Can we limit TDS discharge from Appalachian coal surface mines?

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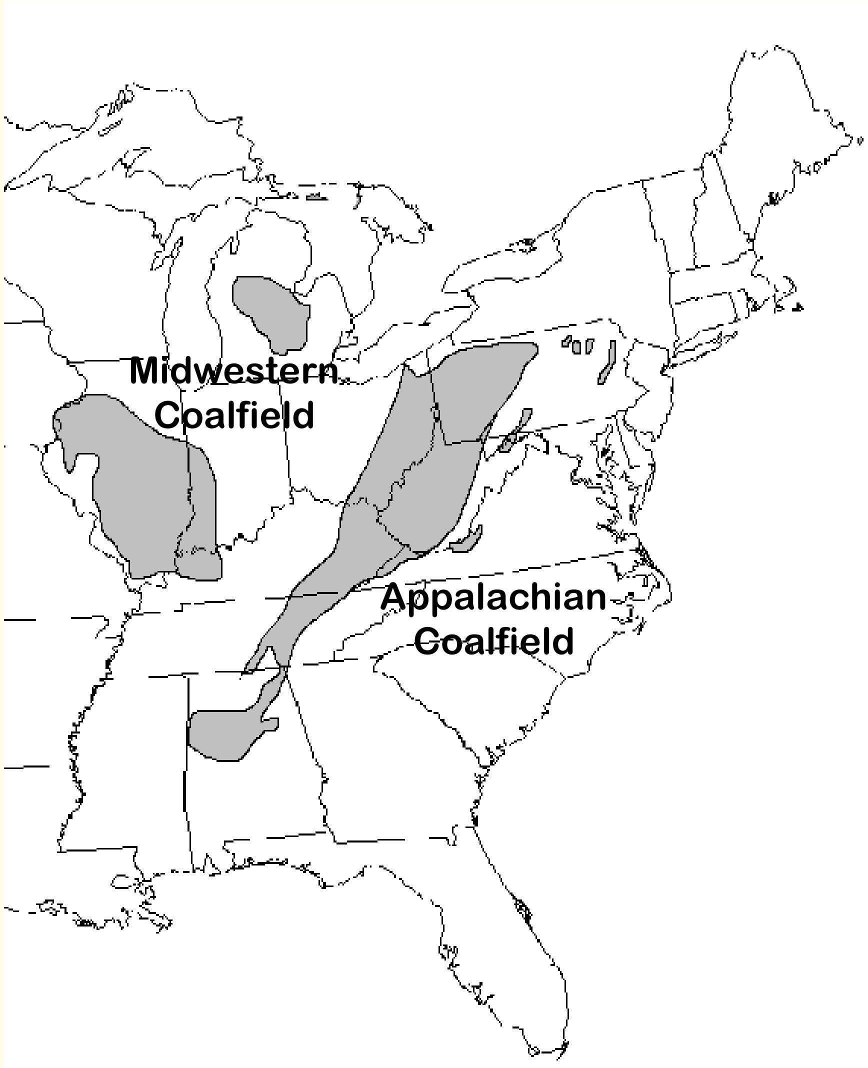
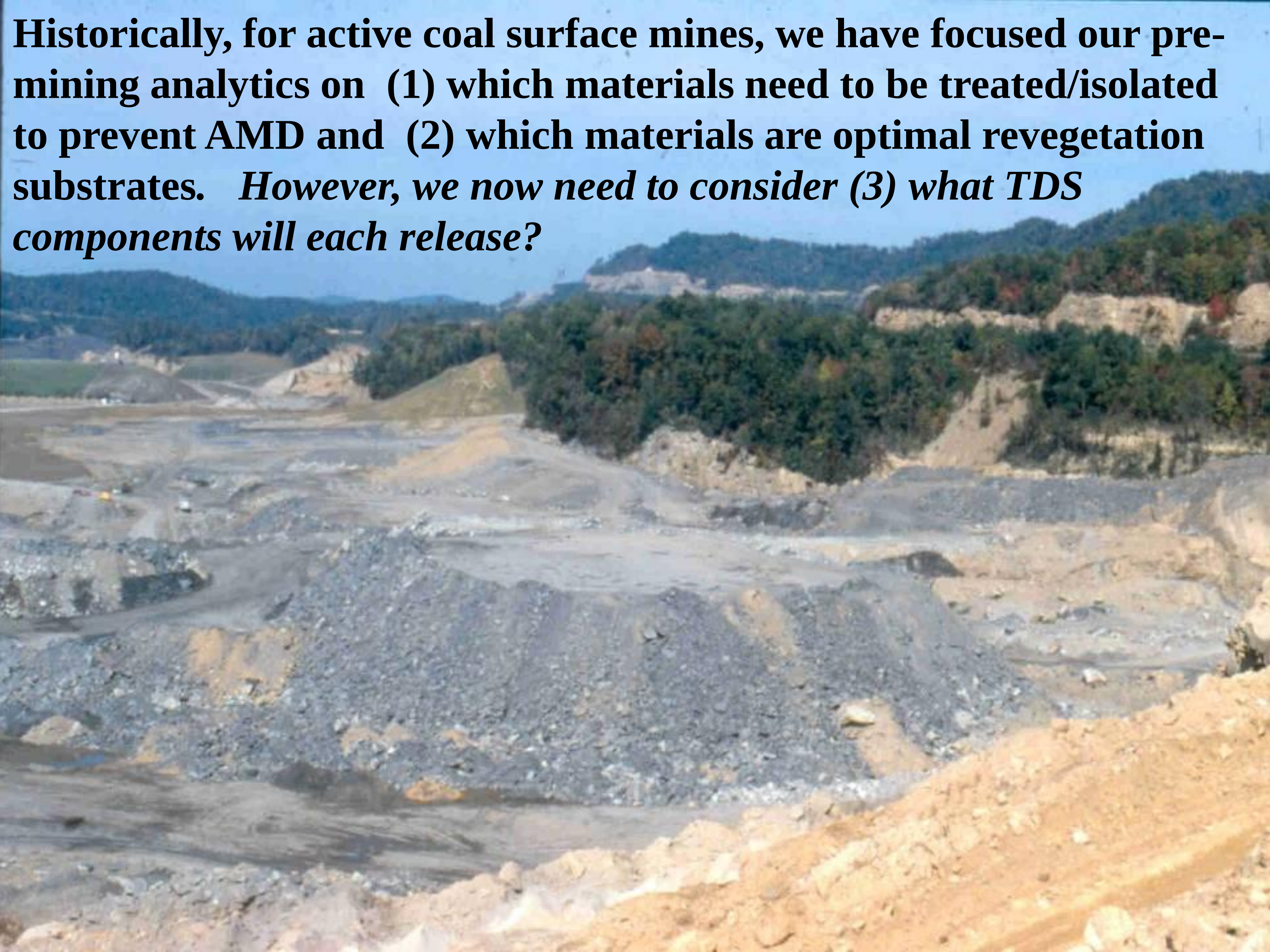
VirginiaTech Crop & Soil Environmental Sciences

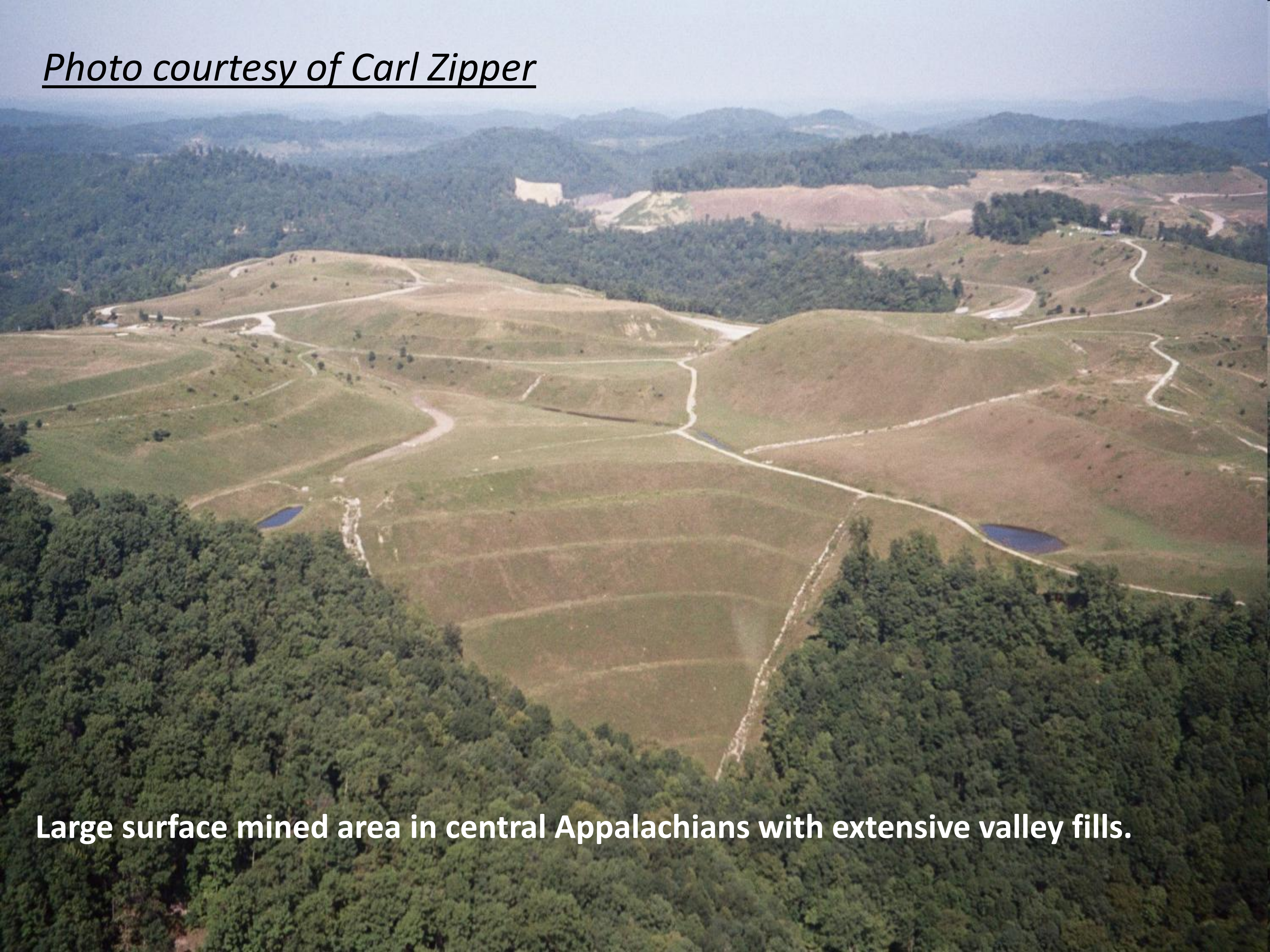
Eastern United States Coalfield Regions



700,000 hectares disturbed by mining in the Appalachian Region

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?***





Large surface mined area in central Appalachians with extensive valley fills.

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. Impacts are primarily to sensitive macroinvertebrates (bugs in streams).

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.

Issues & Industry Response

- **No study to date has been able to derive a direct cause x effect response between any ion and specific bug response.**
- **However most active coal mines in the region discharge at > 1000 us/cm during their active/open phase of operations.**
- **Se is also present in many discharges at levels appreciably higher than current 5 ug/L standard.**
- **Many consultant's presentations and non-refereed "papers" vigorously dispute the linkage between TDS and in-stream response by mayflies etc., but *no* refereed journal articles have been produced to refute the direct association between increasing TDS/EC and loss of sensitive bug taxa.**

Table 1. Summary of studies concerning effects by mining-origin total dissolved solids (measured as specific conductance, SC) on benthic macroinvertebrate communities in the central Appalachian coalfield. † Cormier et al. (2013) describe results of a US EPA (2011) study that is commonly known as the "Conductivity Benchmark" study.

Study	Effect Level	Threshold identification
Green et al. 2000	426 µS/cm	West Virginia Stream Condition Index
Pond 2004	500 µS/cm	Reduced relative abundance of mayflies
Freund & Petty 2007	501 µS/cm	West Virginia Stream Condition Index
Pond et al. 2008	500 µS/cm	Genus-level index, "GLIMPSS"
Gerritsen et al. 2010	180 - 300 µS/cm	West Virginia Stream Condition Index
Bernhardt et al. 2012	308 µS/cm	West Virginia Stream Condition Index & GLIMPSS
Cormier et al. 2013†	300 µS/cm	Protect 95% of native taxa
Timpano et al. 2015a,b (Spring)	903 µS/cm	Virginia Stream Condition Index
Timpano et al. 2015a,b (Fall)	560 µS/cm	Virginia Stream Condition Index

Issues & Industry Response

- **High TDS at many sites can be linked to pre-existing older mine impacts, deep mine impacts via surface seeps and other sources such as road runoff etc.**
- **It is not clear how much of the impact is due to TDS vs. changes in water temperature, lack of forest litter inputs and whether or not the loss of sensitive taxa is a temporal issue (*e.g. will the bugs come back*?)**
- **The coal industry responded via significant financial and in-kind support for ARIES (Appalachian Research Initiative for Environmental Science) due primarily to efforts by Michael Karmis (VT and original SDIMI co-organizer).**

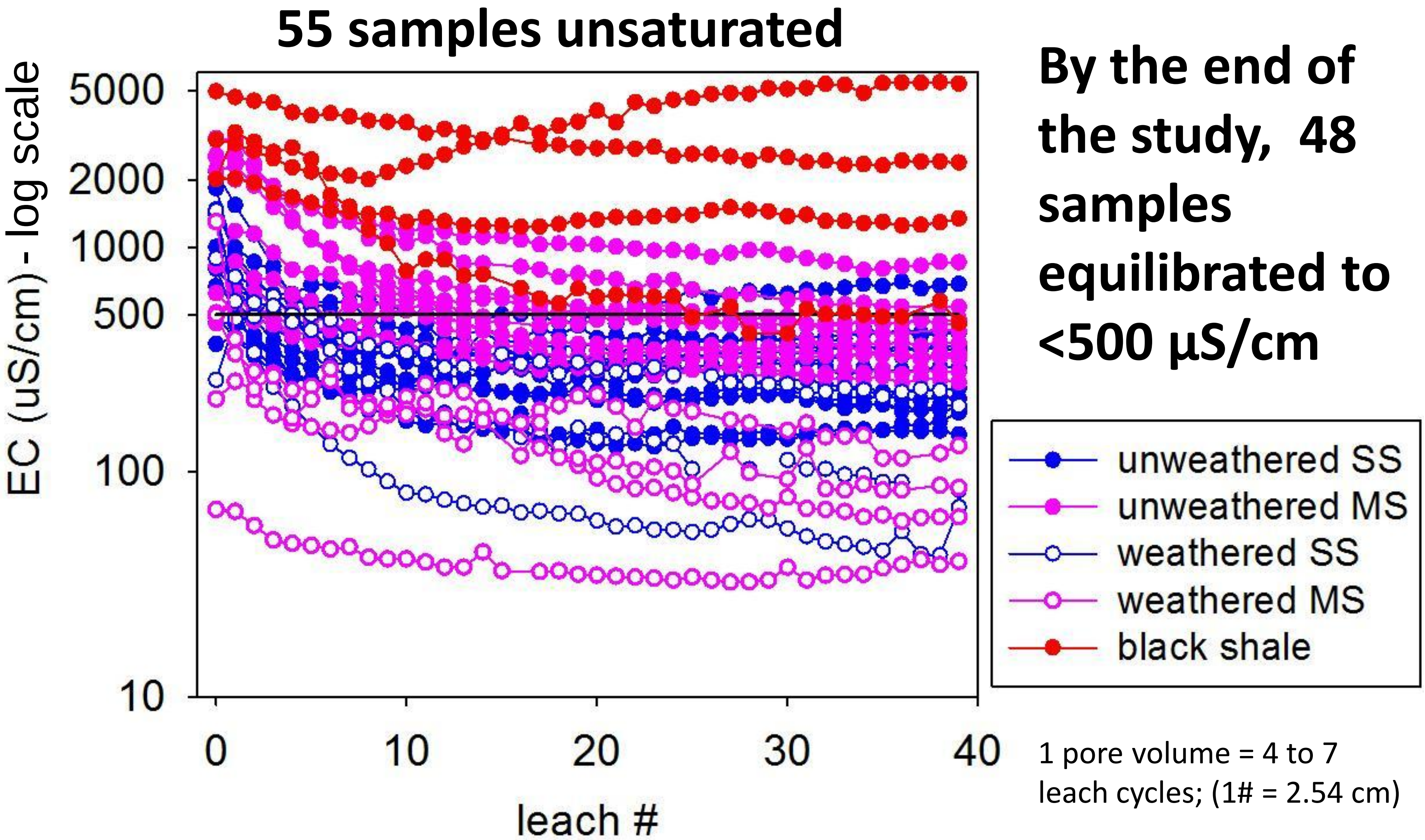
TDS Prediction & Management Research

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.
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.

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

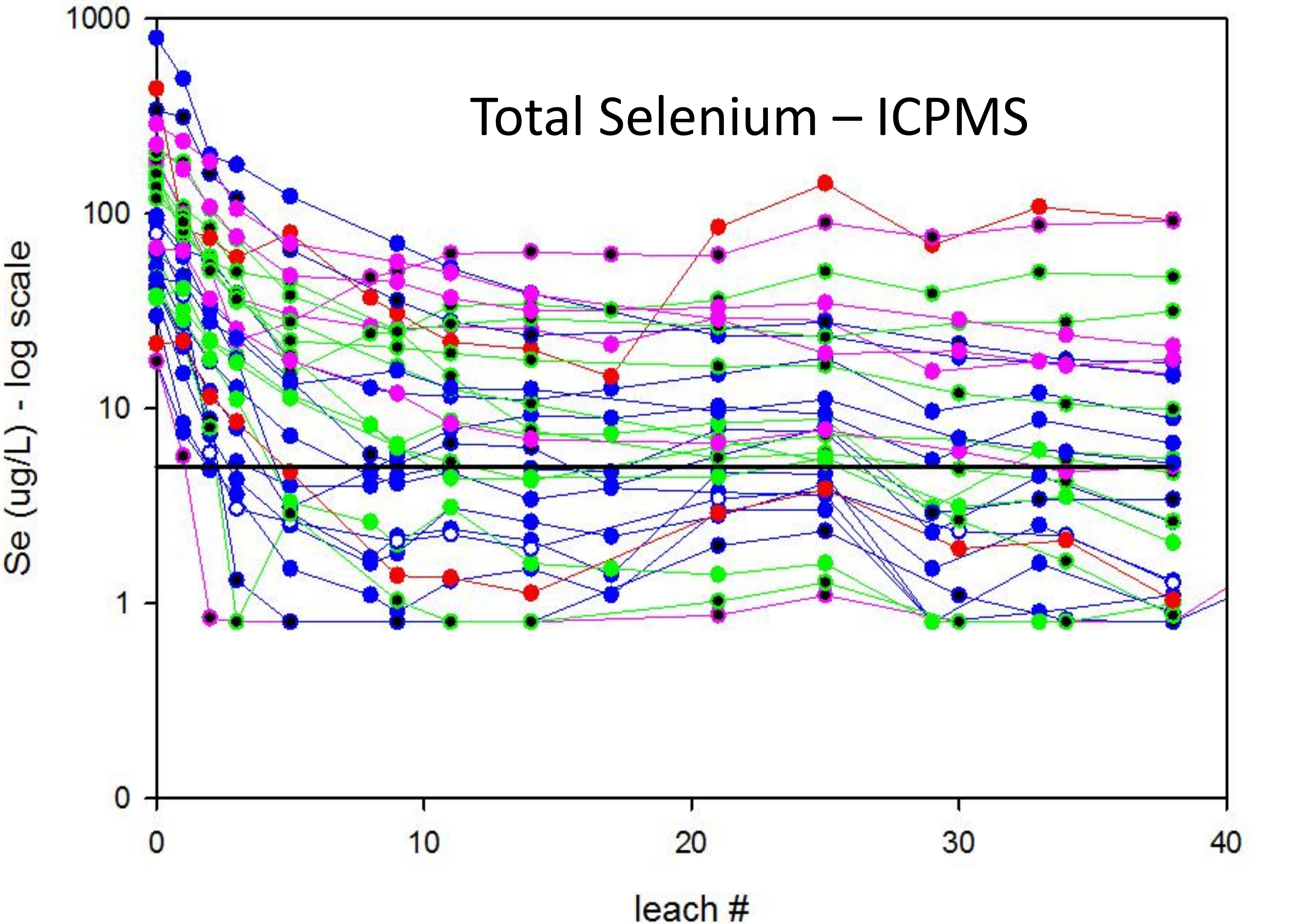
Overall: 1) increased weathering = lower EC/TDS

2) coarser grain size = lower EC/TDS



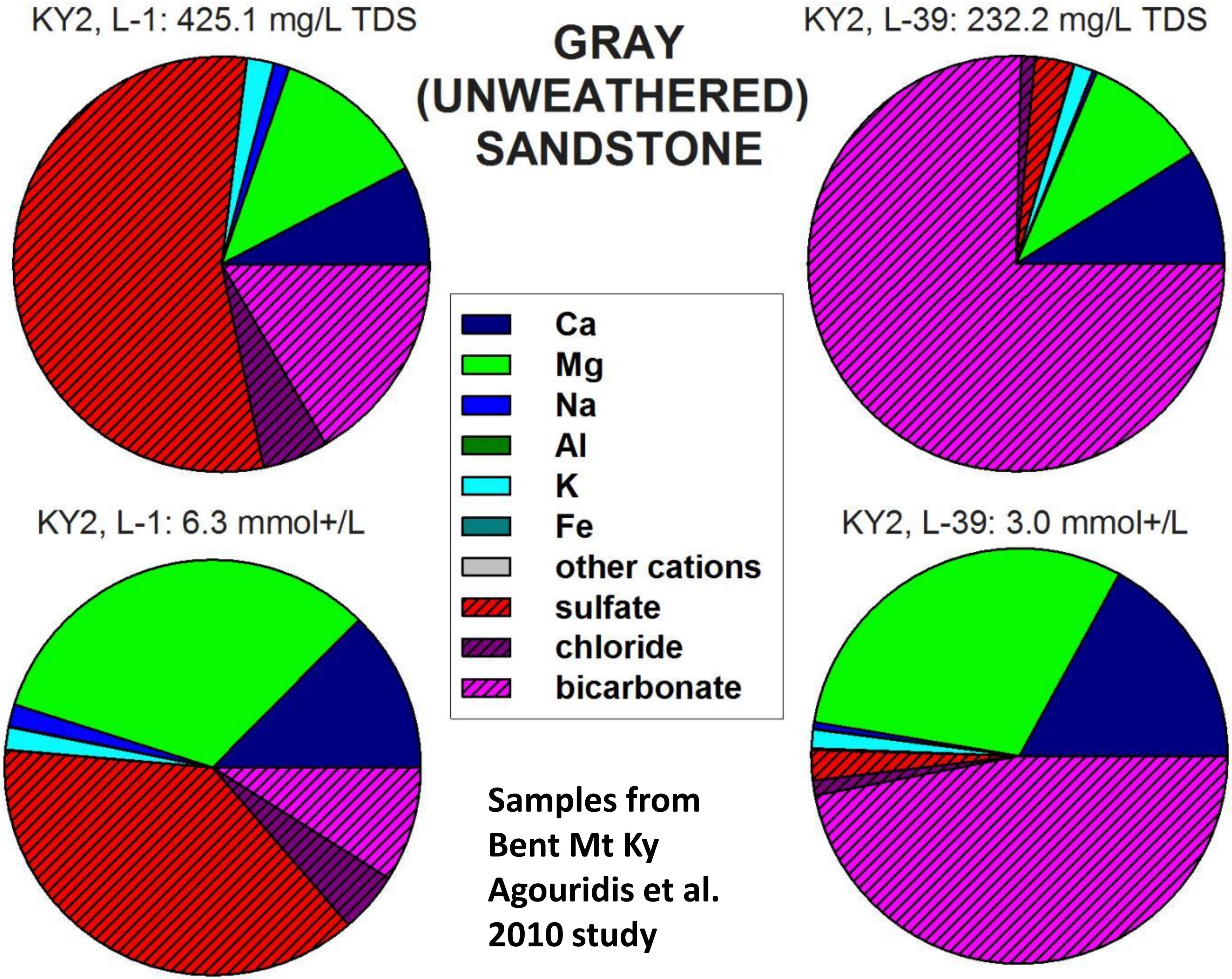
By the end of the study, 48 samples equilibrated to <500 µS/cm

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

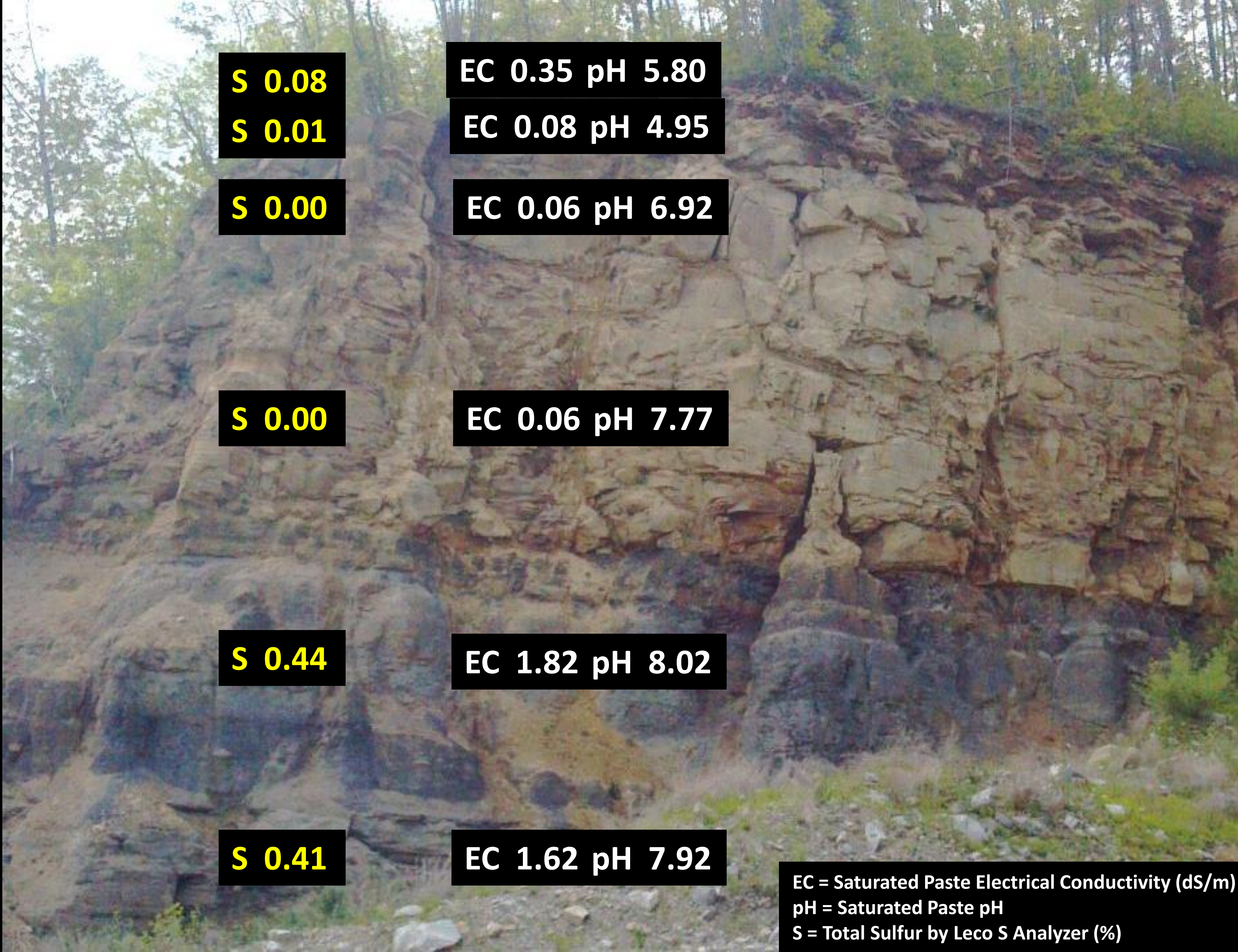


Total Selenium – ICPMS
Se (ug/L) - log scale
1000
100
10
1
0
0
10
20
30
40
leach #

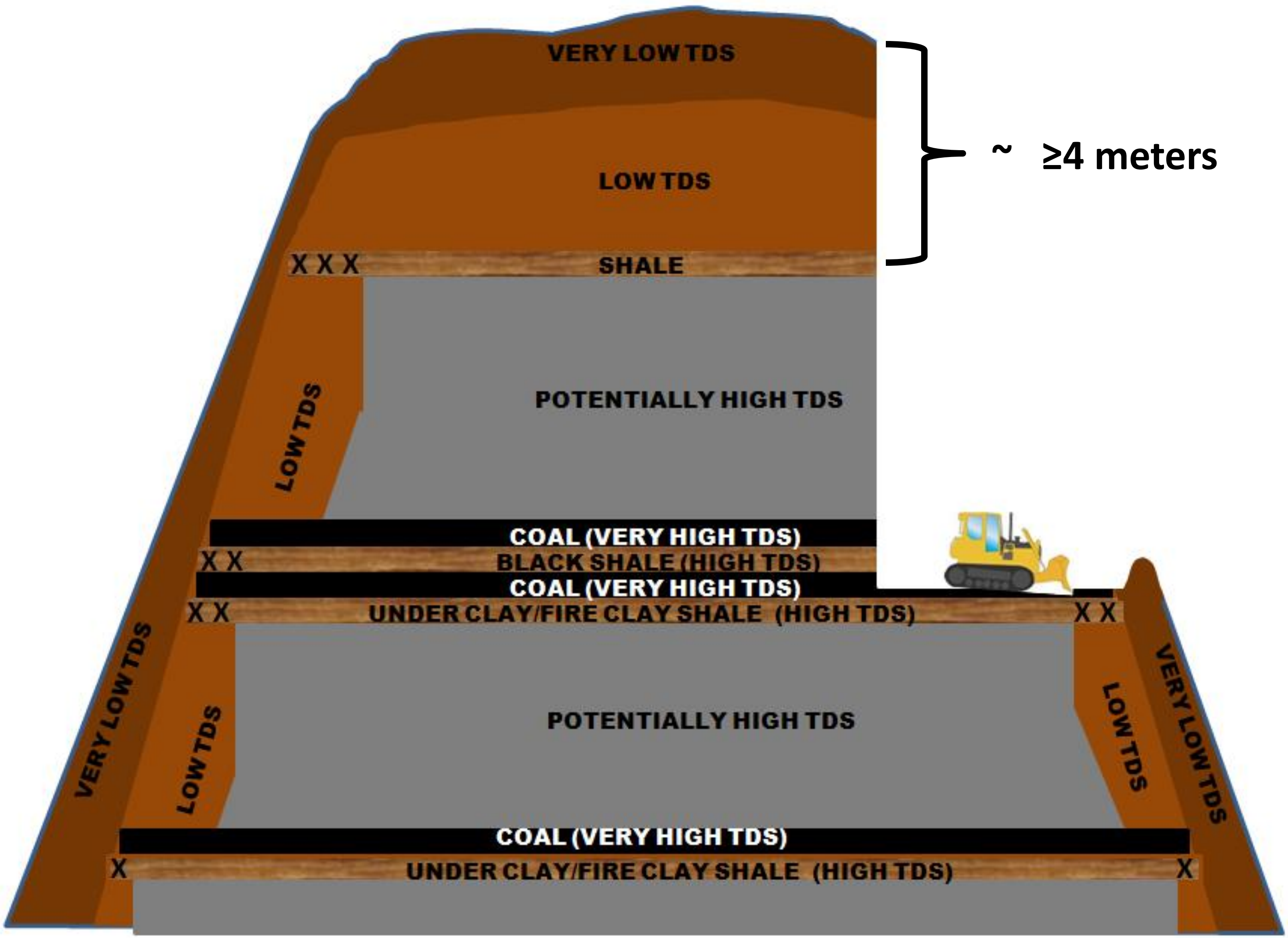
GRAY (UNWEATHERED) SANDSTONE



Samples from Bent Mt Ky Agouridis et al. 2010 study

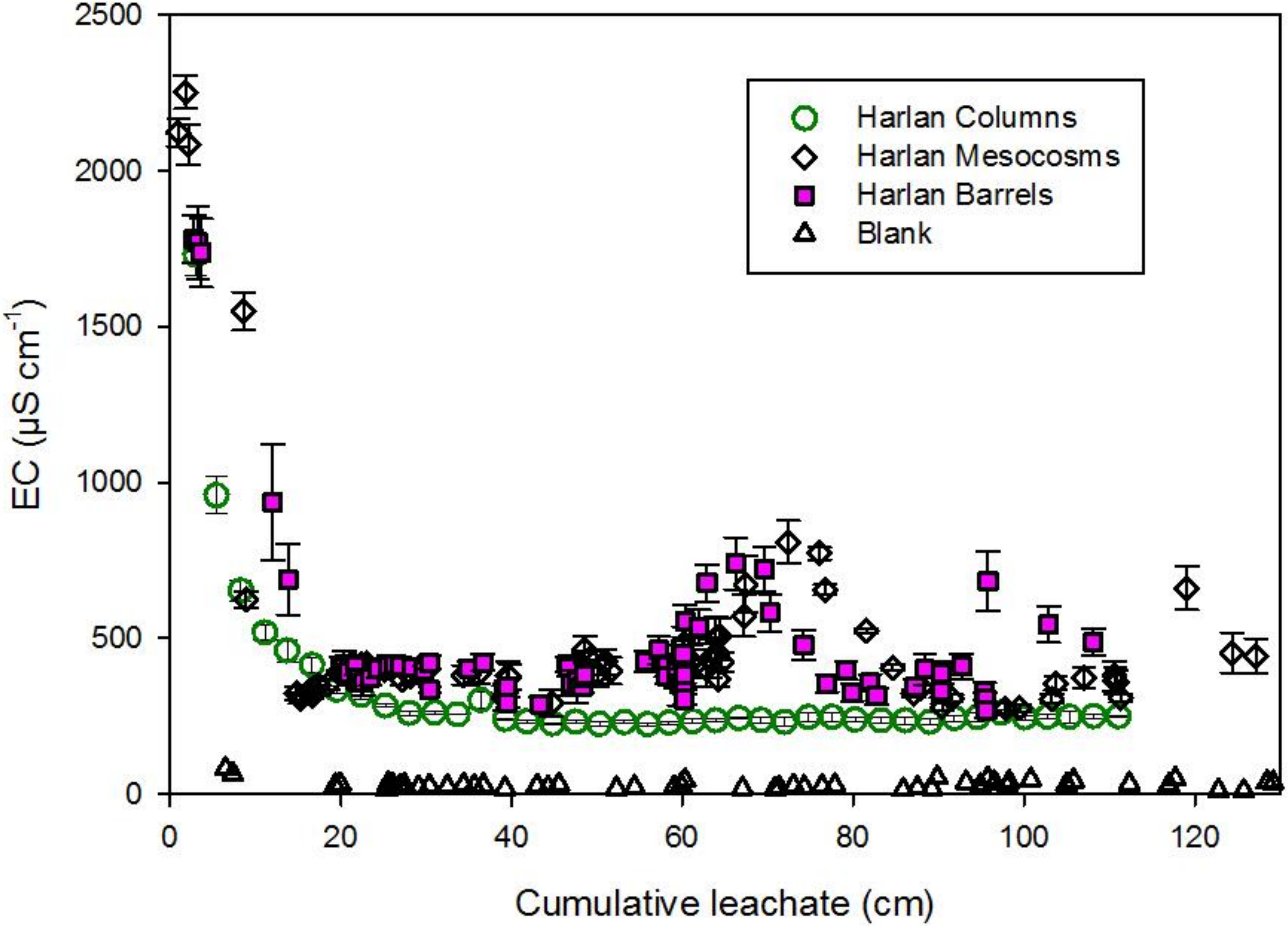

S 0.08
S 0.01
EC 0.35 pH 5.80
EC 0.08 pH 4.95
S 0.00
EC 0.06 pH 6.92
S 0.00
EC 0.06 pH 7.77
S 0.44
EC 1.82 pH 8.02
S 0.41
EC 1.62 pH 7.92
EC = Saturated Paste Electrical Conductivity (dS/m)
pH = Saturated Paste pH
S = Total Sulfur by Leco S Analyzer (%)

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

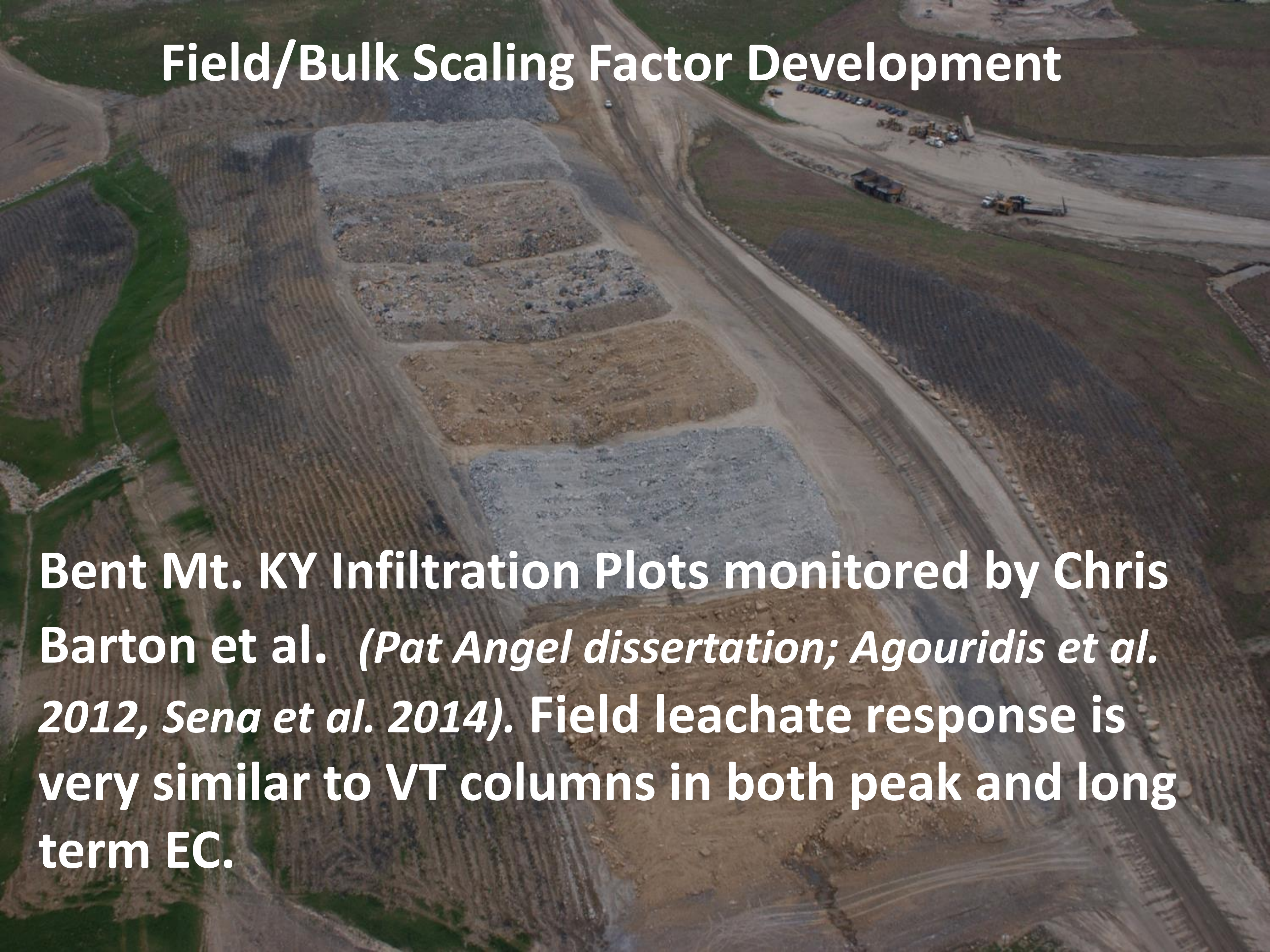


Raw spoil (up to 18”) placed into mesocosms over filter fabric and 10 cm of acid washed gravel. Initiated in October of 2012 and will be continued through 2016.

Large mesocosms (here) supported by OSM and ARIES. OSM supported smaller “barrels” on same site with same spoil (Harlan fm). Barrels received ≤ 5” screened spoils.

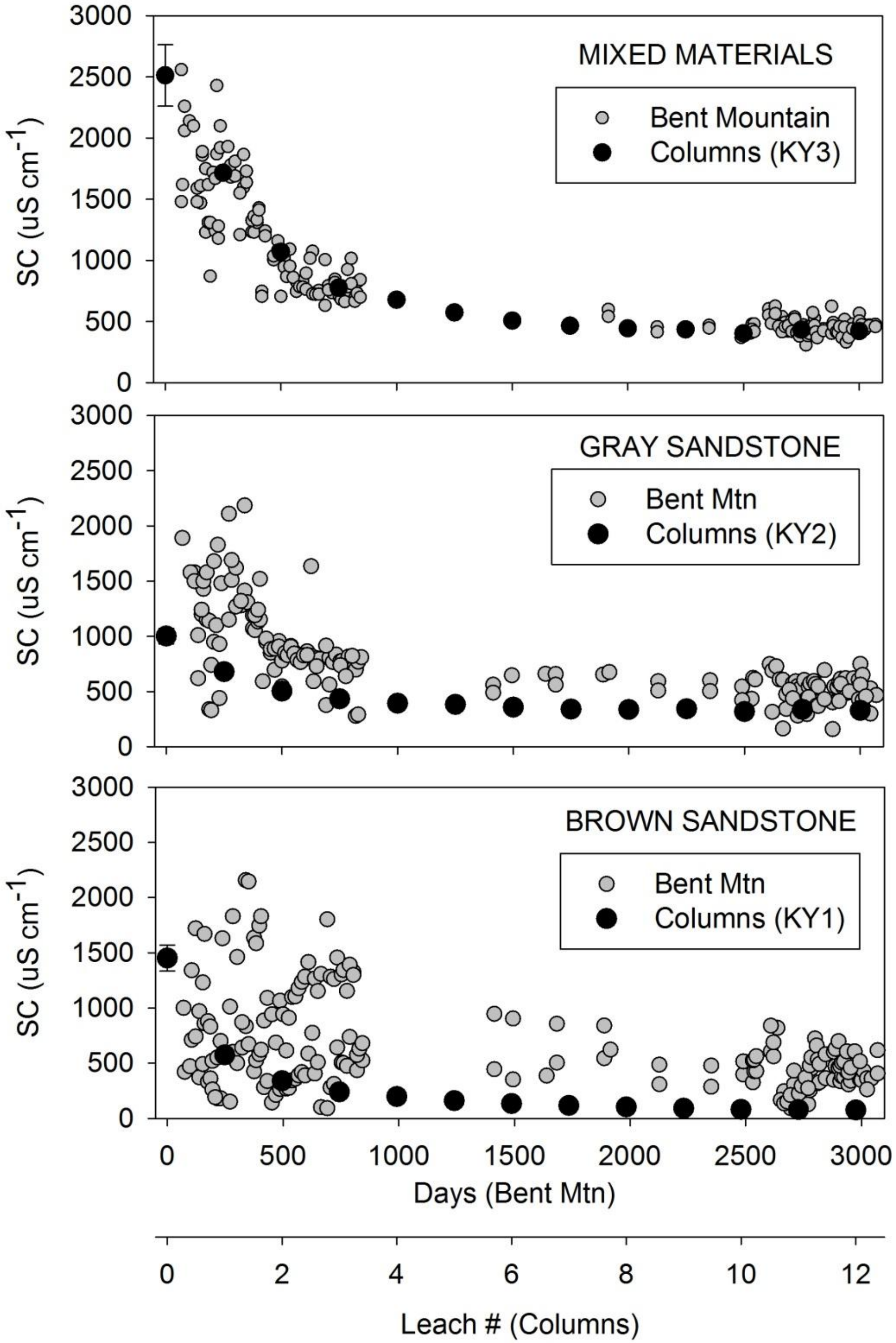


2500
2000
1500
1000
500
0
EC (µS cm-1)
0
20
40
60
80
100
120
Cumulative leachate (cm)
Harlan Columns
Harlan Mesocosms
Harlan Barrels
Blank



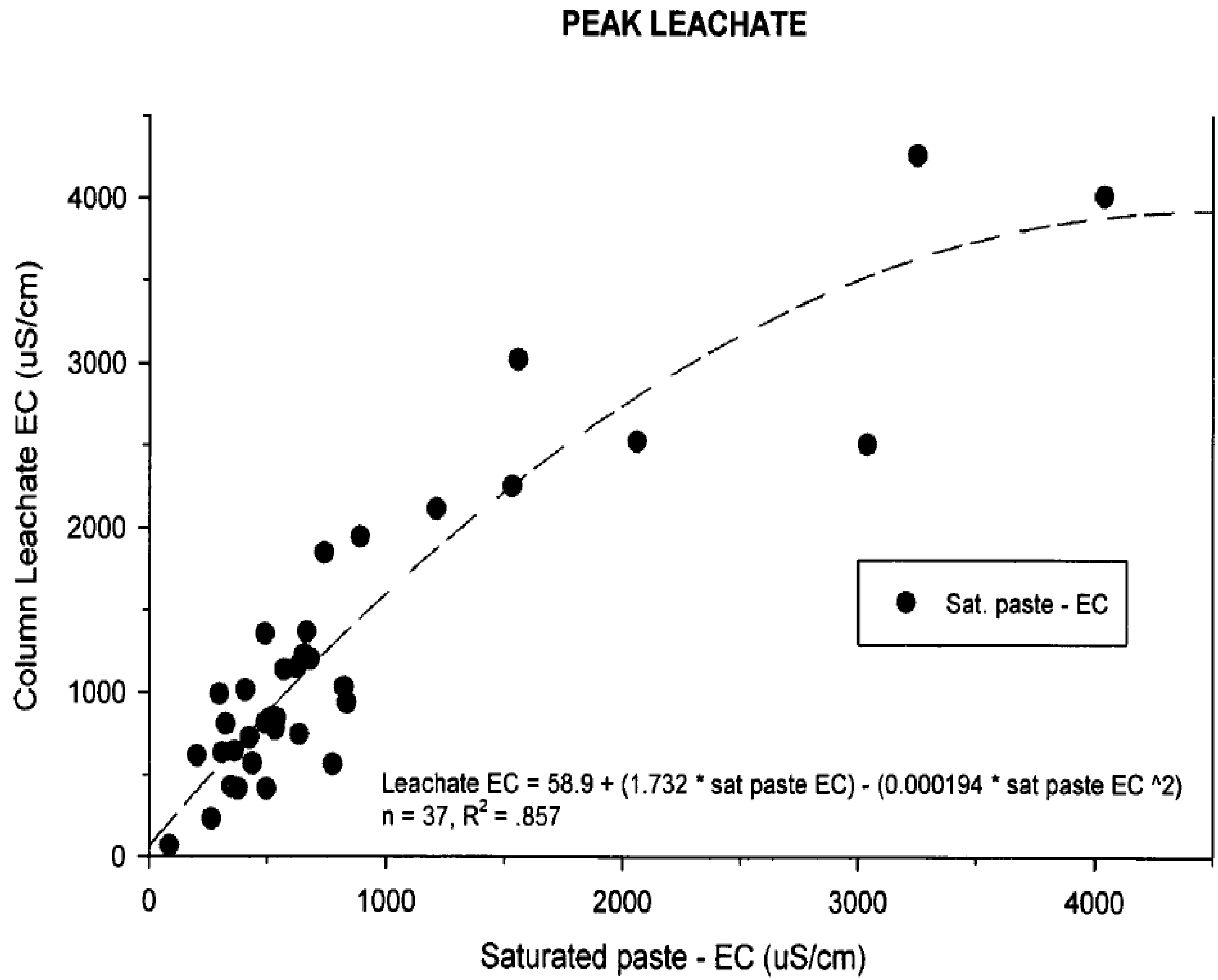
Field/Bulk Scaling Factor Development

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.

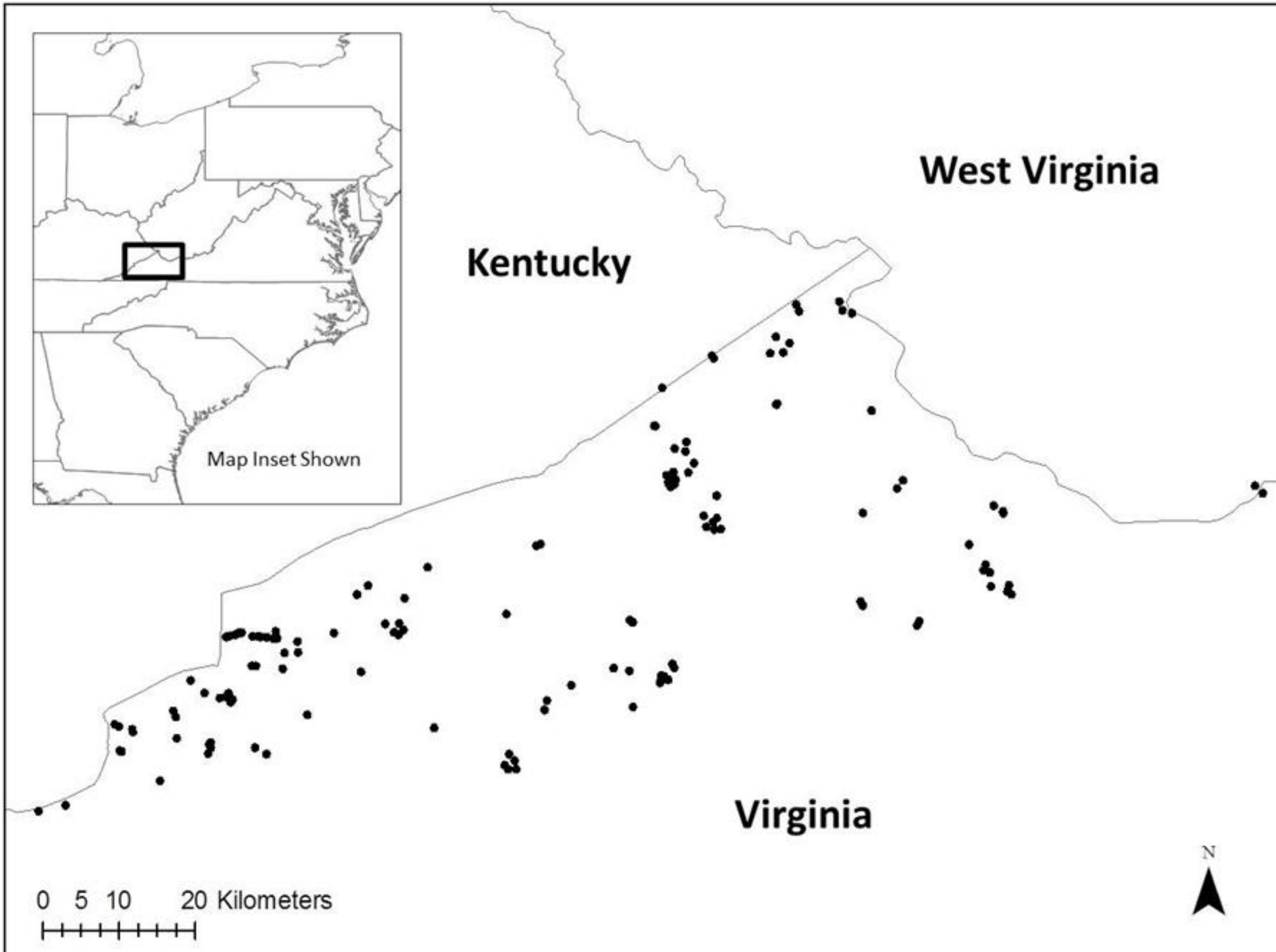


Individual spoil sample leaching data from VT columns and UK Bent Mt. lysimeters. Note the very good correspondence for the mixed materials along with the (a) poorer initial fit for the "gray sandstone", and the (b) fairly consistent under-prediction for the columns vs. the "brown [weathered] sandstone".

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



Curvilinear regression of saturated paste EC vs. "peak column leachate EC". Certain other variables like total-S were also correlated with EC, but did not model across all materials nearly as well as EC tests. Peak column EC = average of first three column leaching events.


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

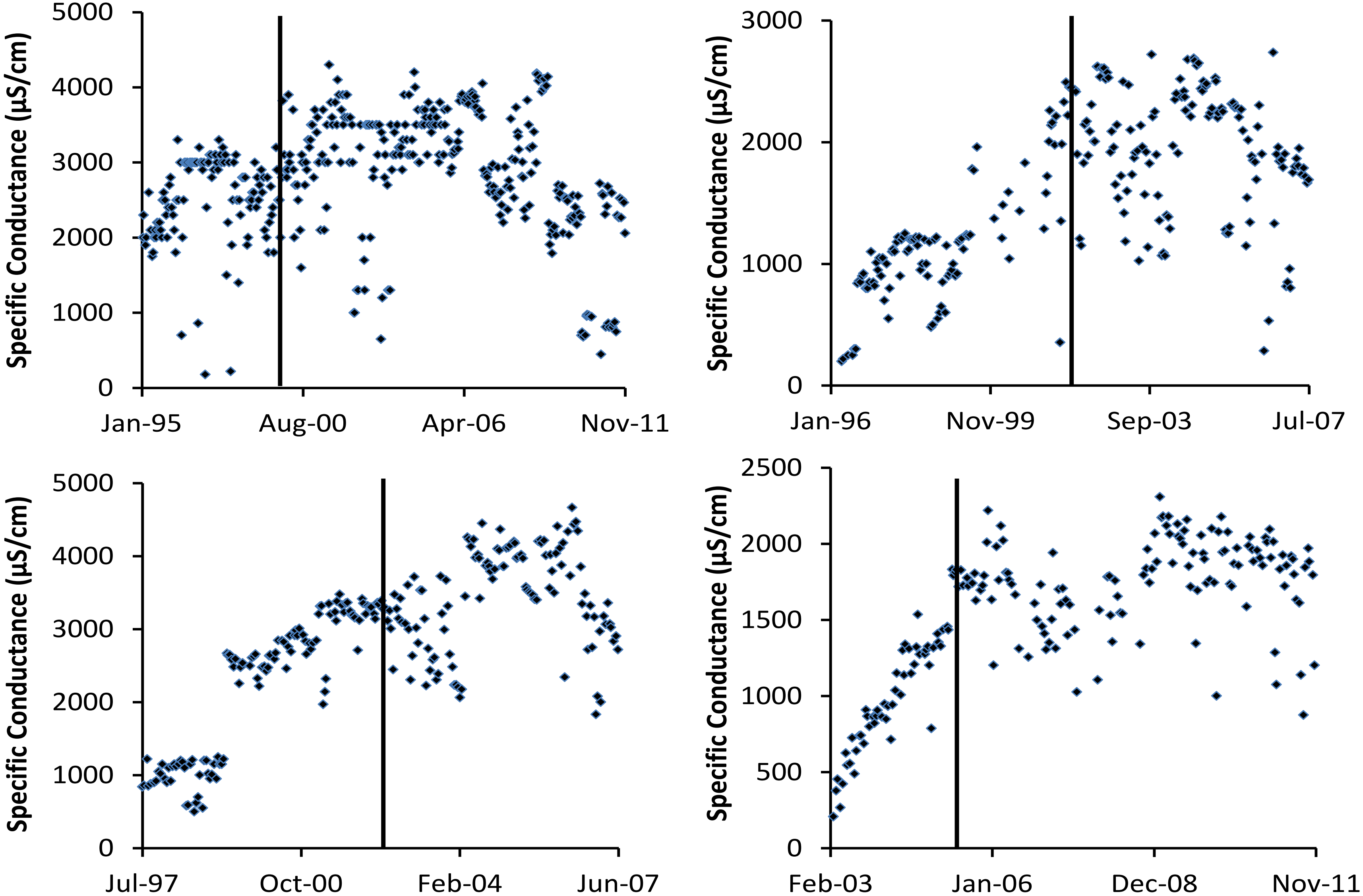


Figure 2. Specific conductance (SC) of water discharges from four Virginia valley fills selected from the dataset studied by Evans et al. (2014) to illustrate a common pattern for such water discharges, as per study findings: ……..

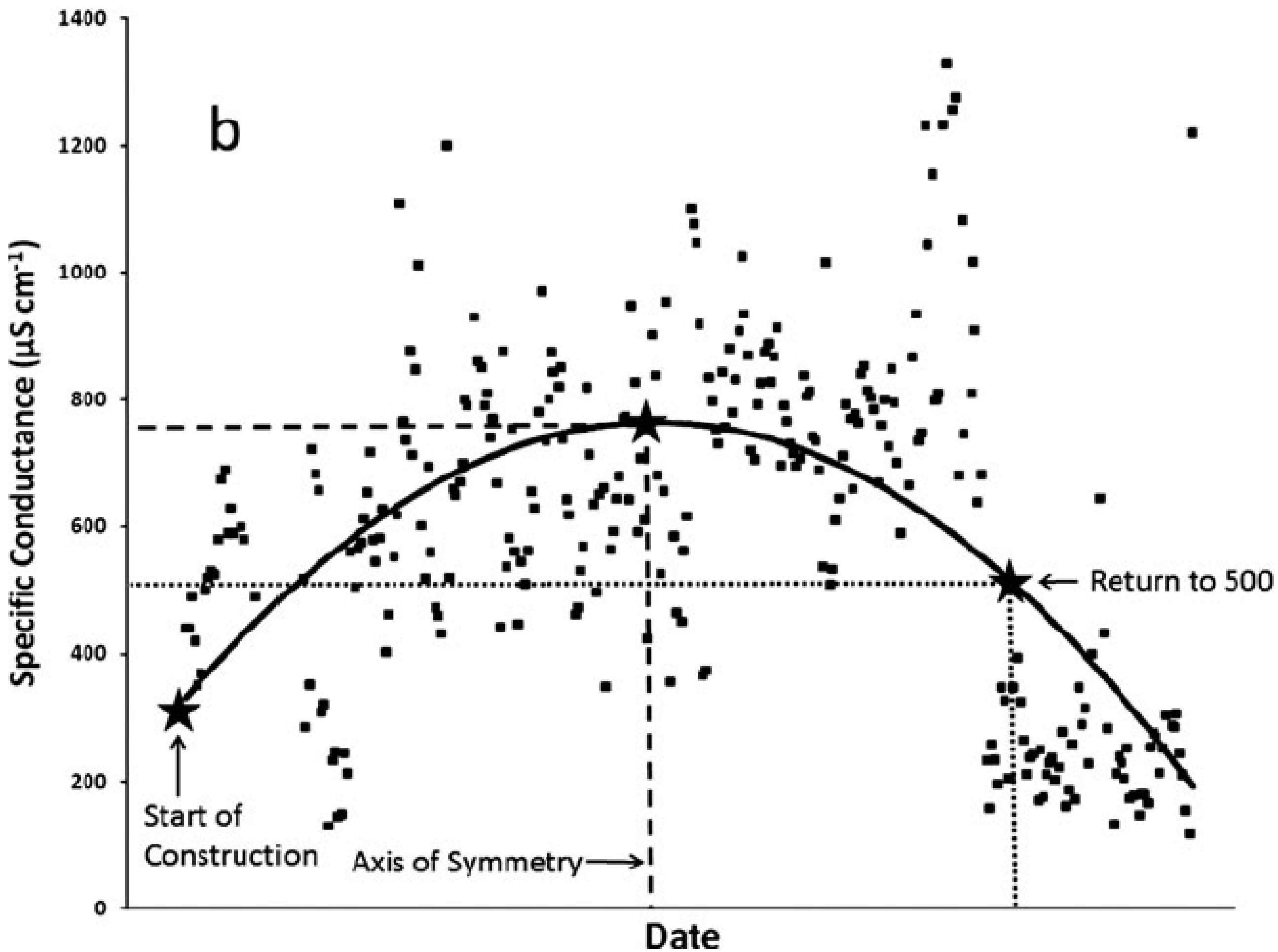


FIGURE 3. Example of Specific Conductance (SC) Data at a Valley Fill with (a) Disturbance Phases Delineated, and (b) a Quadratic Model Fit to Data (solid line), with Axis of Symmetry and the Method for Estimating the Time Required for SC to Return to 500 µS/cm Illustrated.

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

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?

What are the alternatives?

- **Treat discharge via sulfate reducing wetlands. Will still generate relatively high TDS, but anion complement will shift to bicarbonate**
- **Treat via reverse osmosis. Expensive, but could also reduce related Se discharge issues.**
- **Impound relatively clean surface water on site or adjacent to discharge reaches and use it to dilute TDS.**
- **Collect surface discharge and irrigate (or infiltrate) it into adjacent undisturbed forest lands.**

- **We believe the only *practical alternative* is to build low TDS backfills and valley fills *by design*.**

Two experimental fills are being constructed.

Similar strategies are being employed for the 2 fills – but with some differences

Waters emerging from experimental fills are monitored.

Conventional fills constructed in similar strata are also monitored for comparison.

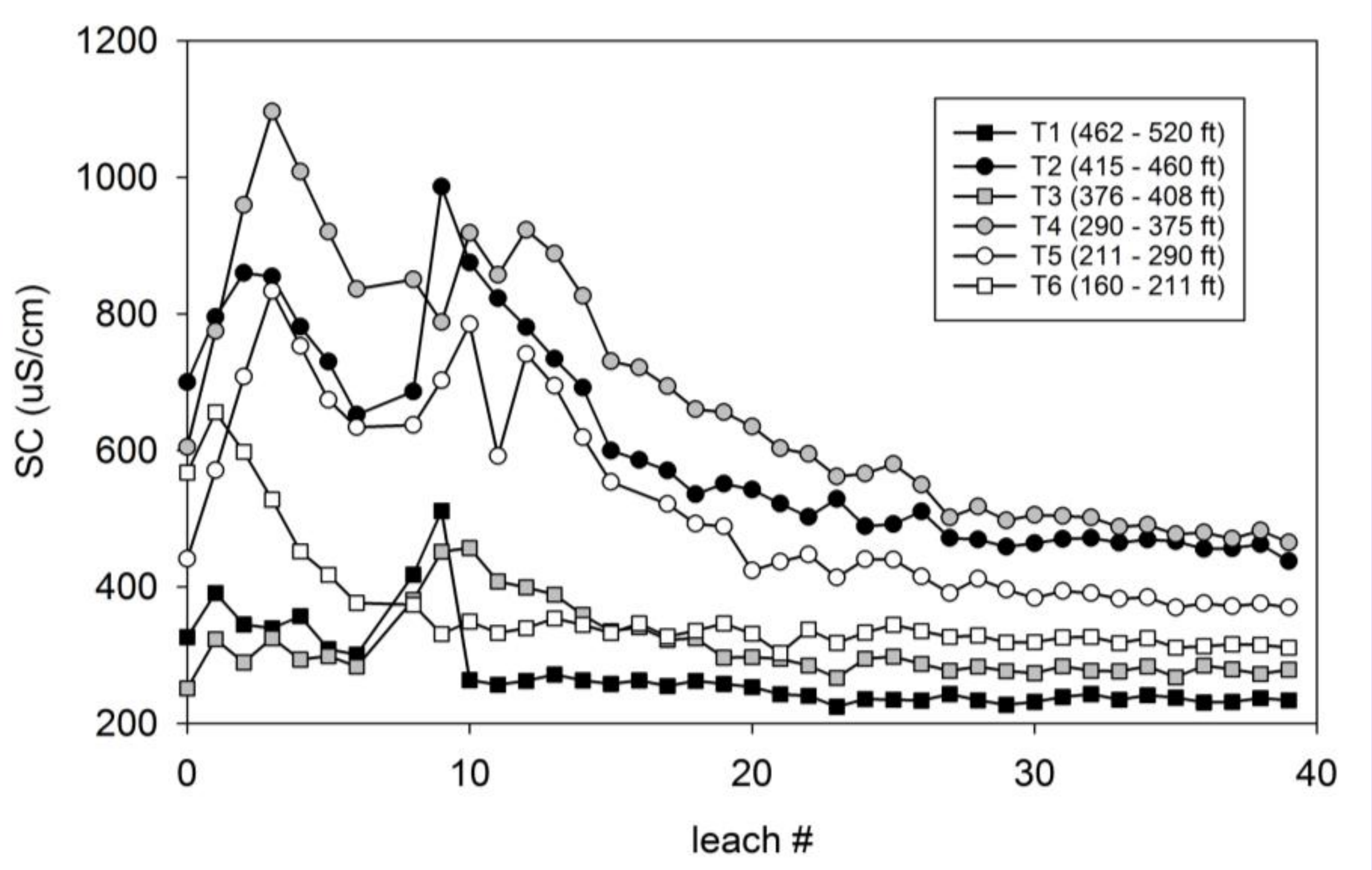
A third experimental fills is being designed.

Interpret Mine-Spoil Testing Results.

For fill construction: we see 4 main rock types

1. Durable rock, low TDS: for drains
2. High TDS (often include shales, anything pyritic): to isolate “high and dry”
3. Bulk fill: Intermediate TDS, unweathered.
4. Weathered spoil and soil materials: Lowest TDS is usually closest to the surface

Test mine rock for TDS generation potentials

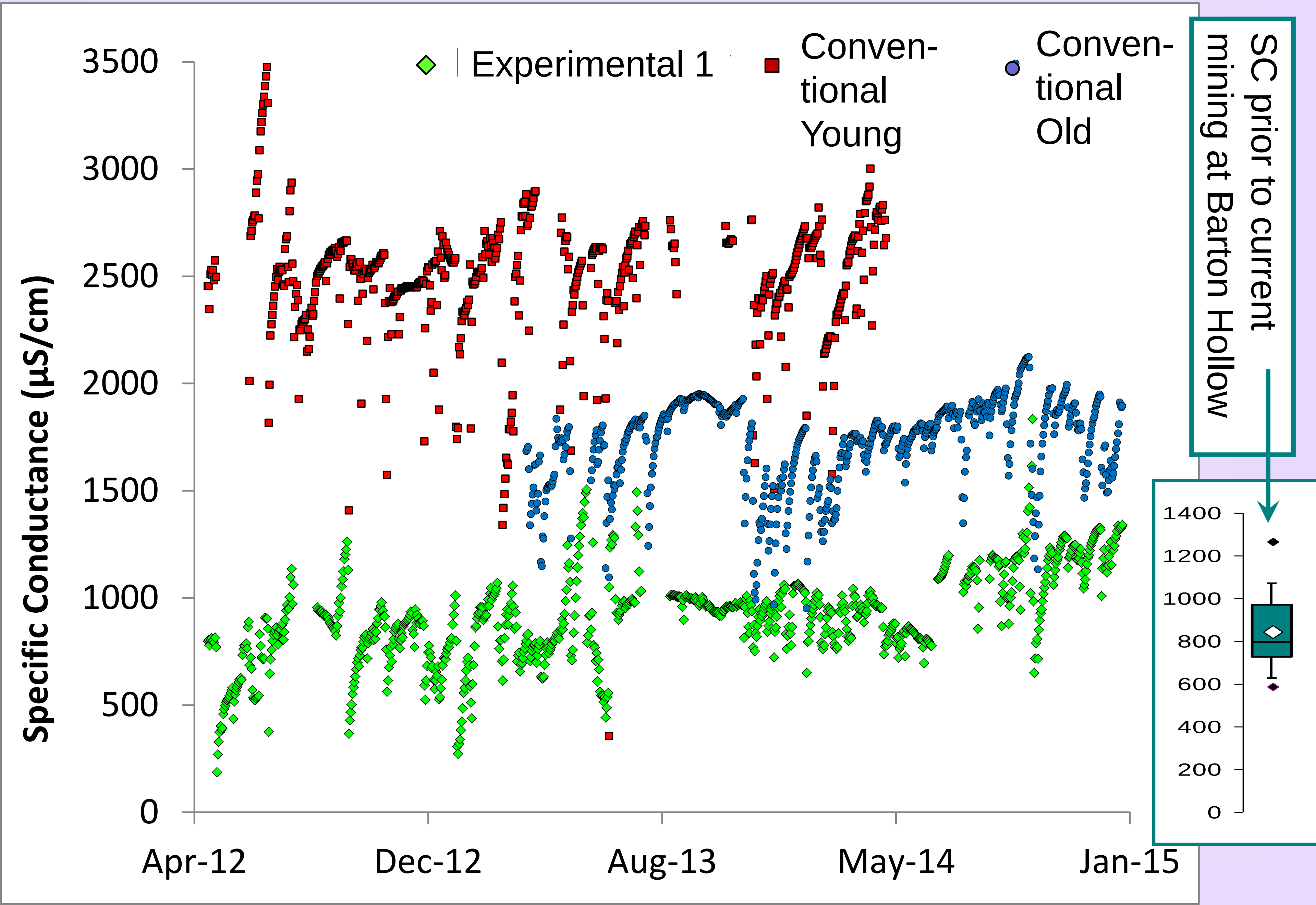


T1: Best for drains. T2: 2nd best

Leach test results:
Z. Orndoff, W.L. Daniels

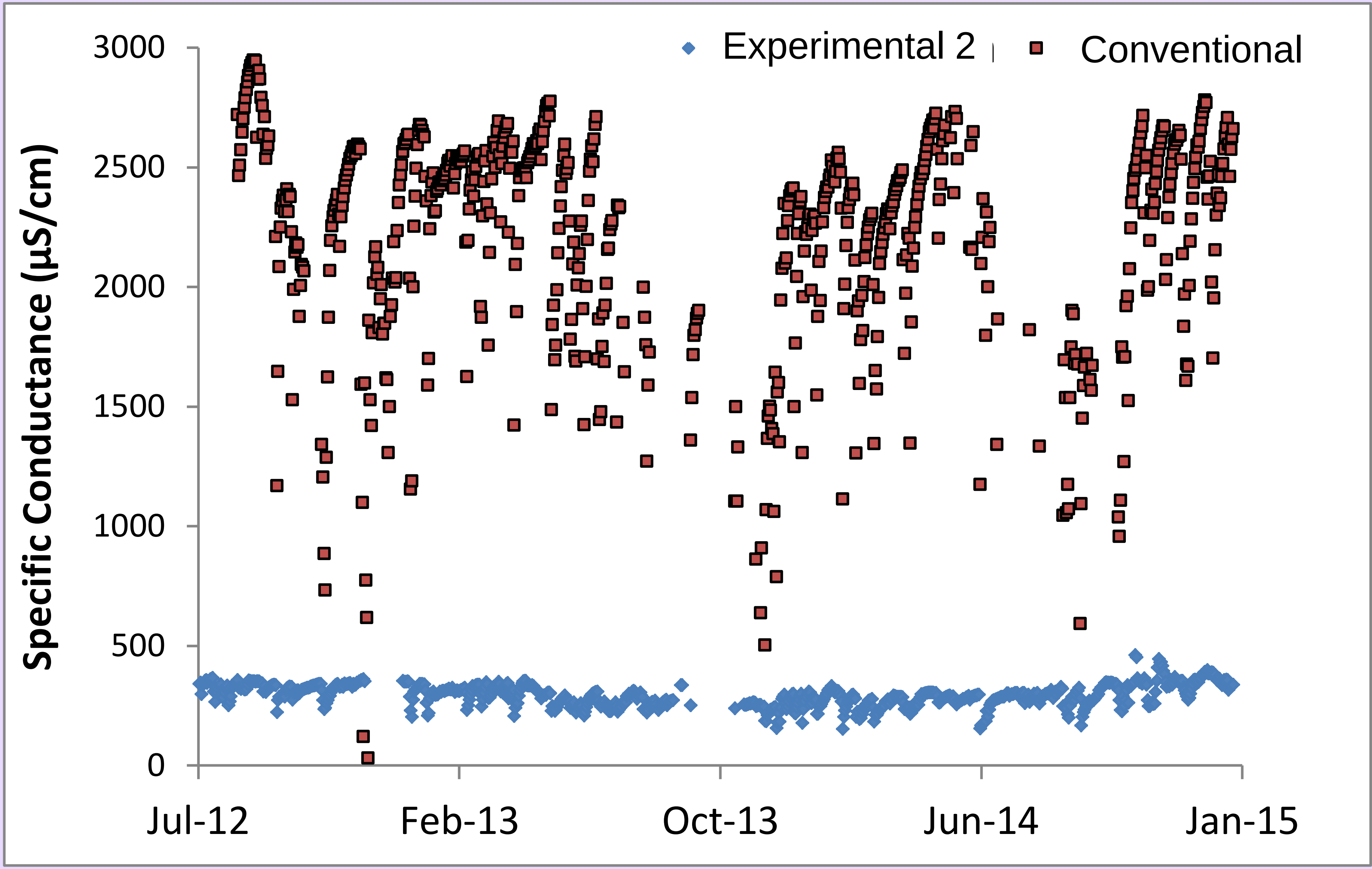
Experimental Fill 1 Site

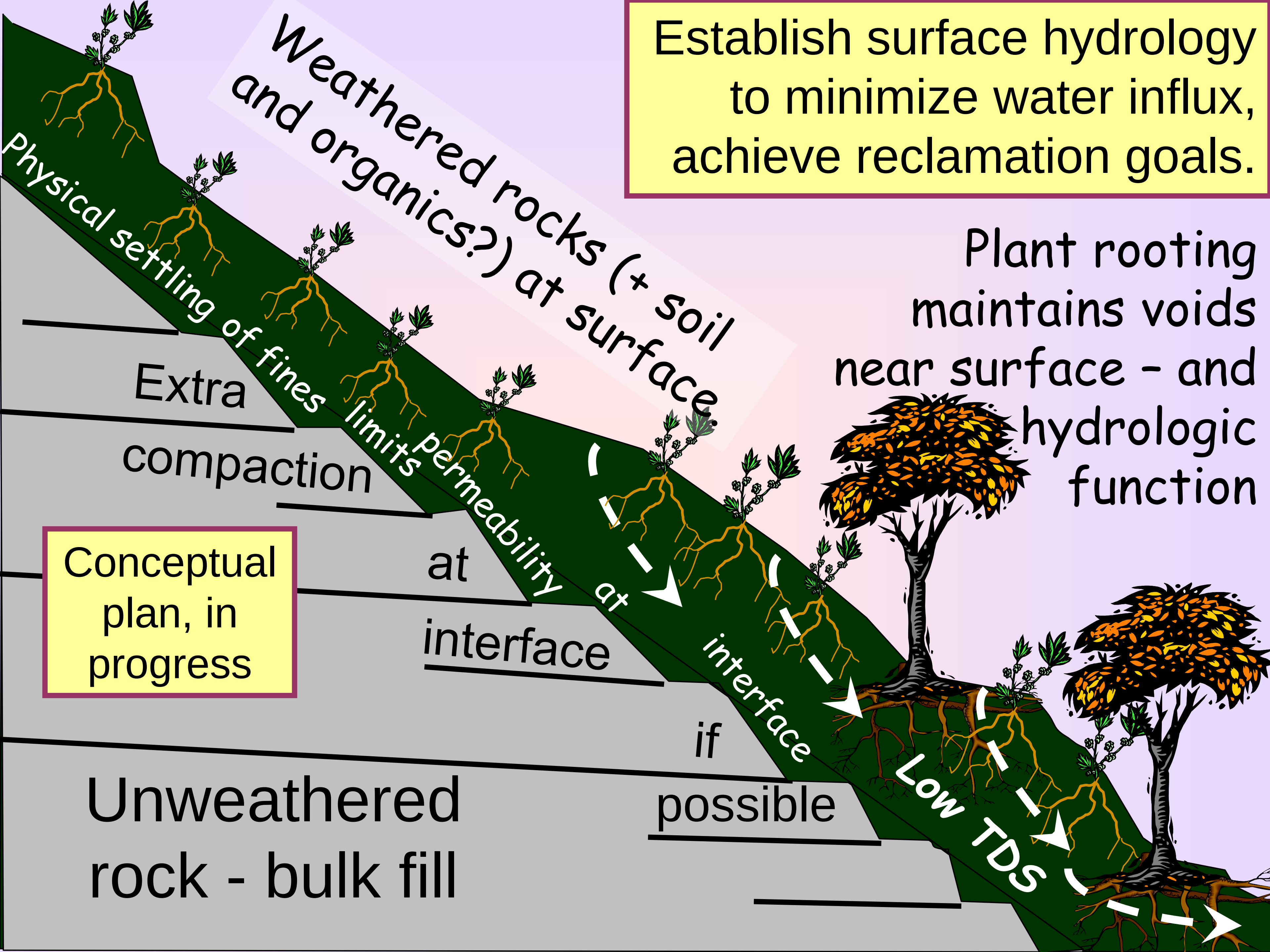
Experimental Fill 1 Site: SC, Mean Daily Values



Experimental Fill 2

Experimental Fill 2 Site: SC, Mean Daily Values




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
Conceptual plan, in progress
Low TDS
Unweathered rock - bulk fill

Forestry Reclamation Approach

Best Management Practices (Burger & Torbert, 1992)

1. Topsoil substitute selection

2. Site preparation

3. Compatible ground cover
4. Professional tree planters

5. diverse, valuable, native species

Conclusions

- **Discharge of waters with elevated TDS to headwater streams is a clear threat to the economic and environmental sustainability of the central Appalachian coal industry. The issue is also intrinsically interlinked with social concerns over the return of these lands to native forest vegetation.**

- **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.**

Conclusions

- **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.**

- **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 unless pre-existing acidic seeps or other confounding factors are present.**

Conclusions

- **Our studies to date indicate that decades following mine closure are required for this to occur, and that most of these fills will more than likely remain >300 us cm^{-1} for longer periods of time. Will the bugs come back?**

- **The chemical nature of these 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, and net biotic effects of this shift in ionic composition are currently unknown.**

So, can we limit TDS discharge from Appalachian coal surface mines?

Yes, but it will take much higher inputs of pre-mine sample analysis and planning and spoil disposal costs will more than likely increase.

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