A FIELD DEMONSTRATION OF AN ALTERNATIVE COAL WASTE DISPOSAL TECHNOLOGY – GEOCHEMICAL FINDINGS

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Conventional Practice: Fine Coal Processing Waste Placed in Coal Slurry Impoundments

Photo courtesy Jack Nawrot, SIUC (ret.)

Challenges with Conventional Practice

- Slurry impoundments are increasingly more costly and difficult to permit, and may have an extended liability due to slope stability concerns and the potential for a long-term sulfate discharge.
- Coal processing waste (CPW) has increased due to greater mechanization and more difficult mining conditions (increased Out-of-Seam Dilution - OSD).
- Regulatory requirements regarding discharges of sulfate and chloride have increased for Illinois Basin coal mines.

Problem Identification*

- Weathering of the mineral matter in coal mine waste can release elevated amounts of Sulfate (SO_4^{2-}) and Chloride (Cl^-).
- Sulfate discharge tracks the rate of pyrite weathering.
- Chloride discharge levels increase with increased crushing in mining and processing.
- Sulfate and chloride anions are "conservative" in the environment.

*Illinois Clean Coal Institute Project: DEV05-8, Chugh *et al.*, 2007
See: https://icci.org/reports/DEV05-8Chugh.pdf

Hypothesis 1: Co-disposal of Fine and Coarse Waste to Minimize Sulfate

- Fine CPW (FCPW) will fill voids in coarse CPW (CCPW) saving space within the refuse pile structure.
- Compaction characteristics can be improved by a broader particle size distribution and increased moisture content.
- Lower permeability for compacted, co-disposed waste will lower the sulfate and chloride mass in mine discharge.
- The increased neutralization potential (NP) of the FCPW can improve the blended refuse acid-base account (ABA).

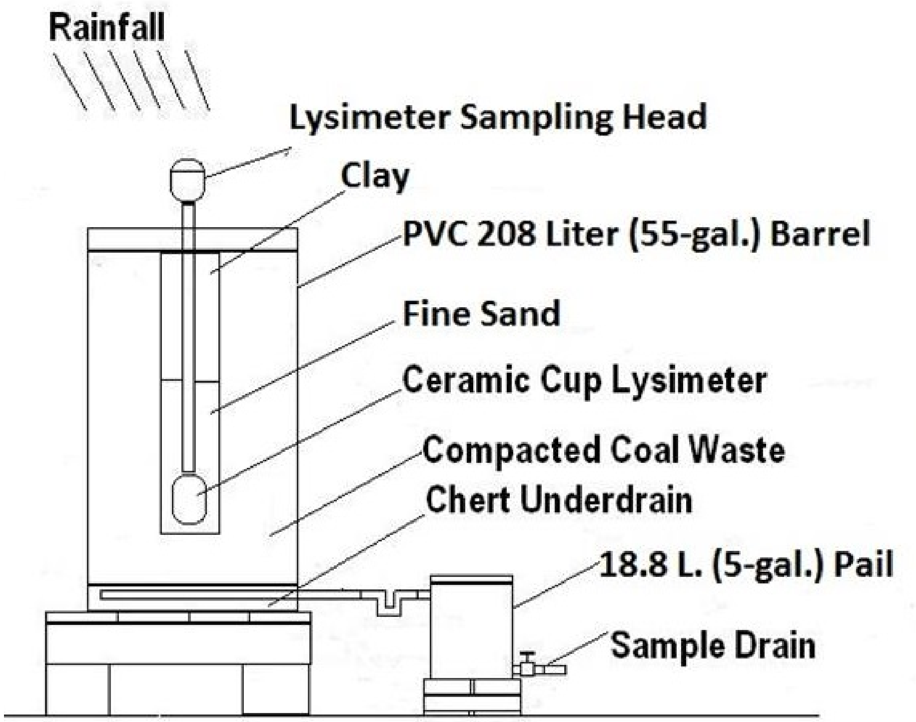
Hypothesis 2: Water Management

- Chloride (Cl^-) is a conservative ion and will leach readily from coal and coal waste.
- A good management practices for Cl^- control from coal refuse areas is to to apply dilution and allow a controlled discharge during periods of higher precipitation.

Testing of Hypotheses: Goals and Objectives

- Two laboratory-scale kinetic tests demonstrated that:
  - Effective management of coal stockpiles will minimize SO_4^{2-} and Cl^- leaching in mine discharge waters.
  - Co-disposal of CCPW and FCPW will improve geochemistry and reduce SO_4^{2-} in mine discharge waters.
- Two field-scale test columns validating laboratory results for coal refuse disposal and demonstrated a desirable level of structural stability.

Initial Field Kinetic Testing: 55-gallon Experiment
(operated May 6, 2011 – September 14 , 2012)



- 6 Columns: 57 cm (22.5-in.) diameter by 85 cm (33.5 in.) tall.
  - Porosity = 16% → 201 kg of coal refuse.
  - Duplicates: CCPW, Blended CCPW and FCPW, and a CCPW/FCPW/Limestone Blend.
  - The initial moisture: coarse refuse was ~ 11%, dewatered fine refuse was ~ 50 %.
  - Compacted to 50% of the Proctor density.
  - Monthly sampling events over 18 months.

Operational Problems: Field Test Columns Severely Damaged by the February 29, 2012 "Leap Day" tornado outbreak

Damage to SIU 55-gallon kinetic test cells.

EF-4 tornado damage to Harrisburg, IL.

https://en.wikipedia.org/wiki/2012_Leap_Day_tornado_outbreak

Reconstructed Field Columns

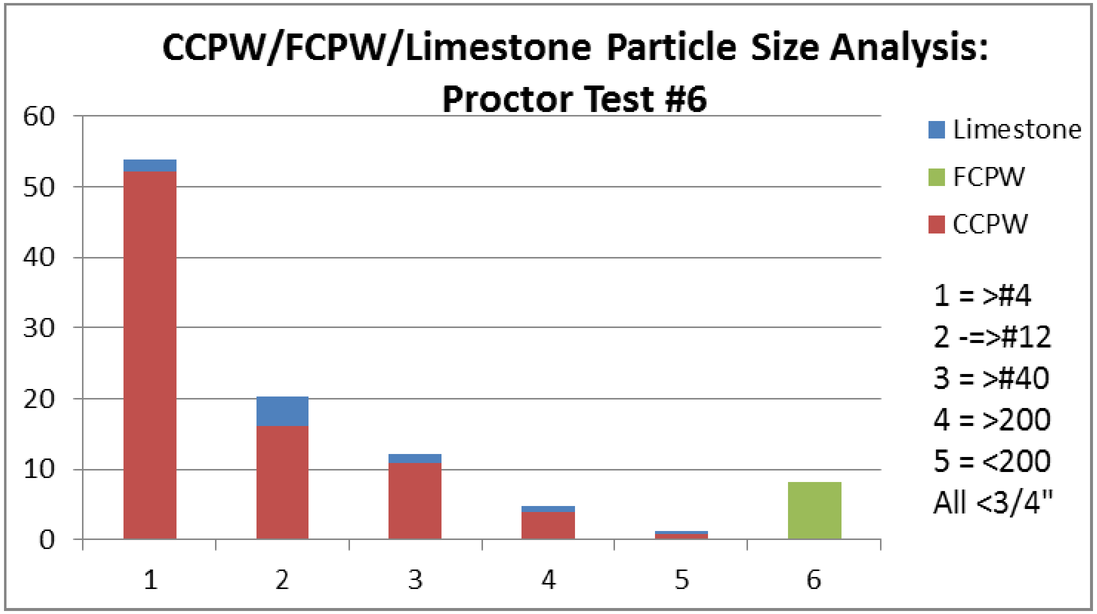
Improved 100-gallon test cells

Improved column study funded by the Illinois Clean Coal Institute (ICCI Project 12/4C-5).

Geochemical properties of blended Springfield (No. 5) and Herrin (No. 6) coal refuse samples

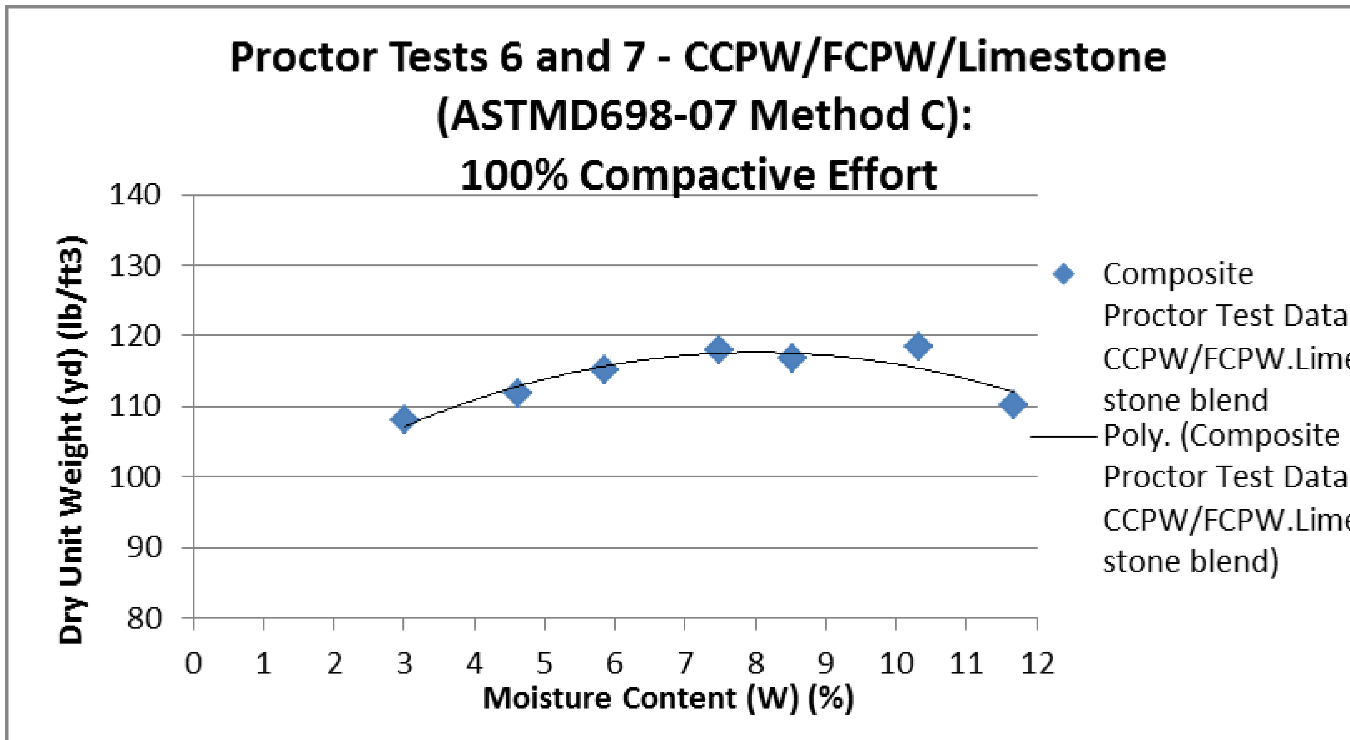
Refuse Fraction	Sulfur Content Mean (%)		Paste pH (median)	MT of $CaCO_3$ equivalent/ 1,000 MT of Material		NNP
	Total	Pyritic		MPA	NP	
Permit Data (coarse)**	5.70 (n = 2)	3.41 (n = 47)	7.12 (n = 47)	106.4 (n = 47)	23.8 (n = 47)	-84.5 (n = 47)
Coarse***	4.55	3.90	6.01	136.6	1.51	-135.1
Fine***	2.56	2.13	7.41	79.06	2.65	-76.41
Blend***	4.15	3.55	7.31	125.1	1.74	-123.3

Analysis by the US. Geological Survey and Illinois Dept. of Natural Resources; ** reported in permit documents for the cooperative mine complex for underground mining of the No. 5 coal; *** from this study (n = 2).



Geotechnical Studies: Particle size and Proctor analysis

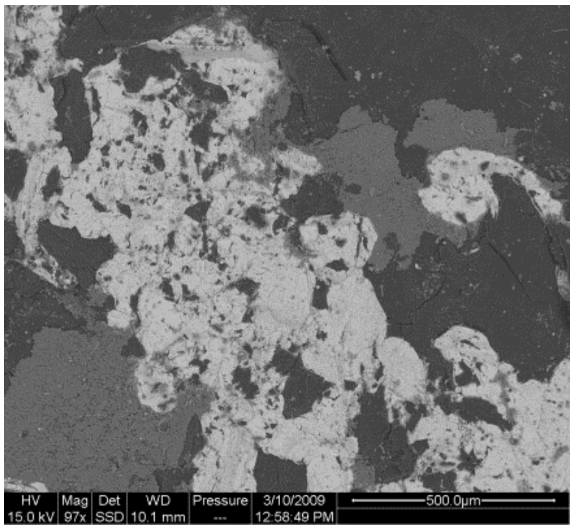
Limestone additions allows an important increase in the moisture content at the peak density.



Improved Column Results

Mineralogy:

Mineralogical composition of the initial material.

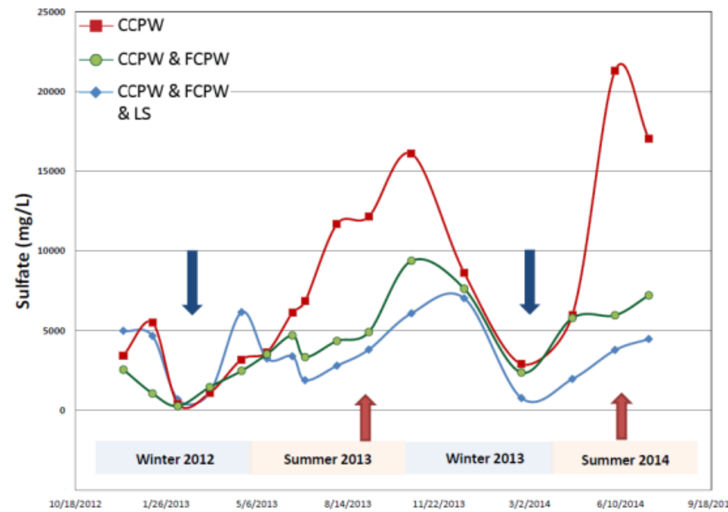


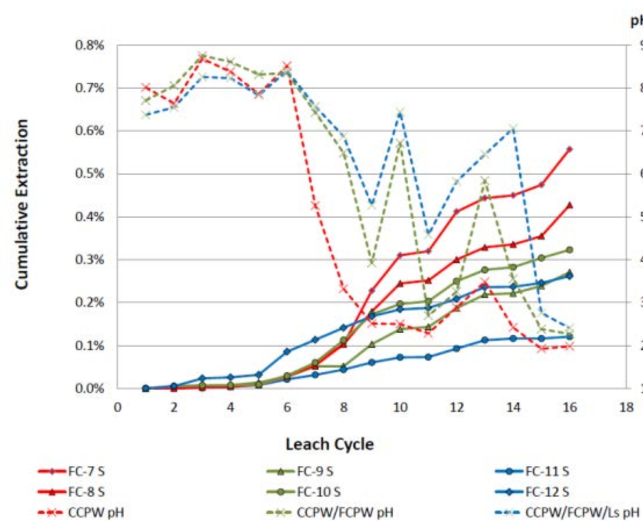
Elemental Extraction:

Normalized elemental concentration data to yield elemental mass loading.

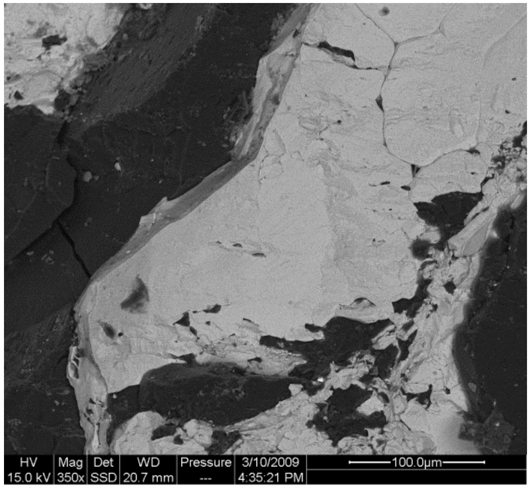
Leachate Chemistry:

Elemental Concentration Trends

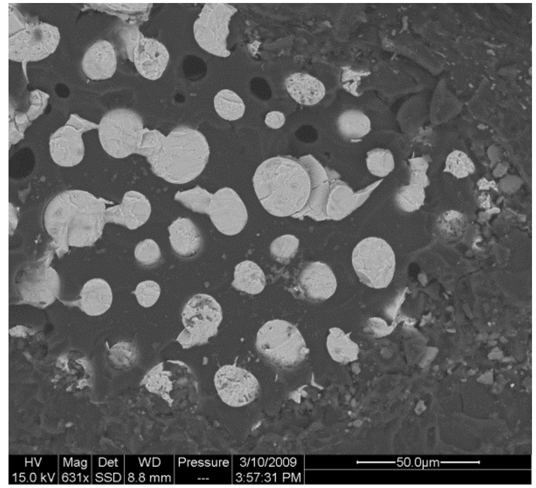




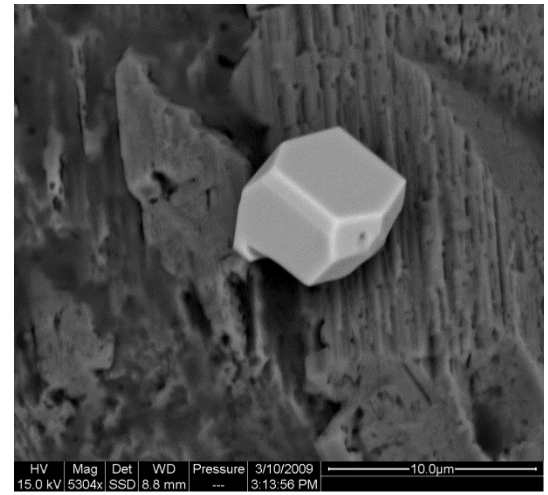
SEM images: Minerals in the Springfield No. 5 coal



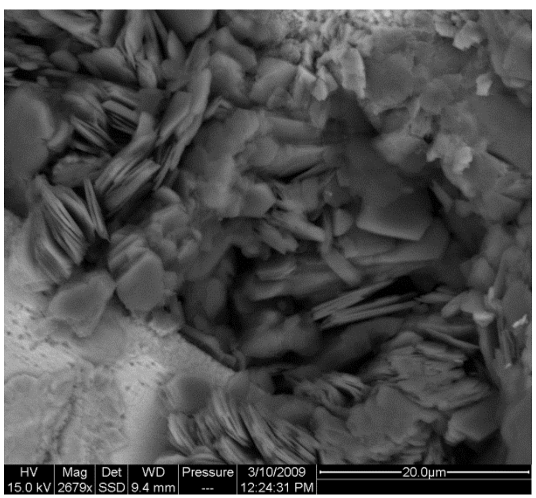
Massive Pyrite



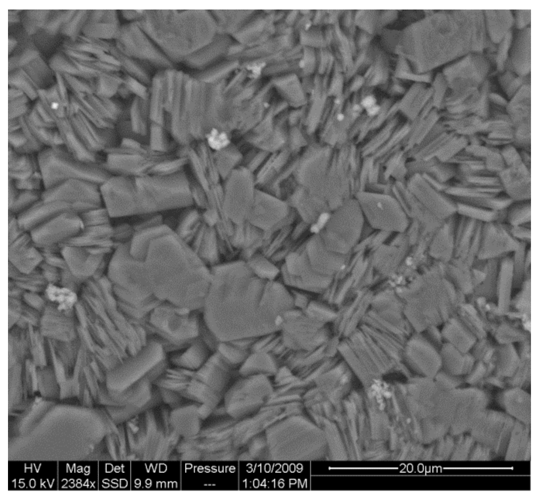
Pyrite Framboids



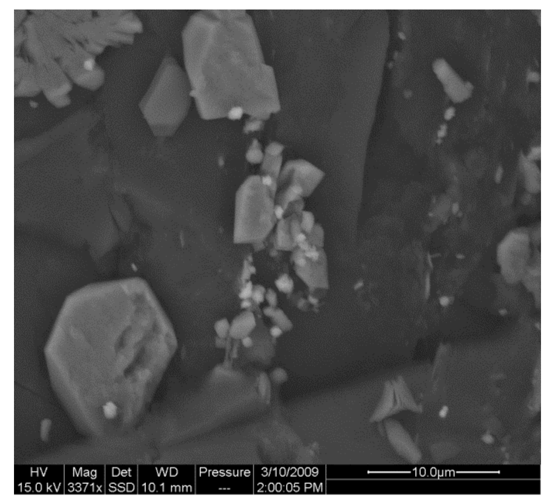
Galena



Gypsum and Kaolinite



Kaolinite



Calcite and Gypsum

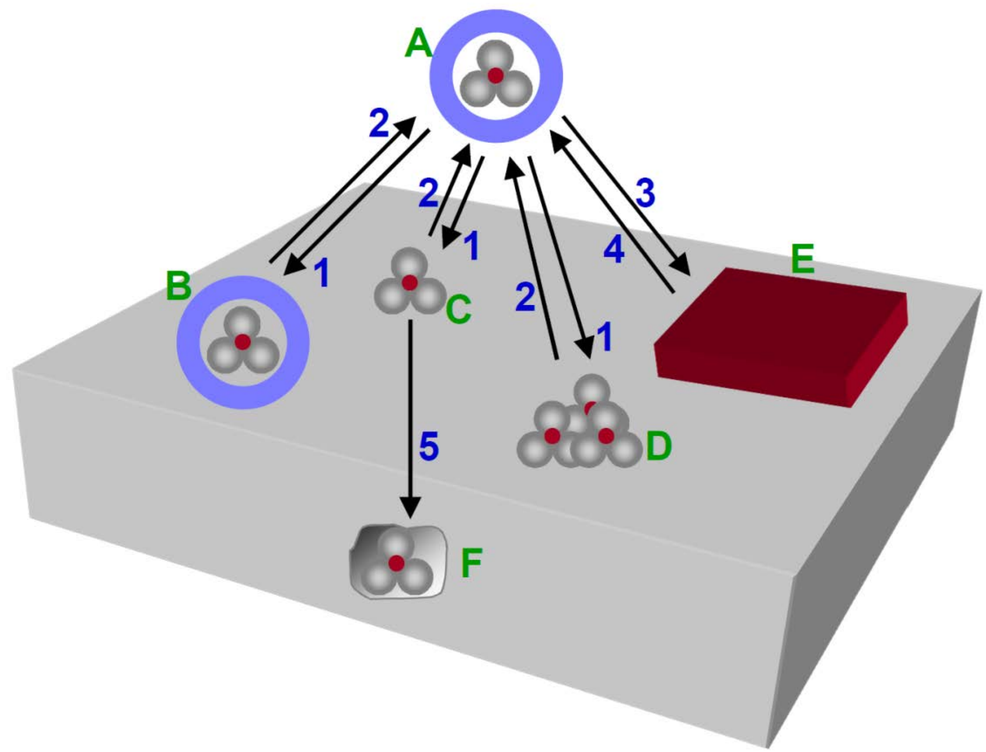
Multiple Geochemical Processes Occur at Solid/Aqueous Solution Interfaces

Processes:

1. Adsorption
2. Desorption
3. Precipitation
4. Dissolution
5. Incorporation

Species Produced:

A. Aqueous ions
B. Outer-sphere complex
C. Inner-sphere complex
D. Multinuclear complex
E. Surface precipitates
F. Solid solution

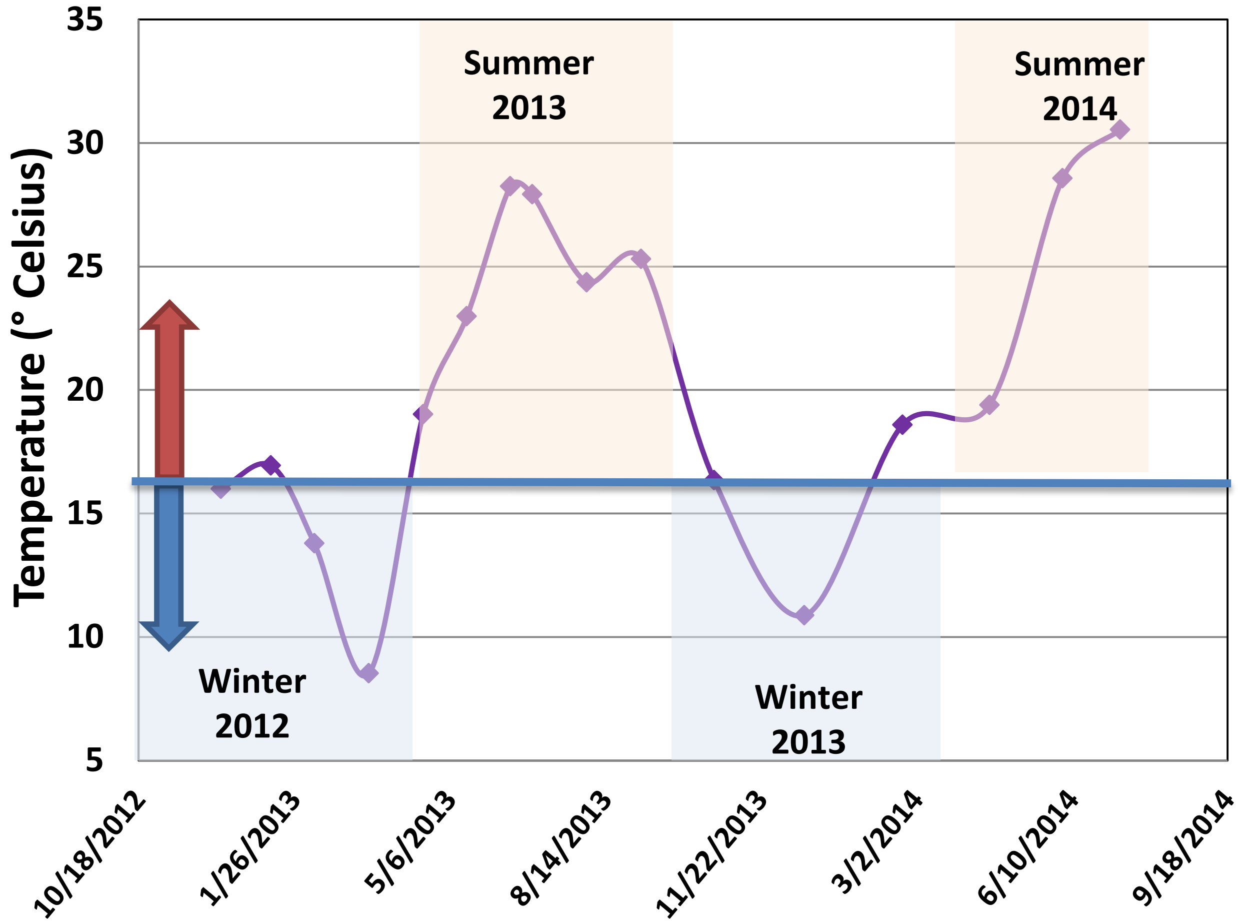


Charlet and Manceau (1993) In: *Environmental Particles, Vol. 2, 117*

New Field Columns:

Temperature Variations

Installation: November 16, 2012
Sampling: December 10, 2012
Experiment Ended: July 11, 2014
Total Duration: 19.3 months



Advantages of Field Column Kinetic Testing:

1) Full-sized particles are used--The impact of a scale factor is minimized.
2) The materials are exposed to “real world” environmental conditions.
    a) Temperature.
    b) Precipitation.

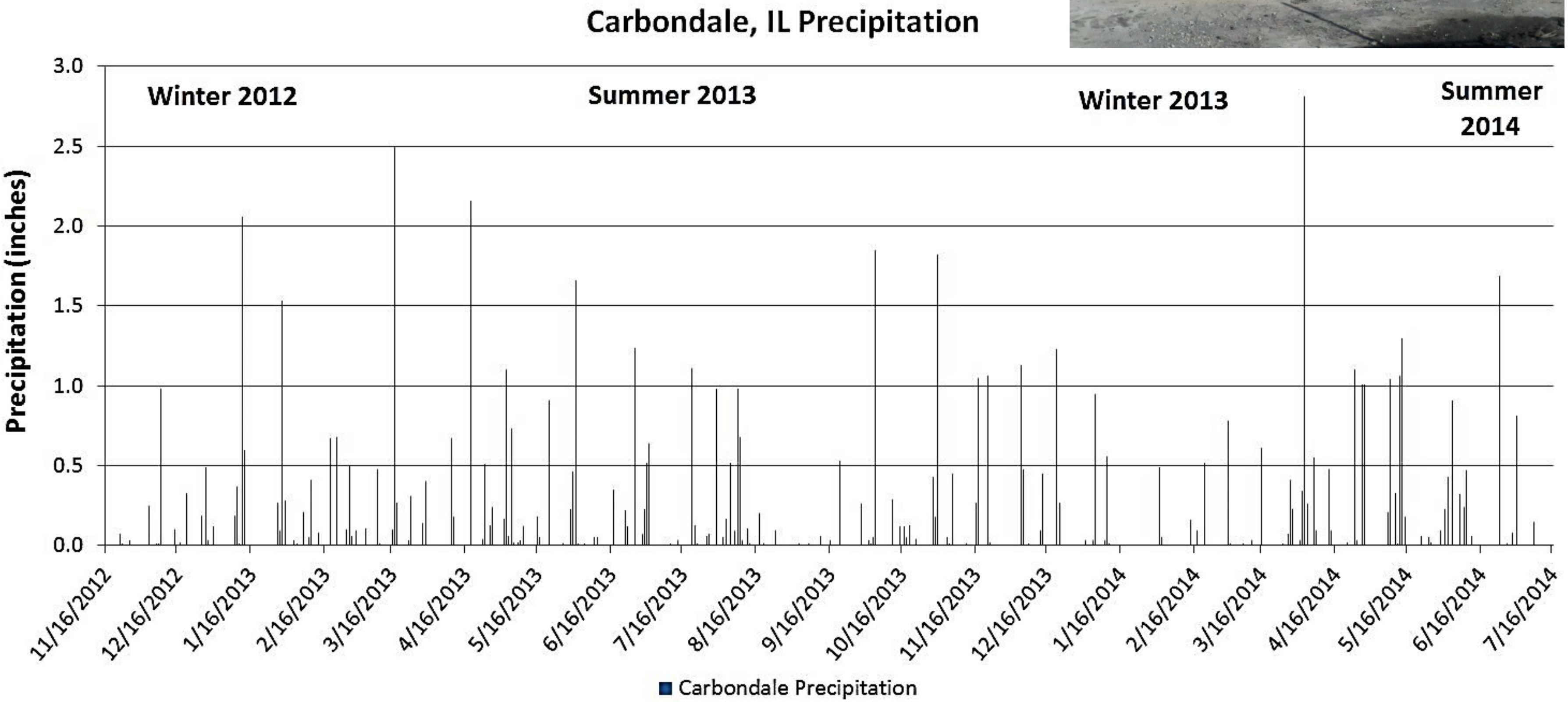
New Field Columns:

Precipitation Patterns

Installation: November 16, 2012

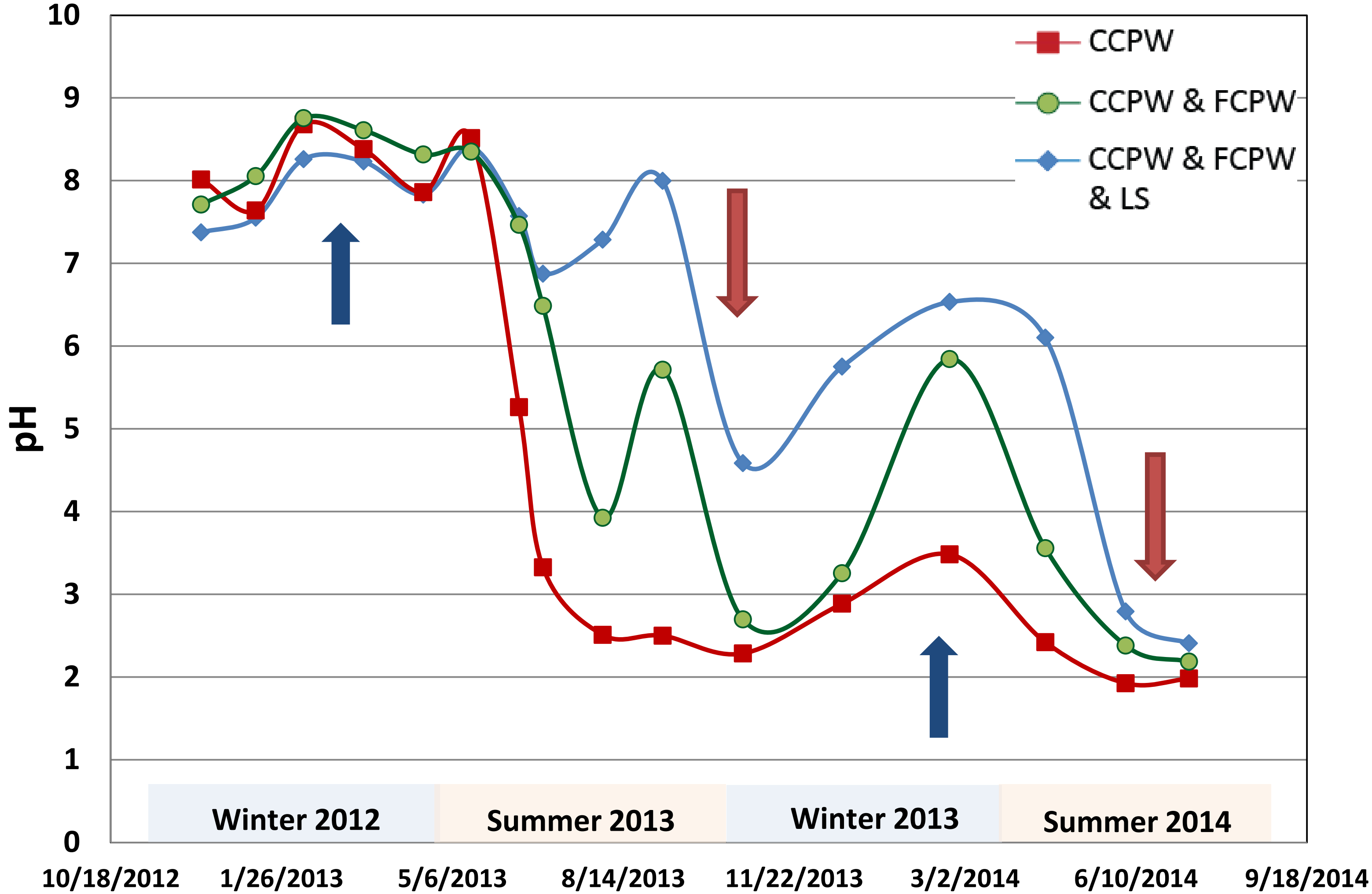
Sampling Initiated: December 10, 2012

Experiment Ended: July 11, 2014



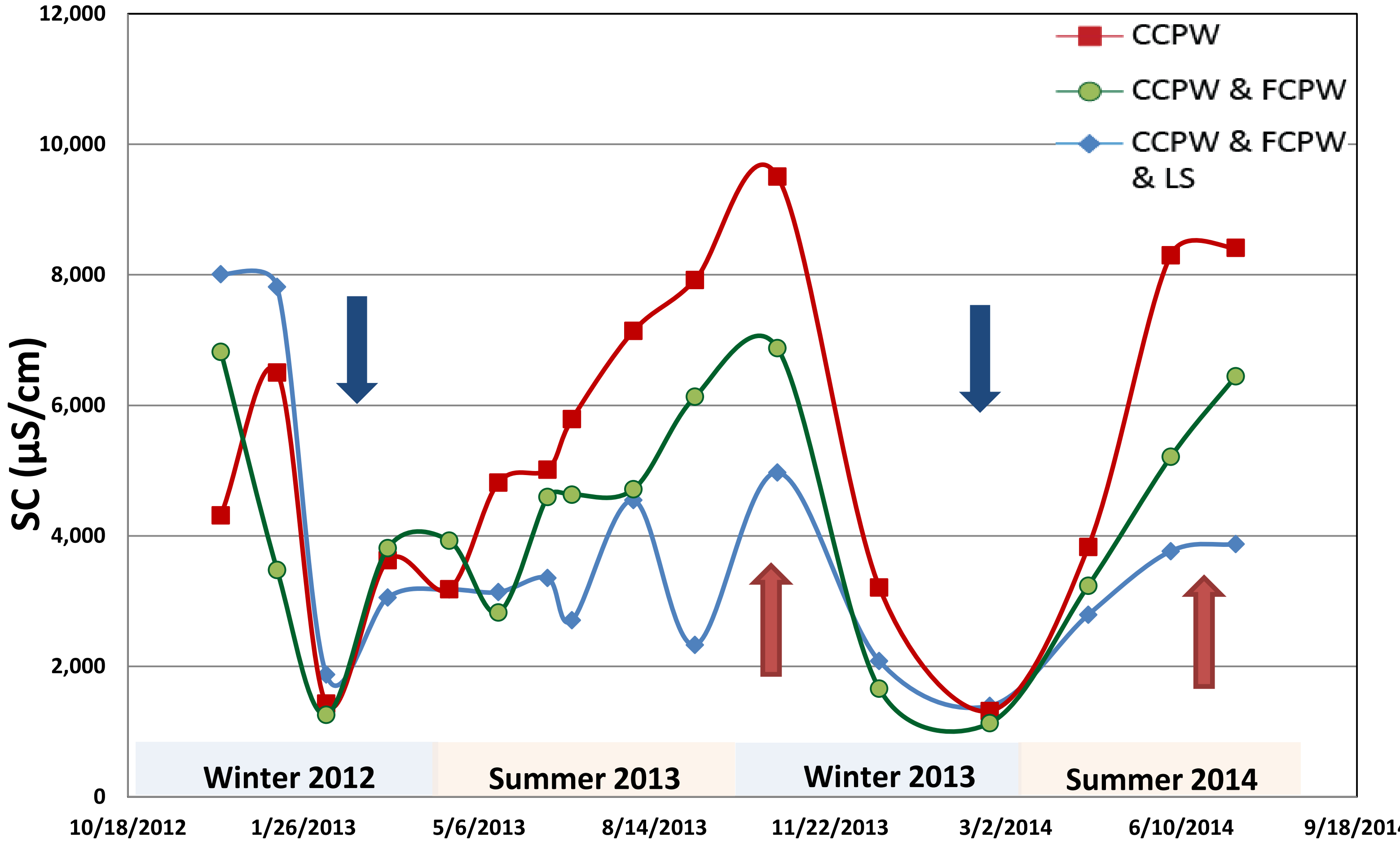
1) Full-sized particles are used--The impact of a scale factor is minimized.
2) The materials are exposed to “real world” environmental conditions.
    a) Temperature.
    b) Precipitation.

Variations in Leachate pH



- Leachate pH declined during the testing for all columns, but an improved pH buffering was evident with the blended refuse.
- Temperature and precipitation had an important effect on leachate pH values, with a step decrease during the spring and summer and higher values during the winter.

Variations in the Conductivity (SC) of the Leachate Solution

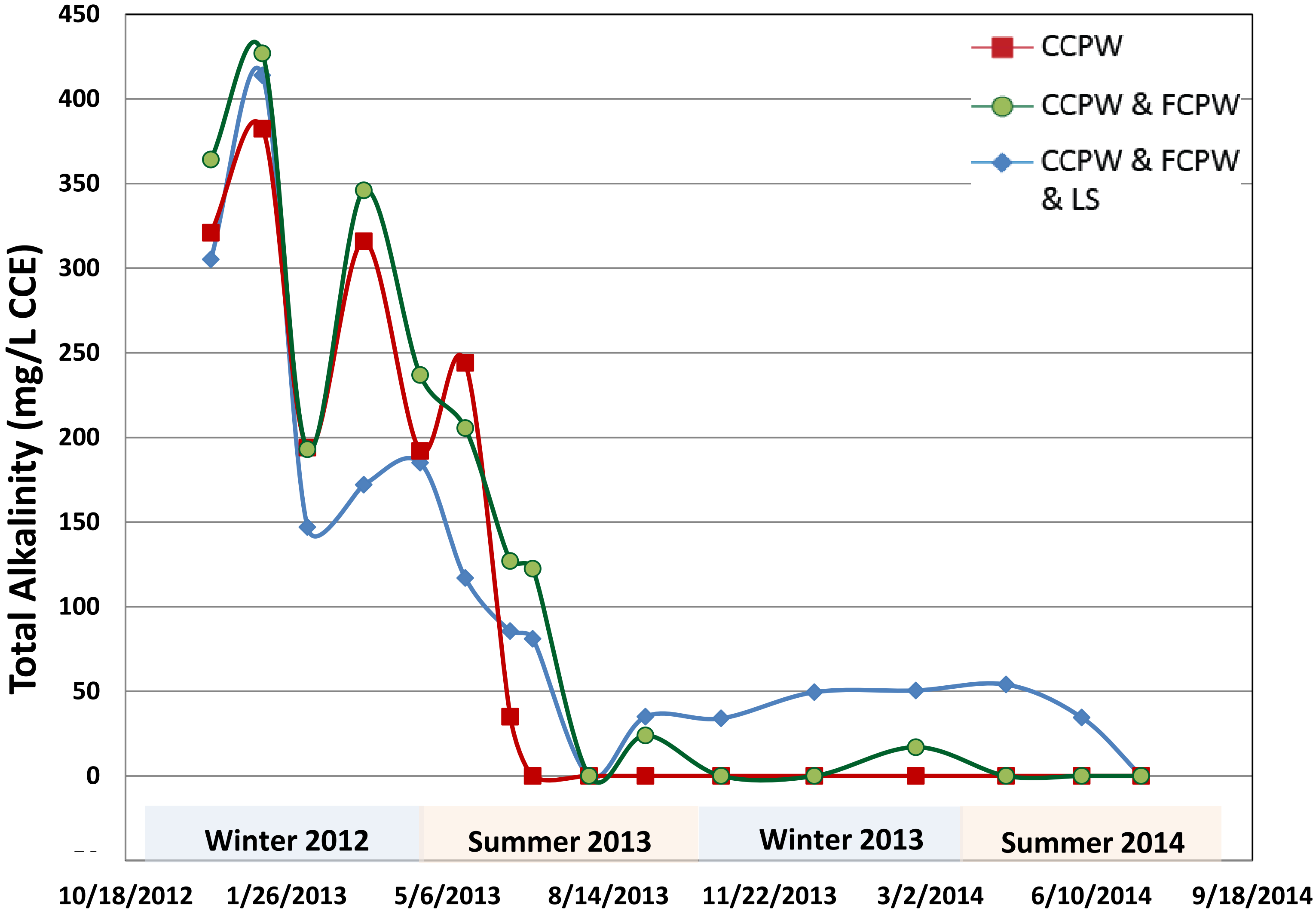


Leachate SC increased during the testing for all columns, but to a lesser extent with the blended refuse.

Temperature and precipitation again had an effect on leachate SC values:

1) A step increase in SC during the summer.
2) Lower SC values during the winter.

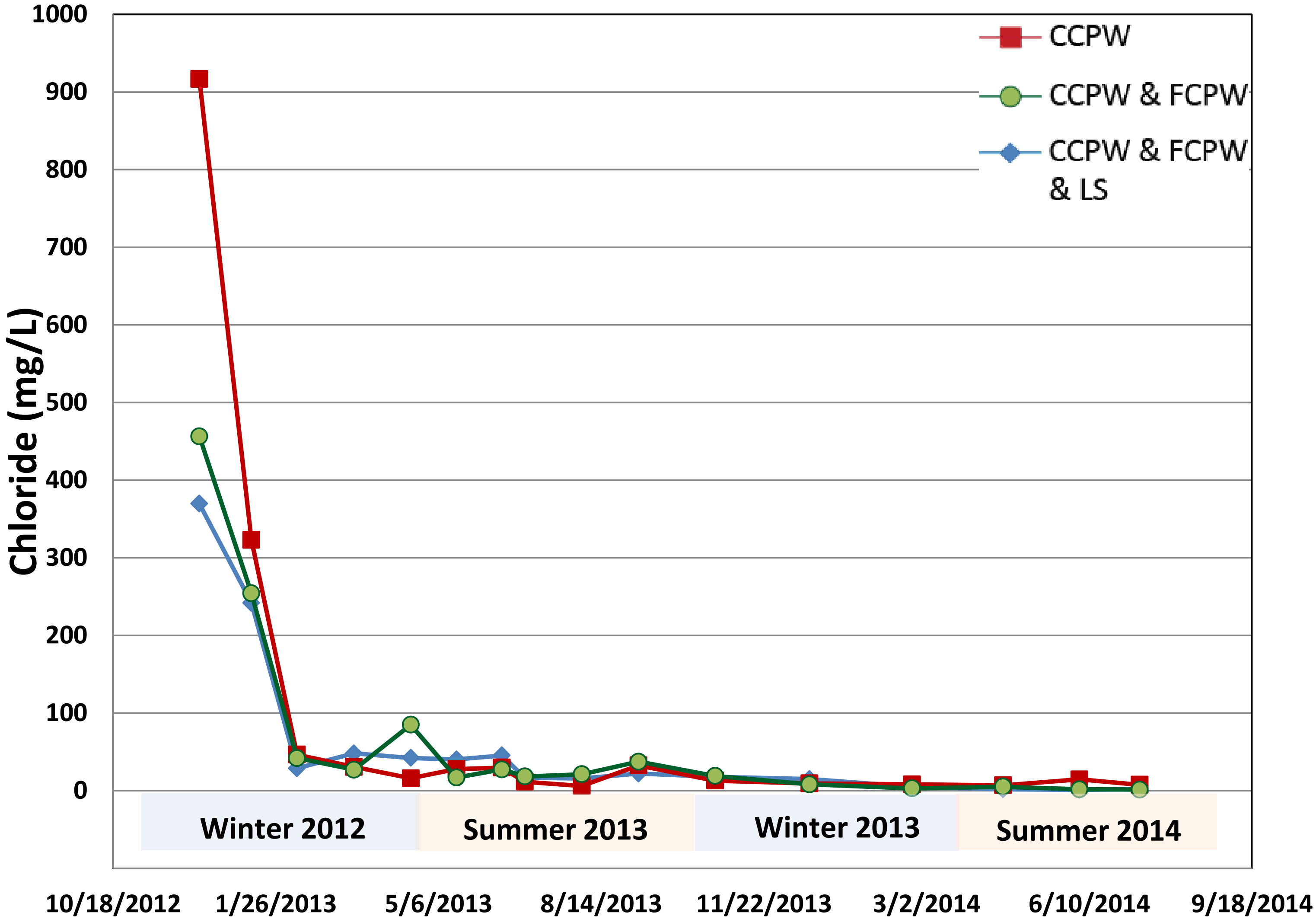
Variations in the Total Alkalinity of the Leachate Solution.



1) Alkalinity in leachate declined rapidly during the first 8 months of testing.

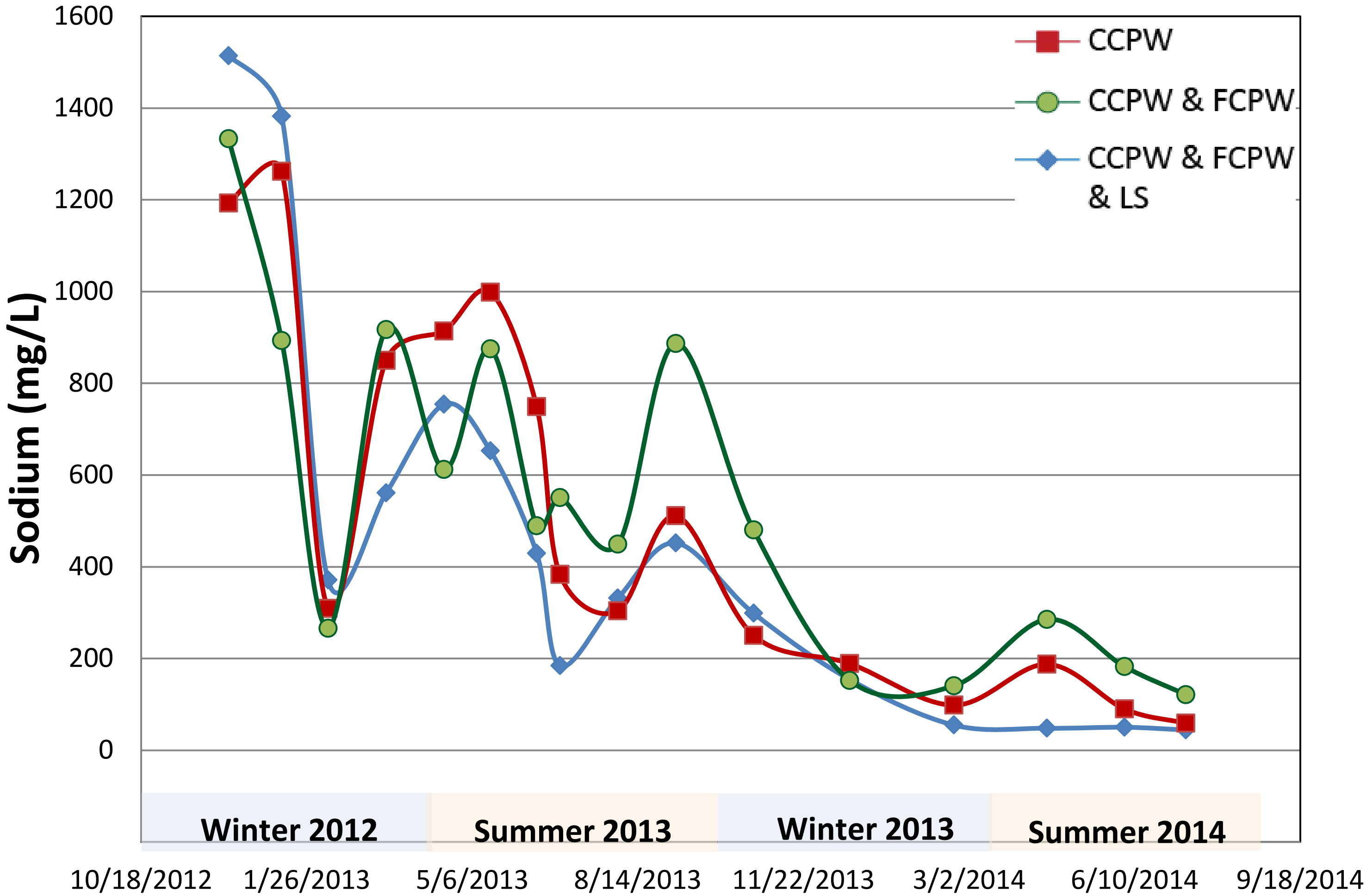
2) Some alkalinity remained in the columns simulating co-disposal with limestone addition.

Chloride Concentrations in the Column Leachate.



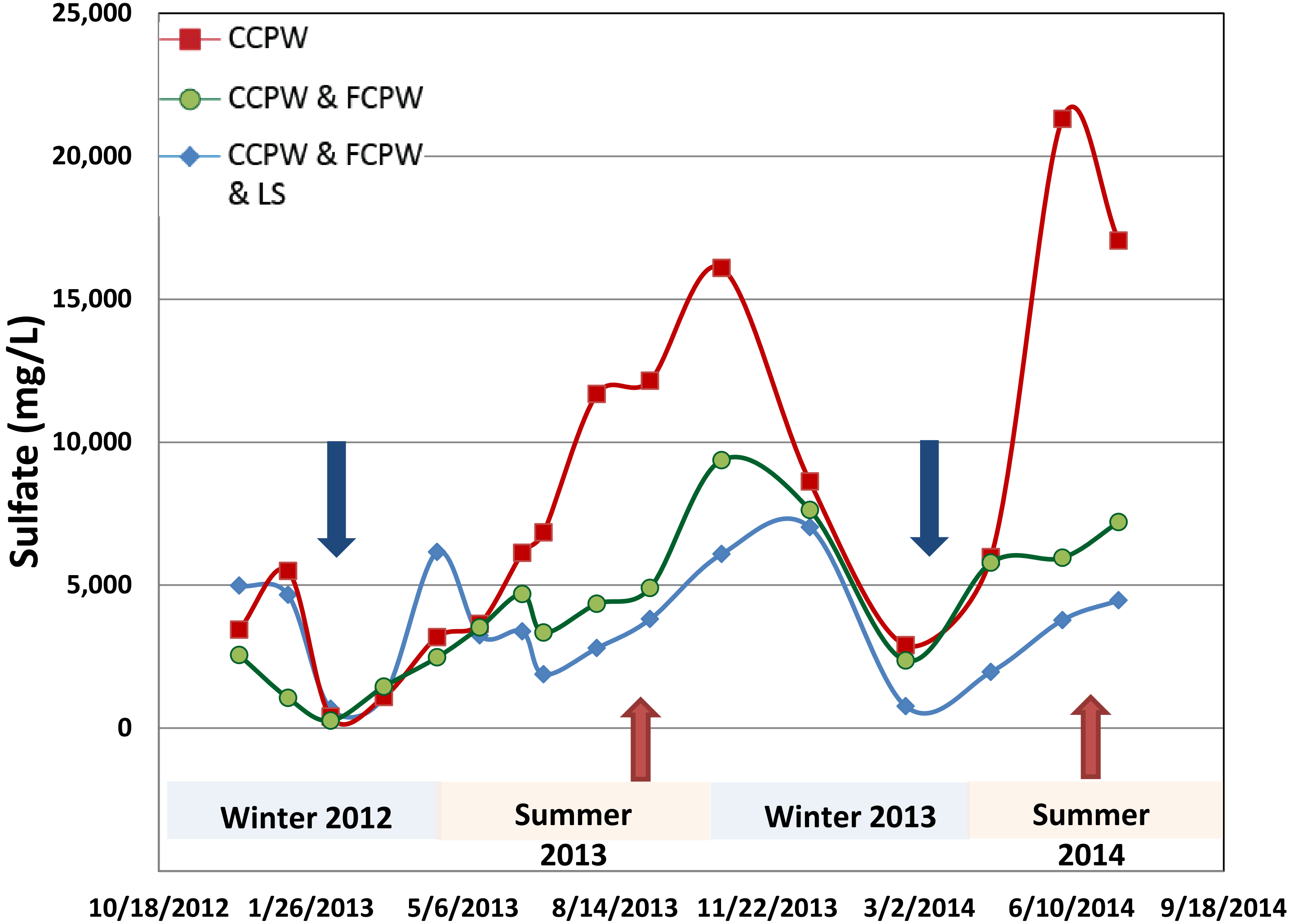
- Chloride, sulfate and bicarbonate were the major anions.
- Chloride was the most readily leached anion, rapidly flushing from the columns.
- Bicarbonate declined at a rate that matched total alkalinity.

Sodium Concentrations in the Column Leachate



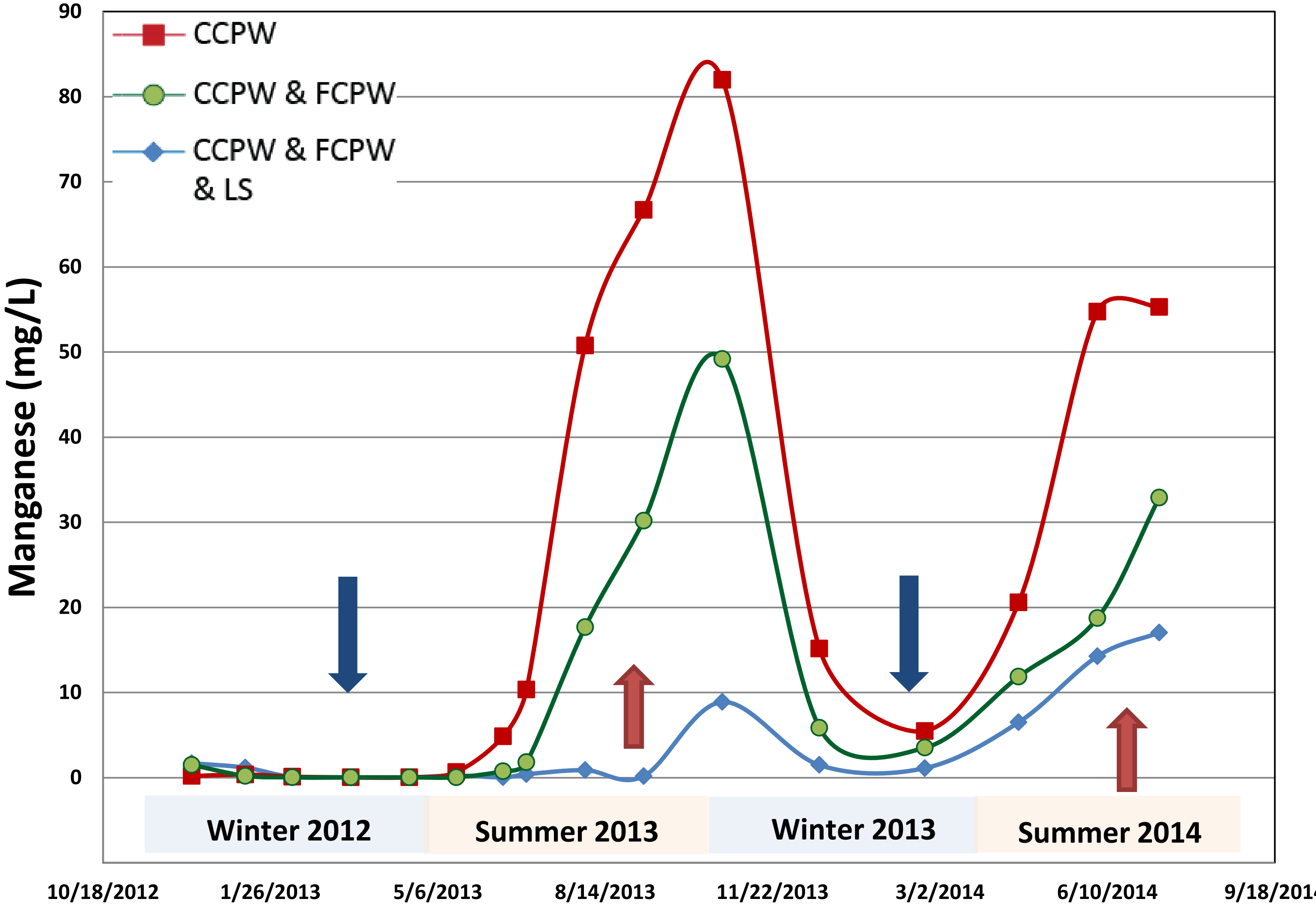
- The alkali metals Na^+ and K^+ were the principle counter ions to Cl^- in the leachate.
- Na^+ declined at a by factor of 10 during the leaching tests.
- Na^+ was present as water-soluble compounds, such as halides (NaCl), sulfates (Na_2SO_4), and possibly nitrates ($NaNO_3$).

Sulfate Concentrations in the Column Leachate



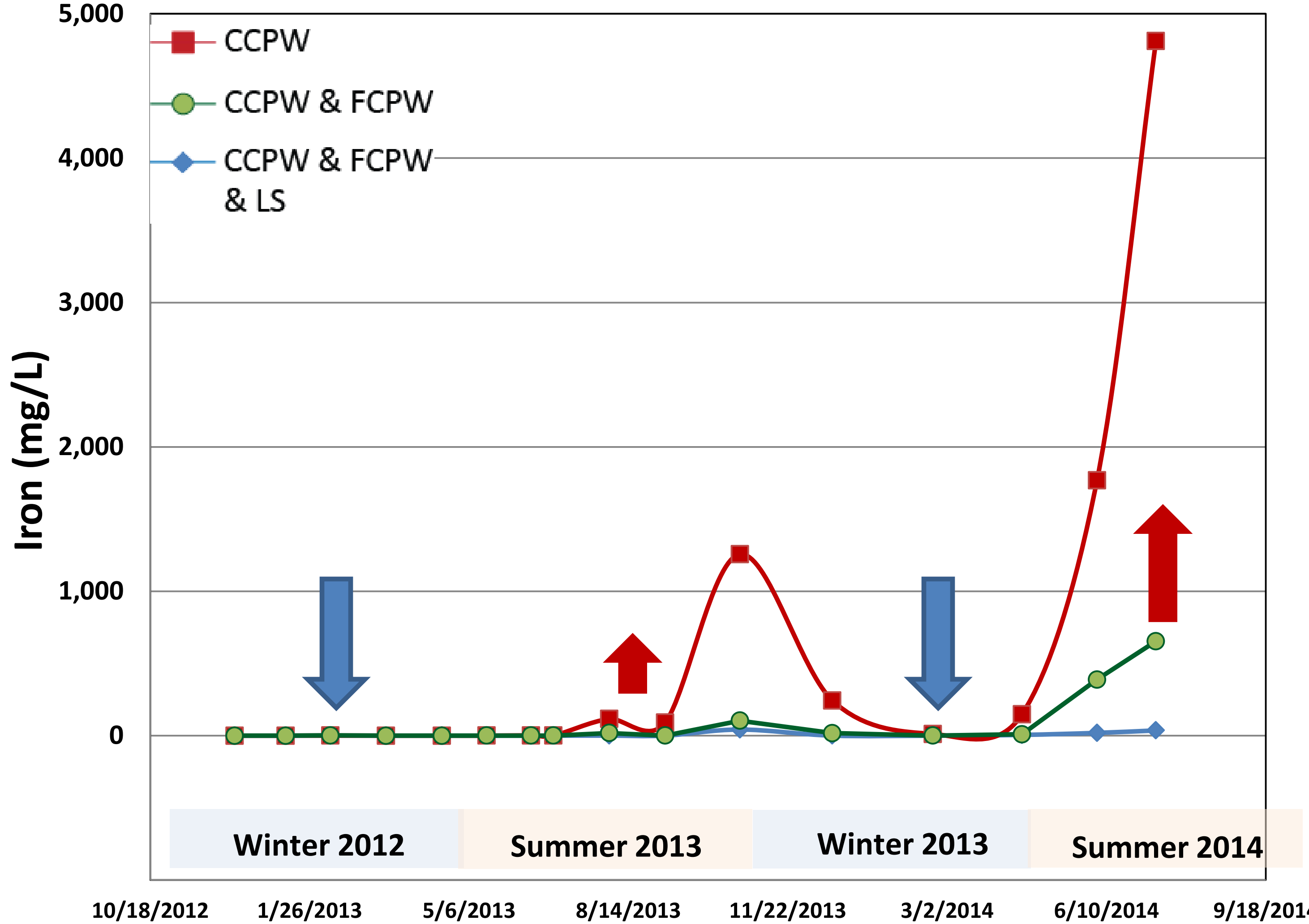
- Sulfate concentrations varied similar to temperature.
- Sulfate concentrations were lower in leachate from the blended refuse columns.

Manganese Concentrations in the Column Leachate



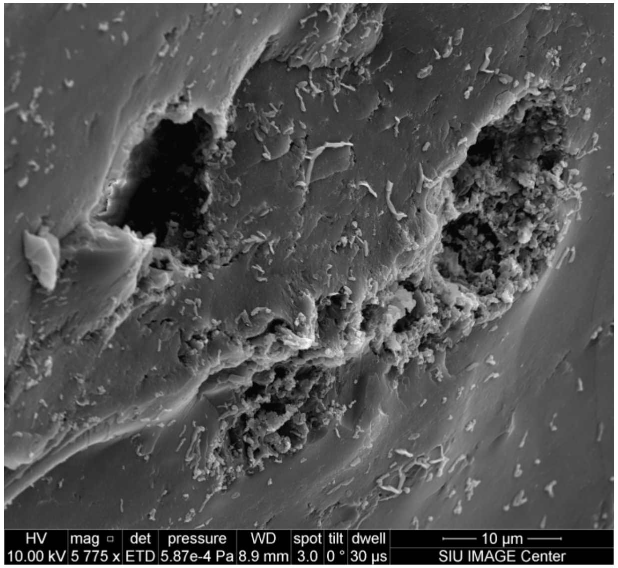
Manganese concentrations varied similar to temperature and SO_4 concentration trends. Manganese concentrations were lower in leachate from the blended refuse columns.

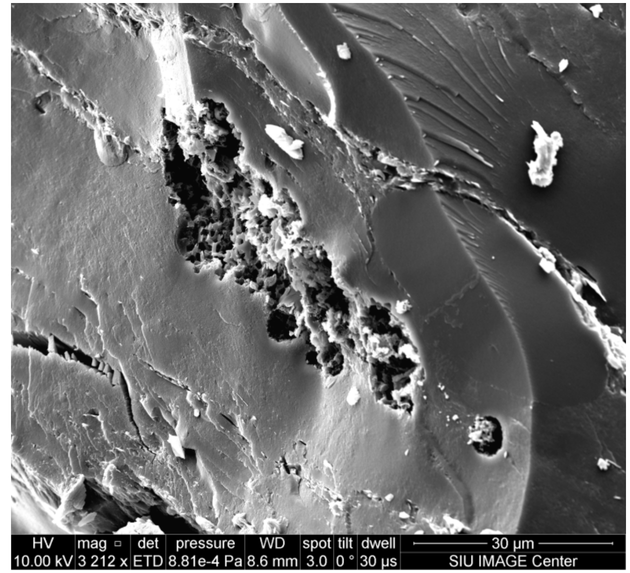
Iron Concentrations in the Column Leachate

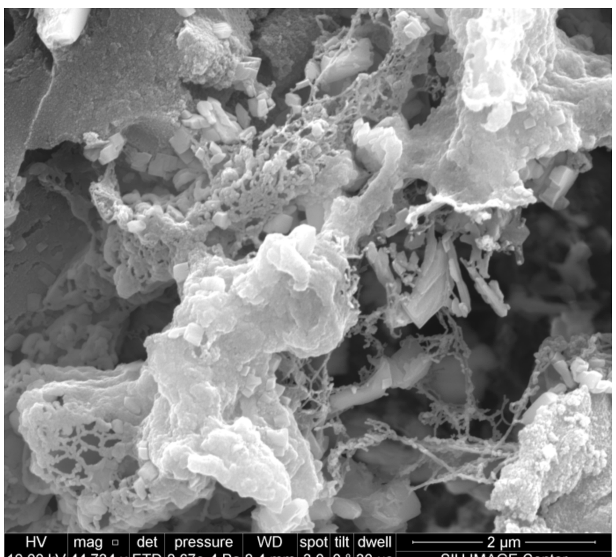


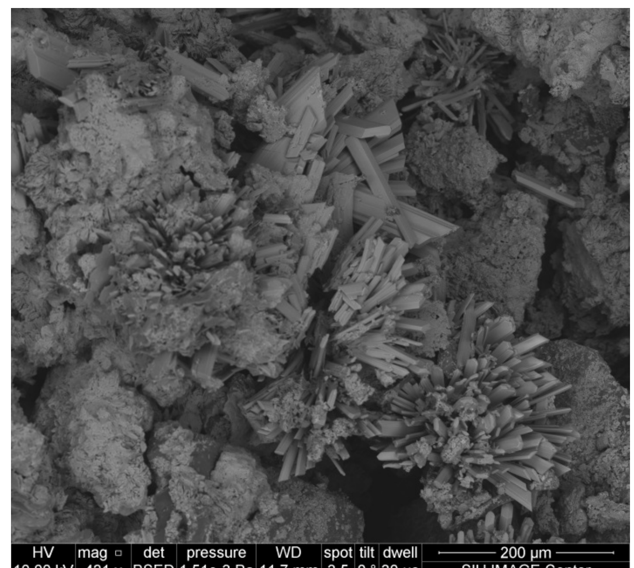
- Iron concentrations remained low for most of the experiment except for the CCPW columns. (> 11 months of testing CCPW leachate iron also tracked changes in temperature and SO_4).
- Iron likely precipitated within the CCPW columns during the earlier testing.

Weathered Coal Samples









Behum et al., 2014

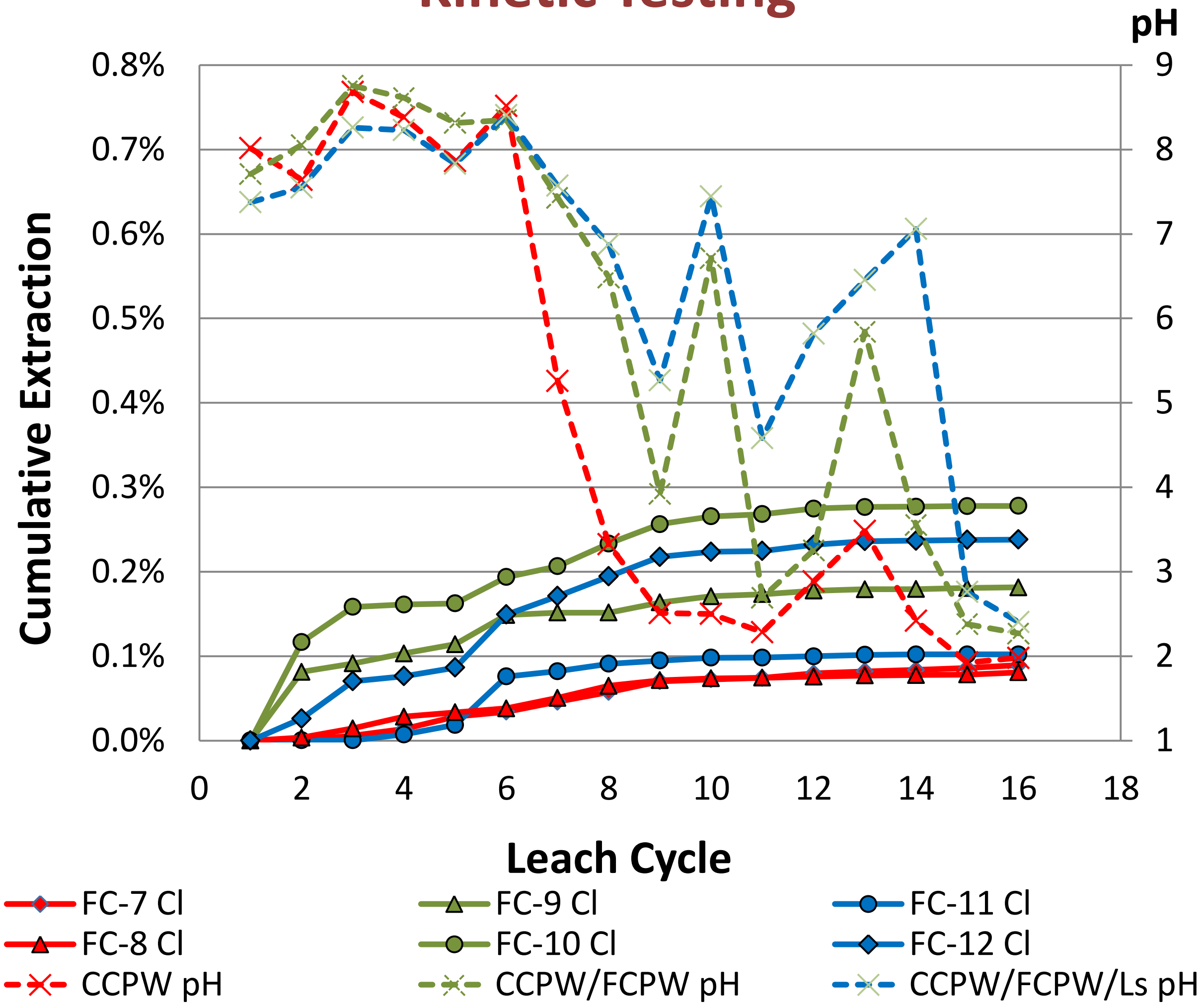
Normalization of Concentration Data

- Variations in precipitation altered field column infiltration rates and as a result the leachate volume.
- Example:

  Cl Load (mg) = Cl Concentration (mg/L)/ Leachate Volume (L)
- The Cumulative % Extraction is then determined using the Cl Load and the original mass of for example Cl contained in the column to determine the % extracted.
- Cumulative % Extraction is then the % Cl load that has accumulated for each sample interval throughout the kinetic test. In this case the sample interval was:

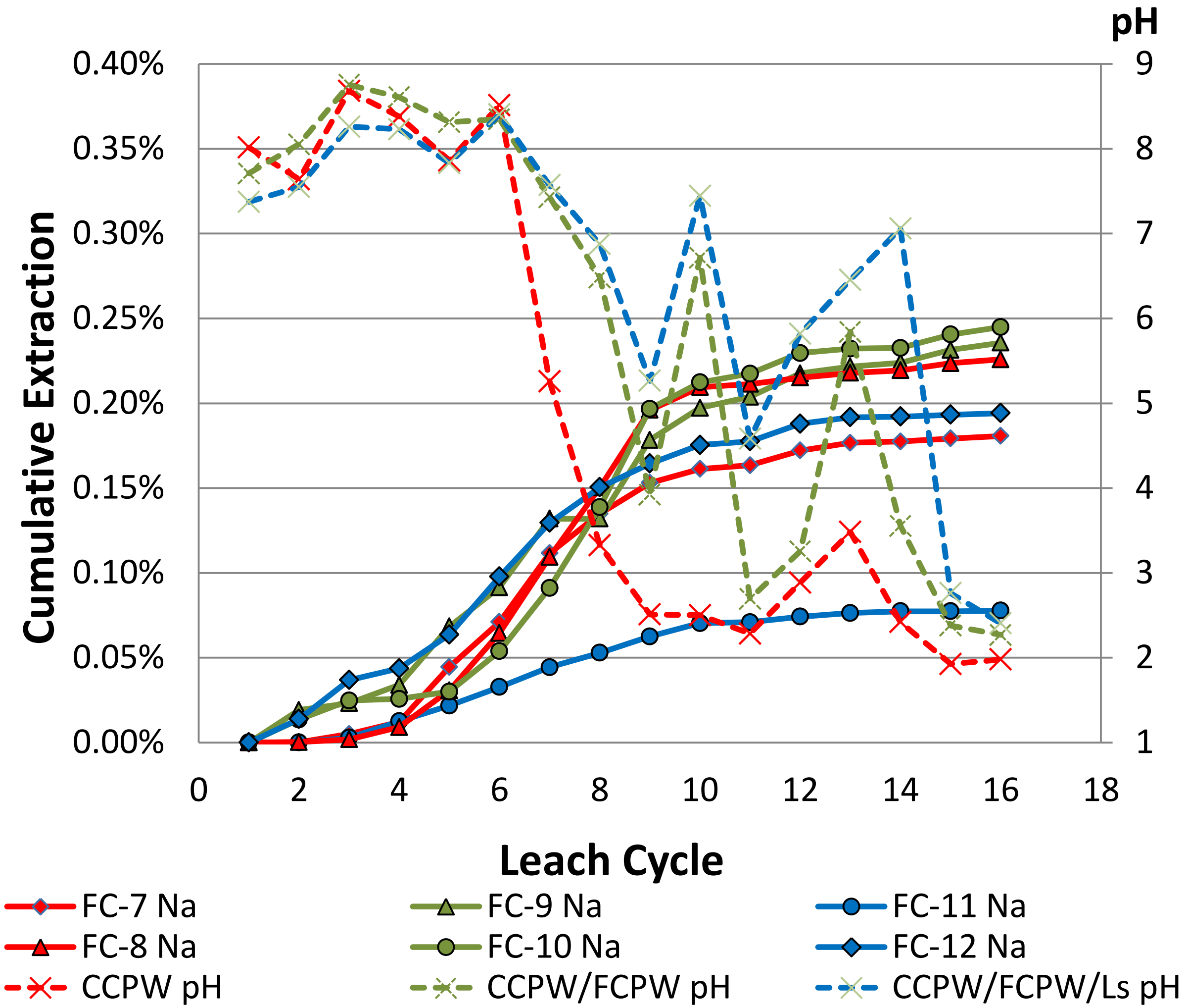
  Sample Interval = 602 day duration/16 samples = 38 days.

Chloride Extraction and pH Trends during Field Kinetic Testing



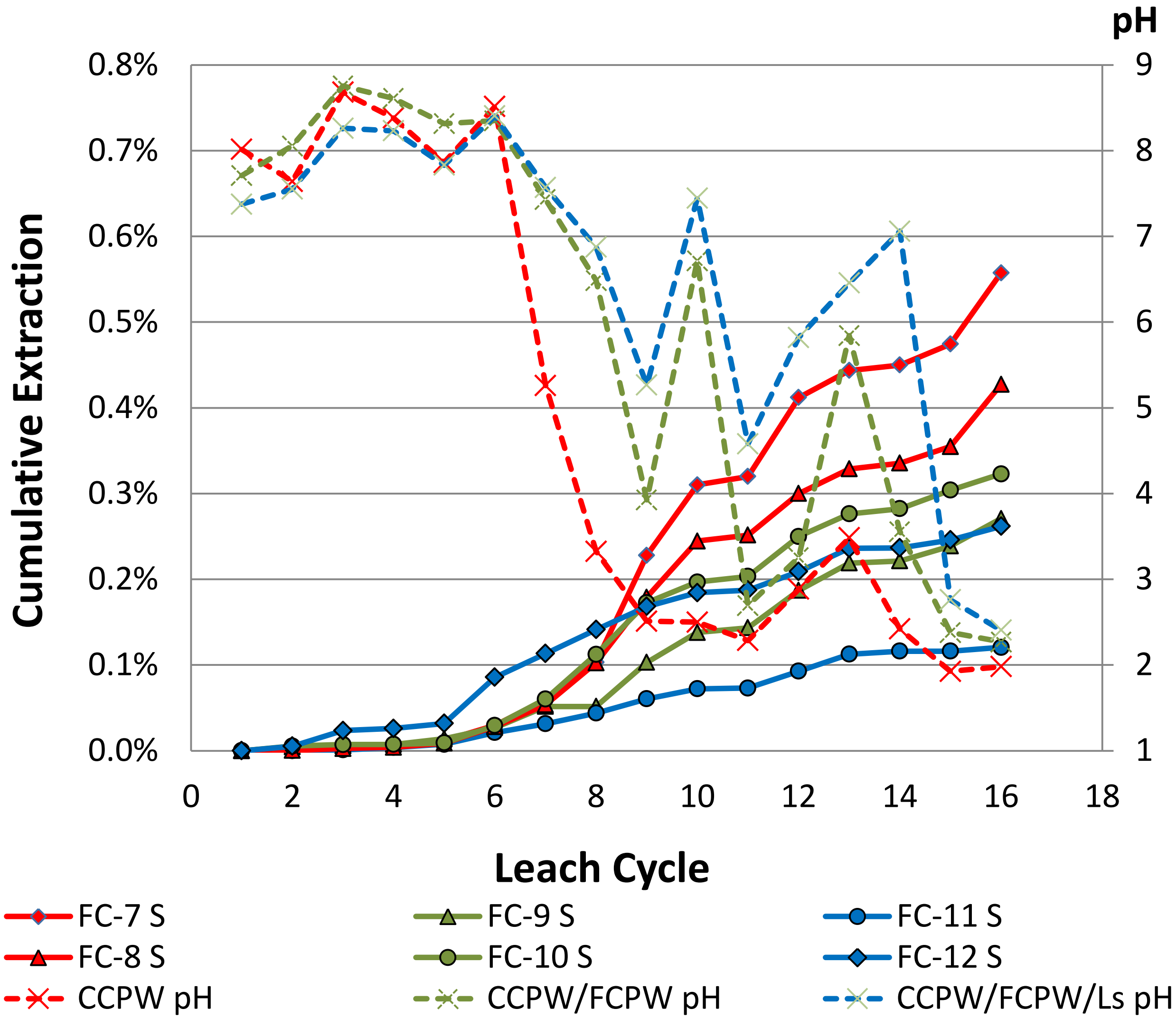
- Cl extraction was higher in the FCPW/CCPW blend due to the addition of FCPW; Cl is more readily leached from fine-grained materials.
- Cl extraction was lower in the FCPW/CCPW/limestone blend due to increased compaction and lower hydraulic conductivity.

Sodium Extraction and pH Trends during Field Kinetic Testing



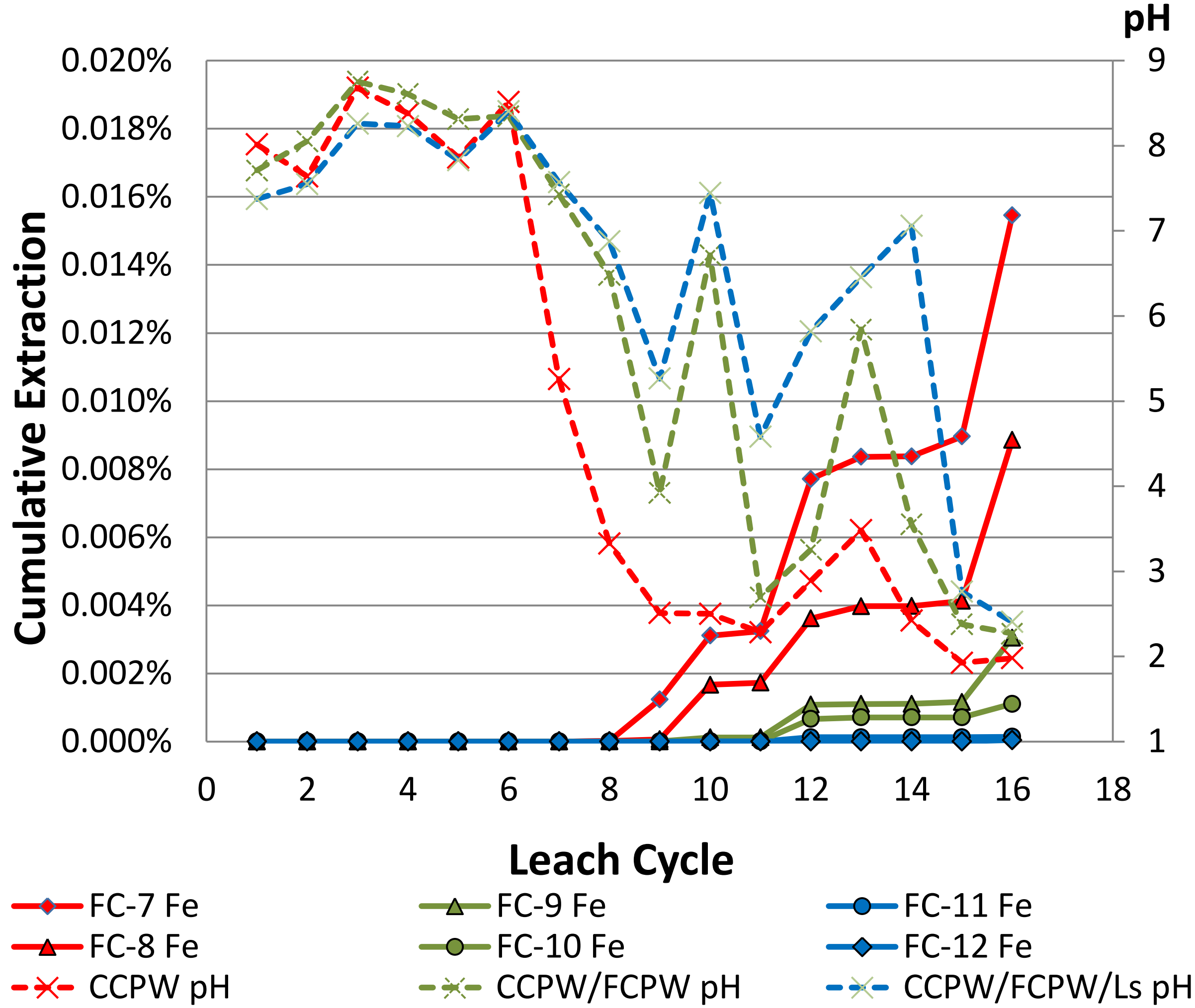
- Na^+ is the counter ion to Cl^- in sodium chloride (NaCl).
- As with Cl, Na extraction was higher in the FCPW/CCPW blend due to the addition of FCPW; Na is more readily leached from finer grained materials.
- Na extraction was lowest in the FCPW/CCPW/limestone blend due to most likely due to an increased compaction and lower hydraulic conductivity.

Sulfate Extraction and pH Trends during Field Kinetic Testing



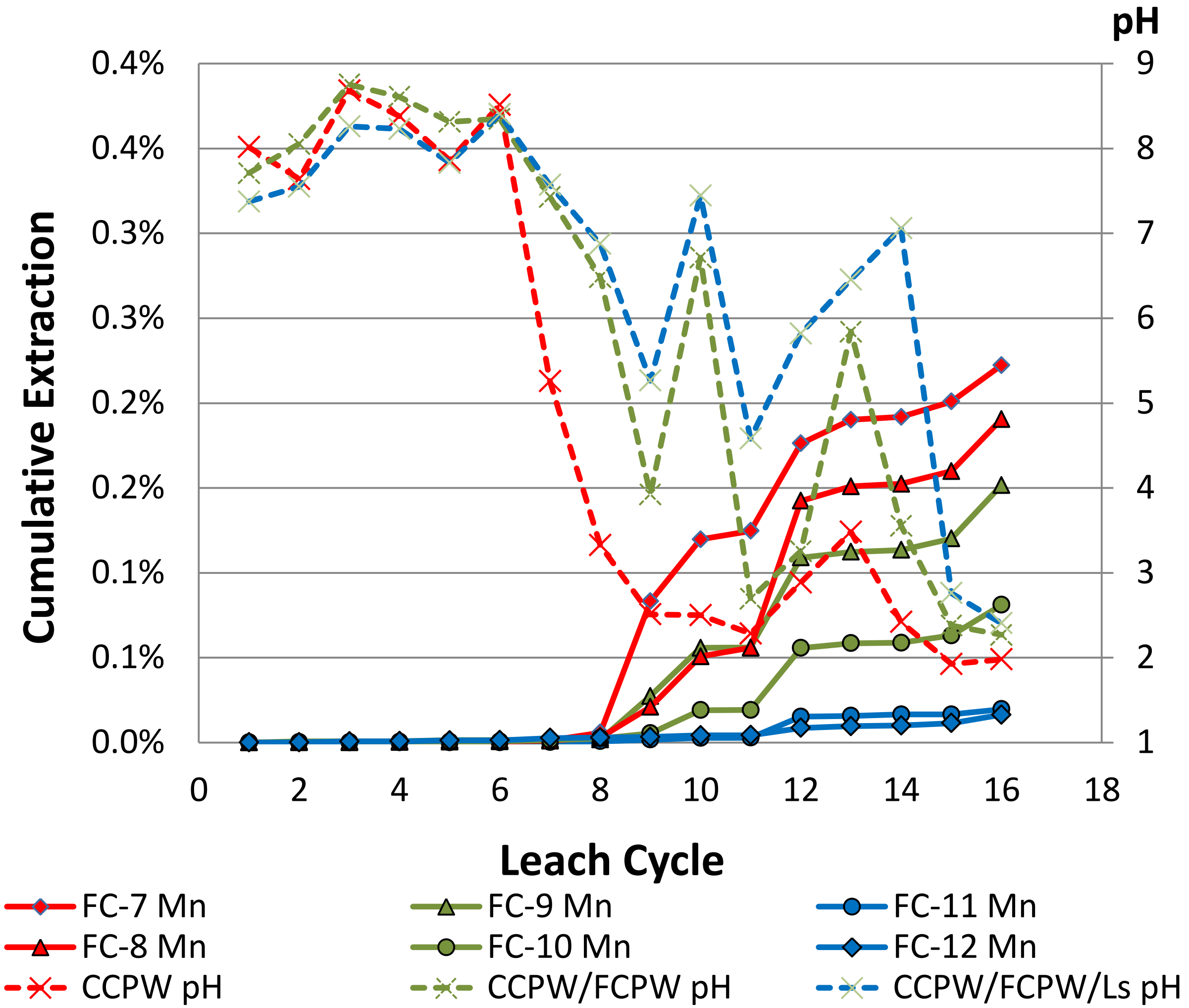
- SO_4 extraction (actually S extraction!) was higher in the CCPW; after 8 months the S was more readily leached from CCPW.
- S extraction was the lowest in the FCPW/CCPW/limestone blend, possibly due to increased compaction and lower hydraulic conductivity.

Iron Extraction and pH Trends during Field Kinetic Testing



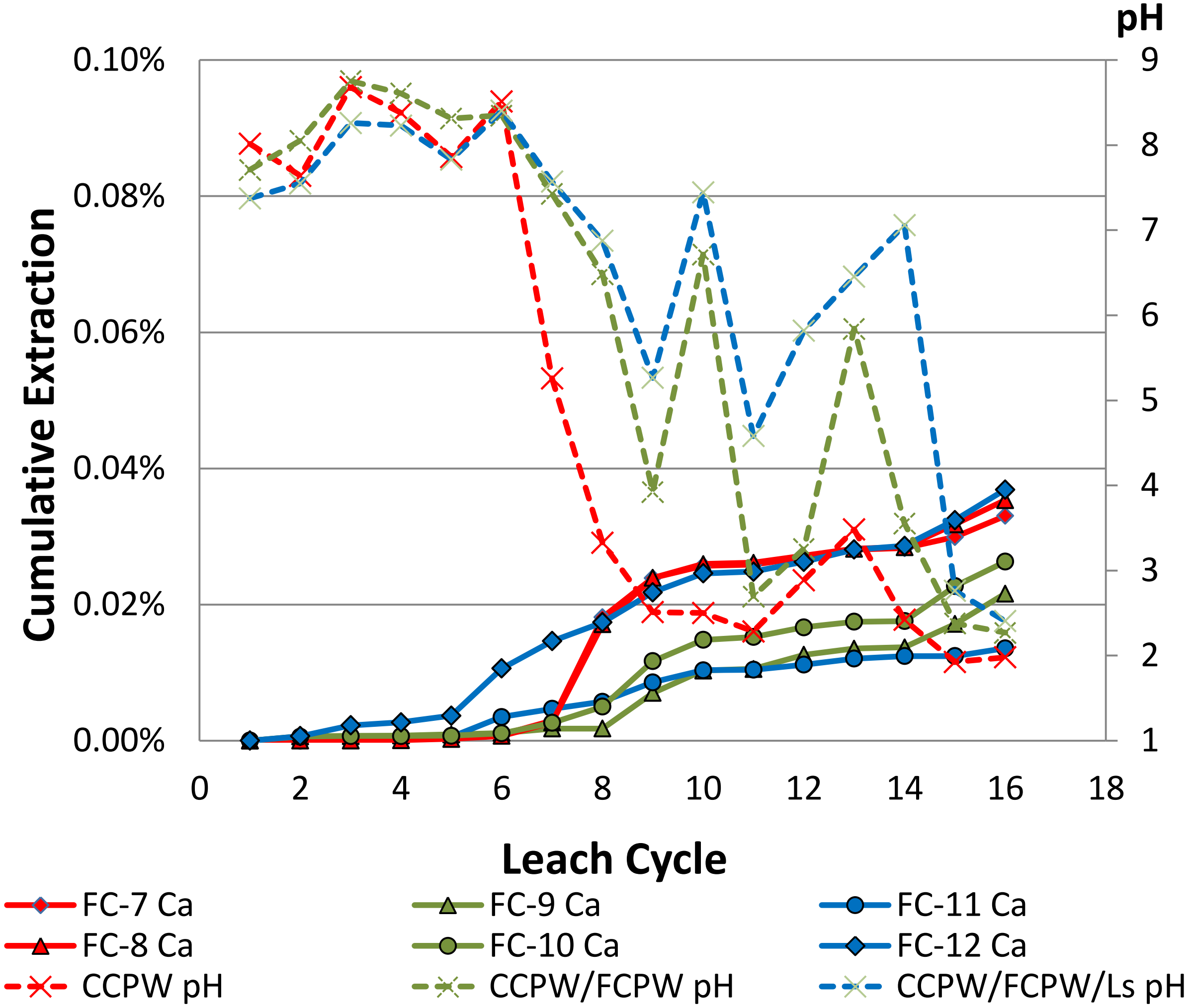
- Fe extraction was higher in the CCPW but only after 8 months of leach testing; Fe was more readily leached from CCPW.
- Fe extraction was the lowest in the FCPW/CCPW/limestone blend, which is most likely due to increased compaction and lower hydraulic conductivity.

Manganese Extraction and pH Trends during Field Kinetic Testing



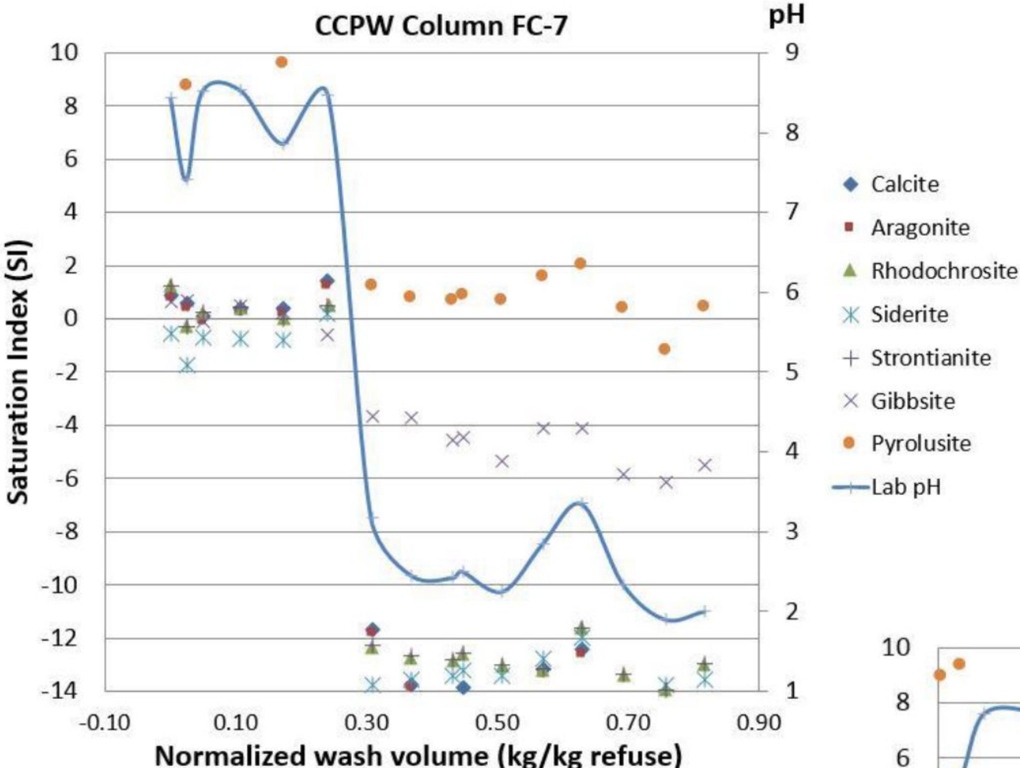
- Mn extraction was higher in the CCPW, but again only after 8 months of leach testing.
- Mn was more readily leached from CCPW and to a lesser extent the CCPW/FCPW blend.
- Mn extraction was the lowest in the FCPW/CCPW/limestone blend, which may be due to increased compaction and lower hydraulic conductivity.

Calcium Extraction and pH Trends during Field Kinetic Testing



- Ca extraction was initially higher in the limestone-amended CCPW/ FCPW blend.
- In the early test period Ca was more readily leached from CCPW and the CCPW/FCPW/Limestone blend.
- Ca extraction was overall lowest for the CCPW/FCPW blend.

Geochemical Modeling Results*

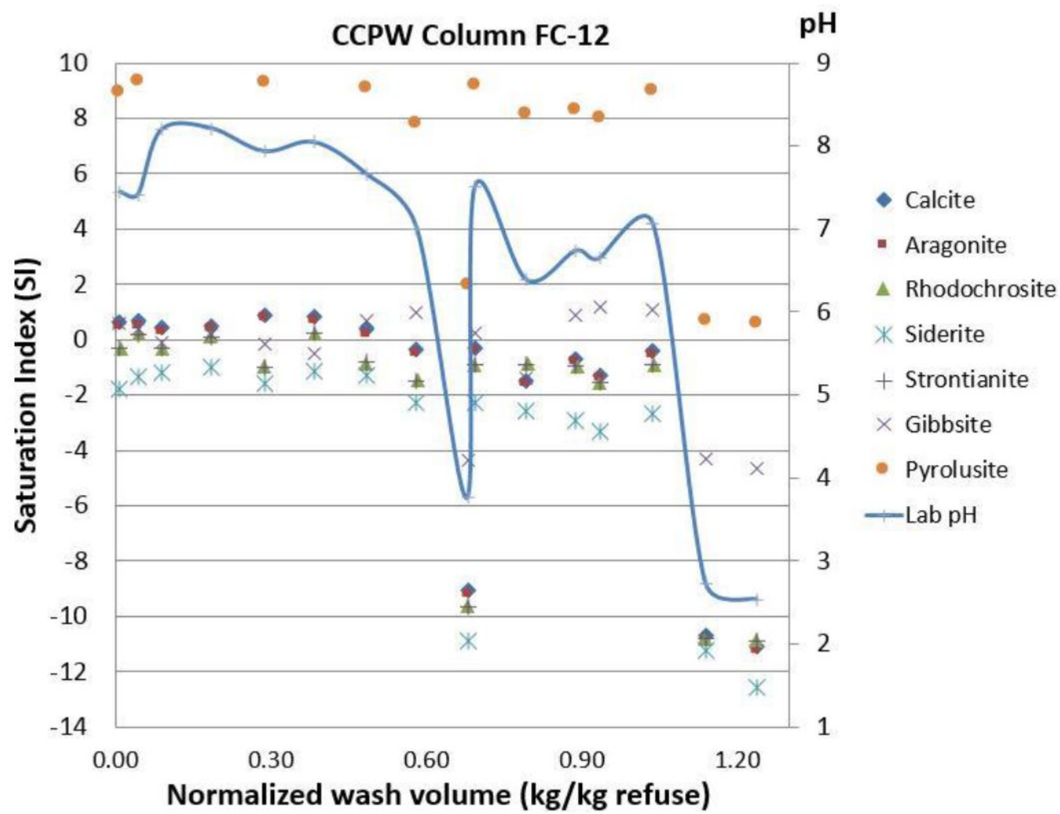


<u>CCPW Columns</u>:

1) Carbonate minerals were stable early leach testing when pH > 6.0
2) Carbonate minerals dissolved as the pH lowered to <4.5

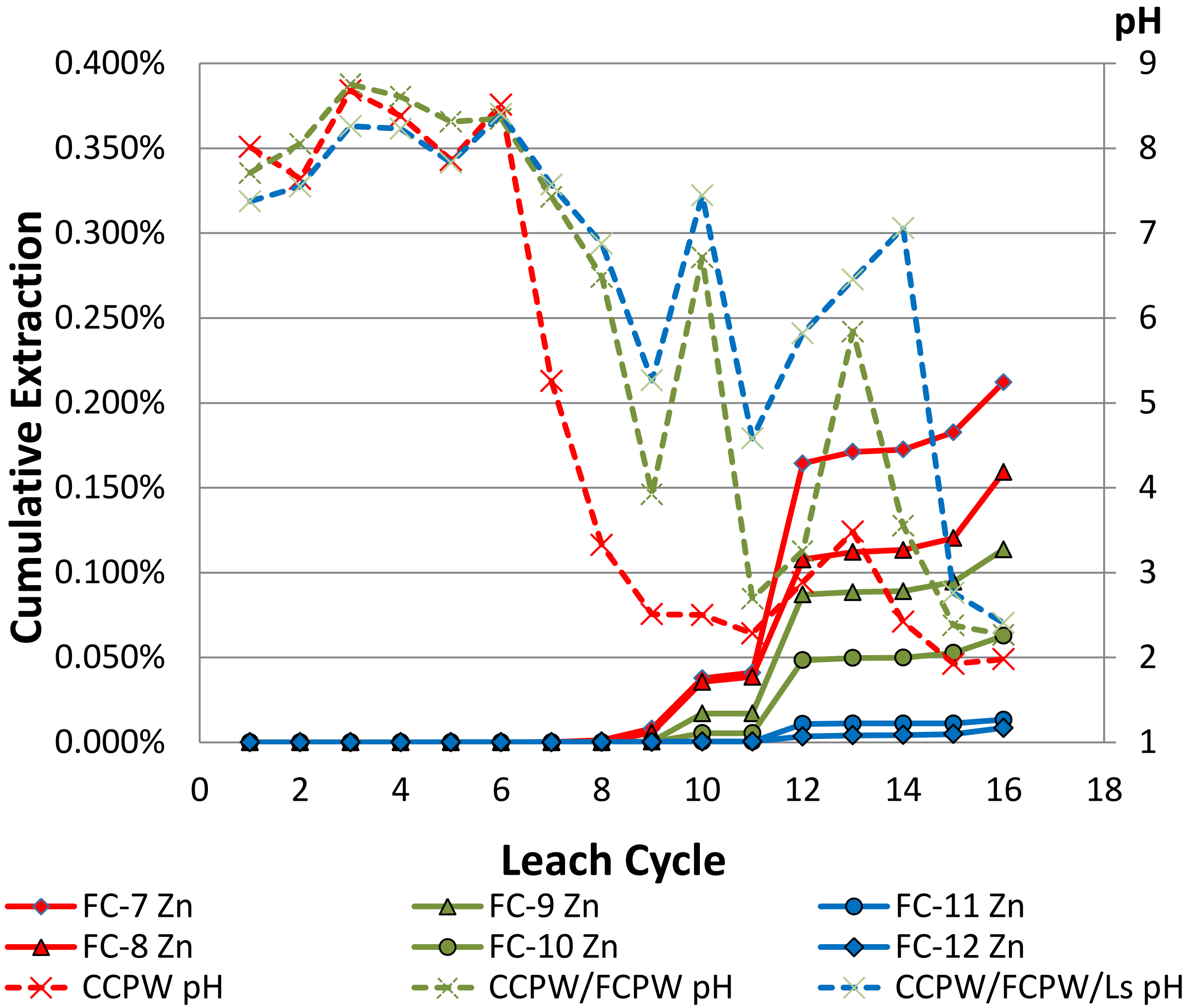
<u>CCPW/FCPW/Limestone Columns</u>:

1) Carbonate minerals were stable though most of the testing where the pH > 6.0
2) Carbonate minerals dissolved whenever pH lowered to <4.5



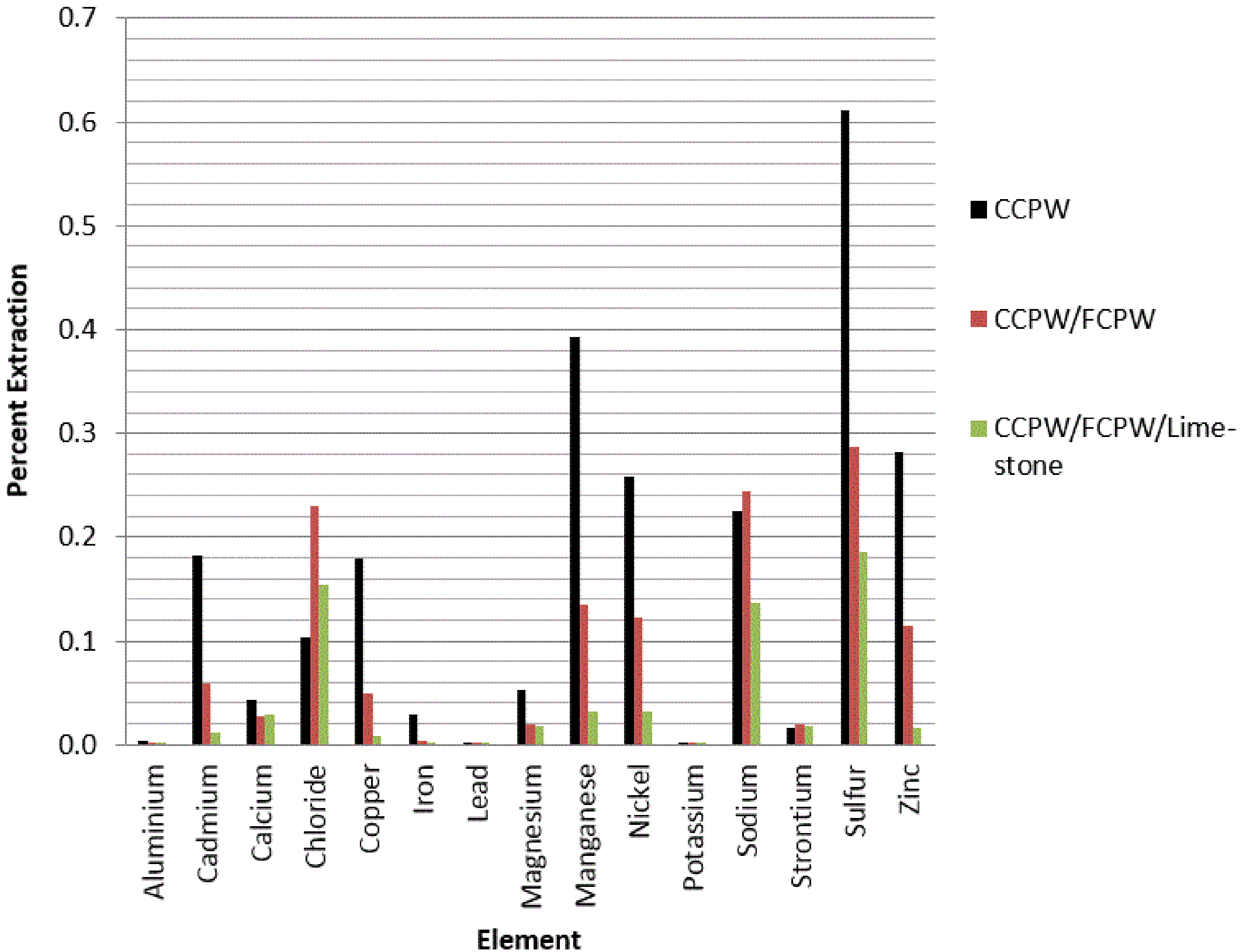
*The SI is compared to the average 0.36 pore volumes flushed from the columns every 38 day leach cycle per the average weight of the blend in the column (kg).

Zinc Extraction and pH Trends during Field Kinetic Testing



- Zn extraction was higher in the CCPW, but again only after 8 months of leach testing.
- Zn was more readily leached from CCPW and to a lesser extent the CCPW/FCPW blend.
- Zn extraction was the lowest by far in the FCPW/CCPW/limestone blend, which may be due to an elevated pH and increased compaction and lower hydraulic conductivity.

Elemental Extraction during Field Kinetic Testing



- Many elements were more readily leached from CCPW and to a lesser extent the CCPW/FCPW blend.
- Chloride and sodium were more easily leached from CCPW/FCPW blends.

Conclusions

- Verified hypotheses that a for Cl^- control is to apply dilution and to meter a controlled discharge during periods of greater precipitation.
- Good management practices for SO_4^{2-} control are to:
  - Compact and cover CCPW within 8 months;
  - Additional improvements are expected with co-disposal of CCPW and dewatered FCPW;
  - Even smaller SO_4^{2-} loading is anticipated with limestone additions to the CCPW/FCPW blend.

Recommendations

- Testing is needed for refuse derived from mining other important coal seams and for the No. 6 seam in central Illinois.
- Additional field kinetic test improvements are suggested:
  - Test cells should be scaled up to > 20 tons and include blends of mechanically dewatered FCPW.
  - Alternative low-cost sources for adding alkalinity (e.g., drying agents such as CCR or CKD) should be explored.

Acknowledgements

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- Peabody Energy, Inc., Equality, IL.
- US Office of Surface Mining Reclamation and Enforcement, Alton, IL.

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Questions?

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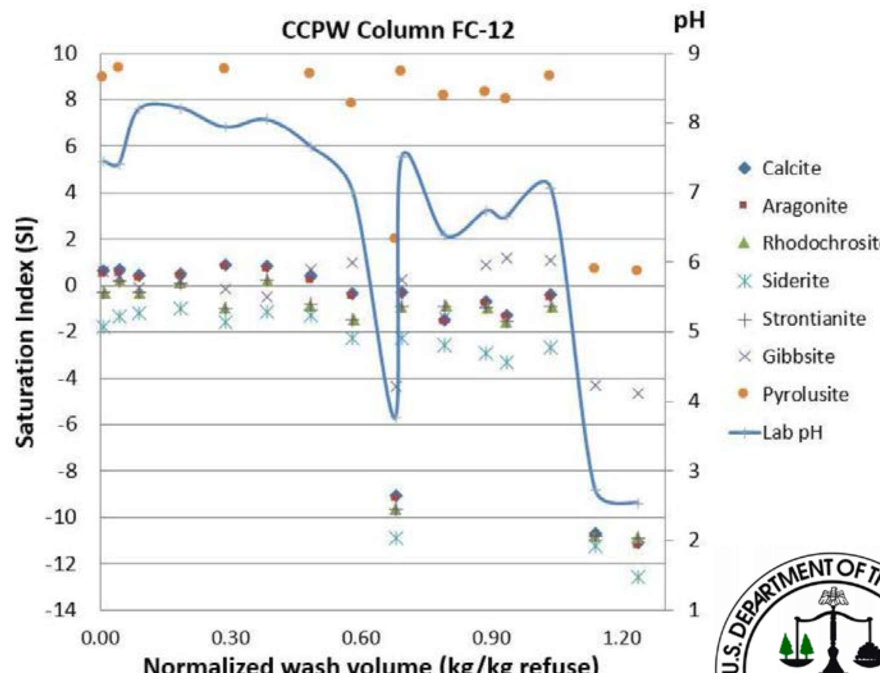

For more information see: https://icci.org/reports/12Lefticariu4C-5Final.pdf