Influence of Pre-Mine Weathering and Rock Type on TDS Release from Appalachian Coal Mine Spoils

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Historically, for active coal surface mines, we have focused our pre-mining analytics on (1) which materials need to be treated/isolated to prevent AMD and (2) which materials are optimal revegetation substrates. ***However, we now need to consider (3) what TDS components will each release?***

This is particularly true for larger operations

TDS/EC Discharge Standards?

Several widely cited study (e.g. Pond et al., 2008), found that streams with high conductivity -- above 500 µs/cm -- were biologically impaired.

On April 1, 2010, USEPA issued new "guidance" requiring measures to mitigate discharges above 300 µs/cm, and a reduction in mine size or cancellation of active or future fills if above 500 µs/cm.

While this guidance was overturned in DC federal court in 2012, TDS remains a dominant state & federal regulatory concern.

Where's it come from?

- **Acid-base reactions**; sulfide oxidation and carbonate neutralization reactions.
- Background **carbonation reactions** in non-sulfidic materials.
- **Hydrolysis** of primary mineral grains.
- **Entrained Cl and SO_4** in rocks (minor).
- Other minor weathering reactions like K release from micas, etc.

Oxidized, pH 5.5 overburden over reduced carbonate (2%) containing overburden at depth.

Overall Objective

The primary objective of this research program is to develop and evaluate methods for characterizing and predicting TDS release potentials, along with it's constituent elements (Se, and other elements of concern), from coal overburden and refuse materials.

Prediction methods must predict short-term peak discharges and long-term release characteristics and component ions.

RECLAIMED VALLEY FILL

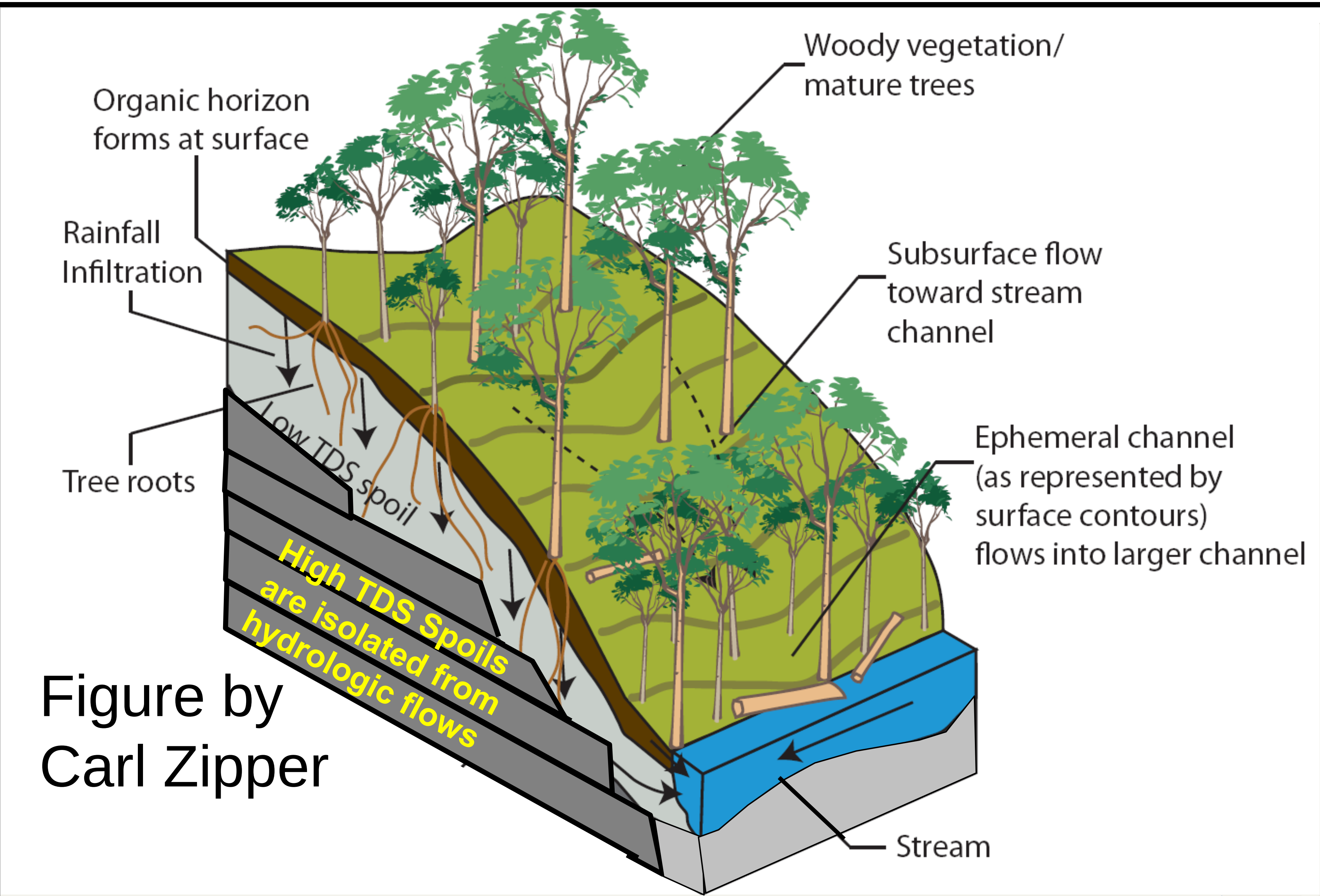


Figure by
Carl Zipper

Specific Objectives

1) To characterize the potential leaching behavior (pH, EC, major cations and anions) of mine spoils and refuse materials using laboratory leaching columns and other methods.

2) To evaluate effects of saturation levels on TDS release from spoil in laboratory leaching columns.

3) To evaluate scaling effects by comparing leachate data from laboratory columns, intermediate field scale barrels and tanks, and larger field scale plots.

4) To evaluate static test predictors in comparison to laboratory leaching columns.

COLUMN SETUP

Capped with 5 cm sand

- Sample volume: 1200 cm^3
- Inside diameter = 7.5 cm
- Height of spoil = ~ 27 cm
- Inside bottom of column:

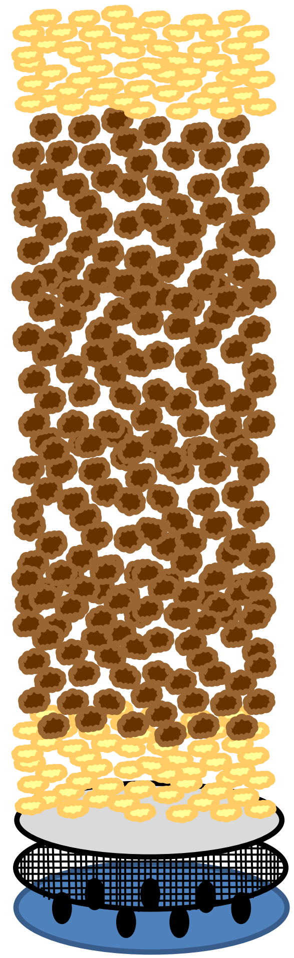
  -- 5 cm (2") sand

  -- Whatman #1 filter

  -- 0.1 mm nylon mesh

  -- perforated plastic disc

- PVC pipe nipple and Tygon tubing for drainage



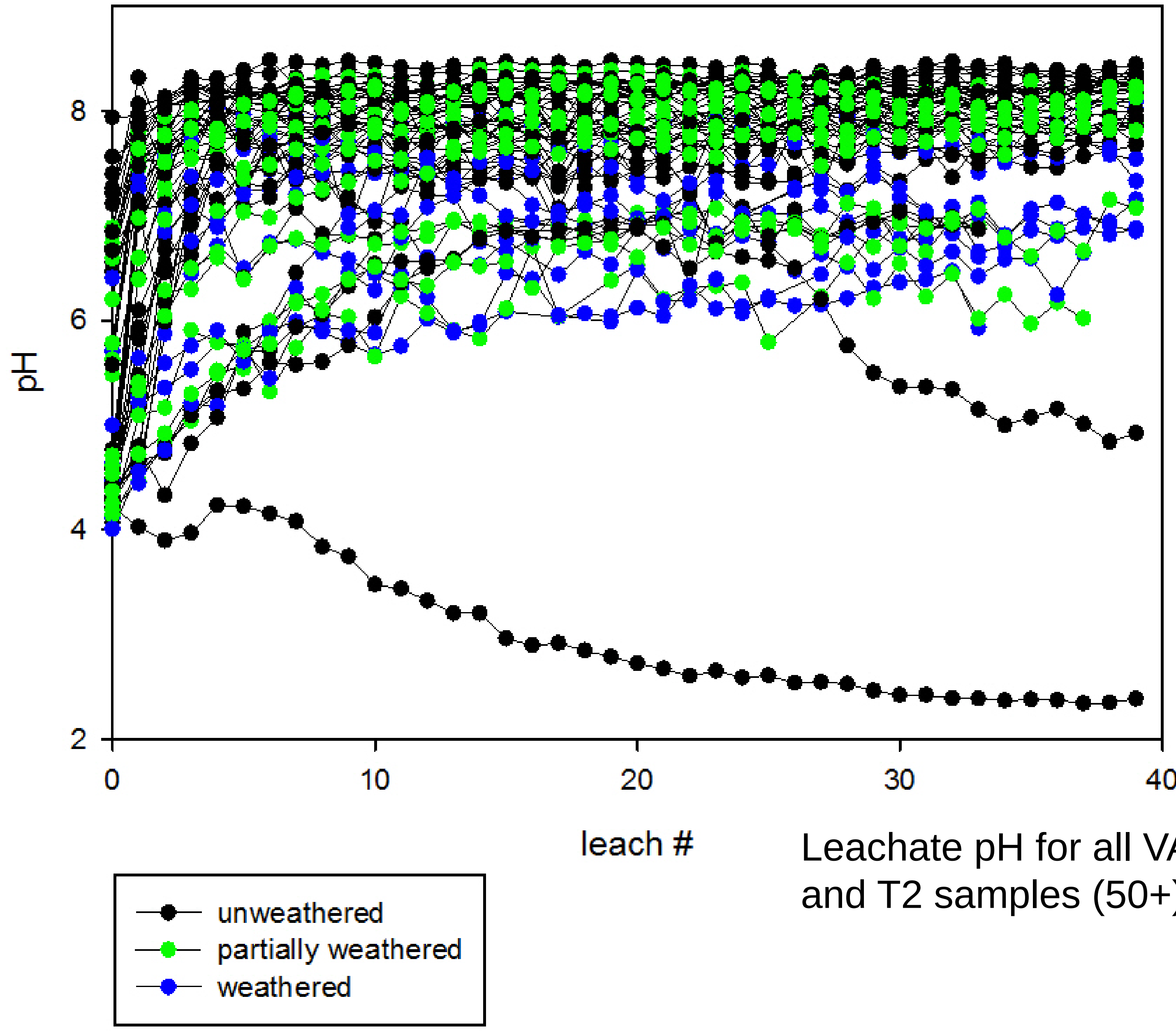
Laboratory Column Leaching Method

BULK SAMPLES (typically 2 x 5-gal buckets) are each:

- Spread out to air-dry.
- Passed through a 1.25 cm (0.5”) sieve.
- Coarse fraction crushed to <1.25 cm.
- All material thoroughly re-blended.
- Subsamples (1200 cm^3, with mass recorded) were collected (cone and quarter) for column leaching, to determine pore volume (within columns), and to determine coarse particle size distribution.
- Subsamples were collected and crushed as appropriate for basic characterization including saturated paste pH/EC and total-S.

Laboratory Column Leaching Method

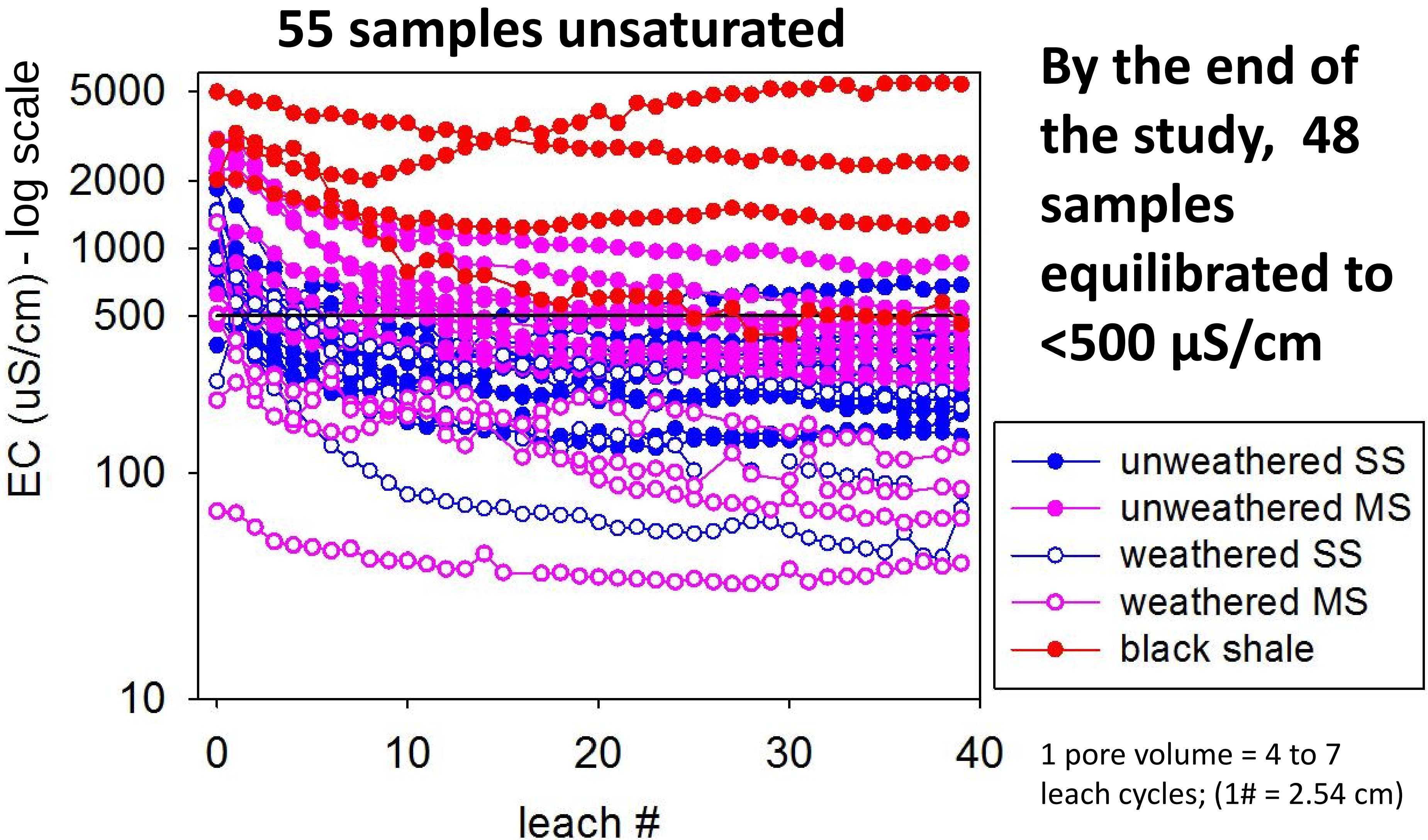
- **Each material run in triplicate (3 columns/material)**
- **Unsaturated: samples initially moistened to maximum water holding, then any amount added = amount drained.**
- **Saturated: drain tube clamped, samples moistened so saturation, drain tube unclamped to collect sample.**
- **Leaching solution: synthetic acid rain with pH=4.6**
- **Simulated rainfall was applied 2x/week (Mon/Thurs)**
- **Each rainfall event = 125 ml (~2.5 cm; 1”)**
- **Leachate (~125 ml) collected after ~24 hrs (Tues/Fri).**
- **Samples analyzed for: pH, EC, major cations and anions.**



Leachate pH for all VA, WV, KY, TN, and T2 samples (50+).

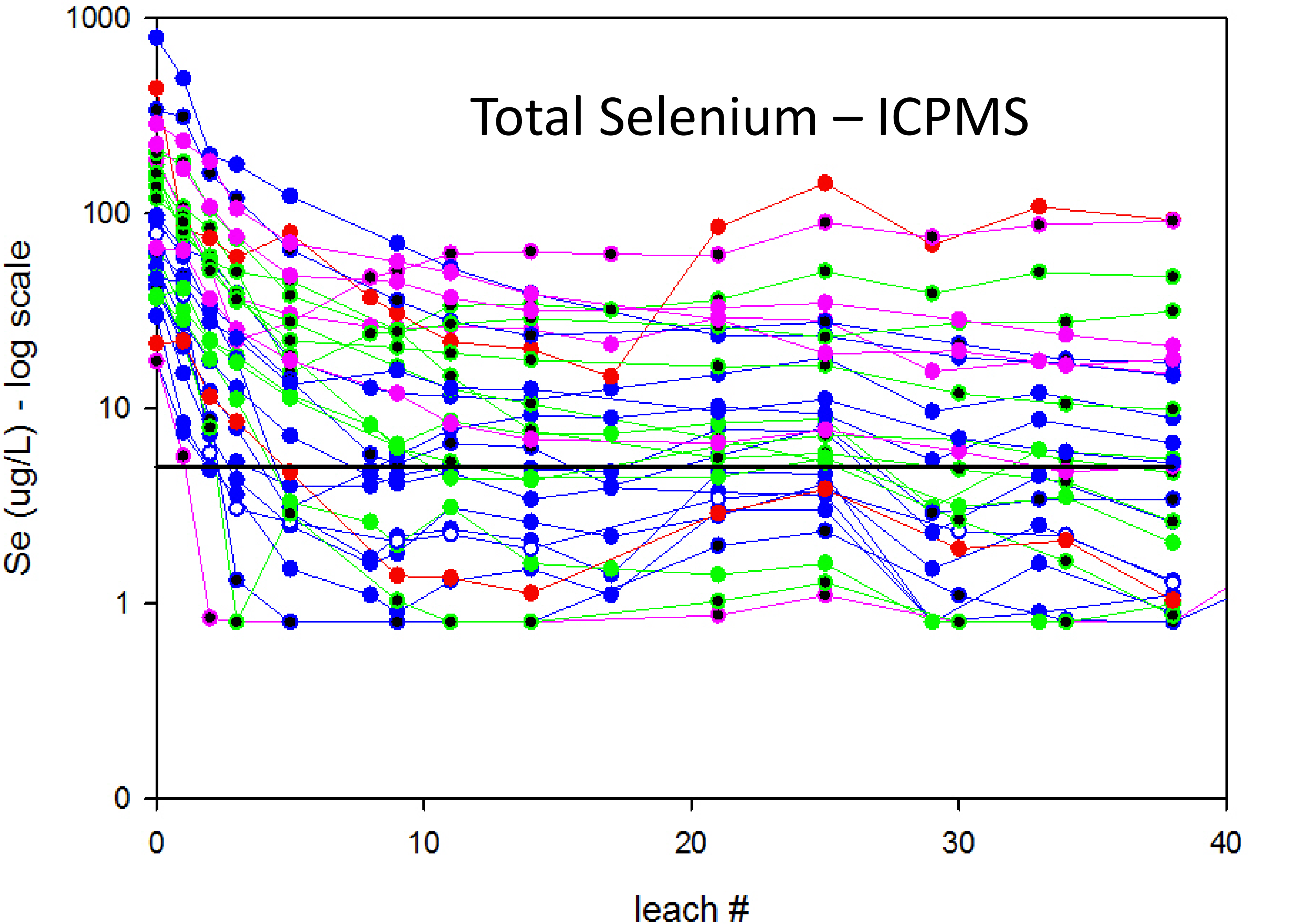
Overall: 1) increased weathering = lower EC/TDS

2) coarser grain size = lower EC/TDS

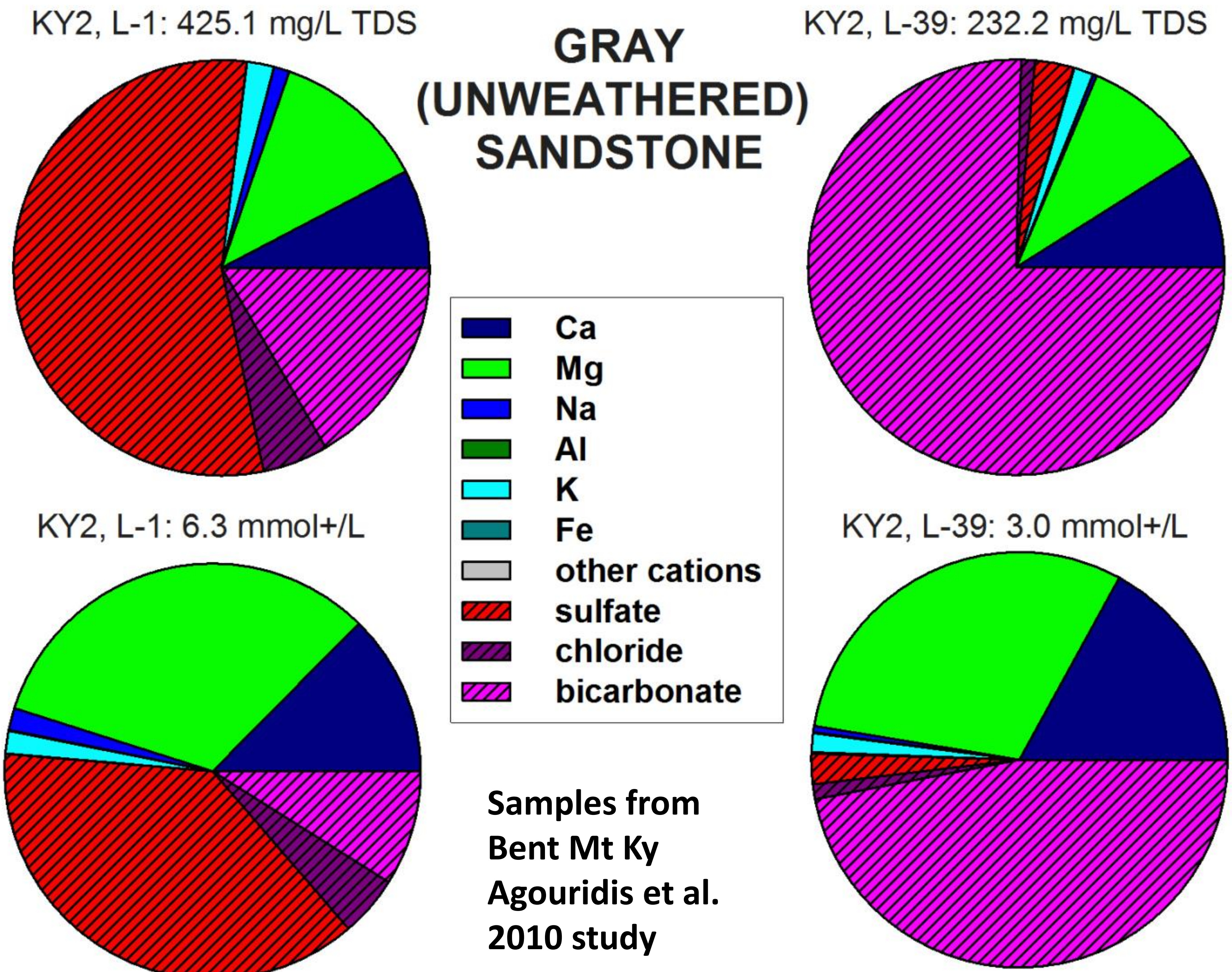


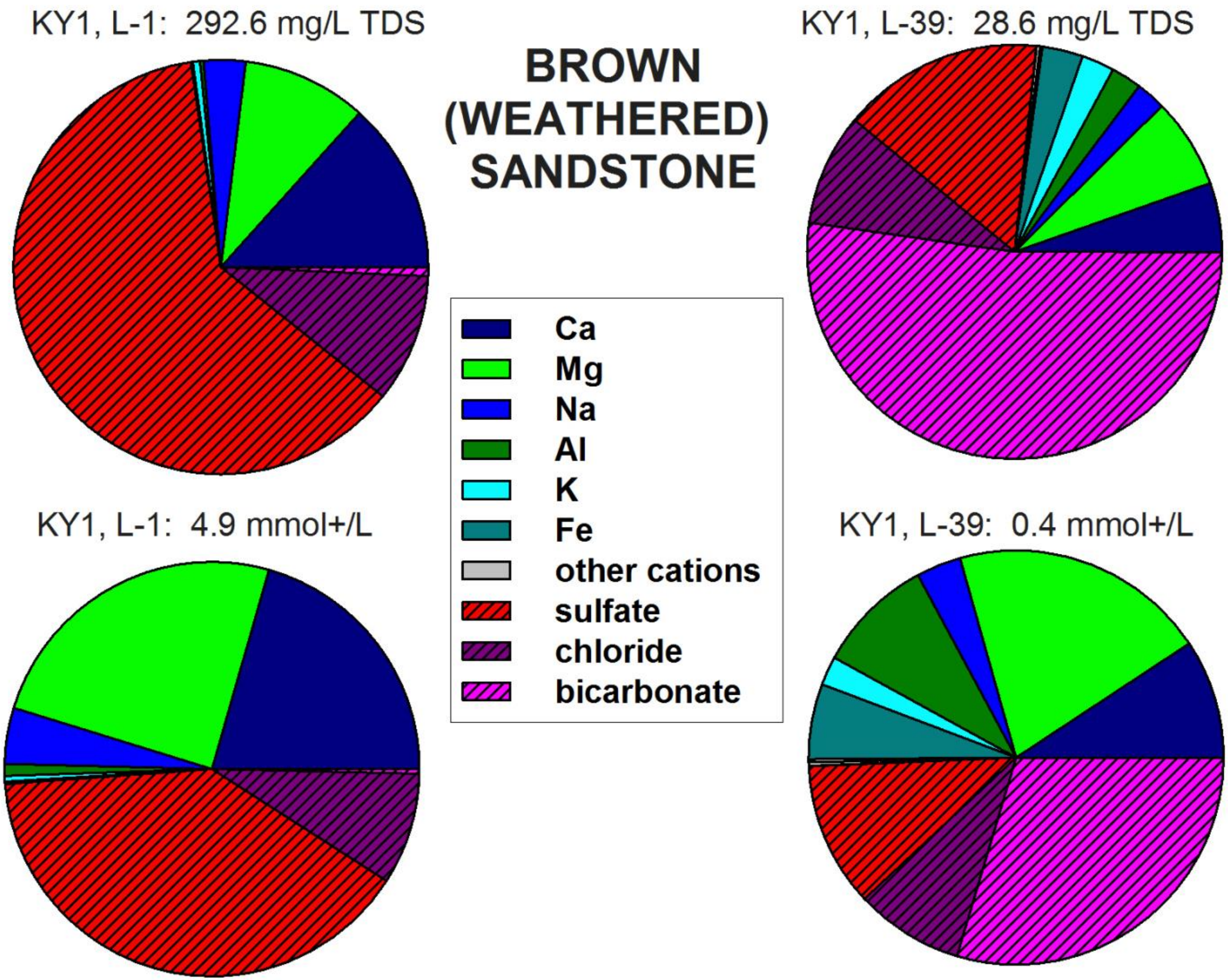
By the end of the study, 48 samples equilibrated to <500 µS/cm

1 pore volume = 4 to 7 leach cycles; (1# = 2.54 cm)



Total Selenium – ICPMS
Se (ug/L) - log scale
1000
100
10
1
0
0
10
20
30
40
leach #


GRAY
(UNWEATHERED)
SANDSTONE
KY2, L-1: 425.1 mg/L TDS
KY2, L-39: 232.2 mg/L TDS
KY2, L-1: 6.3 mmol+/L
KY2, L-39: 3.0 mmol+/L
Ca
Mg
Na
Al
K
Fe
other cations
sulfate
chloride
bicarbonate
Samples from
Bent Mt Ky
Agouridis et al.
2010 study


BROWN
(WEATHERED)
SANDSTONE
KY1, L-1: 292.6 mg/L TDS
KY1, L-39: 28.6 mg/L TDS
KY1, L-1: 4.9 mmol+/L
KY1, L-39: 0.4 mmol+/L
Ca
Mg
Na
Al
K
Fe
other cations
sulfate
chloride
bicarbonate

Scaling Issues and Studies

- **Leaching columns *may* serve as a reliable predictor of TDS leaching potentials over time, but do they accurately estimate maximum short term and equilibrium long-term concentrations?**
- **In general, we assume that column data are worst-case and need to be "scaled" to better resemble and predict field data.**

Scaling Issues and Studies

- For one scaling study (OSM+ARIES), we are testing one common spoil (Harlan fm; raw saturated paste EC ~ 850) using laboratory columns, and field-scale barrels (0.15m^3) and mesocosm tanks (0.85 m^3).

- For a second scaling study (OSM), we are comparing two refuse samples from TN in columns and barrels.

- In a third scaling study (ARIES), we are comparing our column leaching data for the four UK samples with large field-scale lysimeter data from the same spoils at Bent Mountain.

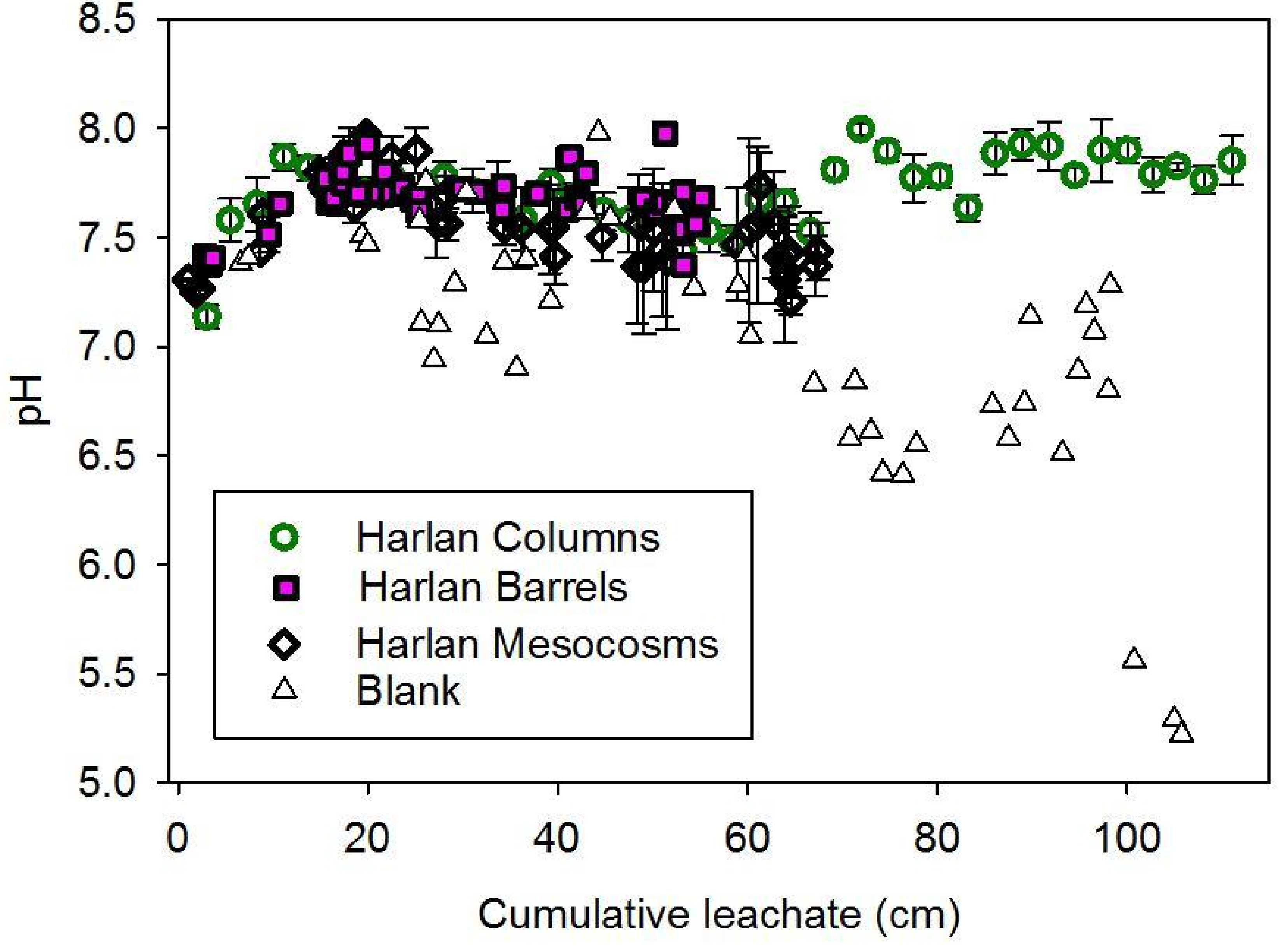
Harlan fm Spoil Collection –Wise

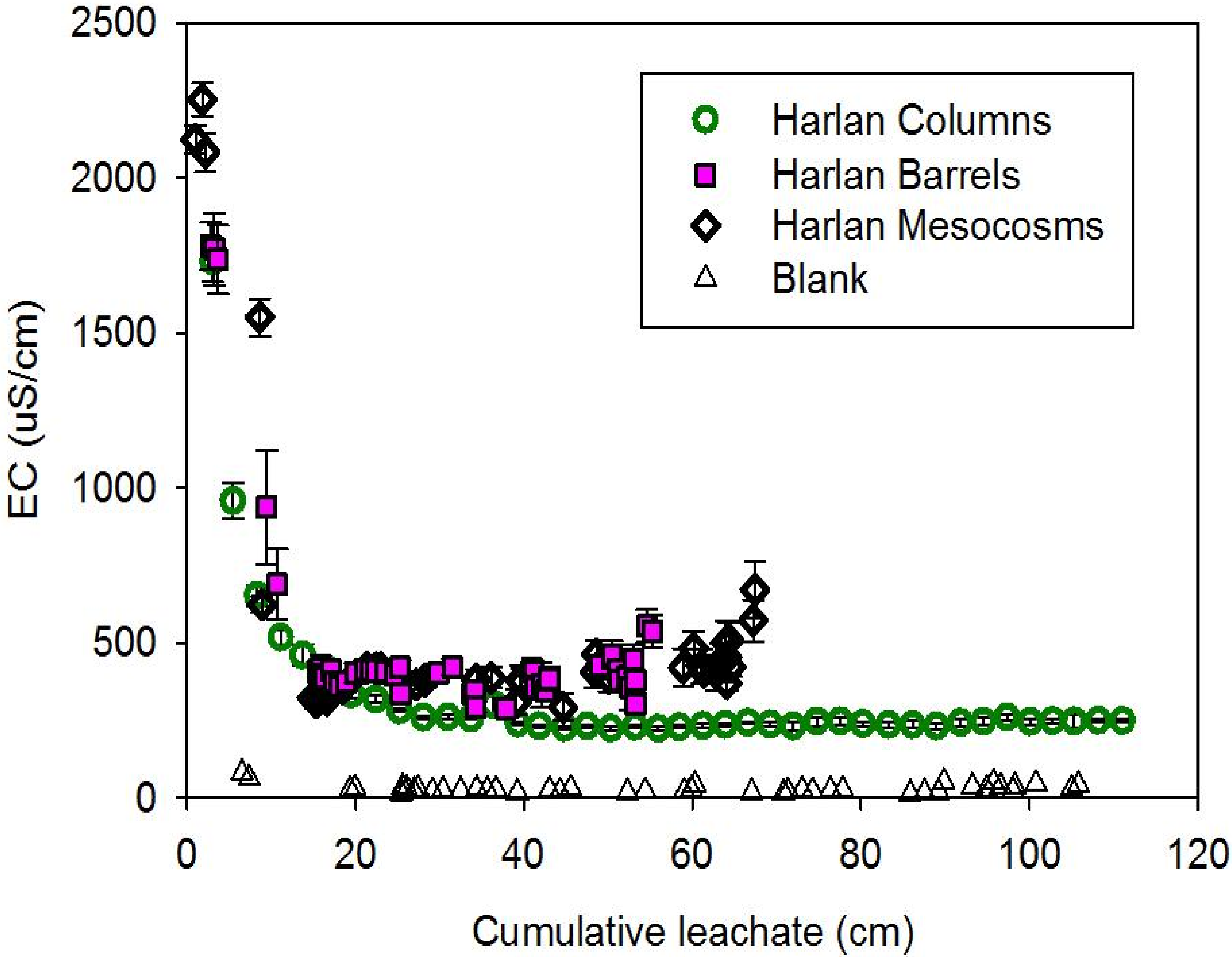

Filter fabric was placed over drainage
layer and then spoils placed in tanks.

Raw spoil (up to 18") placed into mesocosms over filter fabric and 10 cm of acid washed gravel. Initiated in October of 2012 and will be continued through 2014?

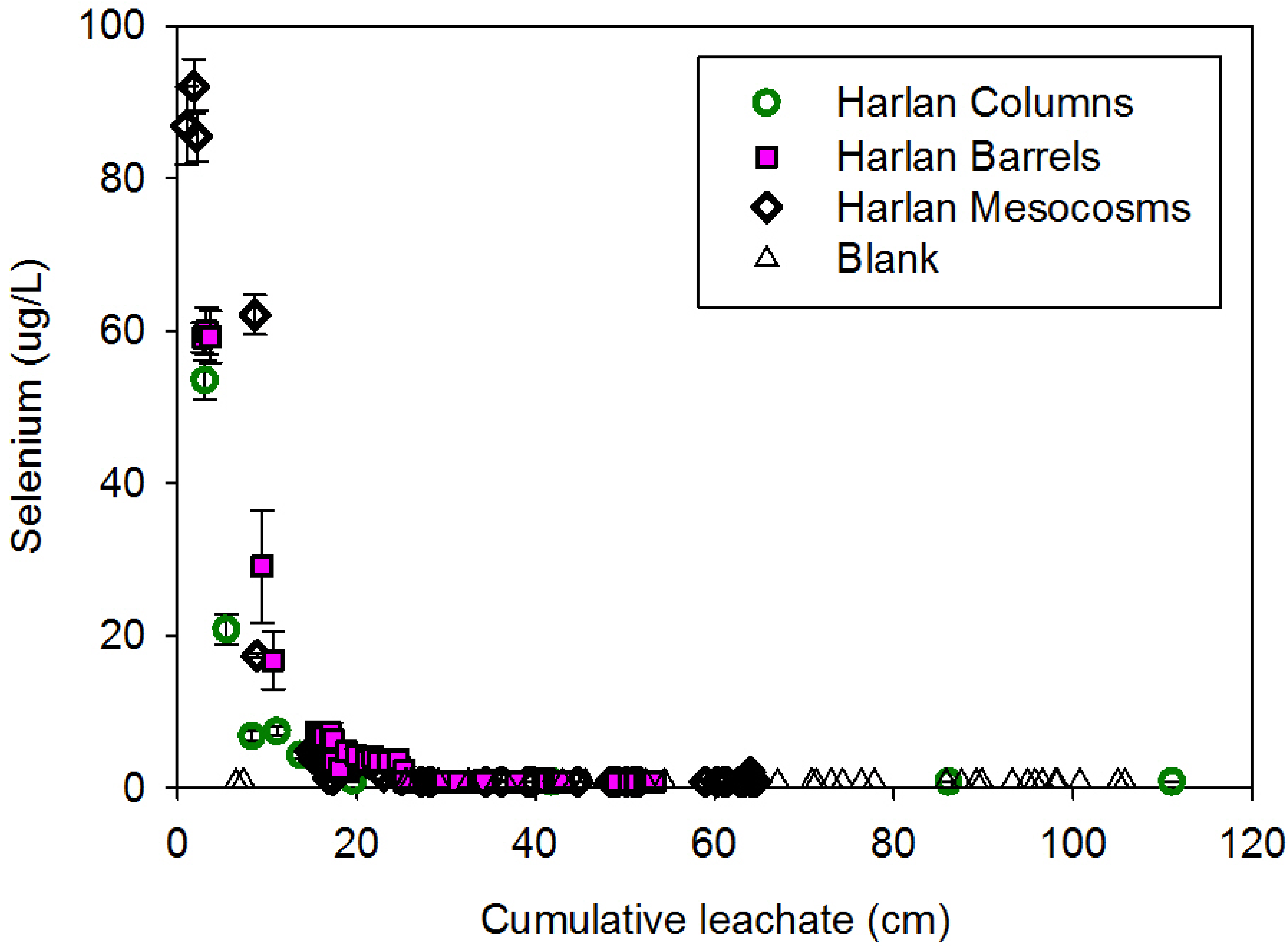
Large mesocosms (here) supported by OSM and ARIES. OSM supported smaller "barrels" on same site with same spoil (Harlan fm) and two coal refuse materials from TN. Barrels received ≤ 5" screened spoils.

Buried barrels receive gravity leachate drainage from the mesocosms.

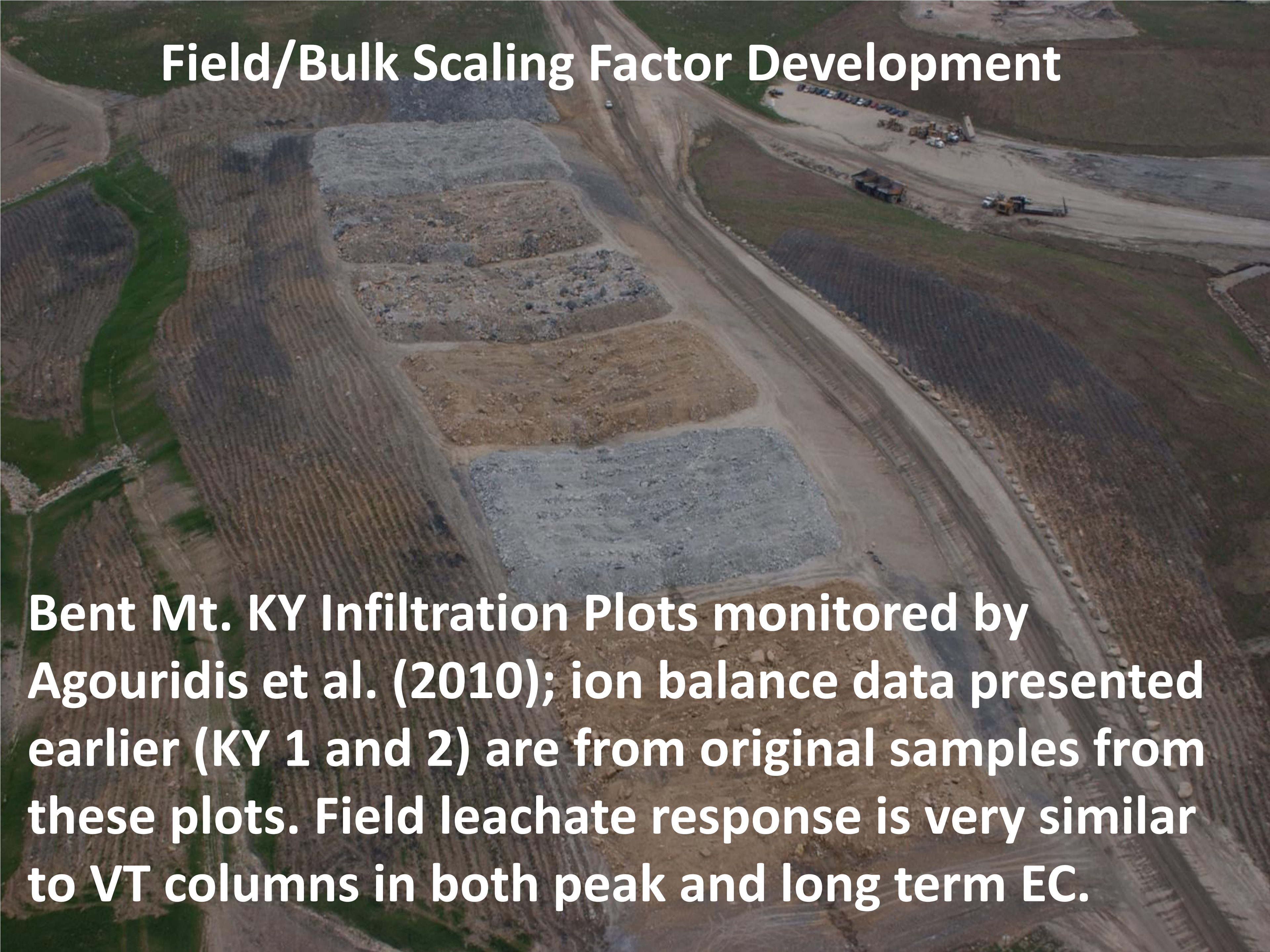

8.5
8.0
7.5
7.0
6.5
6.0
5.5
5.0
pH
0
20
40
60
80
100
Cumulative leachate (cm)
Harlan Columns
Harlan Barrels
Harlan Mesocosms
Blank



2500
2000
1500
1000
500
0
EC (uS/cm)
0
20
40
60
80
100
120
Cumulative leachate (cm)
Harlan Columns
Harlan Barrels
Harlan Mesocosms
Blank

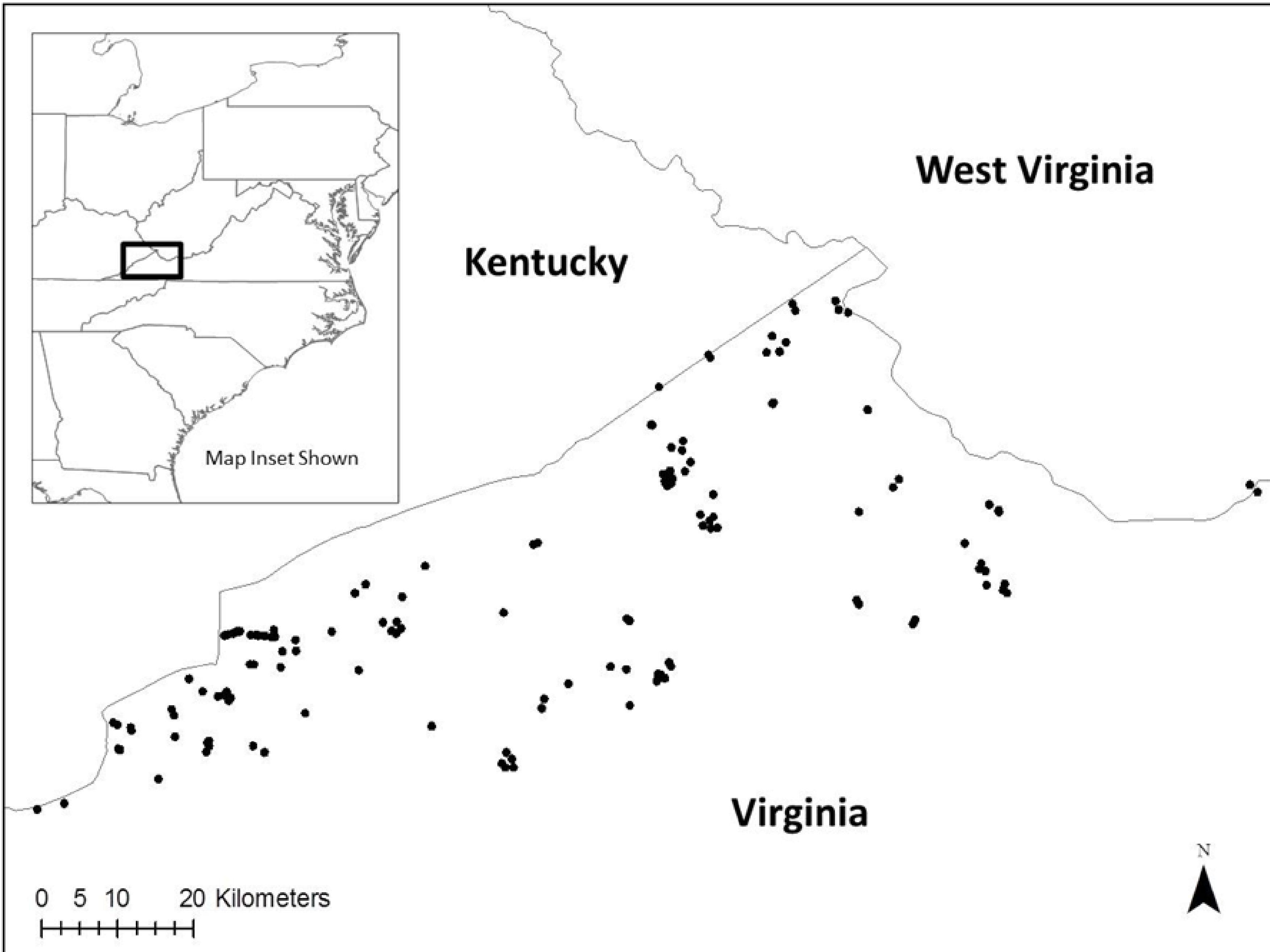

Harlan Columns
Harlan Barrels
Harlan Mesocosms
Blank
Selenium (ug/L)
0
20
40
60
80
100
Cumulative leachate (cm)
0
20
40
60
80
100
120

Field/Bulk Scaling Factor Development

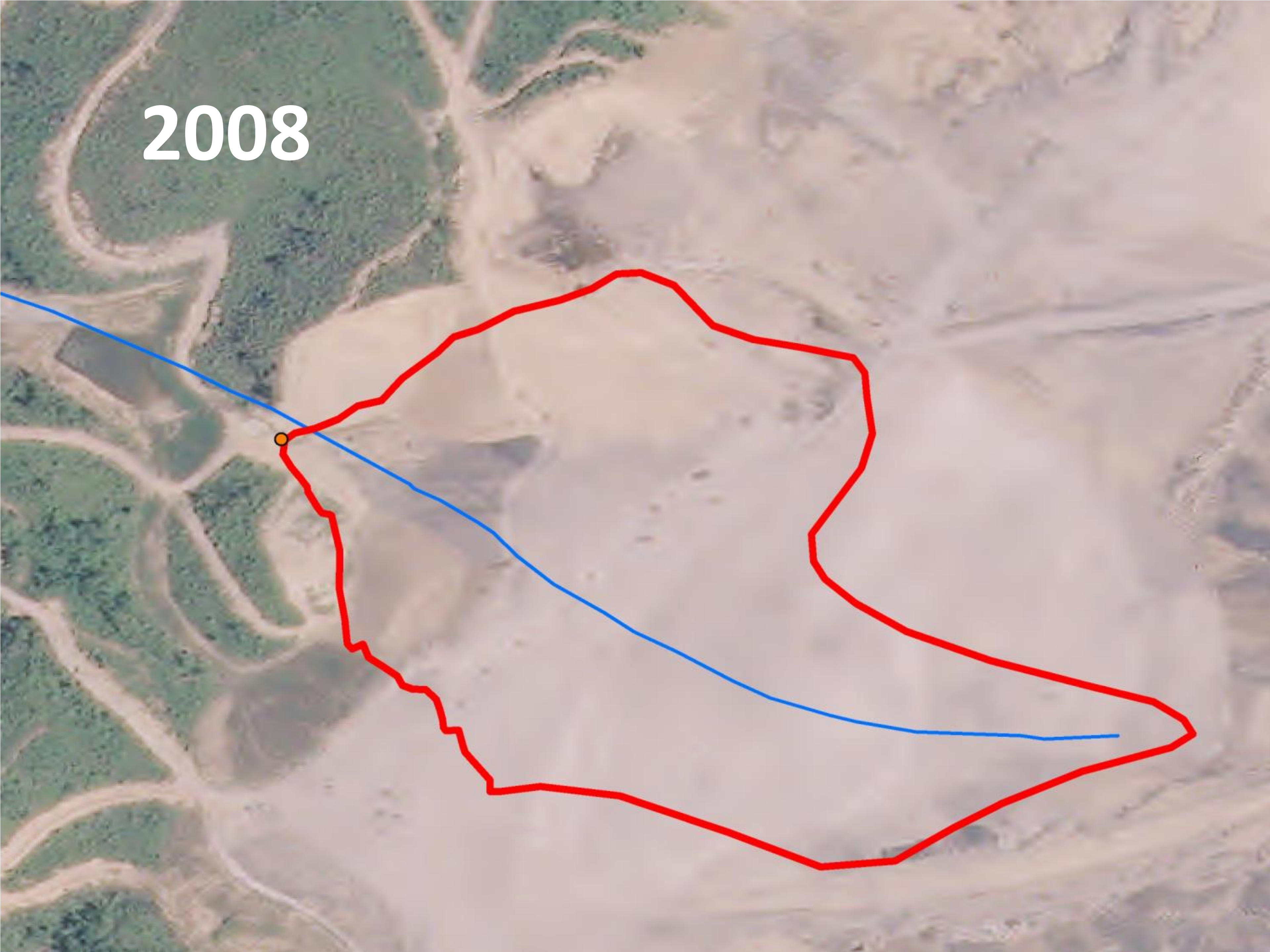


Bent Mt. KY Infiltration Plots monitored by Agouridis et al. (2010); ion balance data presented earlier (KY 1 and 2) are from original samples from these plots. Field leachate response is very similar to VT columns in both peak and long term EC.

Evans, Daniel M., Carl E. Zipper, Patricia F. Donovan, and W. Lee Daniels, 2014. Long-Term Trends of Specific Conductance in Waters Discharged by Coal-Mine Valley Fills in Central Appalachia, USA. Journal of the American Water Resources Association (JAWRA) 1-12. DOI: 10.1111/jawr.12198

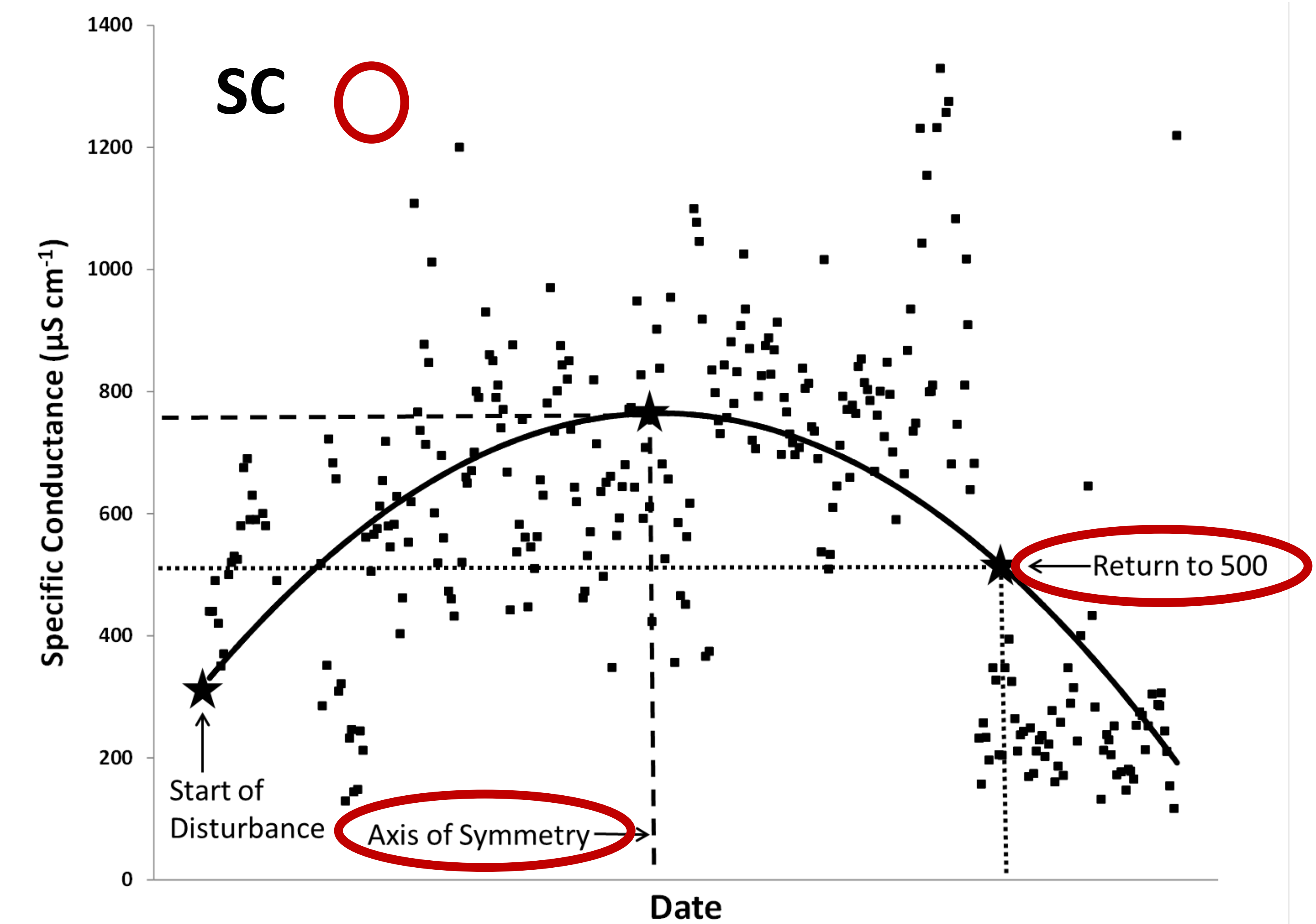

Map Inset Shown
West Virginia
Kentucky
Virginia
0 5 10 20 Kilometers
N

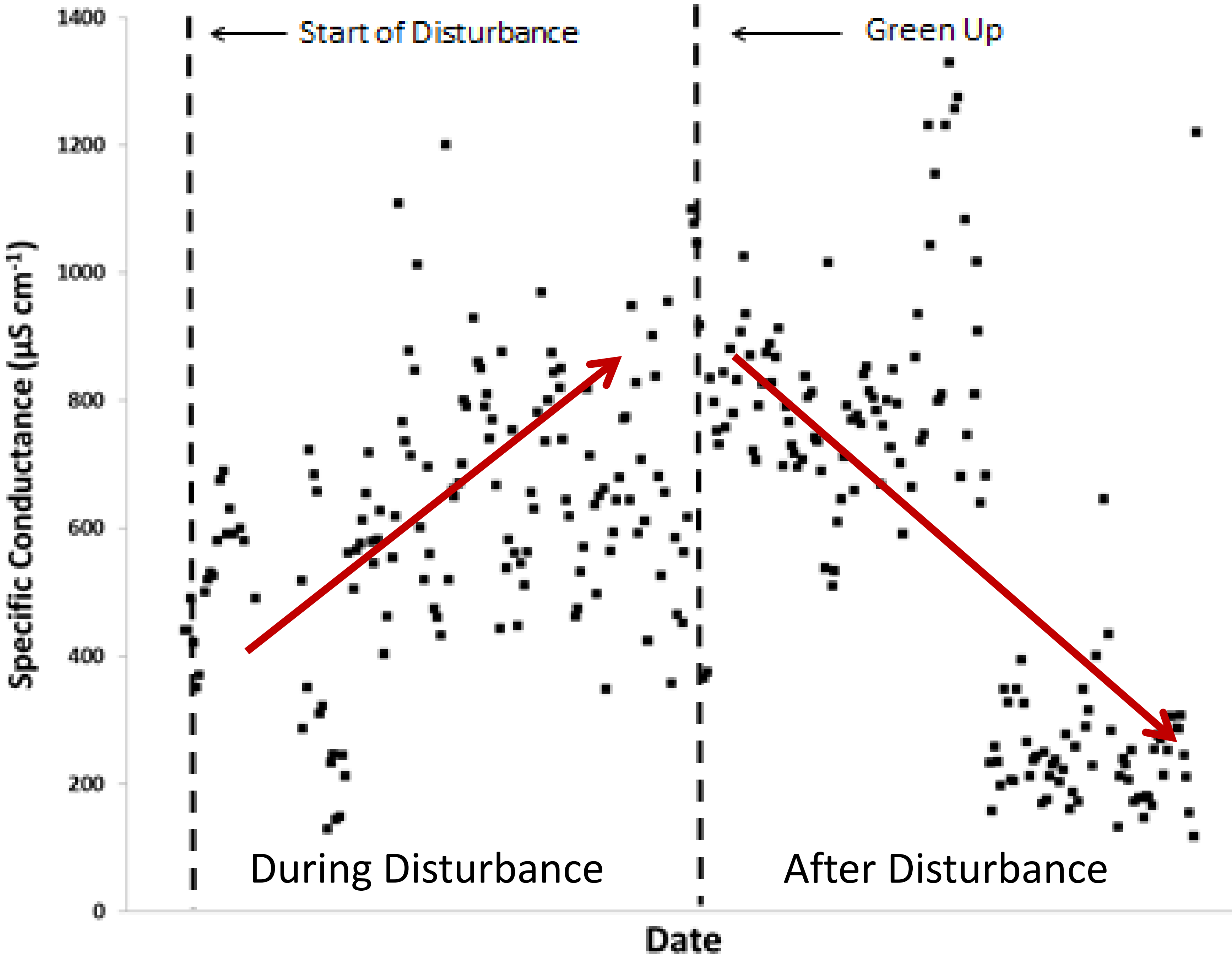

2003


2008


2011

Can we model the peak of SC?
Can we project the return to background levels?




Start of Disturbance
Green Up
Specific Conductance (µS cm-1)
1400
1200
1000
800
600
400
200
0
During Disturbance
After Disturbance
Date

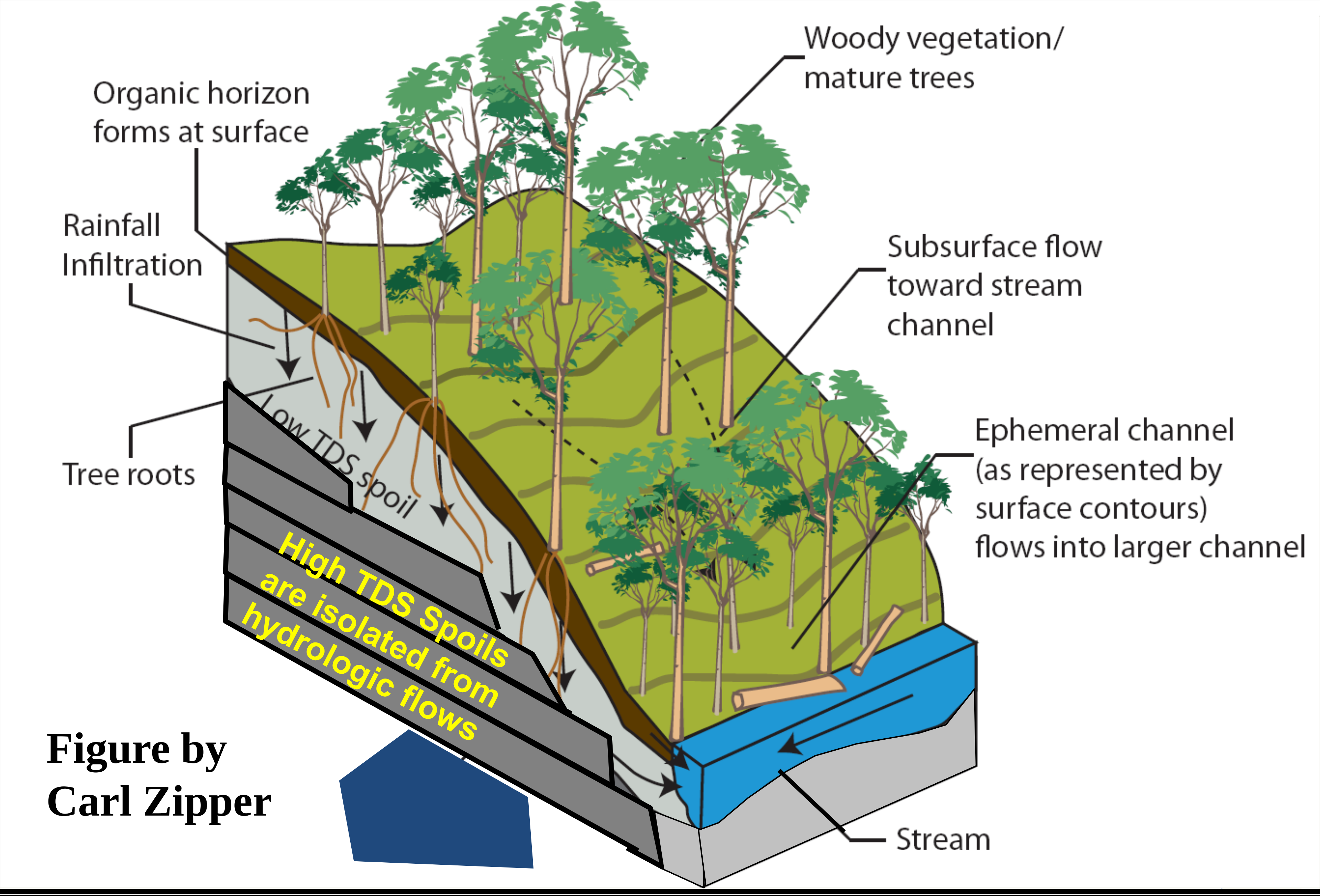
Projecting Future SC levels

- **Of the 77 valley fills with significant negative quadratic terms, 62 had achieved green up.**
- **Of the 62, 16 valley fills had at least 5 years of data past the quadratic peak.**
- **These 16 valley fills are used for more conservative projections.**

Years after Revegetation to 500 µS cm^{-1}

- **12.5 ± 7.6 years for conservative dataset (N=16)**

- **11.5 ± 7.5 years for full dataset (N=62)**



Mined Land, as envisioned: Forest and Hydrologic Restoration, Water Quality Protection.
With agency encouragement, we would seek operational prototypes by industry.

Conclusions -- Columns

- **Mine spoils (> 55) studied in our leaching columns released significant amounts of TDS in their initial first flush leaching event with most spoils initially producing EC of 1000 to > 1500 us/cm.**

- **Leachate EC dropped quickly in all spoils after one to two pore volumes and stabilized at levels < 500 µs/cm.**

- **Pre-mine weathering/oxidation and rock type are the dominant controllers of TDS release for non-acid forming spoils.**

- **Thus, brown oxidized sandstone strata are much less of a TDS elution risk than gray reduced mudrocks and shales.**

Conclusions -- Scaling

- **We continue to believe that this column leaching procedure gives us a reasonably accurate prediction of the propensity for a given non-acid forming spoil to generate TDS over time and also provides important information about both peak and long-term levels of TDS release.**

- **We are encouraged by the fact that observed levels of SC in the field are quite similar to the peak and average EC levels that we have observed for a wide range of spoils in our column studies.**

Conclusions -- General

- **Our extensive field fill discharge data also indicate that over the long term, valley fill discharges in the region studied are declining, and we predict a lag time of approximately 20 years for the average fill to decline to < 500 µs/cm.**

- **Our results do not take in field attenuation processes into account and thus at best should be regarded as internal source estimates for these various constituents.**

- **Extensive work on development of lab predictors for TDS elution is being completed (not reported here). Total-S and saturated paste EC appear to be strong predictors with rock/type grain size secondary.**

Acknowledgments

- **Direct financial support by OSM Applied Research Program-Pittsburgh, Powell River Project, and ARIES (see next slide).**
- **Cooperative work with Jeff Skousen and Louis McDonald at WVU and Carmen Agouridis, Chris Barton, and Richard Warner at UK.**
- **There are simply way too many individuals at Virginia Tech and mining industry cooperators to list here. We deeply appreciate them all!**

ARIES Statement

A portion of the work reported today was sponsored by the Appalachian Research Initiative for Environmental Science (ARIES). ARIES is an industrial affiliates program at Virginia Tech, supported by members that include companies in the energy sector. The research under ARIES is conducted by independent researchers in accordance with the policies on scientific integrity of their institutions. The views, opinions and recommendations expressed herein are solely those of the authors and do not imply any endorsement by ARIES employees, other ARIES-affiliated researchers or industrial members. Information about ARIES can be found at http://www.energy.vt.edu/ARIES