An Appalachian Regional Study to Predict TDS Release from Coal Mine Spoils

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and

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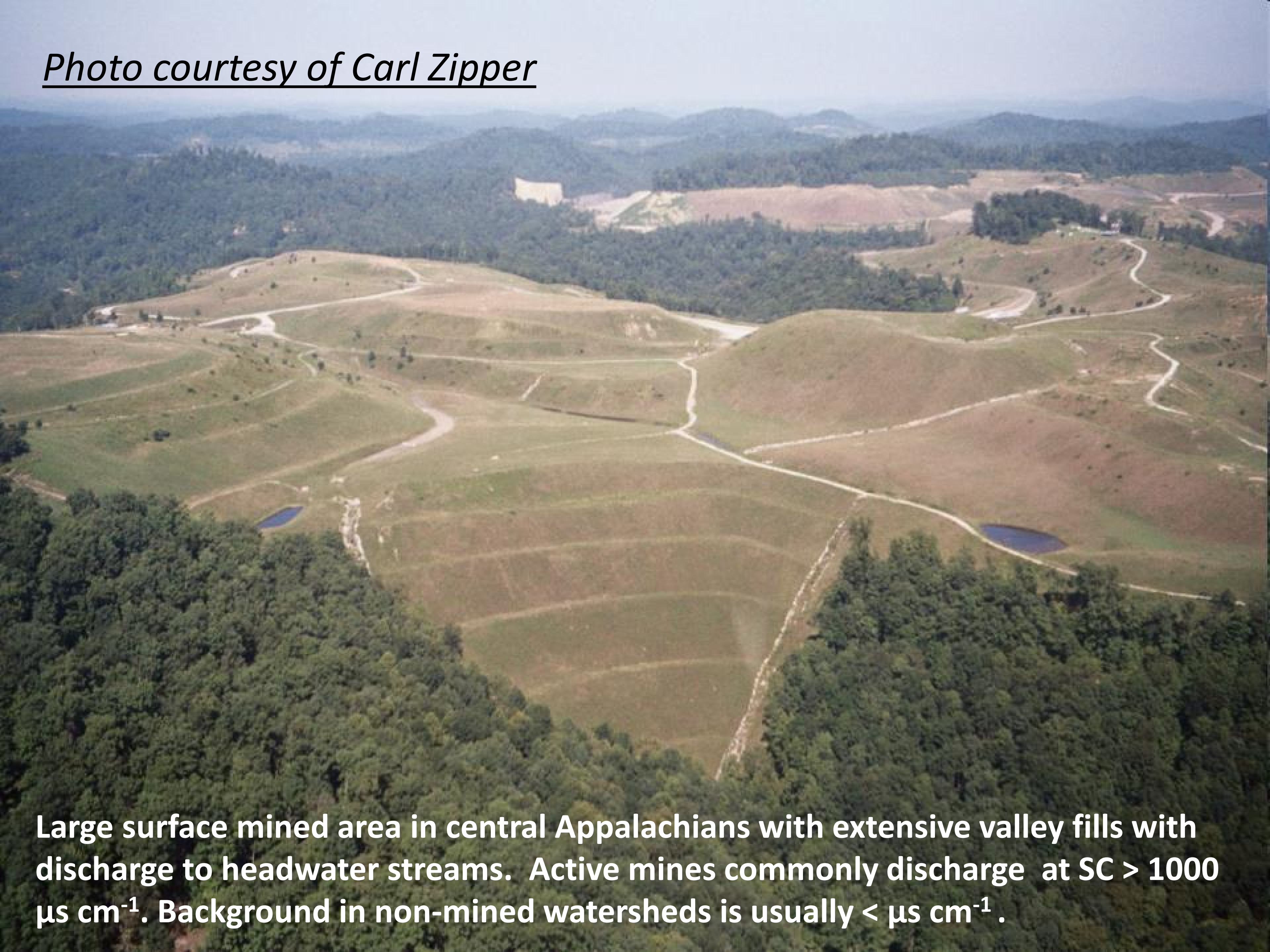


Photo courtesy of Carl Zipper

Large surface mined area in central Appalachians with extensive valley fills with discharge to headwater streams. Active mines commonly discharge at SC > 1000 µs cm^{-1}. Background in non-mined watersheds is usually < µs cm^{-1} .

TDS/EC Discharge Standards?

Several widely cited studies (e.g. Pond et al., 2008), found that streams with high conductivity -- above 500 µs/cm -- were biologically impaired. Impacts are primarily to sensitive macroinvertebrates (mayflies etc.)

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. One active mine permit was suspended.

While this guidance was overturned in DC federal court in 2012, TDS remains a dominant state & federal regulatory concern as seen in recent OSM and state stream protection guidance, etc.

TDS Prediction & Management Research

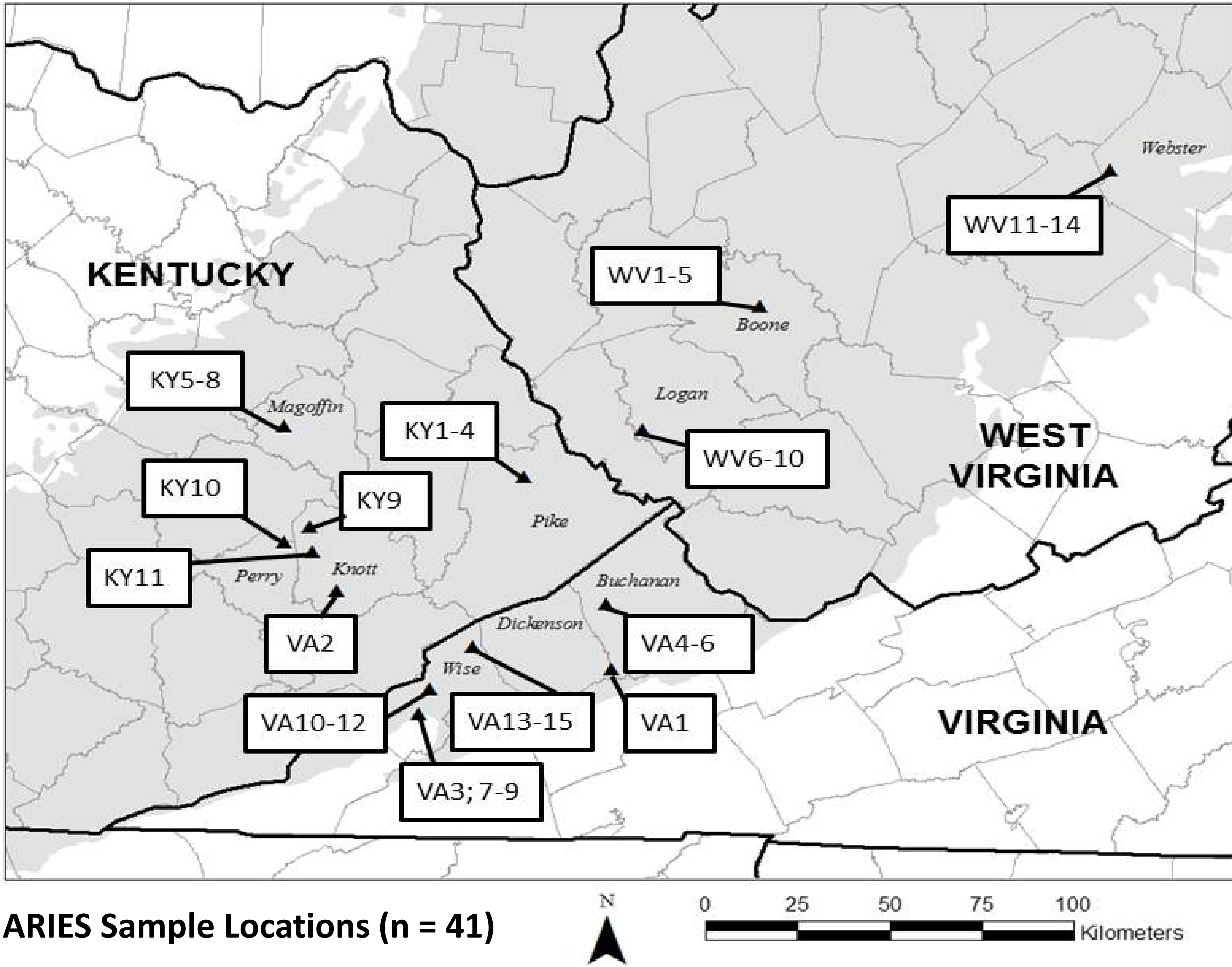
1) Use laboratory leaching columns and other methods to evaluate > 70 regional spoil types.

2) Relate column leaching data to field-scale results.

3) Develop rapid lab and field protocols to identify high TDS potential materials and predict field release levels. Tested over 20 static lab tests.

4) Evaluate a wide range (> 125 of field mine fill discharge data over time and model the temporal response.

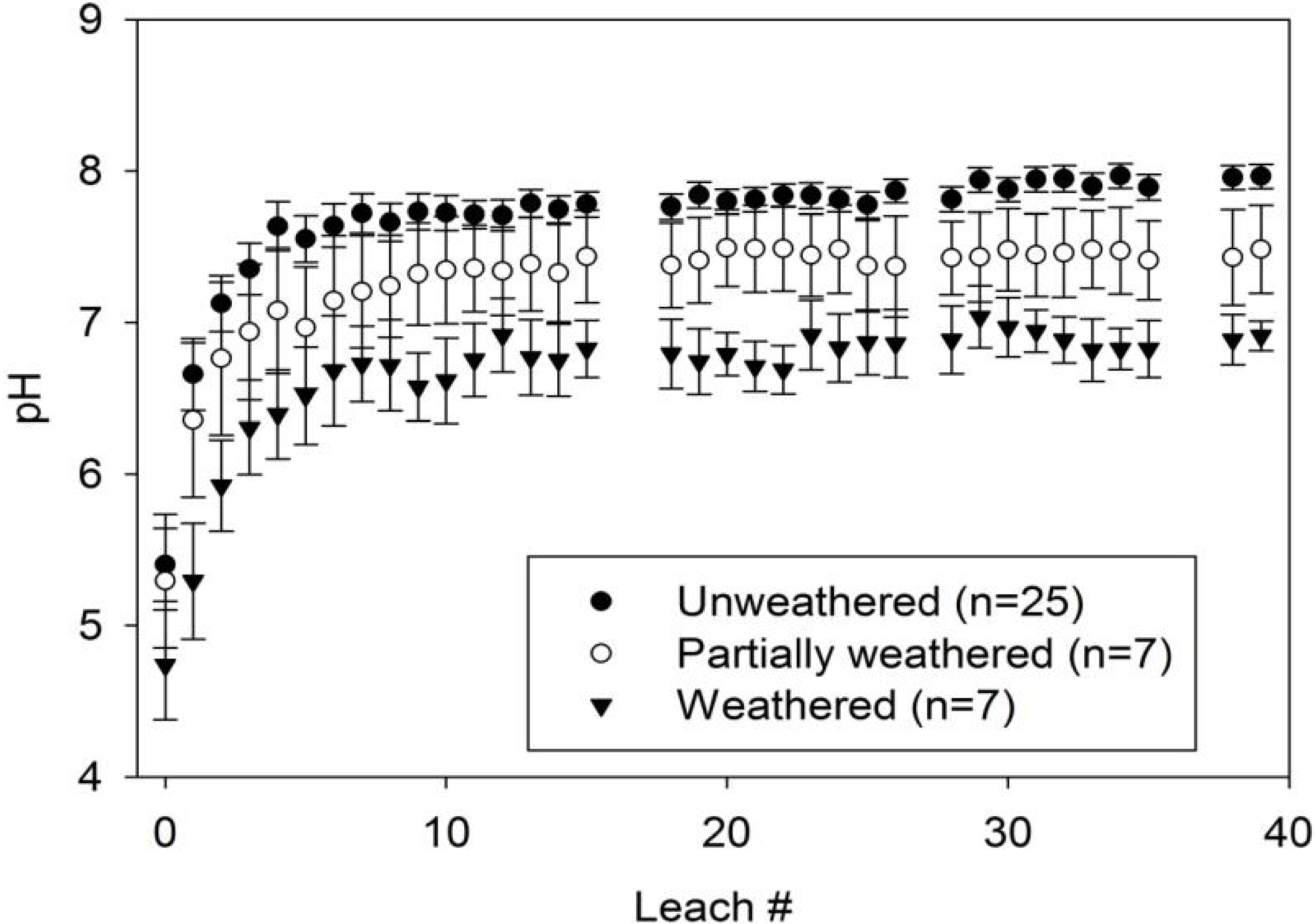
5) Work with the coal industry to apply results and construct prototype low TDS fill designs.



ARIES Sample Locations (n = 41)

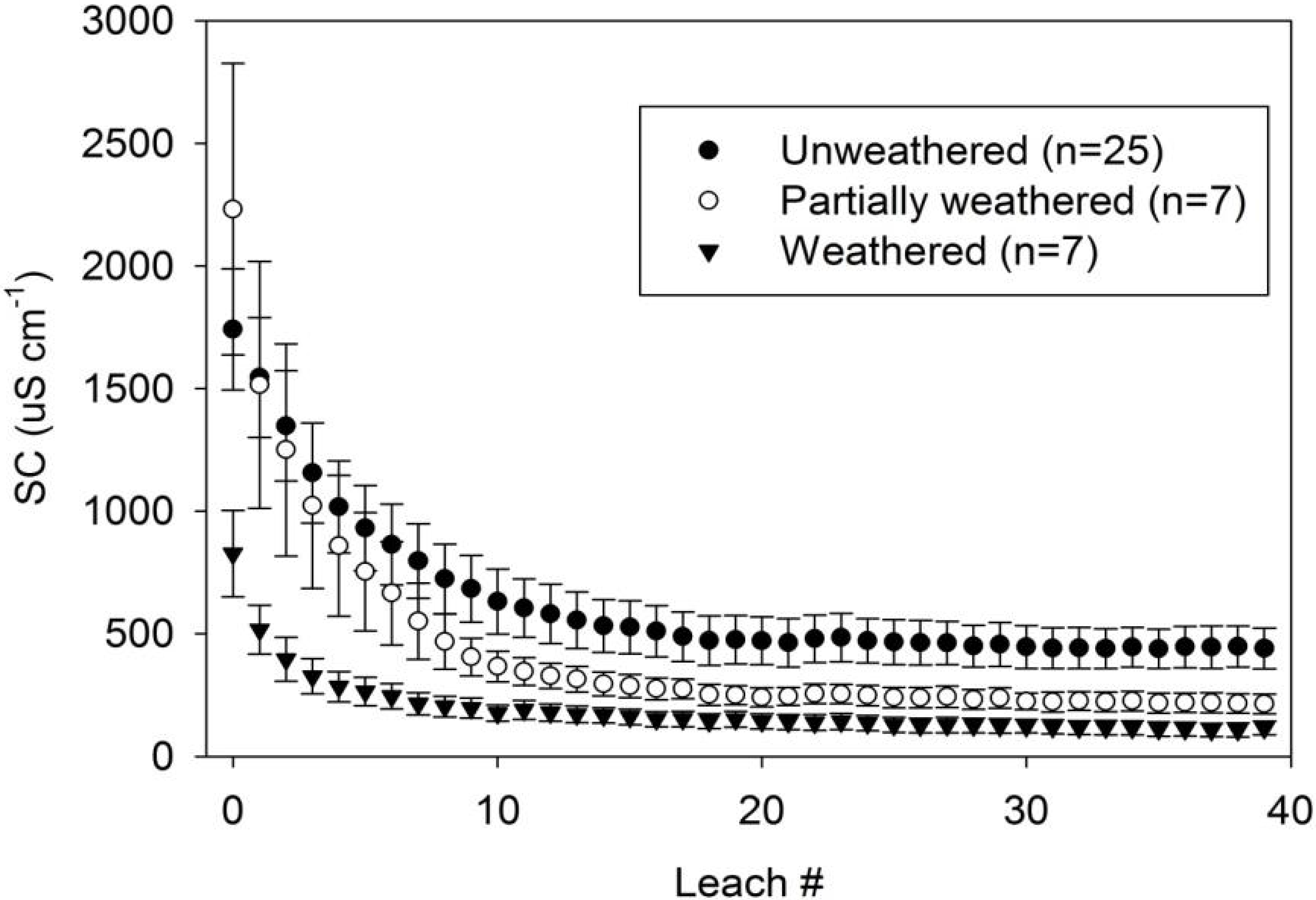
- Over 70 regional spoils have been run in triplicate under unsaturated conditions (3 columns per sample) with simulated rain. Samples include ARIES and individual coal companies.
- Whole spoil crushed & screened to < 1.25 cm.
- Typically run for minimum of 20 weeks (40 cycles) with 2 x 2.54 cm of simulated rain (pH 4.6) per week (1 cycle = 2.5 cm)

pH x Weathering Status for ARIES Samples (n = 39; 2 black shales excluded)

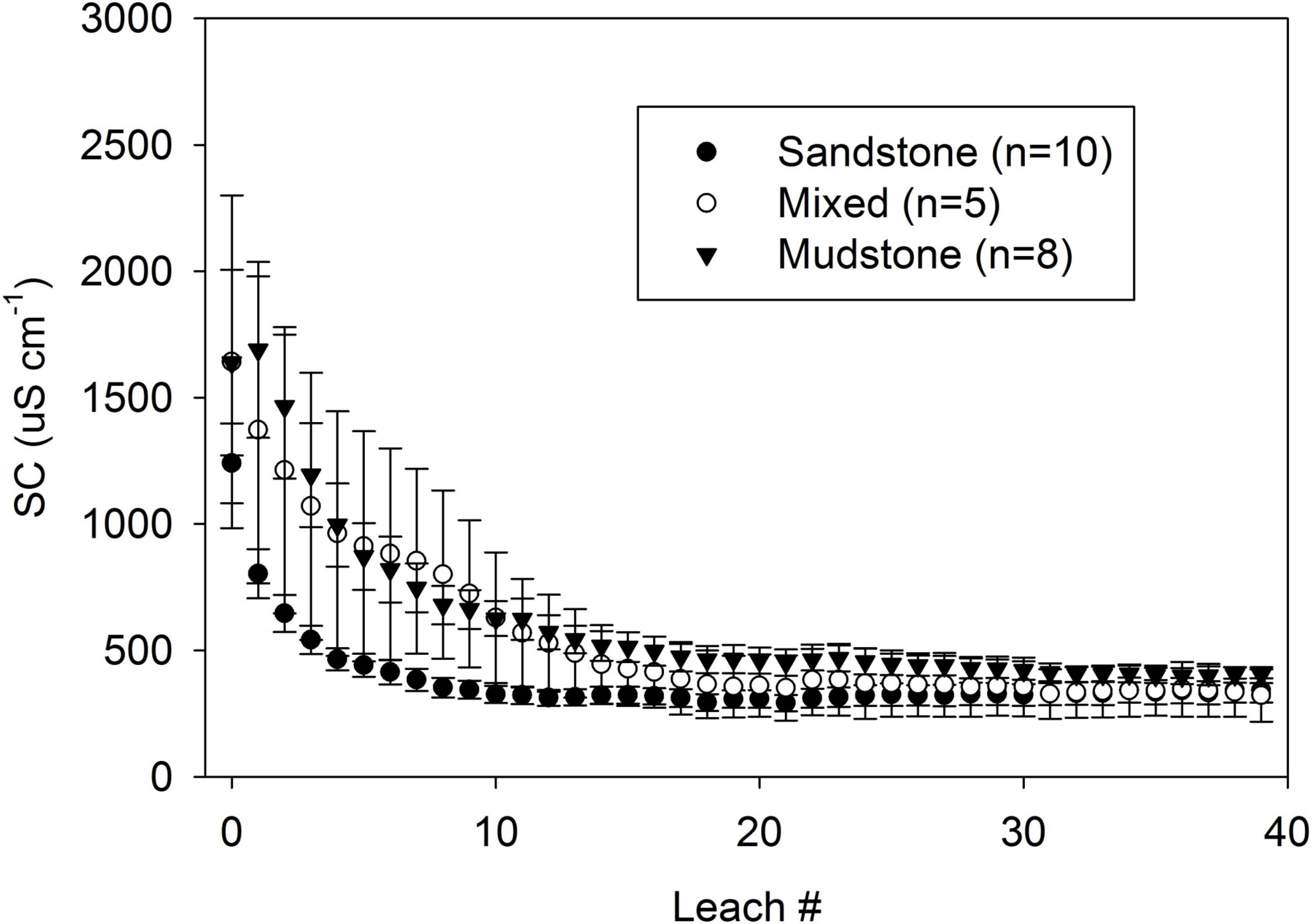


Daniels et al., 2016. Environmental Pollution – *In Press*.

Leachate SC x Weathering Status for ARIES Regional Samples (n = 39)

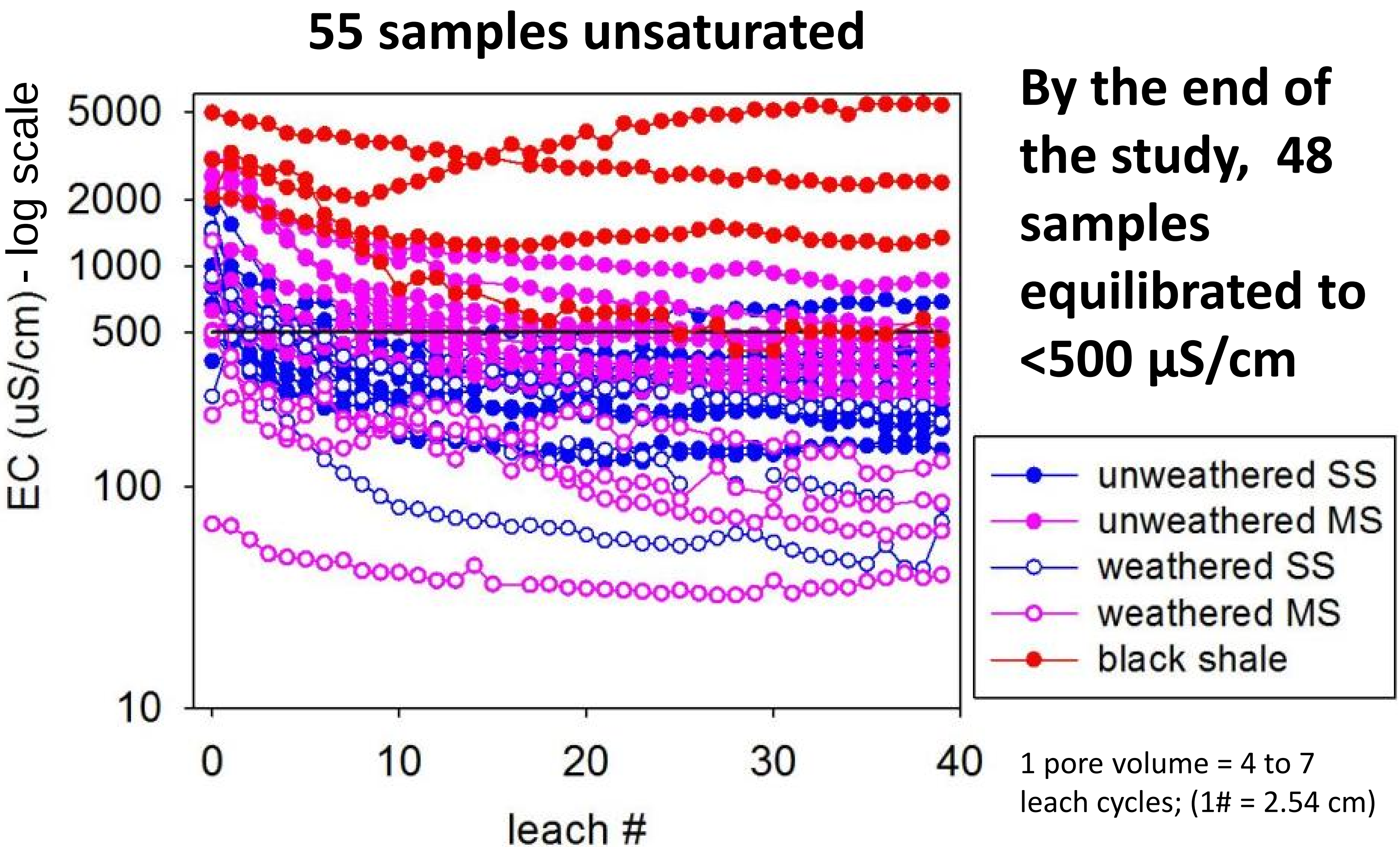


Leachate SC x Rock Type for Unweathered Samples



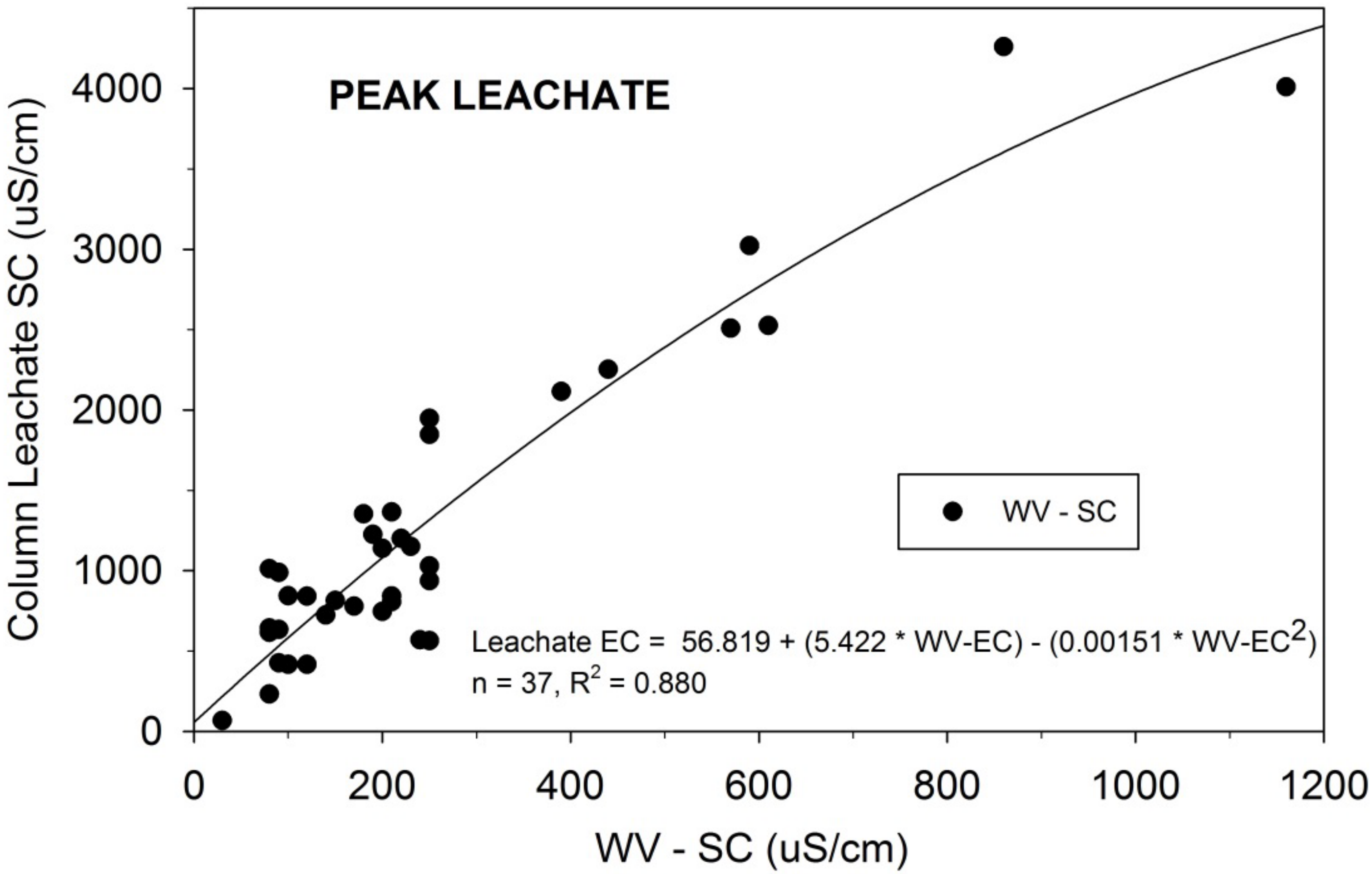
Overall: 1) increased weathering = lower EC/TDS

2) coarser grain size = lower EC/TDS

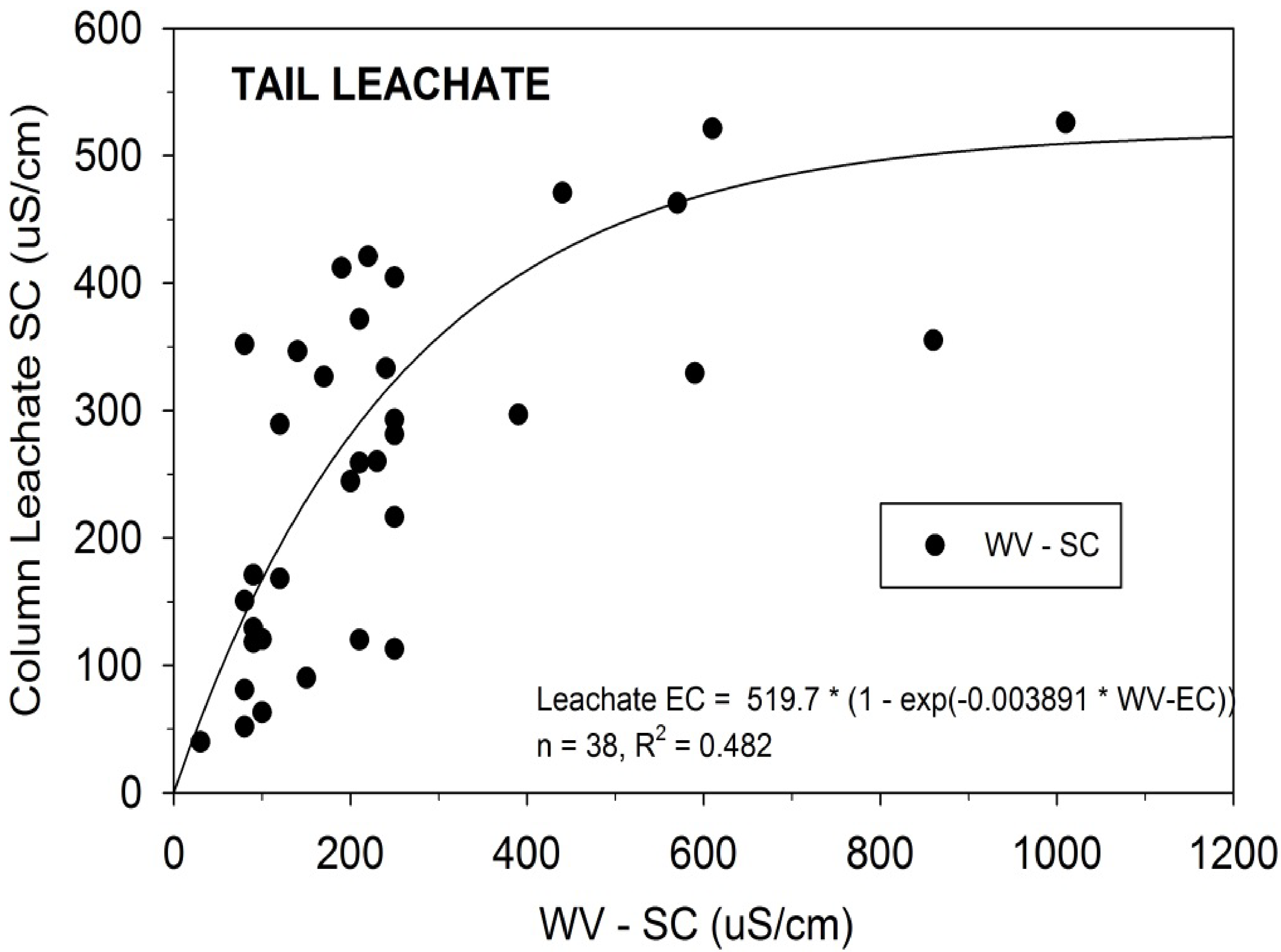


By the end of the study, 48 samples equilibrated to <500 µS/cm

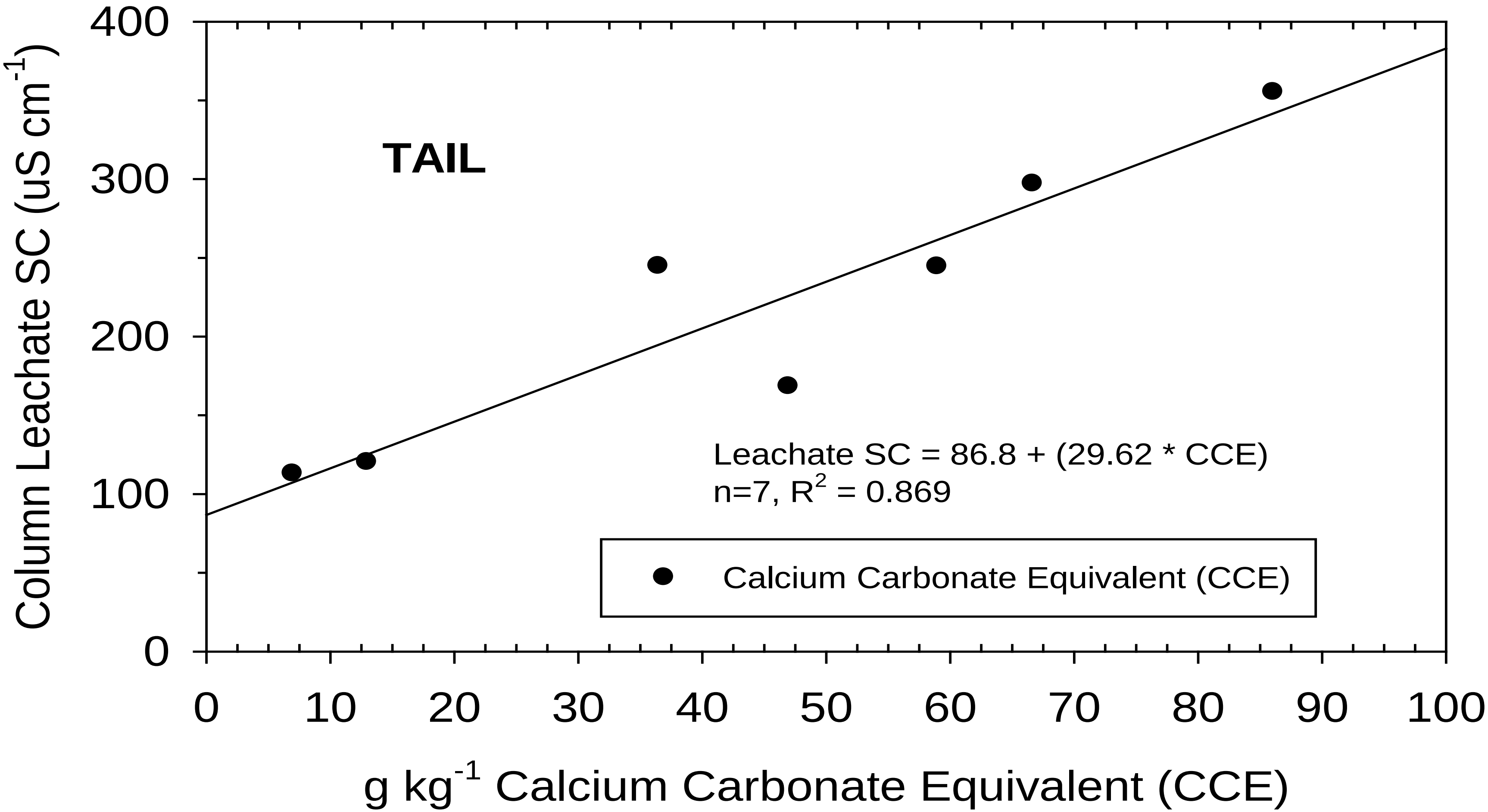
1 pore volume = 4 to 7 leach cycles; (1# = 2.54 cm)

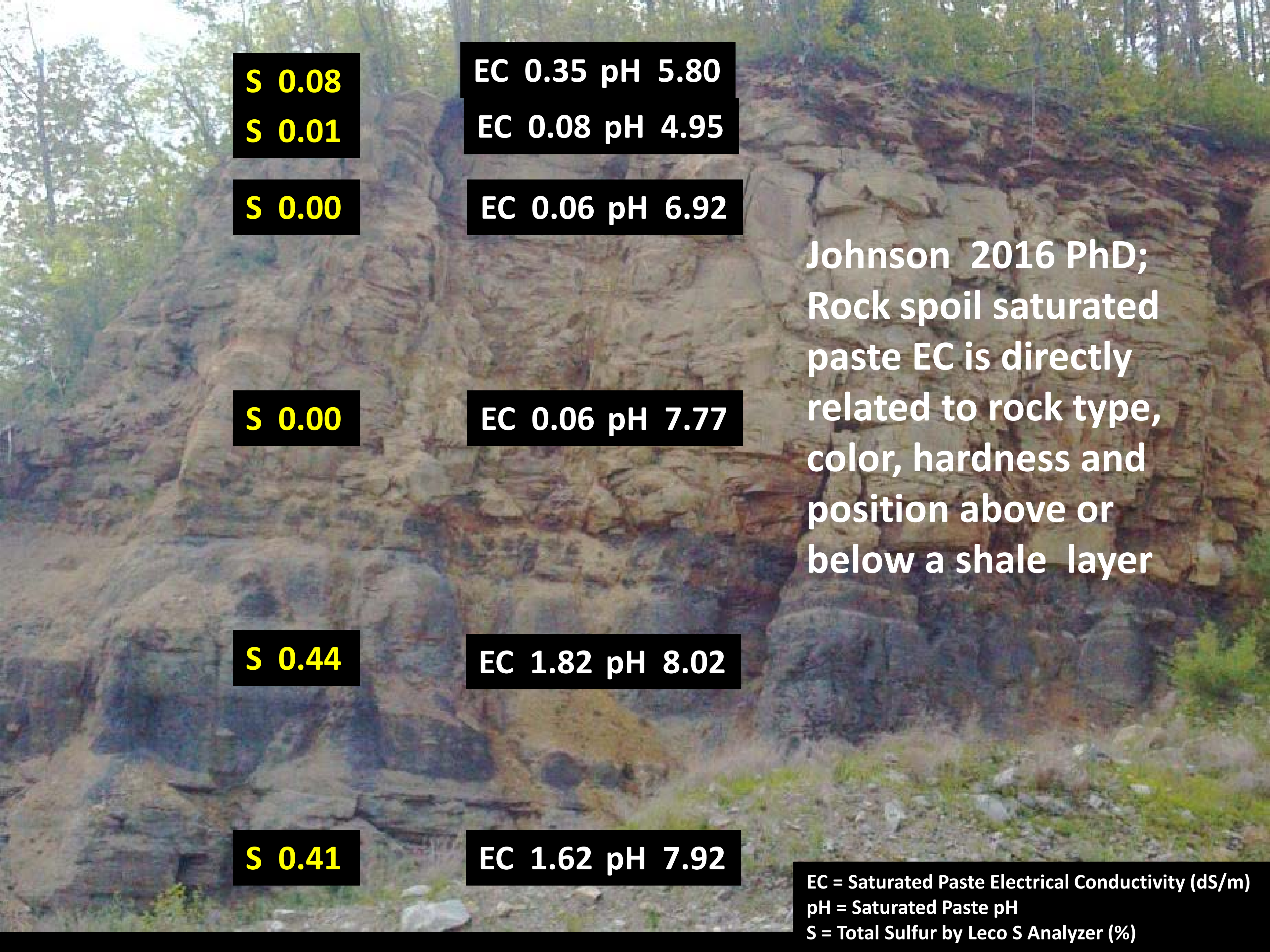


We have evaluated over 20 different static lab tests such as total-S, ABA parameters, various soluble salt (SC) extracts etc. and regressed them against "peak" SC production and longer term semi-stable "tail" SC. The best fit model above is for 2:1 water:spoil SC., but standard SSSA saturated paste extract generates a very similar model (R^2 = 0.856). Total-S generates models with R^2 ~0.65, but sensitive to outliers.

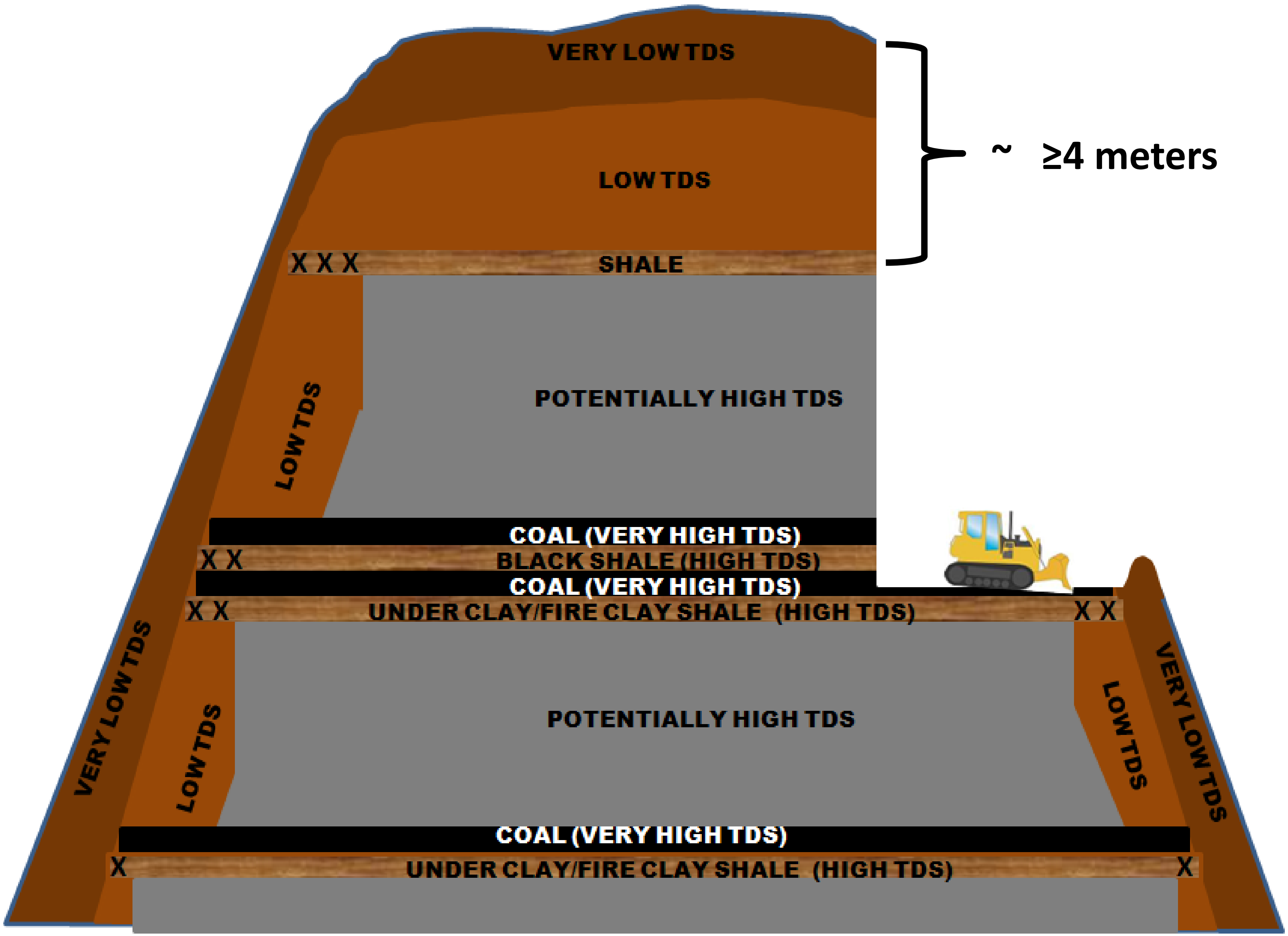

TAIL LEACHATE
Column Leachate SC (uS/cm)
WV - SC (uS/cm)
WV - SC
Leachate EC = 519.7 * (1 - exp(-0.003891 * WV-EC))
n = 38, R2 = 0.482
0
100
200
300
400
500
600
0
200
400
600
800
1000
1200

Mixed Weathering Status Samples Only




S 0.08
S 0.01
EC 0.35 pH 5.80
EC 0.08 pH 4.95
S 0.00
EC 0.06 pH 6.92
Johnson 2016 PhD; Rock spoil saturated paste EC is directly related to rock type, color, hardness and position above or below a shale layer
S 0.00
EC 0.06 pH 7.77
S 0.44
EC 1.82 pH 8.02
S 0.41
EC 1.62 pH 7.92
EC = Saturated Paste Electrical Conductivity (dS/m)
pH = Saturated Paste pH
S = Total Sulfur by Leco S Analyzer (%)

Simplified graphical model by Johnson et al. (2014) of general location of low vs. high TDS materials.



Ross (2015) field leaching "mesocosm study".

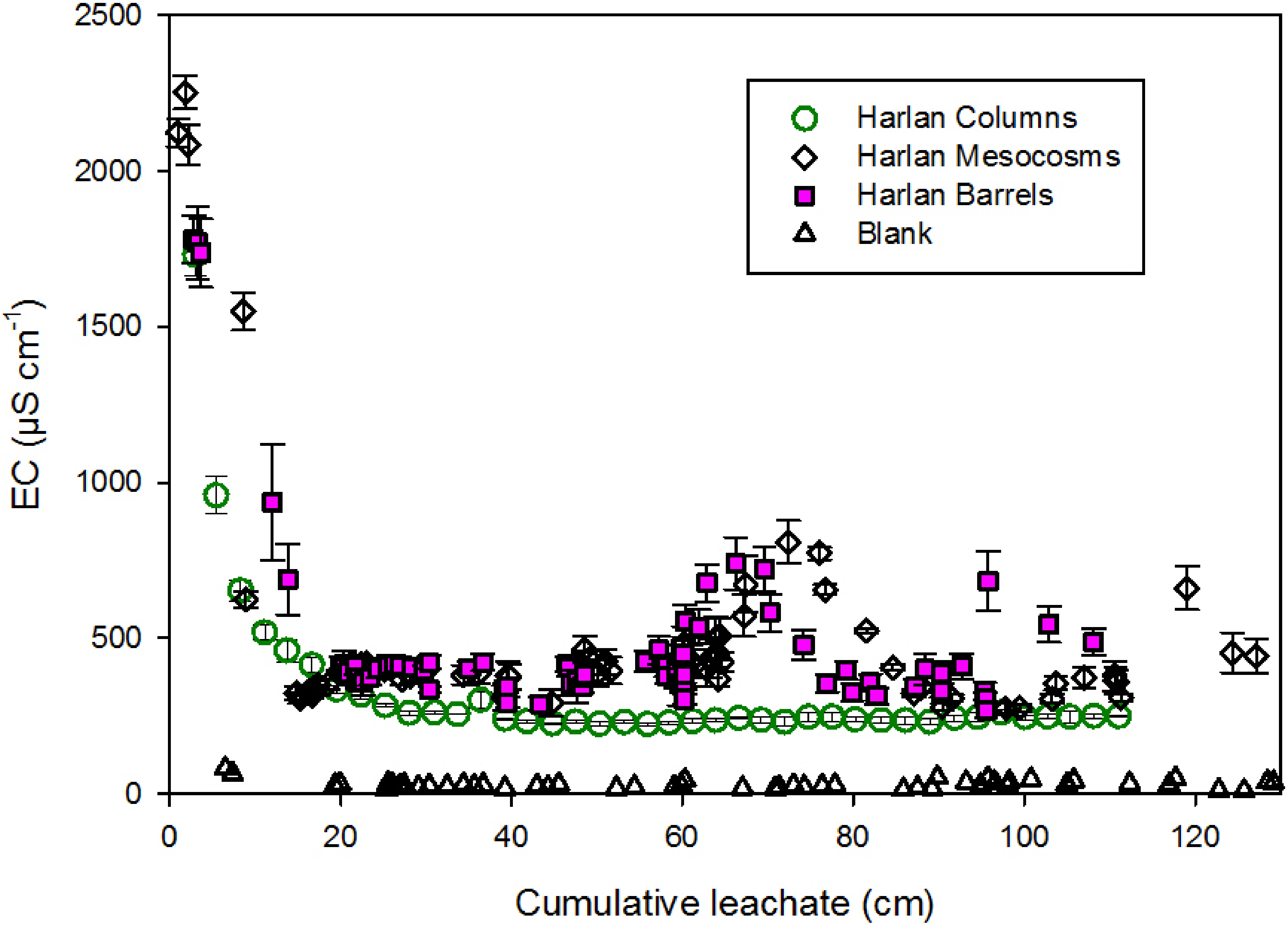
Raw spoil (up to 50 cm) placed into mesocosms over filter fabric and 10 cm of acid washed gravel. Initiated in October of 2012 and will be continued through May, 2016.

The same spoil sized to < 1.25 cm was run in the standard lab columns for one check on "scale effects" in an effort to better relate column results to expected field leaching patterns.

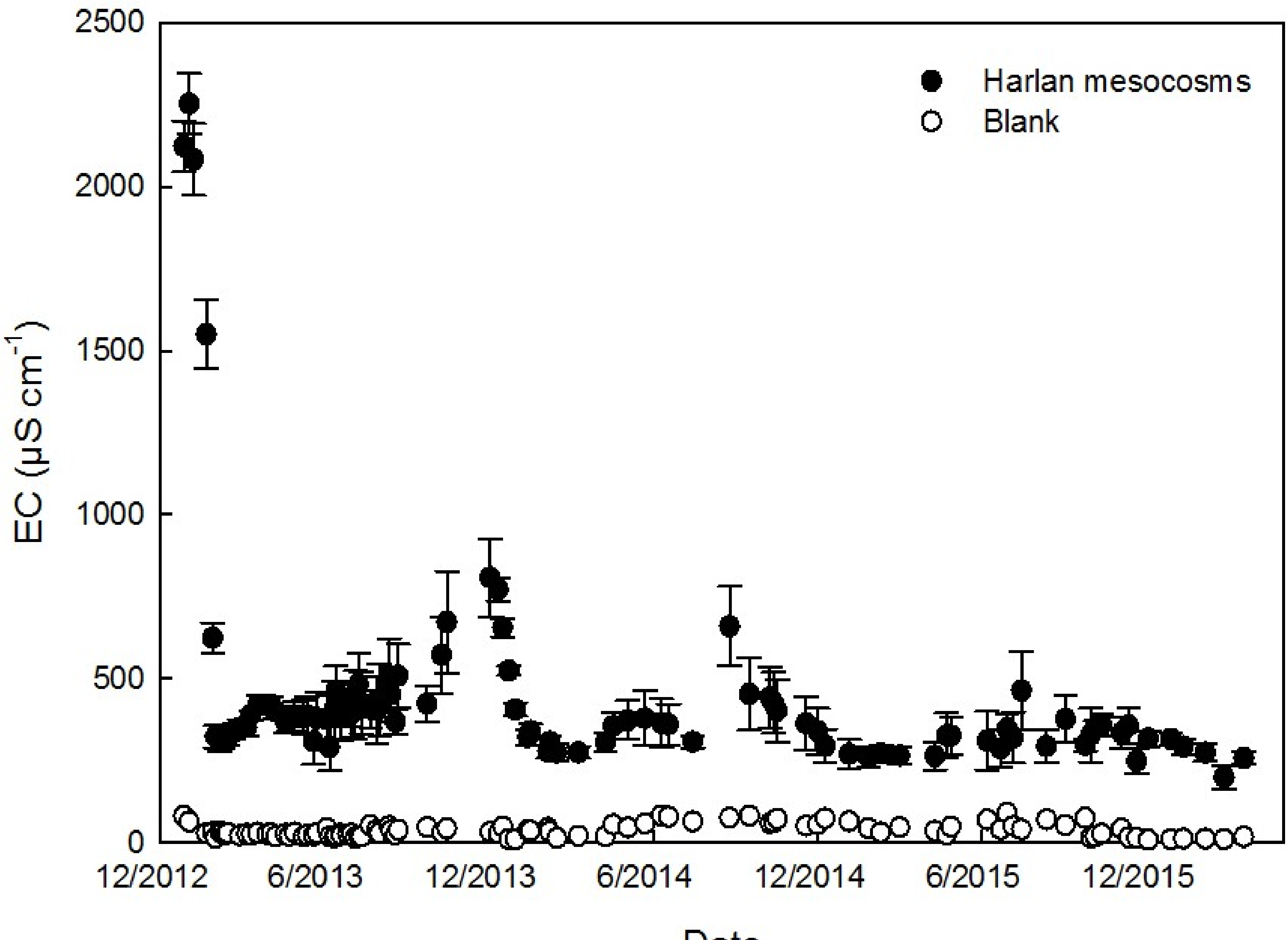
Leachate Collection and Analysis

- Samples collected whenever leachate was produced by a precipitation event (through October 2015)

- Each sample measured for pH and EC
  - Bicarbonate, sulfate, Al, As, Ca, Cd, Cl, Cu, Fe, K, Mg, Mn, Na, Ni, Pb, Se, and Zn.

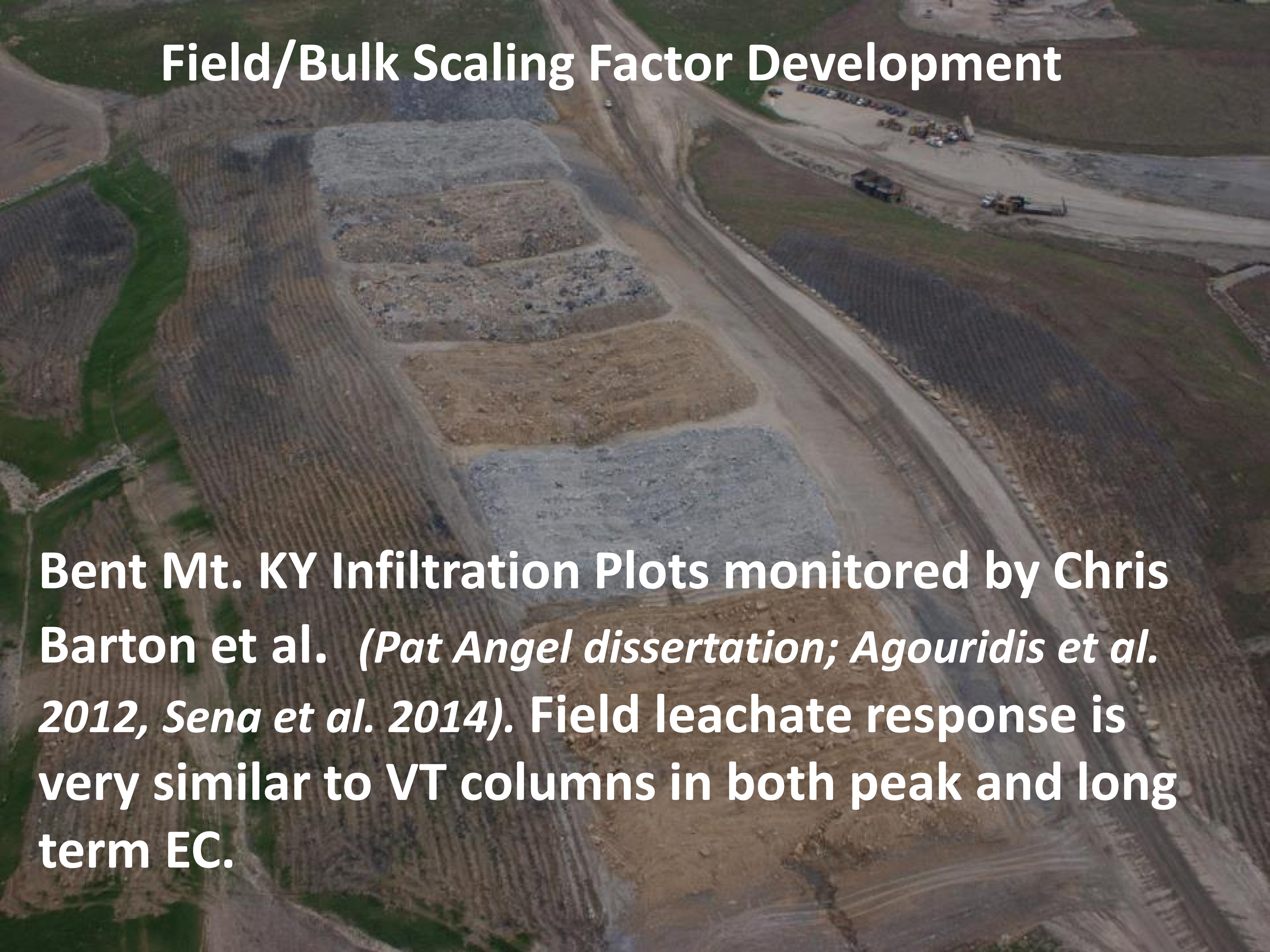


2500
2000
1500
1000
500
0
0
20
40
60
80
100
120
EC (µS cm-1)
Cumulative leachate (cm)
Harlan Columns
Harlan Mesocosms
Harlan Barrels
Blank

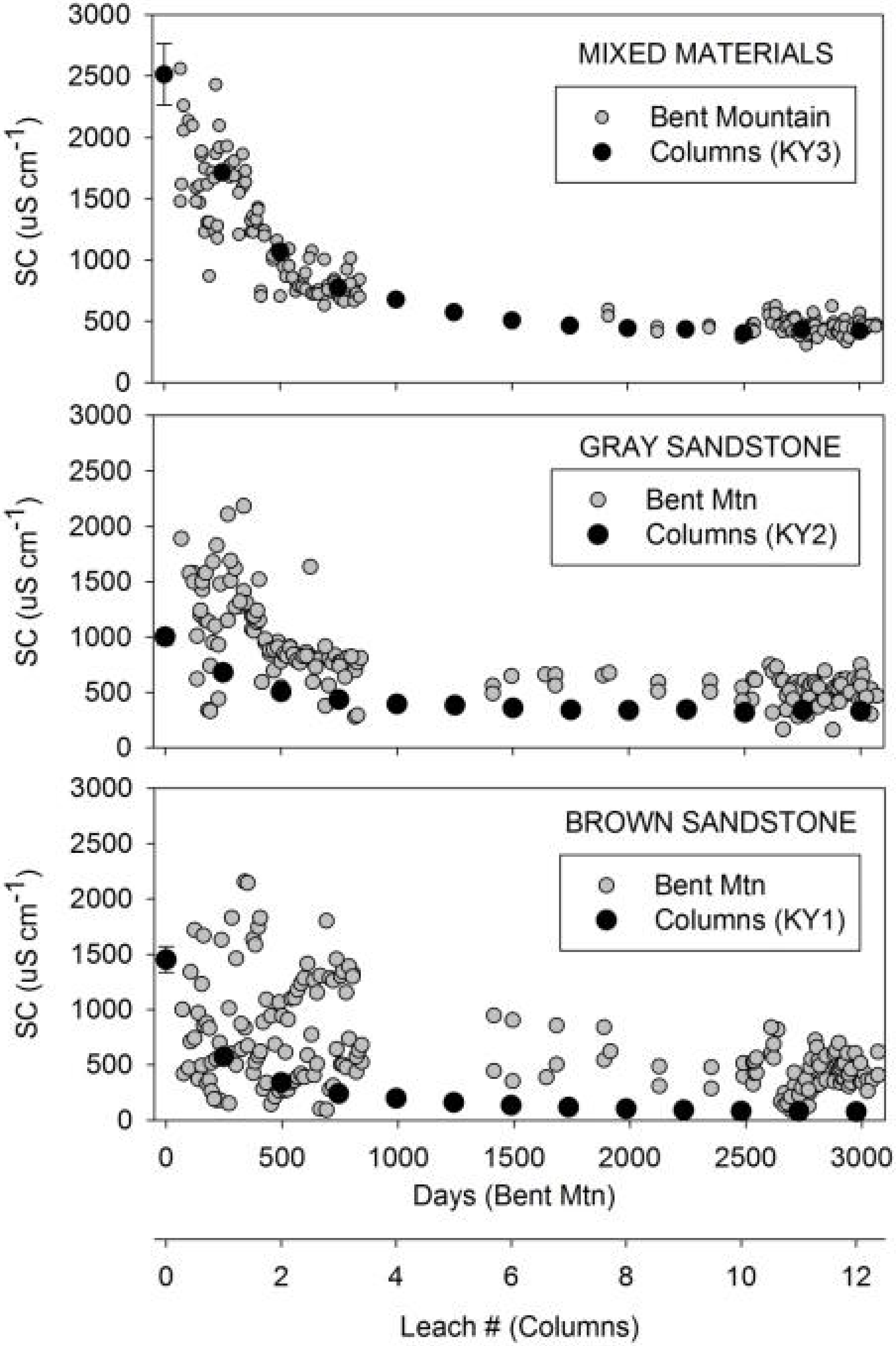


2500
2000
1500
1000
500
0
EC (µS cm-1)
12/2012
6/2013
12/2013
6/2014
12/2014
6/2015
12/2015
Date
Harlan mesocosms
Blank

Field/Bulk Scaling Factor Development

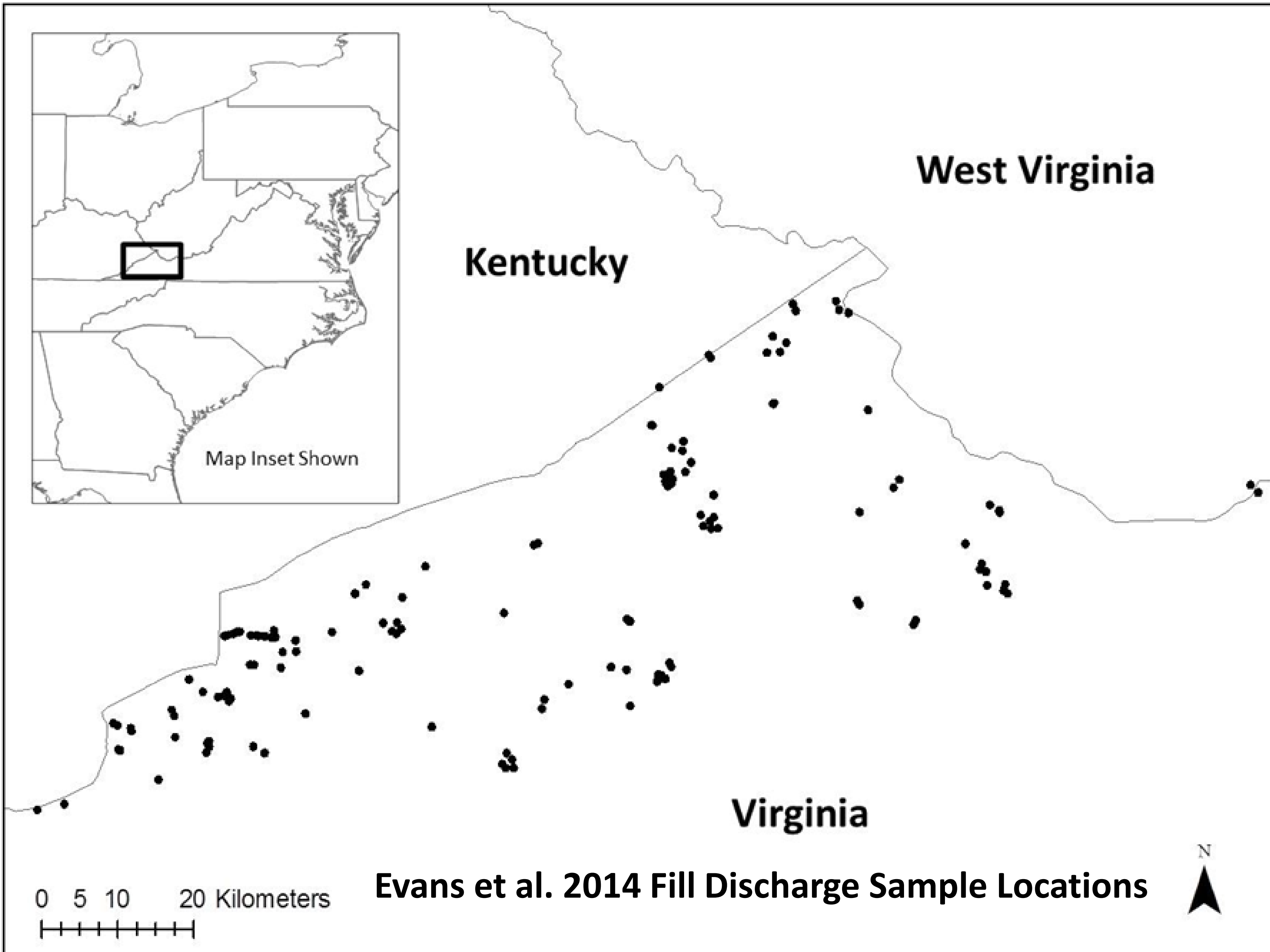


Bent Mt. KY Infiltration Plots monitored by Chris Barton et al. *(Pat Angel dissertation; Agouridis et al. 2012, Sena et al. 2014).* **Field leachate response is very similar to VT columns in both peak and long term EC.**



Individual spoil sample leaching data from VT columns and UK Bent Mt. lysimeters. Note the very good correspondence for the mixed materials along with the (a) poorer initial fit for the "gray sandstone", and the (b) fairly consistent under-prediction for the columns vs. the "brown [weathered] sandstone".

The brown [weathered] sandstone at this particular site is higher in reactive S than the majority of those examined.



Evans et al. 2014 Fill Discharge Sample Locations

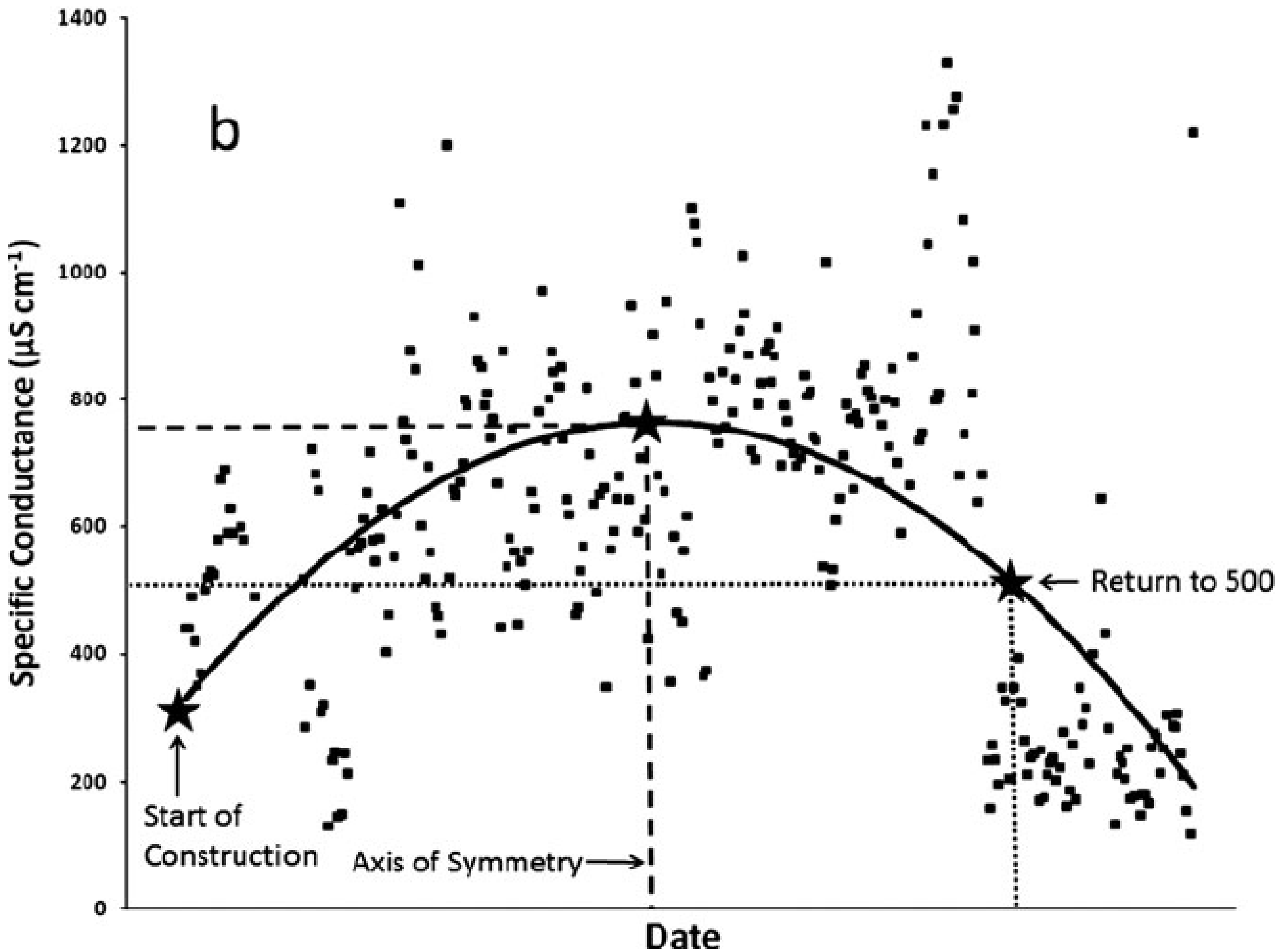
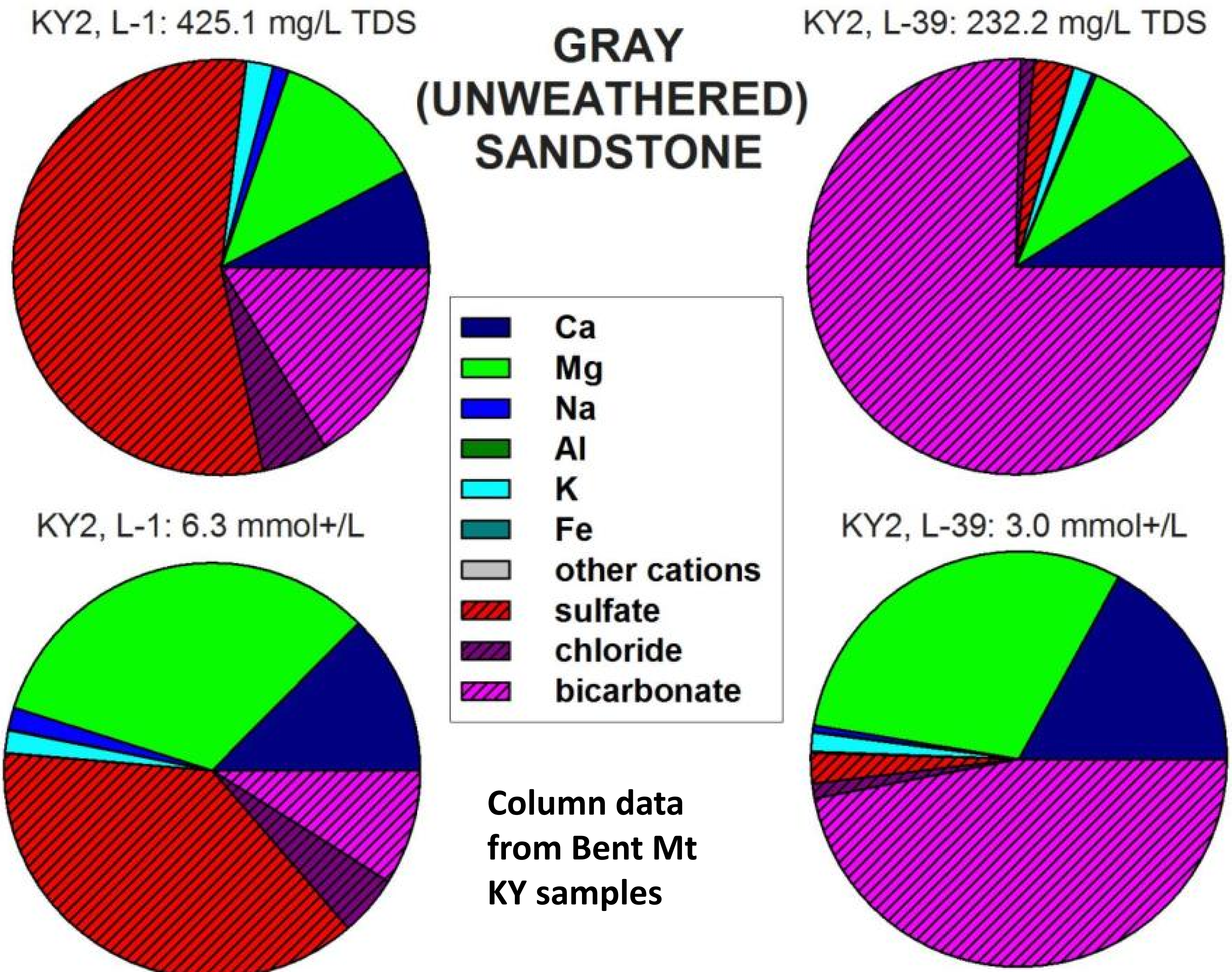


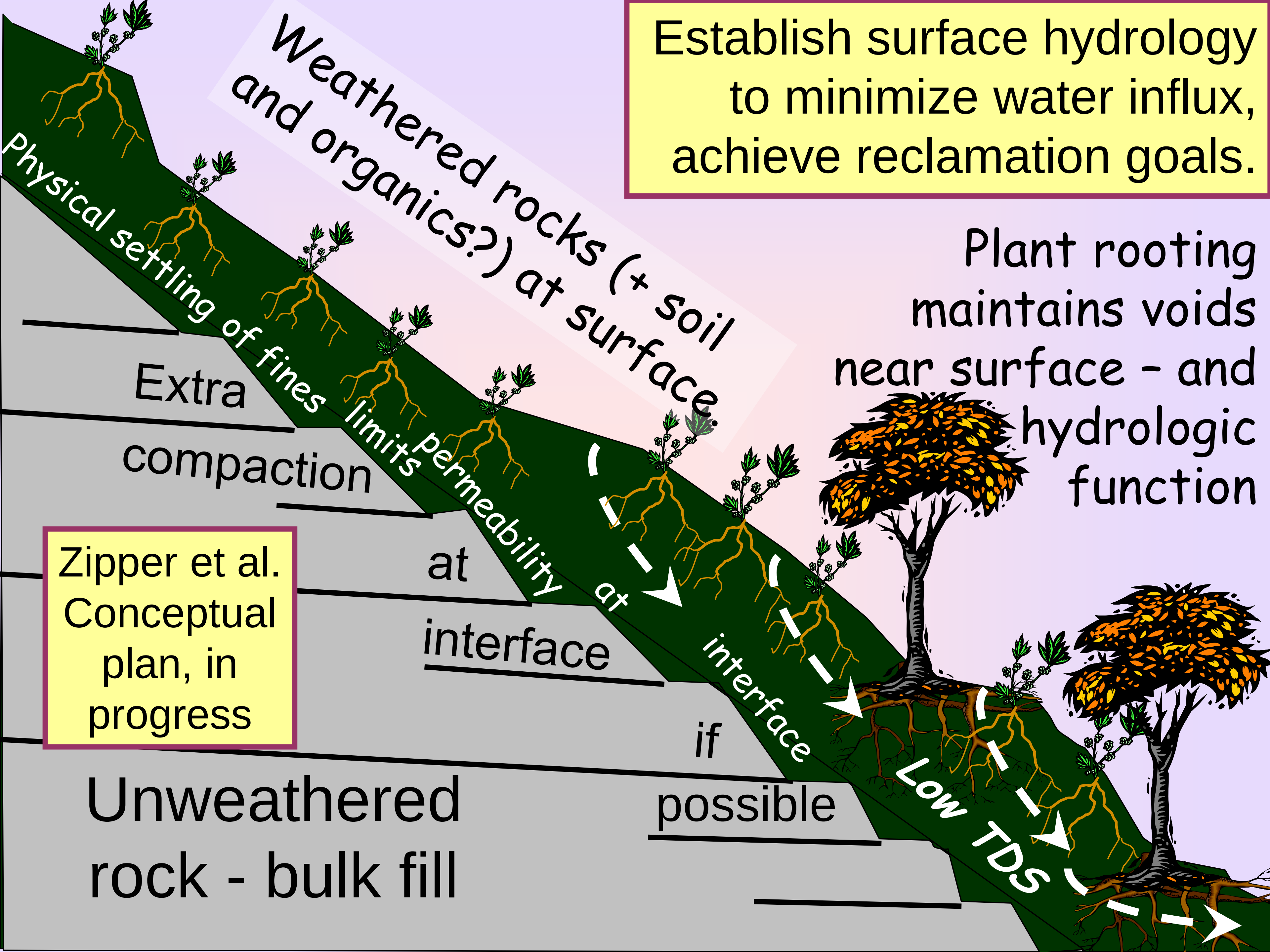
FIGURE 3. Example of Specific Conductance (SC) Data at a Valley Fill with (a) Disturbance Phases Delineated, and (b) a Quadratic Model Fit to Data (solid line), with Axis of Symmetry and the Method for Estimating the Time Required for SC to Return to 500 µS/cm Illustrated.

Field SC data for 137 valley fill discharge points in SW Virginia from Evans et al. 2014 (JAWRA).

Note (a) range of commonly observed values and (b) long term trend of decline for many locations over time.

How much time? 15 to 20 years in the field via the model, but longer for a number of locations. Why?


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
Column data
from Bent Mt
KY samples



Establish surface hydrology to minimize water influx, achieve reclamation goals.
Weathered rocks (+ soil and organics?) at surface.
Plant rooting maintains voids near surface – and hydrologic function
Physical settling of fines limits permeability at interface
Extra compaction at interface if possible
Zipper et al. Conceptual plan, in progress
Unweathered rock - bulk fill
Low TDS

Conclusions

- **A relatively simple combination of lab procedures (e.g. saturated paste EC and total-S) and field indicators (rock type, color and hardness) can be used to clearly and quickly identify problematic materials.**

- **Assuming excessive amounts of net acid-forming materials are either excluded from valley fills or effectively isolated, the SC of discharge waters for the vast majority should decline to < 500 us cm^{-1} over time (years to decades?) unless pre-existing acidic seeps or other confounding factors are present.**

Conclusions

- **In general, brown oxidized strata are lower in TDS risk than non-weathered gray materials. Risk is also related to rock texture; sandstones tend to generate lower TDS than mudrocks or shales. Avoid black shales at all costs; regardless of S content.**

- **New mine-spoil fill construction procedures that isolate these materials from contact with surface runoff or percolating groundwater are under development and appear promising. Final surface soil and water conveyances must be constructed from the lowest TDS producing materials available which will generally be the surface pre-weathered soils and rock saprolites.**

Conclusions

- **The chemical nature of long-term bicarbonate-dominated discharge waters will be fundamentally different, however, from the sulfate-dominated discharge waters that predominate in mining-influenced Appalachian landscapes today. Net biotic effects of this shift in ionic composition are currently unknown, but may be more favorable for re-establishment of sensitive mayfly taxa. This deserves further study.**

ARIES Statement

The majority 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

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- There are simply way too many individuals at VT, UK, WVU and mining industry cooperators to list here. We deeply appreciate them all!