

Long-Term (10-year) Effects of Mine Spoil Weathering on Leachate Quality

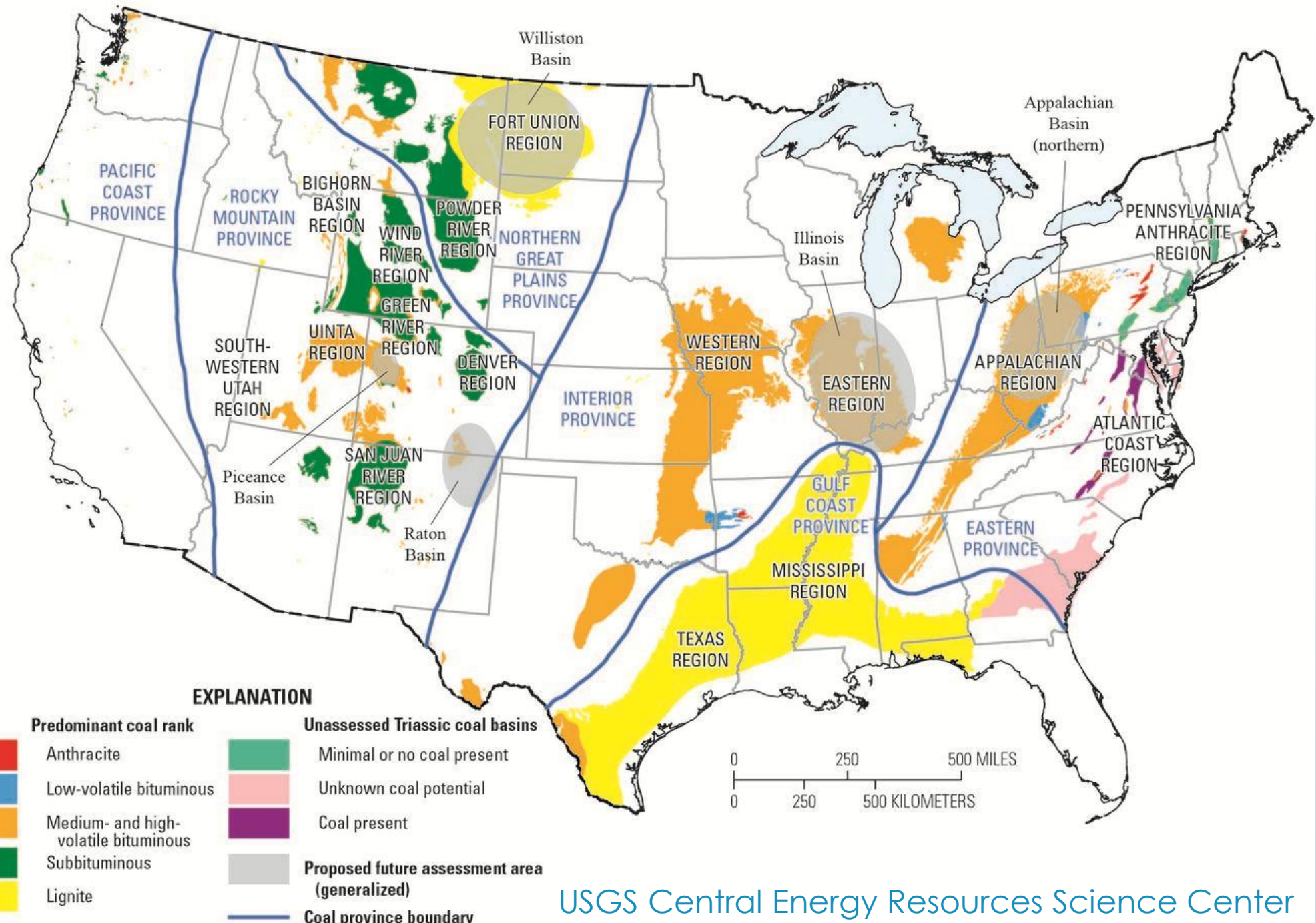
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4 June 2025

ASRS Annual Meeting, Butte, Montana



Coal fields of the conterminous United States—National Coal Resource Assessment updated version



Coal Mining Impacts: In Brief



- **Pre-1977: No federal reclamation/reforestation requirements, regulations varied among states**
- **Some reforestation work, but...**
 - **Many highwalls left**
 - **Unstable slopes (landslides, boulder damage, subsidence)**
 - **Impacts to water quality**
 - **Sedimentation**
 - **Acid mine drainage**
 - **Salts**
 - **Heavy metals**



► SMCRA 1977

- Land returned to approximate original contours
- >90% vegetation cover
- Acid-forming materials isolated from water
 - Acid water leaving a coal mine must be treated to $\text{pH} > 6.0$ with low Fe, Mn, and SO_4
 - Historic focus on acidity and metals, but more recent concerns over effects of bulk salts (TDS) on headwater streams

Top photo (Lee Daniels); Bottom photo (Jeff Skousen)

- **TDS = Total Dissolved Solids expressed as mg/L**
 - **Sum of $\text{Ca}+\text{K}+\text{SO}_4$ etc. in solution. Laborious to analyze for!**
- **Typically estimated by specific conductance (SC) in $\mu\text{S}/\text{cm}$: $\text{TDS}=\text{conversion factor} \times \text{SC}$**
 - **General conversion =0.7 (500 $\mu\text{S}/\text{cm}$ = 350 mg/L)**
 - **More specific conversion factors used in systems dominated by sulfate (0.9), carbonate (0.75), etc.**



Impacts of elevated TDS

- ▶ EPA study found streams with conductivity $>500 \mu\text{S}/\text{cm}$ were biologically impaired (Pond et al. 2008)

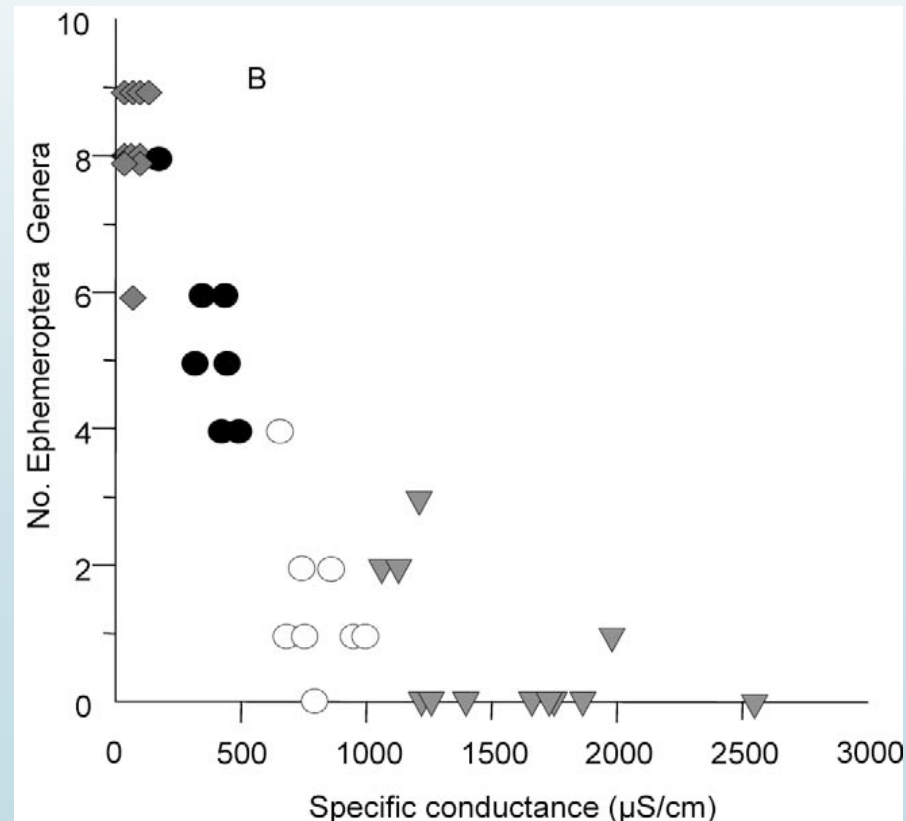


Photo credit: Greg Pond, EPA Region 3

Regulation of TDS/SC

- ▶ **SC in non-impacted Appalachian streams; $<200 \mu\text{S}/\text{cm}$**
(Merricks et al. 2007, Pond et al. 2008, Fritz et al. 2010)
- ▶ **SC in mining-impacted streams; <500 to $>3000 \mu\text{S}/\text{cm}$**
(Hartman et al., 2005; Merricks et al., 2007; Lindberg et al., 2011; Evans et al., 2014)
- ▶ **April 1, 2010 new USEPA “guidance”**
 - ▶ **Mitigate discharges above $300 \mu\text{S}/\text{cm}$**
 - ▶ **Reduction in mine size or cancellation of future fills if above $500 \mu\text{S}/\text{cm}$**
 - ▶ **No formal rule, but VA still uses these values as benchmarks. May be a formal water quality criteria for SC in the eastern coal regions at some point.**



► Sources of TDS in streams

- Runoff and valley fill discharge
- Coal refuse disposal piles

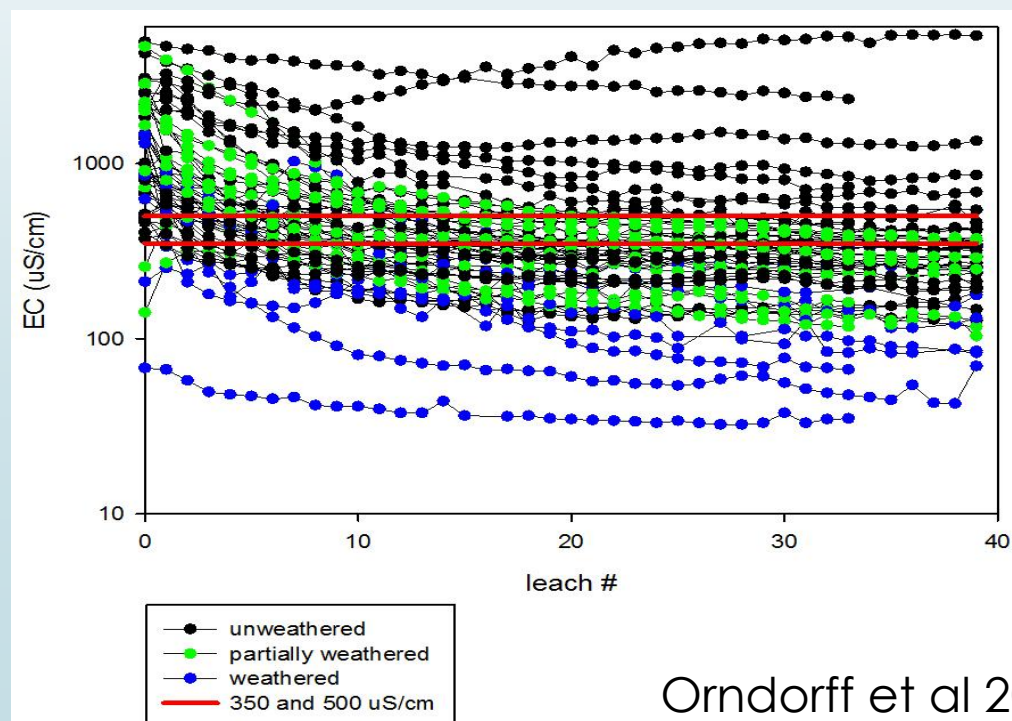
► Mechanisms of TDS release

- Acid-base reactions (sulfide oxidation and carbonate neutralization reactions)
- Background carbonation reactions in non-sulfidic materials.
- Hydrolysis of primary mineral grains.
- Entrained Cl and SO₄ in rocks (minor).
- Other minor weathering reactions like K release from micas, etc.

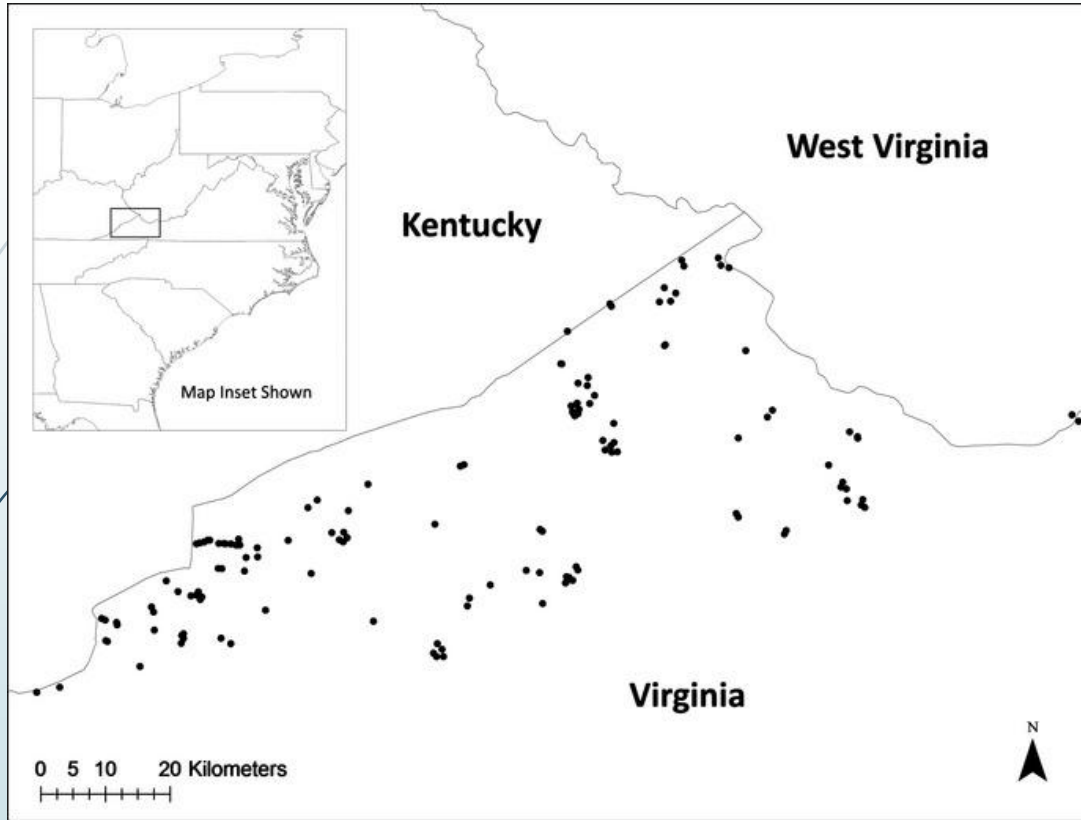
(Daniels et al. 2013, Orndorff et al. 2015)

Past Lab Research

- Spoil and refuse materials leached in lab columns with simulated AR (n=50)
- Goal: develop methods to predict peak and long-term release characteristics of TDS from coal mine spoils
- Use data to isolate potentially “hot” TDS materials and reduce harmful effects on receiving headwater streams
- Columns may reliably predict TDS leaching potentials over time – BUT are short-term peak and long-term equilibrium estimates accurate?



Valley Fill Study




JAWRA
JOURNAL OF THE AMERICAN WATER RESOURCES ASSOCIATION



Technical Paper | [Full Access](#)

Long-Term Trends of Specific Conductance in Waters Discharged by Coal-Mine Valley Fills in Central Appalachia, USA[†]

Daniel M. Evans , Carl E. Zipper, Patricia F. Donovan, W. Lee Daniels

First published: 16 June 2014 | <https://doi.org/10.1111/jawr.12198> | Citations: 38

- Chronosequence study of 137 VF discharges in central Appalachia, data from VDMME

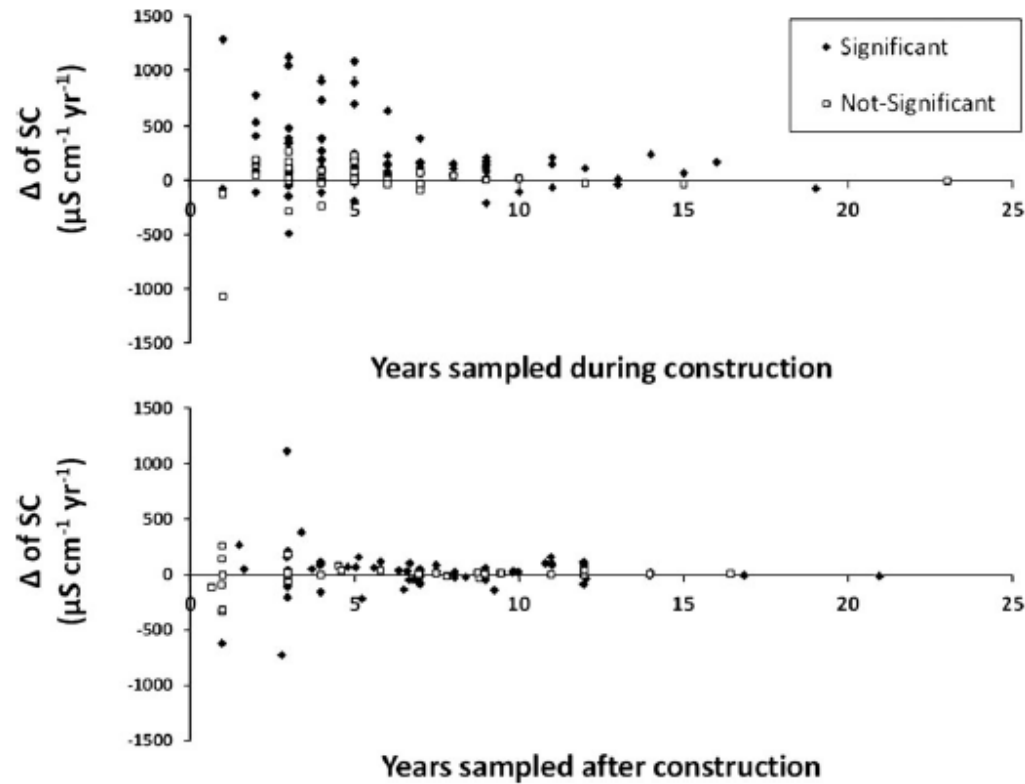
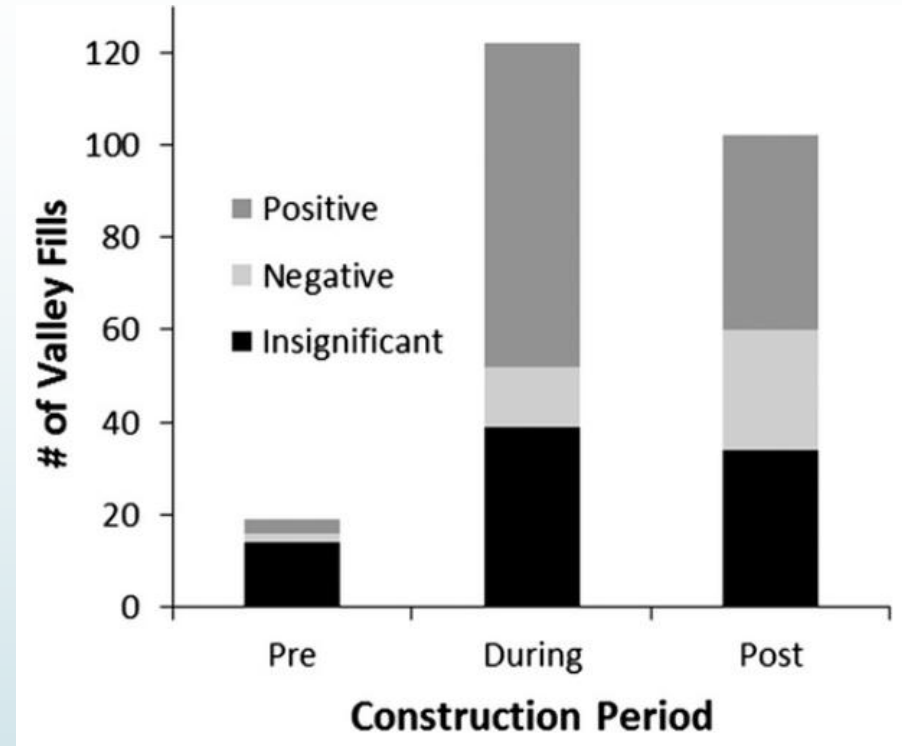


FIGURE 6. Slope of Specific Conductance (SC) over Time during Construction and after Revegetation at Selected Valley Fills (VFs) in Virginia, USA. Note: From simple linear regression ($\alpha = 0.05$). Preconstruction data not shown due to small number of VFs with preconstruction data.



➡ Most VFs had stable/increasing SC during and post-construction

	Projection of Years after Revegetation to Decline to 500 $\mu\text{S}/\text{cm}$		Projection of Years after Start of Construction to Decline to 500 $\mu\text{S}/\text{cm}$		
	Conservative ($N = 16$)	Full Set ($N = 62$)	Conservative Quadratic ($N = 16$)	Full Set ($N = 62$)	Conservative Linear ($N = 15$)
Min	-0.6	-0.6	9.4	5.1	9.6
Max	30.2	37.0	31.2	39.0	55.7
Mean	12.5	11.5	19.2	16.4	22.4
Median	12.2	10.2	19.1	15.2	19.6
SD	7.6	7.5	6.5	7.8	11.2

- Projected time to $<500 \mu\text{S}/\text{cm}$ after start of construction 22.4 ± 11.2 years (15-25 years)

Selenium background



Effects of selenium toxicity on two species of fish. (Upper) One of two **Lepomis** sp. hybrids caught at site 7 showing cranial-facial deformities typical of selenium toxicity. (Lower) Female creek chub (*Semolilus atromaculatus*) from site 10 with lordosis deformity typical of selenium toxicity.

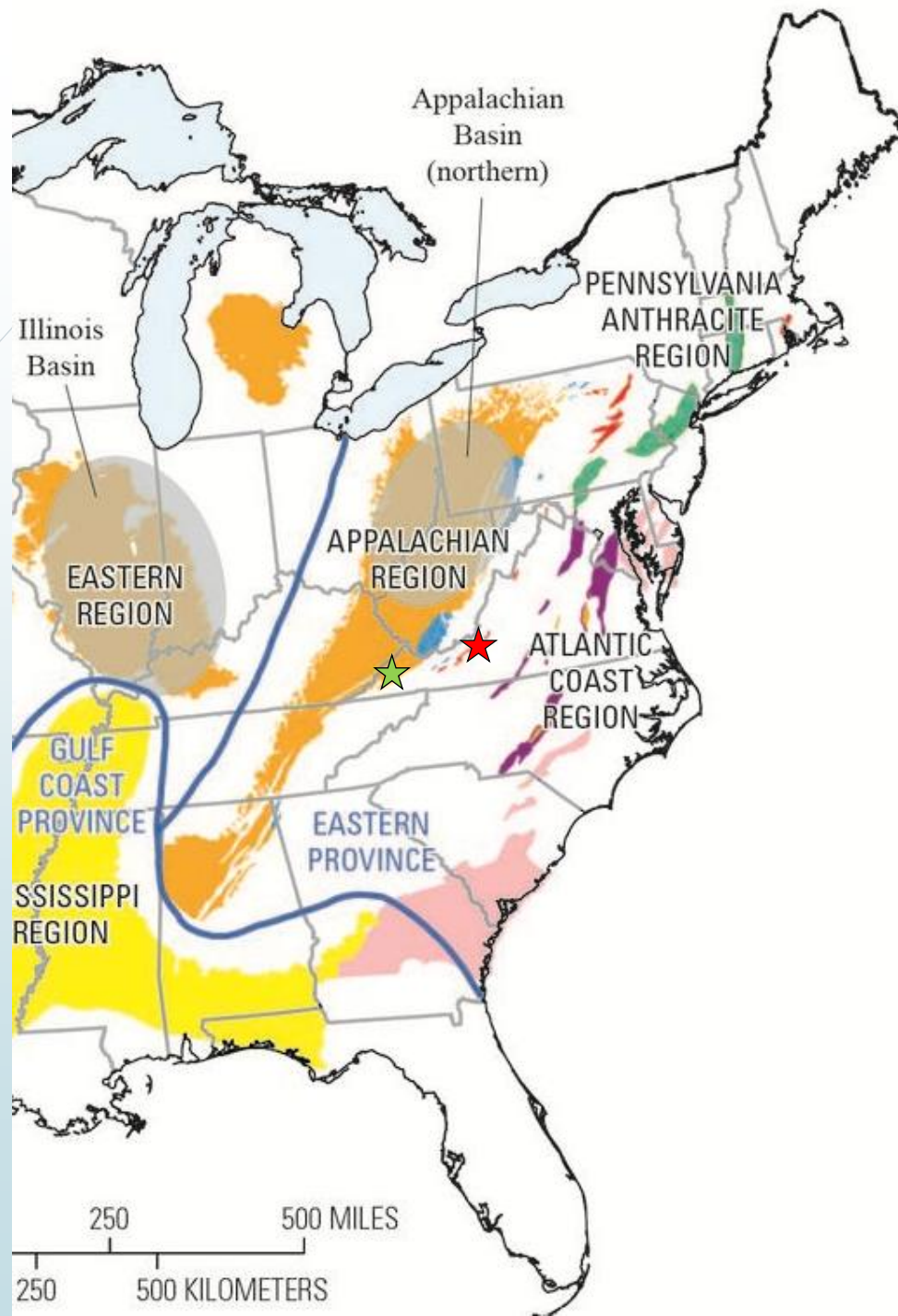
Lindberg et al. 2011

- Contaminant with high toxicity that bioaccumulates (Lemly 2004, Ciancolo et al. 2020)
 - Reproductive problems, deformities, and mortality in fish and invertebrates
- Surface coal mining common source of Se in Appalachian headwater streams (US EPA 2011, Ciancolo et al. 2020)
- Strong correlation between SC and Se in headwater streams, and Se content in macroinvertebrates (Whitmore et al. 2018)
 - Se anions may be transported along with major ions contributing to elevated SC (Pond et al. 2008, Young et al. 2010)

Mesocosm leaching experiment

- ▶ Three 2.5 m³ tanks and three 55 gal (0.2 m³) barrels filled with mine spoil exposed to ambient rainfall
- ▶ Clay Ross (M.S.) investigated leachate quality in columns vs. mesocosms vs. intermediate-sized barrels in first year
 - ▶ Differences in material size (crushed vs. variable particle size)
 - ▶ Leaching area size
 - ▶ Leaching patterns (regular watering vs. natural precip)
- ▶ Focus today on long-term patterns of leachate quality
 - ▶ SC
 - ▶ Se





- ▶ Coal mine spoil material source
 - ▶ Harlan Formation
 - ▶ Mine near Wise, VA
- ▶ Study site
 - ▶ Turfgrass Research Center, Virginia Tech
 - ▶ Blacksburg, VA

Harlan formation Spoil Collection – Wise County, VA



Screening material





Large leaching tanks (mesocosms ~ 2.5 m³) in September, 2012.

Filter fabric was placed over washed quartz gravel layer and then spoils placed in tanks.





- ▶ Largely unweathered sandstones, some weathered materials
- ▶ Material passed through 15 cm screen during collection
- ▶ Larger rocks up to ~50 cm also added





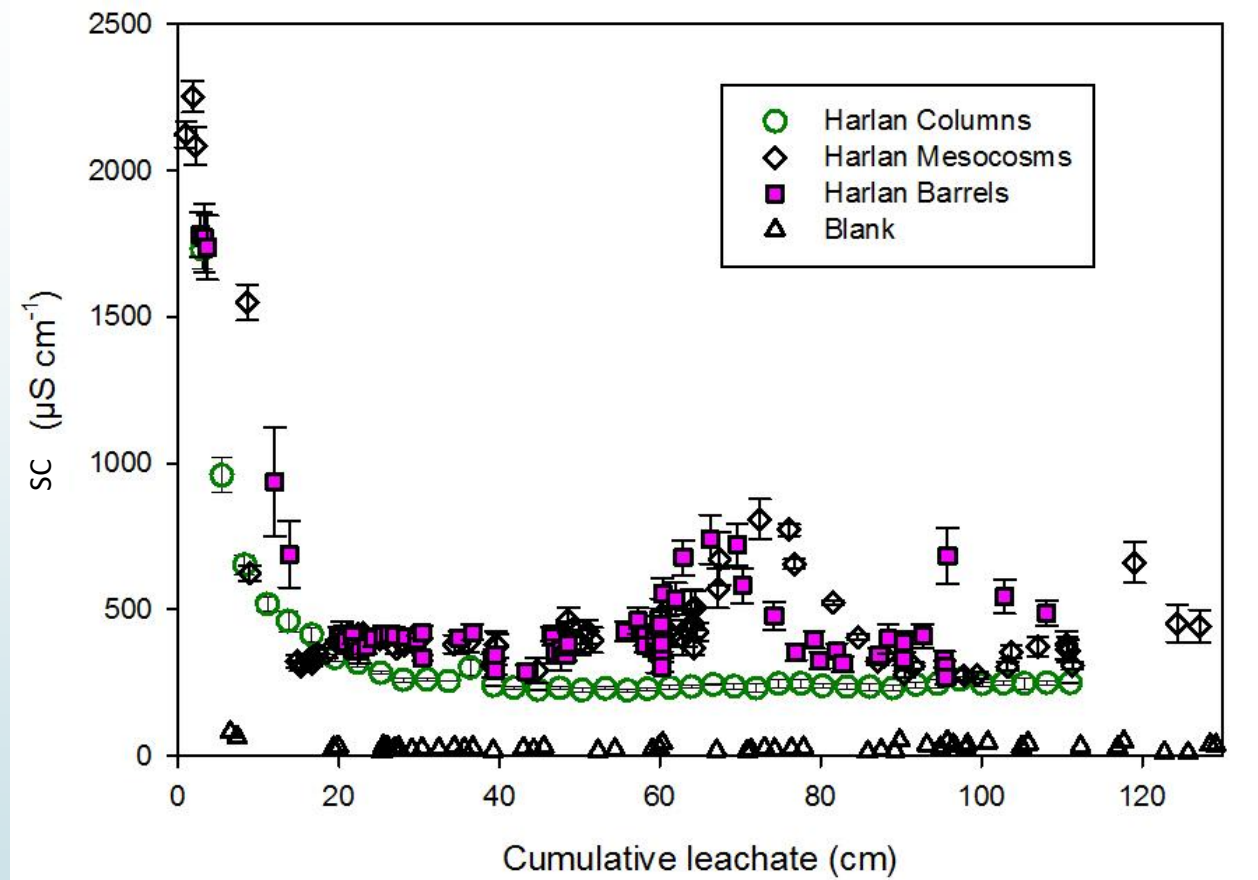
- ▶ **Mesocosm tanks (3, background)**
- ▶ **Harlan spoil barrels (3, foreground)**
 - ▶ **Leachate pumped from bottom of barrel**
- ▶ **One blank barrel containing only gravel and filter fabric**

Leachate Collection and Analysis

- Tanks kept unvegetated and exposed to ambient precip
- Samples collected whenever leachate produced by a precip event (Dec 27, 2012 through May 2022)
- pH and SC
- Bicarbonate, sulfate, Al, As, Ca, Cd, Cl, Cu, Fe, K, Mg, Mn, Na, Ni, Pb, Se, and Zn
 - Every sample through March 2014, then intermittently (\$\$\$)



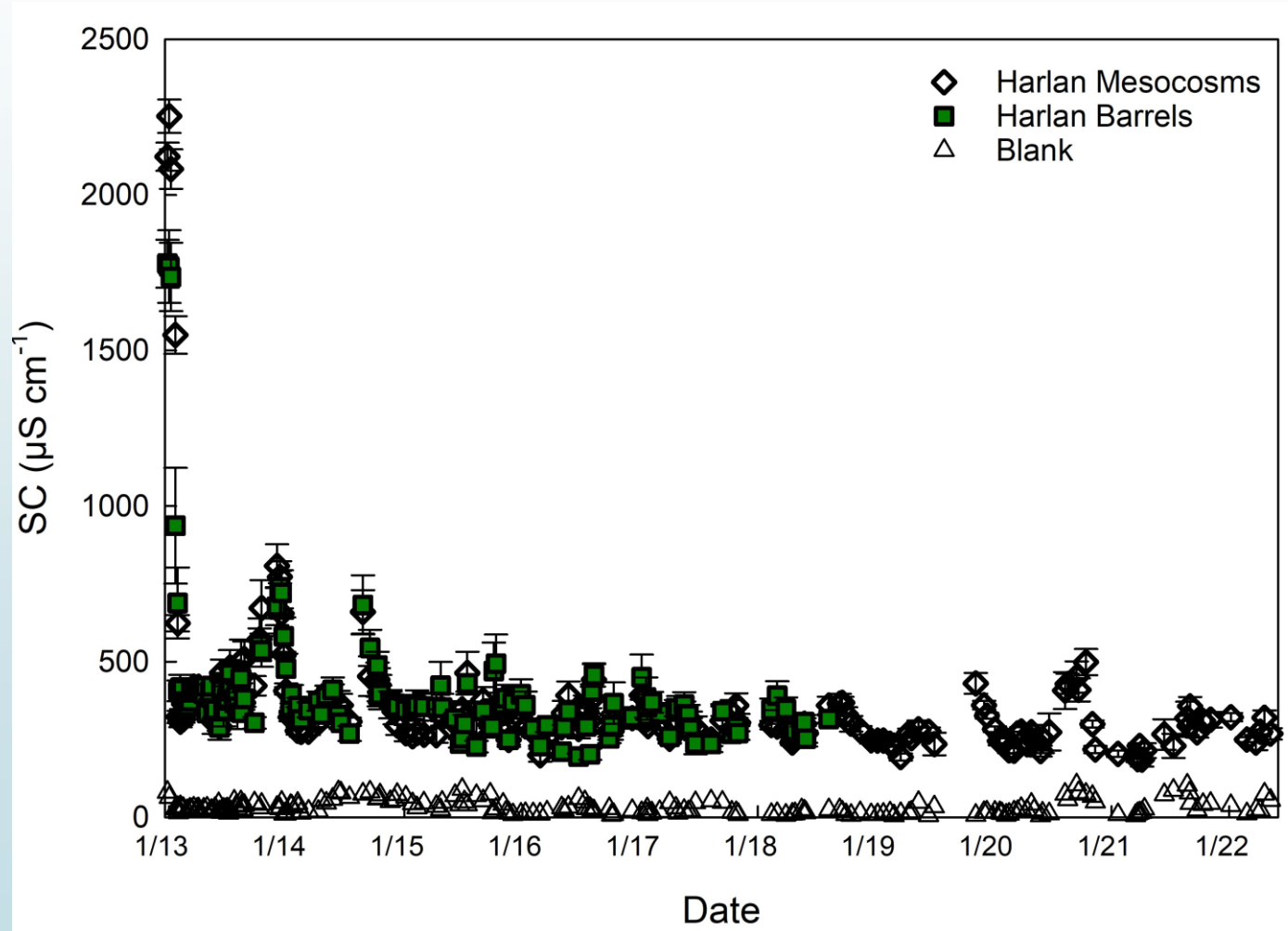
Results from initial study



- Columns: 2 x per week, 20 weeks
- Barrels: 2.3 years
- Mesocosms: 1.5 yrs

- Higher initial peak SC in larger leaching vessels (mesocosms and barrels)
- Spikes in SC later in study (more on this later)

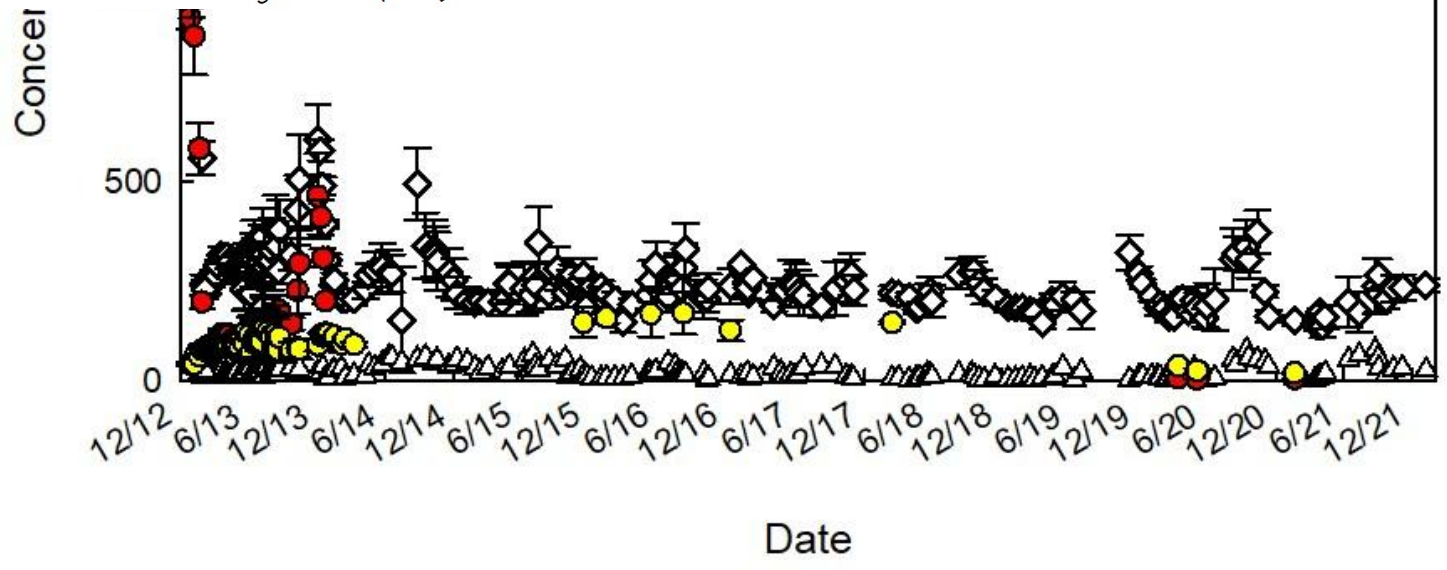
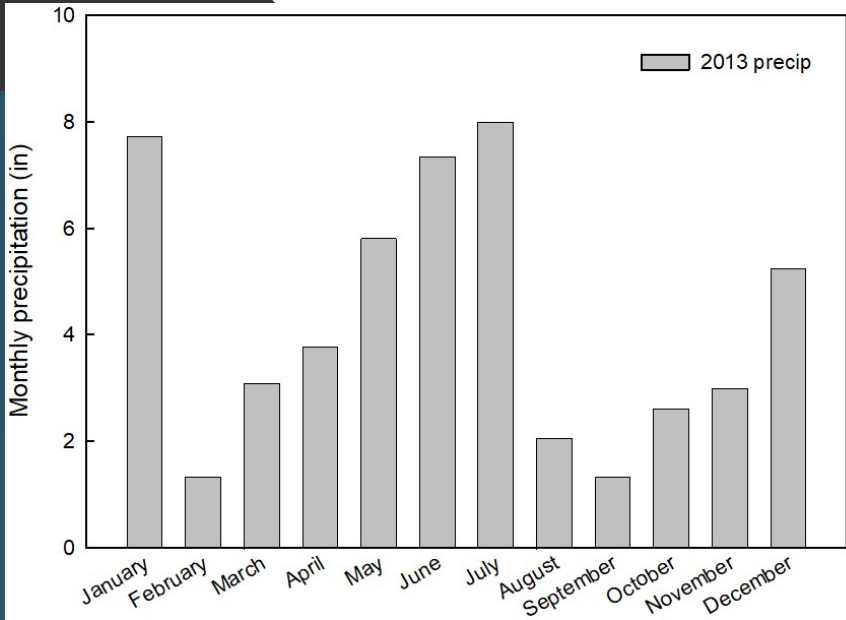
Long-term SC trends



► Initial peaks > 2000 $\mu\text{S/cm}$, stabilized below 350 $\mu\text{S/cm}$

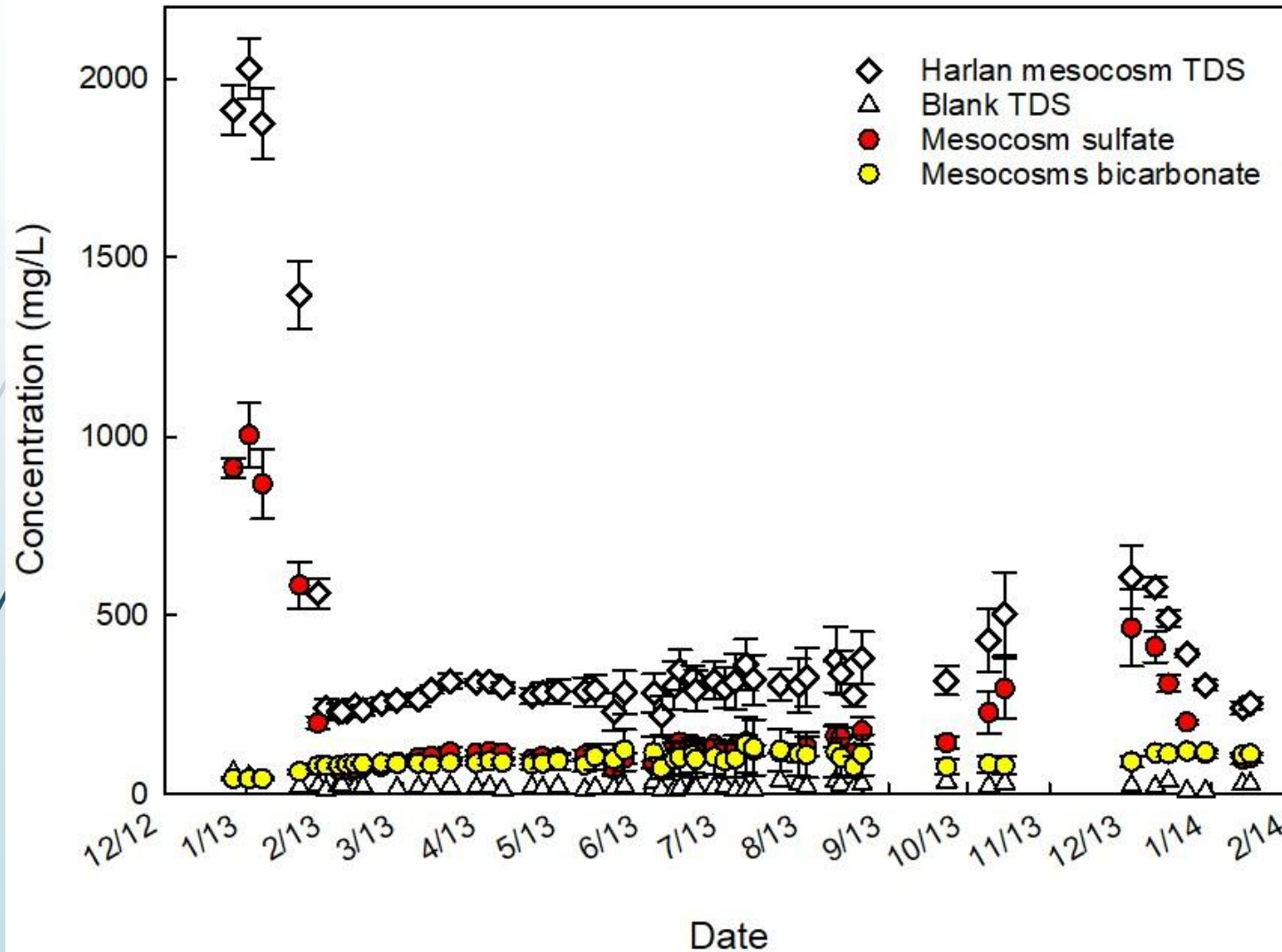
► Seasonal increases every winter

Long-term TDS trends



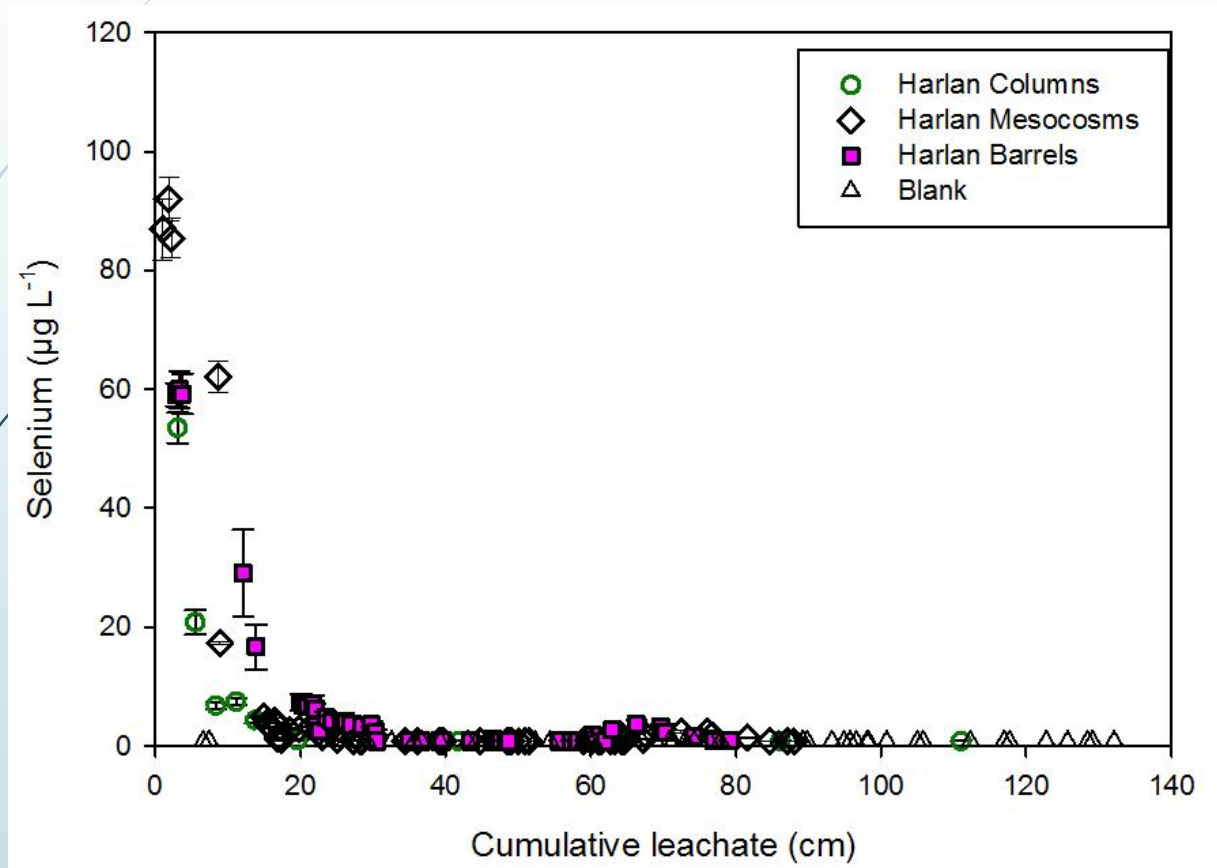
➤ **Seasonal peaks attributed to accumulation of weathering products on spoil surfaces over dry late summer/fall, and release in winter**

Long-term TDS trends



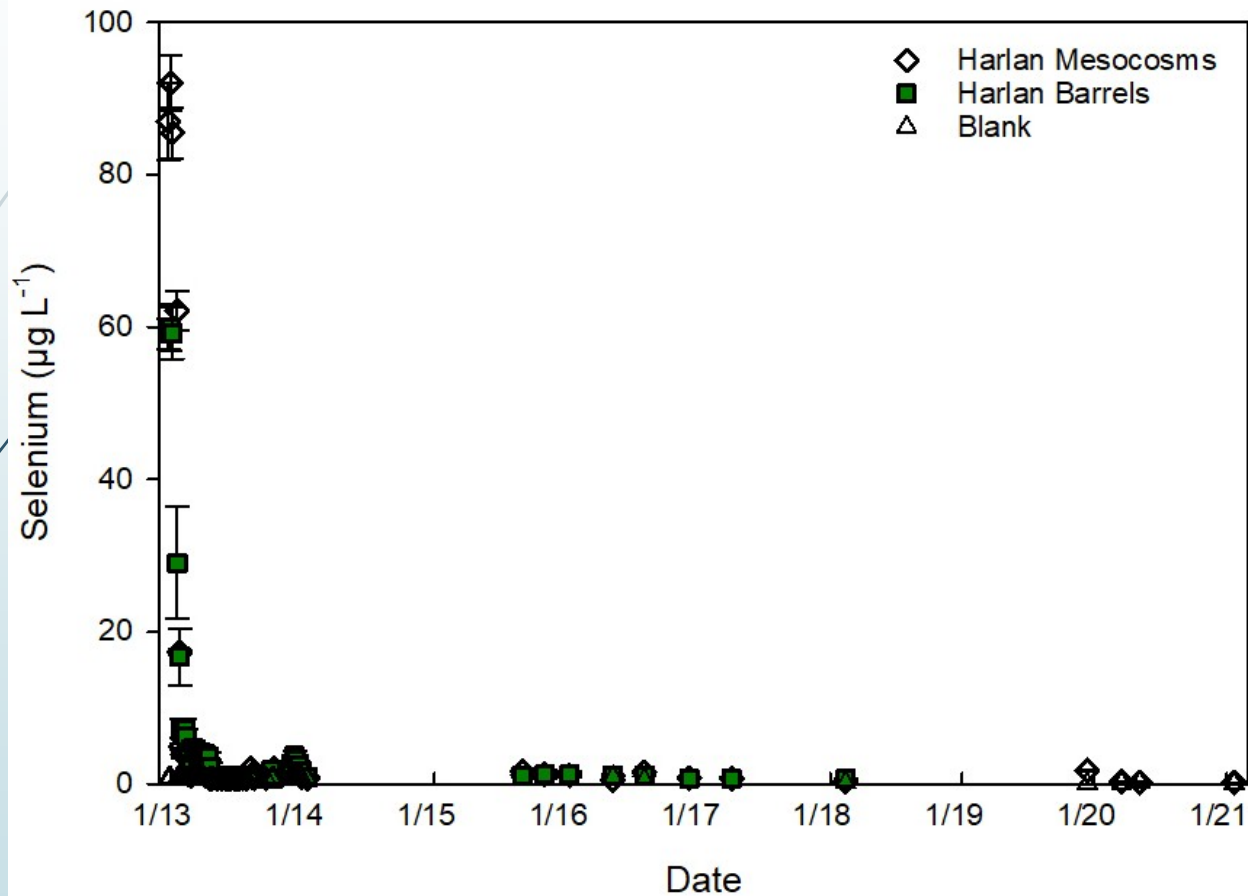
- Seasonal peaks attributed to accumulation of weathering products on spoil surfaces over dry late summer/fall, and release in winter
 - Initially largely sulfate and some bicarbonates
 - Longer term, dominantly as bicarbonate – less seasonal
 - Note: these are concentrations – on a molar basis, bicarbonate to sulfate ratio 1/3 higher

Selenium



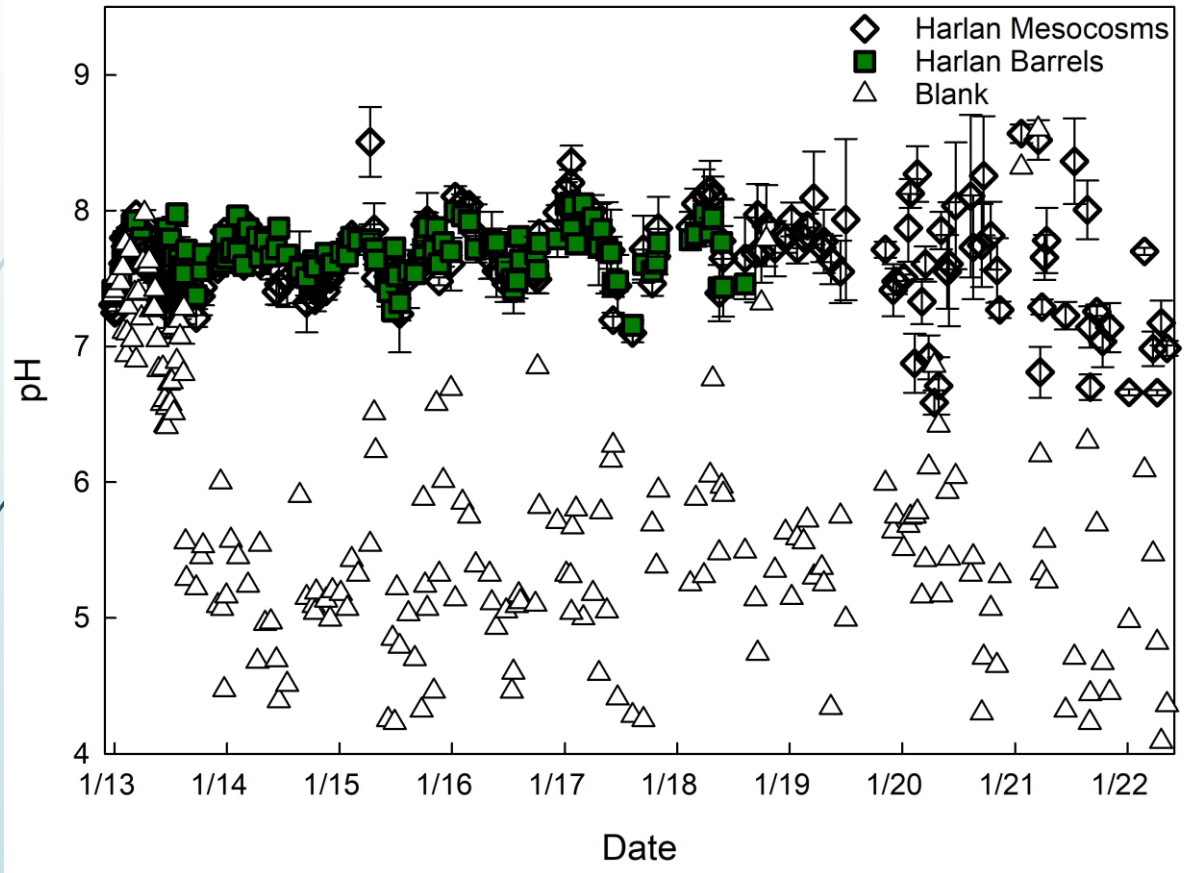
- Higher initial peak Se in larger leaching vessels (mesocosms and barrels)
- Se release much quicker than any other elements as selenite/selenate
 - Essentially “first flush” over first several leach cycles

Selenium



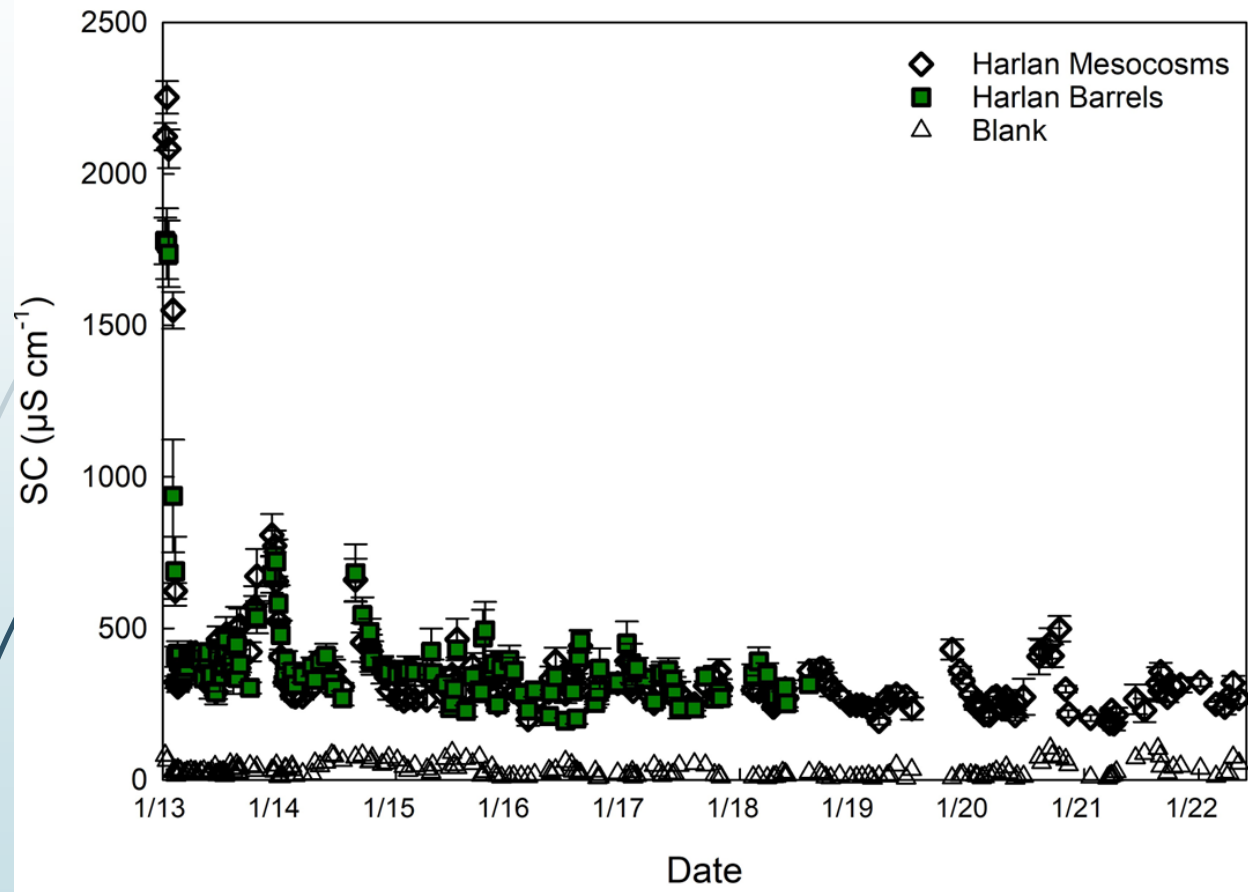
- Higher initial peak Se in larger leaching vessels (mesocosms and barrels)
- Initial Se levels exceed EPA criteria of $5 \mu\text{g/L}$ continuous exposure and $20 \mu\text{g/L}$ acute exposure (USEPA 1987)
- All measurements below $3 \mu\text{g/L}$ by 4-23-14

pH and Selenium



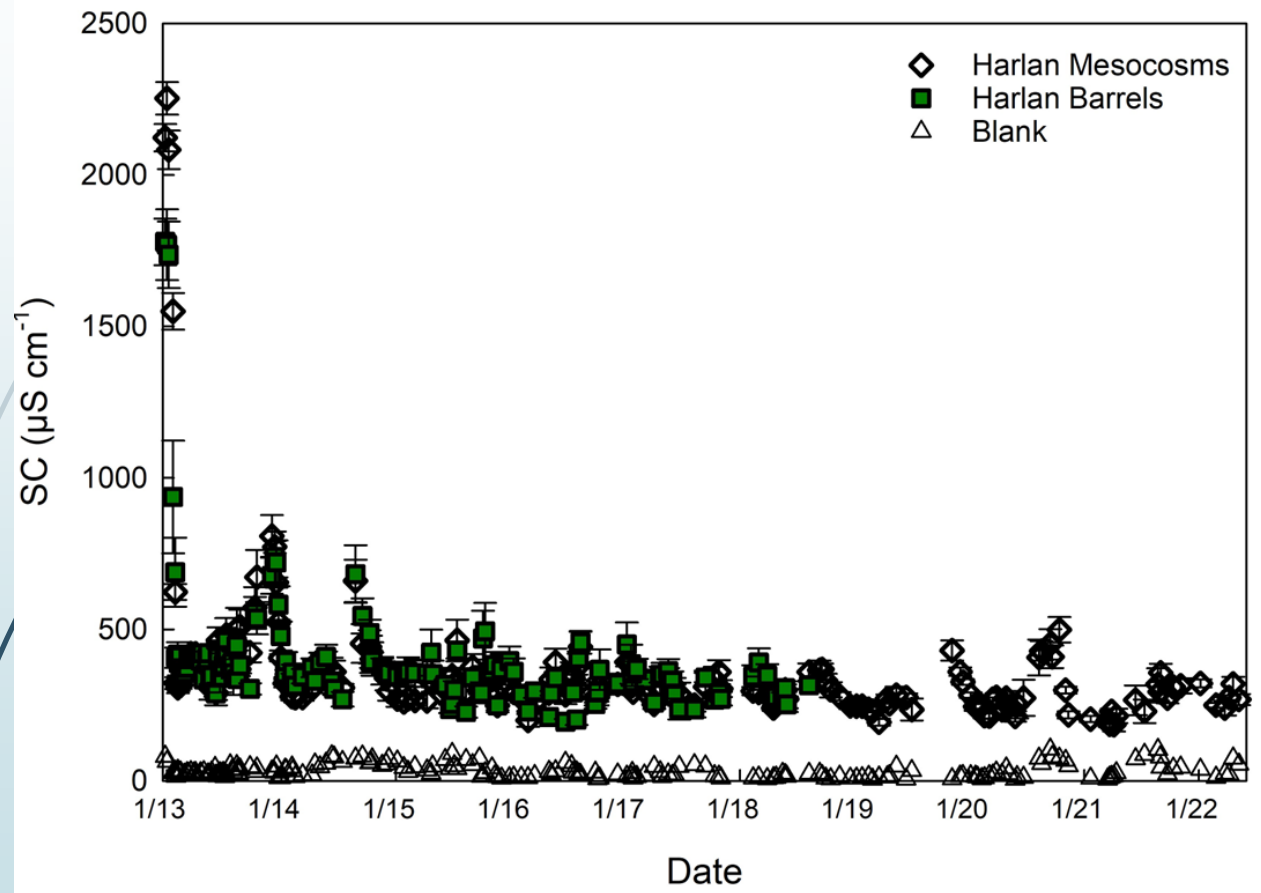
- High pH leachate results in more Se release
- Selenate more soluble at higher pH (>5.5)

Mass Loss



- **TDS=conversion factor x SC**
 - **CF of 0.9 when sulfate dominated ($> 400 \mu\text{S/cm}$)**
 - **CF of 0.75 when bicarb dominated ($< 400 \mu\text{S/cm}$)**
- **Mass loss = TDS x leachate volume**
- **Standard material density table used to estimate total spoil mass (1.75 Mg/m^2)**

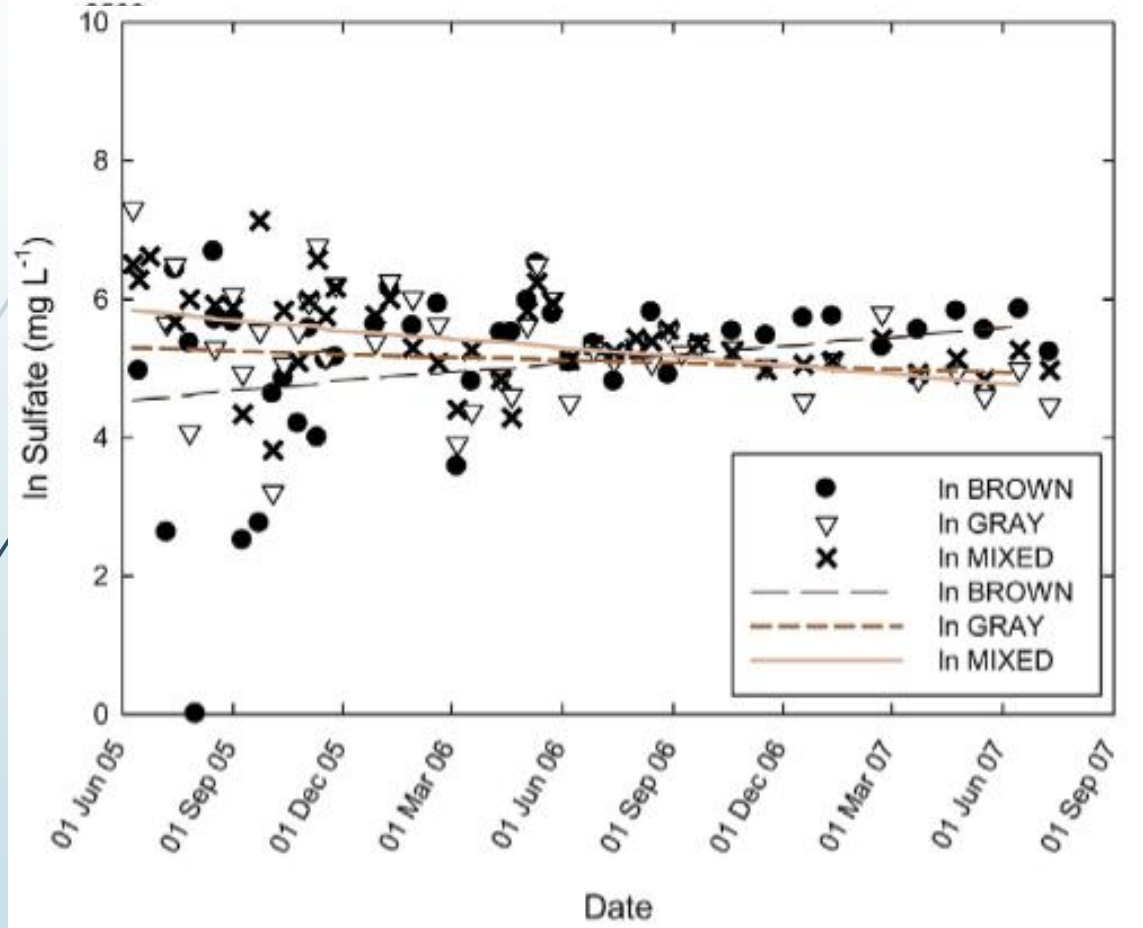
Mass Loss



- Average mass loss per tank 1139 ± 113 mg/kg spoil
- Typical of field-related studies (Clark et al. 2017)
- Barrel mass loss lower (1034 ± 372)

Conclusions and Discussion

- **Overall, similar patterns for larger-scale leaching studies and column studies**
 - **Higher initial SC peak and seasonal (smaller) peaks**
 - **Not observed in column studies, different wet/dry cycles**
 - **Build-up of weathering products in dry months, release in winter**
 - **Time to stabilize $<500 \mu\text{S}/\text{cm}$ ~increases with size (VFs stabilize on decadal scale)**
 - **Mesocosms: $<500 \mu\text{S}/\text{cm}$ by 11-3-20 (8 years)**
 - **Barrels: $<500 \mu\text{S}/\text{cm}$ by 1-25-17 (4 years)**



- **KY study – simulated VFs planted with forests and auto-sampled leachate**
 - **Gray and mixed materials closest comparisons – similar SC peaks followed by quick drop**
 - **Similar mean sulfate concentrations observed (142-226 mg/L)**

Conclusions and Discussion

- ▶ **Observed TDS elution from mesocosm design similar to observations in valley fills**
 - ▶ **BUT timescale and volumes are VERY different**
- ▶ **Though short-term, Se release from “relatively innocuous” materials concerning**
 - ▶ **Expected that Se release will be higher from higher pH spoils**

Thank you!



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- **Powell River Project (powellriverproject.org):** public-private research and outreach partnership between Virginia Tech, other educational institutions and environmental organizations, and natural resource industries, serving the southwest Virginia coalfield region.

