Coal mine drainage contaminant trend prediction in an Appalachian basin, USA

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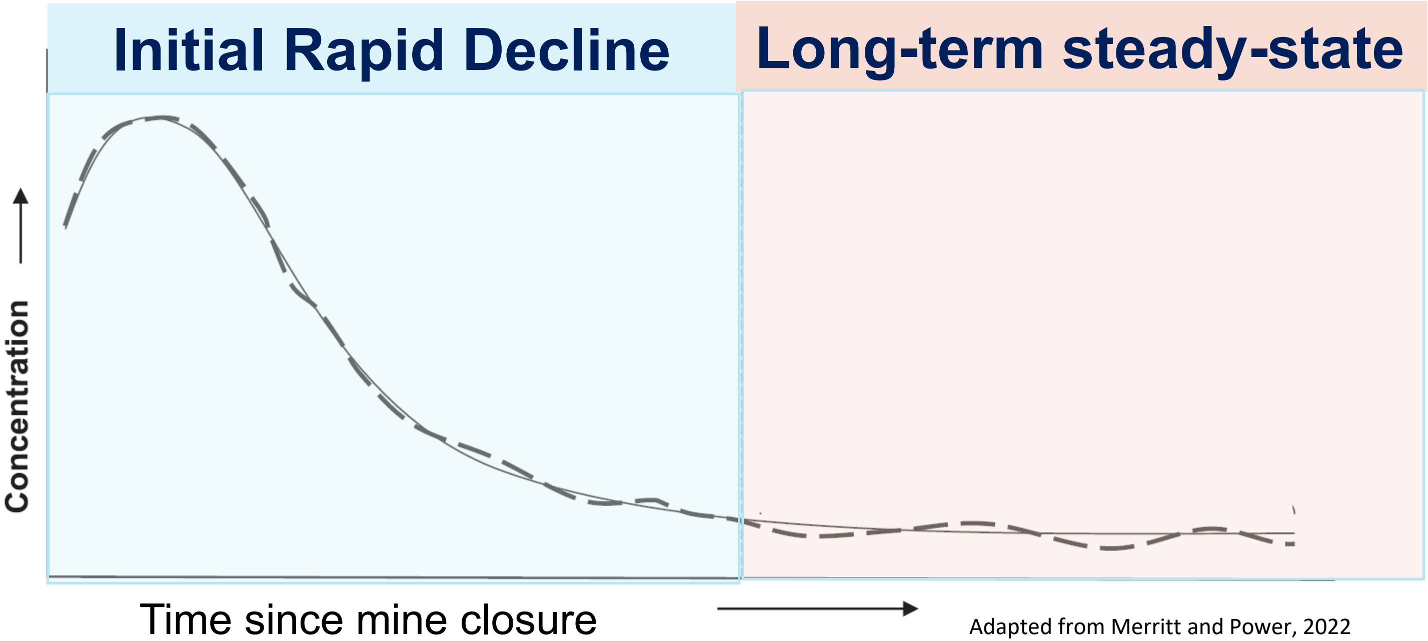
Coal mine drainage (CMD): A major pollutant in Northern Appalachia

- Abandoned underground coal mines release CMD into waterways
- Degrades water sources for decades after mine closure
- **>10,000 miles** Appalachian streams impacted by CMD

CMD generally improves on a decadal time scale



Adapted from Merritt and Power, 2022

Rapid improvement after mine closure and initial flooding, eventually steady state reached

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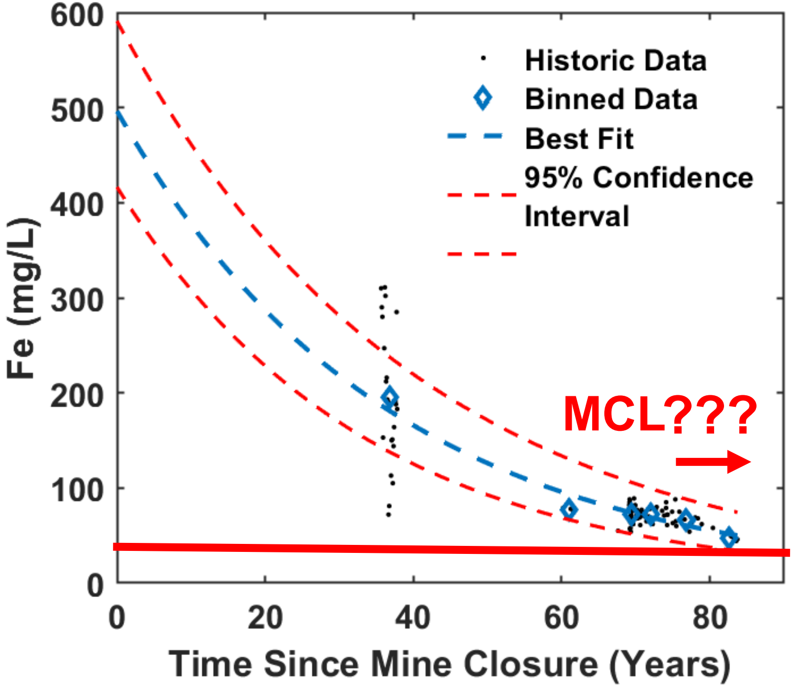
Predicting contaminant trends informs remediation decisions

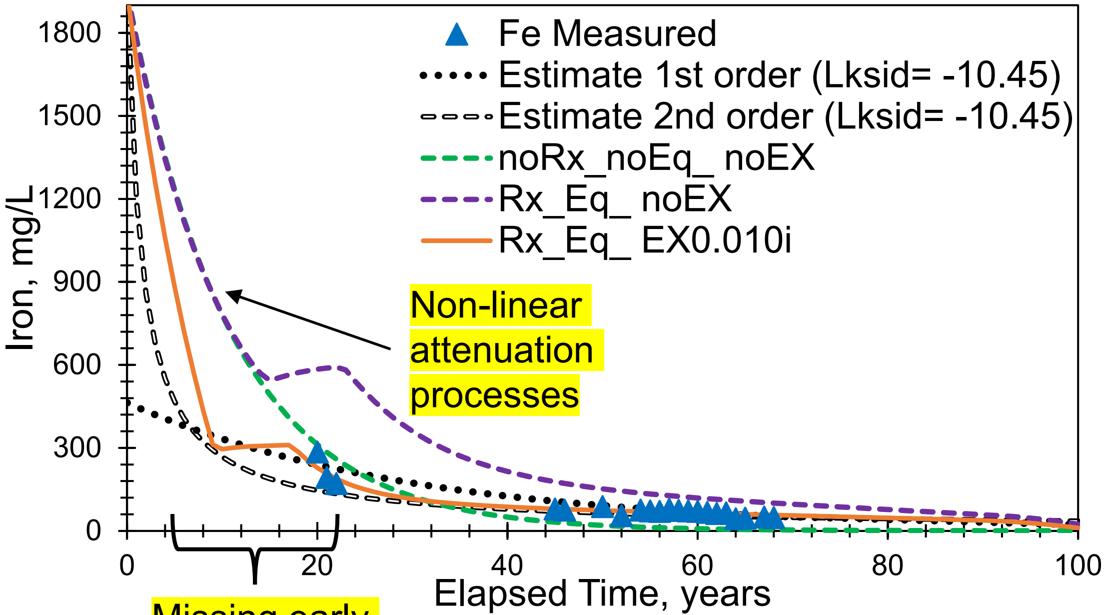
Appalachian coal mine discharge



- Important point of investigation because of the long-term treatment liability and costs

CMD chemistry is difficult to predict

- Non-linear, site-specific hydrogeochemical processes influence contaminate trends
- Fe attenuation depends on oxidation state: $Fe^{III}(OH)_3$ vs. $Fe^{II}CO_3$
- Often early time data in abandoned mines is missing



Non-linear attenuation processes

Missing early data

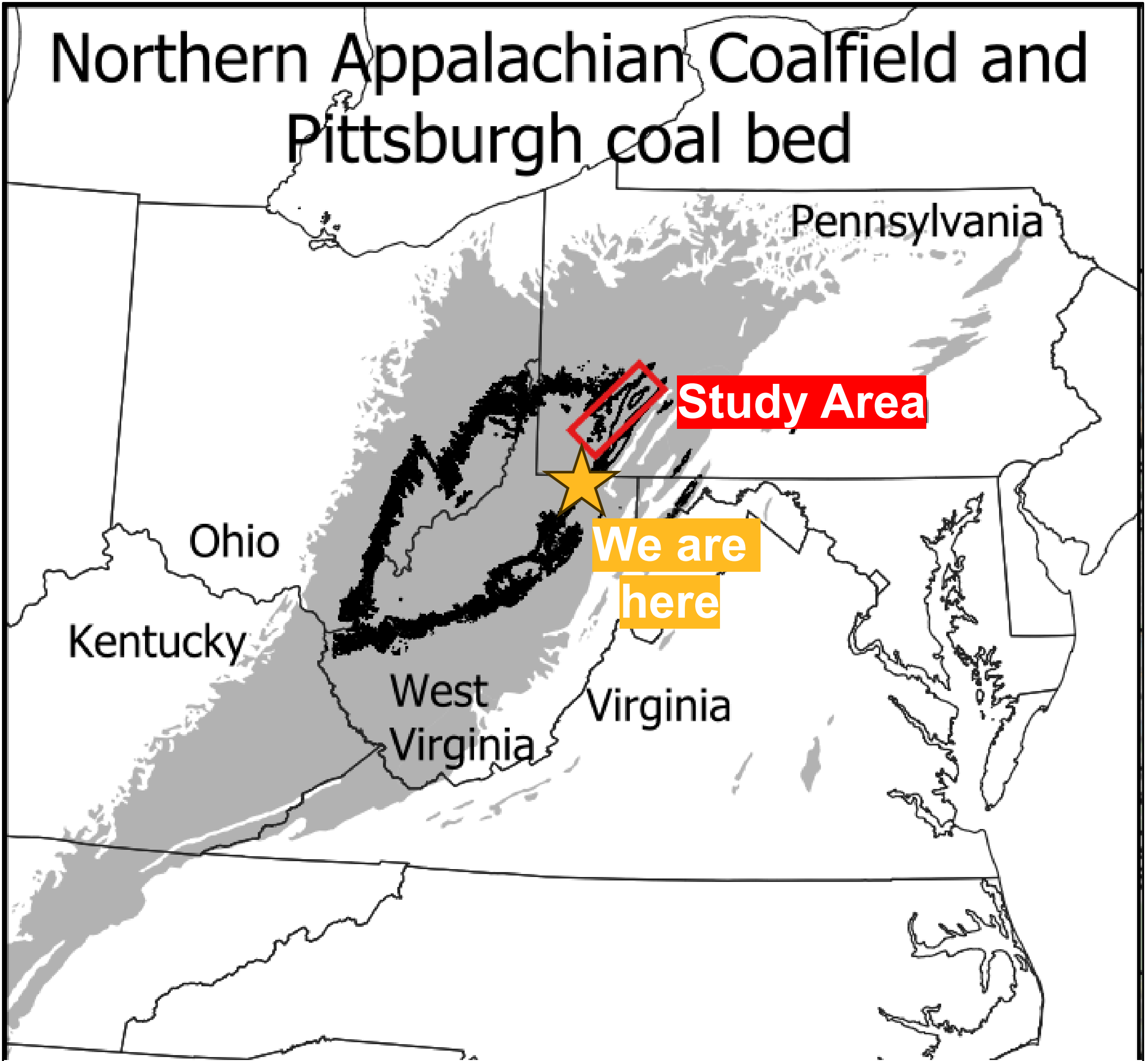
Identify/quantify important processes

Simulate CMD Evolution

Estimate remediation costs as CMD evolves

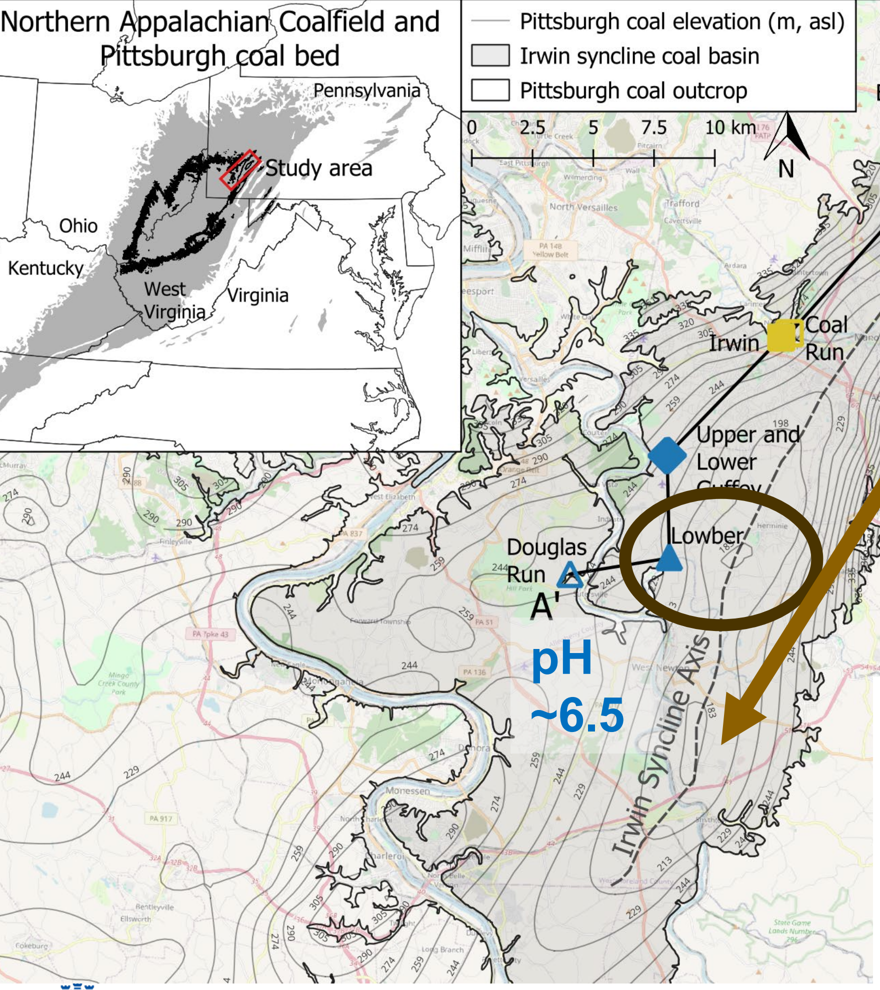
Lowber Discharge

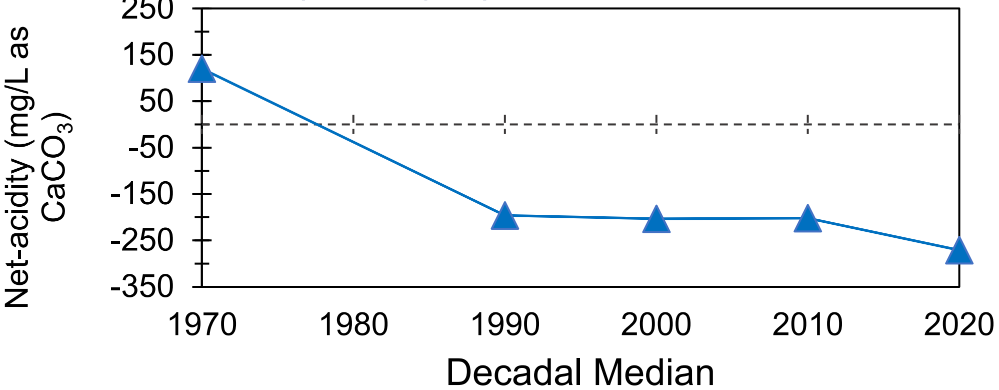
- Located in Irwin Coal Basin



Lowber Discharge

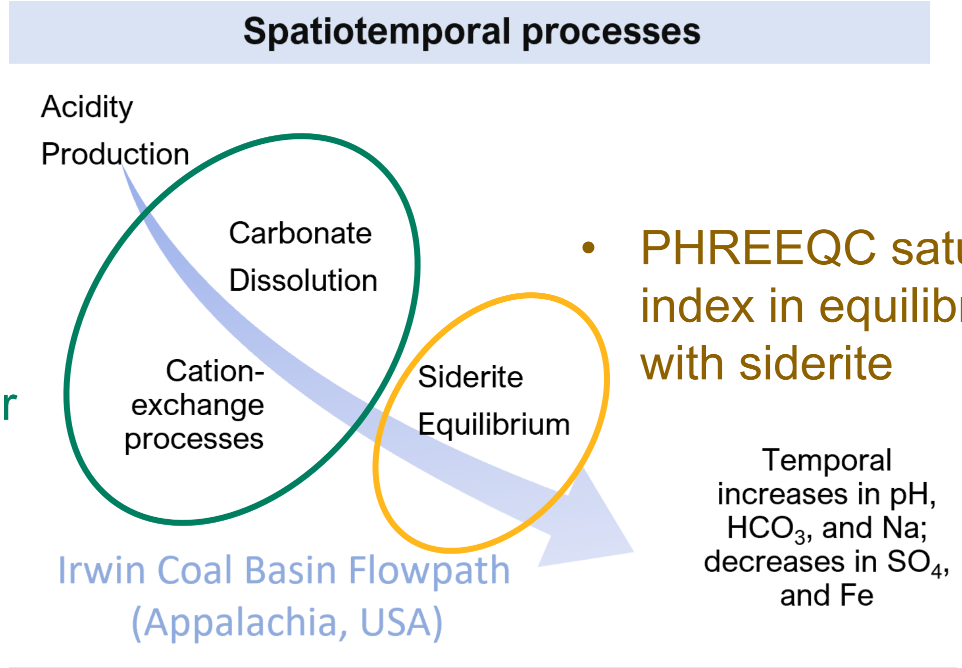
- Located in Irwin Coal Basin
- Series of CMDs that transition from net-acidic to net-alkaline along a depth profile
- Deep (94m), flooded mine with historic data showing net-acidic to net-alkaline transition
- High alkalinity (**360** mg/L as CaCO$_3$), [Na] (**450** mg/L) & Fe (**50** mg/L)





Northern Appalachian CMD: net-acidic to net-alkaline trends

- Clay-rich Overburden mineralogy, CEC measurements, and Na-rich water

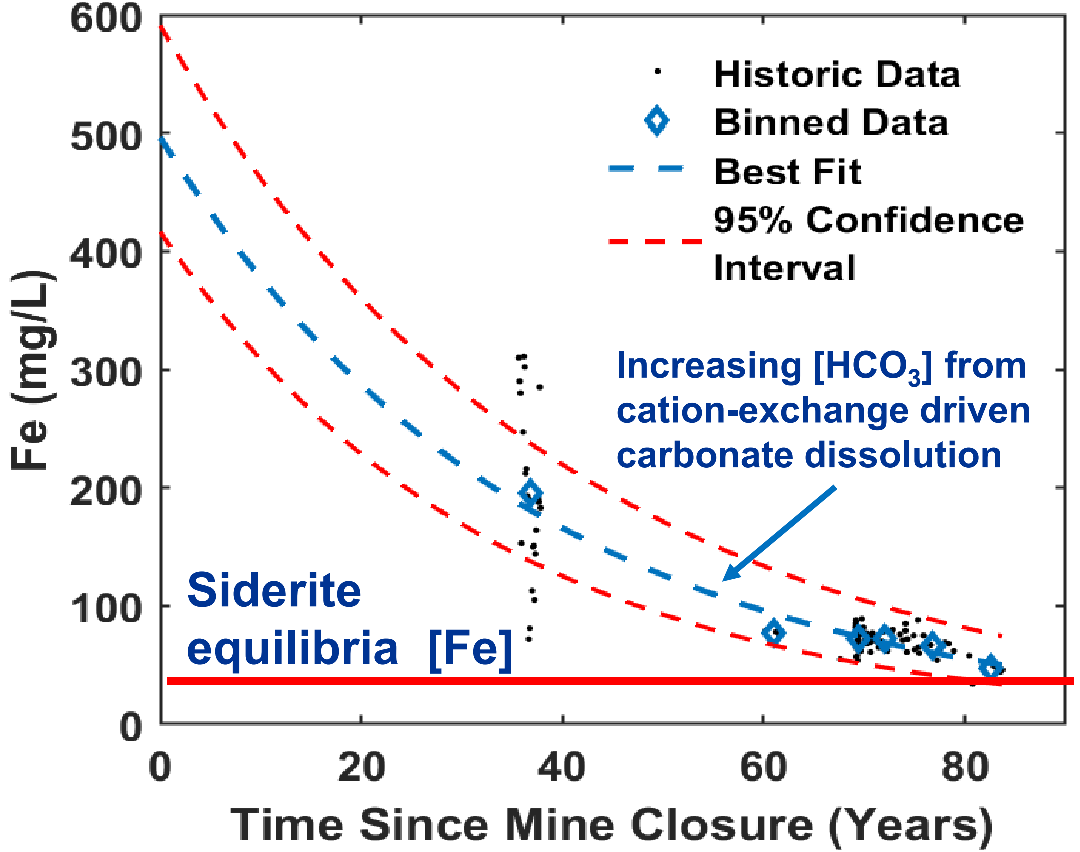


Temporal increases in pH, HCO_3, and Na; decreases in SO_4, and Fe

- PHREEQC saturation index in equilibrium with siderite

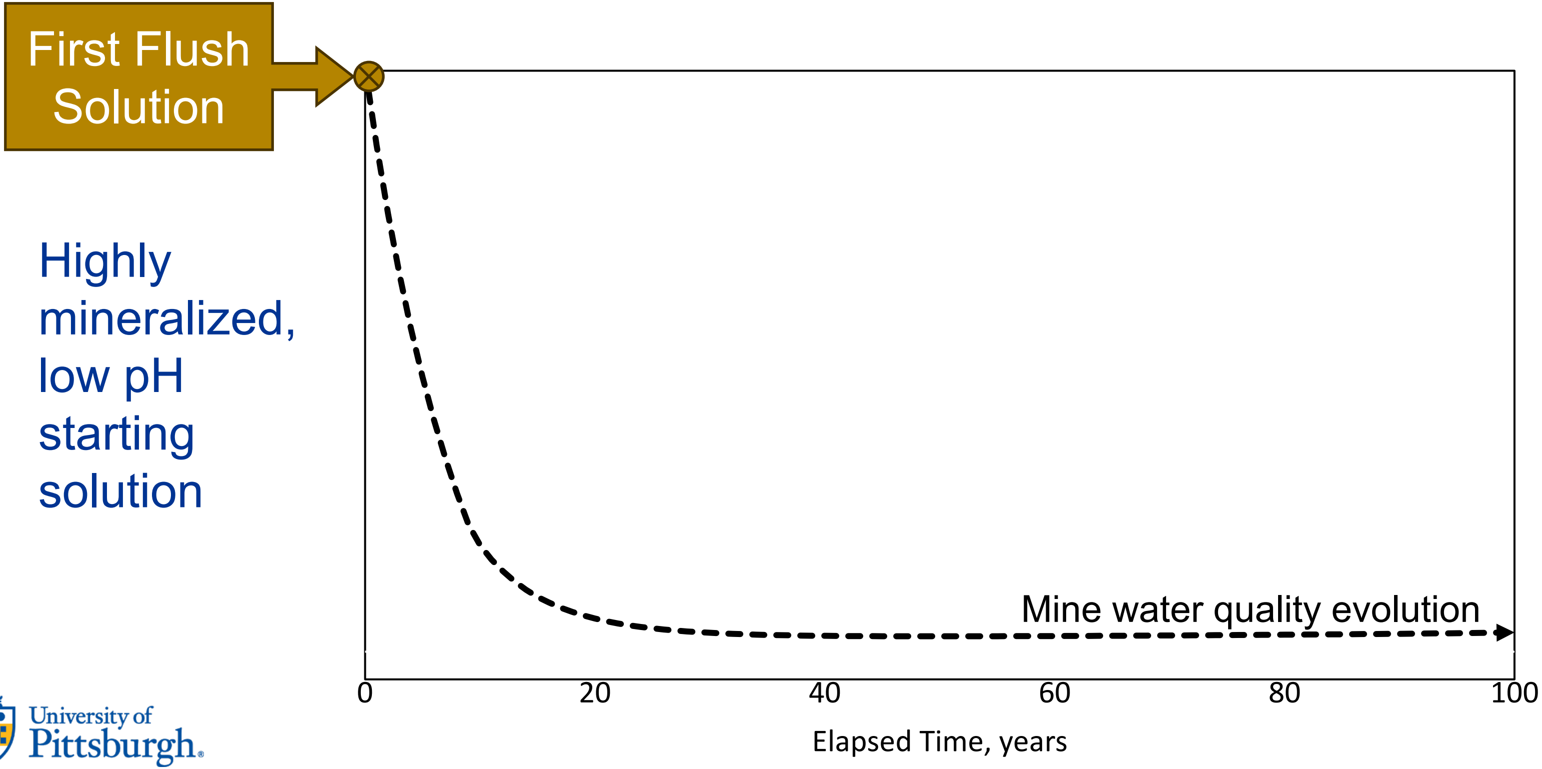
Remediation Prediction Implications

- Incorporating cation exchange and siderite equilibria into predictive models improves long term projection of acidity production


Increasing [HCO_3] from cation-exchange driven carbonate dissolution

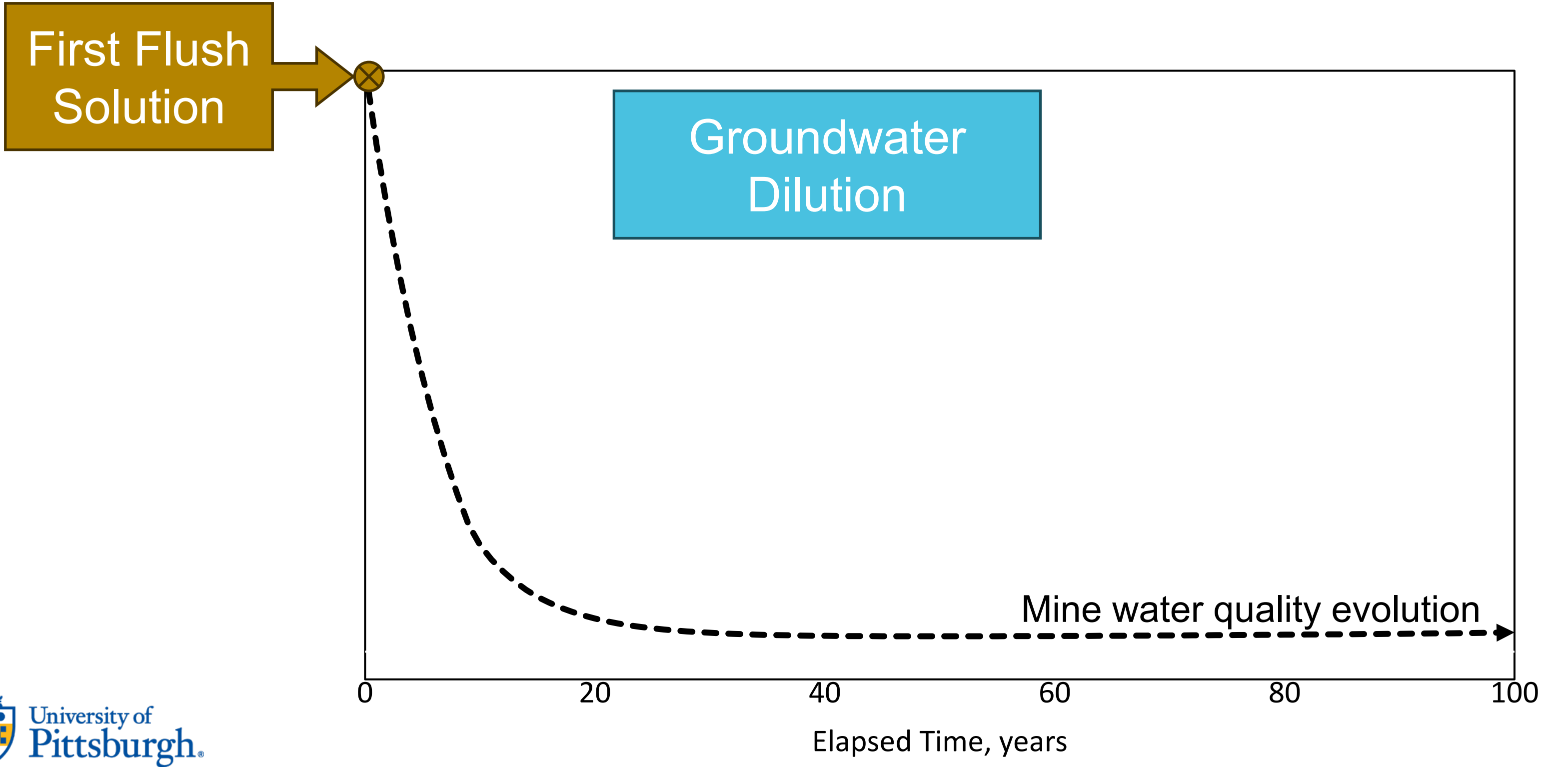
Siderite equilibria [Fe]

New Approach: First flush mixing and reaction model

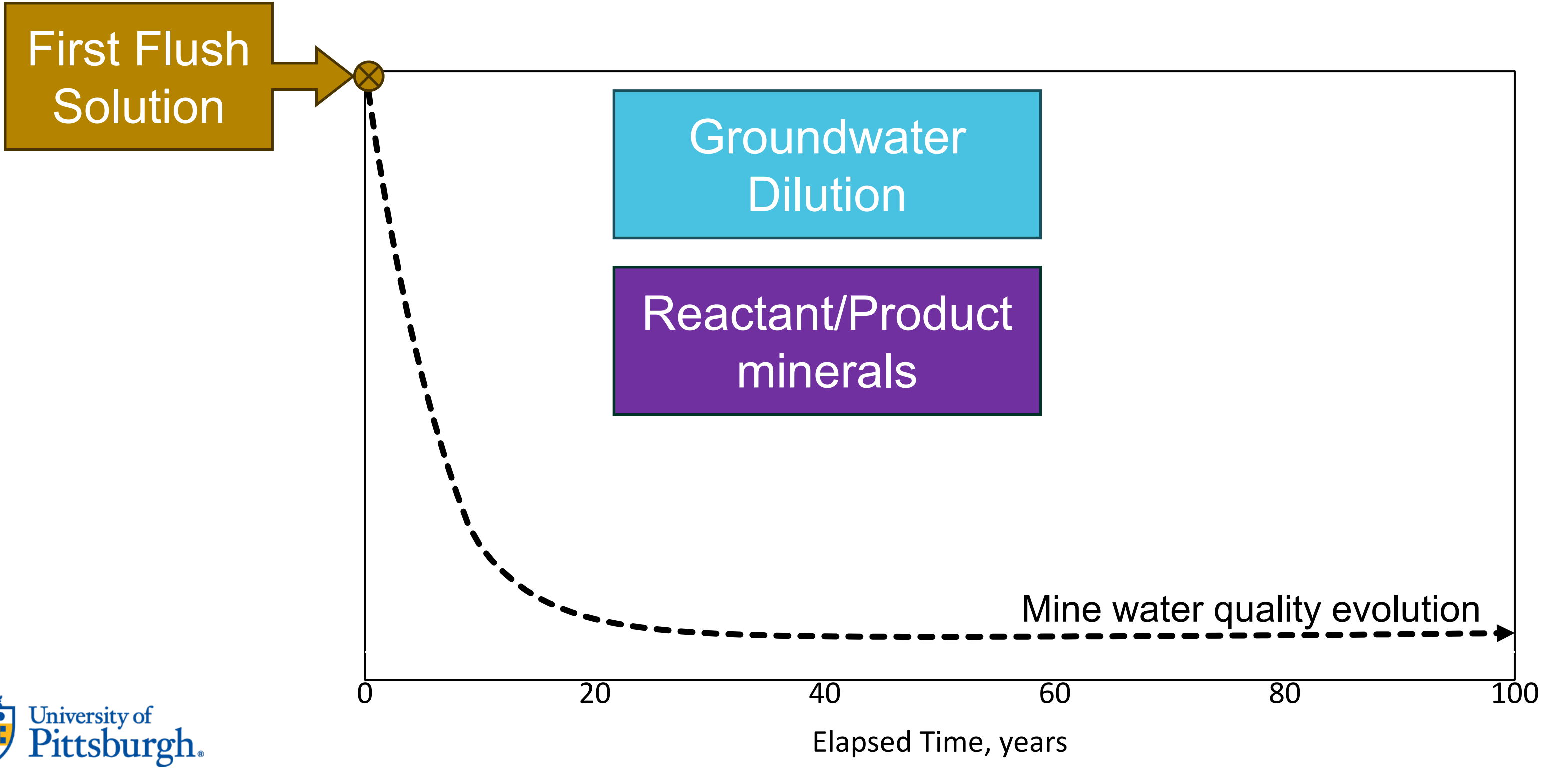


Highly mineralized, low pH starting solution

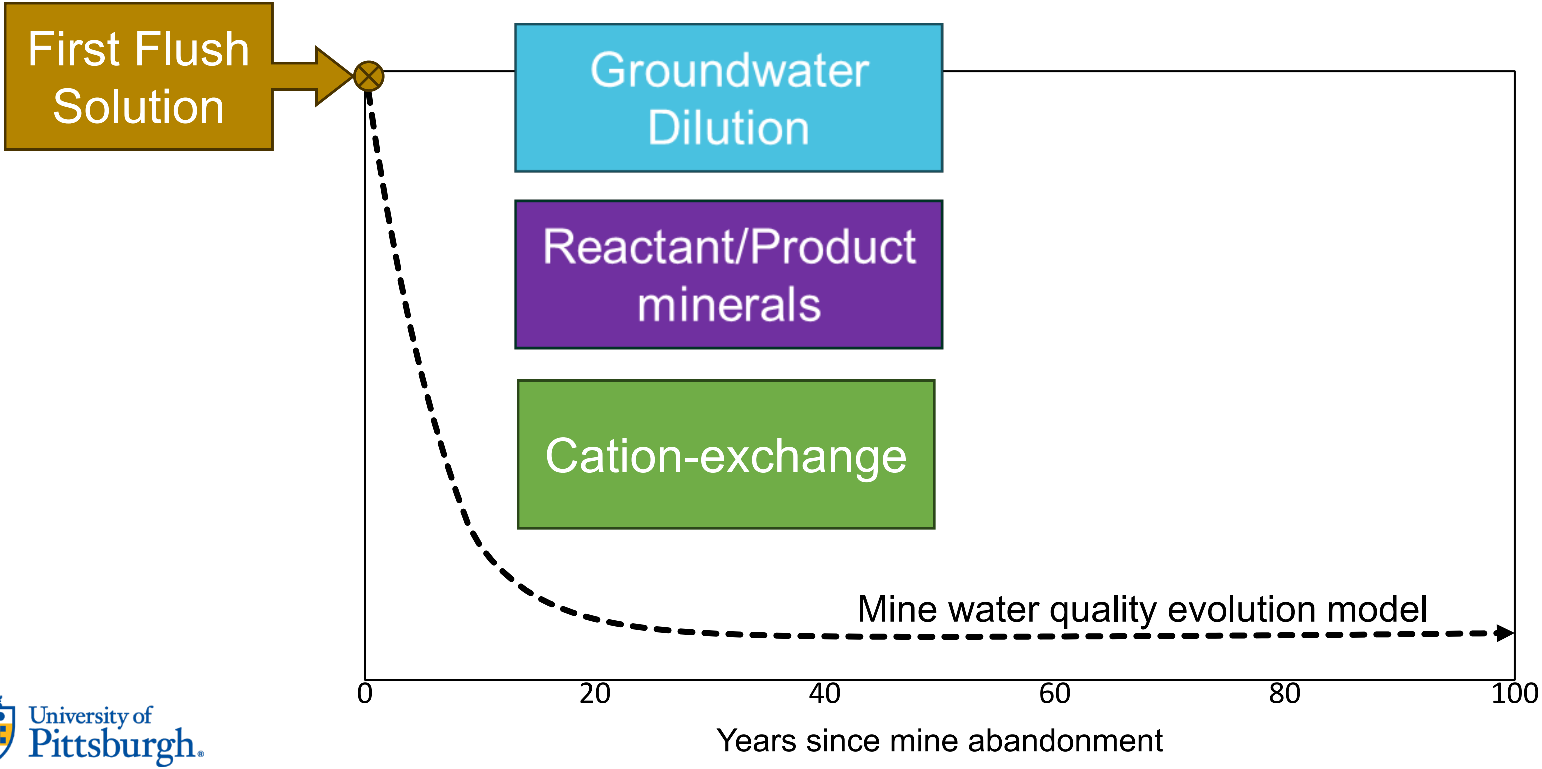
New Approach: First flush mixing and reaction model



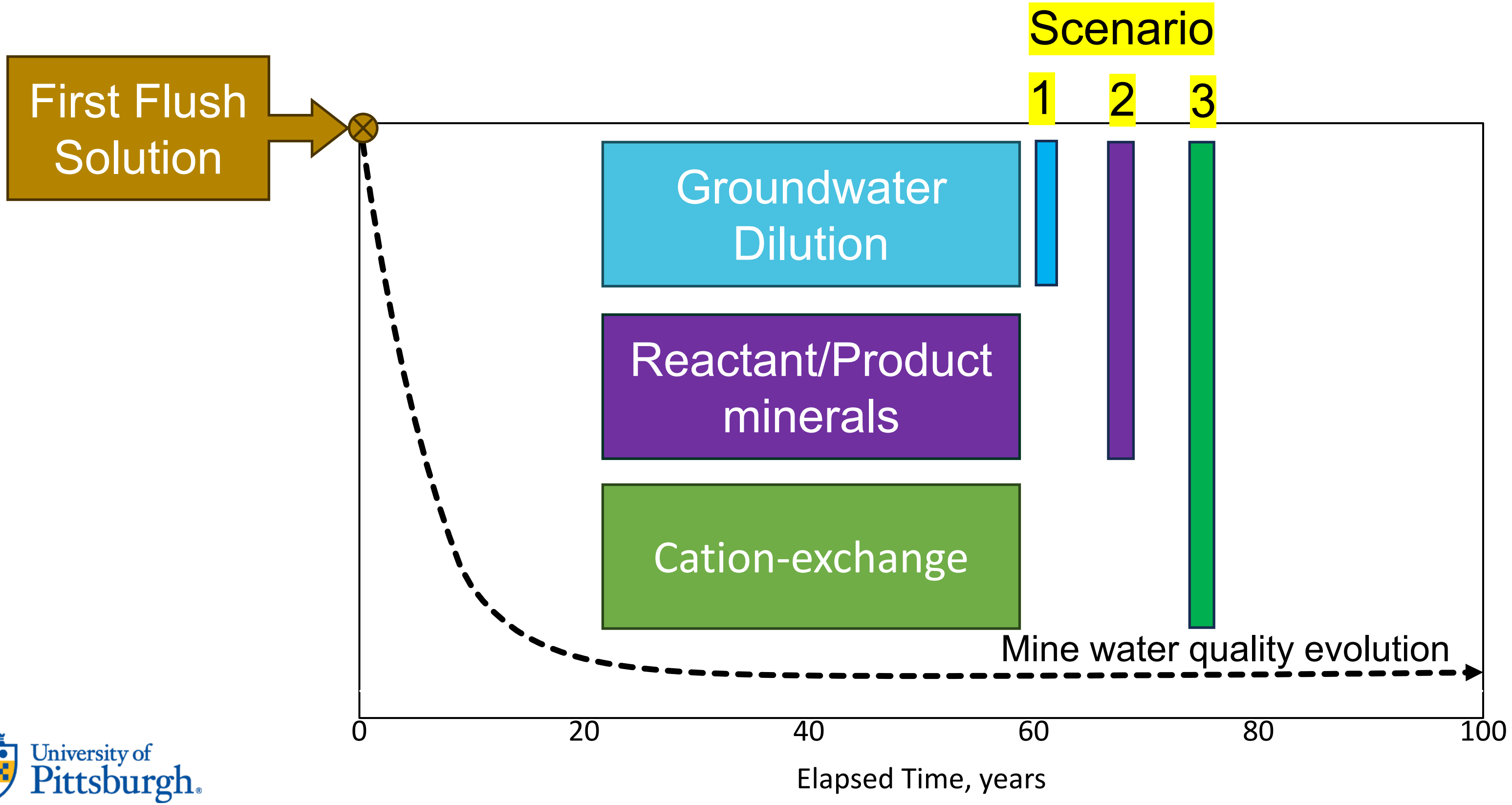
New Approach: First flush mixing and reaction model



New Approach: First flush mixing and reaction model



Three Model Scenarios



First Flush Solution

Scenario

1 2 3

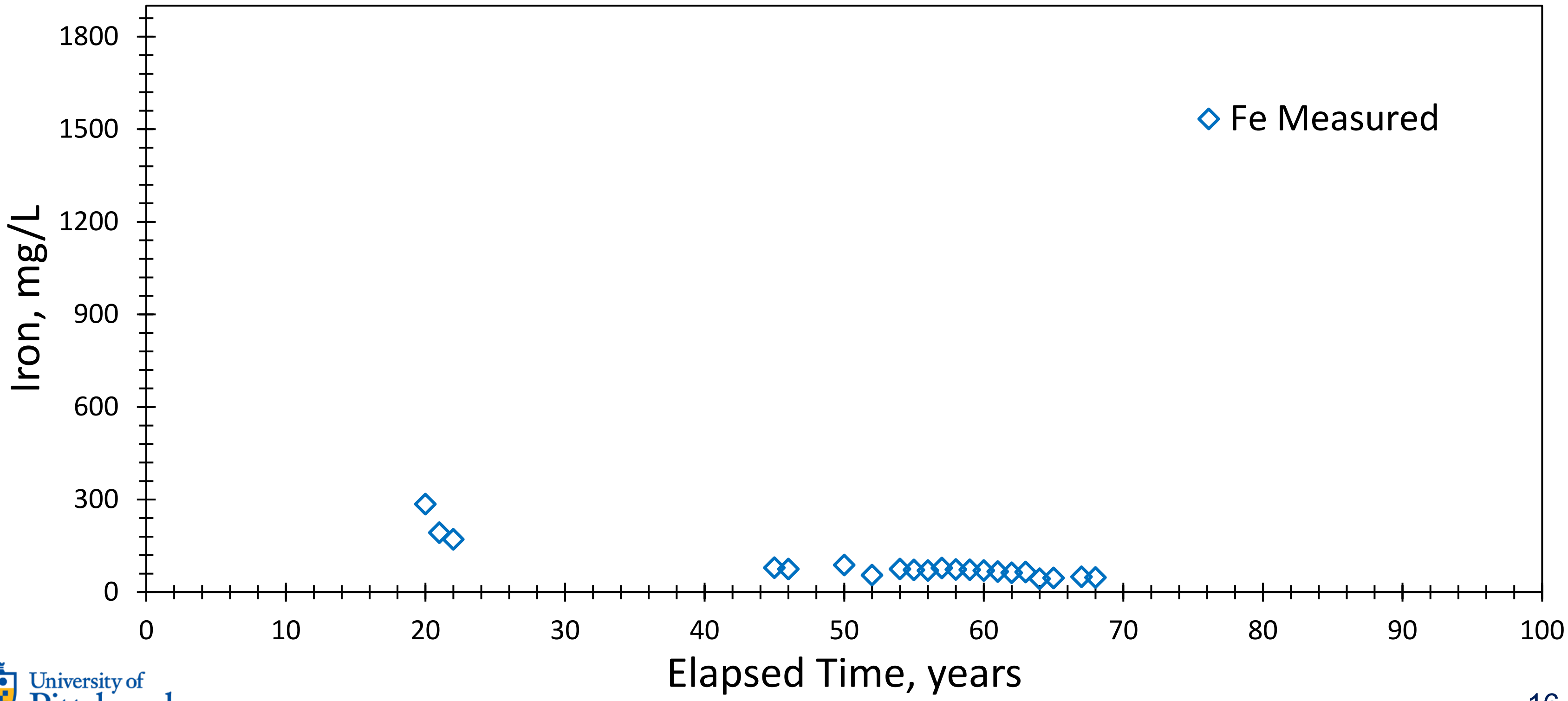
Groundwater Dilution

Reactant/Product minerals

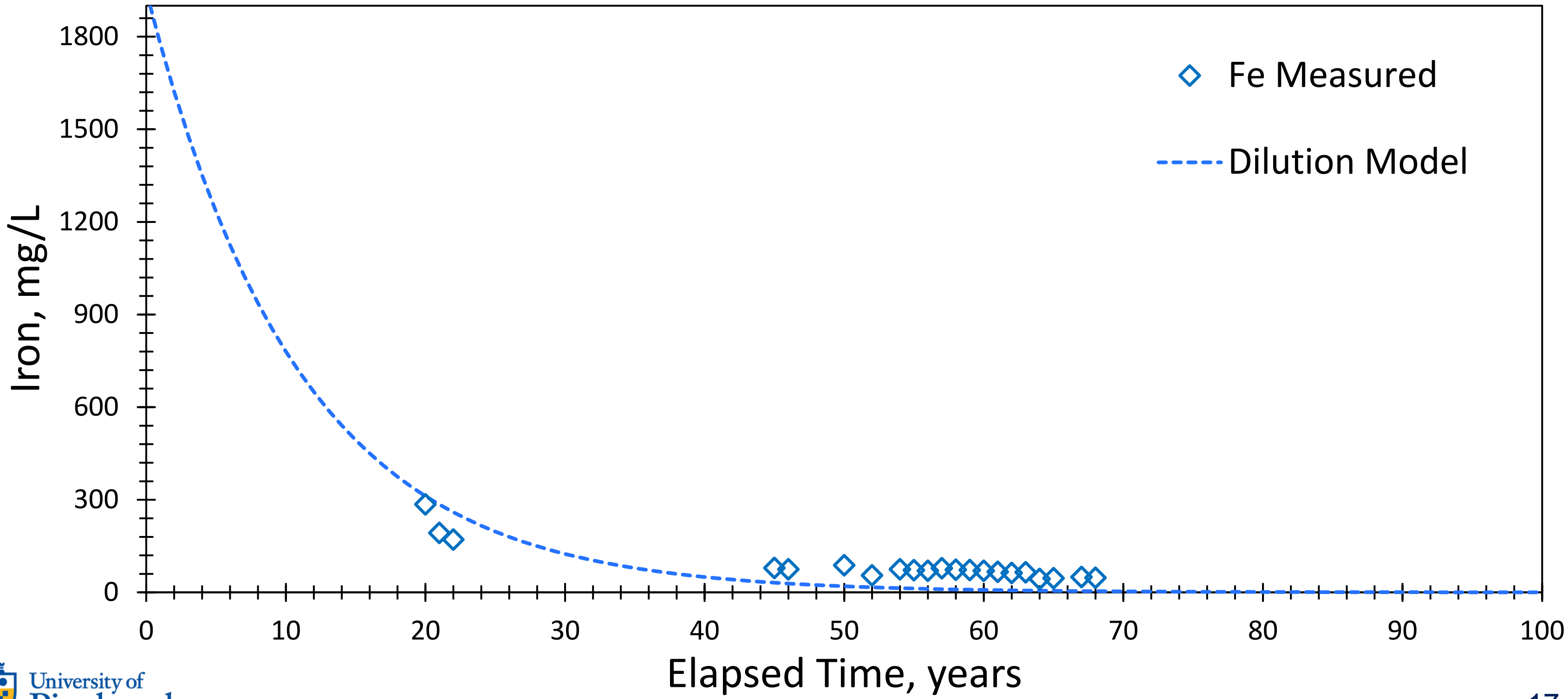
Cation-exchange

Mine water quality evolution

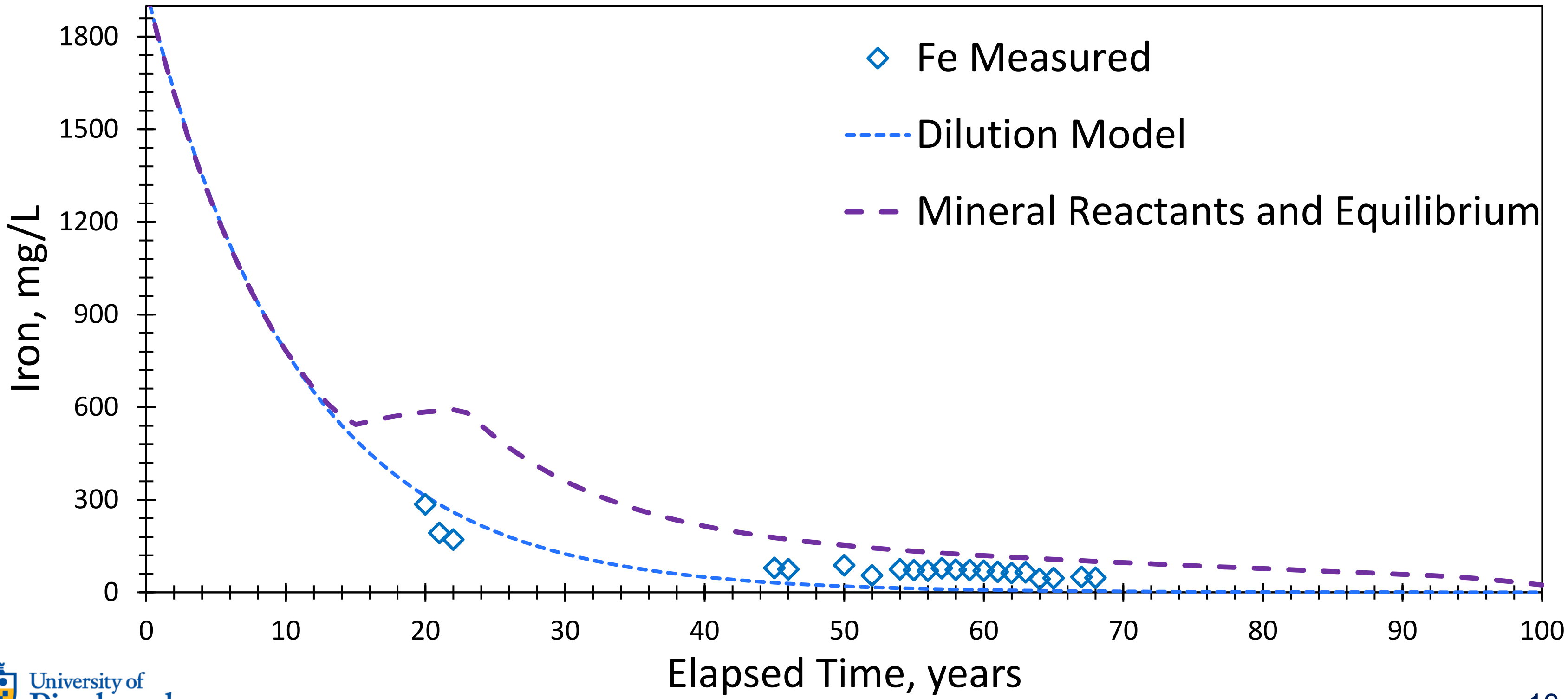
Lowber Discharge Temporal Fe data



Iron Scenario 1: Groundwater dilution



Iron Scenario 2: Dilution and mineral reaction and equilibrium



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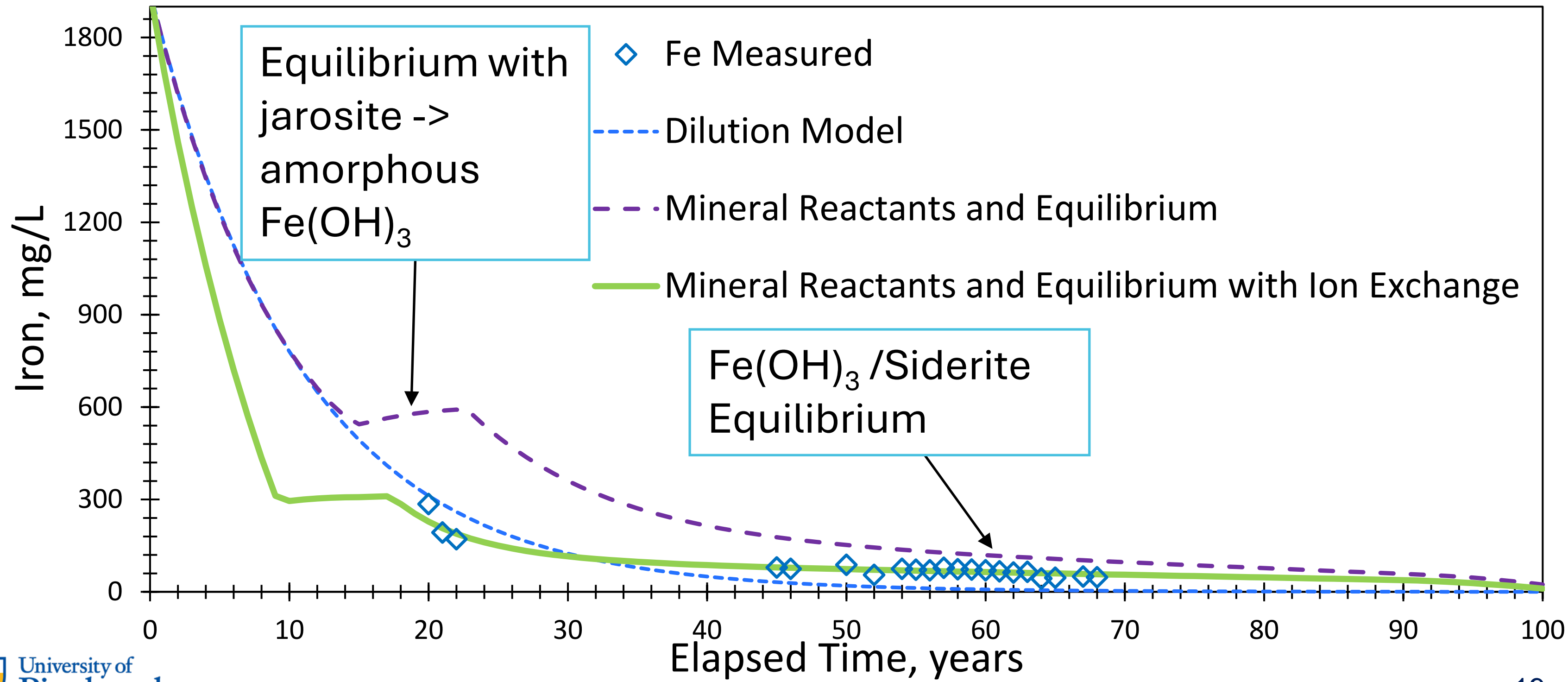
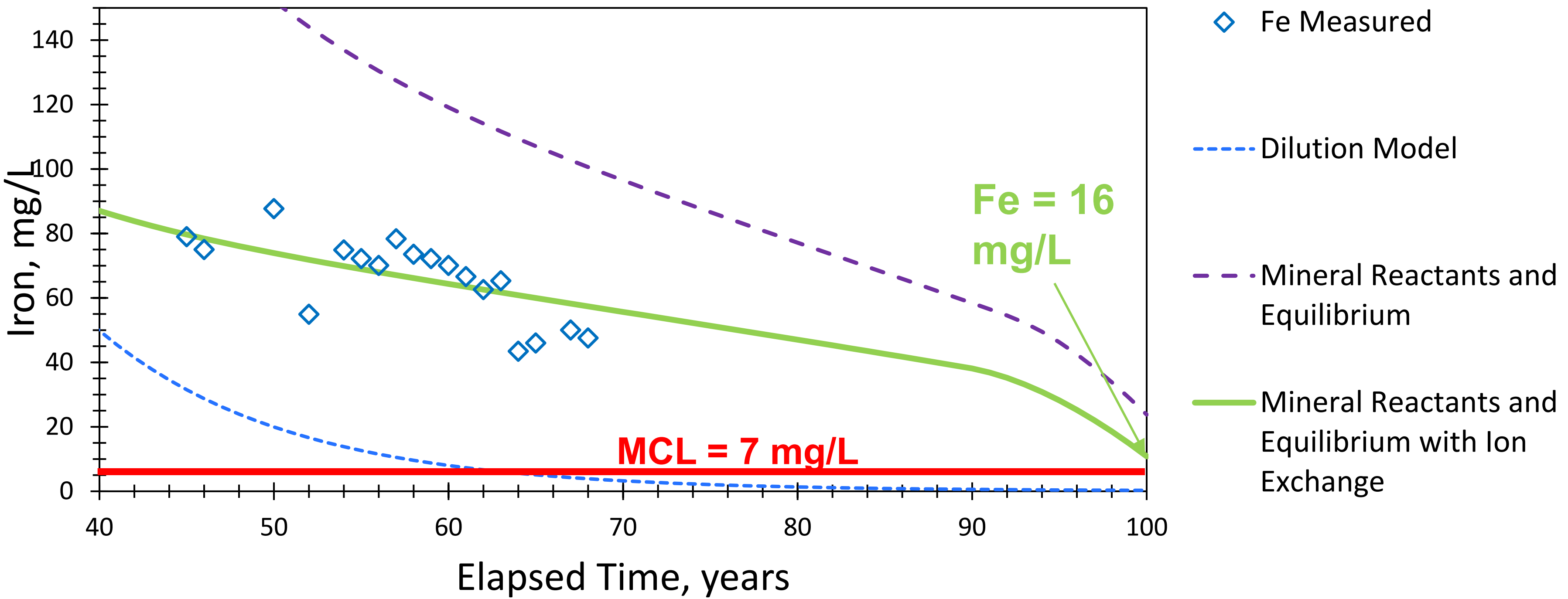
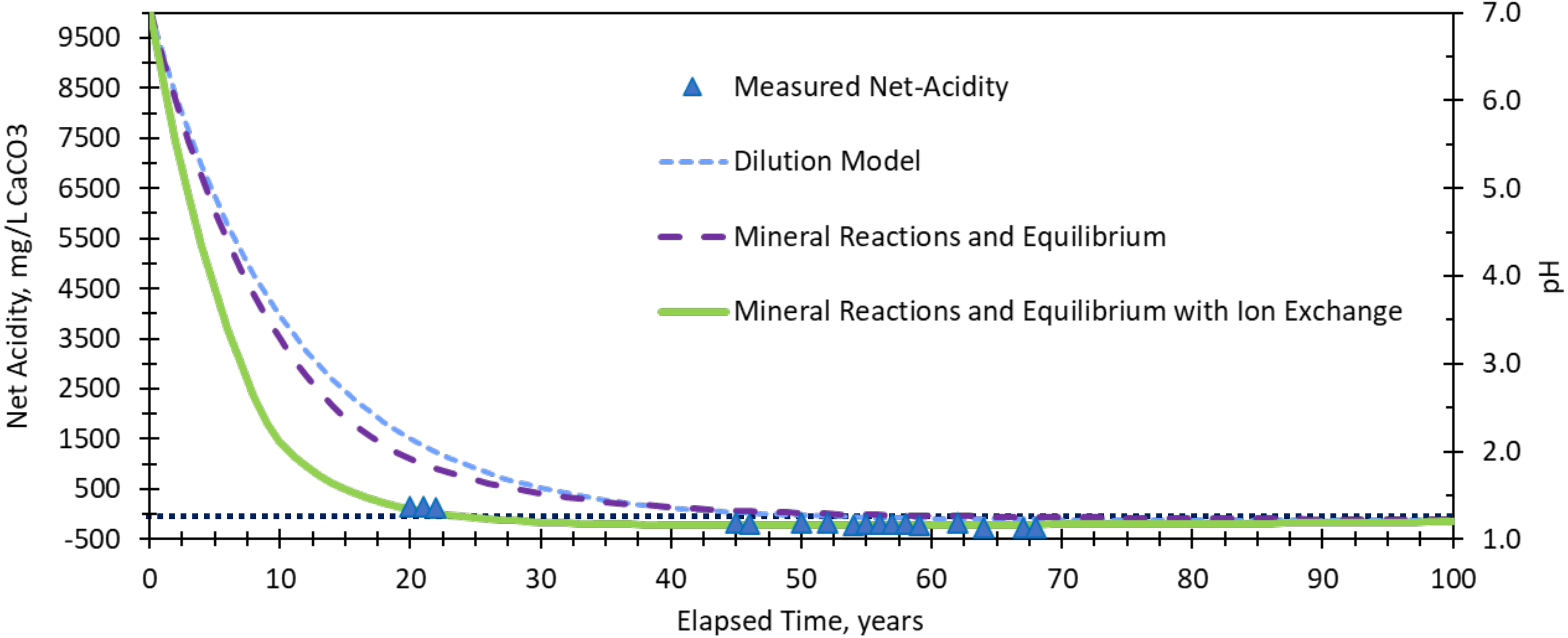
Iron Scenario 3: Mineral dissolution with cation exchange



Iron Scenario 3: Mineral dissolution with cation exchange



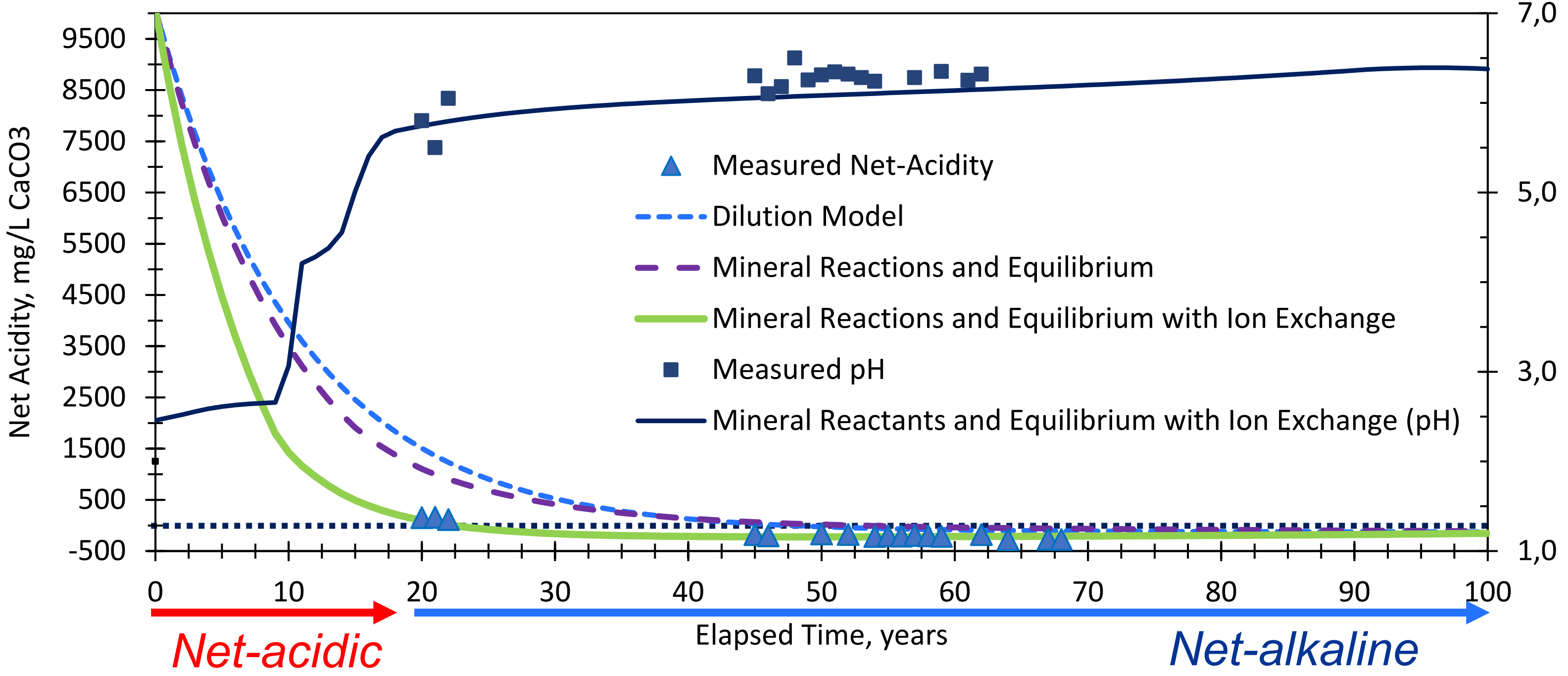
Cation-exchange influences temporal alkalinity production



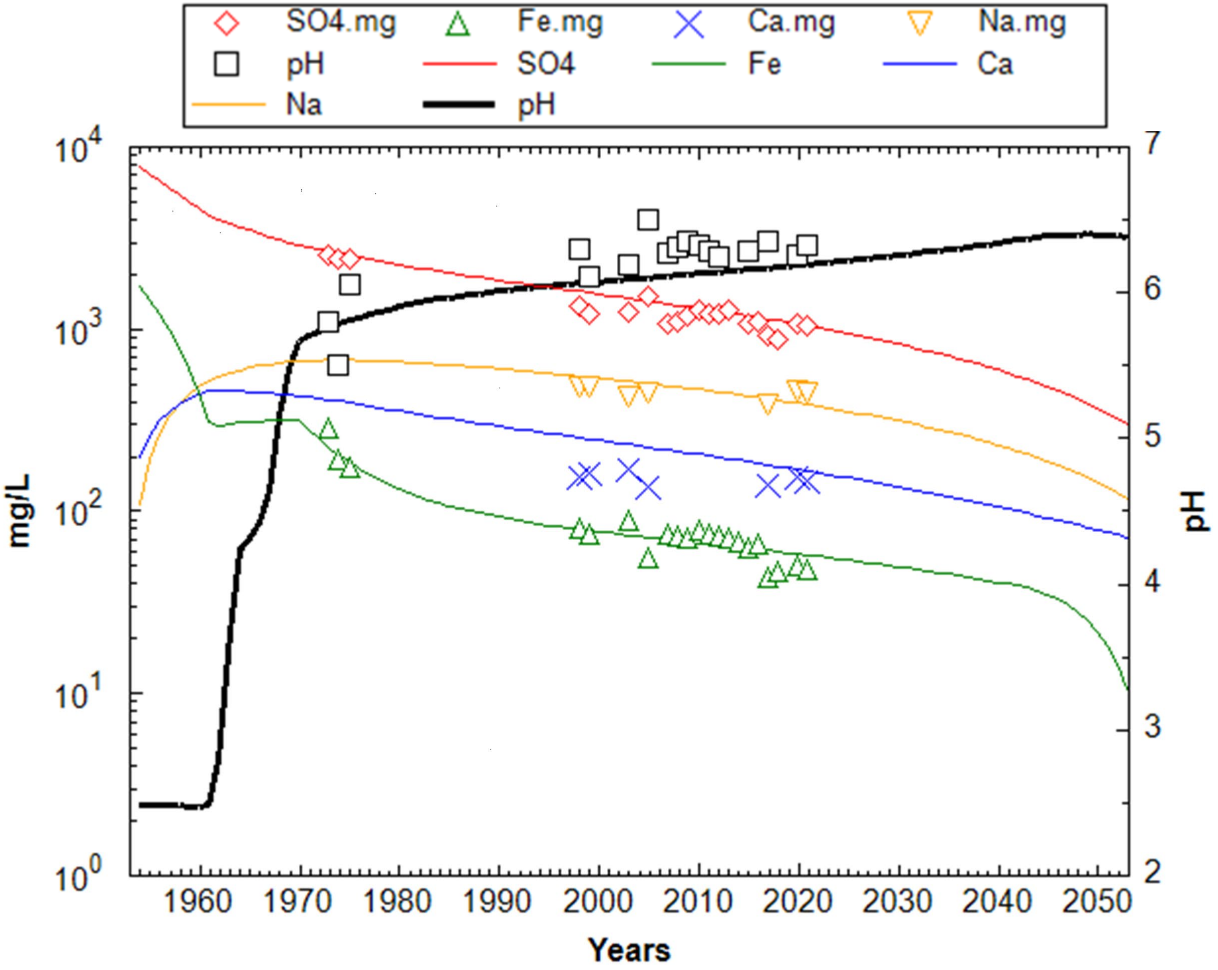
Net-acidic

Net-alkaline

Cation-exchange influences temporal alkalinity production

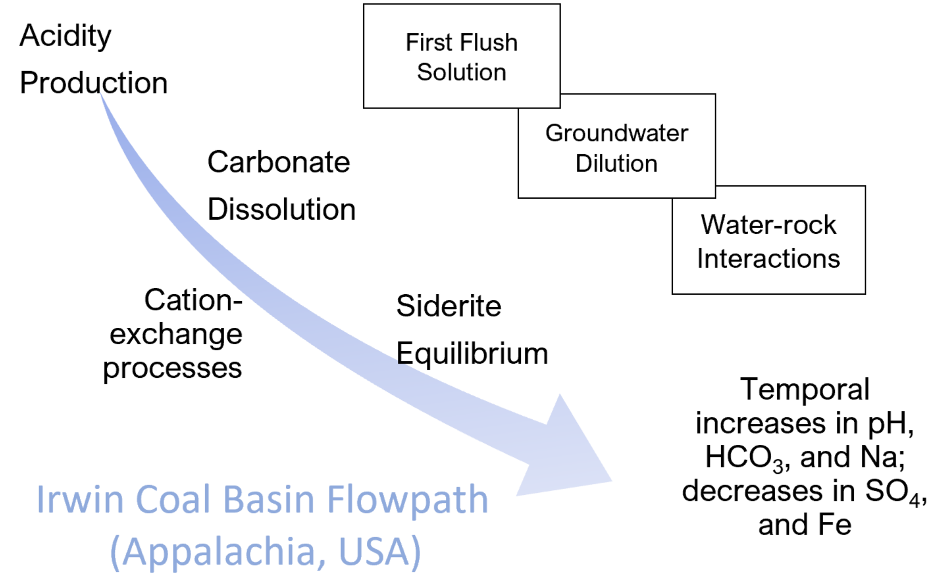


Geochemical Evolution of Lowber 1953-2053



Northern Appalachian Coal Mine Drainage: Net-acidic to net-alkaline trends

Spatiotemporal processes



Acidity Production

Carbonate Dissolution

Cation-exchange processes

Siderite Equilibrium

First Flush Solution

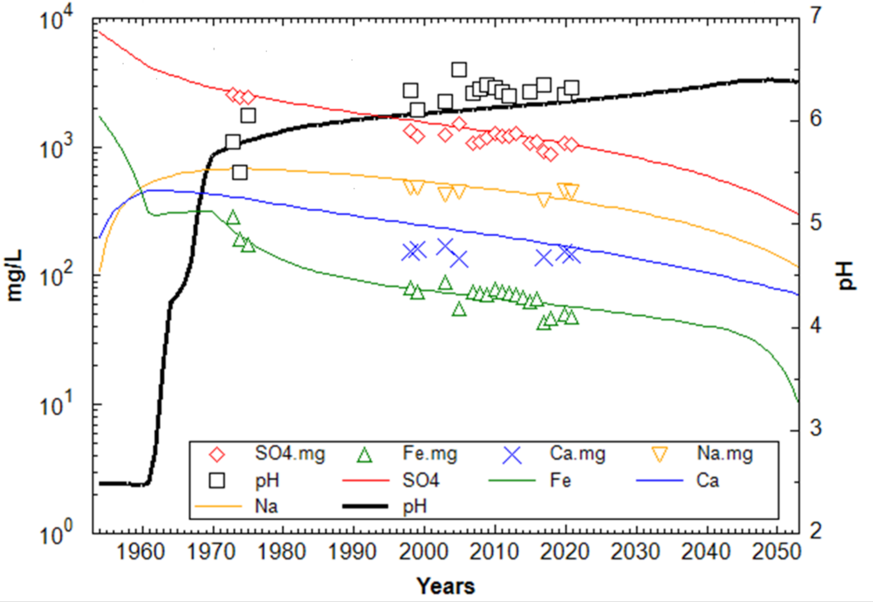
Groundwater Dilution

Water-rock Interactions

Temporal increases in pH, HCO_3, and Na; decreases in SO_4, and Fe

Irwin Coal Basin Flowpath (Appalachia, USA)

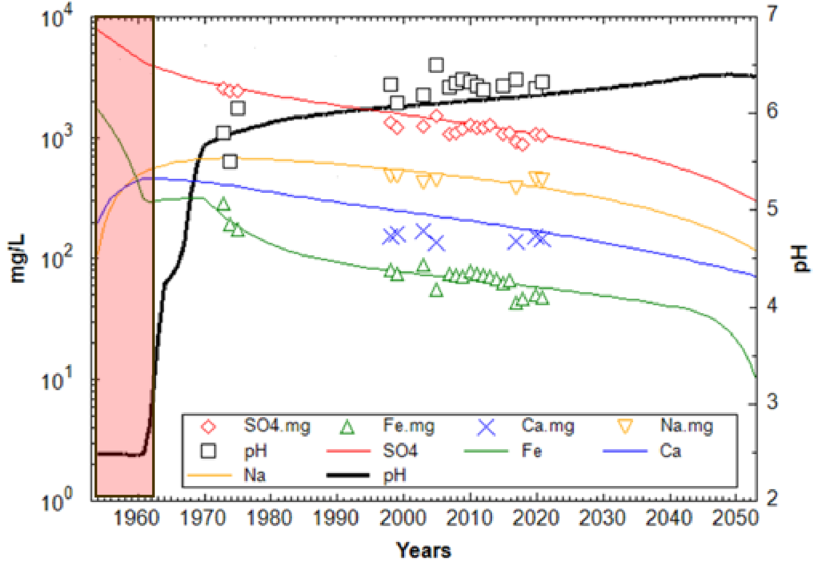
First-flush geochemical evolution model



How can we use predictive modeling to inform remediation decisions?

Long-term treatment strategies can be optimized

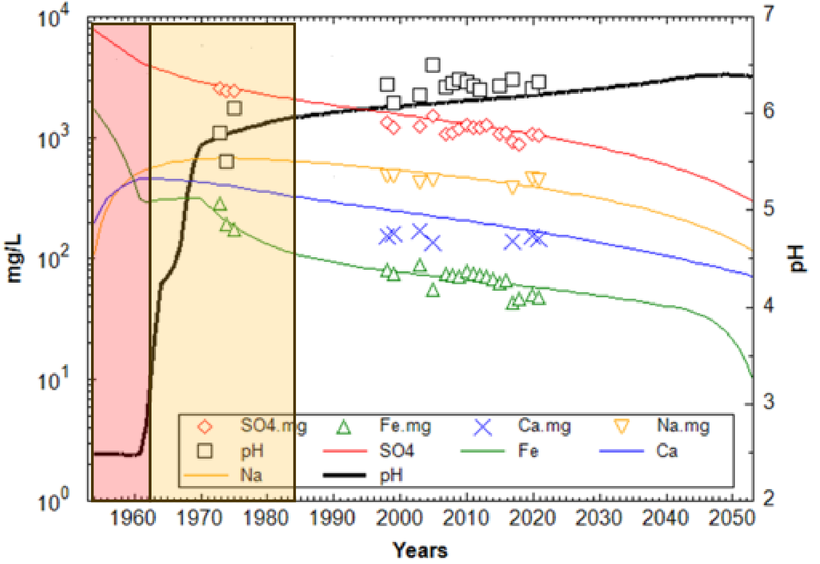
First-flush geochemical evolution model



- With models that accurately predict future CMD contaminant trends:
- CMD initially acidic after abandonment
- Requires costly active treatment that continuously dose CMD with chemicals

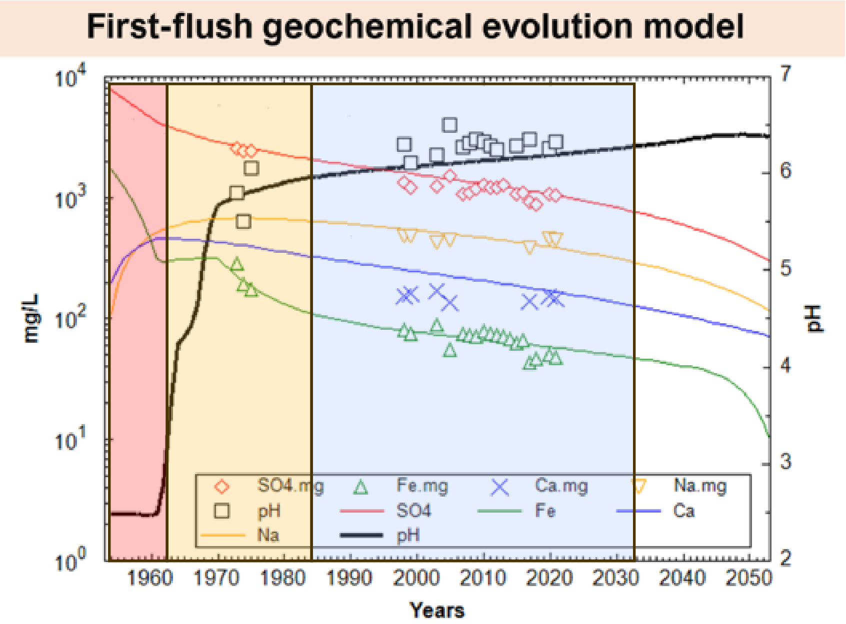
Long-term treatment strategies can be optimized

First-flush geochemical evolution model



- Minewater chemistry initially evolves to net-alkaline character:
- Some components of treatment may be scaled back

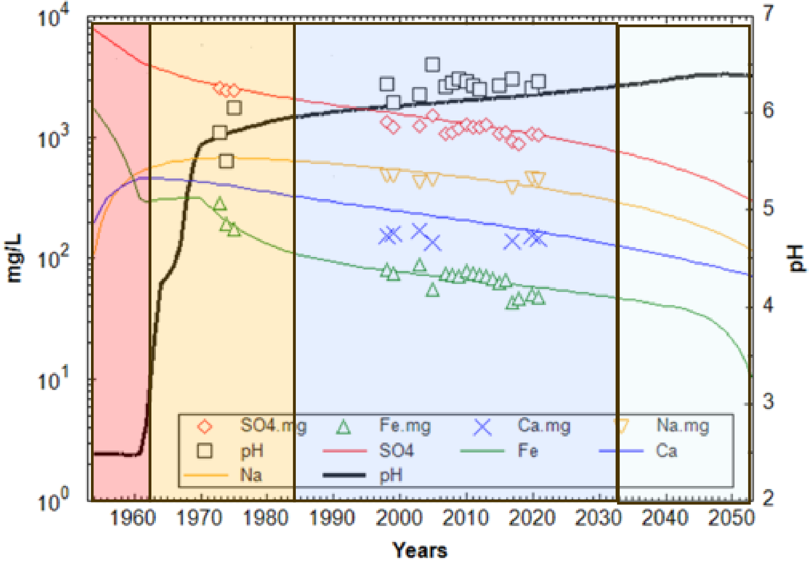
Long-term treatment strategies can be optimized



- Minewater chemistry continues to evolves to net-alkaline character with decreasing Fe and acidity:
- Passive treatment system

Long-term treatment strategies can be optimized

First-flush geochemical evolution model



- Minewater chemistry continues to evolve to net-alkaline character with decreasing Fe and acidity:
- Passive treatment system downsize

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Lowber Passive Treatment system

- Constructed in 2006
- Passive treatment system with six settling ponds and one wetland
- Promote the oxidation of Fe^{2+} and settling of Fe(III)oxyhydroxides

Lowber Passive Treatment system

Current influent chemistry:

- Fe-rich (48mg/L)
- pH: 6.3
- Net-acidity:

-262 mg/L $CaCO_3$

(net-alkaline)

Lowber Passive Treatment system

Effluent:

- Fe: <1 mg/L
- pH: ~7.0
- Falls below the maximum contaminant level for effluent mines

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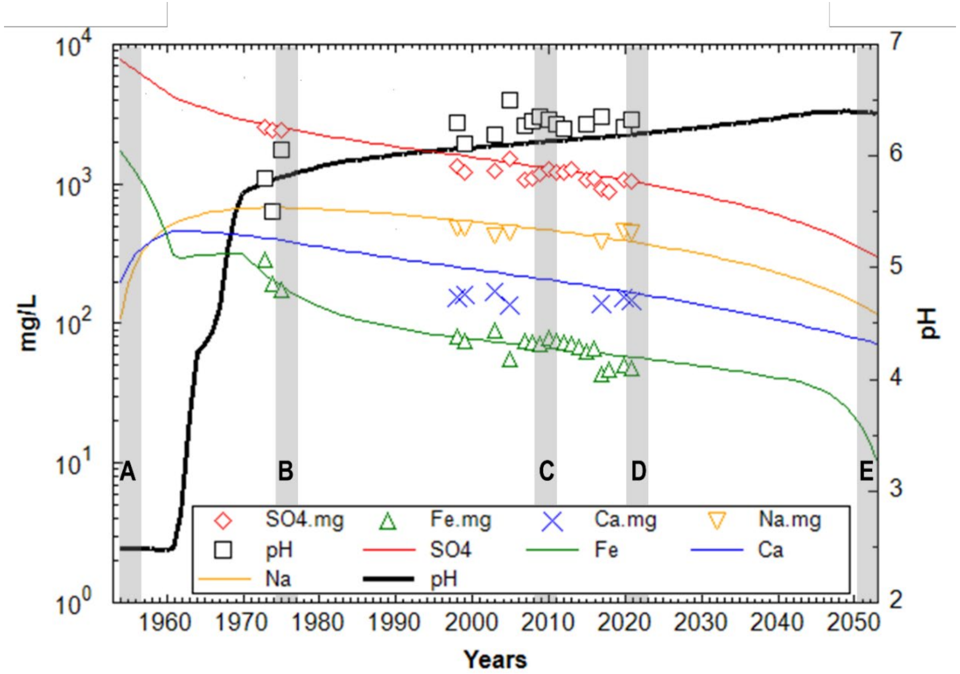
How does treatment technology and cost of net-acidic to net-alkaline Lowber CMD change over time?

A: Initial first flush (1953-1963)
B: Early net-alkaline transition (1970s)
C: Treatment installation (2007-2012)
D: Current net-alkaline (2020s)
E: Future conditions (2043-2053)



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Treatment strategy selected for each case using :

A: Initial first flush (1953-1963)
B: Early net-alkaline transition (1970s)
C: Treatment installation (2007-2012)
D: Current net-alkaline (2020s)
E: Future conditions (2043-2053)

AMDTREAT

AMDTREAT

- AMDTreat was developed cooperatively by:
  - Office of Surface Mining and Reclamation and Enforcement (OSMRE)
  - Pennsylvania Department of Environmental Protection (PADEP)
  - U.S. Geological Survey (USGS)
  - West Virginia Department of Environmental Protection (WVDEP)

AMDTREAT

2 Objectives:

- Provide ability to develop **site-specific cost estimates** to treat mine drainage.
  - Active and passive technologies

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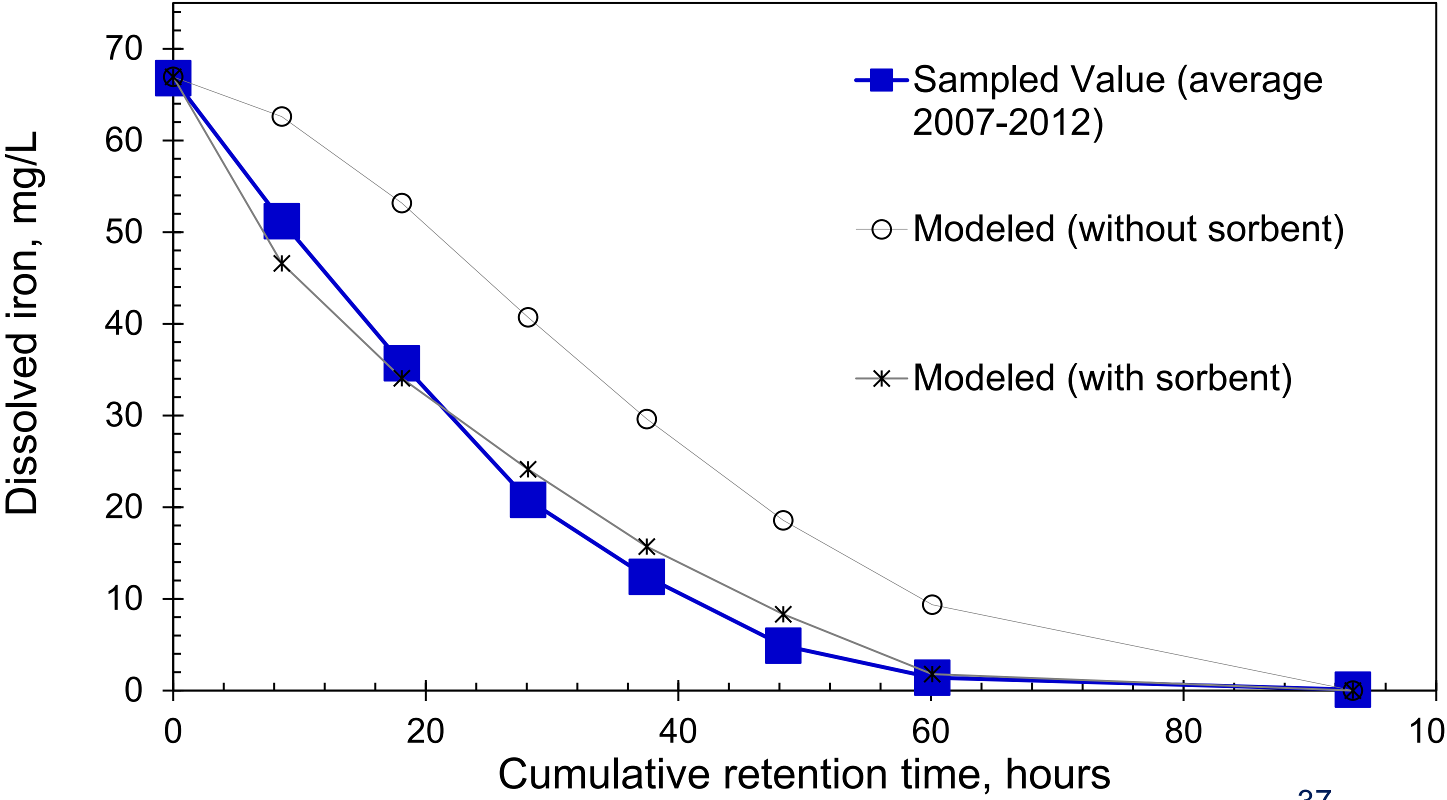
AMDTREAT

2 Objectives

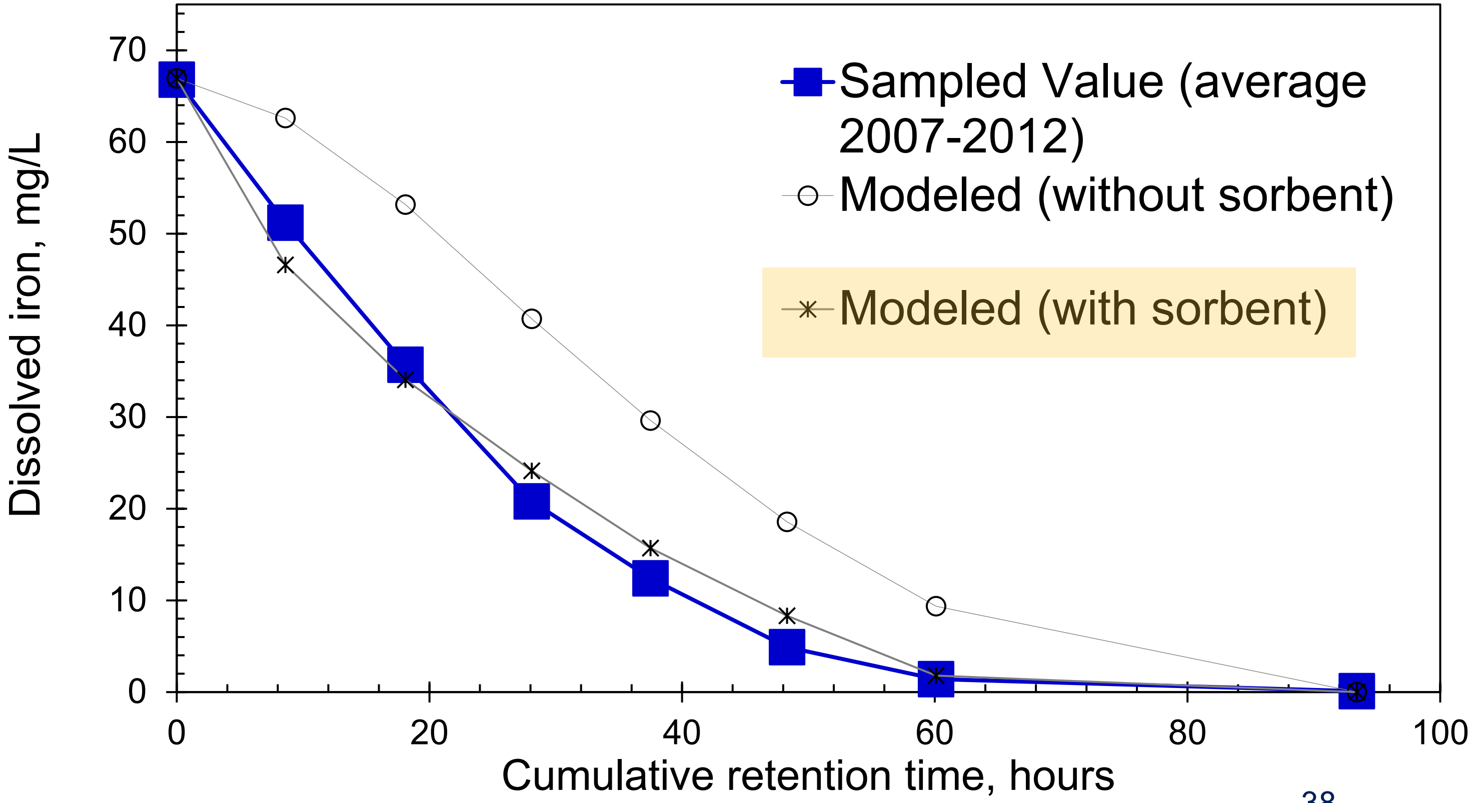
- Provide ability to develop **site-specific cost estimates** to treat mine drainage.
  - Active and passive technologies
- Provide the **ability to geochemically model mine drainage treatment.**
  - **PHREEQ-N-AMDTreat** is a geochemical modelling tool capable of simulating changes in pH and solute concentration for a range of active and passive treatment technologies

Phreeq-N-AMDTreat vs. Real Lowber treatment data



Phreeq-N-AMDTreat vs. Real Lowber treatment data

- Fe sorbent is a key variable in the model to accurately predict minewater treatment



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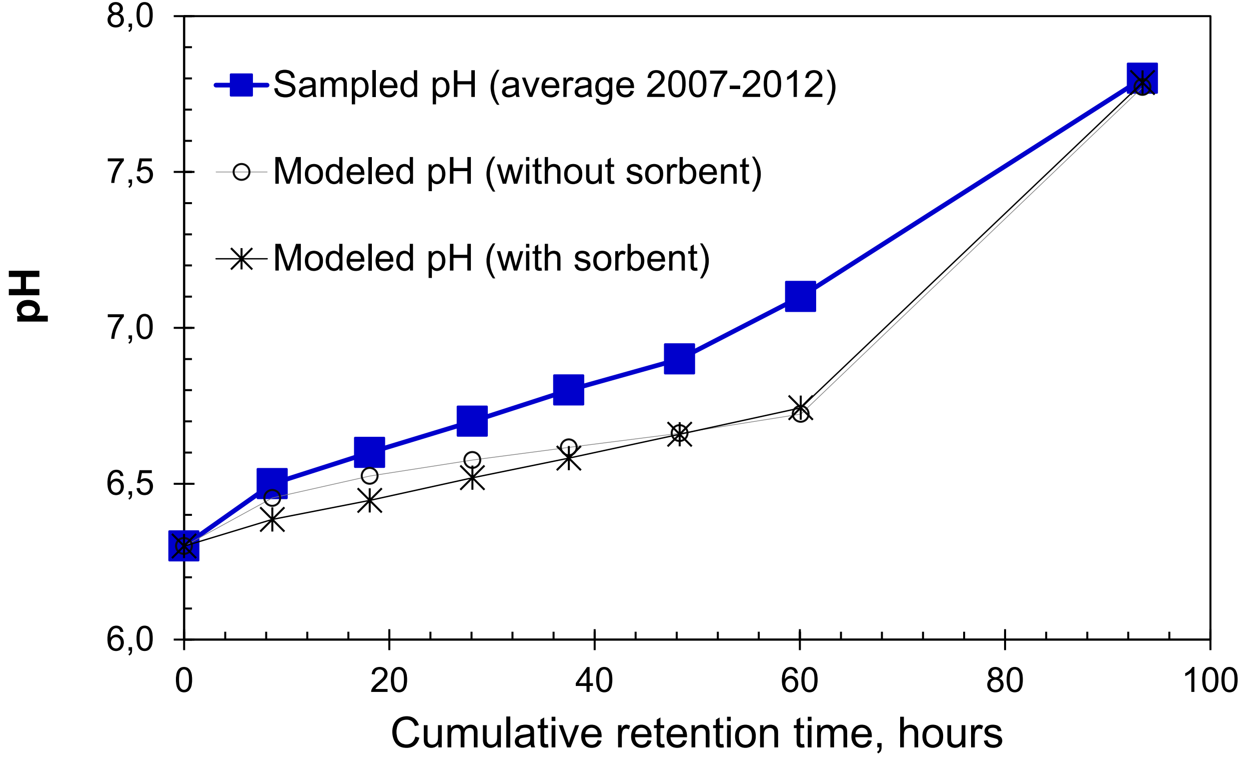
Phreeq-N-AMDTreat vs Real Lowber data

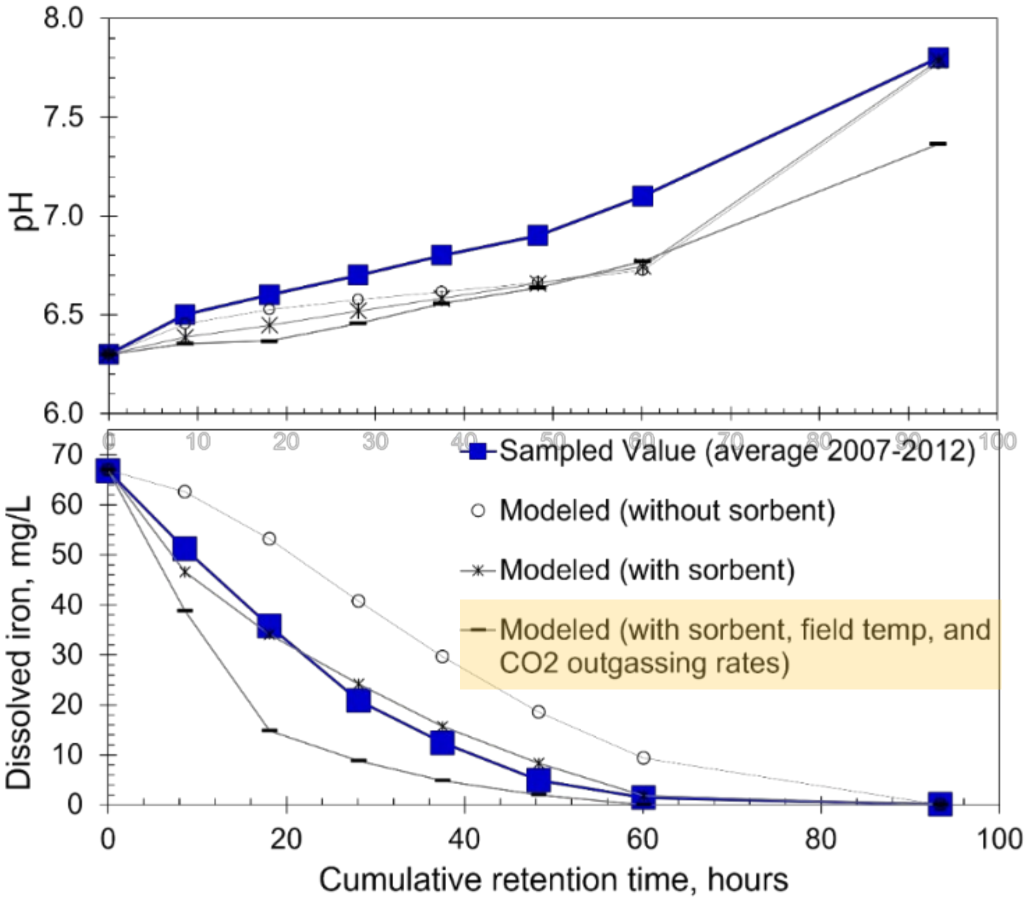


- Modeled pH was underestimated
- Averaging pH in sample data may have resulted in an overestimation

$$pH = -\log[H^+]$$

Phreeq-N-AMDTreat vs Real Lowber data

- P_{CO2} calculations are pH and temperature sensitive
  - Averaging pH data affected calculations
- However, still produced similar default vs. calculated CO_2 outgassing rates



AMDTreat: Cost-analysis of treatment over time

A: Initial first flush (1953-1963) **B:** Early net-alkaline transition (1970s)	**Active treatment** • Same footprint, different chemicals added
C: Treatment installation (2007-2012) **D:** Current net-alkaline (2020s) **E:** Future conditions (2043-2053)	**Passive treatment** • Same footprint of current passive treatment system in place

AMDTreat: Cost-analysis of treatment over time

Net-Present Value (75 years)
$33.1 million

A: Initial first flush (1953-1963)
B: Early net-alkaline transition (1970s)

C: Treatment installation (2007-2012)
D: Current net-alkaline (2020s)
E: Future conditions (2043-2053)

$1.7 million

AMDTreat: Active treatment cost estimates over time

Time Period	**Treatment Technology**	**Capital Cost** USD	**Annual O&M Costs** USD	**Net Present Value** USD	**Project Footprint** hectares
A:1953-1963	Decarbonation, Lime, Reaction Tank, Clarifier, Wetland	3,080,000	970,000	33,000,000	0.935
B: 1972-1975	Decarbonation, H_2O_2, Reaction Tank, Clarifier, Wetland	2,580,000	560,000	19,400,00	0.935

- CMD chemistry improved from net-acidic to net-alkaline
- Switch from lime to hydrogen peroxide decreased annual costs

AMDTreat: Passive treatment cost estimates over time

Time Period	**Treatment Technology**	**Capital Cost** USD	**Annual O&M Costs** USD	**Net Present Value** USD	**Project Footprint** hectares
C: 2007-2012	Decarbonation, Ponds (6), Wetland (1)	1,560,000	42,000	2,350,000	5.19
D: 2017-2021	Decarbonation, Ponds (6), Wetland (1)	1,560,000	41,000	**2,140,000**	5.19
E: 2043-2053	Decarbonation, Ponds (6), Wetlands (1)	1,510,000	23,000	**1,720,000**	5.19

Actual Capitol Costs vs AMDTreat cost estimate

Time Period	**Treatment Technology**	**Capital Cost**	**Annual O&M Costs**	**Net Present Value**	**Project Footprint**
		USD	USD	USD	hectares
C: 2007-2012	Decarbonation, Ponds (6), Wetland (1)	1,600,000	42,000	2,350,000	5.19
D: 2017-2021	Decarbonation, Ponds (6), Wetland (1)	1,600,000	41,100	**2,140,000**	5.19
E: 2043-2053	Decarbonation, Ponds (6), Wetlands (1)	1,510,000	23,000	**1,717,000**	5.19

2006 Capitol costs: ~$1.3 million ($1.9 million with inflation)

20% underestimation of reported costs

Sludge removal is limited by:

- **Site Storage**
- **Available Funds**

Conclusions

- We identified important spatiotemporal trends affecting the net-acidic to net-alkaline transition in deep minepools
- Late-stage Fe concentrations are influenced by siderite equilibrium acting as a source and sink of Fe in deep minepools
- CEC influences the timing of net acidic to net alkaline transition and ion composition.
- Forward modeling approaches that include dilution, mineral reactions, and CEC are needed to describe contaminant and major ion evolution accurately.
- Changes in CMD management strategies may be warranted as CMD chemistry improves on a decadal timescale
- User background experience and knowledge on actual industry costs is essential for making cost estimates of treatment systems

Thank you

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West Virginia University