Thermal and Hydrogeochemical Modelling of Arsenic Treatment in Mine Impacted Water and the Implications of Climate Change on Treatment Costs

Prepared by:

EA Engineering, Science, and Technology, Inc., PBC

Drummond “Dusty” Earley III, Ph.D., P.G.
dearley@eaest.com

For CEMS:

May 2021

Arsenic in Geothermal Mine and Natural Water Discharge

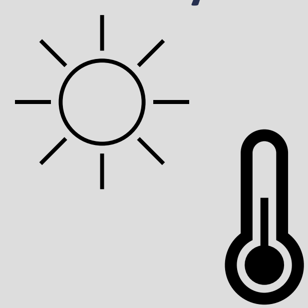
Gold Mine Operation, NV USA

- Natural As levels in mine pit dewatering groundwater above MCL:
  - Treat at head of cooling channel with ferric chloride
  - Some rebound downstream, unknown cause, detailed study
  - Endothermic sorption hypothesis, laboratory study isotherms:
    - Banerjee (2008, ppt Fe)
    - Partey (2008, natural Fe media)
    - Feng et al. (2012, ppt Fe)
    - 25°C and higher
  - Model fits data: confidential report of finding
  - Conflicting theoretical predictions

Yellowstone National Park

- USGS studies of hotspring discharges into Yellowstone river
  - As rebound noted but more complex system
  - Use geochemical modeling to fit public data, test endothermic sorption hypothesis
  - Model fits data

- Billings MT ferric coagulation water treatment plant efficiency low in winter months. Kinetic versus sorption efficiency?



YELLOWSTONE RIVER, YELLOWSTONE NP

Earley et al. 2019, Tailing and Mine Waste

Mine Water Treatment in Cold Climates

Seasonally Variable Treatment ←

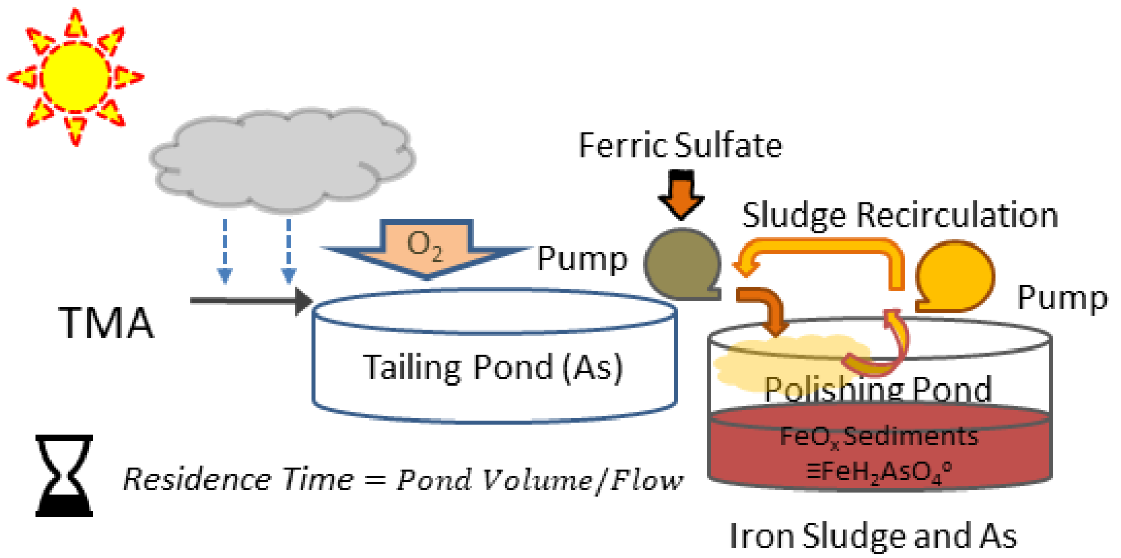
- Closed Mine, Canada
  - As contaminated drainage from mill tailings impoundment
  - Optimization of ferric sulfate dosing system

Pre and Post ARD Treatment Modeling

- Mineral Creek, Colorado, U.S.
  - USGS study (Runkel et al., 2005 and 2008) of ARD and As impaired in stream flows in San Juan County
  - Water quality modeling using OTEC, pre and post lime dosing

Geochemical Data for Upper Mineral Creek, Colorado, Under Existing Ambient Conditions and During an Experimental pH Modification, August 2005

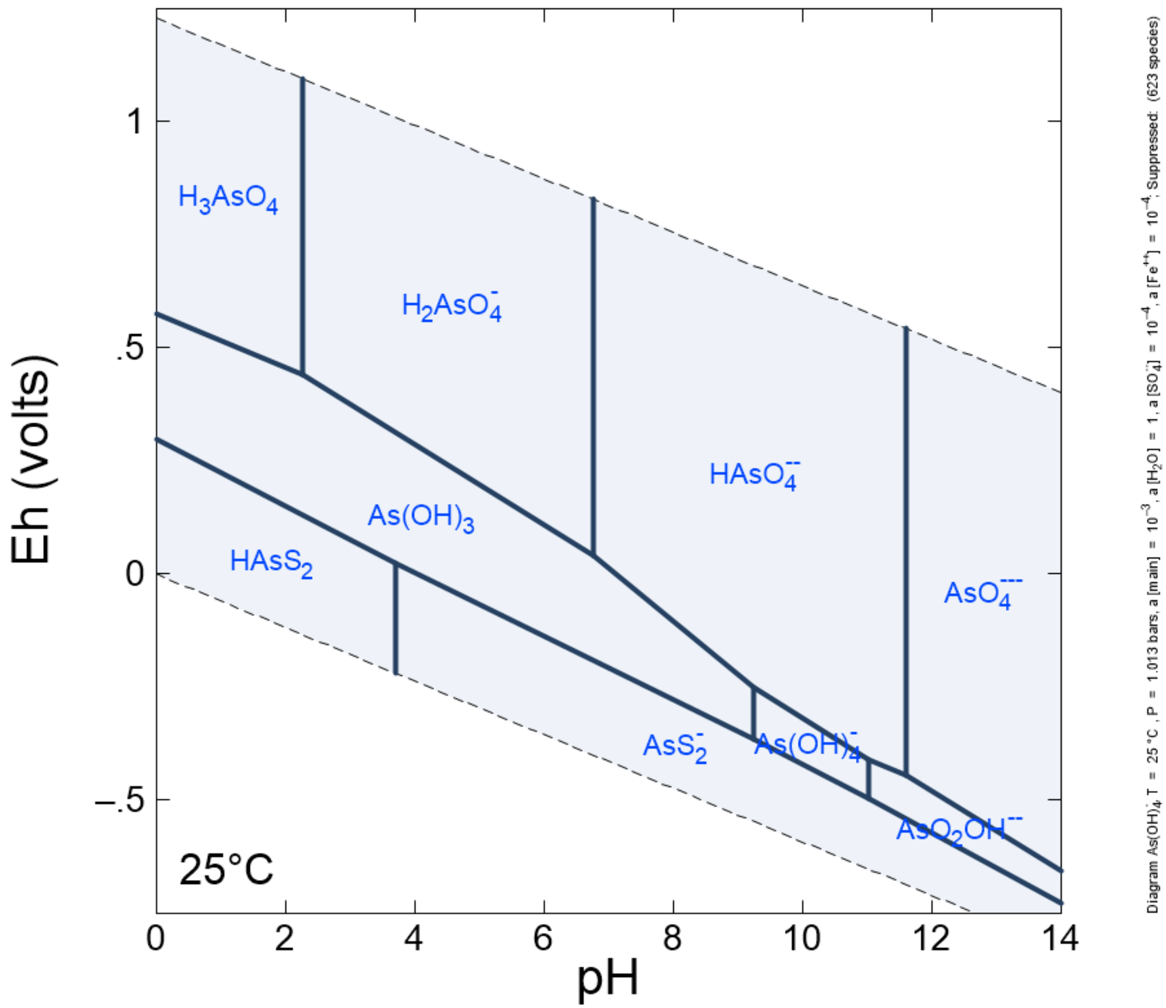
Arsenic Treatment by Ferric Coagulation



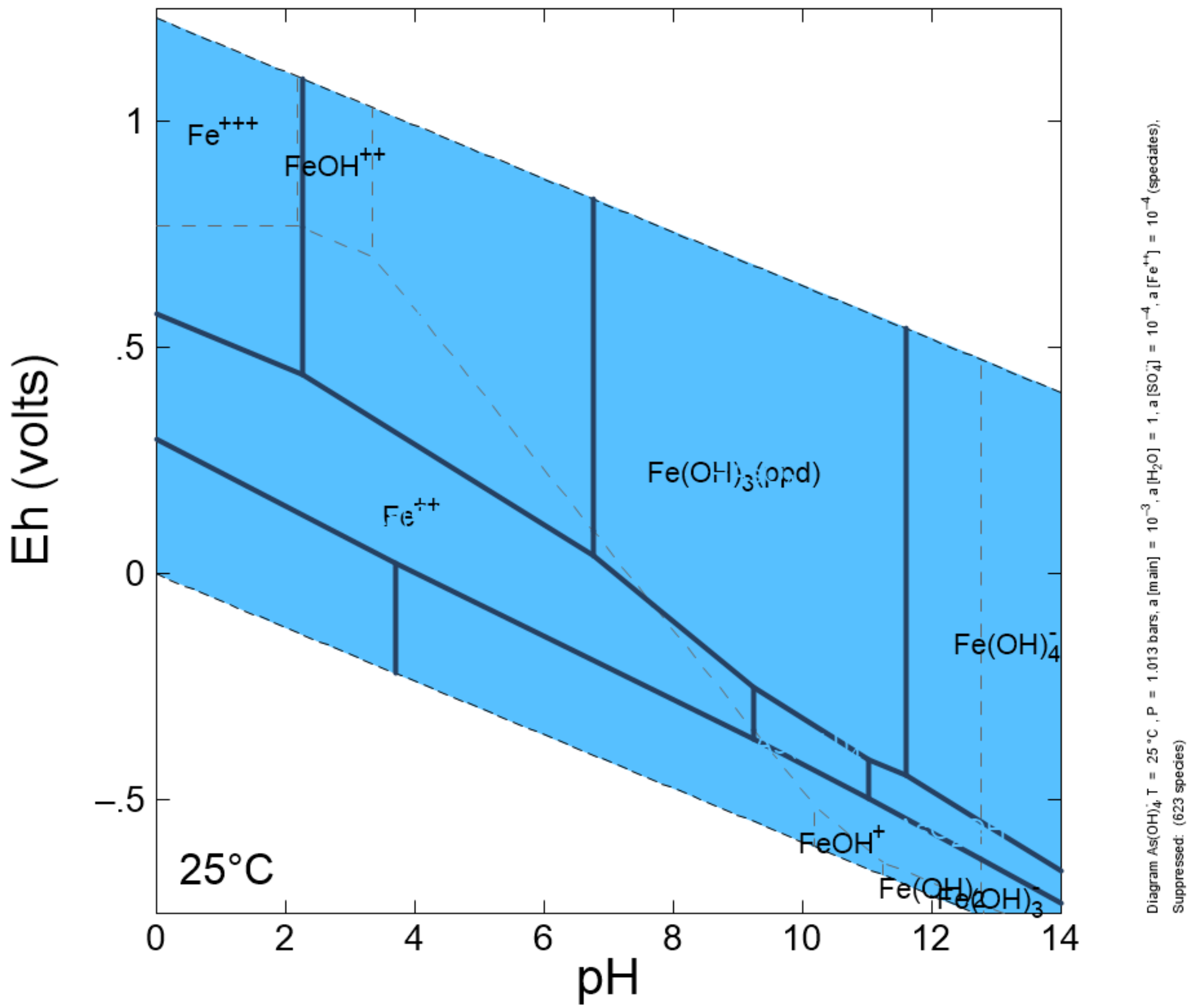
$$Fe_2(SO_4)_3 + H_2O = Fe(OH)_3 + H_2SO_4$$

$$\equiv FeOH^o + AsO_4^{3-} + 3H^+ = \equiv FeH_2AsO_4^o + H_2O \text{ [Arsenate]}$$

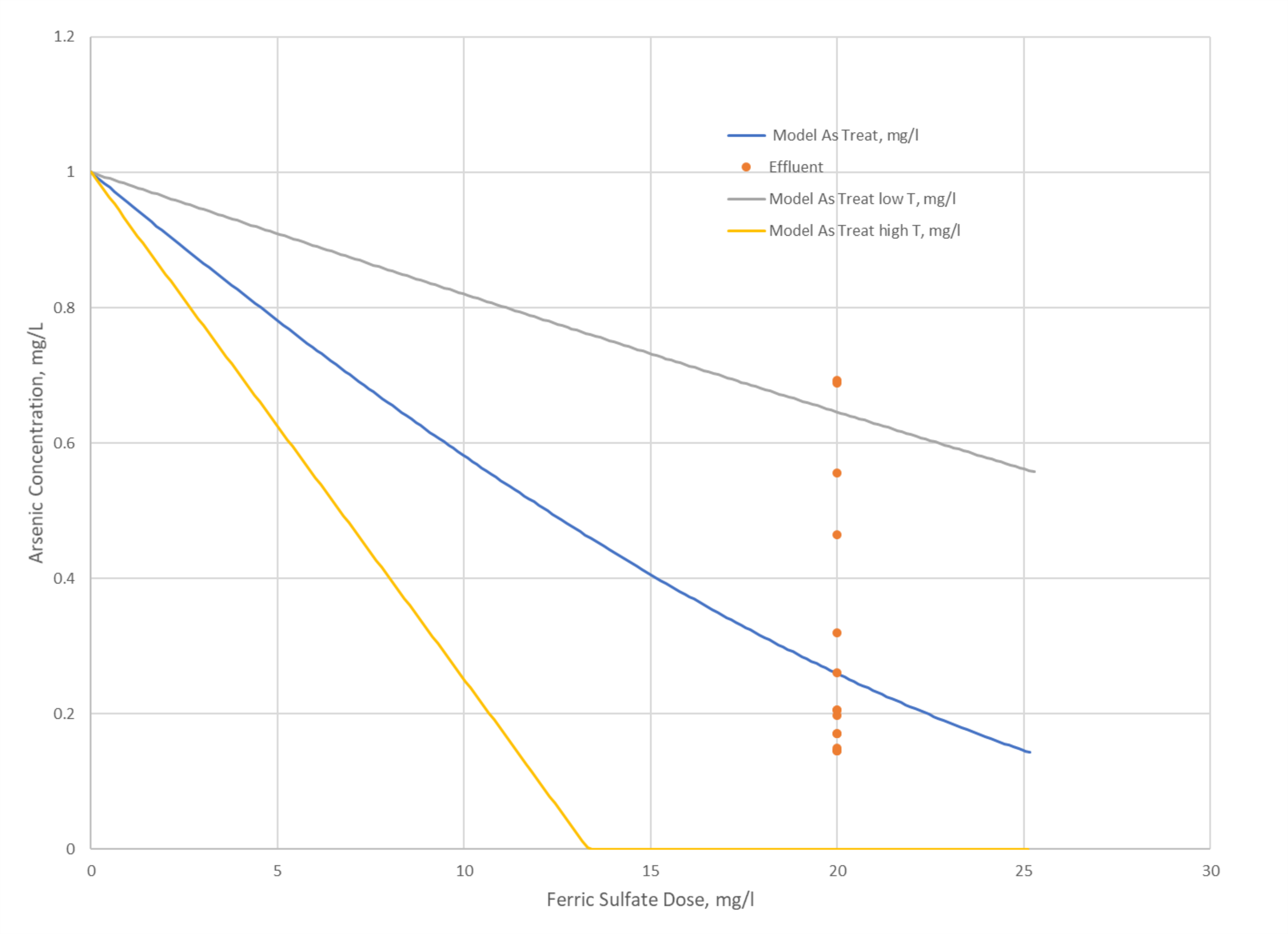
$$\equiv FeOH^o + H3AsO_4^0 = \equiv FeH_2AsO_3^o + H_2O \text{ [Arsenite]}$$



Eh (volts)
1
.5
0
–.5
0
2
4
6
8
10
12
14
pH
25°C
H_3AsO_4
$H_2AsO_4^-$
$HAsO_4^{--}$
AsO_4^{---}
$As(OH)_3$
$HAsS_2$
AsS_2^-
$As(OH)_4^-$
AsO_2OH^{--}
Diagram $As(OH)_4^-$, T = 25 °C , P = 1.013 bars, a [main] = 10^{-3}, a [H_2O] = 1, a [SO_4^{--}] = 10^{-4}, a [Fe^{++}] = 10^{-4}; Suppressed: (623 species)



Fe+++
FeOH++
Fe(OH)3(ppd)
Fe++
Fe(OH)4-
FeOH+
Fe(OH)2
Fe(OH)3-
25°C
Eh (volts)
pH
1
.5
0
–.5
0
2
4
6
8
10
12
14
Diagram As(OH)4-, T = 25 °C , P = 1.013 bars, a [main] = 10^-3 , a [H2O] = 1 , a [SO4--] = 10^-4 , a [Fe++] = 10^-4 (speciates),
Suppressed: (623 species)



Model As Treat, mg/l
Effluent
Model As Treat low T, mg/l
Model As Treat high T, mg/l
Arsenic Concentration, mg/L
1.2
1
0.8
0.6
0.4
0.2
0
0
5
10
15
20
25
30
Ferric Sulfate Dose, mg/l

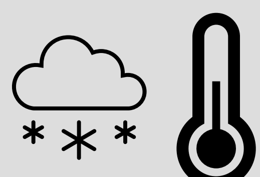
Mine Water Treatment in Cold Climates

Seasonally Variable Treatment

- Closed Mine, Canada
  - As contaminated drainage from mill tailings impoundment
  - Optimization of ferric sulfate dosing system

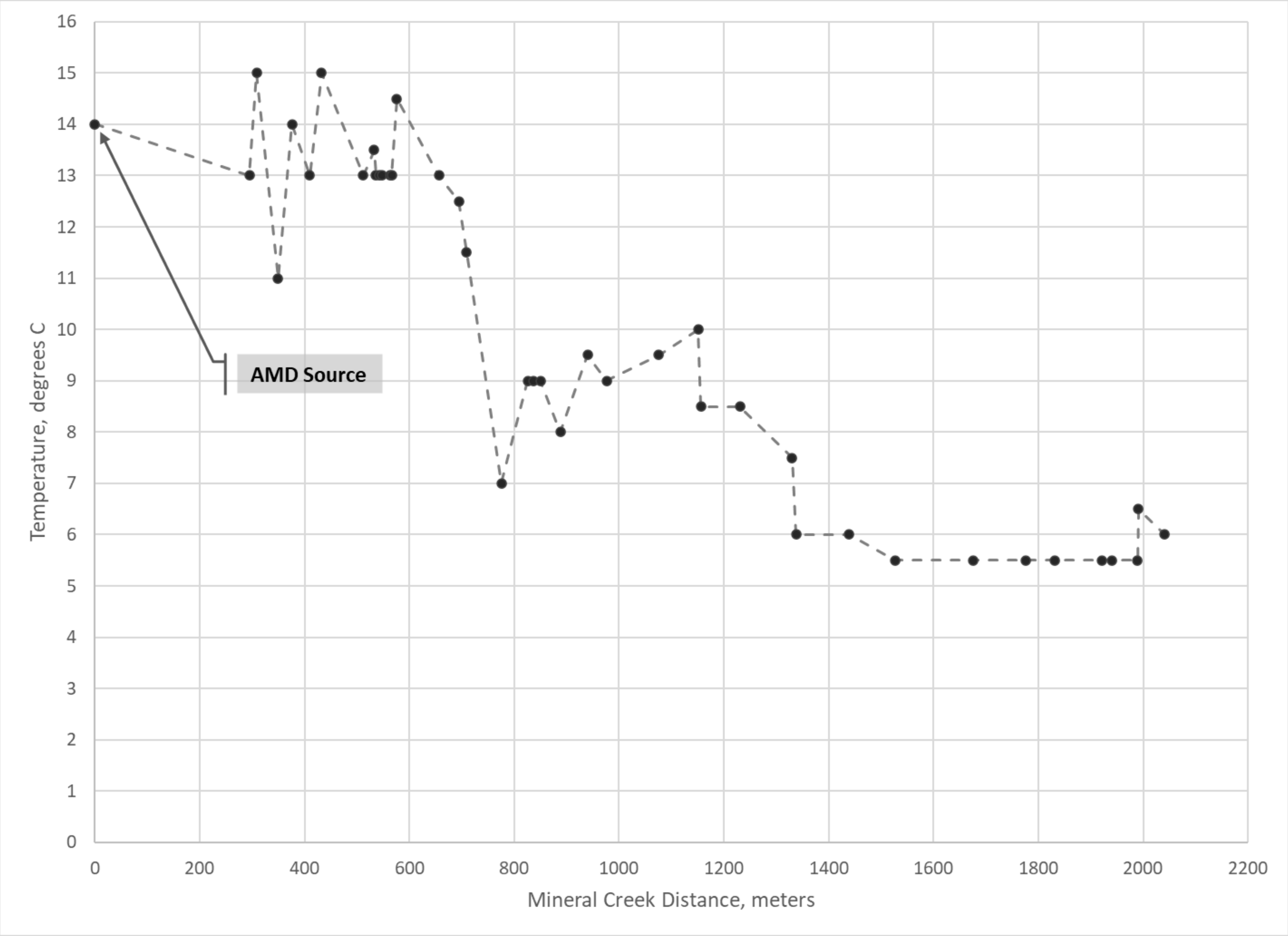
Pre and Post ARD Treatment Modeling ←

- Mineral Creek, Colorado, U.S.
  - USGS study (Runkel et al., 2005 and 2008) of ARD and As impaired in stream flows in San Juan County
  - Water quality modeling using OTEC, pre and post lime dosing

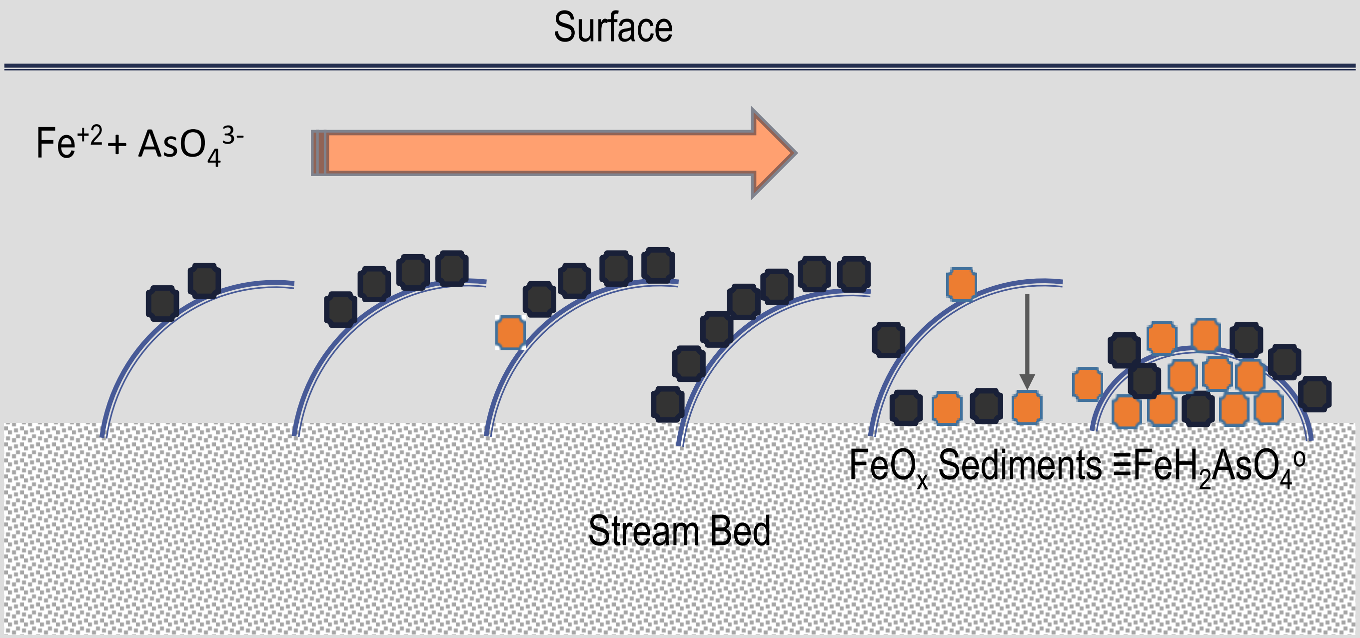


Geochemical Data for Upper Mineral Creek, Colorado, Under Existing Ambient Conditions and During an Experimental pH Modification, August 2005

Temperature of Creek Water



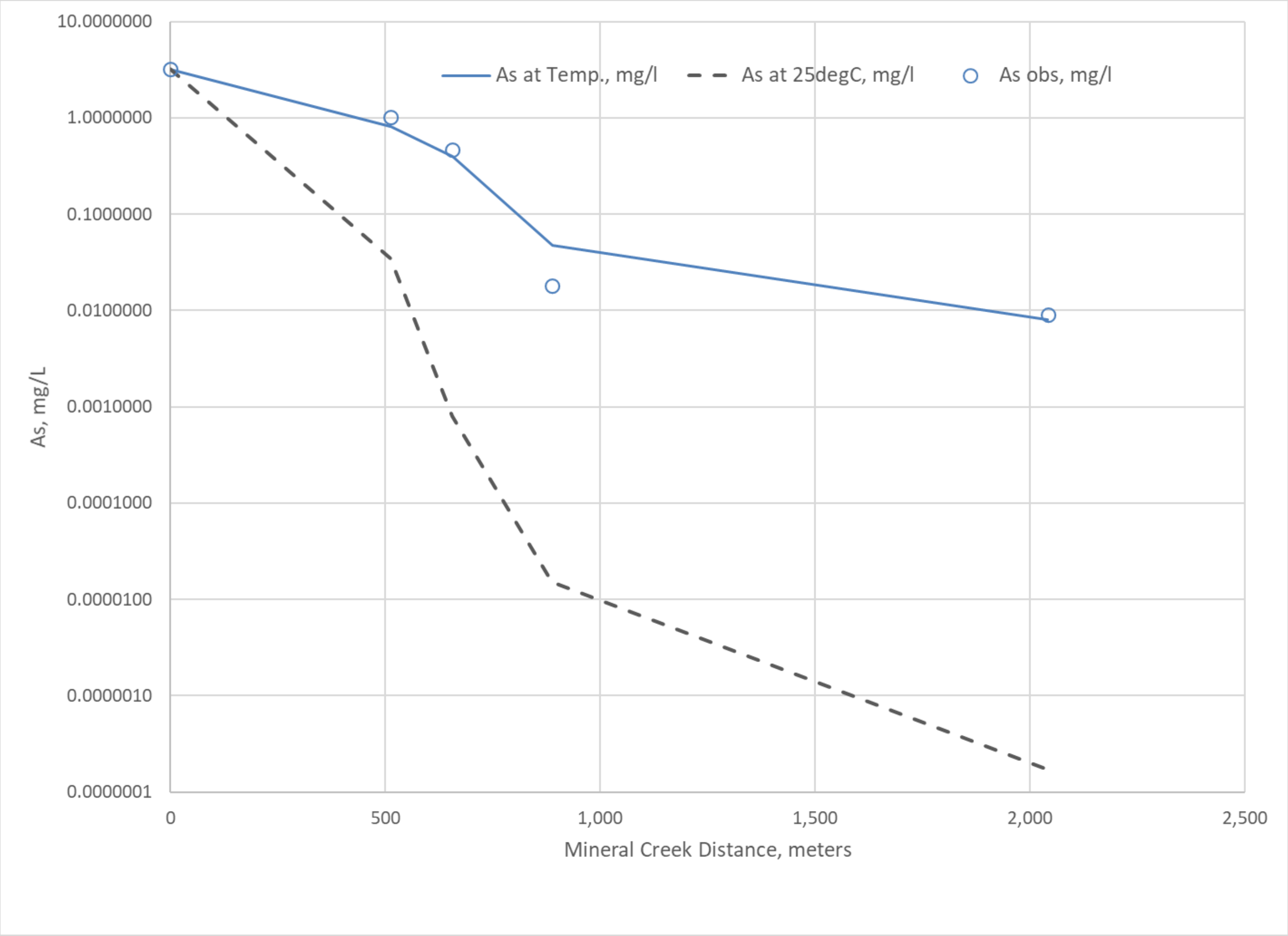
Natural Attenuation of As on Iron Oxide



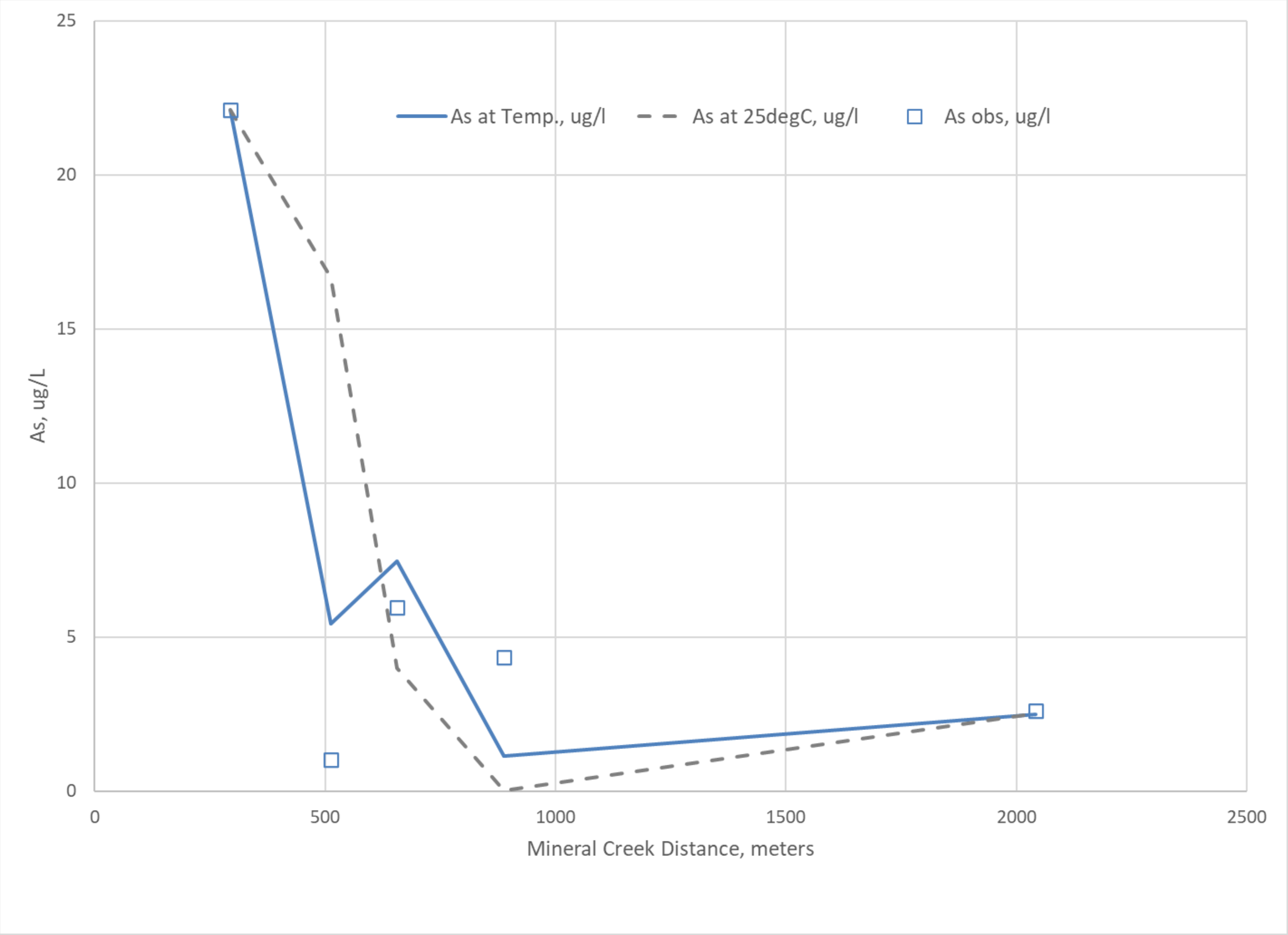
$$Fe^{+2} + 0.25O_2 \text{ (dissolved gas)} + 2.5H_2O = Fe(OH)_3 + 2H^+$$

$$\frac{dMFe[+2]}{dt} = n[w]k[+]mFe[+2]mO_2(aq)a\hat{\ }2OH[-](1 - \frac{Q}{K})$$

Pre Treatment Simulation Results



Post Treatment Simulation Results



Conclusions

- ✓ Geochemical modeling can be a useful tool for water treatment design, however, complicated for colloidal iron transport in streams
- ✓ Treatment system optimization needs to consider seasonal temperature variation. Savings of ~$500 per gpm in chemical reagent (ferric sulfate) costs.
  - Cost of exceedance?
- ✓ Other applications:
  - Mine pit lakes and pit dewatering systems
  - Aquifer recharge systems, cold spring flow injection
  - Sludge disposal, As retainment in cold climates vs TCLP
  - Water treatment costs in the future under climate change?
    - Good news? Rising temperatures decreases costs…
    - Bad news? Variable climate results in variable treatment doses and effluent limit compliance.

Thank You!

“The poison arsenic spring flows

Until purified by the red iron earth

On a warm summer day”

Dusty Earley
Senior Geochemist
dearley@eaest.com