Progress Toward Updated Subsoil SAR Remediation Guidelines Below the Root-Zone

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Overview

- Introduction to SAR effects
- Water table modeling
- Leaching column experiments
- Remediation of SAR effects
- Conclusions and next steps

Introduction to SAR effects

SAR and hydraulic conductivity

- Water transport and soil structure can be affected by excess sodium
  - measured as high Sodium Adsorption Ratio, or SAR
- Caused by dispersion or swelling of clay particles
  - e.g., smectites in prairie soils
  - Root-zone SAR particularly problematic
  - may cause surface crusting, hard-pan, or poor infiltration
  - worsened by shear from rain-drops or tillage, and wet/dry cycles

- Root-zone SAR generally covered by SCARG guidelines
- What about subsoil SAR?

Subsoil SAR effects

- High SAR can greatly reduce hydraulic conductivity (K_{sat})
  – especially in fine, clayey soils

- Subsoil SAR may potentially result in root-zone water-logging or perched water table

- Subsoils generally less sensitive to SAR than root-zone soils for several reasons:
  – Not exposed to severe wet-dry cycles
  – Not exposed to shearing and impact from rain-drops
  – Not exposed to tillage
  – Not exposed to abrupt dilution by low-EC rainwater or snowmelt (related to SAR / EC interactions)

SAR/EC interactions from literature

- **High EC can protect from SAR effects**
  - helps prevent dispersion
  - protection may diminish as salt is leached

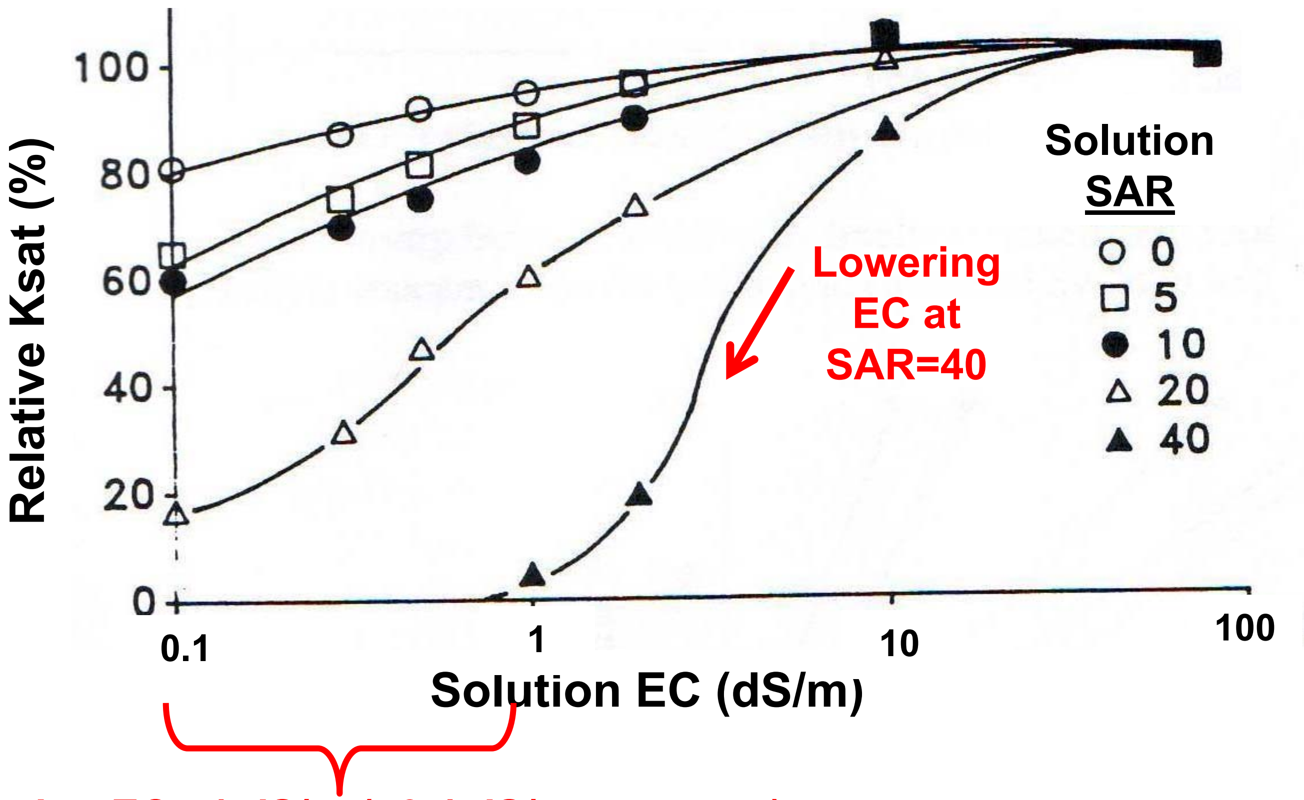
- **Useful research by Curtin *et. al* on SAR and EC**
  - Agriculture and Agri-Food Canada, Saskatoon, 1993
  - experiments focused on repacked topsoil and relevance to irrigation
  - topsoil typically sensitive due to shearing by tillage and low EC raindrops

- **Measured hydraulic conductivity loss at various EC/SAR combinations**
  - expressed as relative K_{sat} (%)
  - results highly dependent on texture (clay content)

SAR/EC from literature (cont'd)

- Example literature curves at 27.5% clay (loam / clay loam)

Loam/clay loam (27.5% clay) – "Willows" soil (Curtin, 1993)



Solution EC <1 dS/m (<0.4 dS/m sat paste):
Primary relevance for topsoil and irrigation

- With this soil, a solution SAR of 40 resulted in a 10- to 20-fold K_{sat} reduction at low solution EC (<2 dS/m)
  – likely a problem for root-zone soils with rain drops / tillage
- But, what K_{sat} reductions in <u>subsoil</u> are potentially significant?

Water table modeling

Water table modeling

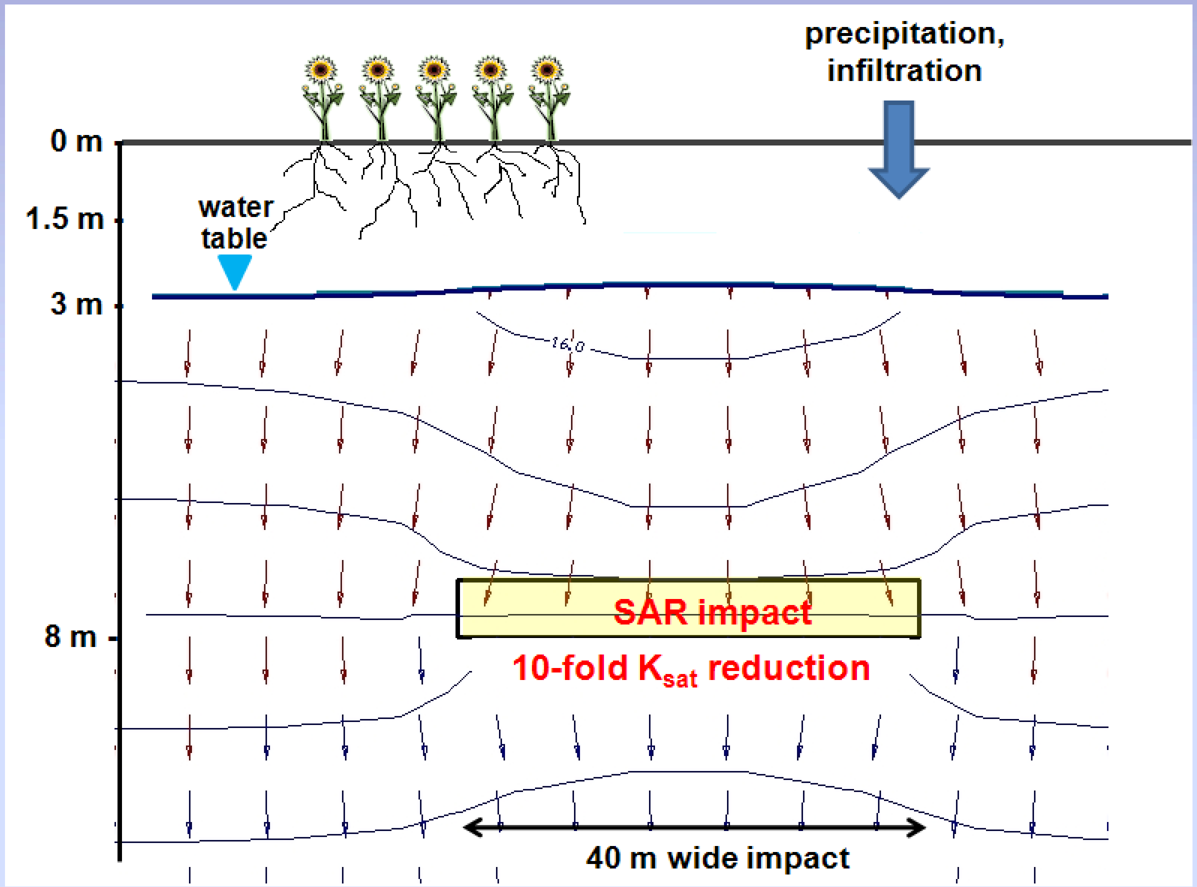
- SAR effects on water table can be modeled in 3-dimensions using program such as Modflow™
  - helps give context to potentially significant K_{sat} reductions

- SAR effects on water table a function of many factors:
  - K_{sat} reduction
  - original water table depth
  - infiltration rate
  - vertical gradient
  - impact size
  - impact depth

- Intuitively, deeper and smaller subsoil SAR impacts likely have less effect on shallow water table

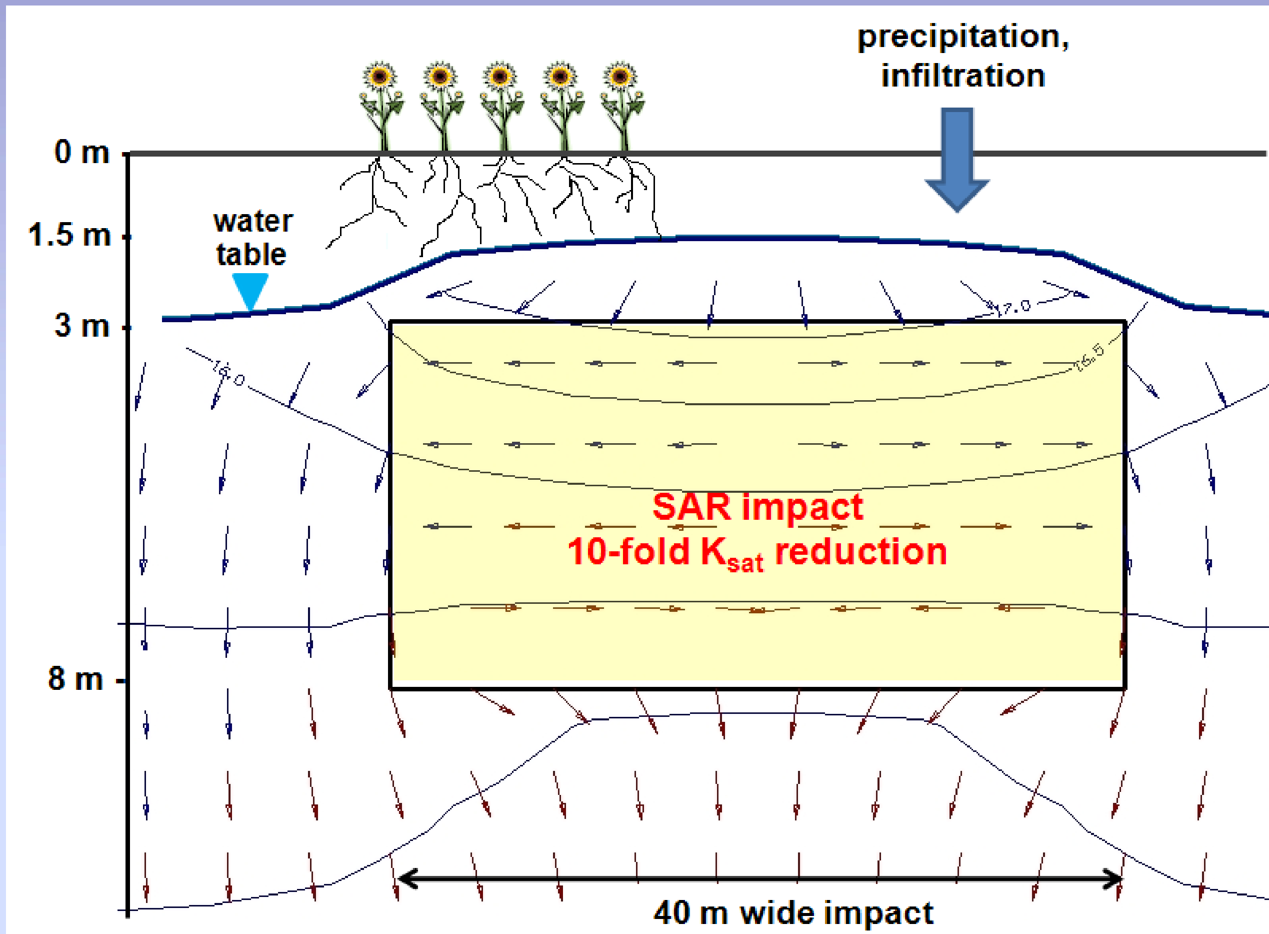
Modeling subsoil SAR effects

- **Changes in water table modeled by varying several parameters**
  - ***e.g.*, 3 m water table, 30 mm/year infiltration, 40 m wide impact, $1x10^{-8}$ m/s K_{sat} (vertical)**



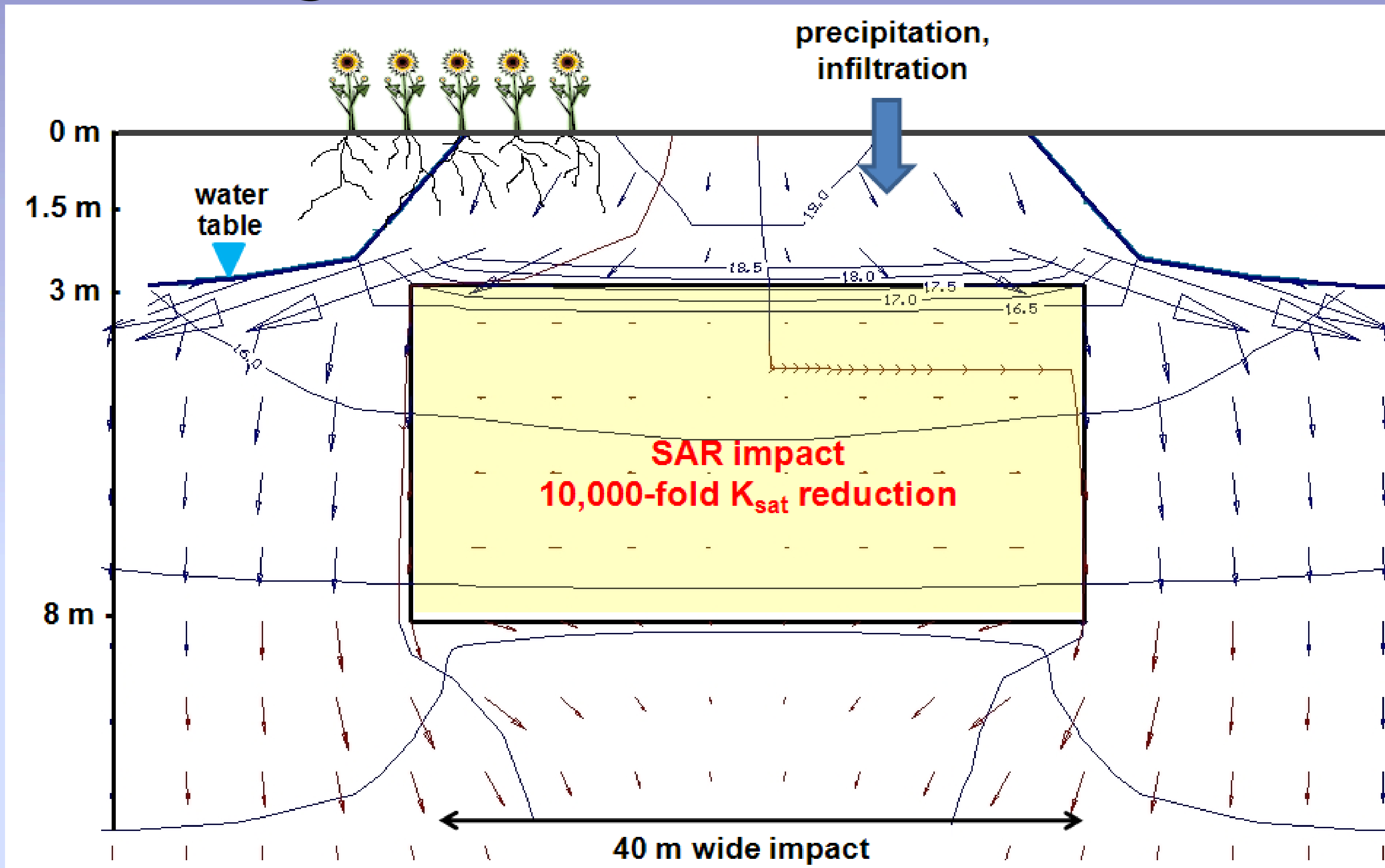
- **Here, deep SAR impact with 10-fold K_{sat} reduction has essentially no effect on water table**
  - **what if impacts are shallower?**

Modeling subsoil SAR effects (cont'd)



- **Here, shallower impact with 10-fold K_{sat} reduction has some effect on water table, but does not water-log the root-zone**
  - **what if impacts are more severe?**

Modeling subsoil SAR effects (cont'd)



- Here, shallower impact with 10,000-fold K_{sat} reduction (10^4) causes severe root-zone water-logging
- Significantly less K_{sat} reduction needed to cause water logging if shallower impacts and water table (*eg*, 1.5 m) ****modeling ongoing****

Defining significant SAR effects

- Overall, subsoil K_{sat} reductions of 10- to 100-fold appear to be tolerated in many model scenarios
  - especially deeper, smaller impacts or deeper water tables
- In many cases, natural K_{sat} variability over a site may span several orders of magnitude (100-1,000 fold) despite similar lithology/SAR
  - Shelby tube results below show examples of such variability

Borehole	Depth (m)	% clay	Texture	Ksat (m/s)
Site 6-32, BH08-20	2.0 - 2.5	28	Clay loam	$4x10^{-9}$
	3.1 – 3.4	38	Clay loam	$2x10^{-10}$
	4.0 – 4.5	41	Clay loam	$1x10^{-9}$
	5.2 – 5.7	43	Clay loam	$8x10^{-11}$
Site 4-3, BH08-33	2.0 – 2.4	24	Loam	$1x10^{-7}$
	3.0 – 3.3	25	Loam	$1x10^{-8}$
	4.8 – 5.3	22	Loam	$2x10^{-9}$

Defining significant SAR effects (cont'd)

- **In dry climates or soils with poor water-holding capacity or deep water tables, some scenarios where a shallower water table may be beneficial can be envisioned**
  - ***e.g.*, potentially more water available for plant roots**
  - **suggests K_{sat} reductions may not always be detrimental**

- ***Overall, for subsoil SAR, it appears K_{sat} reductions should potentially be considered on an order-of-magnitude scale (e.g., approaching 10-fold or more) for effects to be significant***
  - ***what EC/SAR combinations may cause these magnitudes of K_{sat} losses?***

Leaching column experiments: Phase 1

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- **Preliminary 2009 experiments developed and refined leaching column methodology**
  - **tested solution SAR up to 40**
  - **tested various leaching column types**
  - **see Equilibrium presentation from PTAC Soil and Groundwater Forum (March 2010) for details – online –**

- **Performed numerous column experiments in early 2010 to extend previous 2009 results**
  - **additional soil types**
  - **higher solution SAR values (up to 69)**

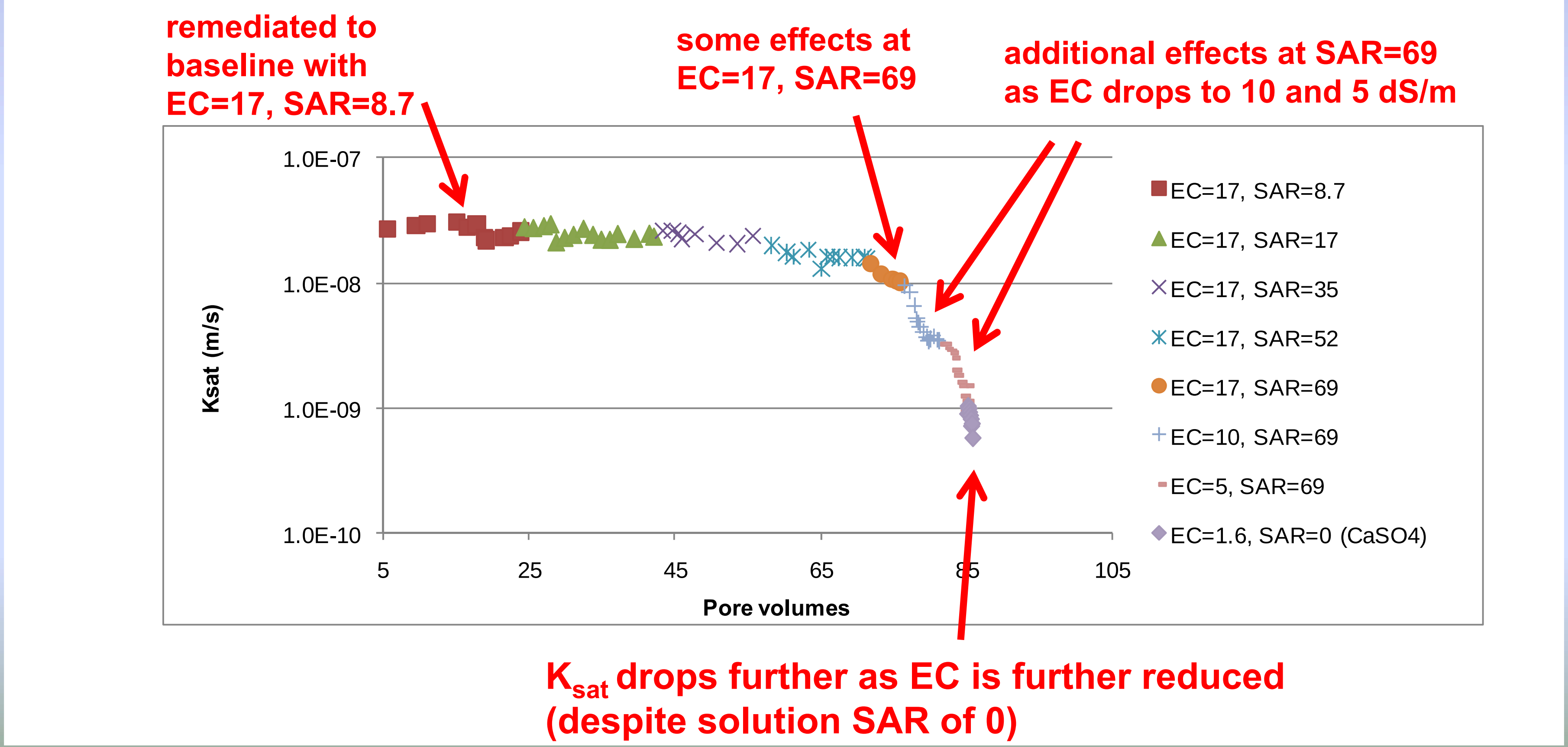
SAR = 69 Series

- **Tested several columns to see effects of solution SAR=69**

(equivalent to sat paste SAR of approx 40, relatively heavy SAR impact)

<u>Example #1:</u> repacked soil (clay loam)

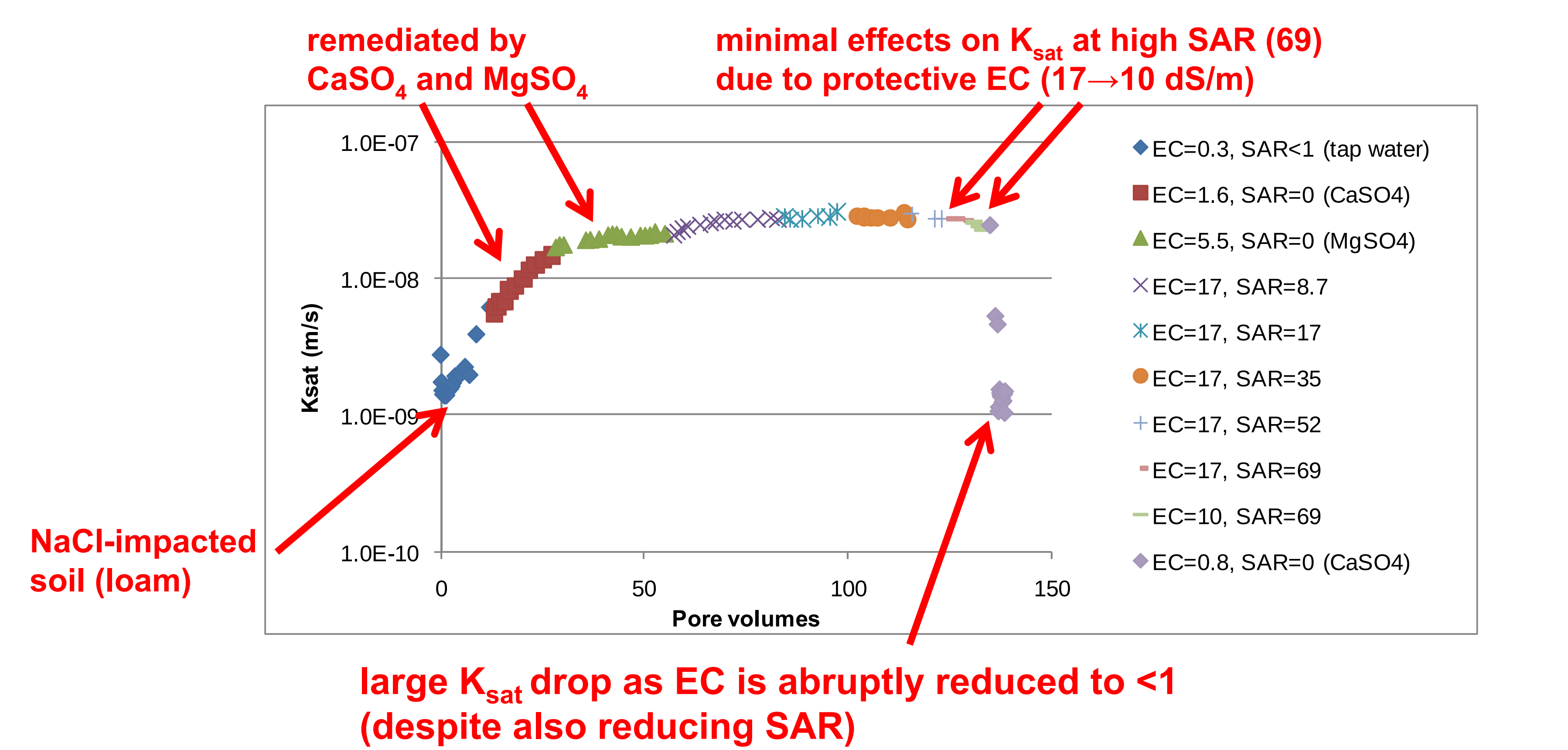
– **Initial baseline achieved with solution EC=17, SAR=8.7**
  (equivalent to approximately sat paste EC=6, SAR=5)



SAR = 69 series (cont'd)

Example #2: Repacked soil (loam)

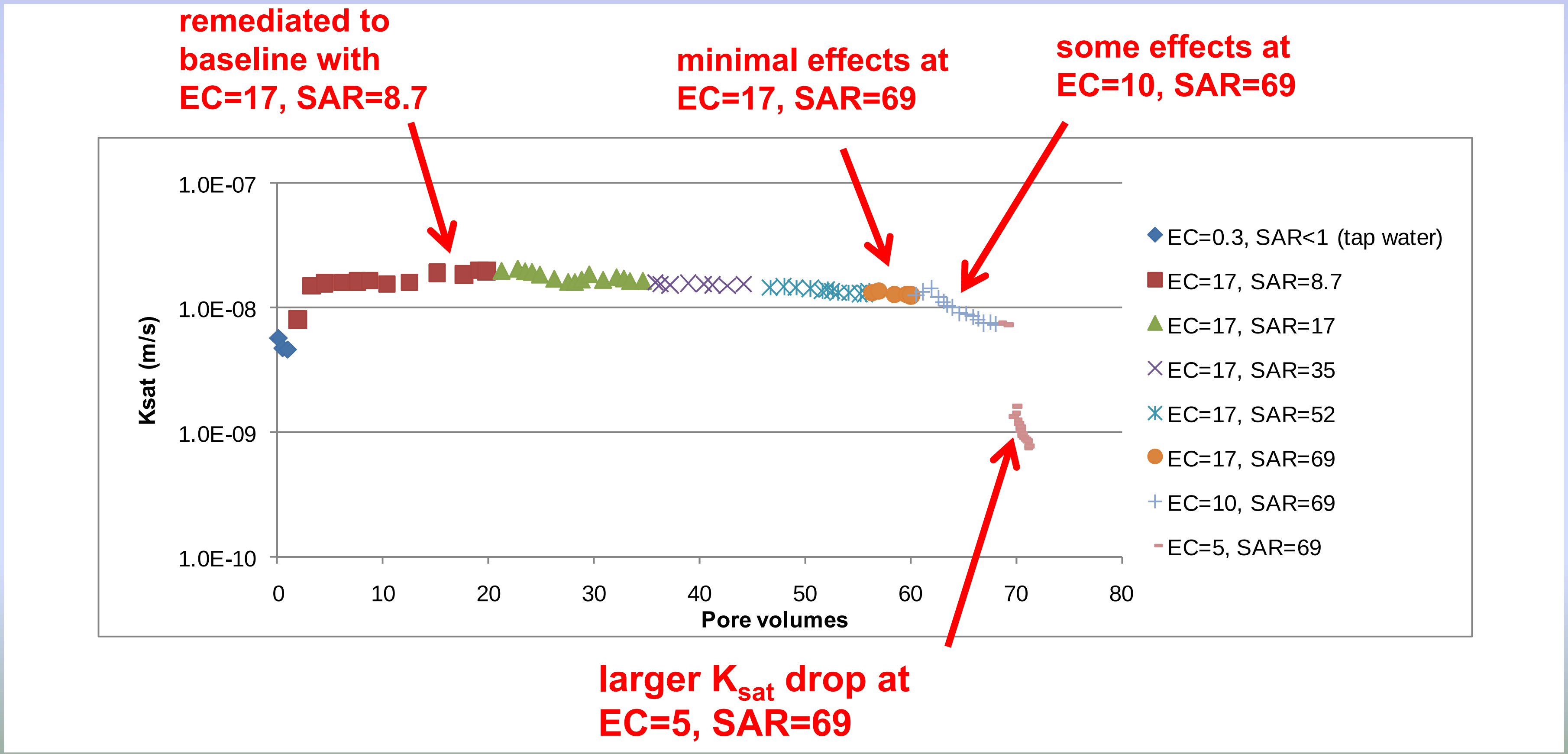
- From one of several sites in Medicine Hat area
- NaCl-impacted soil first remediated with gypsum and magnesium sulfate
- Then leached with SAR up to 69



SAR=69 series (cont'd)

<u>Example #3:</u> **Undisturbed soil core (clay loam)**

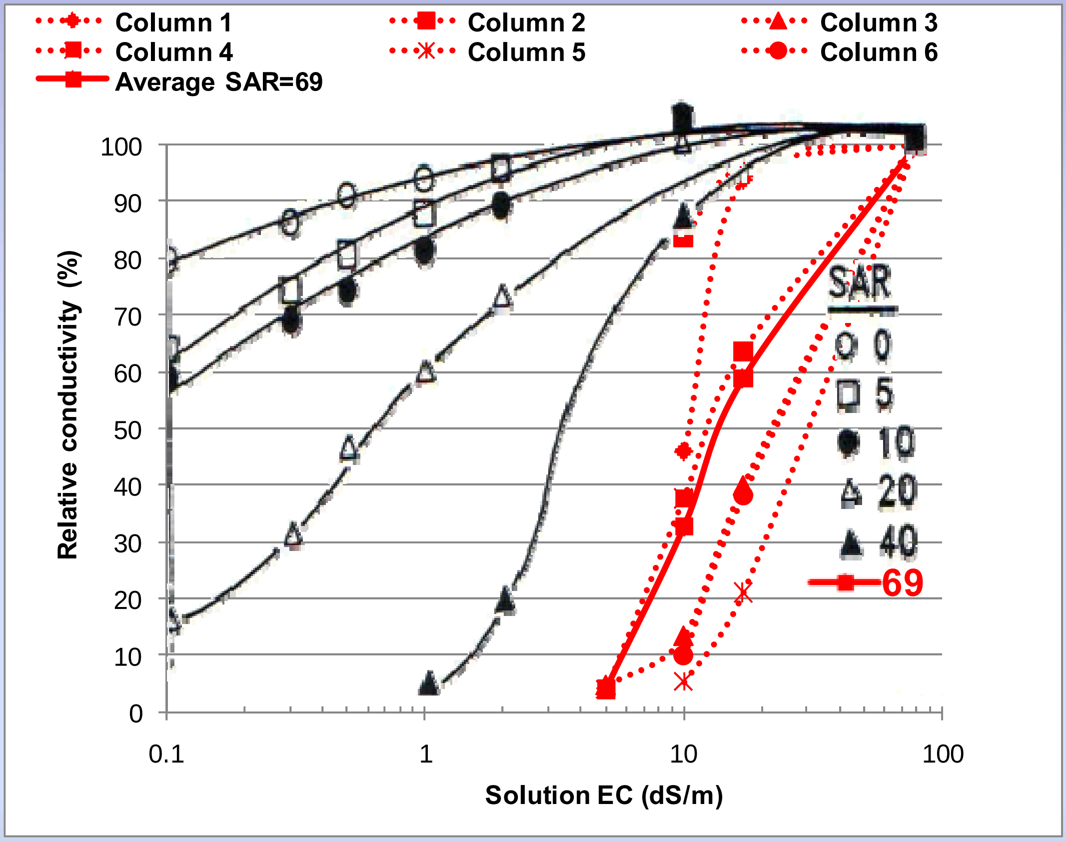
- **Sodic soil remediated with EC=17, SAR=8.7**
- **Then leached with SAR up to 69 then dropped EC**



SAR=69 experiments summary

- Results from six SAR=69 experiments shown overlain on Curtin's 'Willows' soil below

- Fits overall pattern, but extends to higher SAR (69 vs 40)



- Additional examples also shown in presentations at:

– Exova Environmental Seminar (Jan 2011) –online–

– PTAC Soil and Groundwater Forum (March 2011) –online–

Leaching column experiments: Phase 2

2010 leaching column experiments: Phase 2

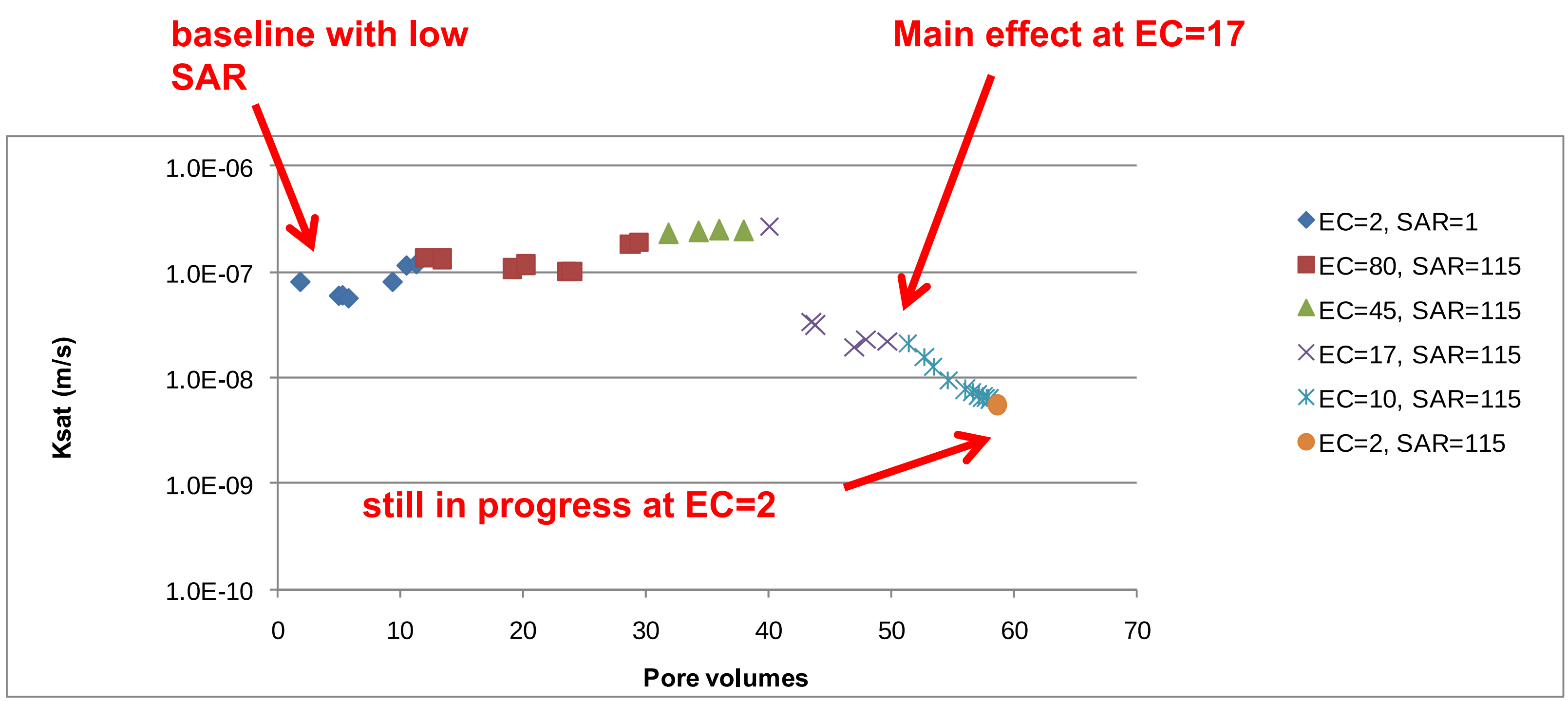
- Results from Phase 1 expanded by investigating:
  - higher SAR values (up to solution SAR = 115)
  - lower SAR values (solution SAR = 10 - 40)
  - low conductivity soils
  - coarse / sandy soils
  - organic / peat soils

Higher SAR

- Tested new columns at higher SAR up 115

<u>Example #4:</u> clay loam soil

- – Dropped EC from 80 to 2 with fixed SAR of 115
- – Main effects as EC drops to 17, further effects at lower EC

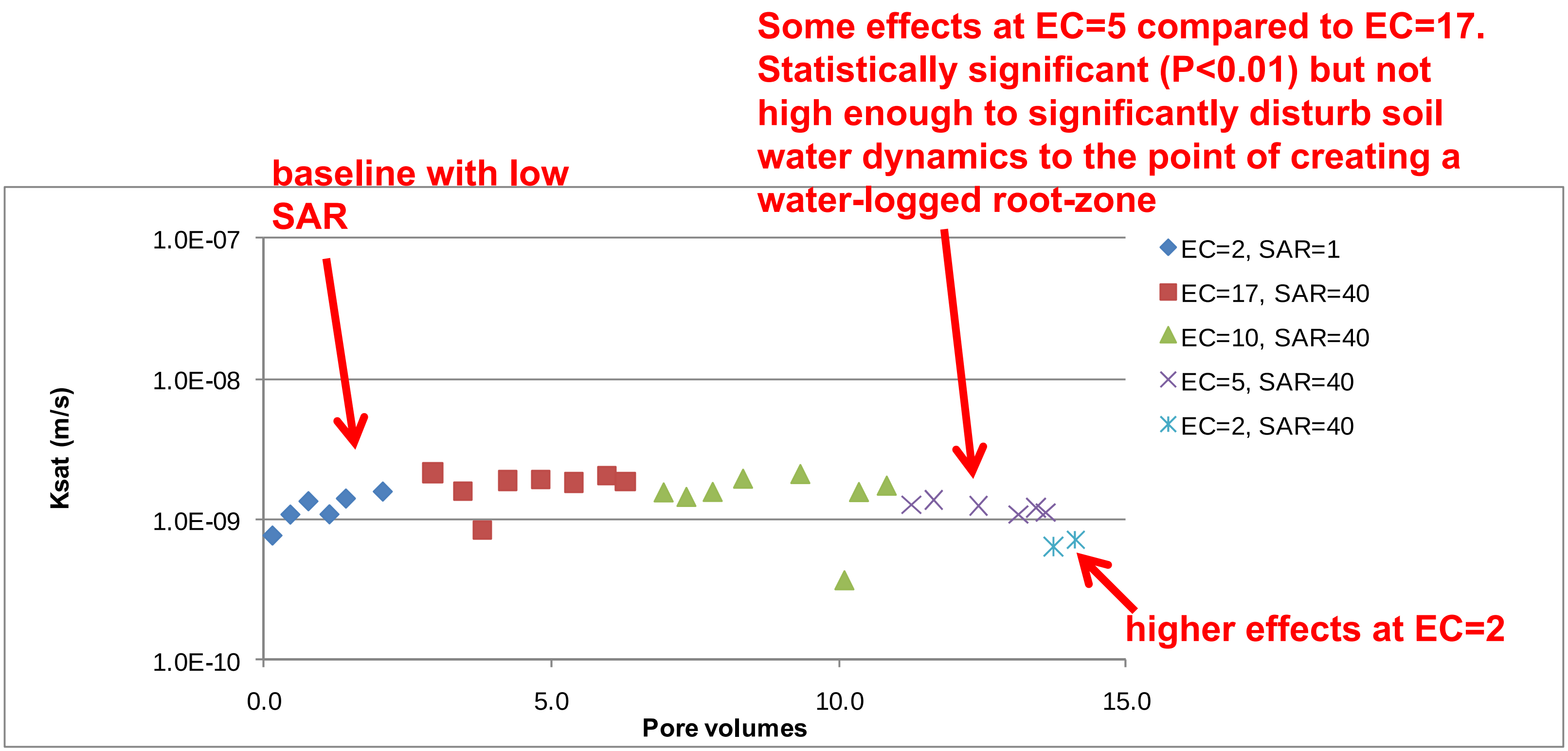


Lower SAR

- Also did some series at lower SAR of 10-40

Example #5: clay loam soil

- One of numerous columns from a field of sites near Lloydminster
- Dropped EC from 17 to 2 with fixed SAR of 40
- Main effects as EC drops to 2

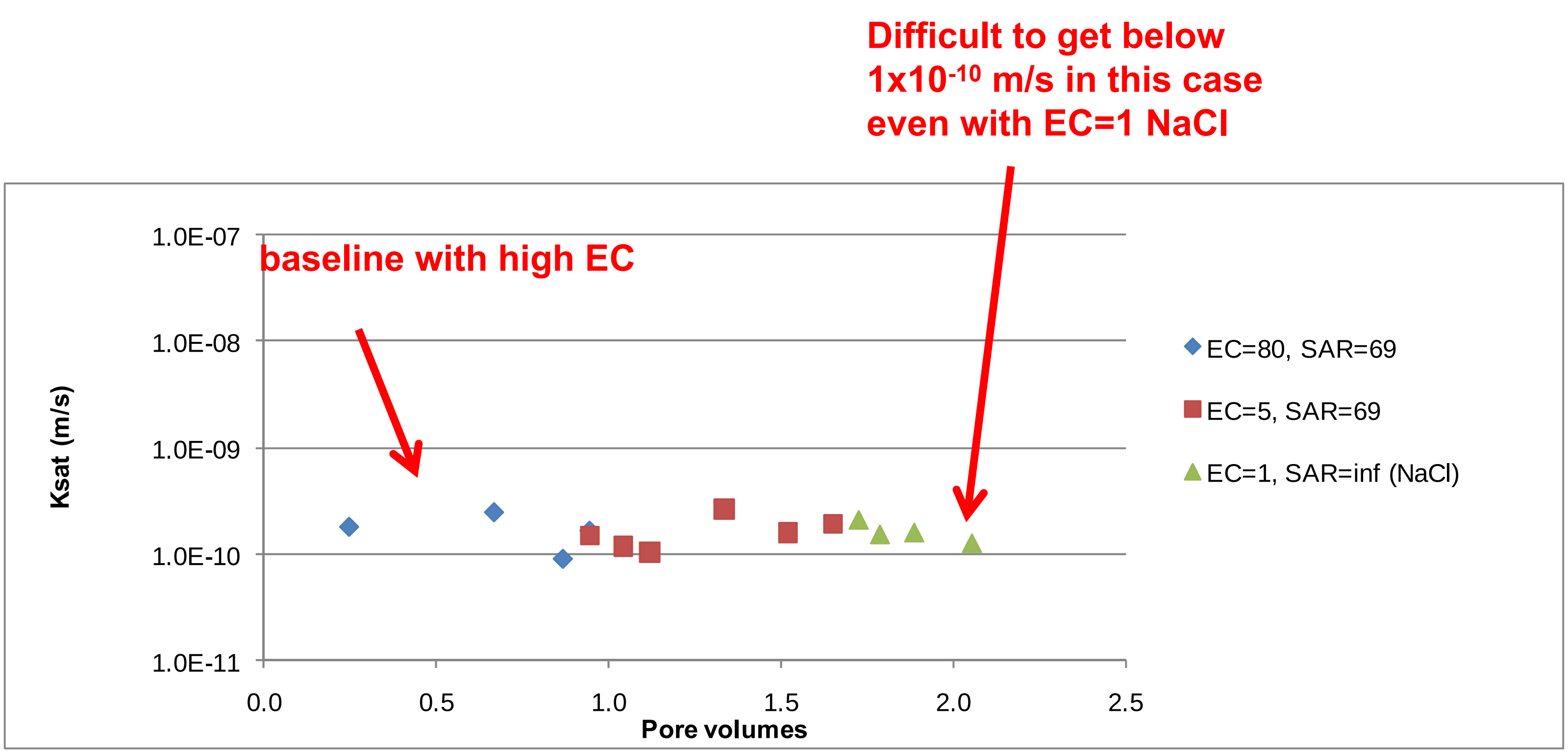


Low conductivity soils

- Tested low-conductivity background soils for context (approx 10^{-10} m/s unimpacted)

<u>Example #6:</u> clay loam soil

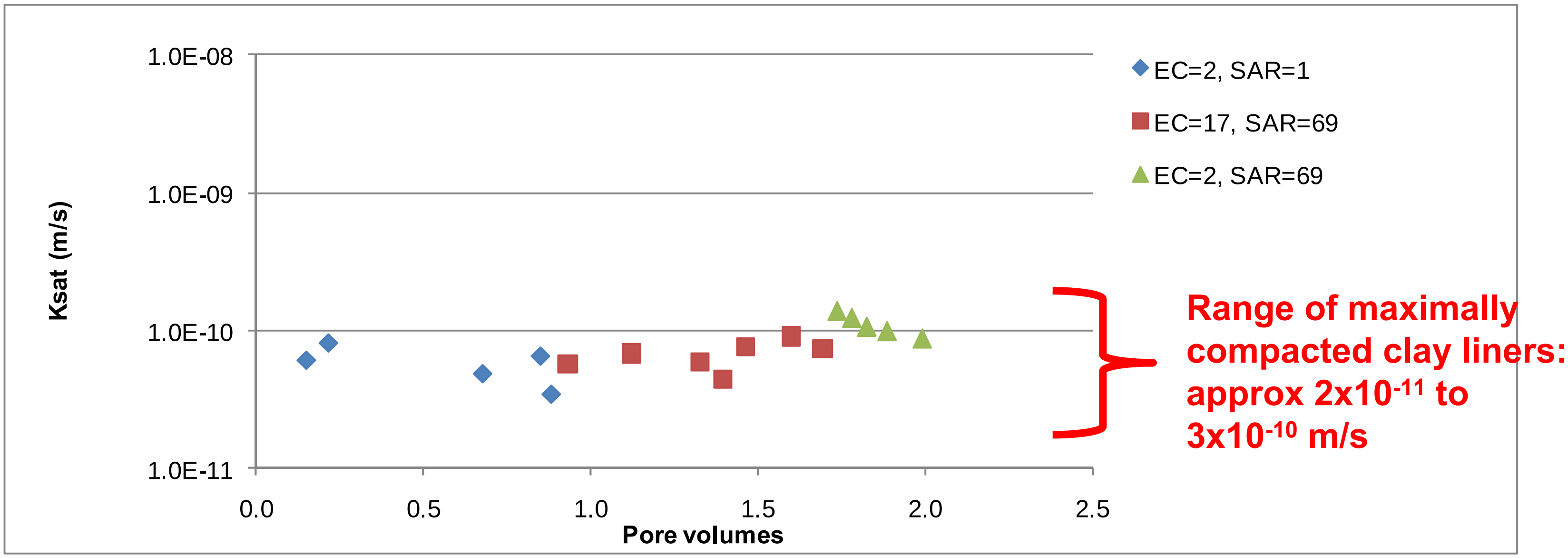
- Very little change from high-EC baseline to harsh low-EC NaCl solution



Low conductivity soils (cont'd)

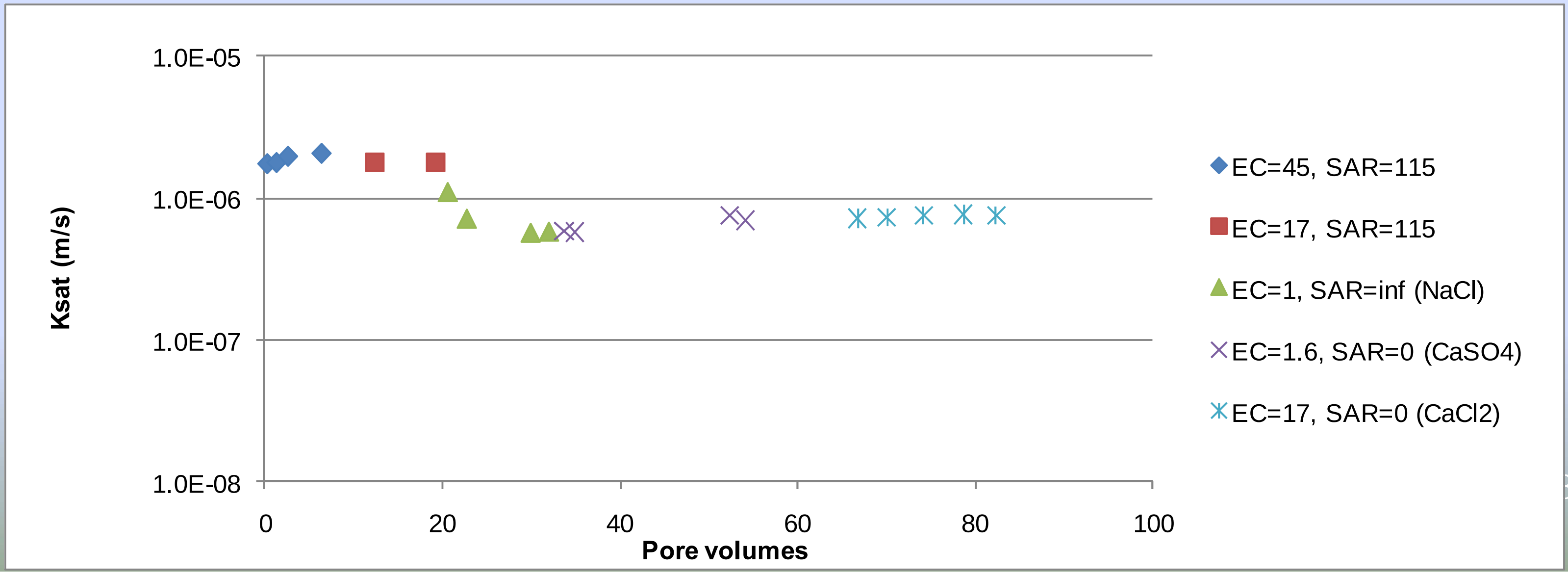
Example #7: clay loam soil

- Unimpacted tight clay from near Lloydminster
- Varies approx 3-fold between 4×10^{-11} and 1×10^{-10} m/s over large EC/SAR range
- To compare, compacted clay liners must be $<10^{-9}$ m/s



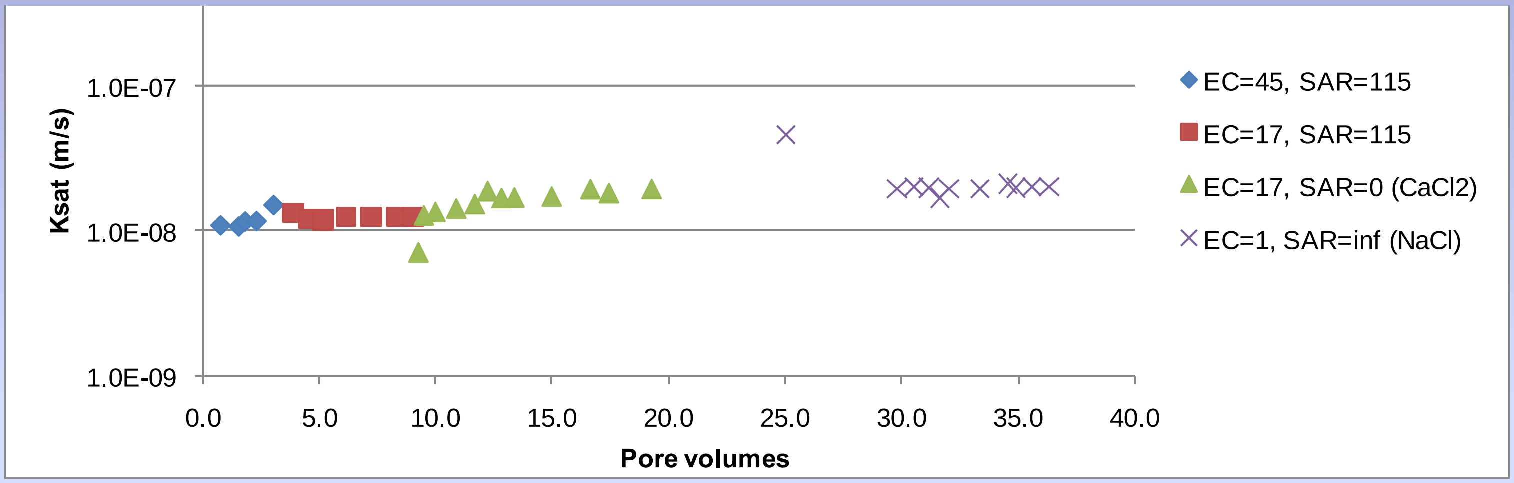
Coarse / sandy soils

- Examined effects of SAR on coarse / sandy soils
- Experiments show generally low sensitivity to SAR
  – K_{sat} changes were generally less than 1 order of magnitude
- <u>Sandy example #1 (undisturbed core)</u>:
  – moderate effect at harsh, pure NaCl solution (EC~1)
  – otherwise, no significant changes over large EC/SAR ranges

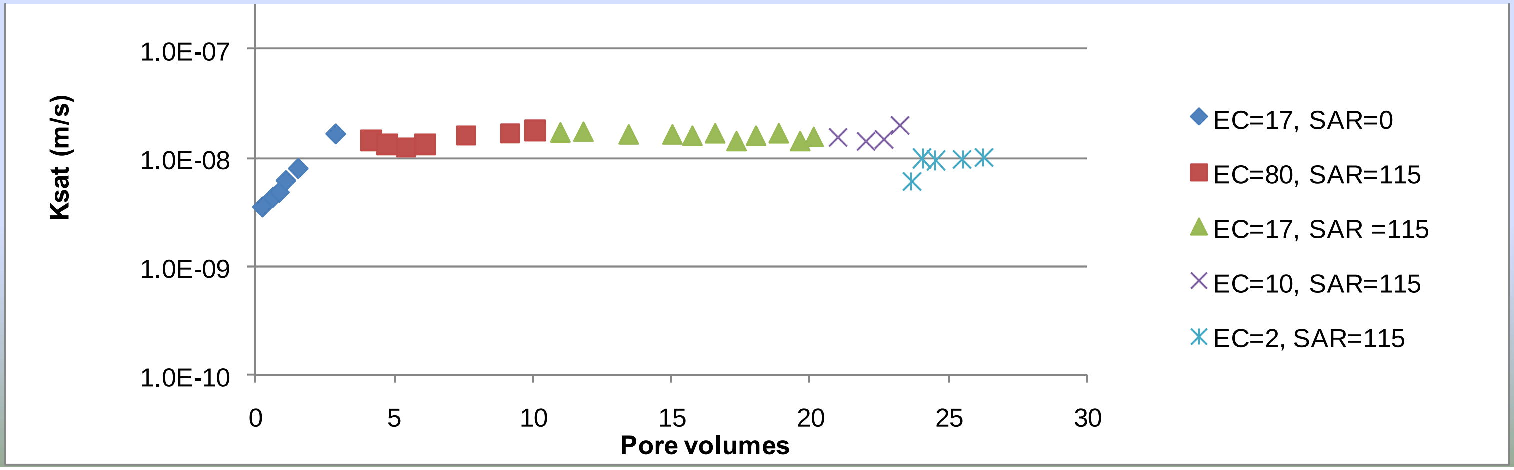


Coarse / sandy soils (cont'd)

- **Sandy example #2 *(undisturbed core):***
  – no significant changes over large EC / SAR ranges
  – note that not all sandy soils have high initial K_{sat}



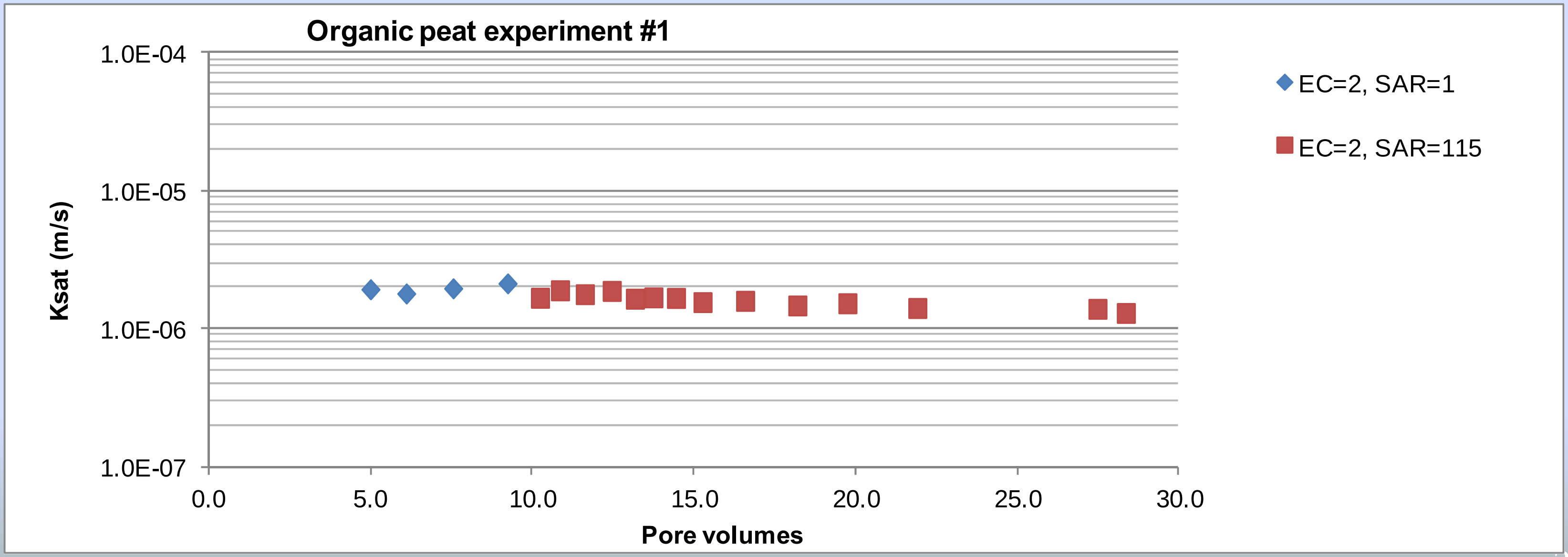
- **Sandy example #3 *(repacked soil):***
  – No significant changes over large EC range at SAR=115



Organic soils

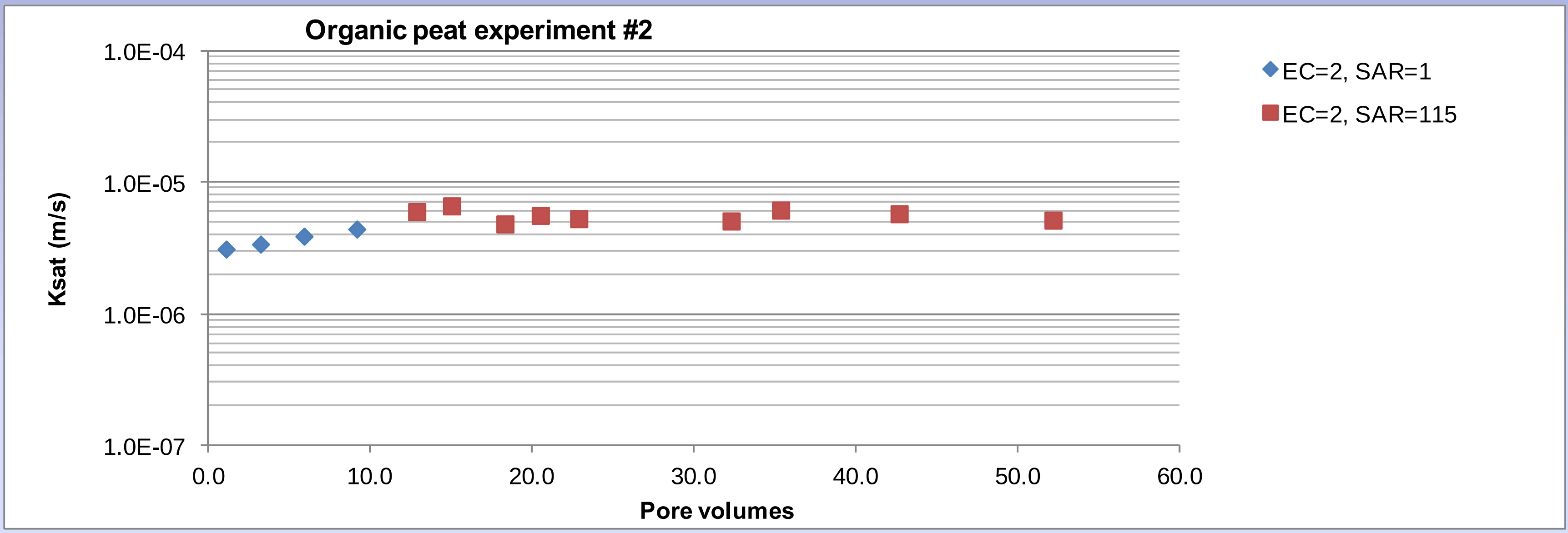
- **Examined effects of SAR on organic peat soils**
  - **70 – 80% organic matter**
  - **500-700% saturation percentage**

- **<u>Organic example #1 (undisturbed core)</u>:**
  - **Base-lined with EC=2, SAR=1**
  - **Minimal effects with harsh SAR=115 solution (EC~2)**



Organic soils (cont'd)

- **Organic example #2 (undisturbed core):**
  - also minimal effects



- **In both examples, saturated paste SAR ~30+ at completion of experiment**

- **Overall, preliminary results suggest minimal SAR effects on some peat soils**
  - may reduce / eliminate the need to remediate SAR-impacted peat soils

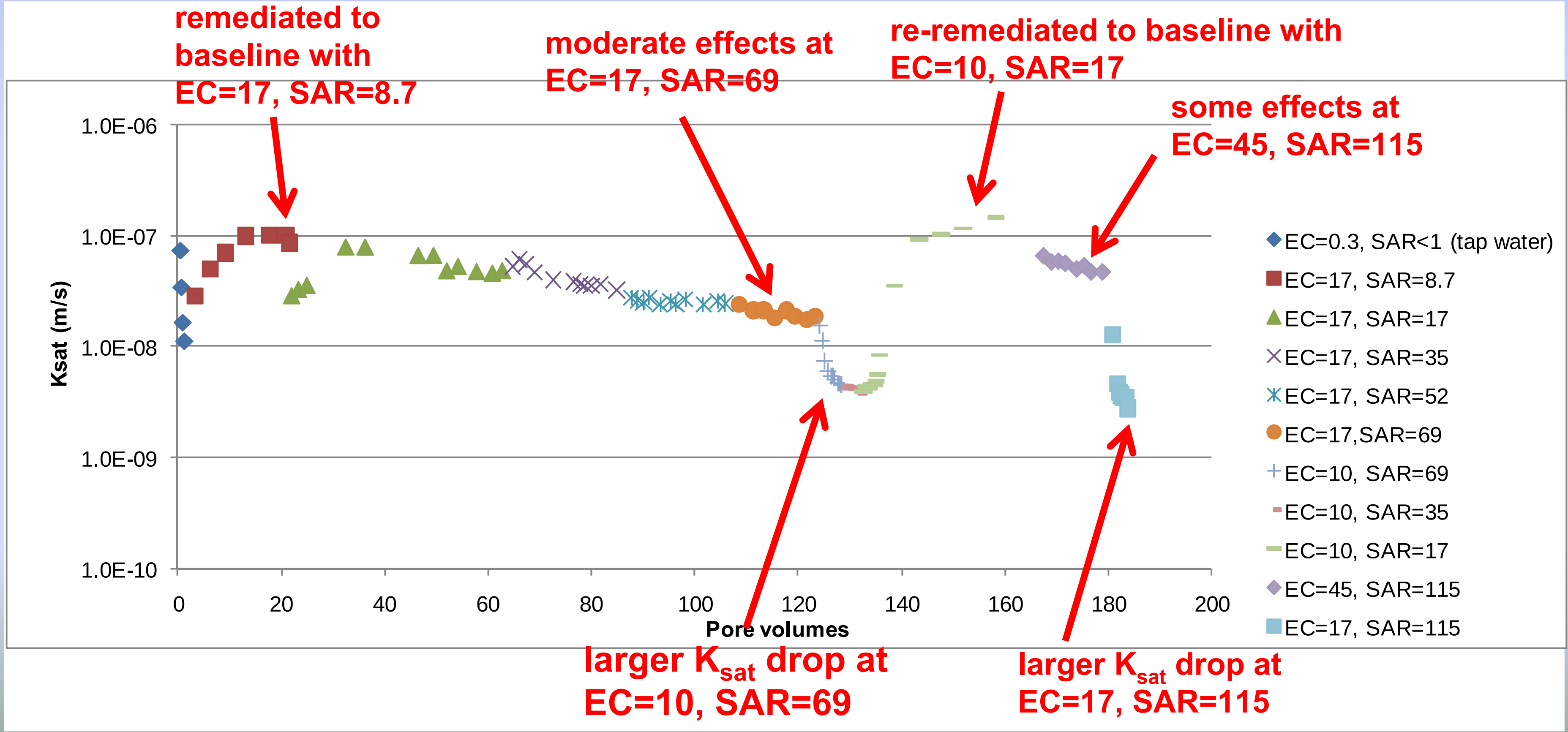
Remediation of SAR effects

Remediation of SAR effects

- One example from Phase 1 showed remediation to baseline with calcium or magnesium sulfate salts
  - also relevant for natural attenuation of SAR impacts with background salinity

<u>Remediation example #2:</u>

- two remediation cycles to essentially baseline K_{sat}
- no visible side-effects, good apparent reversibility in this case



Remediation of SAR effects (cont'd)

- In some cases, development of flow channels suggests remediation of severely-impacted soils may not be completely homogenous in all cases
  - macroscopic voids or channels may develop as soils are remediated from a severely dispersed/swelled state
  - likely an effect similar to shrinkage cracking

- However, in general, it appears many SAR effects may be reversed given sufficient time while leaching with low SAR and/or high EC

Conclusions and next steps

Conclusions

- Excess subsoil SAR may cause water-logging or water-table perching
  - a function of depth and area of impacts as well as K_{sat} reduction
  - can be estimated via three-dimensional water-table modeling
- Leaching columns useful for studying SAR effects
  - allows studying the interactions between SAR, EC, and K_{sat}
  - allows useful comparisons with previous work from literature
- High SAR values may reduce K_{sat} by up to 1-3 orders of magnitude
  - largest effects typically occur at lowest EC's
- Some soils may be less sensitive to SAR
  - Some coarse soils
  - Some low-conductivity soils
  - Some organic / peat soils
- Many SAR effects appear to be reversible
  - calcium and magnesium salts can be effective for remediating SAR
  - sufficiently high EC can also reverse SAR effects in many cases

Next steps toward subsoil SAR guidelines

- Continued leaching column experiments on subsoils
  - additional EC/SAR combinations
  - additional soil textures
  - additional replicates
- Further evaluation of the reversibility of SAR-induced K_{sat} losses
  - relevant for remediation options
  - relevant for natural attenuation
- Further three-dimensional water table modeling as a function of magnitude, size, and depth of SAR impacts
  - important for choosing appropriate effect levels
  - relevant for guideline development
- Synthesis of results from many (currently 50+) leaching column experiments along with water-table modeling to generate subsoil SAR guideline recommendations
- Results from this experimental work are to be incorporated into Subsoil Salinity Tool (SST)

Thank-you!

Questions?