Estimating Water Quality Trends in Abandoned Coal Mine-pools

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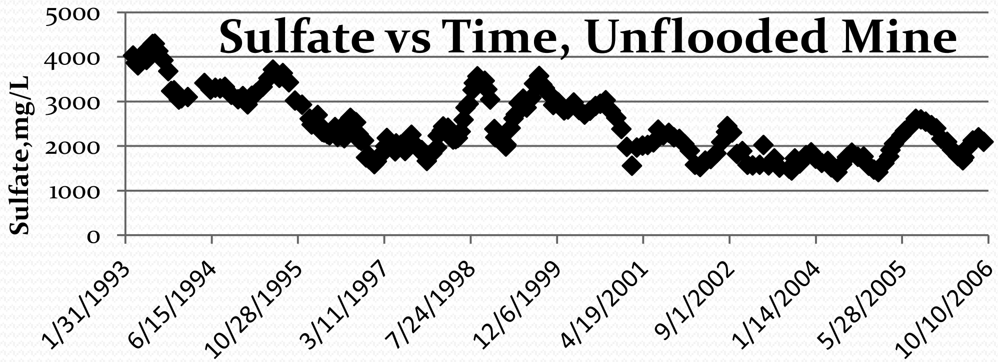
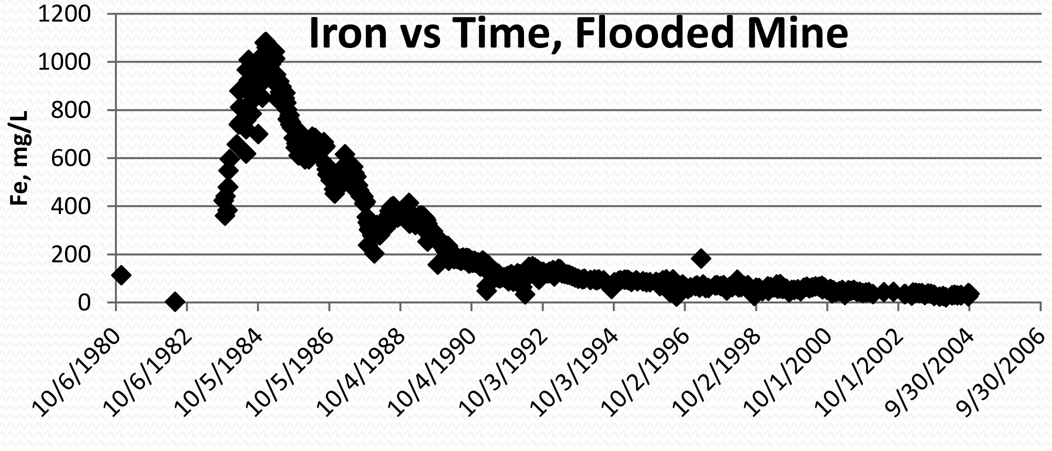
Long Term Water Quality

- How fast does mine-pool chemistry change?
- What is the final or long term chemical composition?
- Is there a systematic trend to the observed changes?

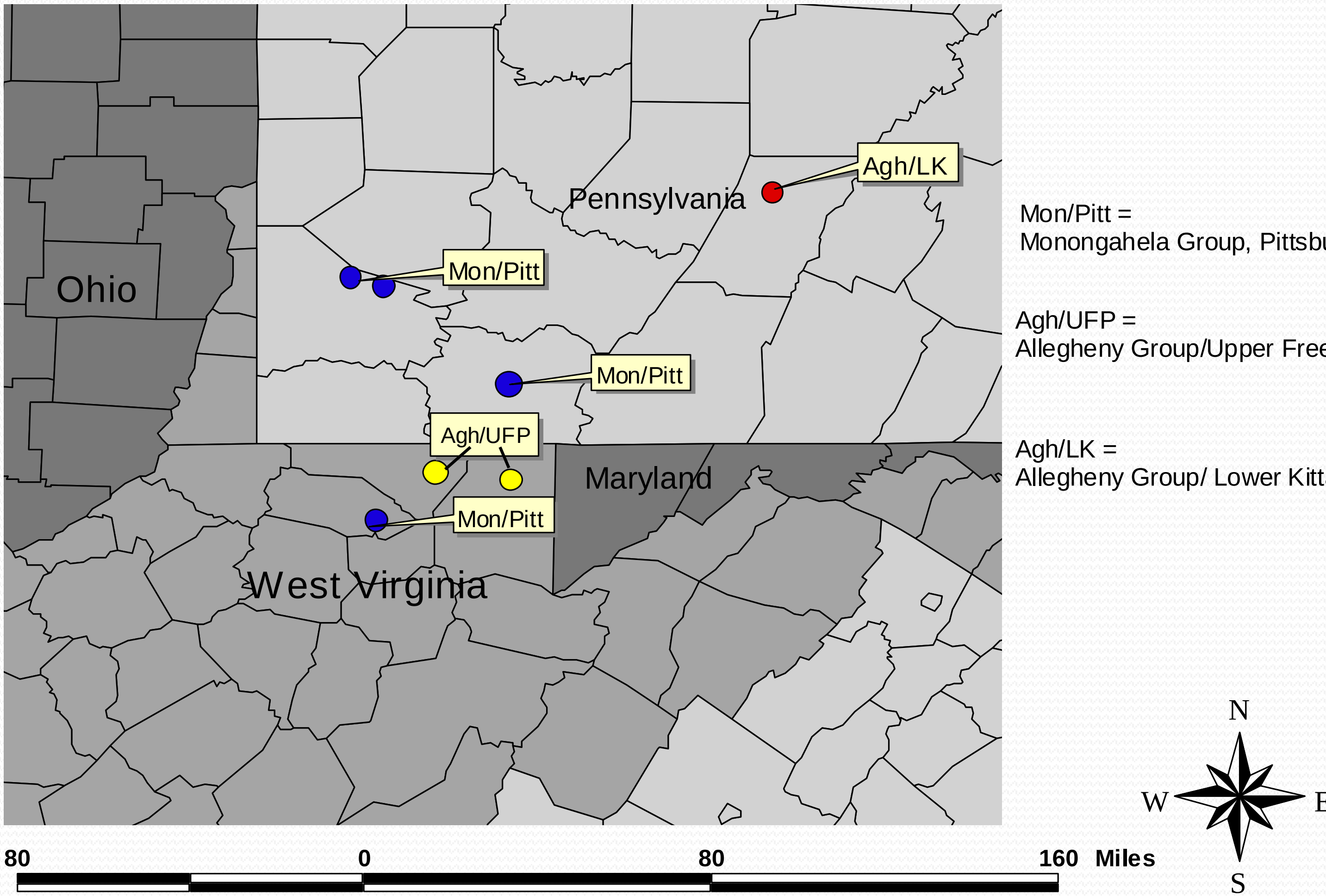




Background

- Objective – Identify a math function that describes changes in chemical composition of underground coal mine-pools over time.
- Five closed underground coal mines, Pennsylvania and West Virginia. Three flooded, two mostly unflooded mines.
- Period of record, 13 to 35 years, "n" ranged from 230 to > 1200 samples.

Mine-pool Locations, Group and Coal Bed



Mon/Pitt =
Monongahela Group, Pittsburgh Coal

Agh/UFP =
Allegheny Group/Upper Freeport Coal

Agh/LK =
Allegheny Group/ Lower Kittaning Coal

Related Studies

- WVU(Skousen, Demchak, Mack, McDonald etc.)
  - 40+ mines, limited # sampling events over 30 years
  - Acidity, Iron, Sulfate concentration decreased ~50 to 80%

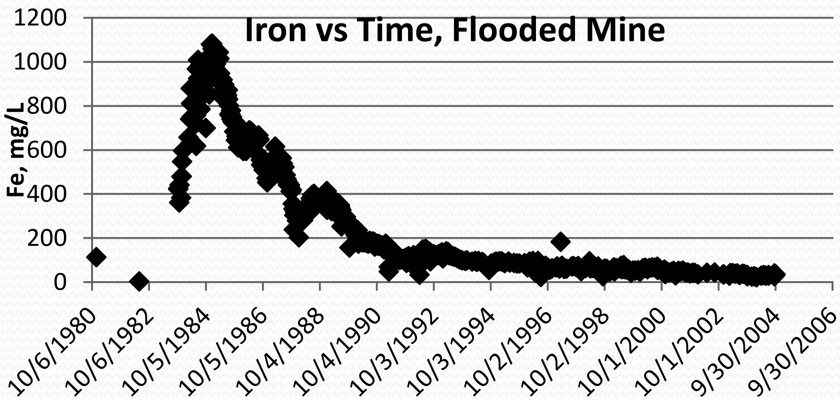
- Britain-Reductions in acidity and iron over several decades. Iron concentrations stabilized at 1 to 40 mg/L. Flooding at one mine; Fe 3x greater than predicted

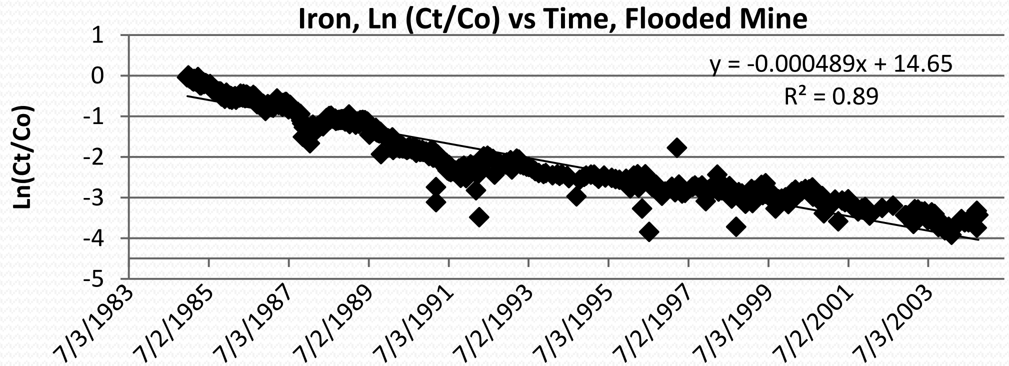
- Basin Observations – Allegheny River tributaries:
  - Acidity concentration declined 63% over 30 years. pH increase.

Time Series Concentration Data
Approximate 1st Order Decay Function

$$C_t = C_o \times e^{-kt}$$

C_t = concentration at time t
C_o = concentration at time zero
e = base e, approximate value of 2.718
k = decay constant, rate of concentration change per unit time
t = time





Constants Fitted for :

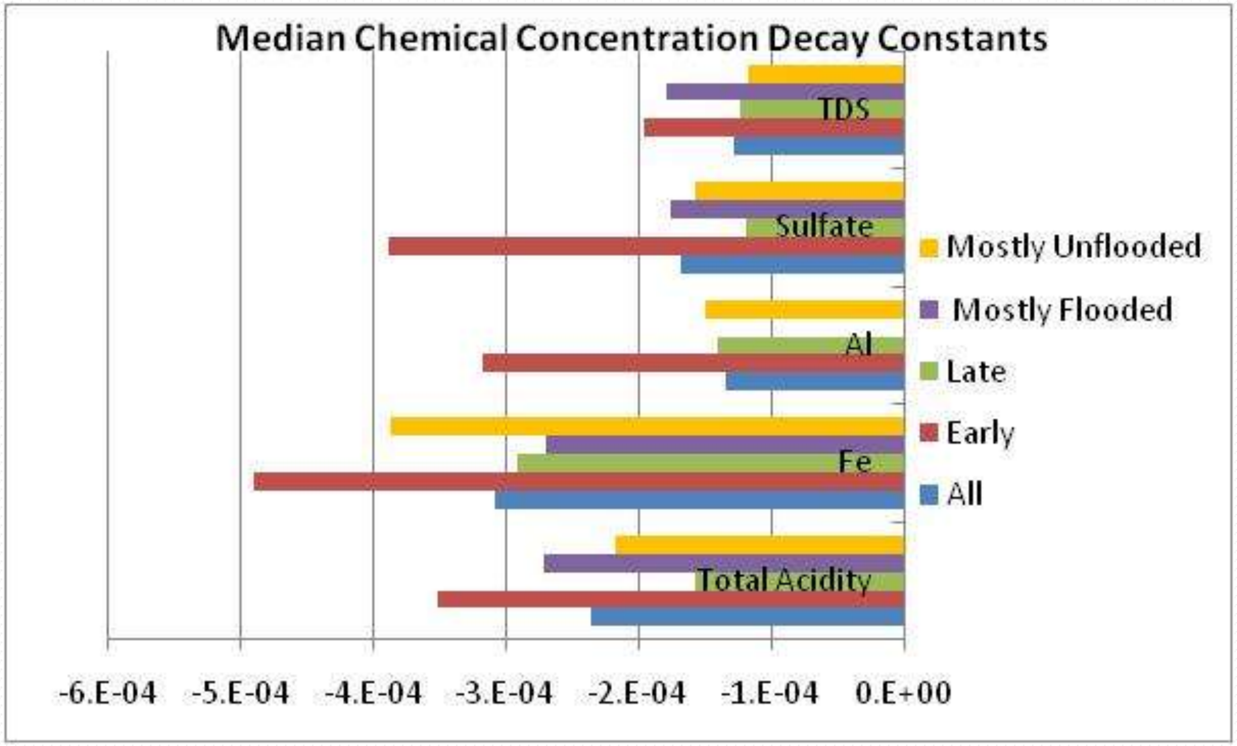
- **Total Acidity**
- **Iron**
- **Aluminum**
- **Total Dissolved Solids**
- **Sulfate**

Decay Depends on Initial and Long-term Flushing, Flooding Extent, and “Unanticipated Events”

Decay Constants derived as:

- A single value for the entire period of record.
- Dividing the record based on initial and long term flushing, and computing separate decay values for each.
- Examining semi-log scale plots of concentration against time for rate changes, shown by change in slope.

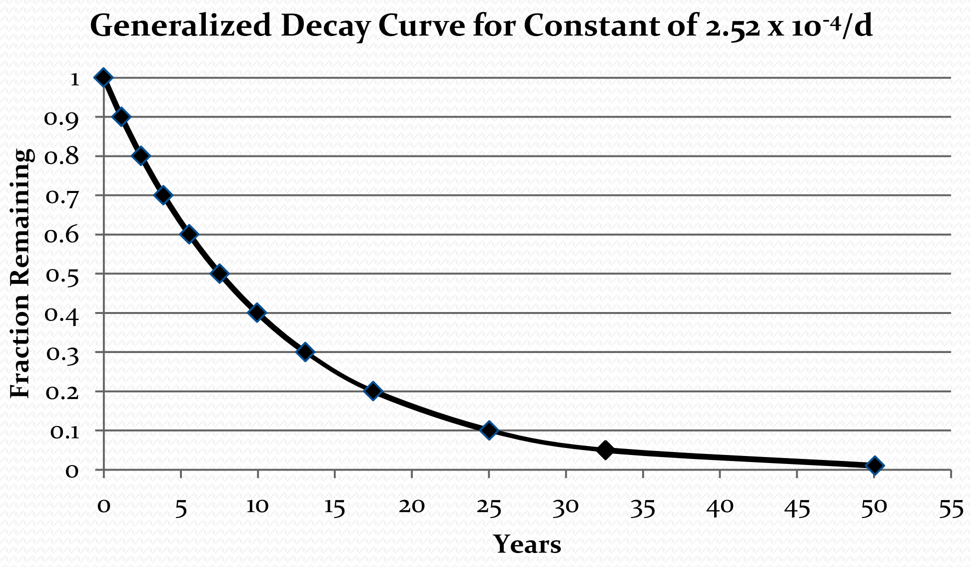
Decay Constant Summary by Parameter



1. Range about 1 order magnitude
2. Median K about -1.5 to -2 x 10^{-4}/day
3. K greater during early flush, less during long term
4. TDS, Al slowest decay

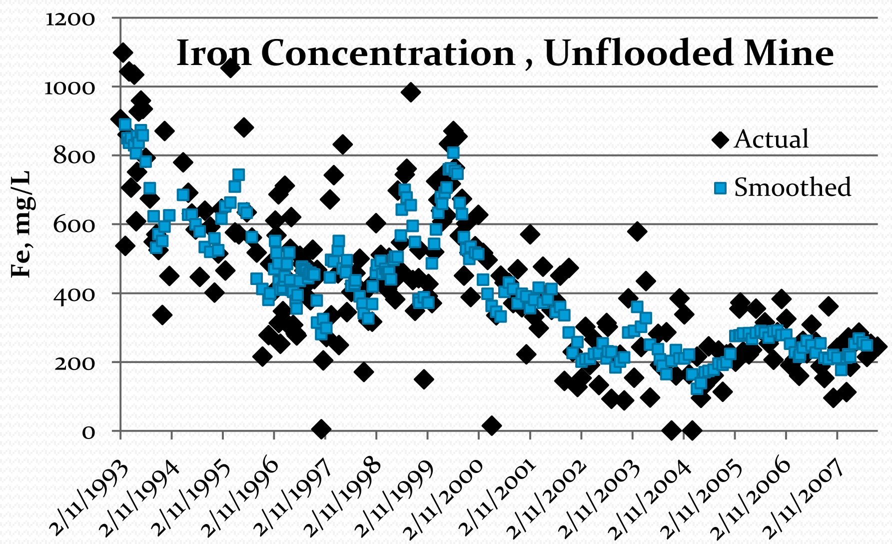
What We Would Like To See (But Not What We Get)

Fraction Remaining	Years
1	0.0
0.9	1.1
0.8	2.4
0.7	3.9
0.6	5.6
0.5	7.5
0.4	10.0
0.3	13.1
0.2	17.5
0.1	25.0
0.05	32.6
0.01	50.1

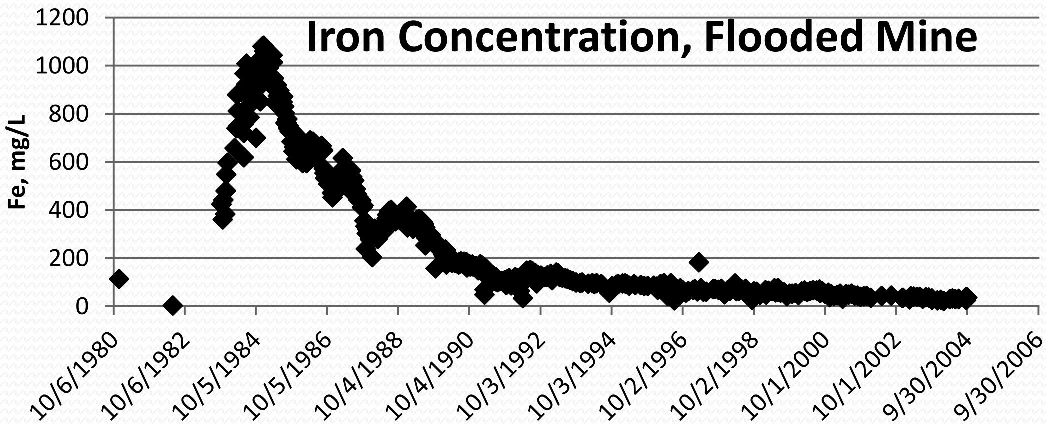


Flooded vs Unflooded (Alkaline vs Acid)

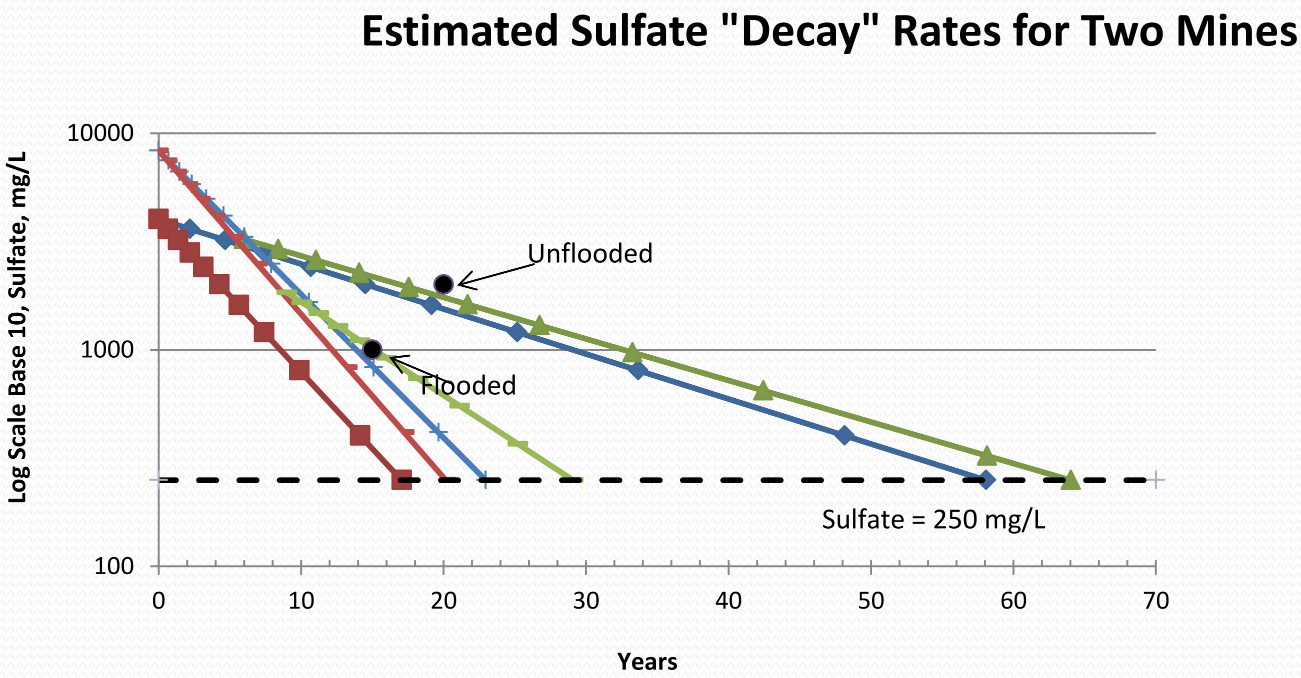
Declined to ~25% of Starting Concentration



Declined to ~3% of Starting Concentration



Estimated Sulfate "Decay" Rates for Two Mines



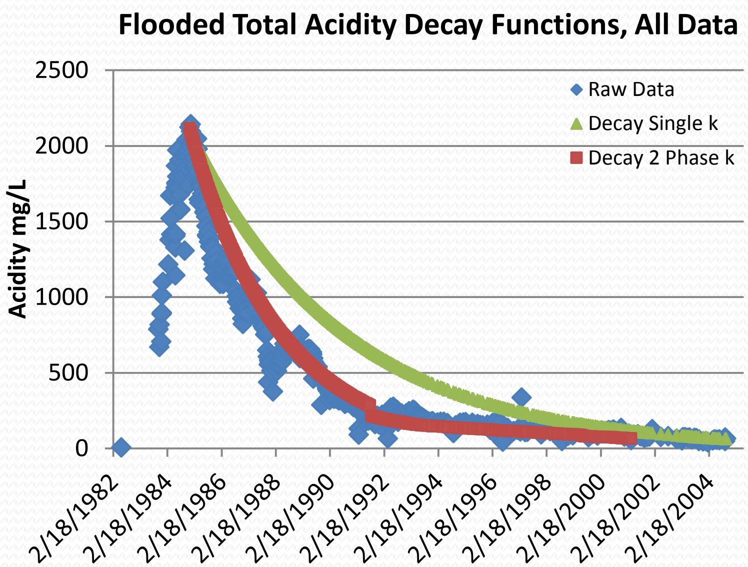
Estimated times to attain water quality goal is on the order of decades. Dependent on initial concentration and value for K .

How Closely Does the Decay Constant Estimate What Actually Happens ?

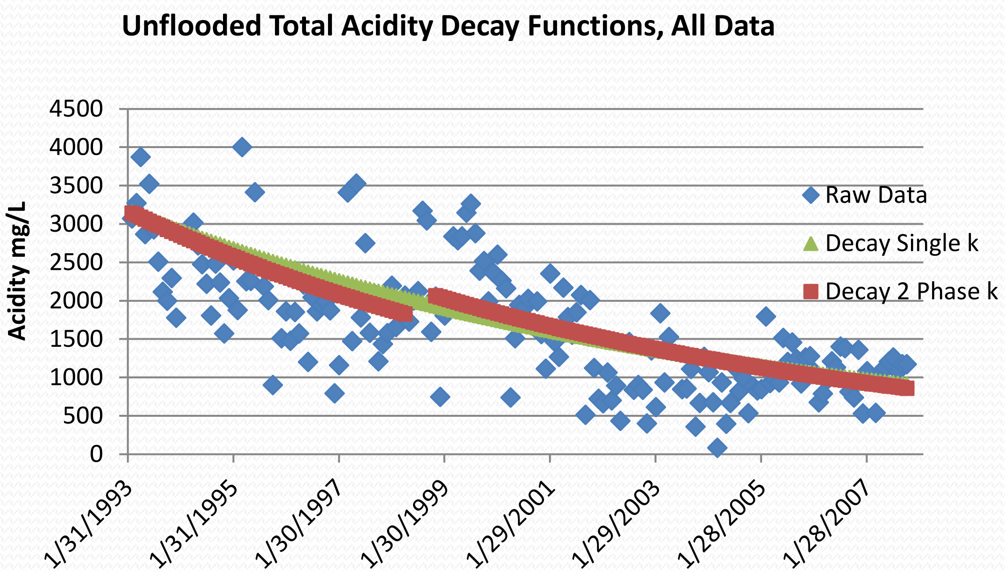
Mine	Acidity Estimated mg/L	Acidity Actual mg/L	Iron Estimated mg/L	Iron Actual mg/L	Sulfate Estimated mg/L	Sulfate Actual mg/L
Mine 1 (acid, unflooded)	25 (50 years)	31 (50 years)	<0.1 (50 years)	6.6 (50 years)	399 (50 years)	235 (50 years)
Mine 5 (net alkaline, flooded)	112 (35 years)	69 (35 years)	53 (35 years)	43 (35 years)	693 (35 years)	266 (35 years)

A Trend Estimator, Not an Exact Predictor

Decay Constant Fitting, Single and 2 Phases



Flooded.

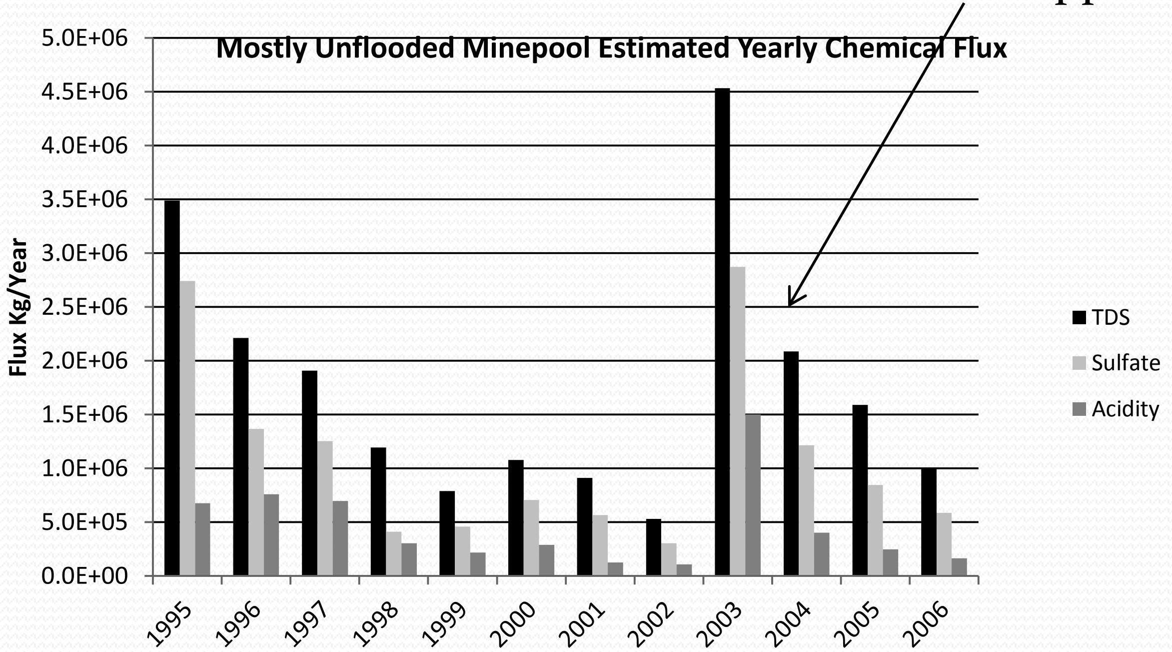


Unflooded.

Modeling decay in 2 phases improves fit between actual and estimated data.

Loading and Unanticipated Events

The mine blowout happened here!



Loading follows the same type of decay pattern as concentration data.

Variable Pumping Rate Affects Chemistry

Discharge [2] (gpm)	pH	Alkalinity	Iron	Sulfate	Manganese	Aluminum
3250	6.7	230	32.6	298.6	0.60	0.5
6500	6.5	169.3	47.7	401.5	1.00	6.5

What Does the Decay Constant Represent ? Chemical Rx , Flushing or Both?

- "Box" model analysis compared expected chemistry under slow and fast flushing rates.
- Slow flushing rate model produced reasonable results. Fast flushing model did not.
- Conclude - magnitude of decay constant mostly dependent on flushing rate of products from the mine-pool(The chemistry happens faster than the flushing).

Conclusions

- The decay equation is useful for estimating long term trends for total acidity, Fe, Al, sulfate and TDS concentration. Decay constants are on the order of -10^{-4}/d. Loading trends may also follow a decay function.
- Chemical decay can be divided into early and long term flushing.
- Time to reach specified water quality concentrations is on the order of decades. Most decay predictions ranged from about 30 to 70 years.
- Decay rates are useful for long term trend estimates. The decay function does NOT account for seasonality or short term transient events.
- A box model flushing analysis suggests that decay is mostly a flushing function.

What We Need to Do Better

- Improve our ability to predict starting composition of the mine water at closure. We often rely on experience of analogues of nearby mines believed to have similar conditions.

- Understand what happens at long time frames. Do concentrations continue to decrease or attain some constant value?