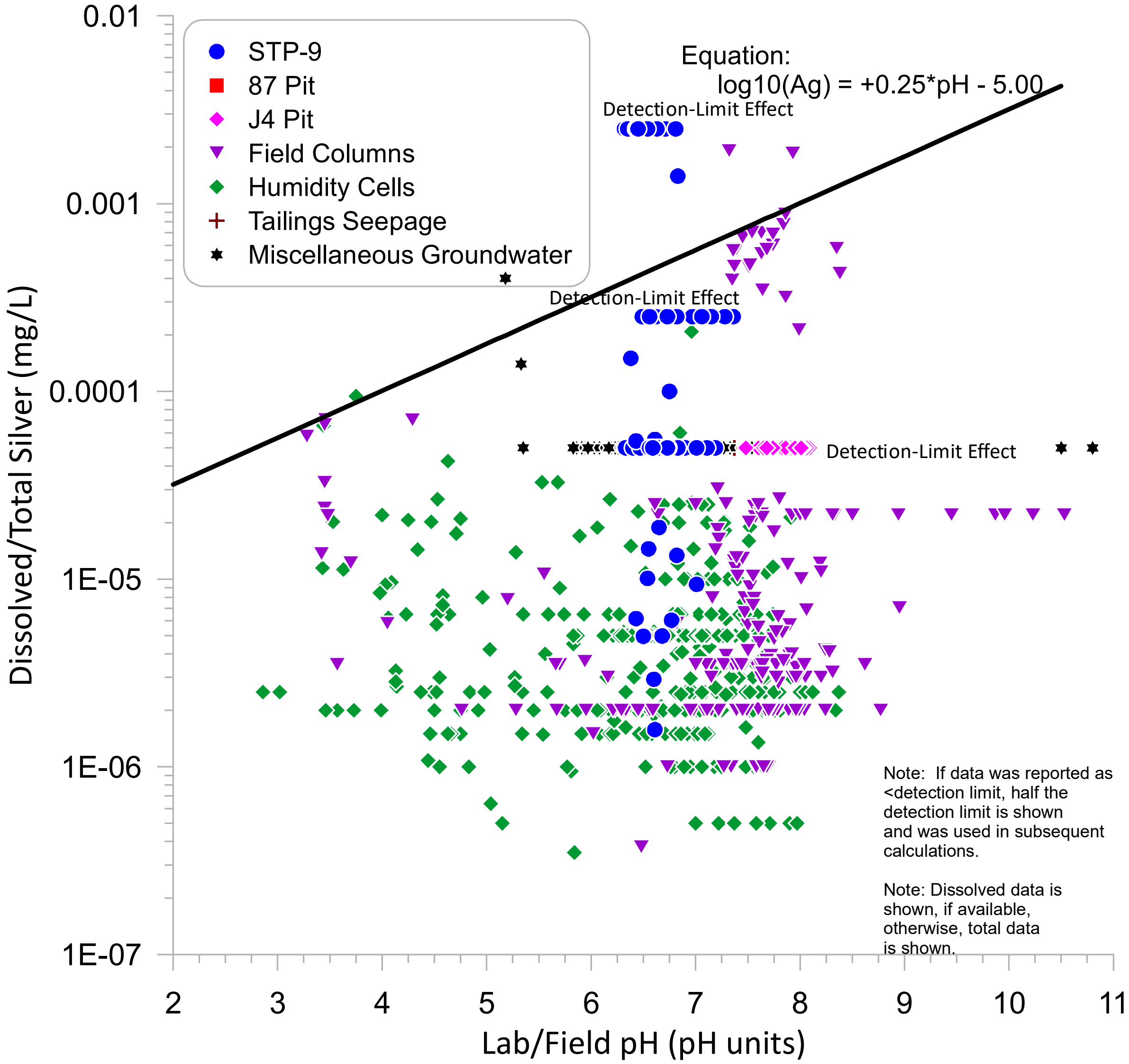


Figure A33. Silicon vs. sulphate at the Troilus Gold Project, showing the sulphate-dependent maximum equation.



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Note: Dissolved data is shown, if available, otherwise, total data is shown.

Figure A34. Silver vs. pH at the Troilus Gold Project, showing the pH-dependent maximum equation.

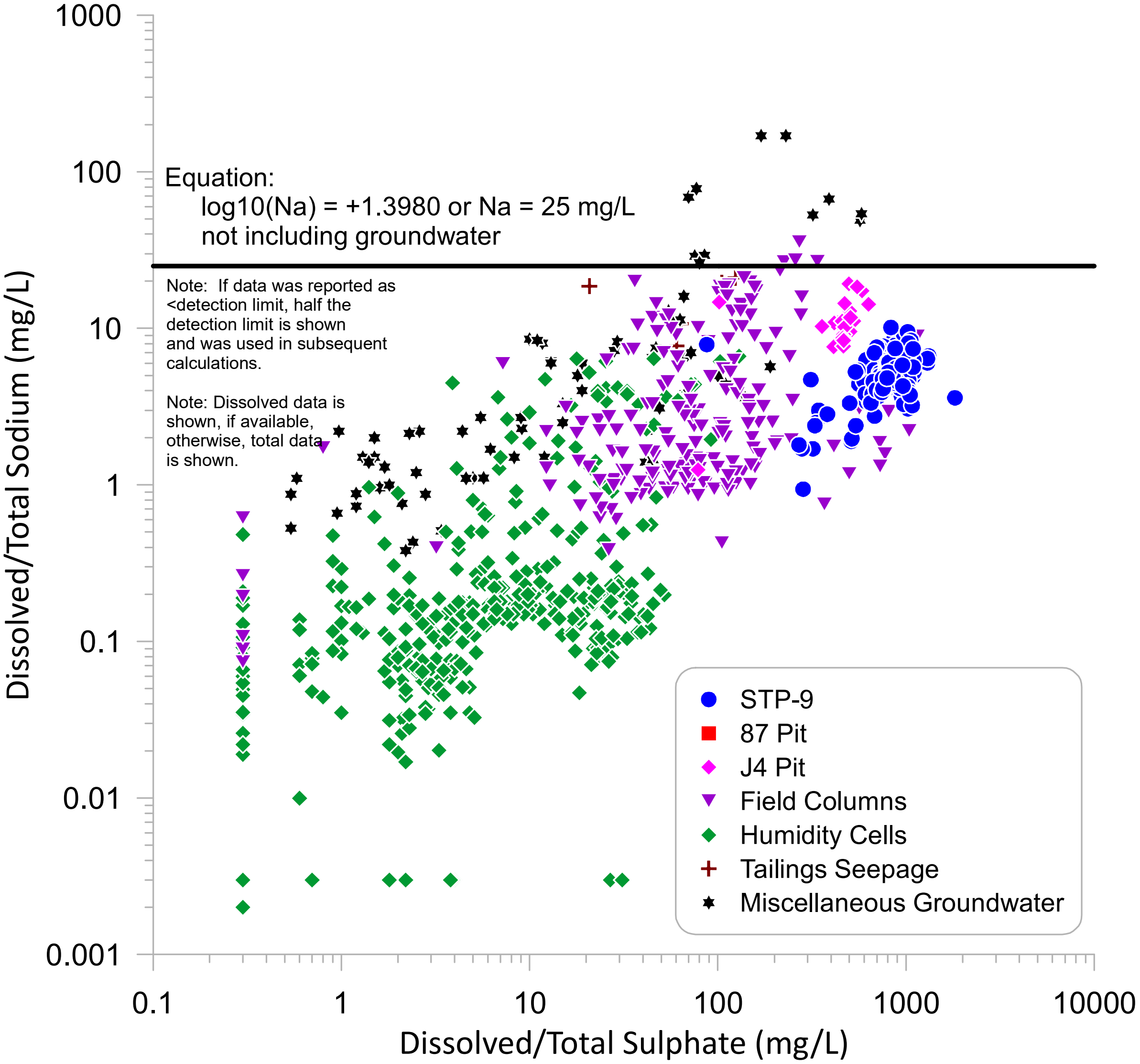


Figure A35. Sodium vs. sulphate at the Troilus Gold Project, showing the sulphate-dependent maximum equation.

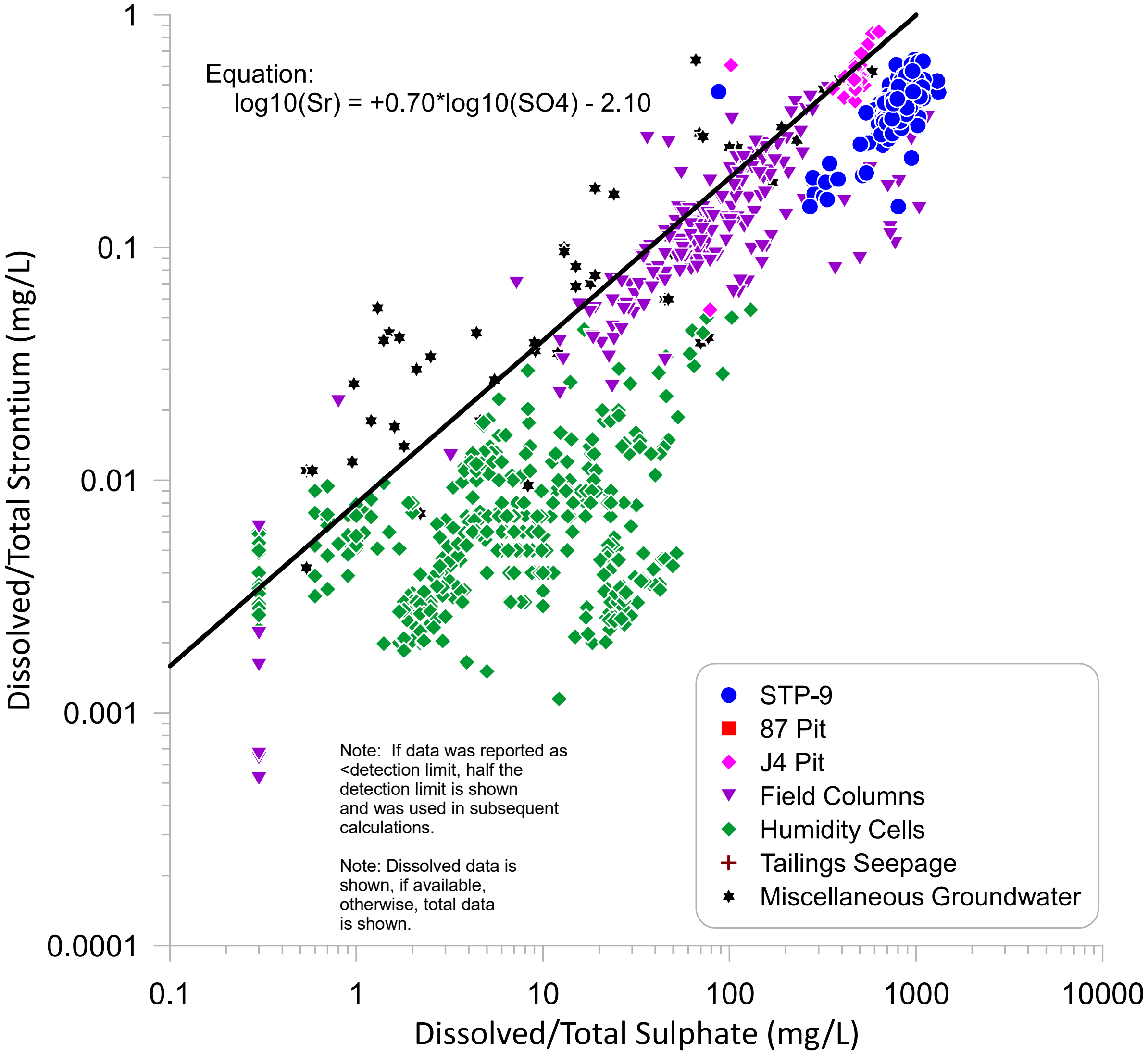
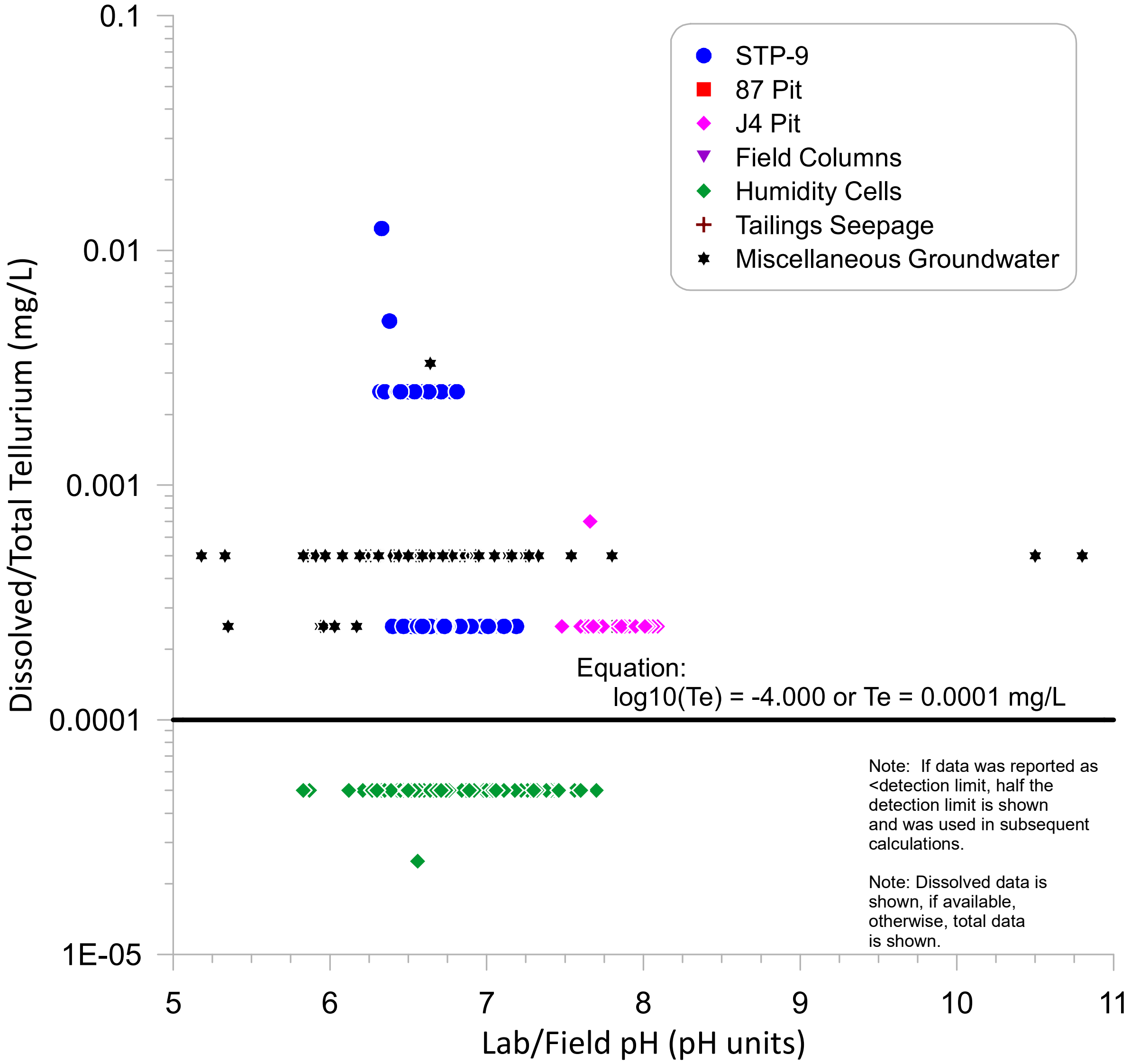


Figure A36. Strontium vs. sulphate at the Troilus Gold Project, showing the sulphate-dependent maximum equation.



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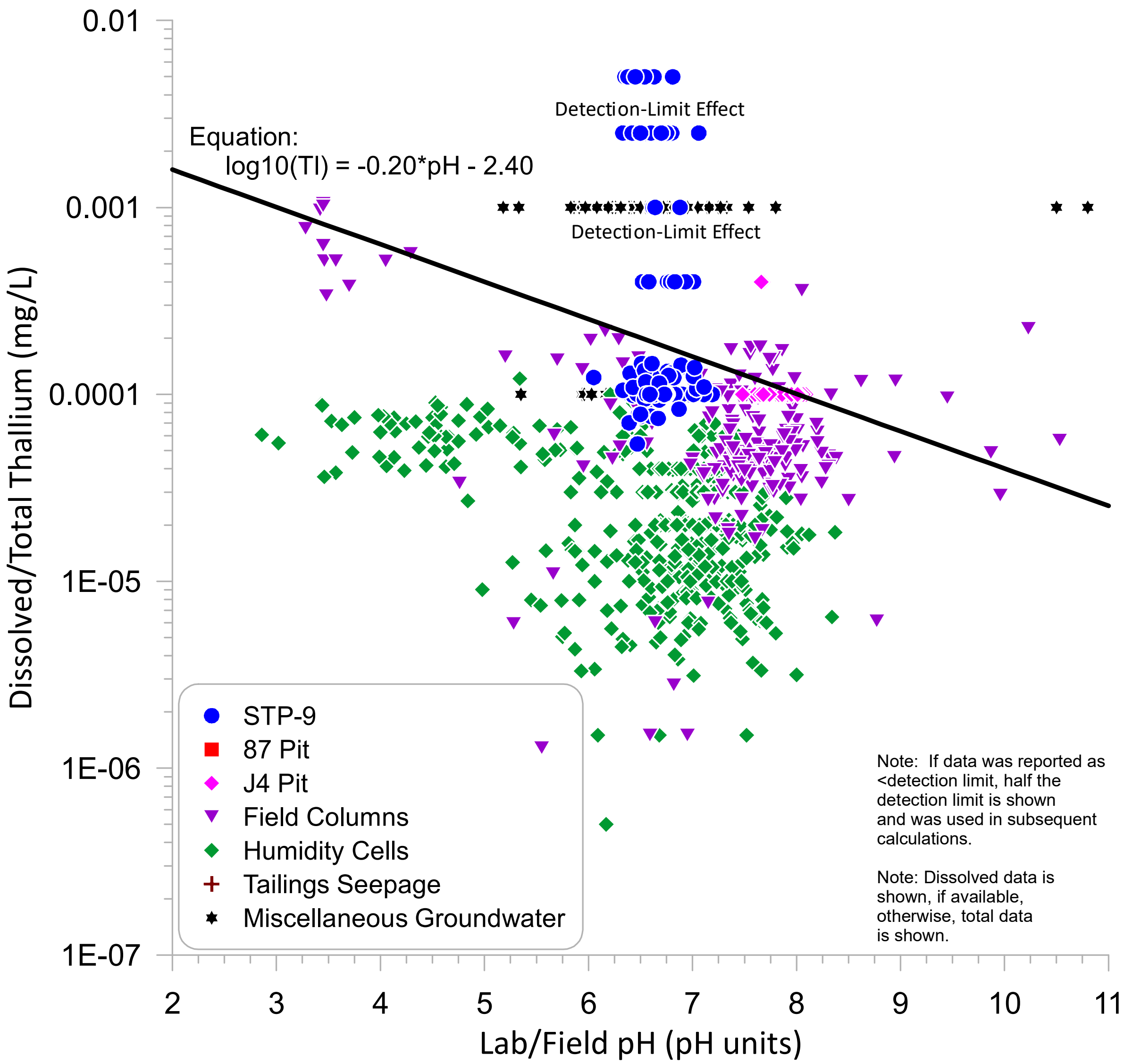
Note: Dissolved data is shown, if available, otherwise, total data is shown.

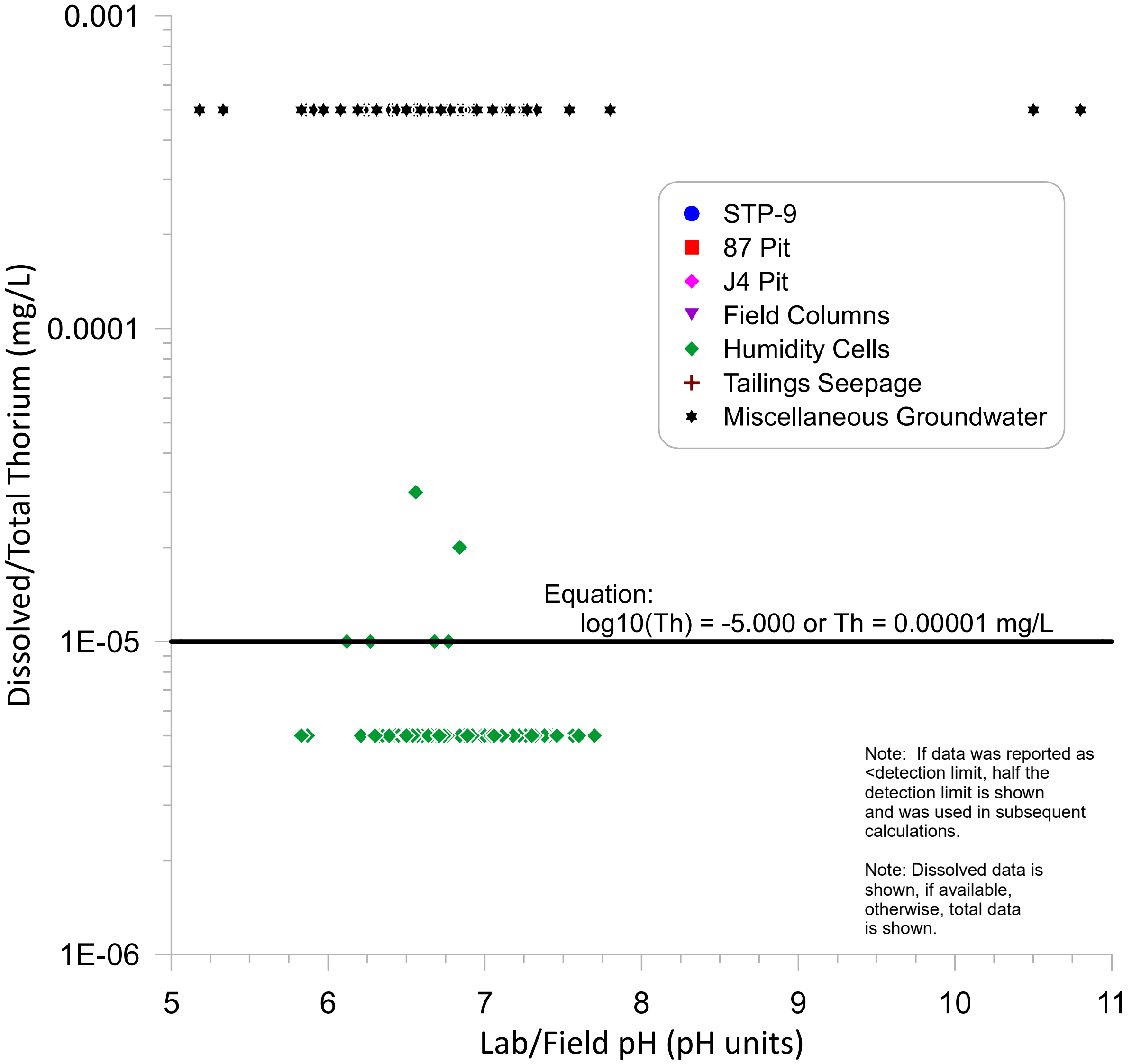
Figure A37. Tellurium vs. pH at the Troilus Gold Project, showing the pH-dependent maximum equation.



Note: If data was reported as <detection limit, half the detection limit is shown and was used in subsequent calculations.

Note: Dissolved data is shown, if available, otherwise, total data is shown.

Figure A38. Thallium vs. pH at the Troilus Gold Project, showing the pH-dependent maximum equation.



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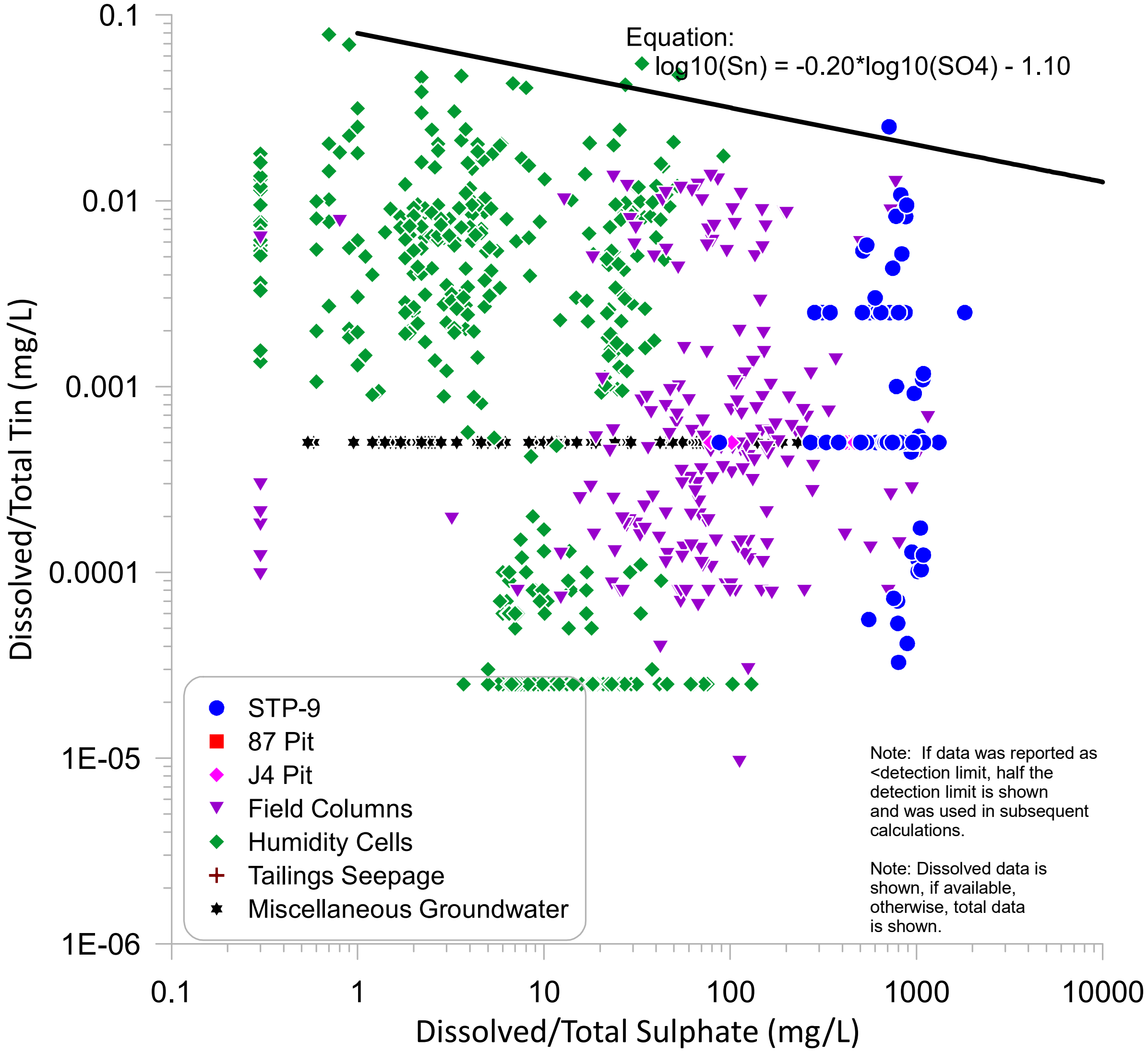
Note: Dissolved data is shown, if available, otherwise, total data is shown.

Figure A39. Thorium vs. pH at the Troilus Gold Project, showing the pH-dependent maximum equation.



Note: If data was reported as <detection limit, half the detection limit is shown and was used in subsequent calculations.

Note: Dissolved data is shown, if available, otherwise, total data is shown.

Figure A40. Tin vs. sulphate at the Troilus Gold Project, showing the sulphate-dependent maximum equation.

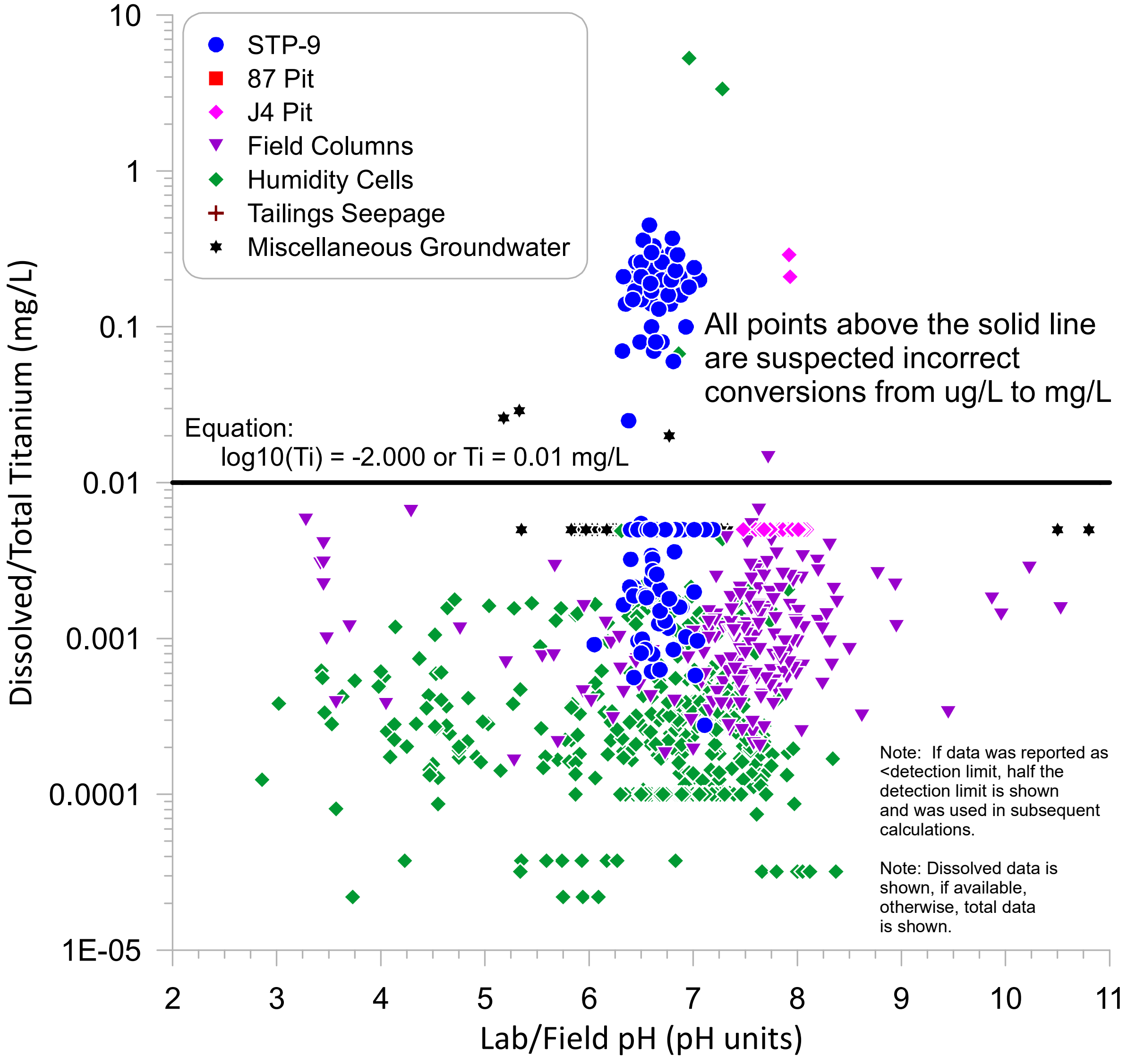


Figure A41. Titanium vs. pH at the Troilus Gold Project, showing the pH-dependent maximum equation.

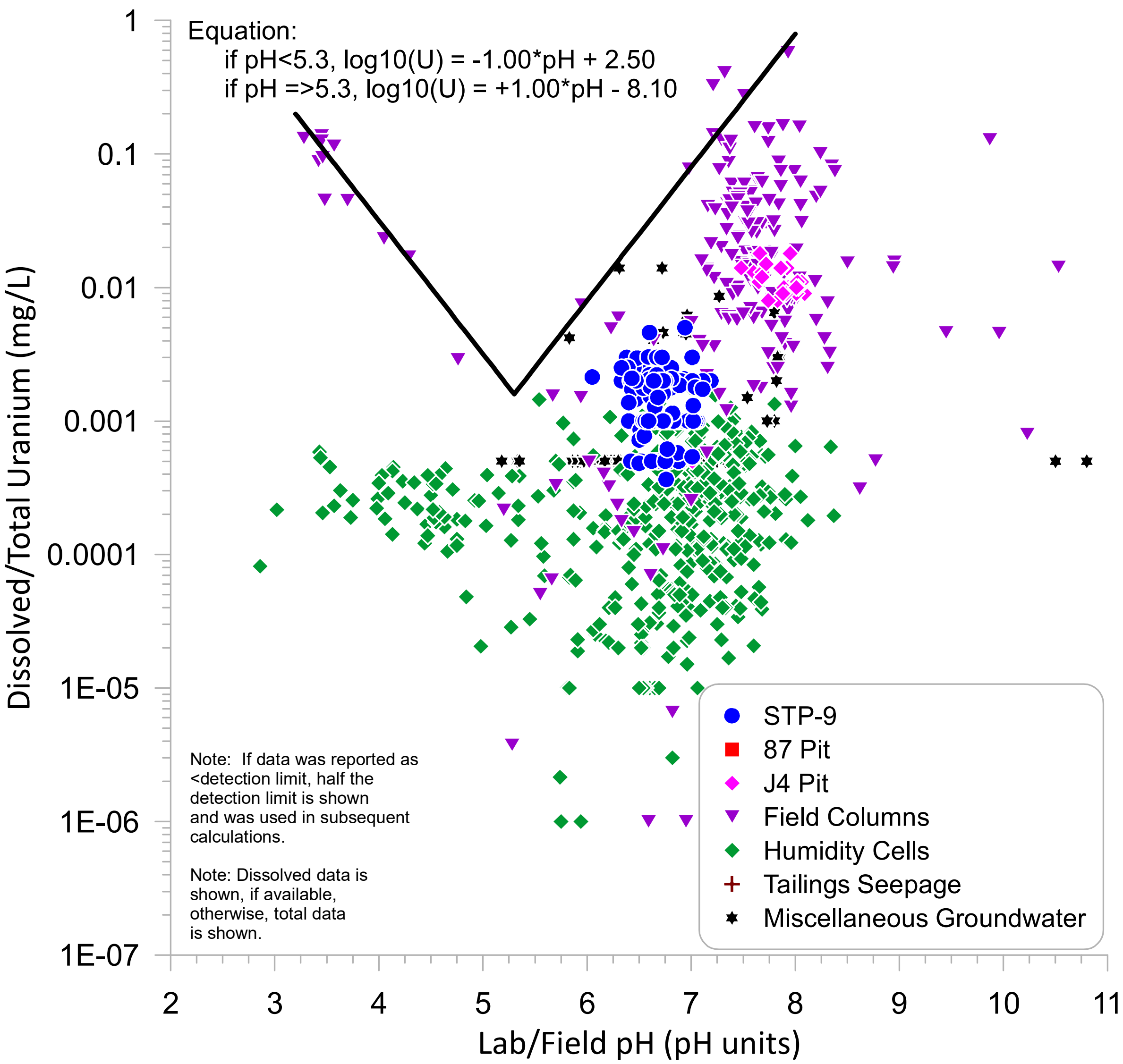
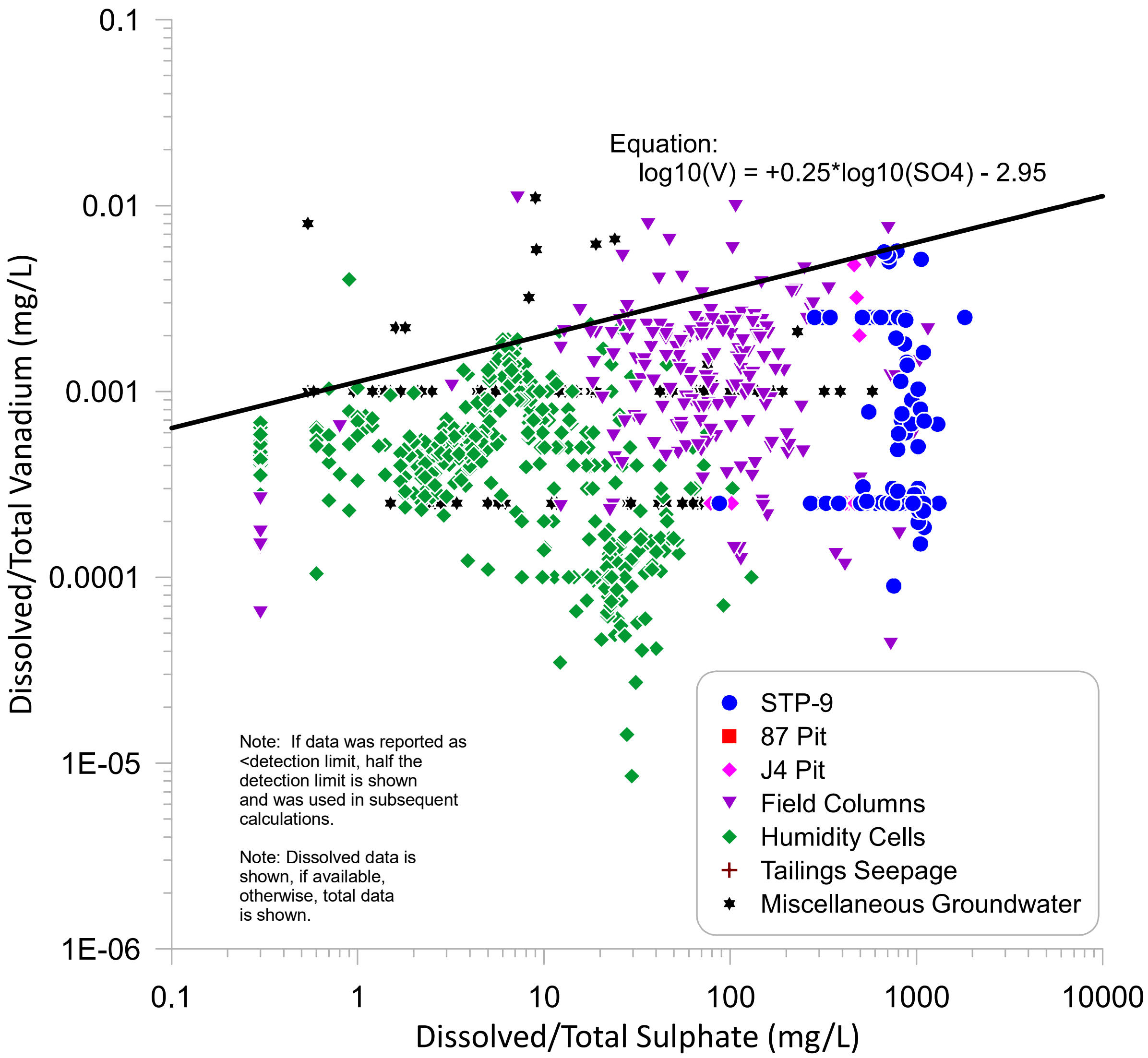


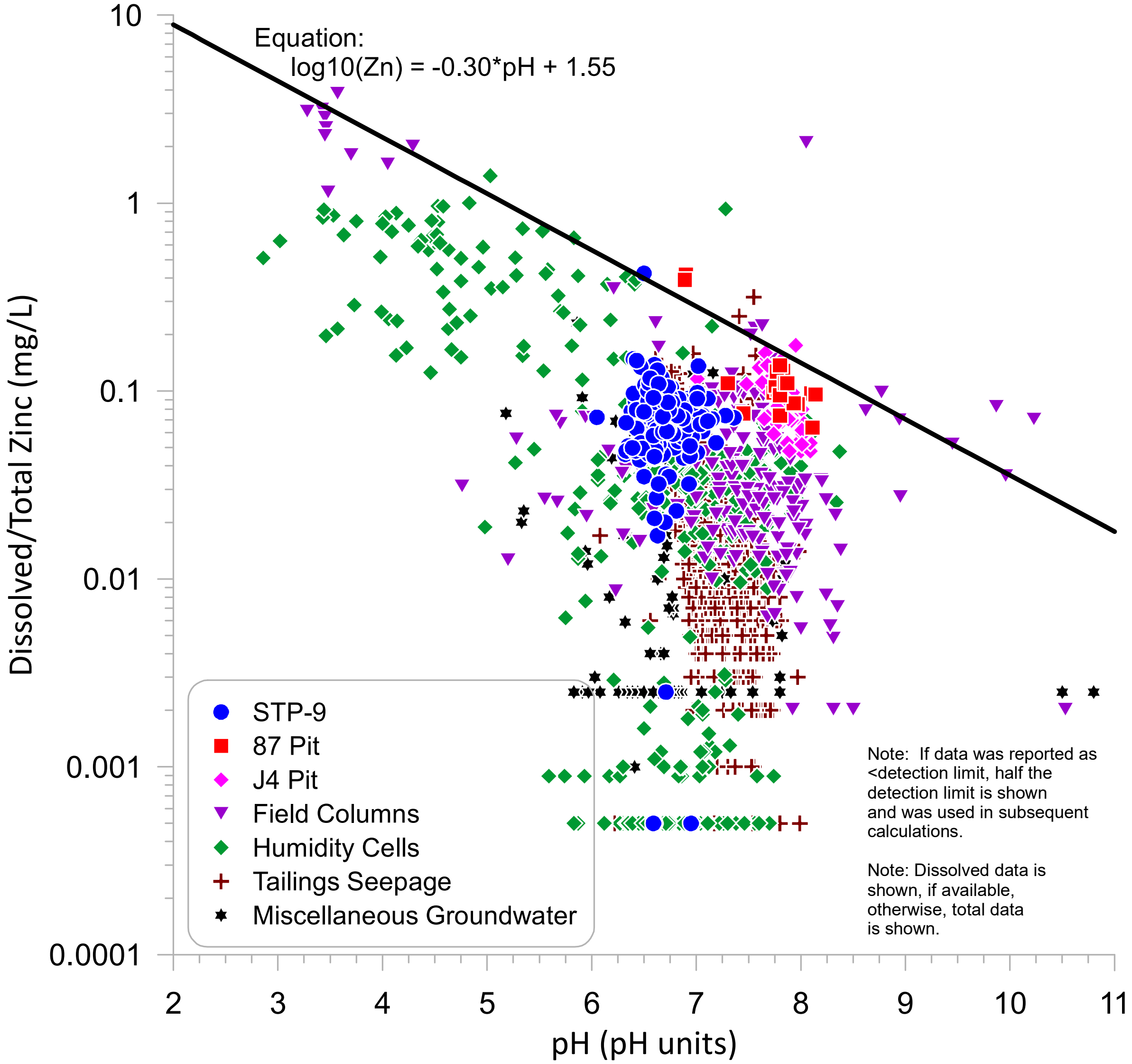
Figure A42. Uranium vs. pH at the Troilus Gold Project, showing the pH-dependent maximum equation.



Note: If data was reported as <detection limit, half the detection limit is shown and was used in subsequent calculations.

Note: Dissolved data is shown, if available, otherwise, total data is shown.

Figure A43. Vanadium vs. sulphate at the Troilus Gold Project, showing the sulphate-dependent maximum equation.



Note: If data was reported as <detection limit, half the detection limit is shown and was used in subsequent calculations.

Note: Dissolved data is shown, if available, otherwise, total data is shown.

Figure A44. Zinc vs. pH at the Troilus Gold Project, showing the pH-dependent maximum equation.