Approach for Estimating a Probable Range of Pit Lake Concentrations for Mine Pits with Sulfide Wall Rock

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Outline

- What is a probabilistic model?
- Benefits using a probabilistic approach
- Methods
- Example presentation of results
- Limitations and ongoing challenges
- Summary

Limitations of Modeling

"All models are wrong, but some are useful"

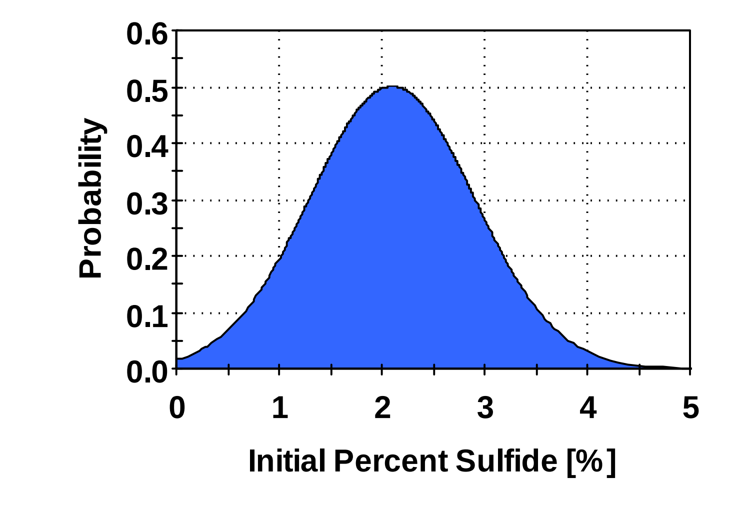
- George E.P. Box, statistician

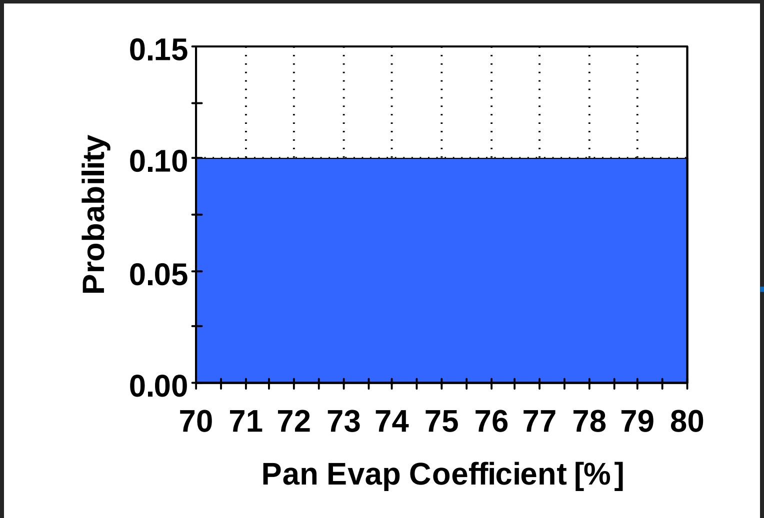
- Scaling of lab data (temp, grain size, accelerated weathering)
- Thermodynamic database: assume constants are correct and that our system is in equilibrium
- Assume complete mixing of ponds
- Complex mechanisms (cyanide attenuation, sorption) are simplified. Some are not modeled (coprecipitation)

- We can model uncertainty using Monte Carlo methods (represent inputs as range of values to get range of outcomes)
- We can avoid scaling issues by using field testing results as much as possible

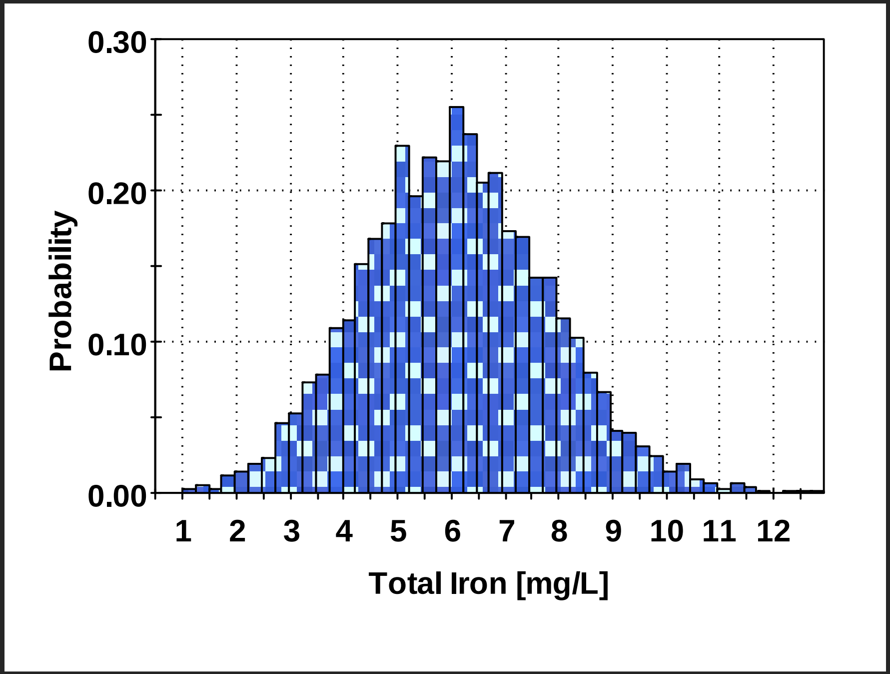
What is a probabilistic model?

INPUTS





OUTPUTS



Benefits of Probabilistic Models

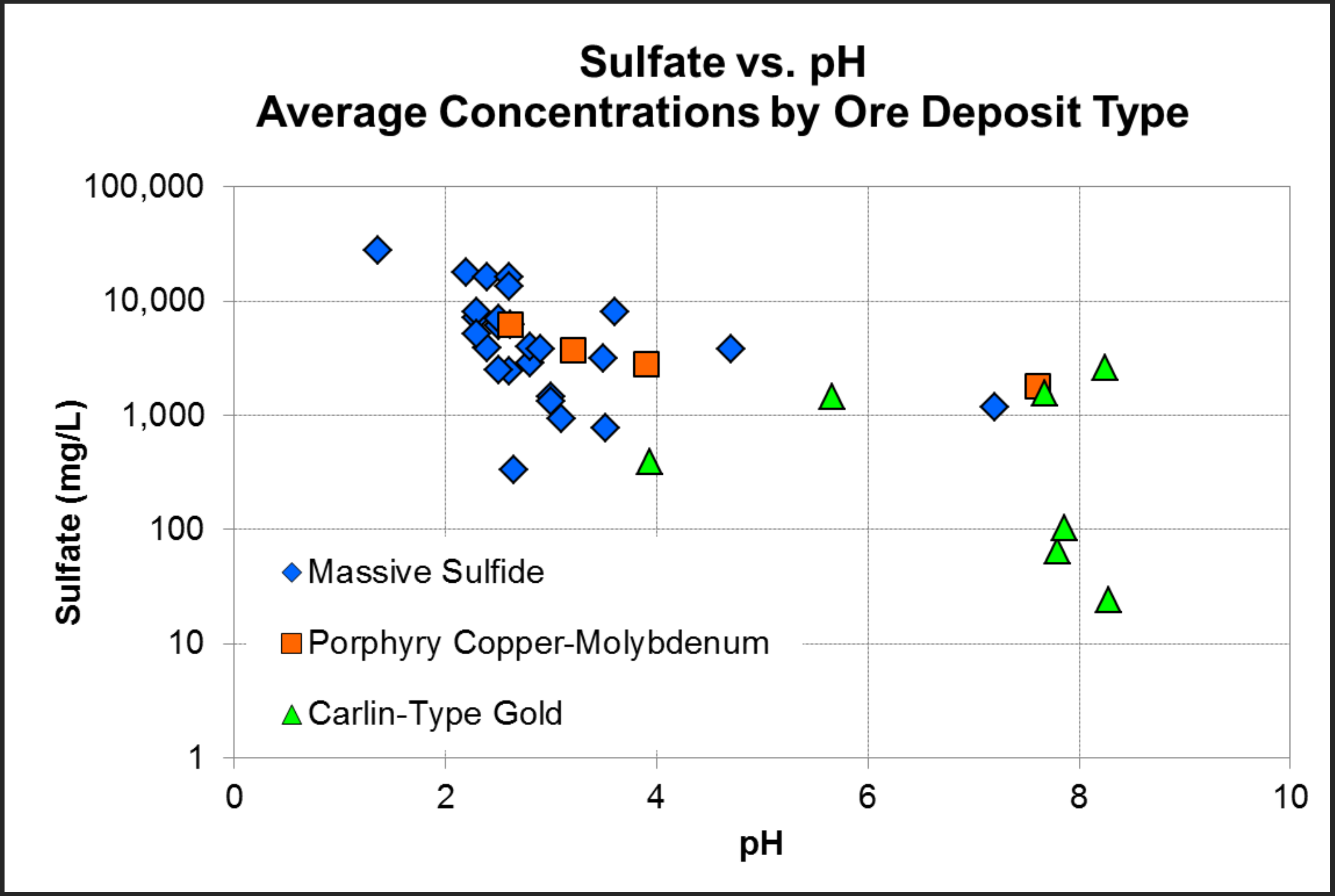
- Probabilistic models may reduce comments on EISs by allowing parties to "agree to disagree"
- Why is this important?
  - Rosemont (AZ): **>43,000 comments;**
  - NorthMet (MN): **>50,000 comments;**
  - Average EIS contractor cost for the DOE in 2013: **$2.9 million***
  - Federal Agencies are moving towards requiring EIS's for changes to existing projects

*U.S. Government Accountability Office, National Environmental Policy Act: Little Information Exists on NEPA Analyses, April 2014

Benefits of Probabilistic Models

- Increases understanding of project risks
  - Helps with: closure cost estimates, alternatives analyses, etc.
- Worst-case scenario isn't always obvious for complex, dynamic systems

Benefits of Probabilistic Models



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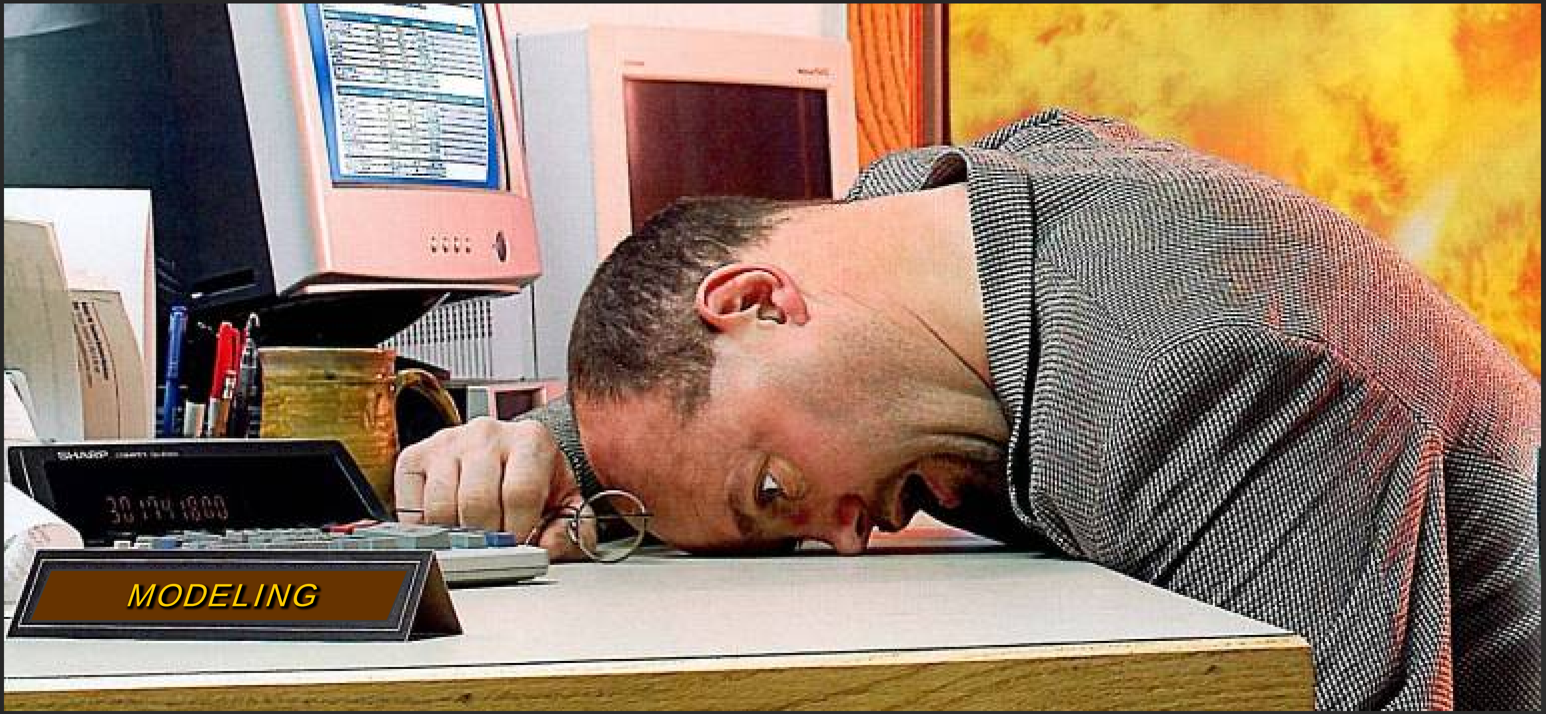
Data from INAP Pit Lake Database

Modeling Methods



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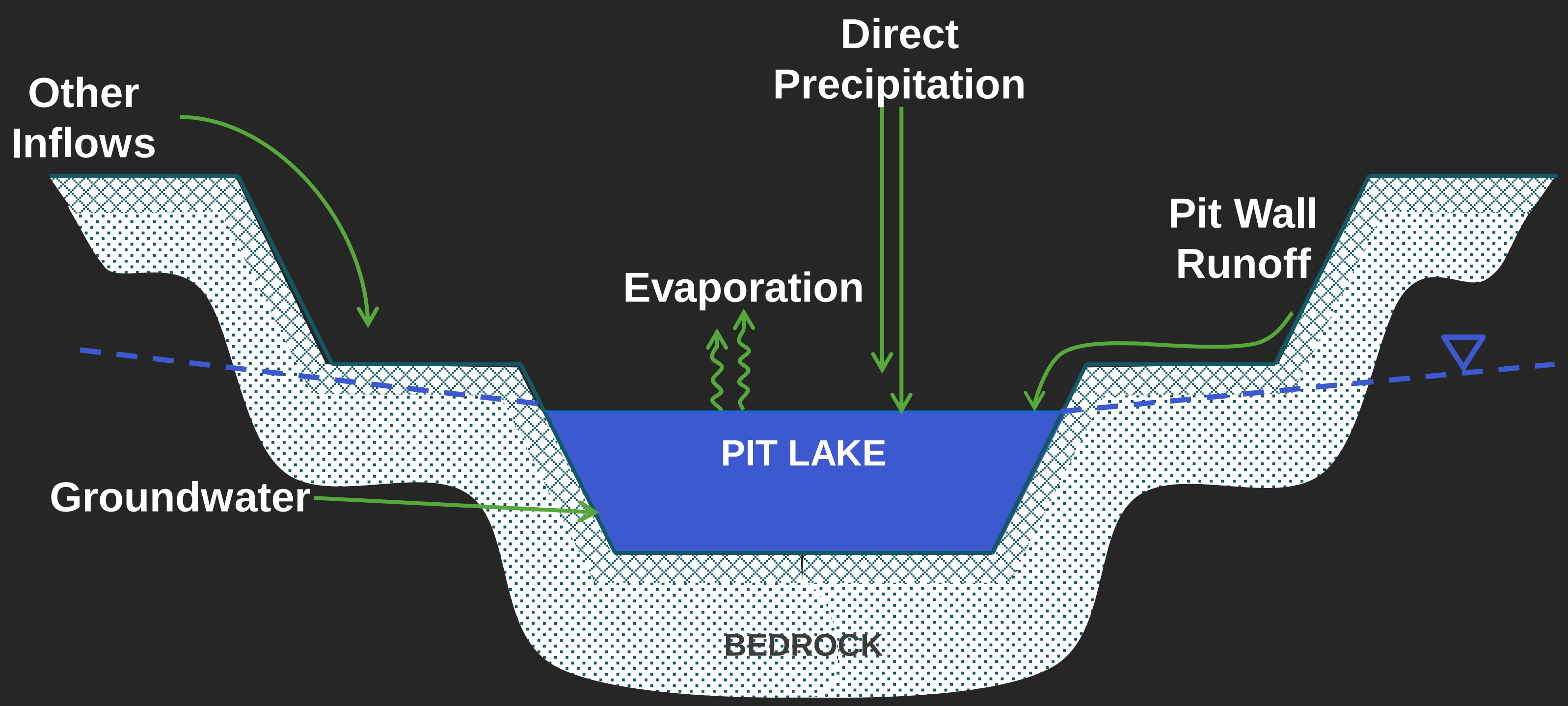
Conceptual Water Balance



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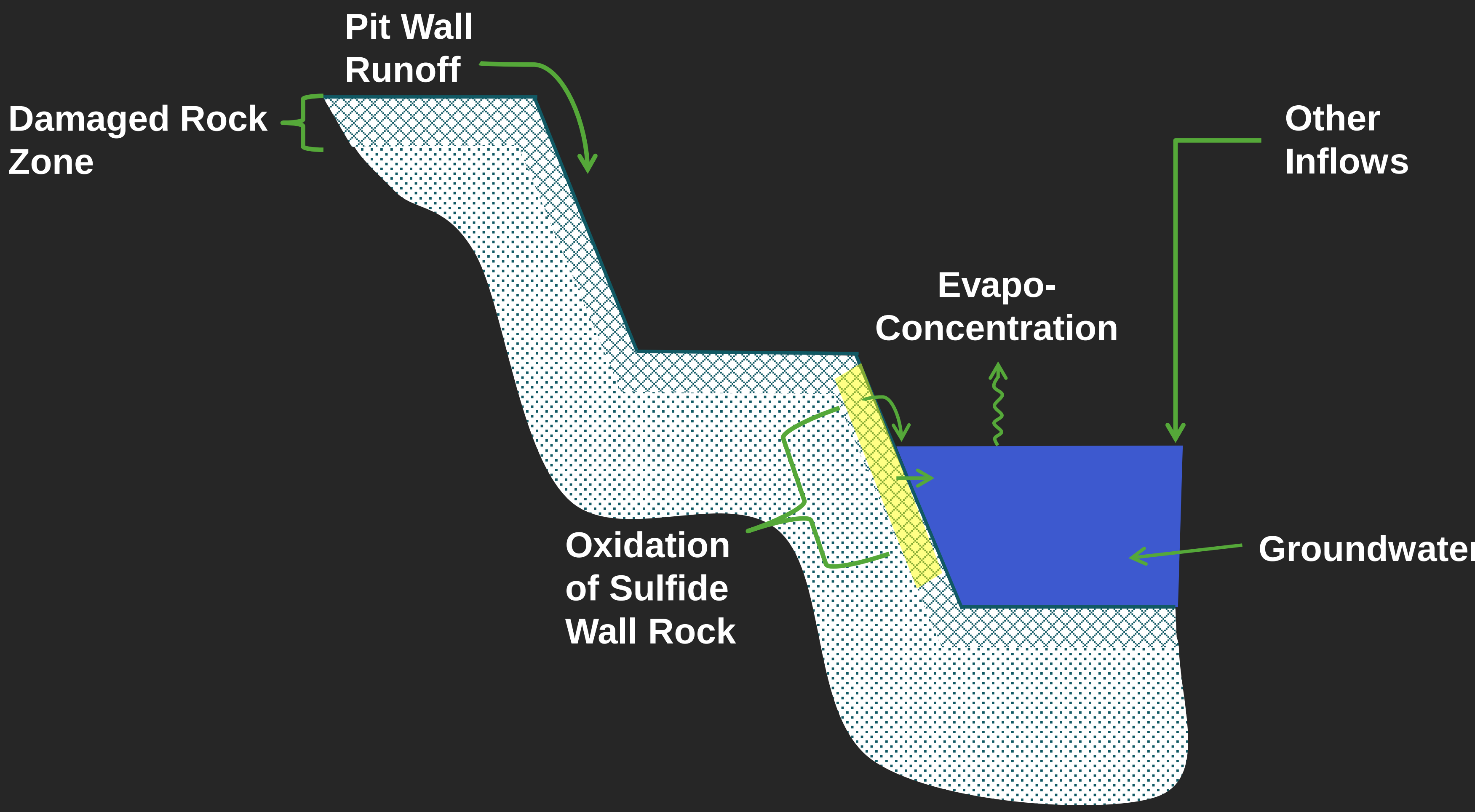
Conceptual Solute Balance



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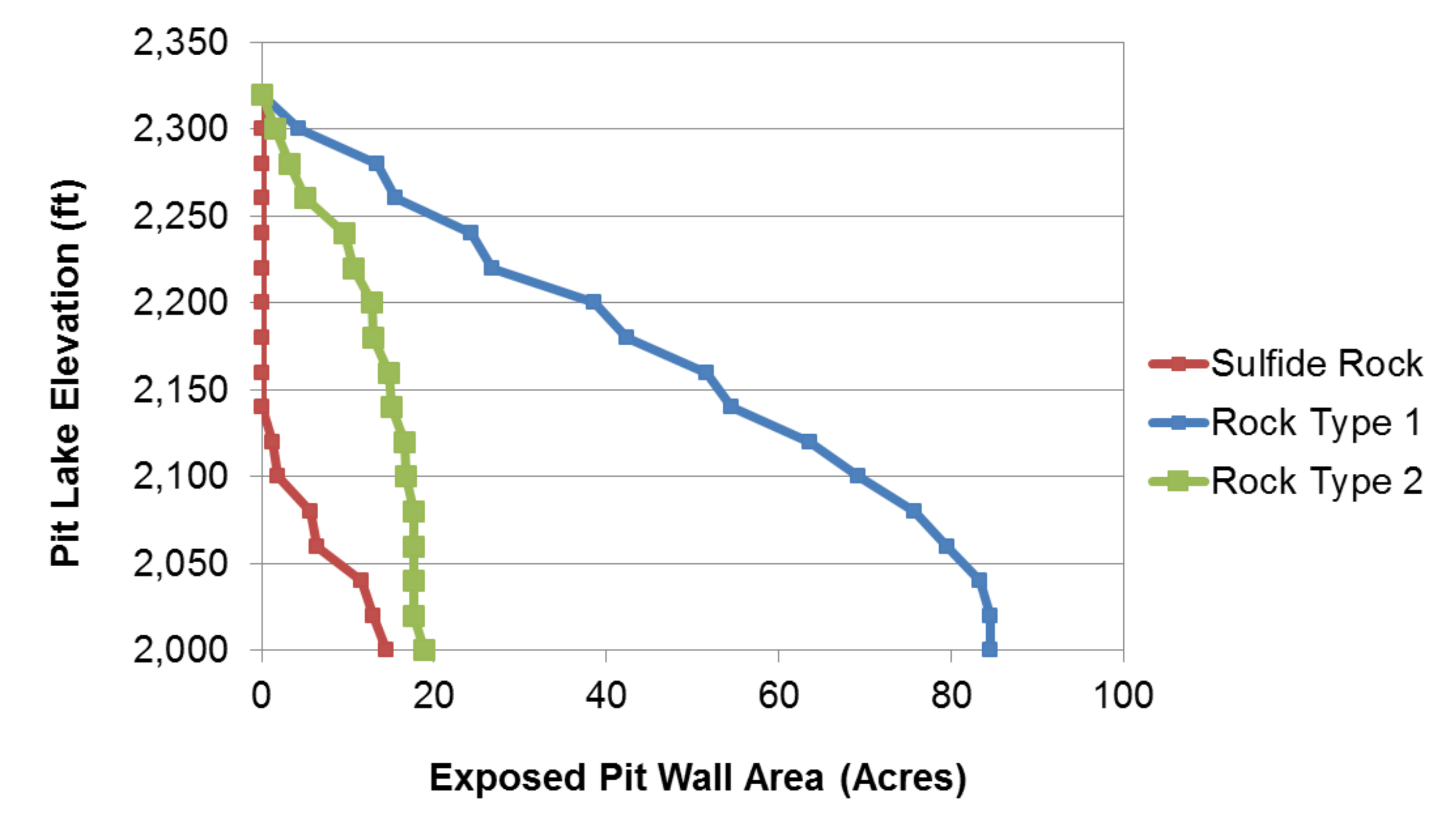
Pit Wall Runoff

$$Pit\ Wall\ Runoff =$$
$$Concentration * Flow\ Rate + Solutes\ Released\ from\ Sulfide\ Oxidation$$



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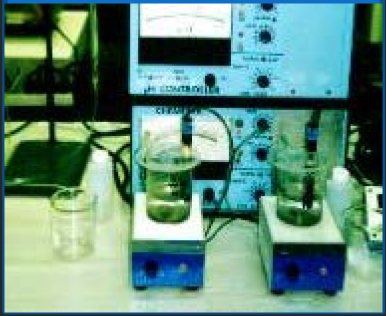
Available Data

- Data available for modeling depends on the phase of the project.

Better Modeling Data →

Static Tests
- ABA
- Whole rock
- Leach Tests (MWMP, SPLP)
- NAG



Kinetic Tests
- Humidity cells

Field Tests
- Field barrels
- Test plots

Field Data
- Site samples

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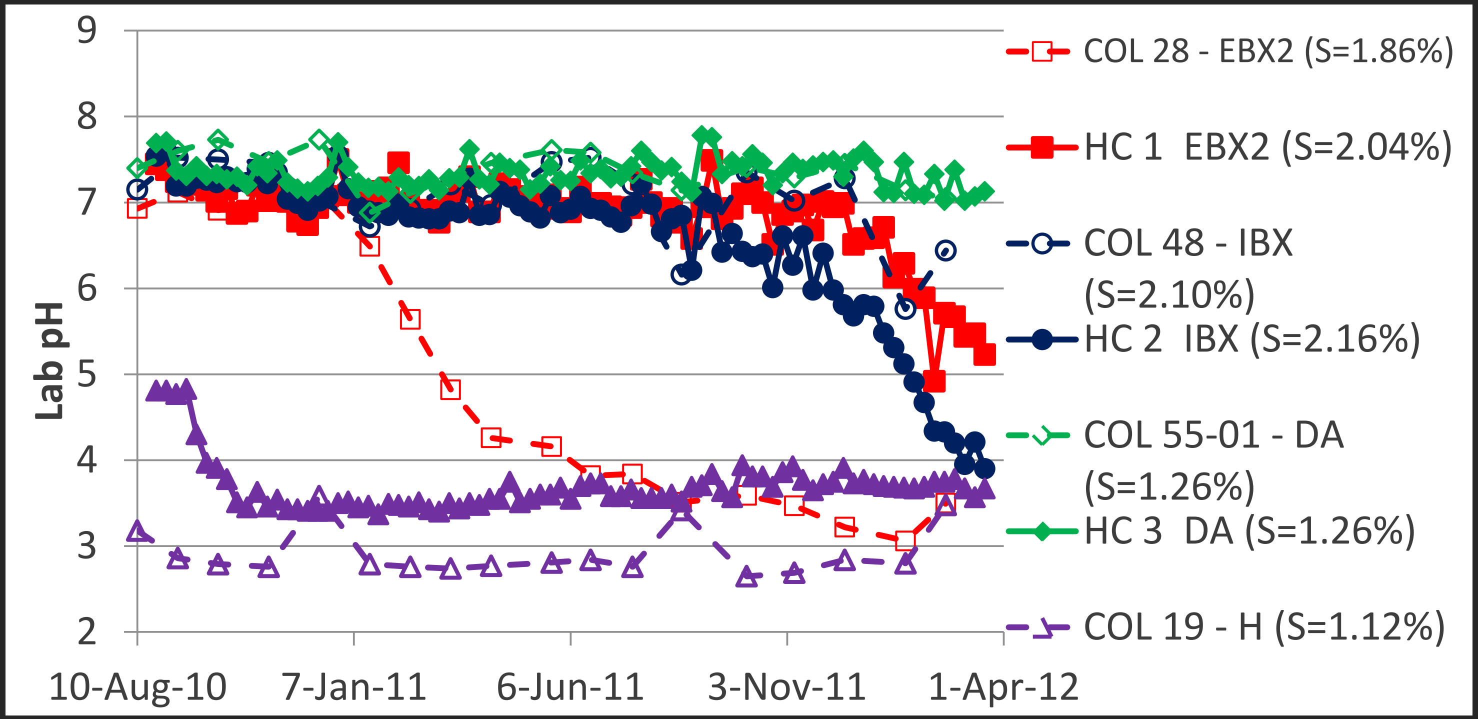
Kinetic Program Comparing FB and HC



- Field barrel acidity greater and faster
- Humidity cells have such high flush rates that they do not develop “hot spots” or acidic micro-environments where the sulphide oxidizing bacteria thrive.

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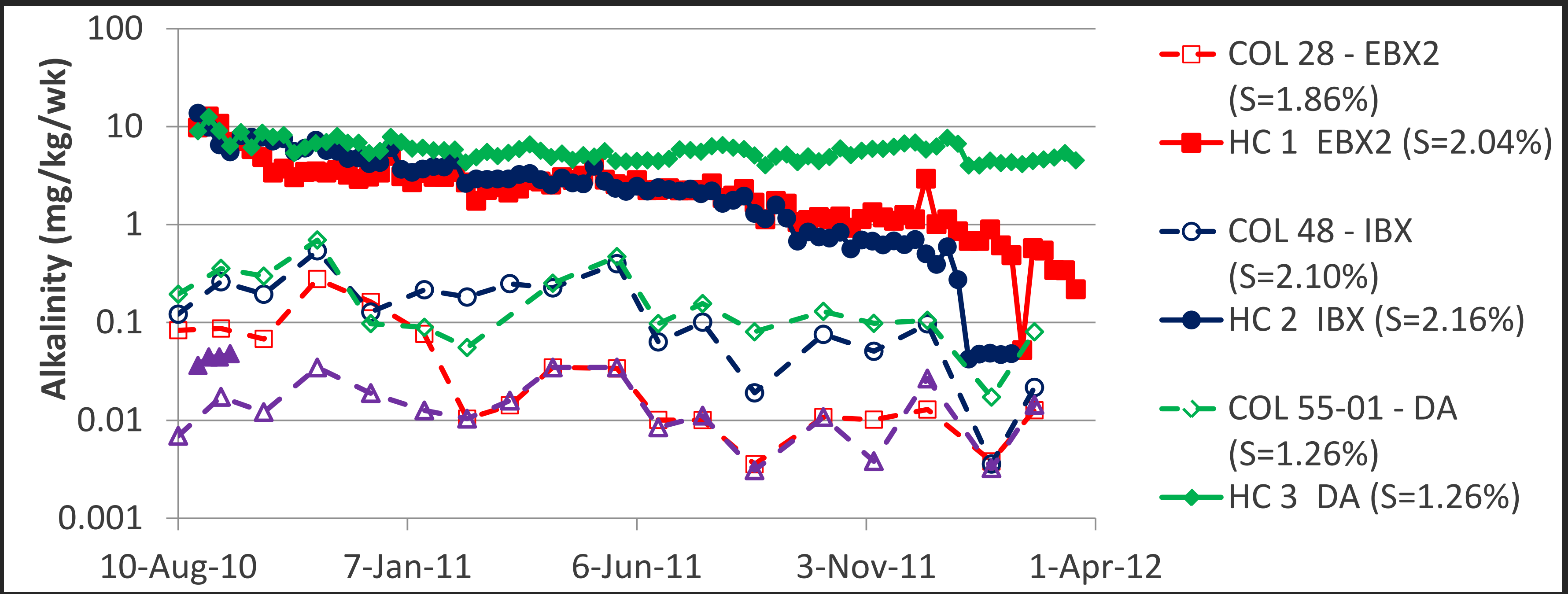
Kinetic Program Comparing FB and HC



- Greater flush of alkalinity in the humidity cells than in the field barrel due to high water infiltration rates and volumes

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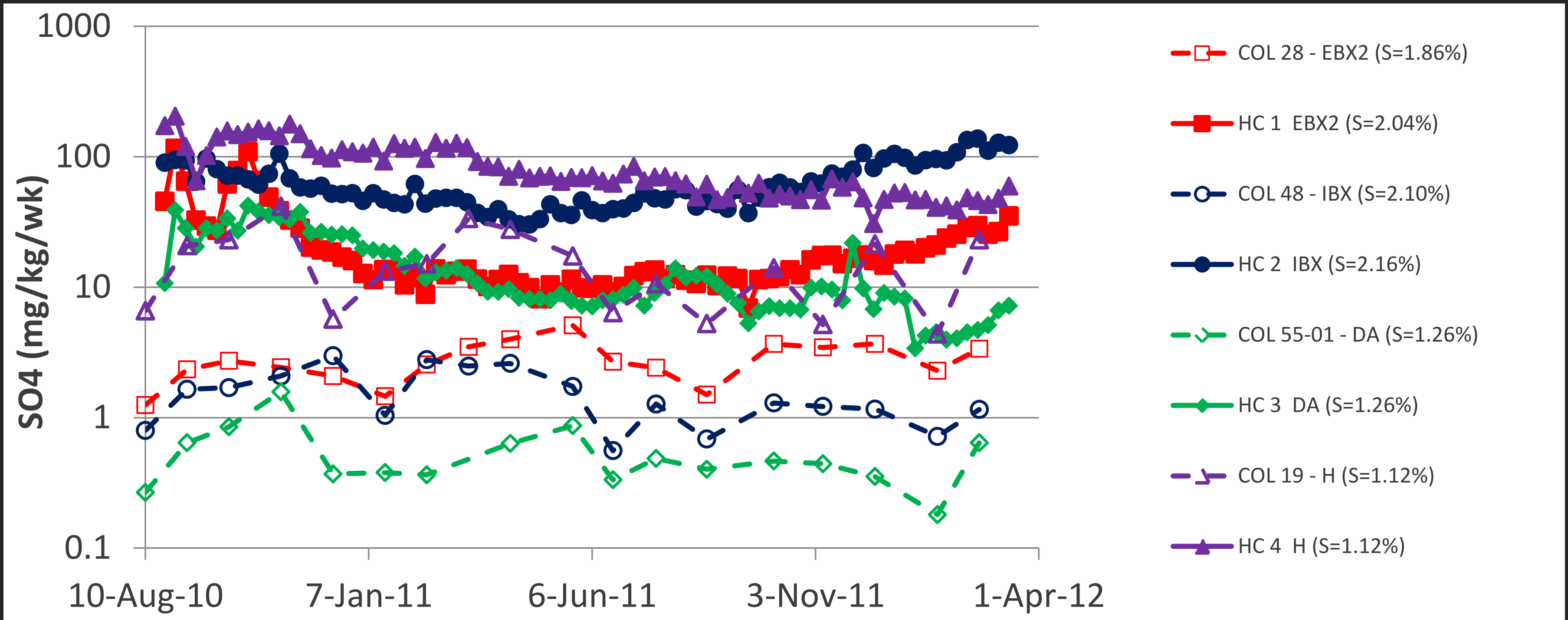
Kinetic Program Comparing FB and HC



- Greater sulphate release in the humidity cell tests than in field barrels due to lack of secondary mineral precipitation

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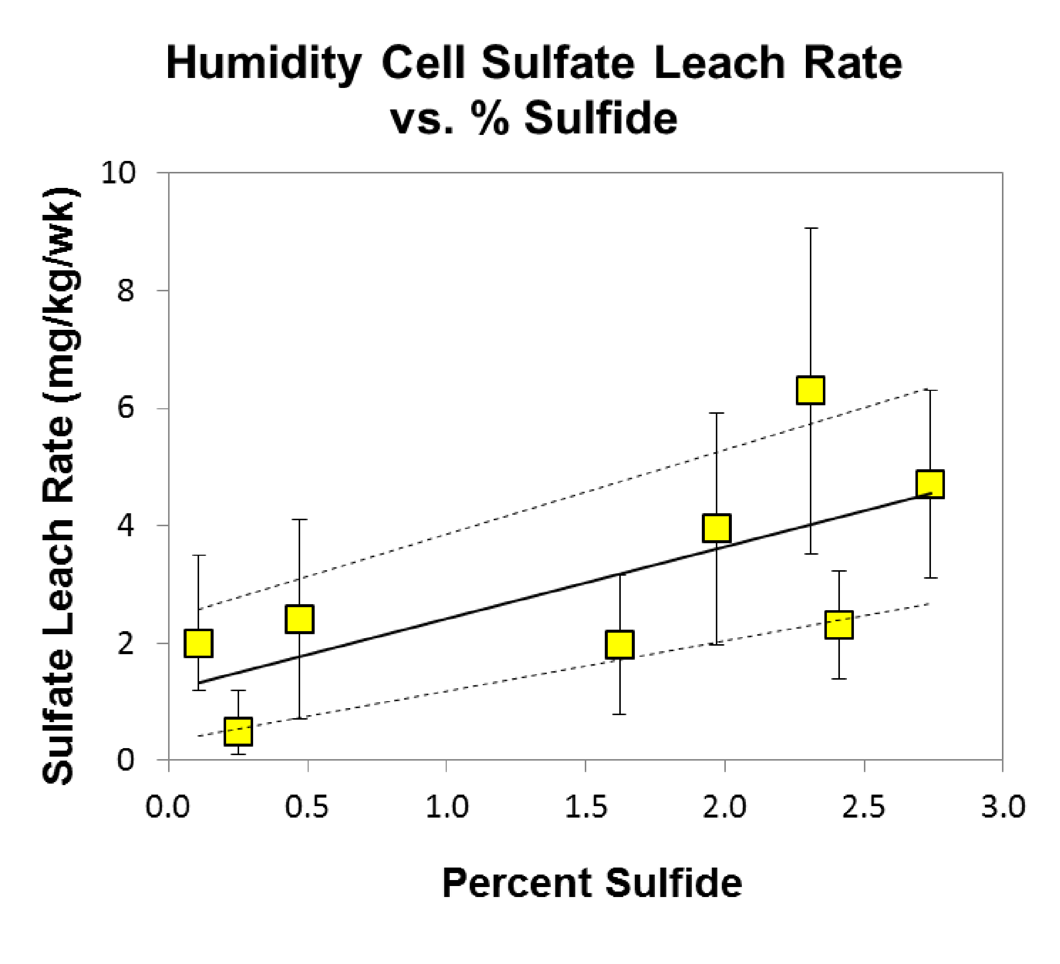
Solute Release from Sulfide Oxidation

- Rate of sulfate formed from oxidation of sulfide wall rock was estimated based on humidity cell data.

- Defined in model by slope and y-intercept



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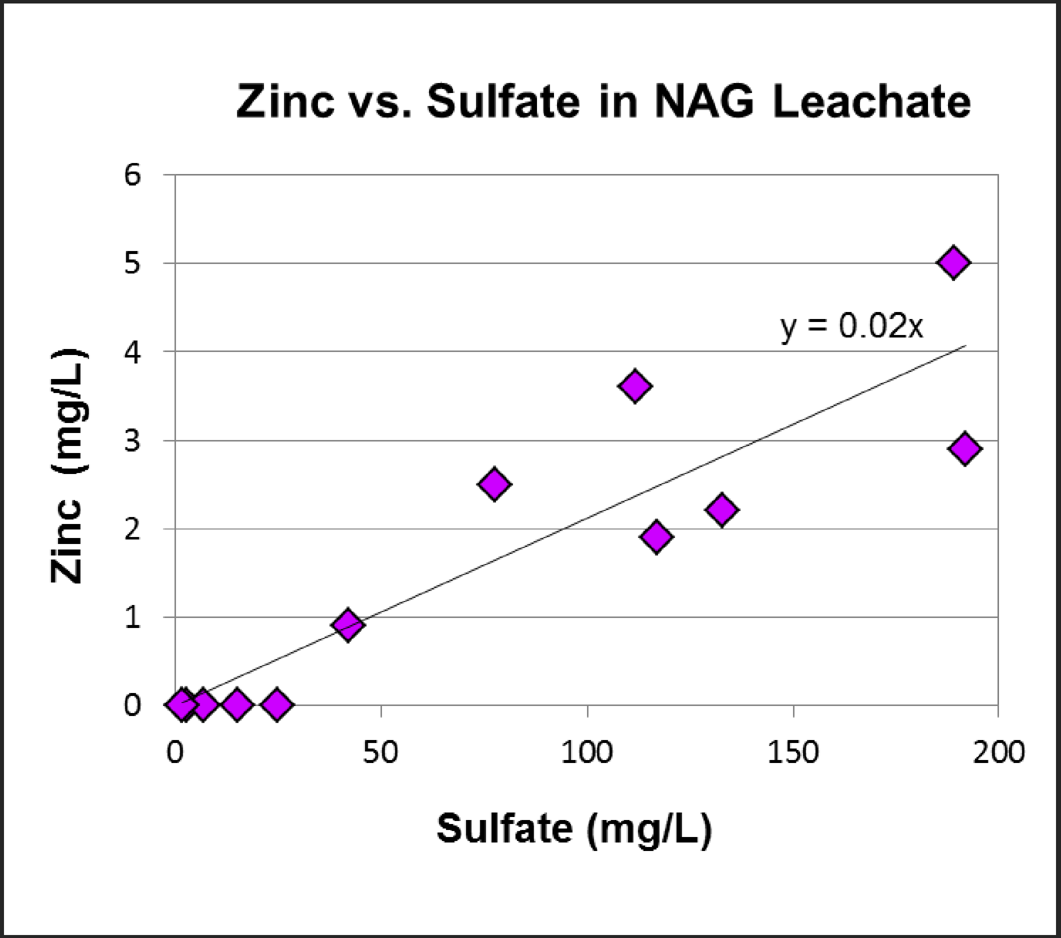
Solute Release from Sulfide Oxidation

- Solute assumed to be released from sulfide oxidation if statistically significant correlation exists between sulfate and the solute in NAG Leachate

- Solute release modeled as ratio to sulfate release.



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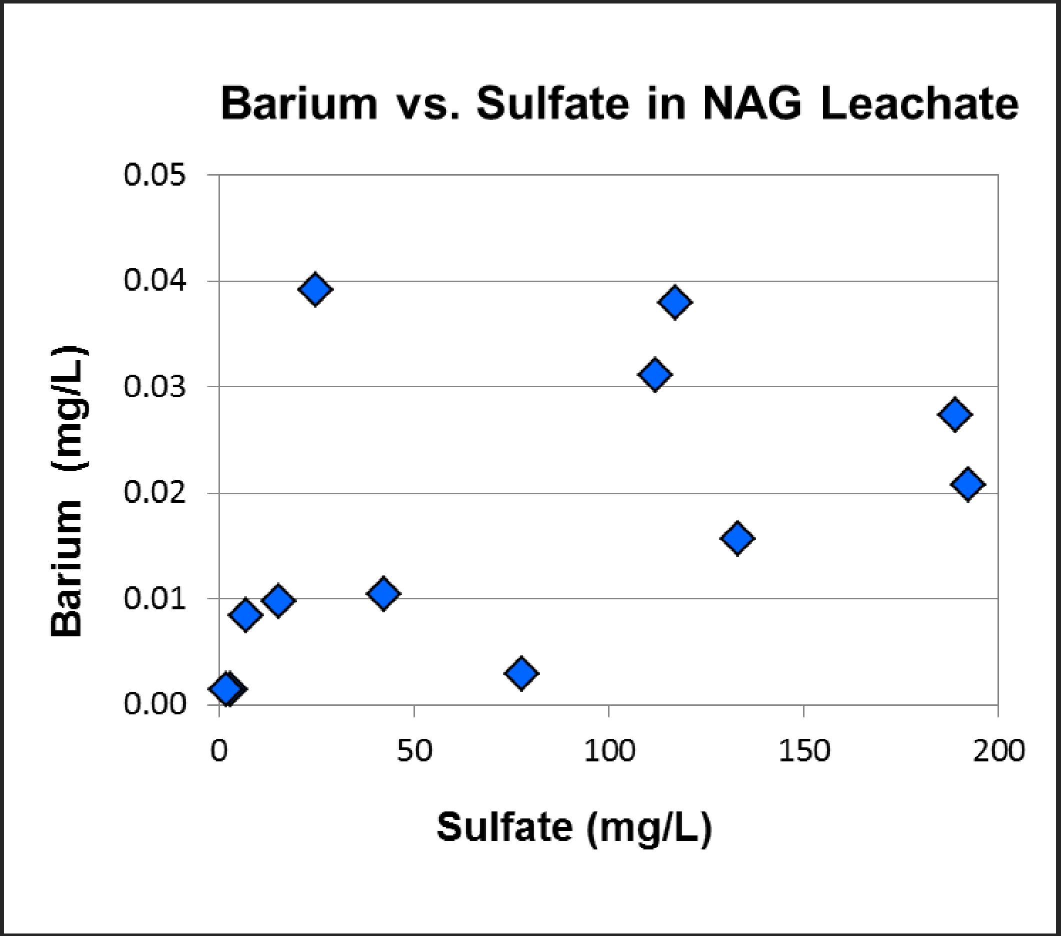
Solute Release from Sulfide Oxidation

- If solute is not correlated to sulfate concentrations in NAG leachate, then it is not released with sulfide oxidation in the model.
- Solute can still be released from pit wall runoff based on leach test results.



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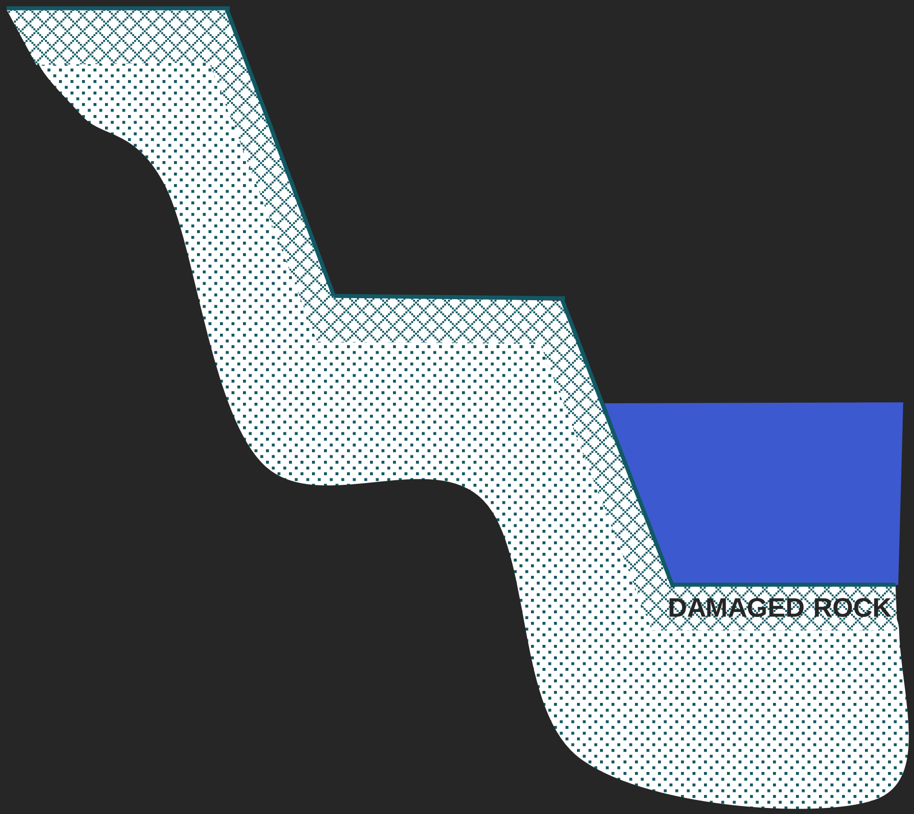
Damaged Rock Zone Properties

Parameter	Min	Max
Thickness[1]	3 m	15 m
Size Factor[2]	0.05	0.2
Percent in Contact with Runoff[3]	30%	90%
Sulfate Leach Rate	From Humidity Cell Data	



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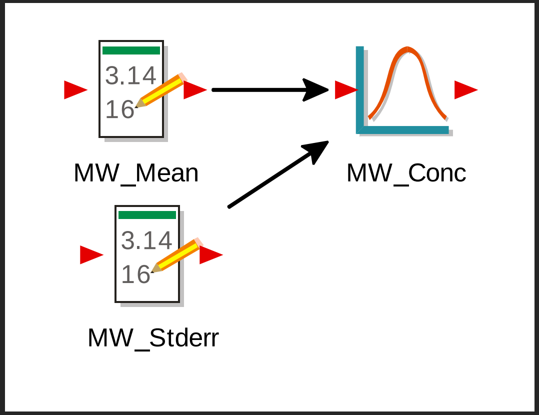
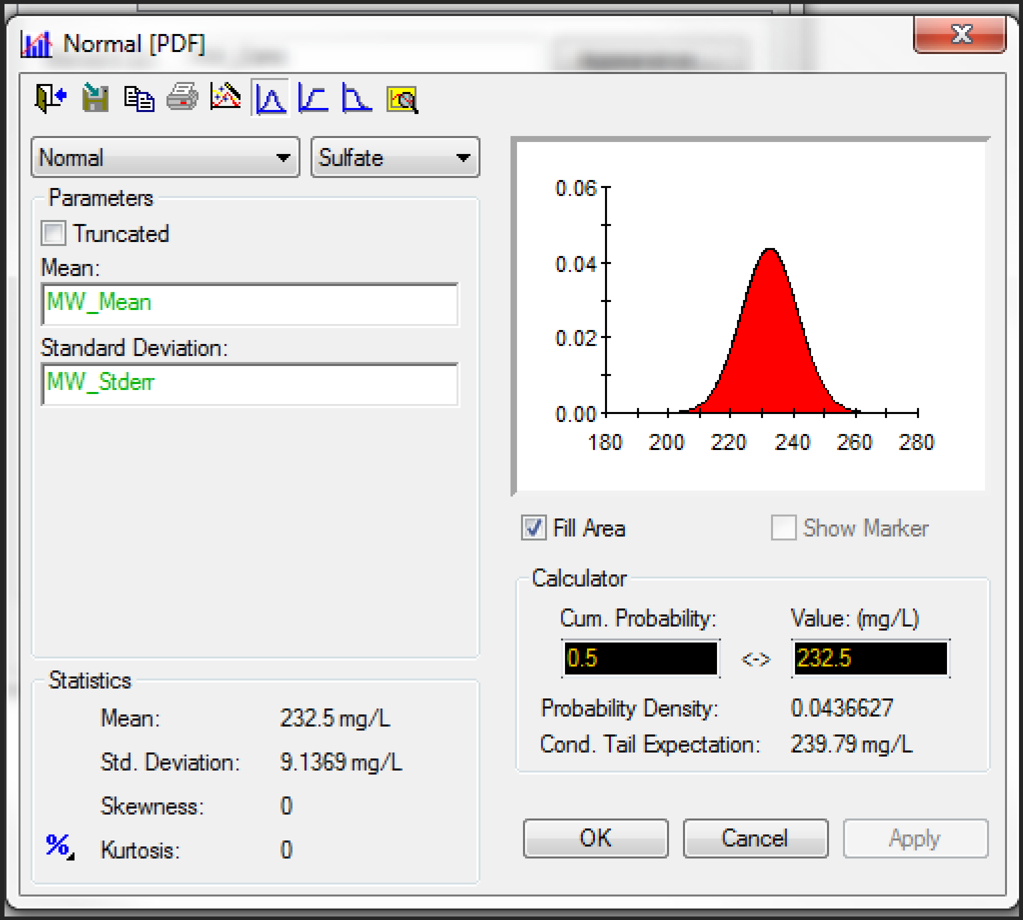
[1]Radian 1997; McClosky et al. 2003
[2]Malmstrom et al. 2000; Lopez et al. 1997
[3]Frostad et al. 2005; Hollings et al. 2001

Model Input

- Inflow concentrations are defined by probability distribution, in this case normal distribution, defined by mean and standard error of the mean





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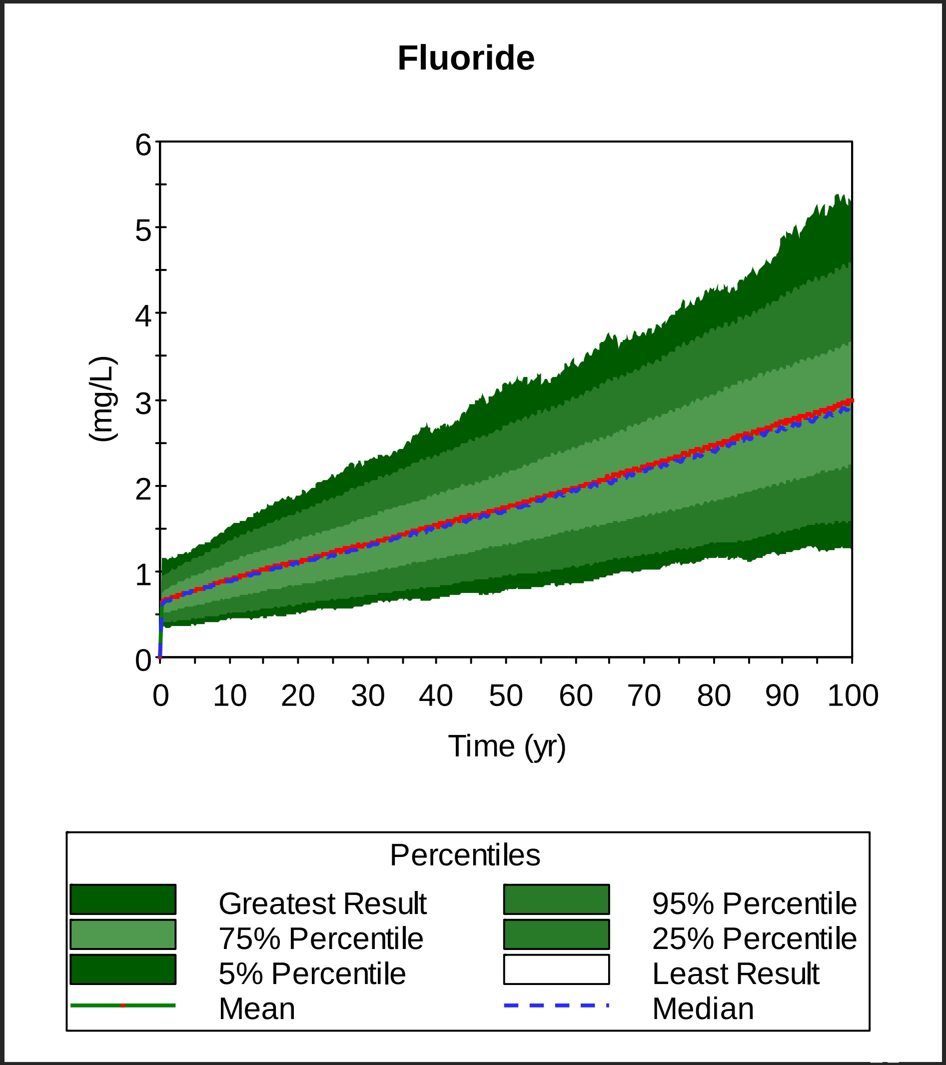
Solute Balance Simulations

- GoldSim uses Monte Carlo method for propagating uncertainty in model inputs into uncertainties in model outputs.
- Simulations conducted several thousand times (realizations)
- For each realization, a different parameter value is selected from the input probability distribution.



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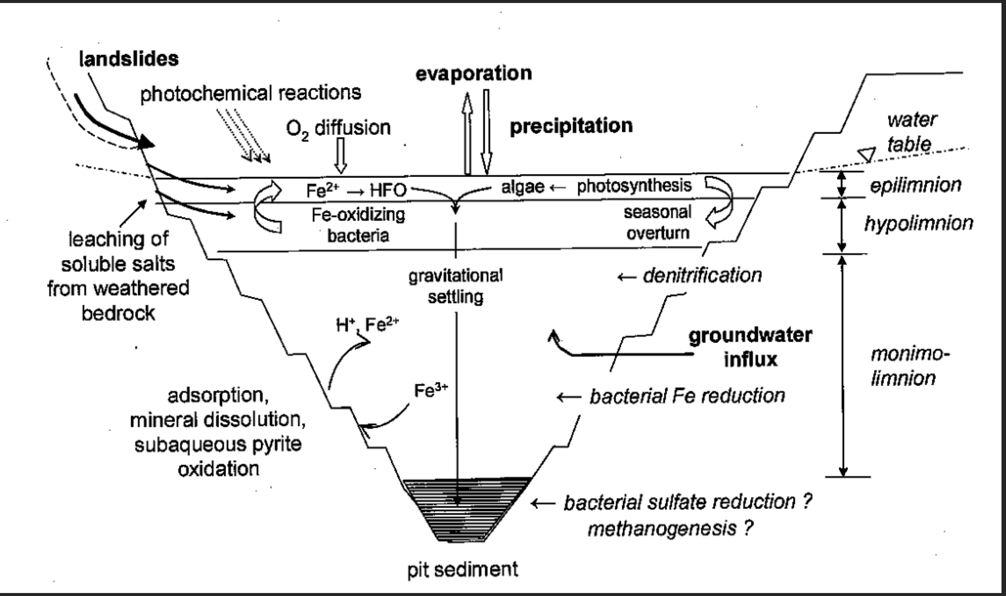
Geochemical Controls

- Bulk concentrations from the GoldSIM are analyzed for geochemical controls using PHREEQC:
  - Atmospheric O_2 and CO_2
  - Solubility controls for probable mineral phases in pit lakes*
  - Sorption to precipitated ferrihydrite



Summary Chemical Processes

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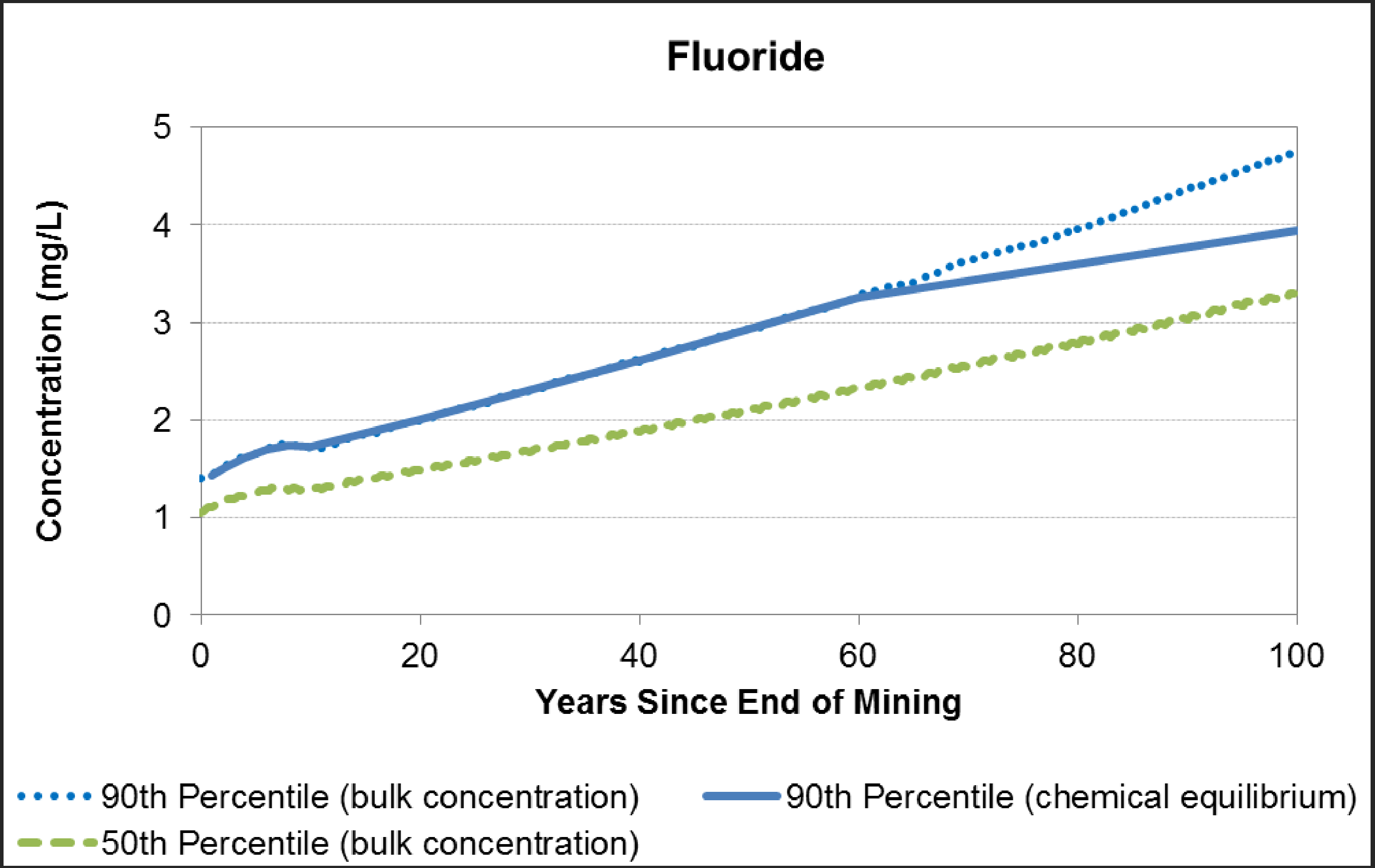
*Eary, L.E., Geochemical and equilibrium trends in mine pit lakes, Applied Geochemistry 14 (1999) 963-987

Model Results



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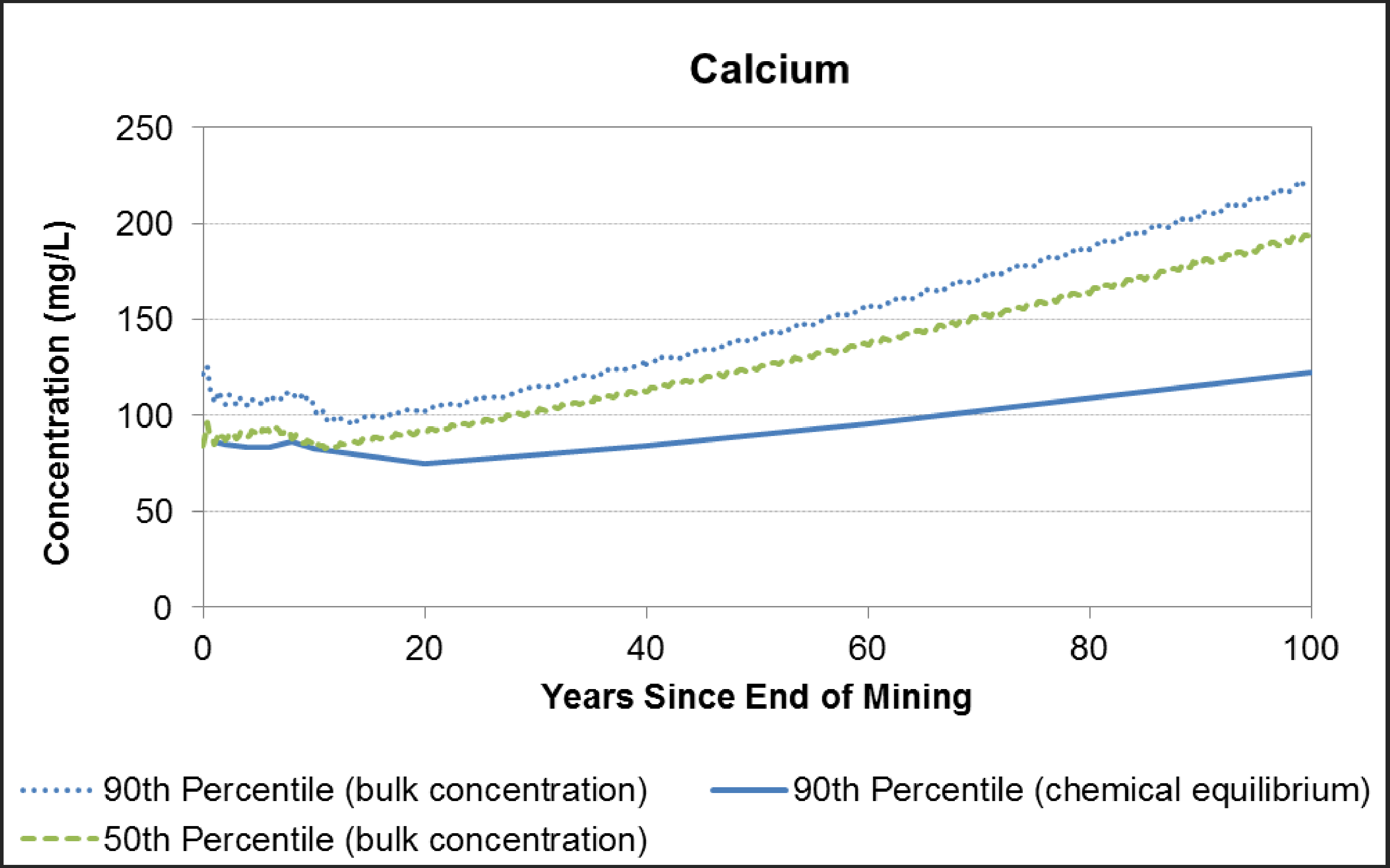
Model Results



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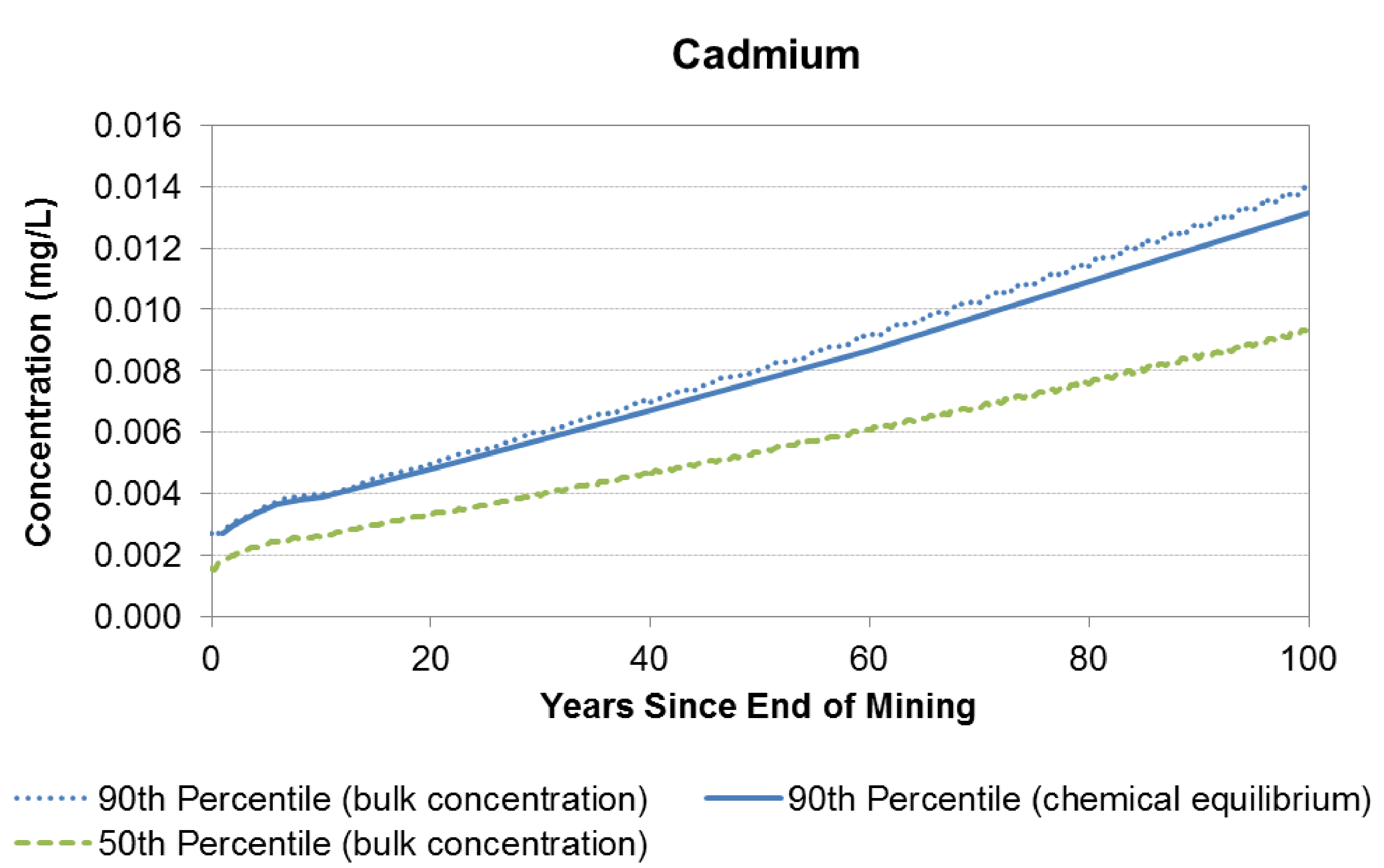

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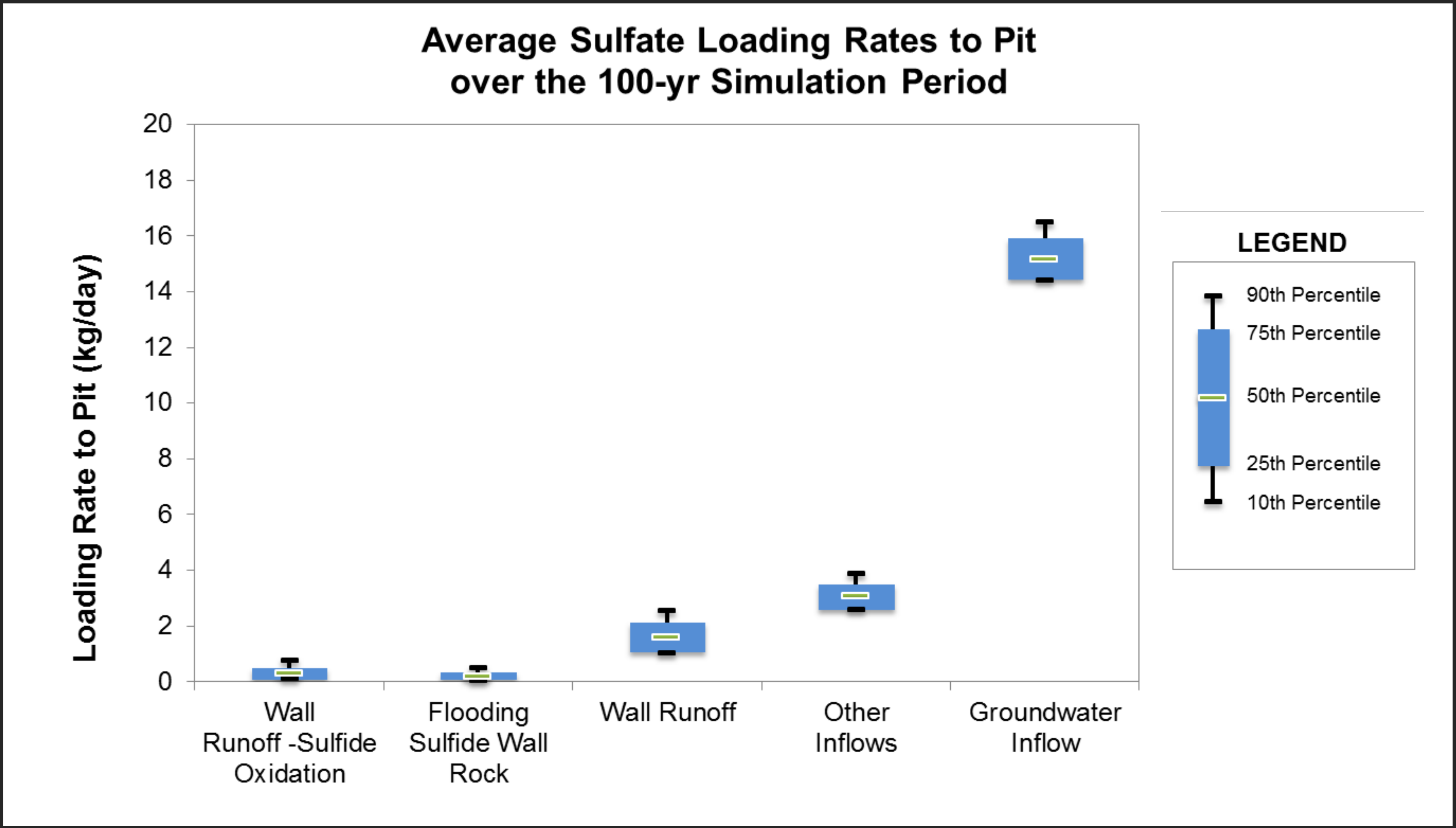
Model Results



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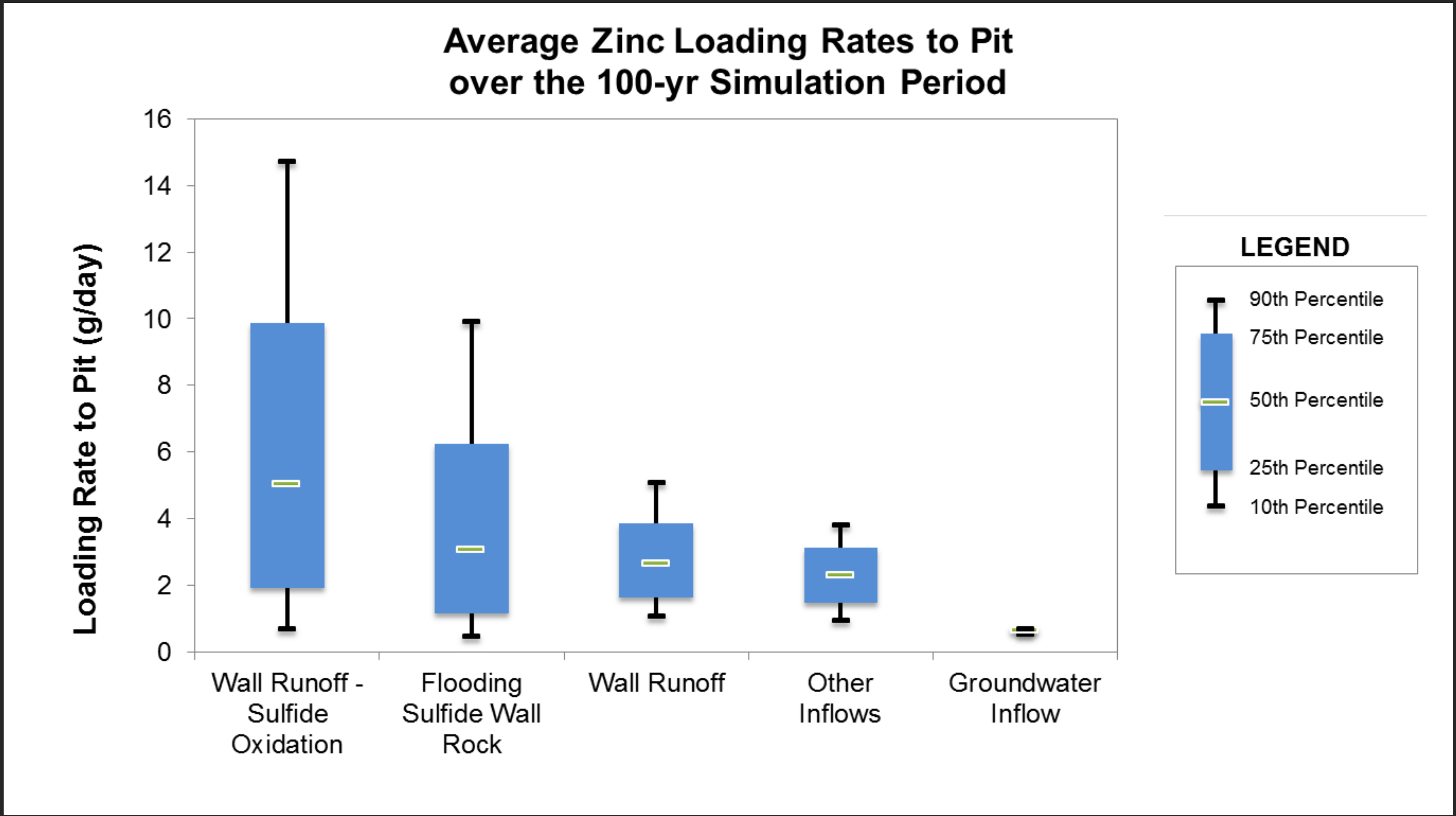

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Summary

" Doubt is not a pleasant condition, but certainty is absurd"

- Voltaire

- Focus should be on capturing the uncertainty
- Oxidation of sulfide wall rock is a large source of uncertainty and commonly represented inaccurately
- Allows parties to "agree to disagree"

Ongoing Challenges

- When you set a percentile, there won't be any interest in lower percentiles.

- 90^{th} Percentile precedent:
  - Idaho Cobalt EIS
  - PolyMet EIS
  - Ecological Risk Assessment Guidance

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