Numerical History Matching – SCAL Data

Why is it necessary?

SCA 2019 - Pau

Lloyd's Register

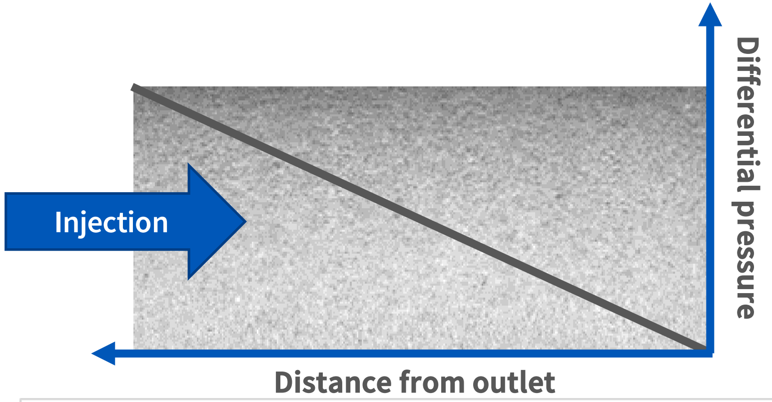
PAU FRANCE
2019 SCA SOCIETY OF CORE ANALYSTS

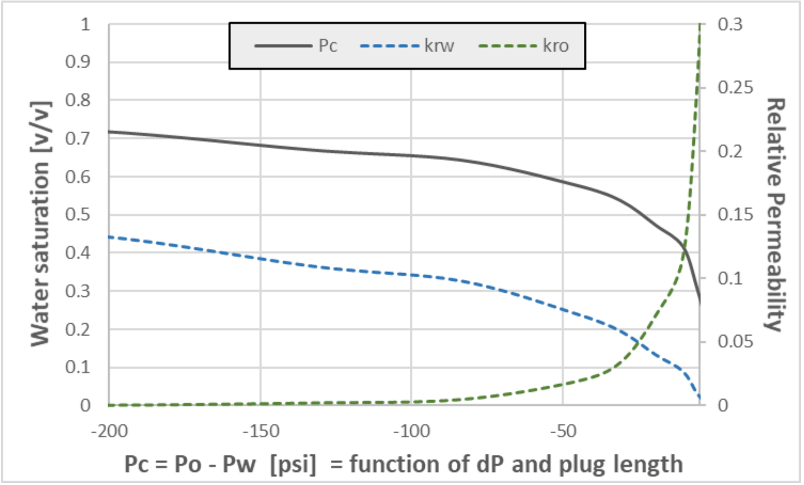
Overview

- Boundary effects resulting in relative permeability errors
- Field implications
- QC checks prior simulation

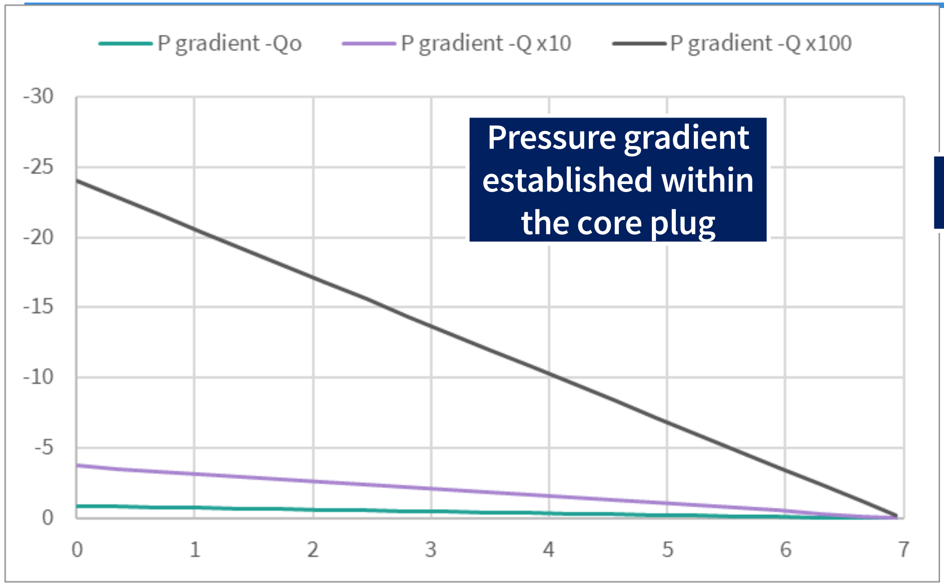
Capillary interference (simplified)

- Saturation is a function of capillary pressure (wettability), distance from Pc=0 and fluid pressure gradient
- In a coreflood, a fluid pressure gradient is applied across the plug, creating:
  - saturation gradient as a function of Pc
  - relative permeability gradient as a function of Sw
- Gradients produce error in direct calculation, since equations assume equal properties throughout

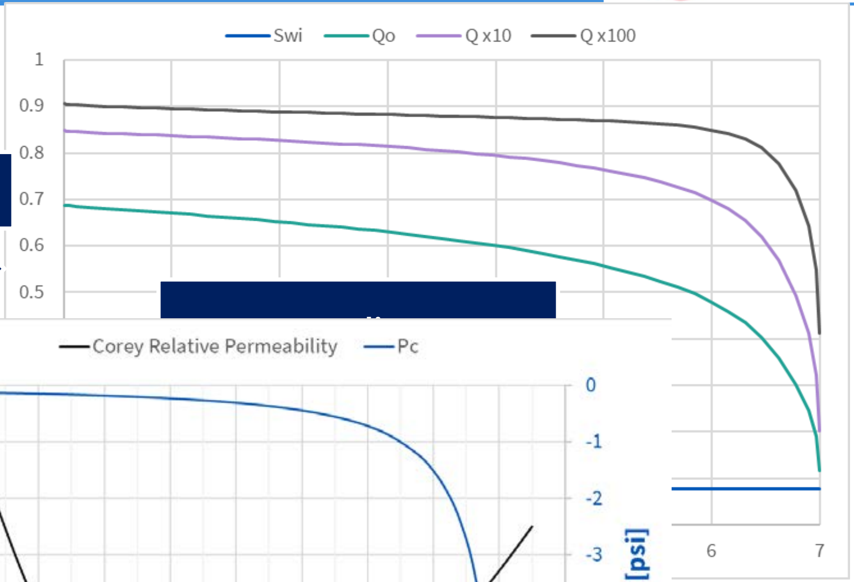


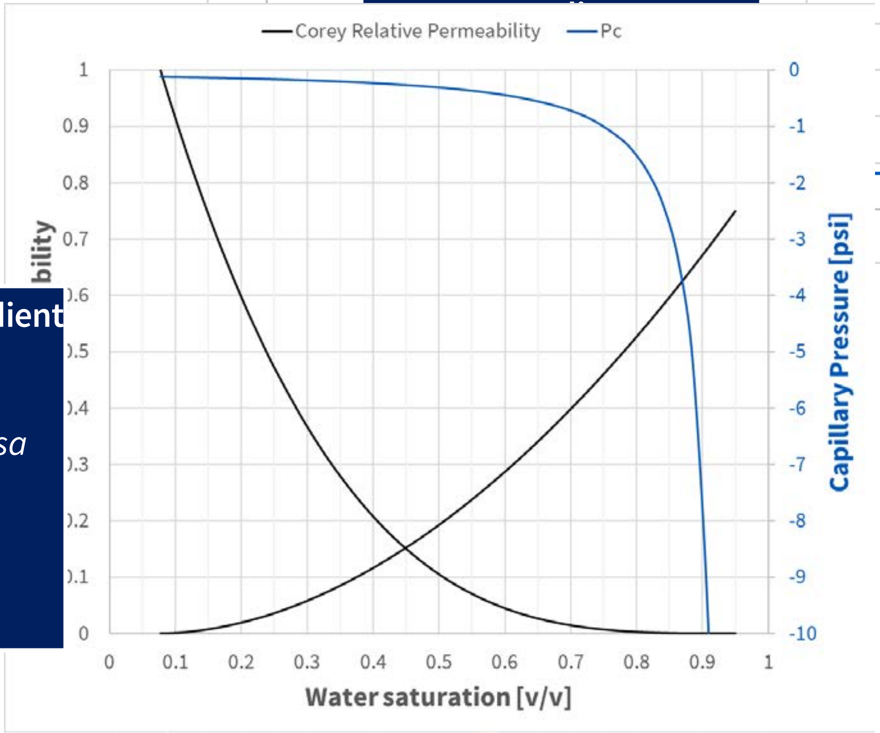


Capillary End Effects



Pc = Po - Pw

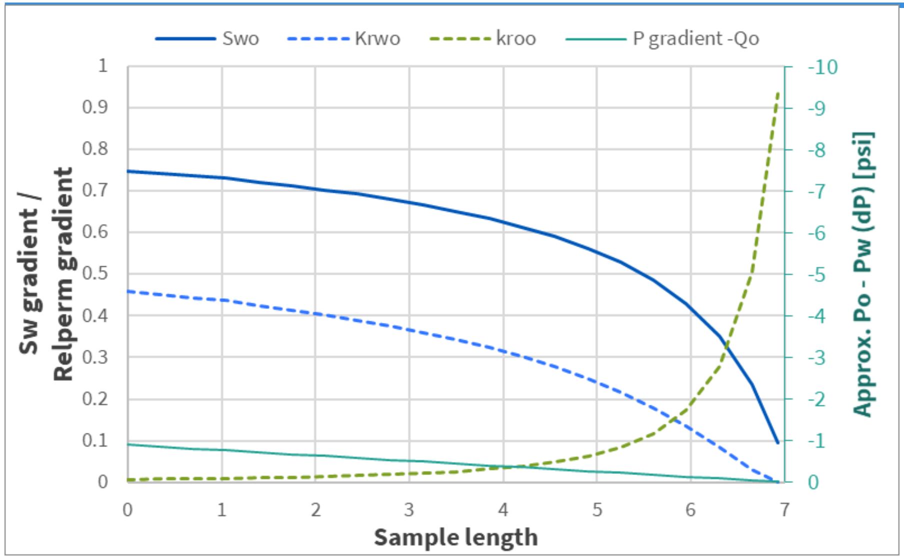


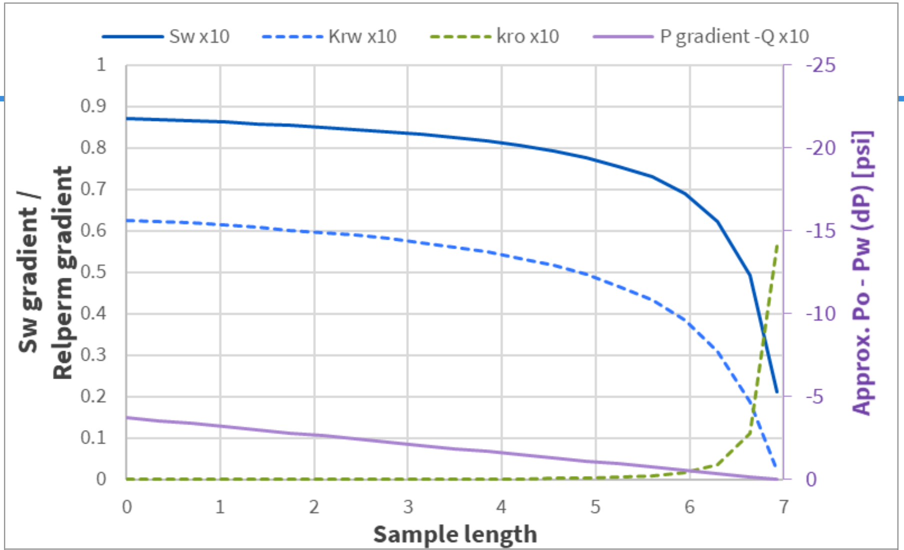


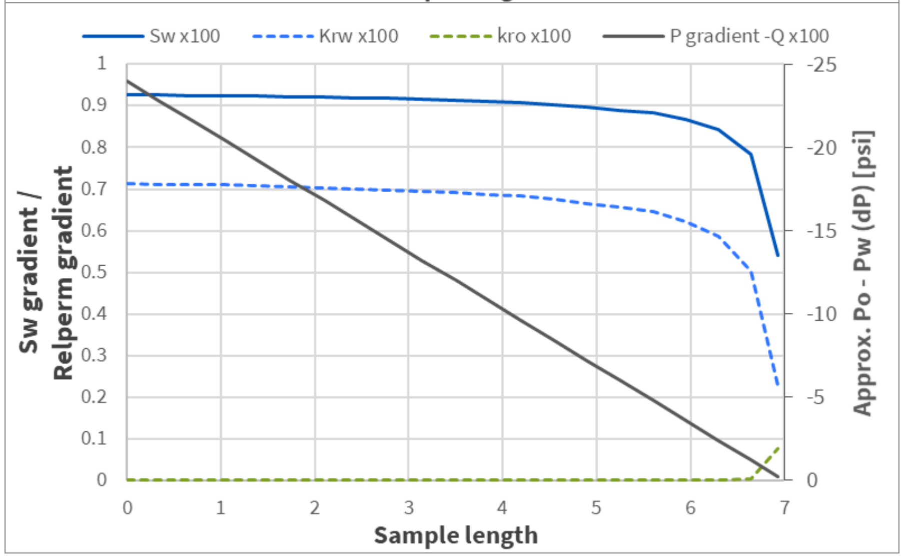
Pc curve describes Sw attained under a particular pressure gradient
(Pc = Po – Pw ≈ dP = f {L})

NB. - Pc = independent of relative permeability (kr) – *& vice versa*
- Pc = static ¦ kr = dynamic
- kr describes how fluids are moving in the progression towards the final static (steady) state (Pc)

Capillary End Effects





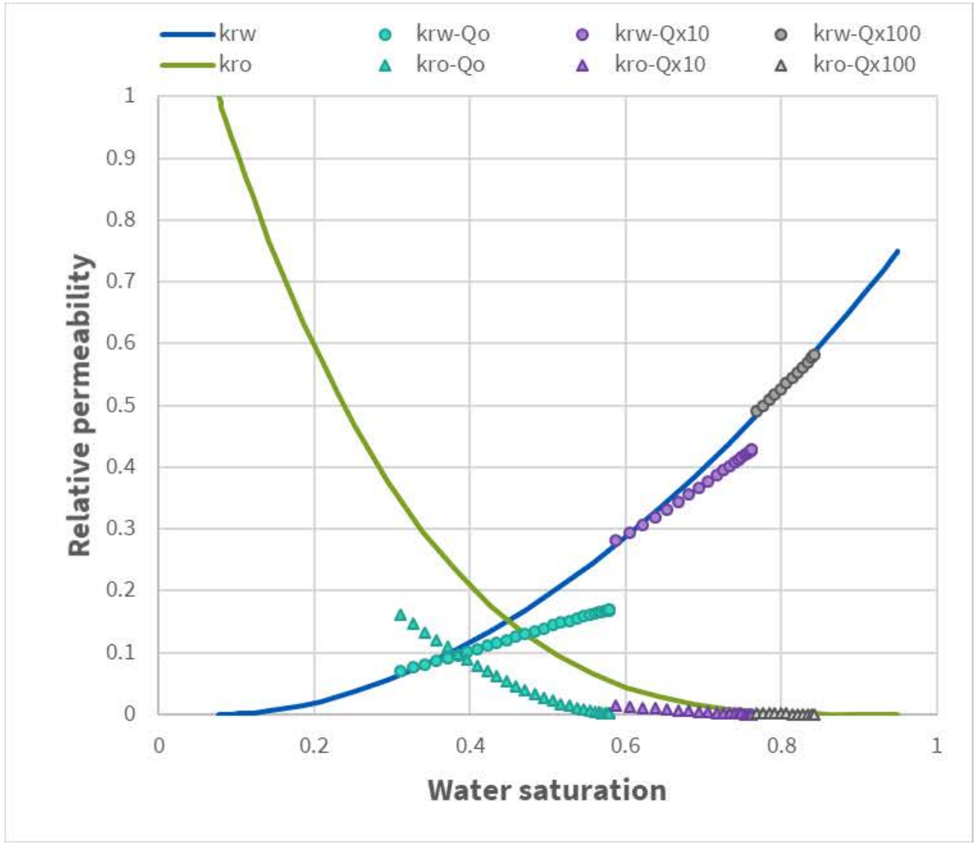


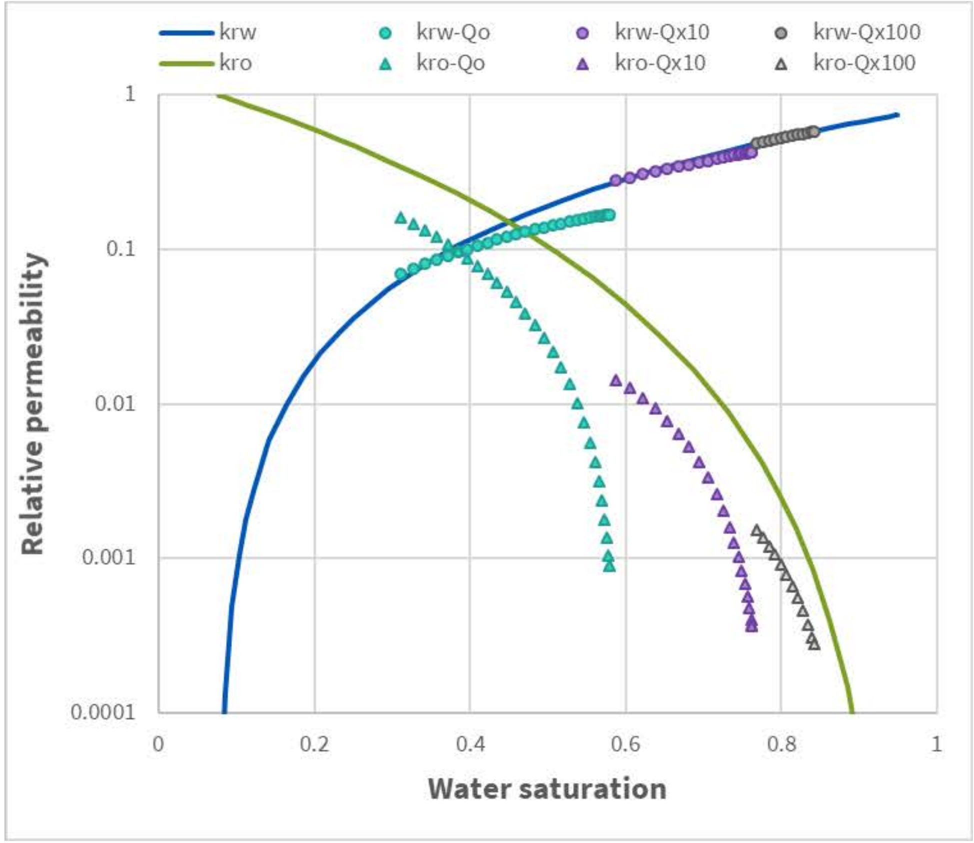
Performing analyses at different rates or different differential pressures, will result in:

1. different pressure gradients →
2. different saturation gradients →
3. different kr gradients →
4. different errors in relative permeability

Capillary end effect

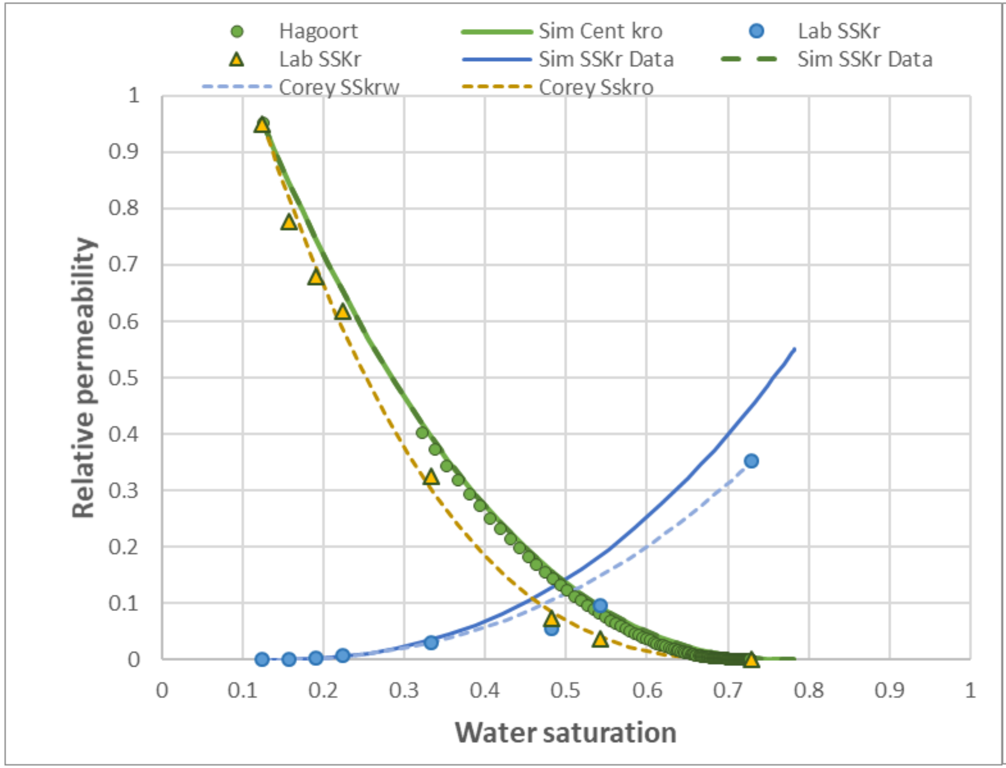
- Effect on analytical USS relative permeability (assumes Pc = 0)

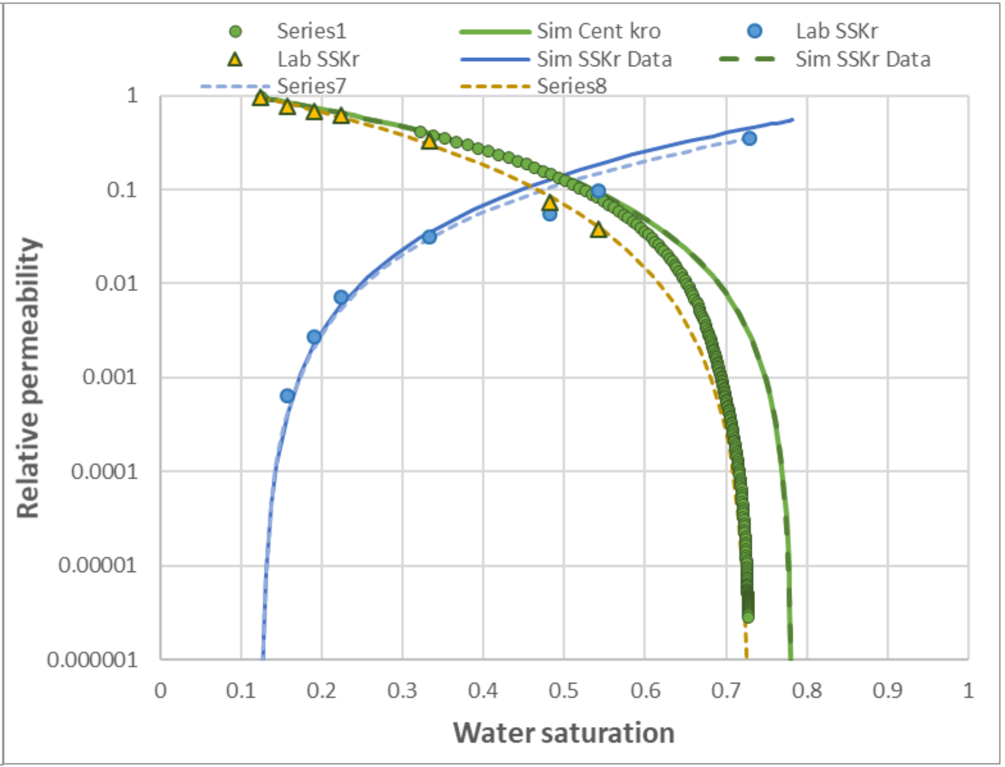




Capillary end effect

- Effect on SS & centrifuge relative permeability (assumes Pc =0)





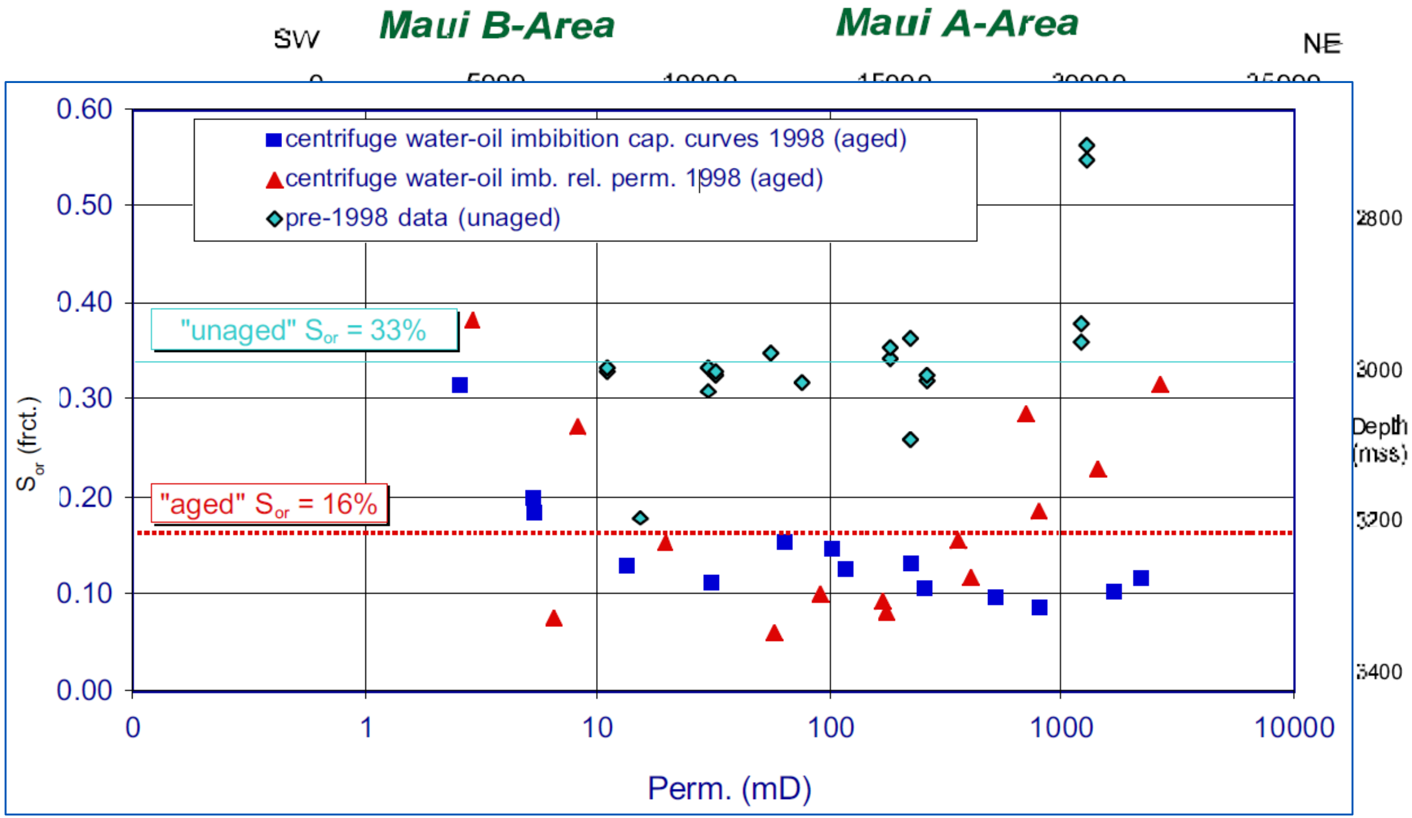
Summary of boundary effects

- Suppression of recovery resulting in overestimate of residual oil saturation
- Error in analytically derived relative permeability (assuming Pc=0)
- Flooding does not always achieve residual saturation – even with bump floods

Impact on field calculations

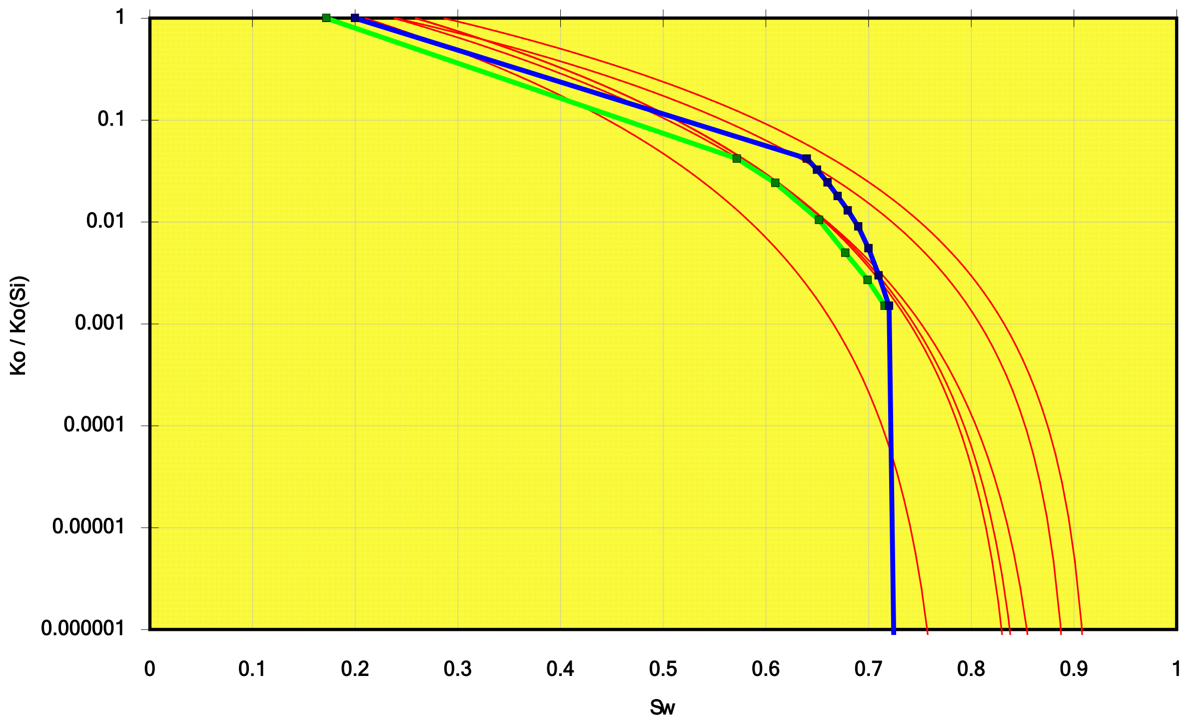
- Error in residual oil saturation – SPE 68741
  - 12.2 MM m^3

- Sor error = 17%



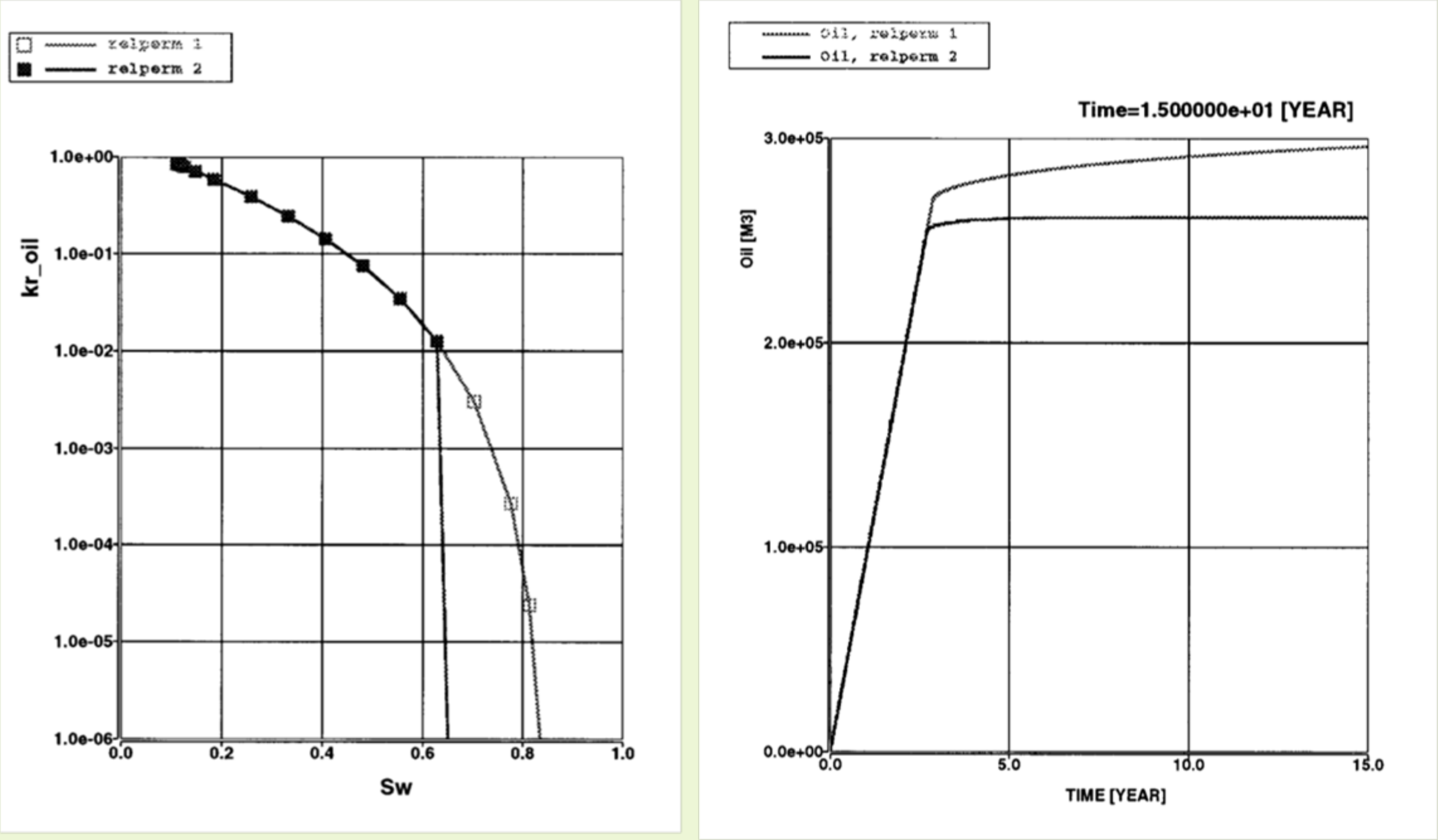
Impact on field calculations

- Error in residual oil saturation – flooding vs. centrifuge



Impact on field calculations

- Error in residual oil saturation



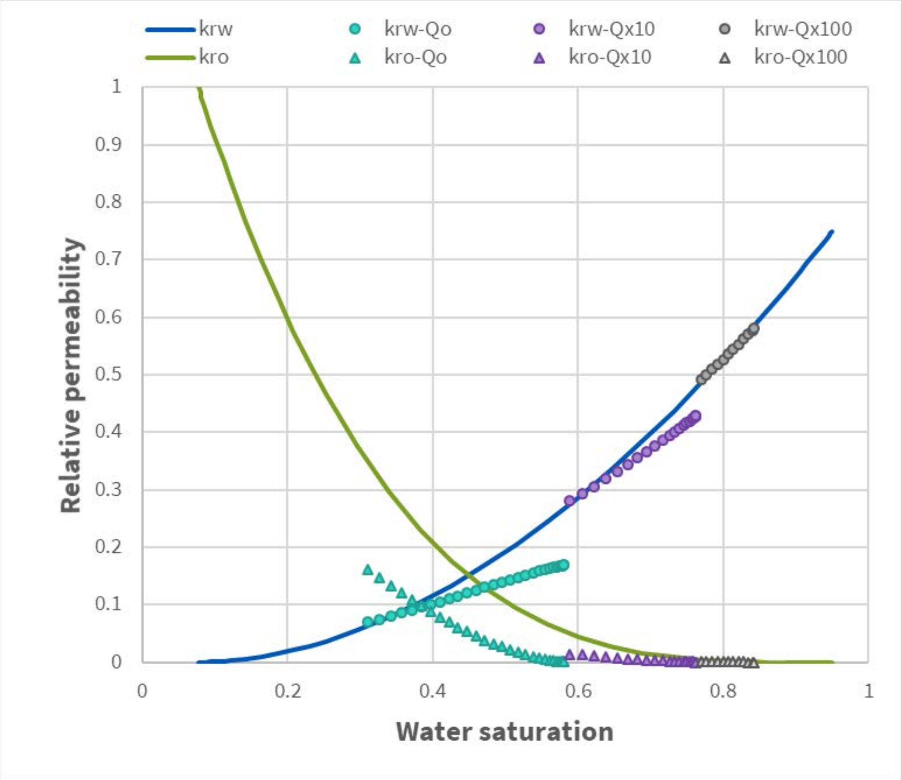
Impact on field calculations

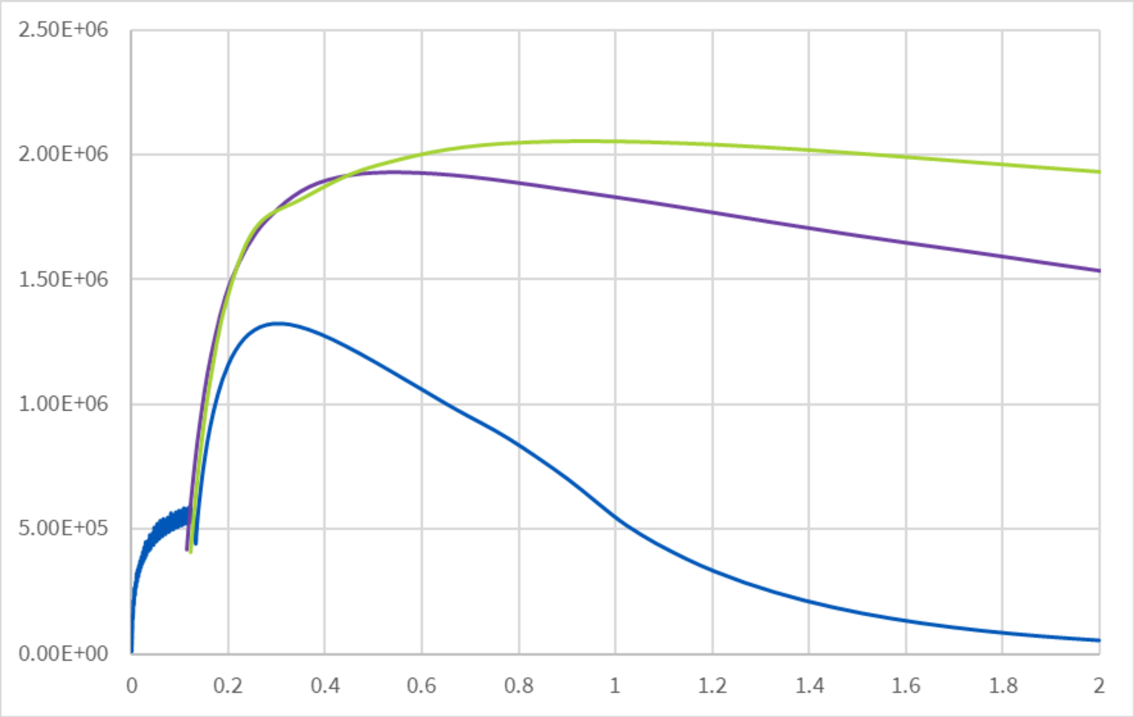
Region	Current	Old
North Sea 1	15%	28%
North Sea 2	15	25-30
North Sea 3	14	29
North Sea 4	10-15	-
Middle East 1	20	
Middle East 2	15-25	
Middle East	10-20	
South America	10	>= 40
Africa	15-20	25-35

Jos Maas – Coreflood simulation training 2013

Impact on field calculations

- Different relative permeability result in different production profiles

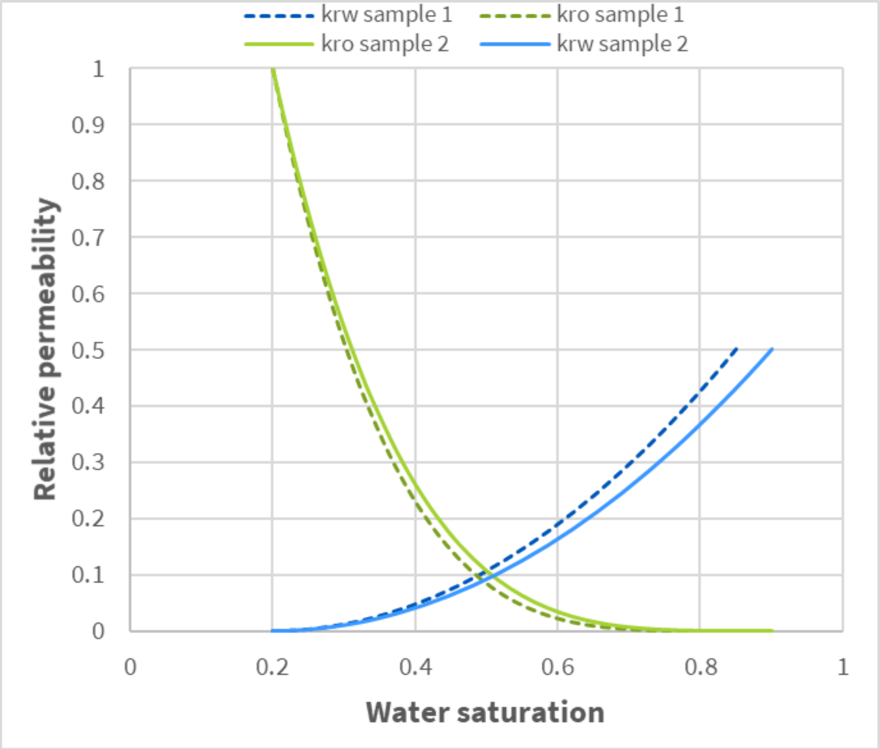




Impact on field calculations

- Error in residual oil saturation
  - Case shown has a 5 saturation unit difference in Sor (0.10 and 0.15)
    - Swi = 0.2,
    - Nw = 2,
    - No = 4,
    - krw' = 0.5
  - Difference in RF = 7%
  - For 300 MMbbl (48 MM m^3) = 21 MMbbl
    - approx. 1.3 billion USD @ $60 /bbl

$$RF = \frac{(1 - S_{wi} - S_{or})}{(1 - S_{wi})}$$

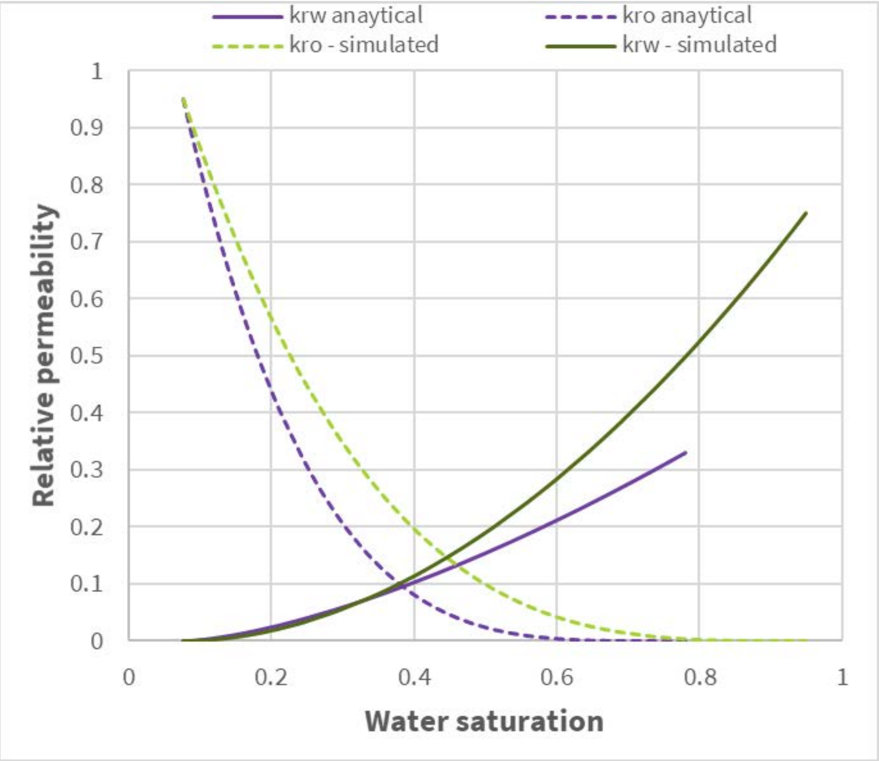


Impact on field calculations

- Error in analytical relative permeability
  - Case shown

$$RF = \frac{(1 - S_{wi} - S_{or})}{(1 - S_{wi})}$$

Property	Analytical	Simluated
Sor	0.22	0.05
Nw	1.5	1.9
No	4.0	3.4
Krw'	0.33	0.75



  - Difference in RF = 19%
  - For 300 MMbbl (48 MM m^3) = 56 MMbbl
    - approx. 3.4 billion USD @ $60 /bbl

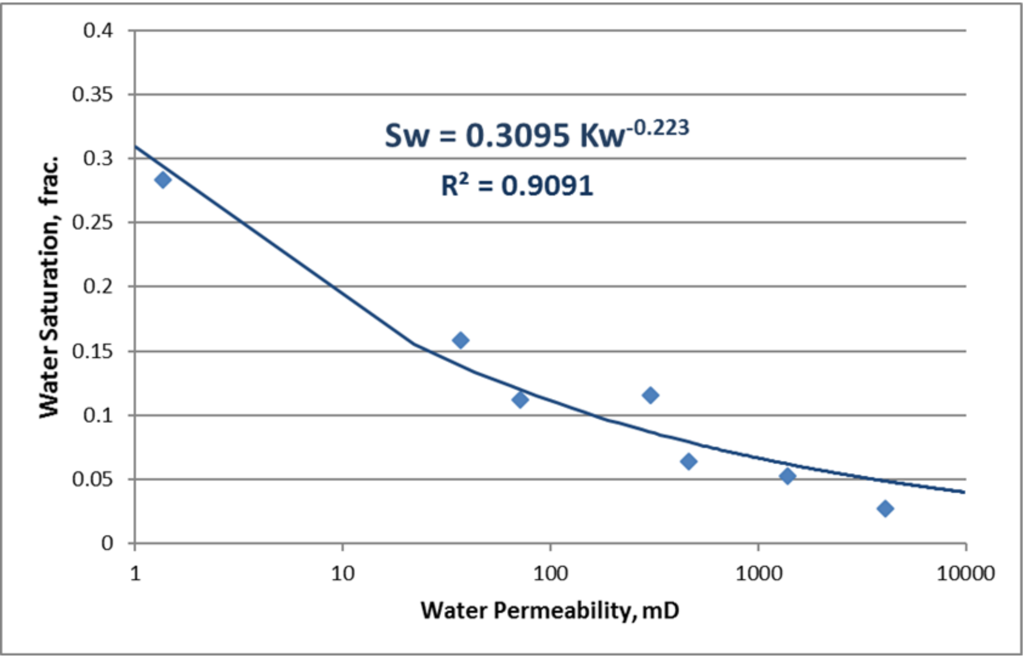
QC Checks

- Sample selection – homogeneity
  - most coreflood simulators ascribe homogeneous properties
- Wettability - Essential
- Swi – Check against petrophysical dataset
- Endpoint permeability – statistical or property-based correlations
  - Ko @Swi, Kg @Swi, Kw @Sor, kg @Sor+Swi (hence, corresponding kr)
- Capillary pressure – same or sister sample, or petrophysical correlations
- Sor (or final water saturation – Swf) – cross-check and correlate

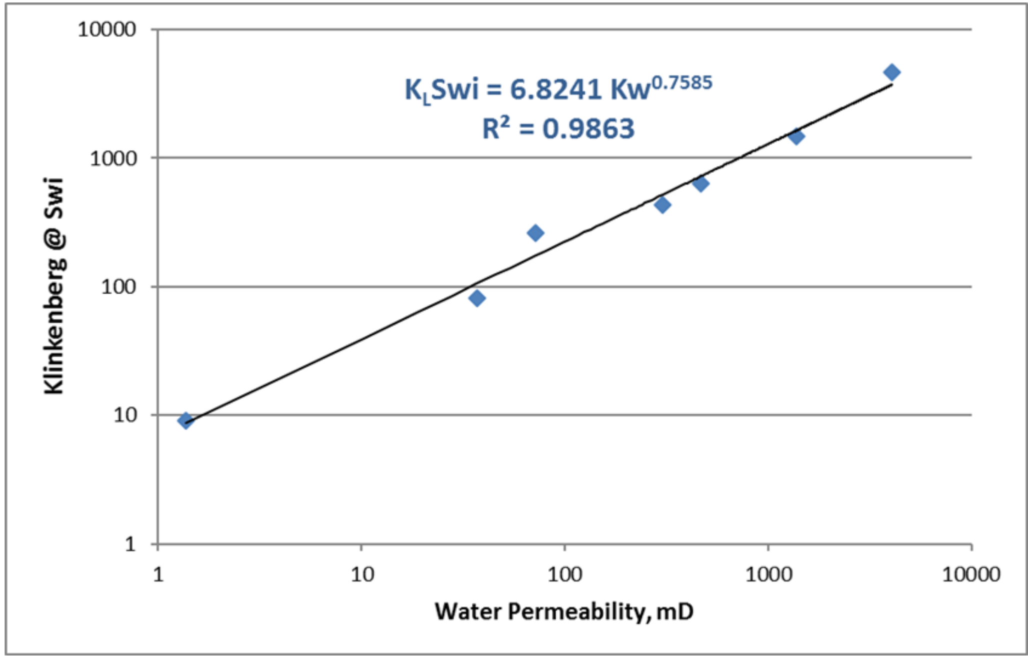
QC Checks – Endpoint correlations

- Attempt to determine relative permeability endpoints correlations and/or variance

S_{wi} versus k_w



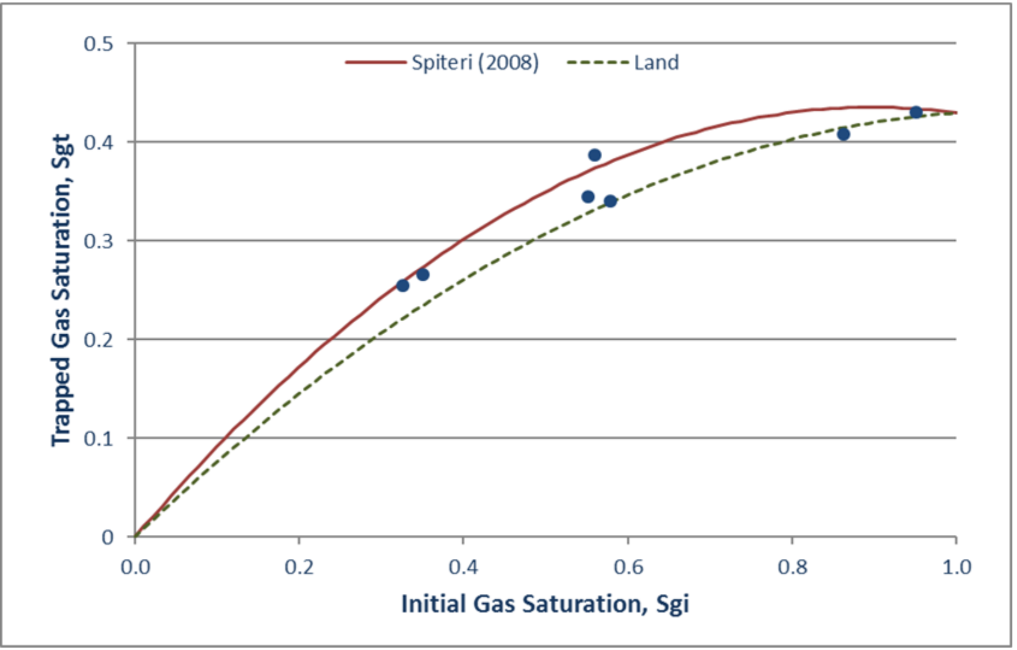
$k_L@S_{wi}$ versus k_w



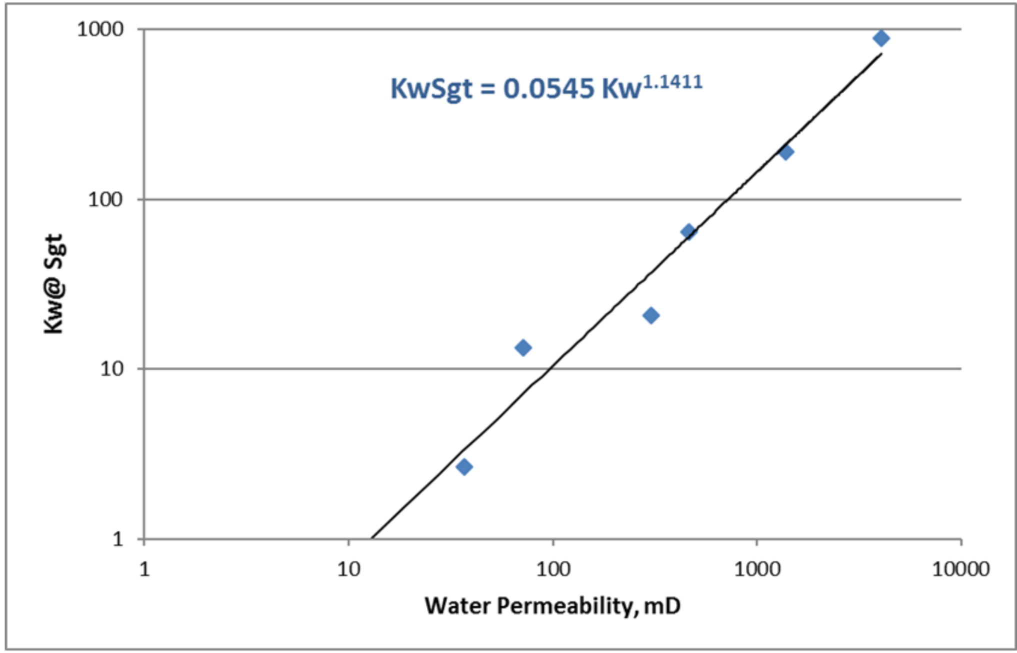
QC Checks – Endpoint correlations

- Attempt to determine relative permeability endpoints correlations and/or variance

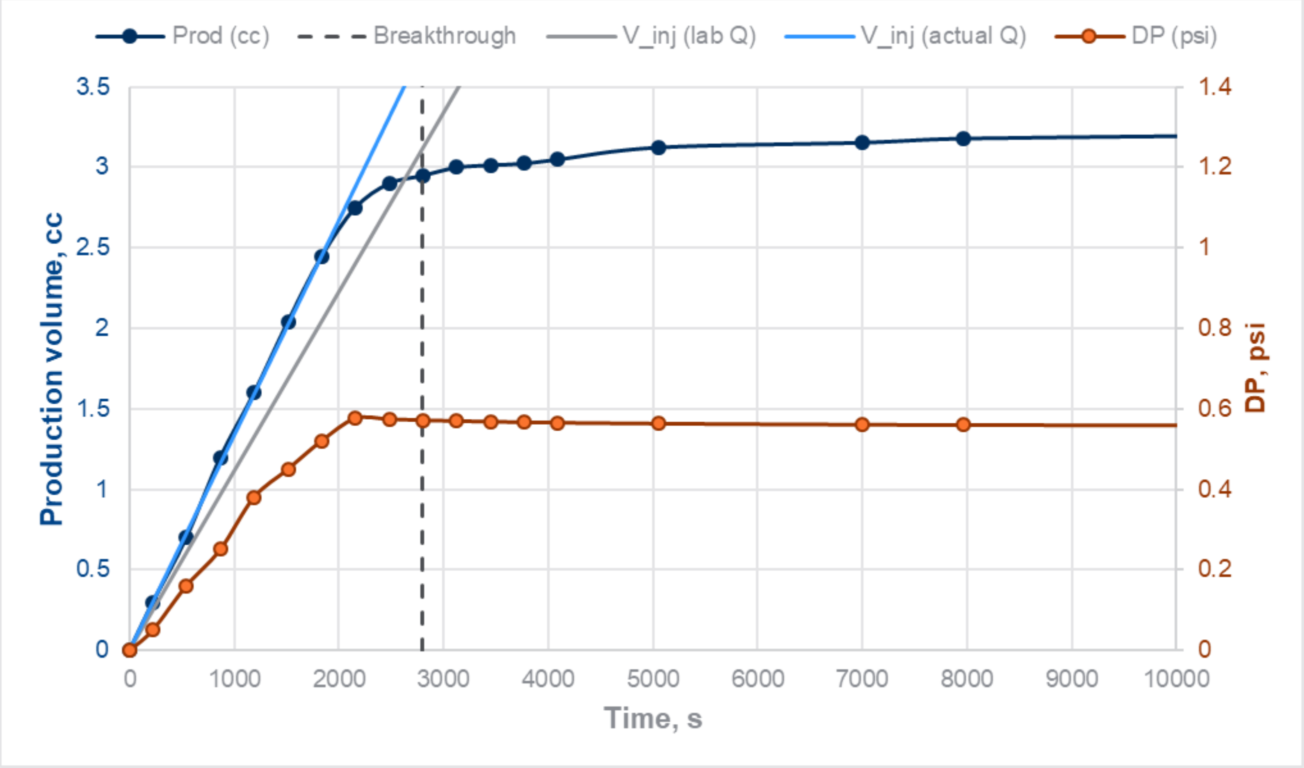
S_{gr} versus S_{gi}



$k_w@S_{gt}$ versus k_w



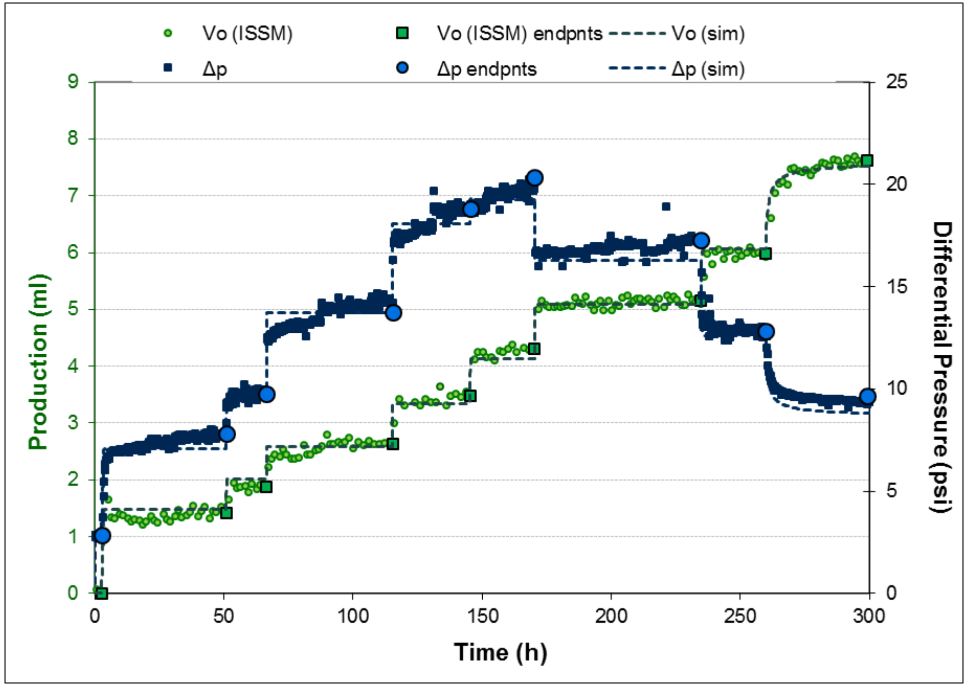
USS – QC checks

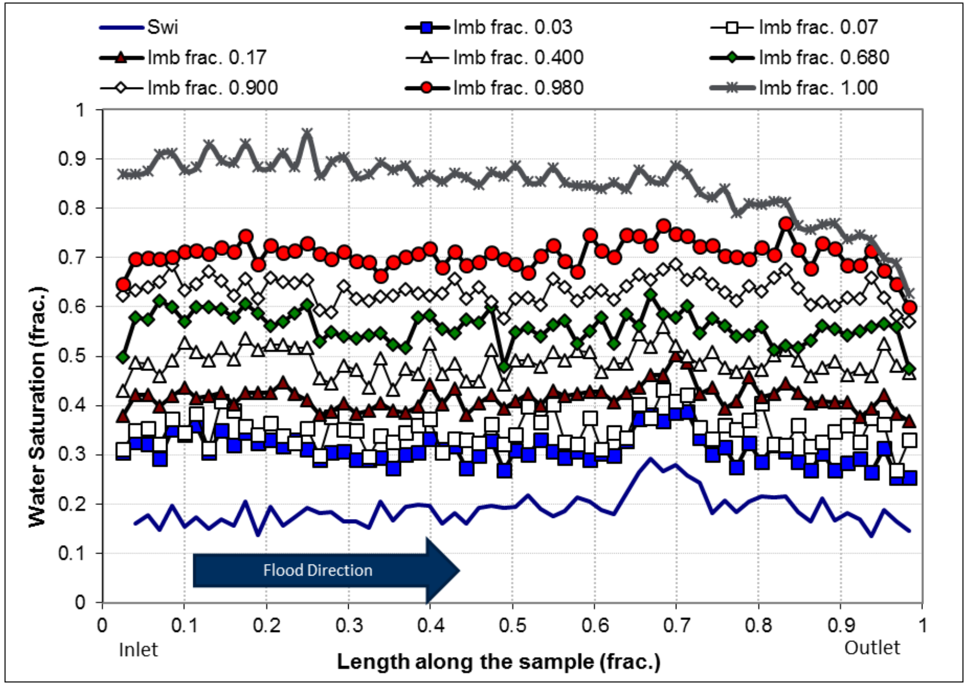


- Check Swi & Swf (or other phase saturations)
- Check production values
- Check breakthrough time aligned in production and dP
- Check linear production = linear injection
  - above case had 17% rate error = 17% effective k error = 17% kr error

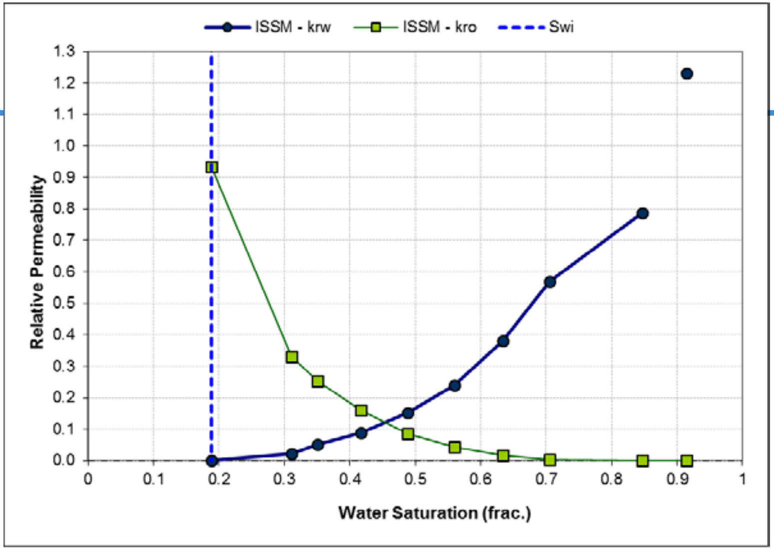
SS – Example Data

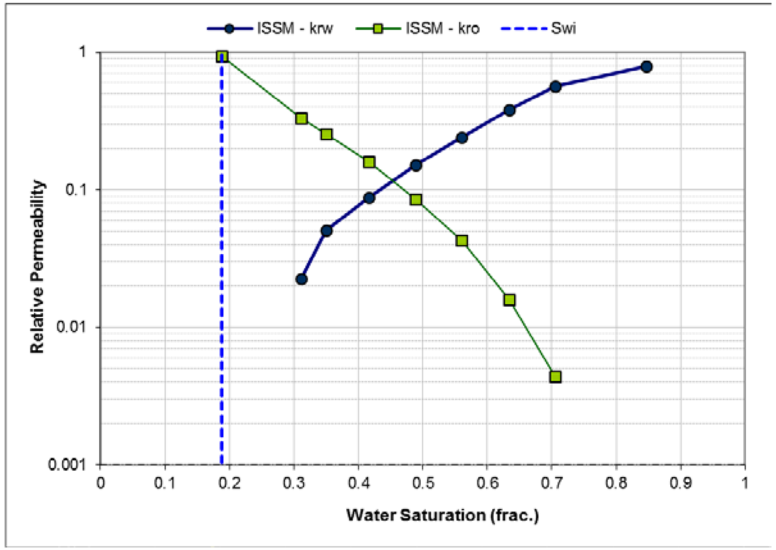
- Check Swi, Swf (other phase saturations if required)
- Plot and check stabilised production and dP versus time
- Check ISSM calculations – particularly error in SS scans





SS – Example Data





Imbibition Relative Permeability - Analytical

					Base permeability:	ko(Swi)		10.1	(mD)	
Rate		Water					S_w			
Water (ml/hr)	Oil (ml/hr)	Fraction F_w	Δp (mbar)	Δp (psi)	k_w (mD)	k_o (mD)	ISSM (frac.)	k_{rw} (frac.)	k_{ro} (frac.)
0.00	60.00	0.000	195	2.84	0.00	9.5	0.188	0.000	0.935
1.50	58.50	0.025	539	7.82	0.23	3.4	0.311	0.022	0.330
4.20	55.80	0.070	670	9.7	0.51	2.57	0.351	0.051	0.253
10.20	49.80	0.170	941	13.6	0.9	1.64	0.416	0.088	0.161
24.00	36.00	0.400	1278	18.54	1.5	0.87	0.489	0.152	0.086
40.80	19.20	0.680	1369	19.86	2.4	0.43	0.560	0.241	0.043
54.00	6.00	0.900	1146	16.63	3.9	0.16	0.633	0.381	0.016
58.80	1.20	0.980	835	12.11	5.8	0.04	0.706	0.569	0.004
60.00	0.00	1.000	616	8.94	8.0	0.00	0.847	0.787	0.000
600	10 x Bump	1.000	3943	57.2	12.5	0.00	0.914	1.230	0.000

Thank you

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