Synthetic Models and Simulations of Pilot 3 in Ash Creek Field

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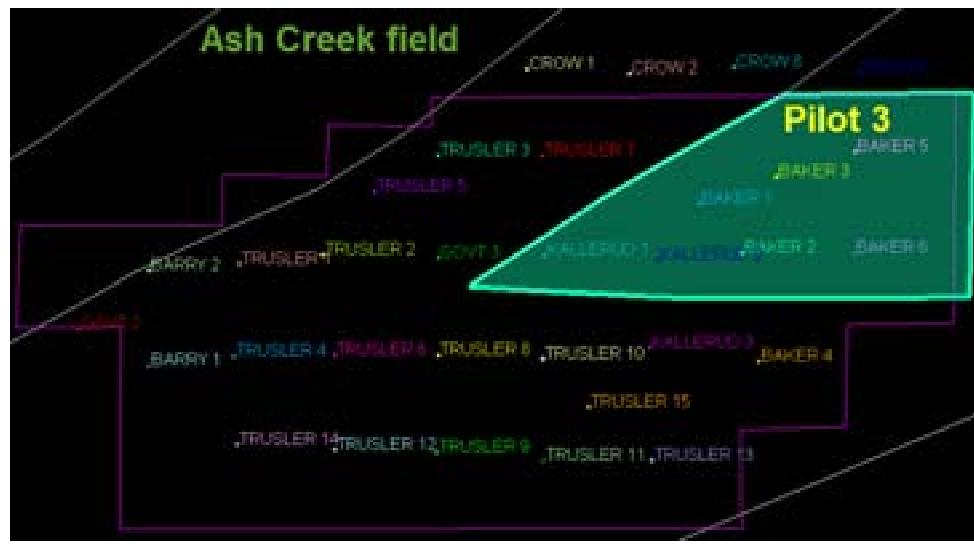
Background and objective

How do the high K strikes in the core data possibly impact the oil production in Ash Creek field ? in Pilot 3 ?

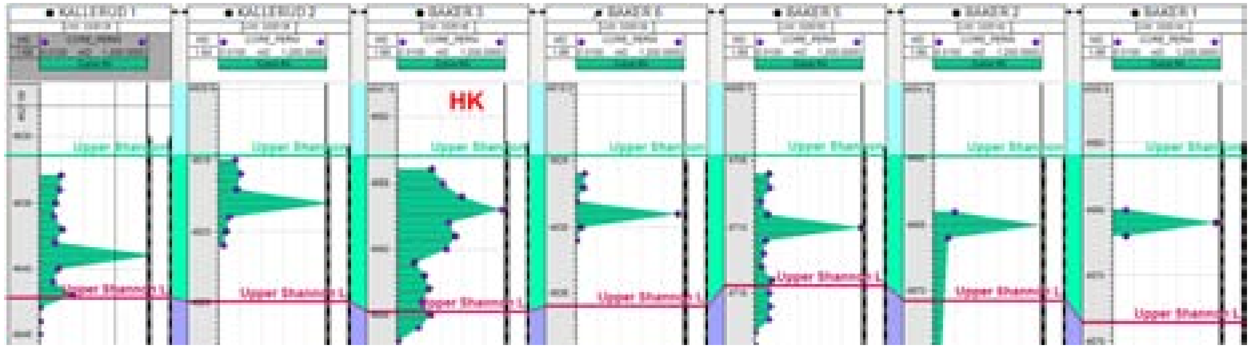
Outline:

- Introduction & model settings
- Comparison of the simulation results
- Primary analysis of Ash Creek data
- Conclusions

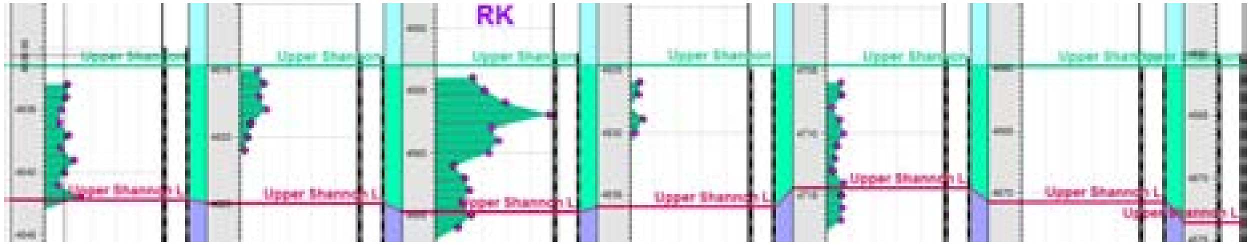


Introduction and Model Settings

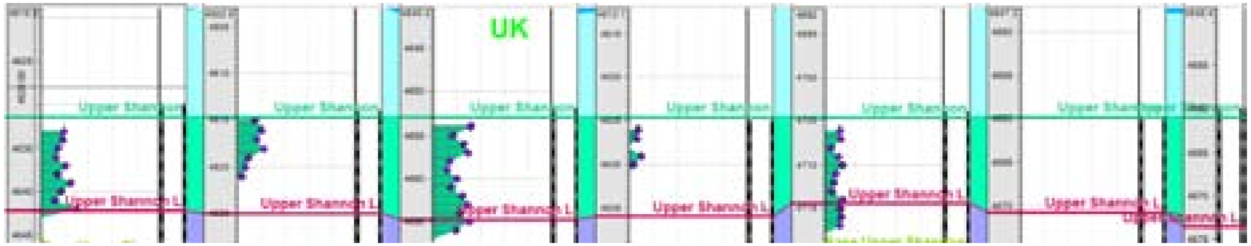
Permeability Model Definitions



HK: High permeability strikes, exaggerated permeability at wells.

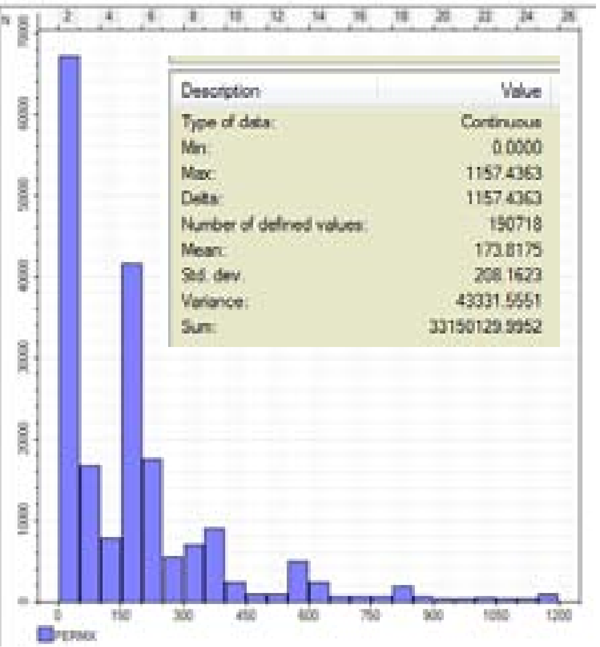


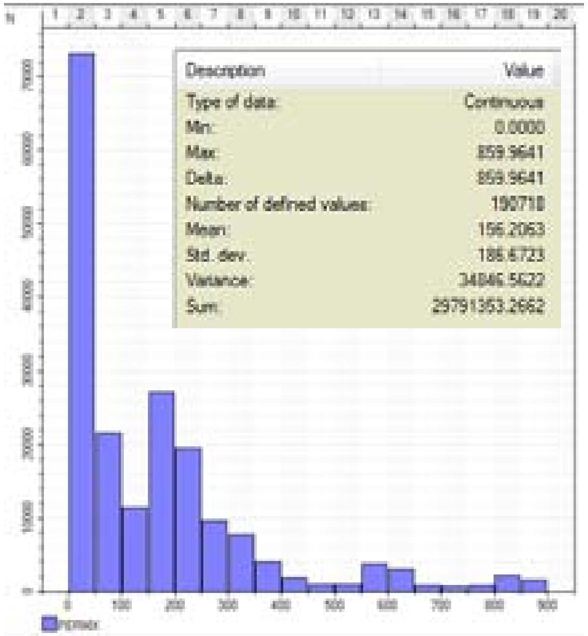
RK: Real permeability at wells.

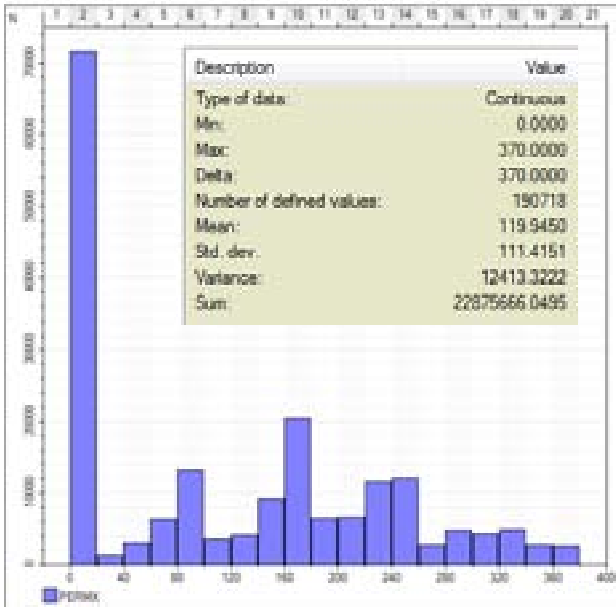


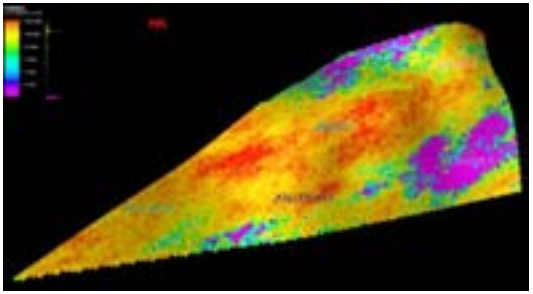
UK: Uniformed permeability, mitigated permeability at wells.

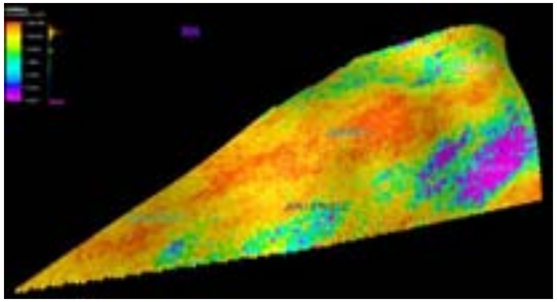
Statistical Analysis of Three Permeability Models

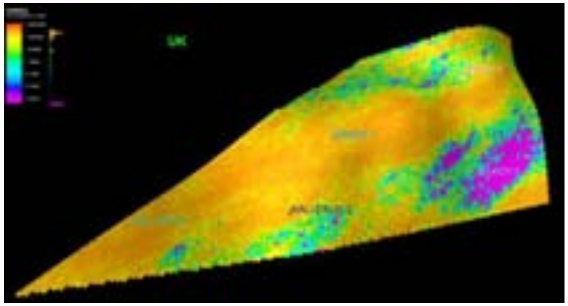










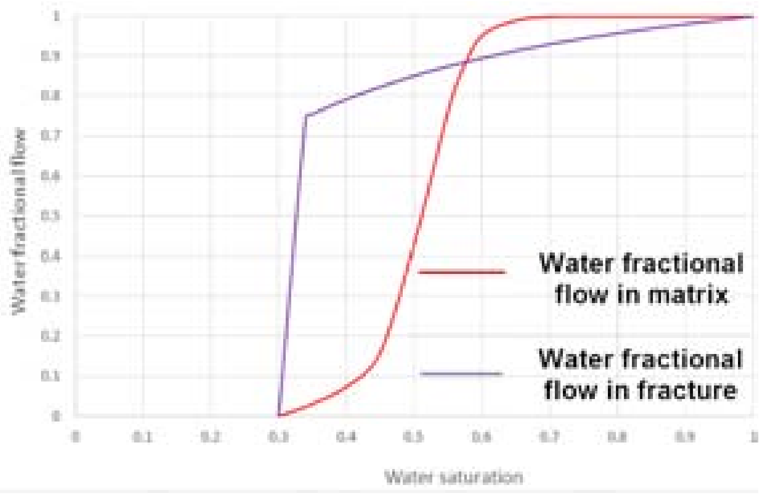


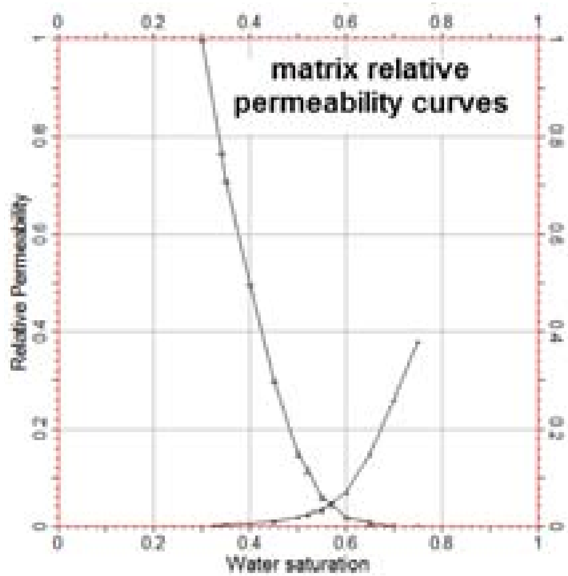
Relative permeability cases

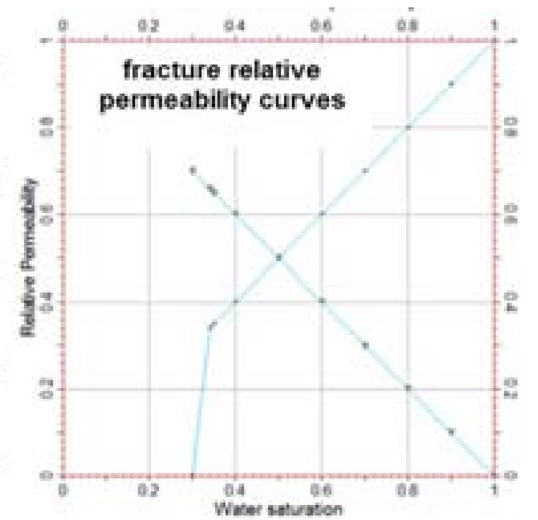
M: all cells use matrix relative permeability curves

D1: cells having k>800 md use fracture relative permeability curves

D2: cells having k>600 md use fracture relative permeability curves

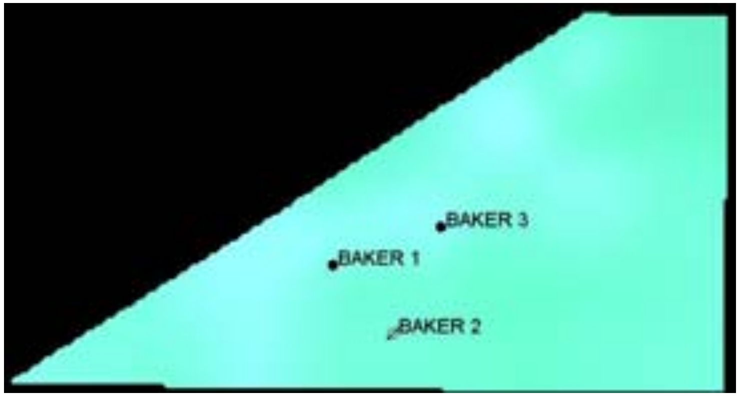




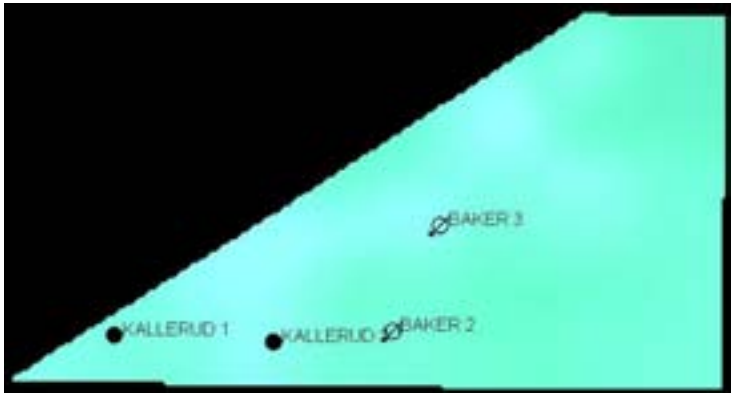


Drainage Area

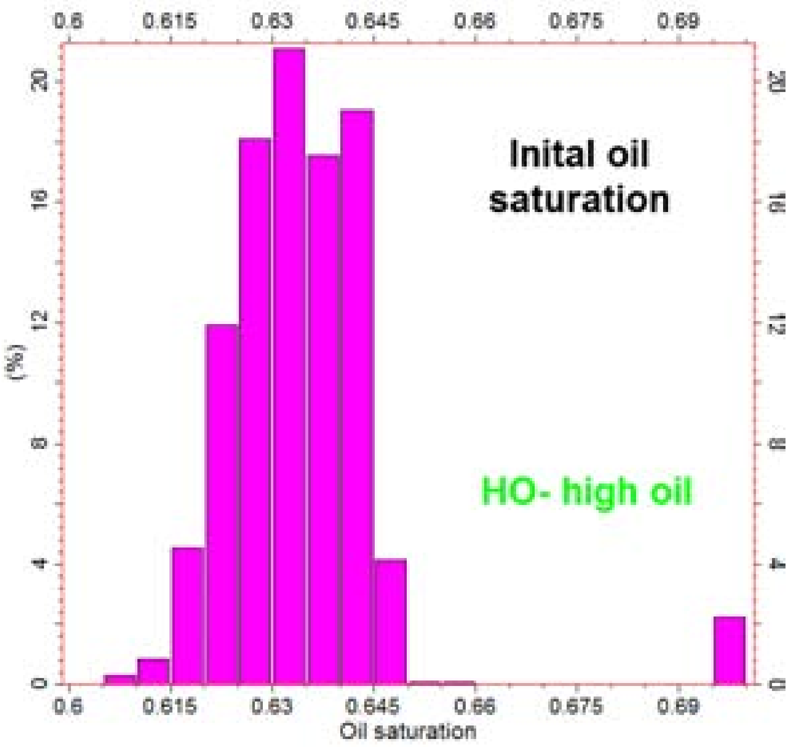
S: small area:
injectors: Baker 2
producers: Baker 1, Baker 3

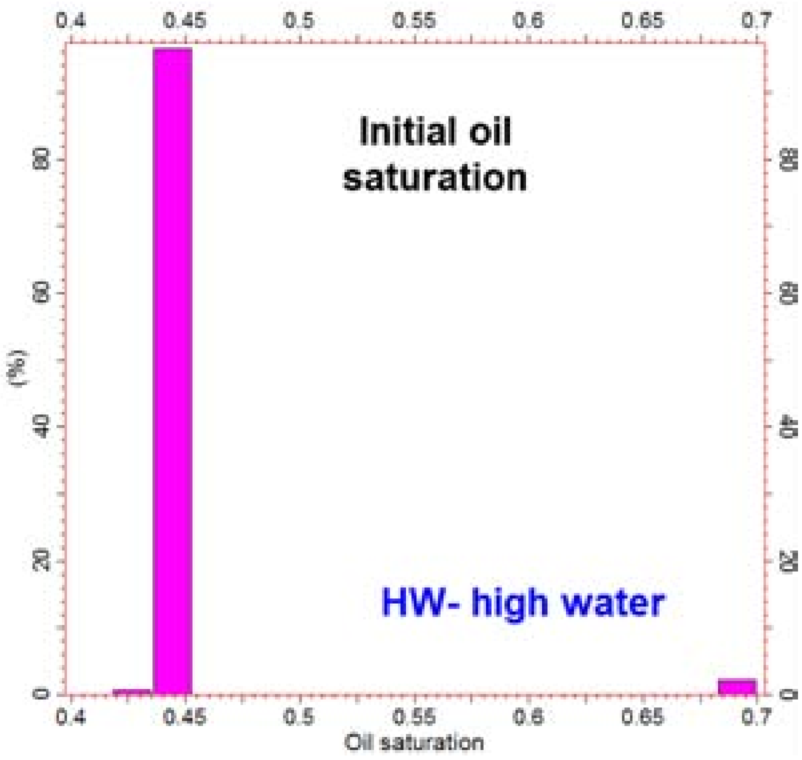


L: large area:
injectors: Baker 2, Baker 3
producers: Kallerud 1, Kallerud 2



Initial Oil Saturation: High Oil vs. High Water





Injection & Production Conditions at Wells

Constant injector pressure (1600 Psi) at all cases
Constant producer pressure (200 psi) at all cases

Simulation settings:

Cell size: 50’ x 50’ x 1’
Number of cells: 190,718
Simulation starting time: 1/1/2016

Modelling Factors:

Permeability at wells: HK, RK, UK
Relative permeability curves: **M**(all matrix) , **D1**(K>800 md), **D2** (k>600 md)
Drainage area: **S** (small area), **L** (large area)
Initial oil saturation: HO(high oil), HW (high water)

Simulation Scenarios:

S	HK	RK	UK	HK	RK	UK
M	S-HK-M-HO	S-RK-M-HO	S-UK-M-HO	S-HK-M-HW	S-RK-M-HW	S-UK-M-HW
D1	S-HK-D1-HO	S-RK-D1-HO	S-UK-D1-HO	S-HK-D1-HW	S-RK-D1-HW	S-UK-D1-HW
D2	S-HK-D2-HO	S-RK-D2-HO	S-UK-D2-HO	S-HK-D2-HW	S-RK-D2-HW	S-UK-D2-HW

L	HK	RK	UK	HK	RK	UK
M	L-HK-M-HO	L-RK-M-HO	L-UK-M-HO	L-HK-M-HW	L-RK-M-HW	L-UK-M-HW
D1	L-HK-D1-HO	L-RK-D1-HO	L-UK-D1-HO	L-HK-D1-HW	L-RK-D1-HW	L-UK-D1-HW
D2	L-HK-D2-HO	L-RK-D2-HO	L-UK-D2-HO	L-HK-D2-HW	L-RK-D2-HW	L-UK-D2-HW

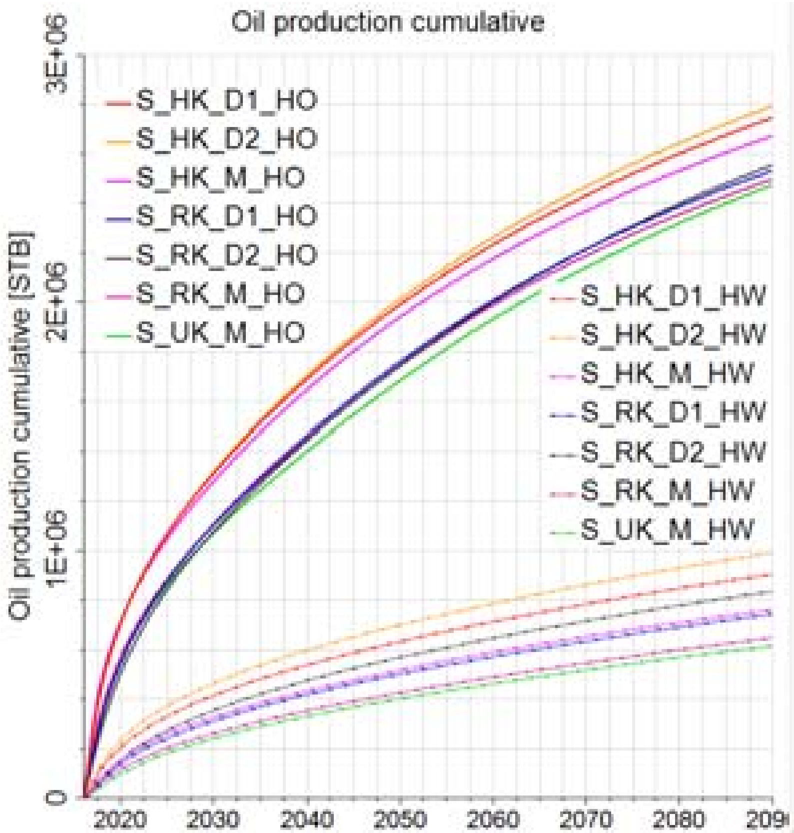
Comparison of the Simulation Results

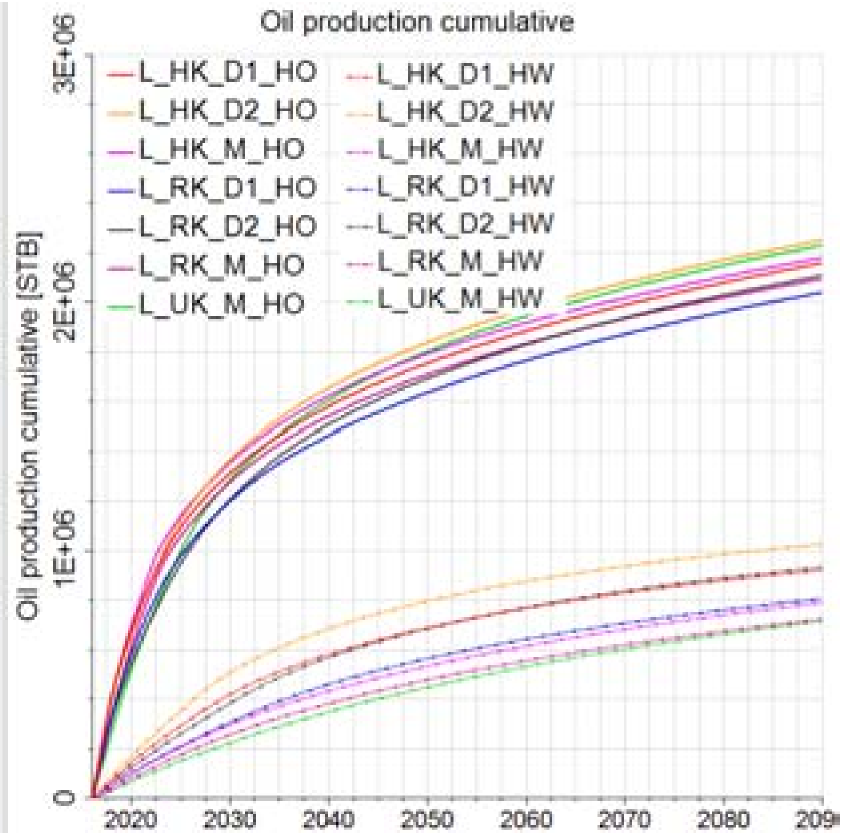
Cumulative Oil Production

HO, S: HK-high, RK-middle, UK-low; L: HK-D2-high, UK-high, RK-low

HW,S: HK-high, RK-middle, UK-low; L: HK-high, RK-middle, UK-low

HO cases high vs. HW low; S cases high vs. L cases low



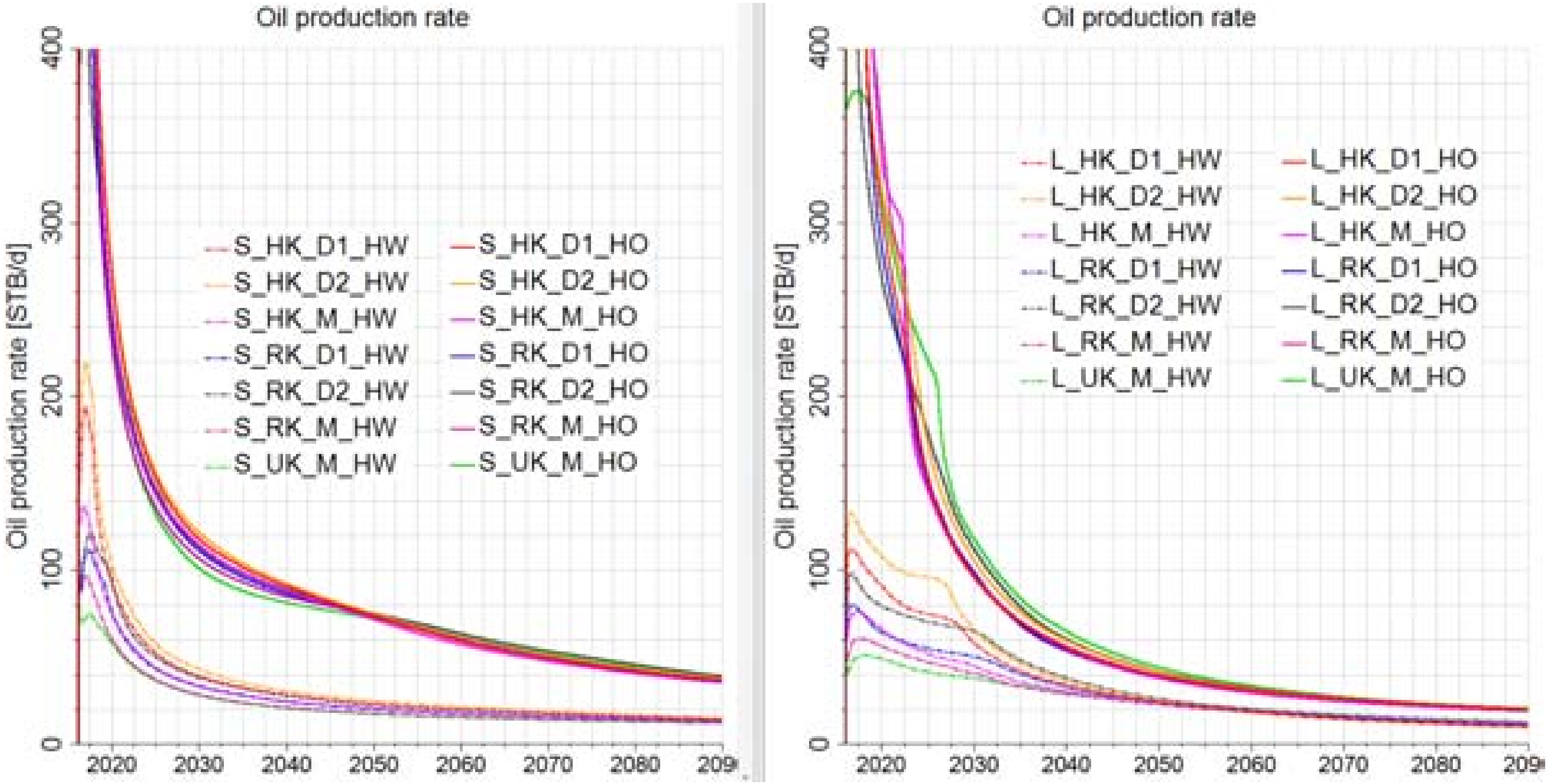


Oil Production Rate

HO,S: HK-high-to-low, RK-middle, UK-low-to-high; L: UK-high, HK-middle, RK-low

HW,S: UK-low, RK-middle, HK-high; L: UK-low-to-high, HK-high-to-low, RK-middle

HO cases high vs. HW cases low; S cases decline slow vs. L cases fast

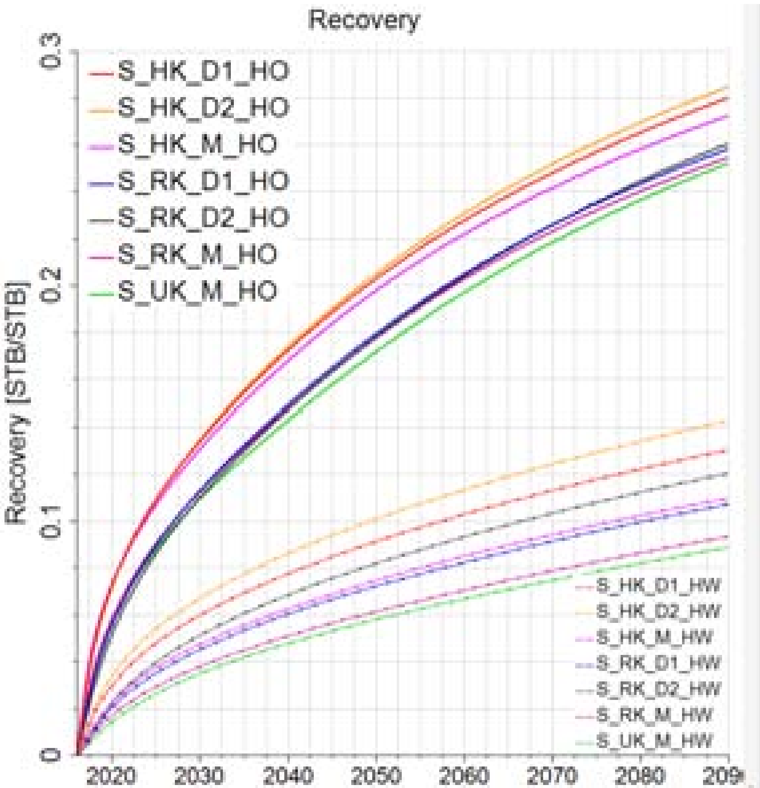


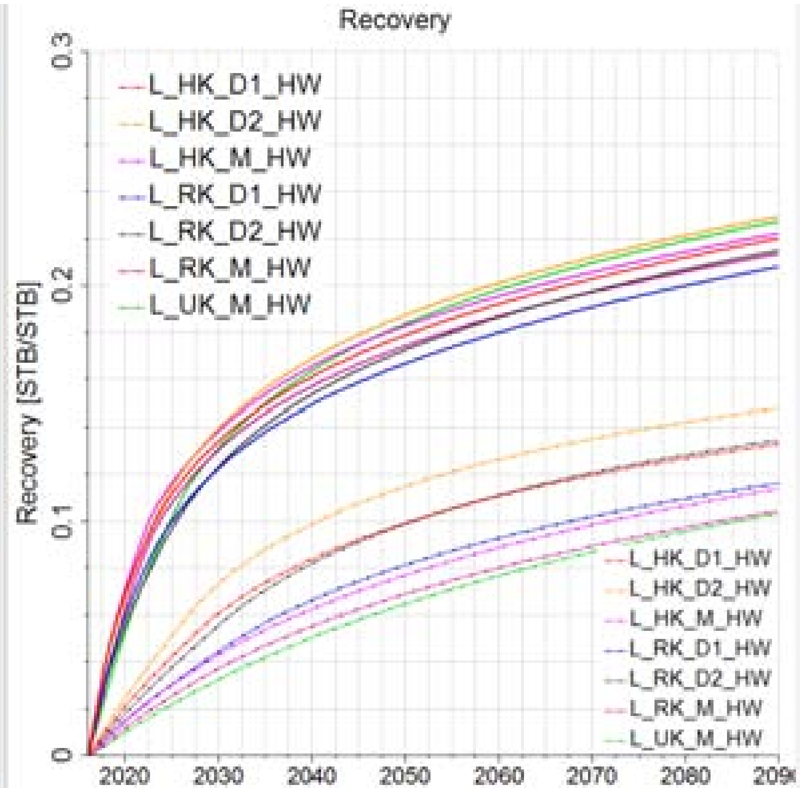
Oil Recovery

HO, S: HK-high, RK-middle, UK-low; L: HK-D2-high, UK-high, RK-low

HW,S: HK-high, RK-middle, UK-low; L: HK-D2-high, UK-low, RK-middle

HO cases high vs. HW cases low; S cases high vs. L cases low



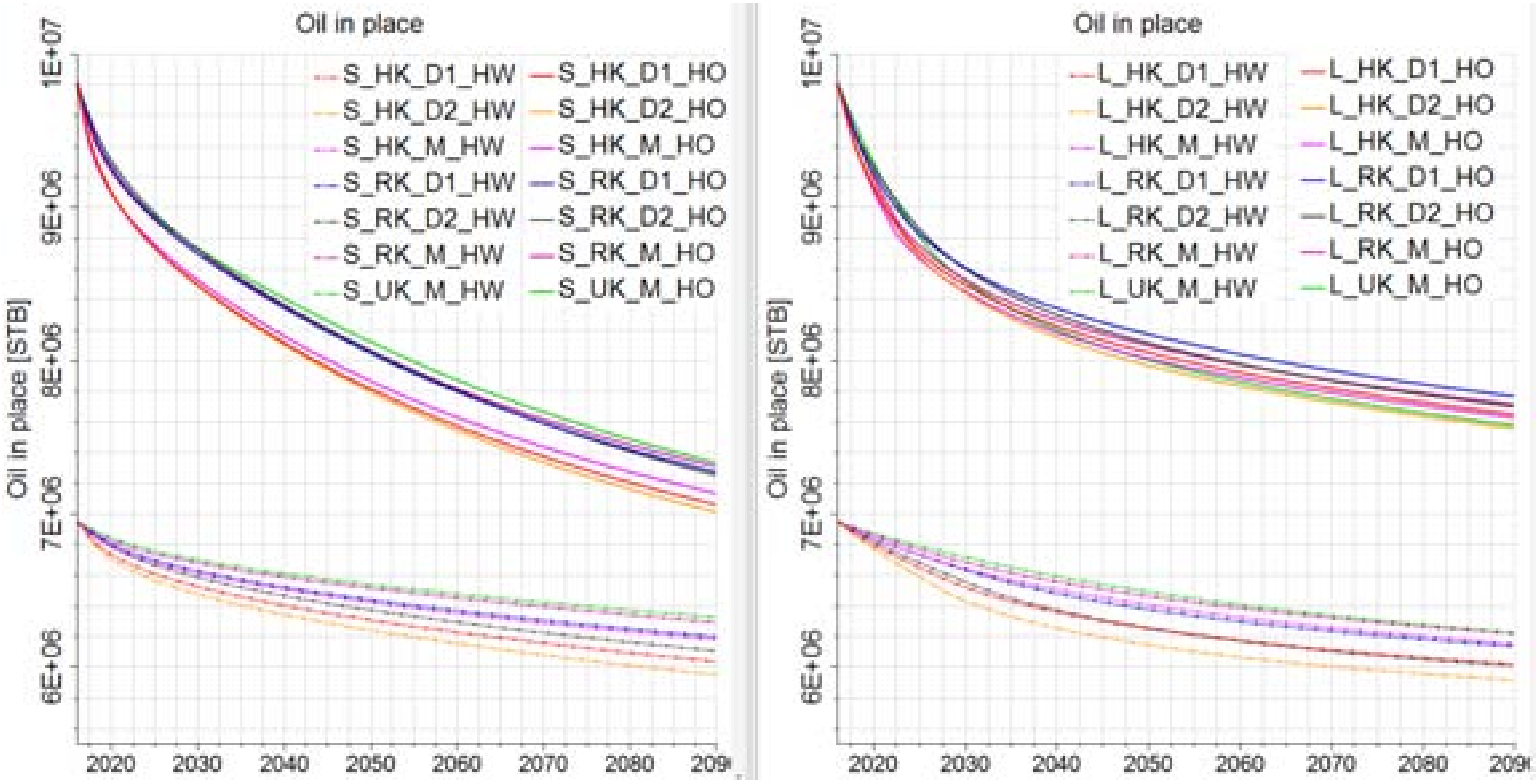


Oil in Place

HO,S: UK-high, RK-middle, HK-low; L: RK-high, HK-middle, UK-low

HW,S:UK-high, RK-middle, HK-low; L: UK-high, RK-middle, HK-low

HO cases high vs. HW cases low; S cases low vs. L cases high

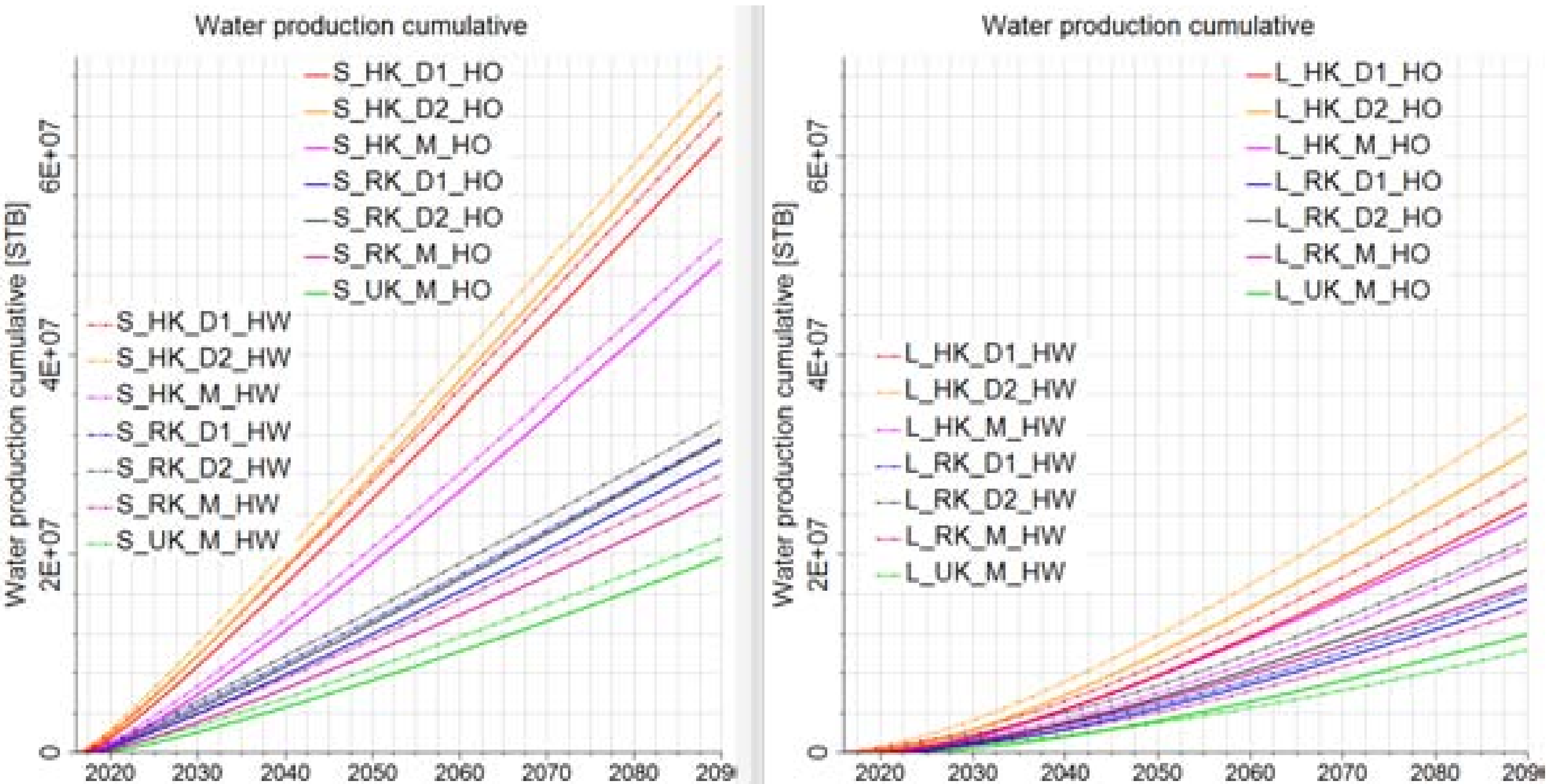


Cumulative Water Production

HO,S: HK-high, RK-middle, UK-low; L: HK-high, RK-middle, UK-low

HW,S:HK-high, RK-middle, UK-low; L: HK-high, RK-middle, UK-low

HW cases high vs. HO cases low; S cases high vs. L cases low

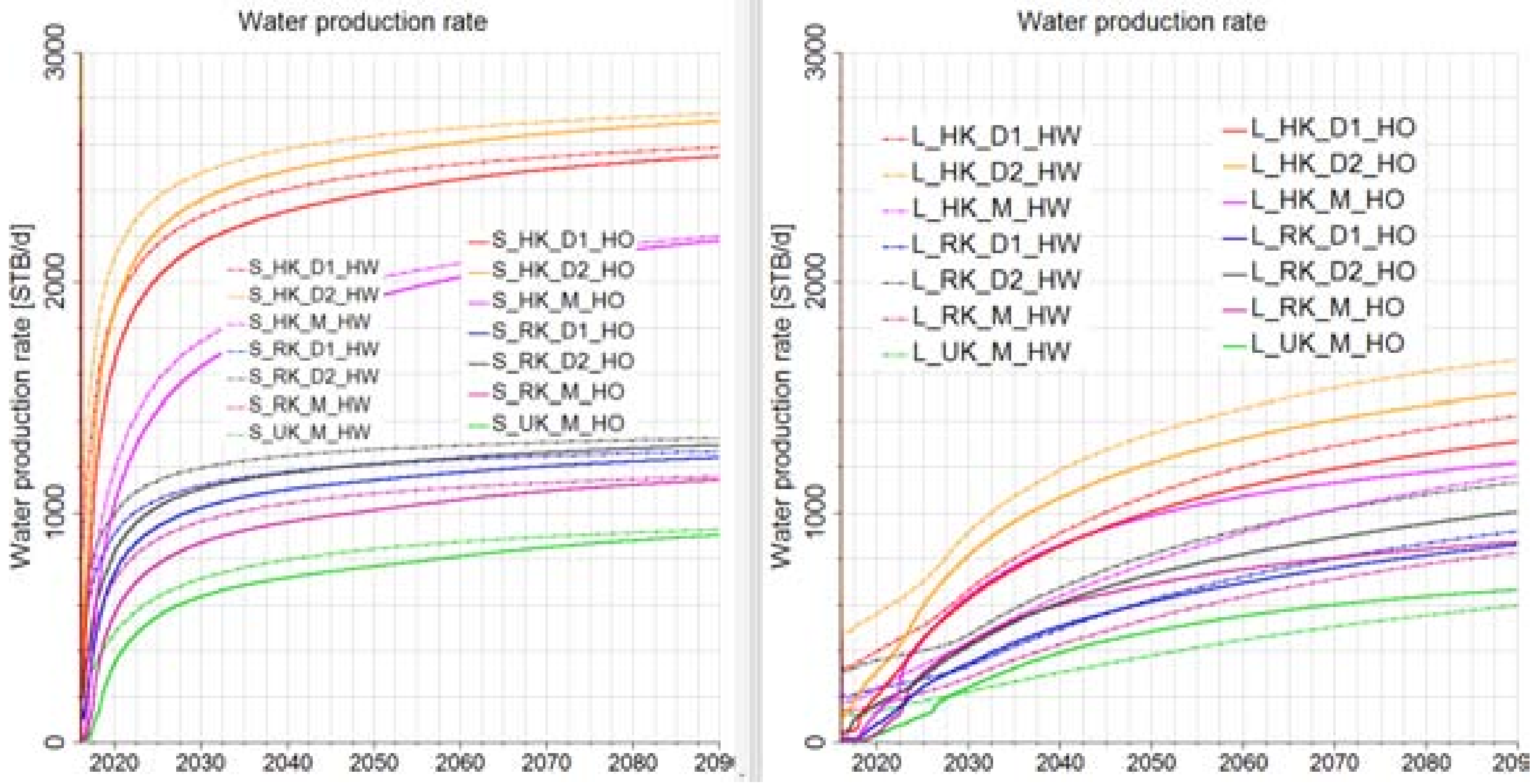


Water Production Rate

HO,S: HK-high, RK-middle, UK-low; L: HK-high, RK-middle, UK-low

HW,S:HK-high, RK-middle, UK-low; L: HK-high, RK-middle, UK-low

HO cases low vs. HW cases high; S cases high vs. L cases low

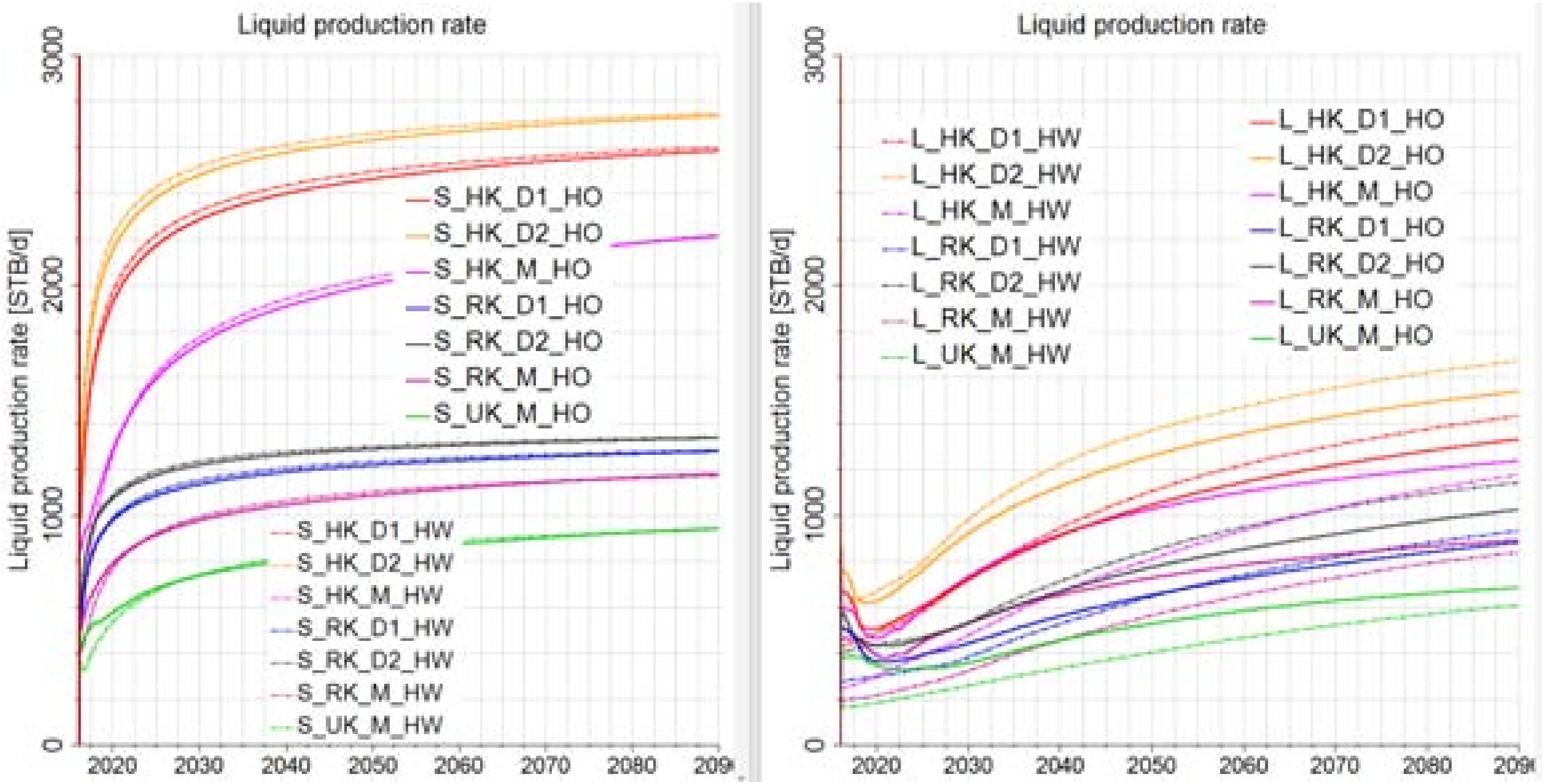


Liquid Production Rate

HO,S: HK-high, RK-middle, UK-low; L: HK-high, RK-middle, UK-low

HW,S:HK-high, RK-middle, UK-low; L: HK-high, RK-middle, UK-low

HO cases low vs. HW cases high; S cases high vs. L cases low

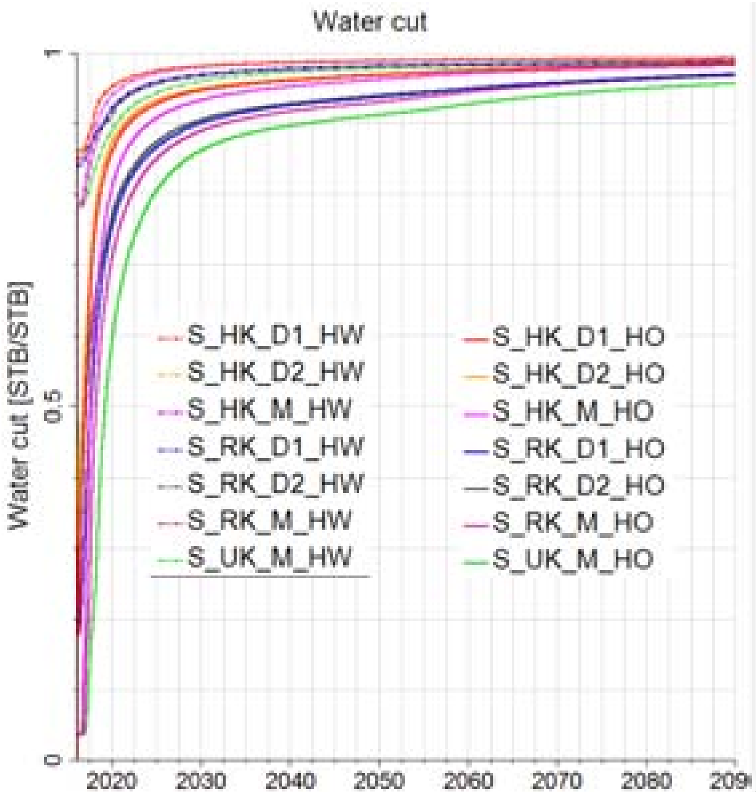


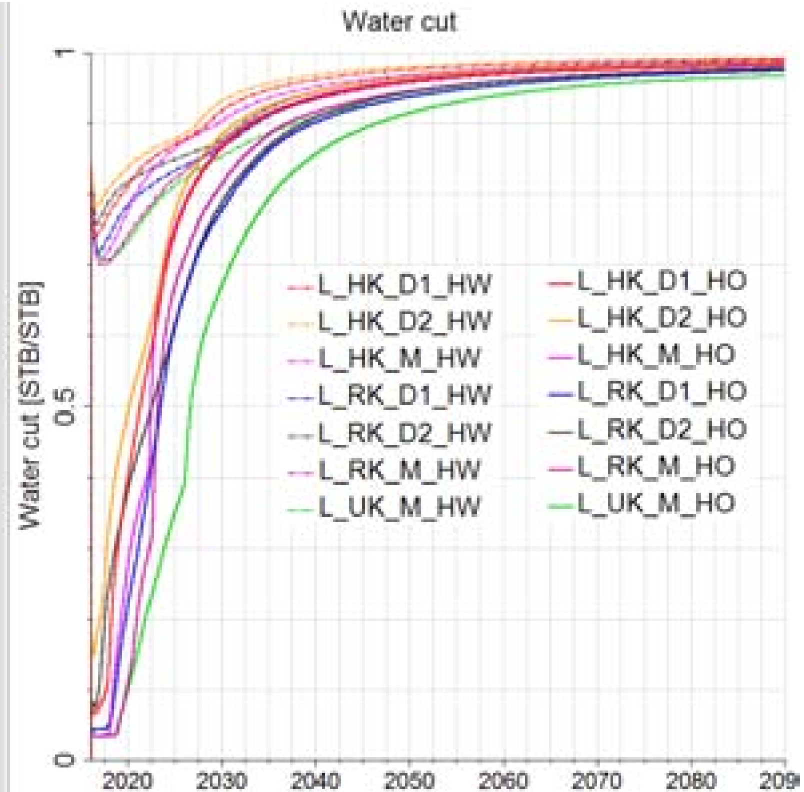
Water Cut

HO,S: HK-high, RK-middle, UK-low; L: HK-high, RK-middle, UK-low

HW,S:HK-high, RK-middle, UK-low; L: HK-high, RK-middle, UK-low

HO cases low vs. HW cases high; S cases increase fast vs. L cases slow



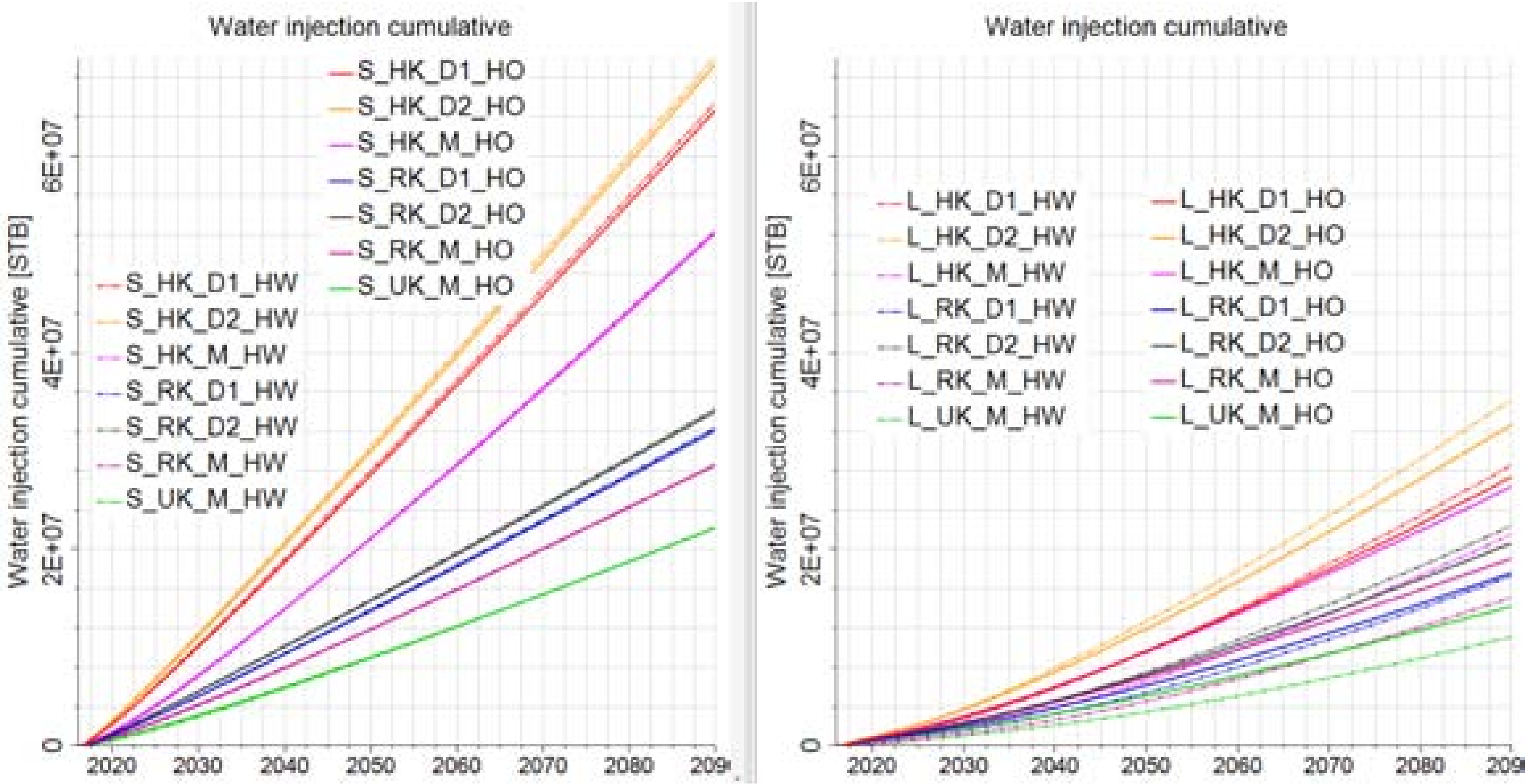


Cumulative Water Injection

HO, S:HK-high, RK-middle, UK-low; L: HK-high, RK-middle, UK-low

HW,S:HK-high, RK-middle, UK-low; L: HK-high, RK-middle, UK-low

HW cases are similar to HO cases; S cases high vs. L cases low

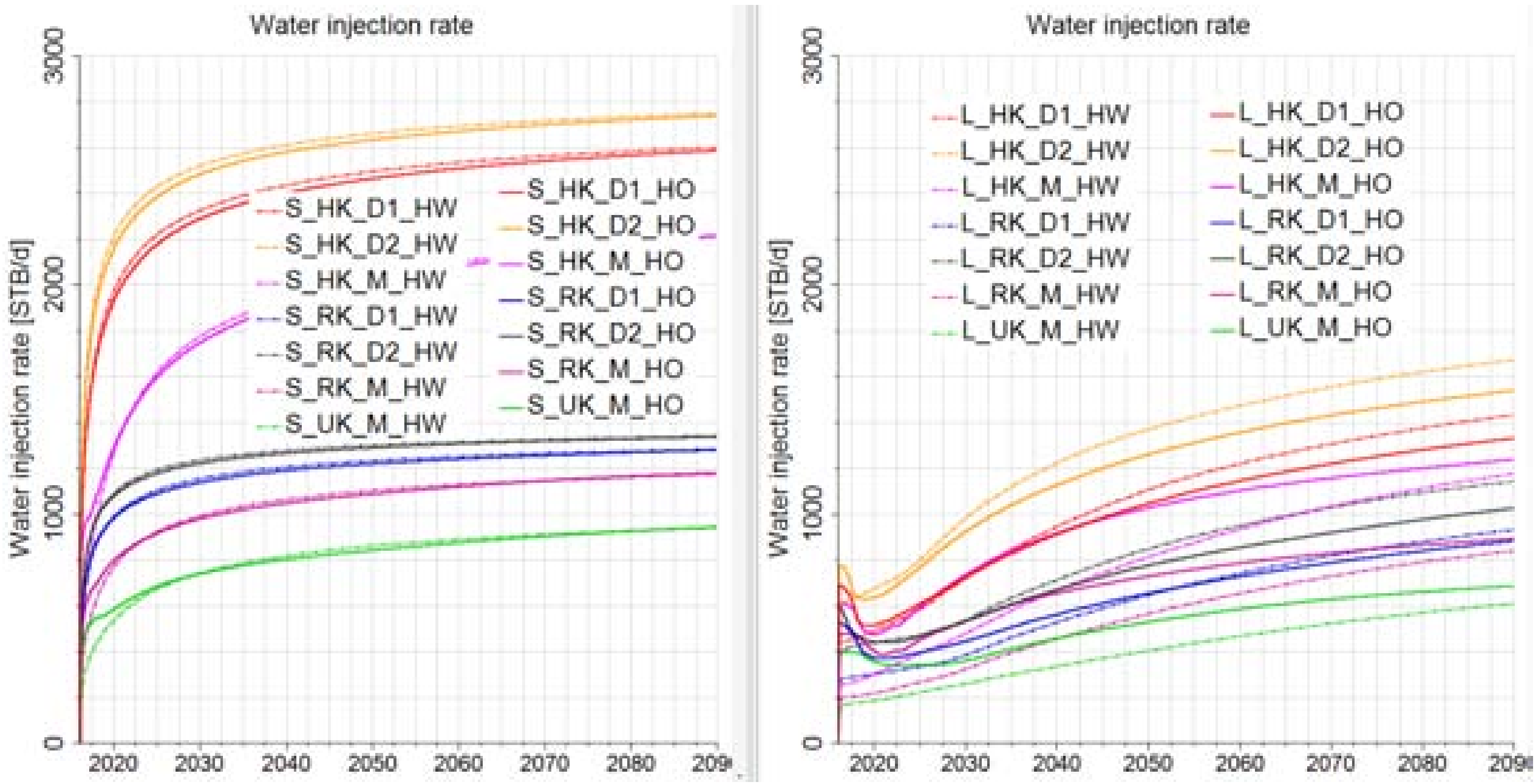


Water Injection Rate

HO,S: HK-high, RK-middle, UK-low; L: HK-high, RK-middle, UK-low

HW,S: HK-high, RK-middle, UK-low; L: HK-high, RK-middle, UK-low

HW cases similar to HO cases; S cases high vs. L cases low

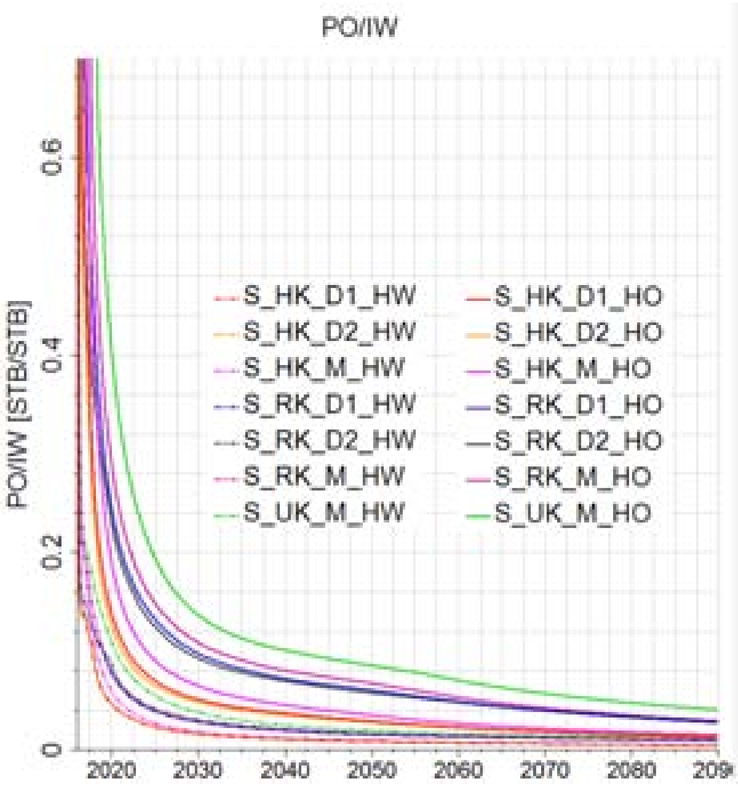


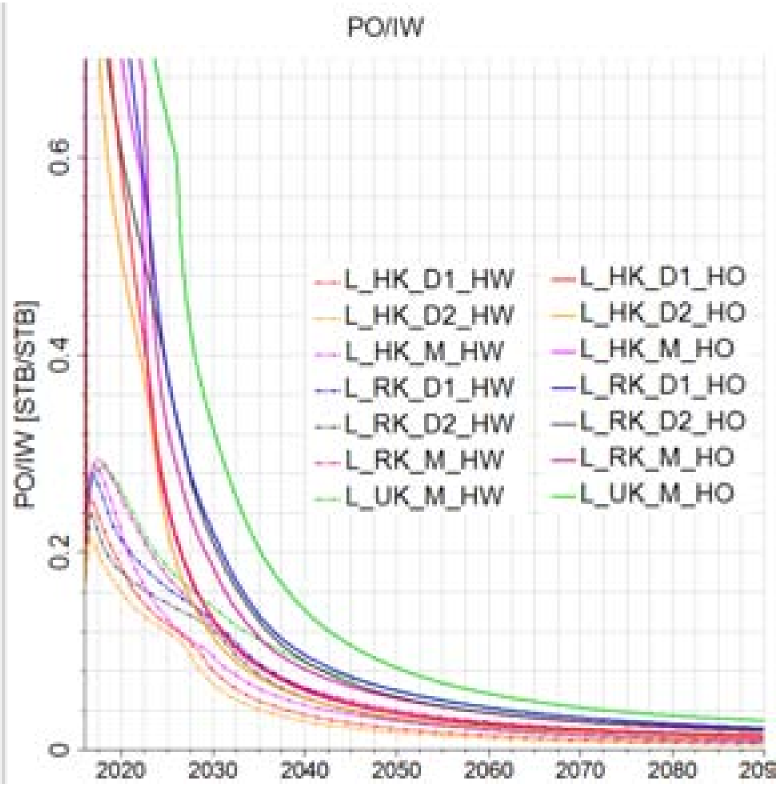
Injection Efficiency: Produced Oil Rate /Injected Water Rate

HO,S: HK-low, RK-middle, UK-high; L: HK-low, RK-middle, UK-high

HW,S:HK-low, RK-middle, UK-high; L: HK-low, RK-middle, UK-high

HW cases low vs. HO cases high; S cases low vs. L cases high



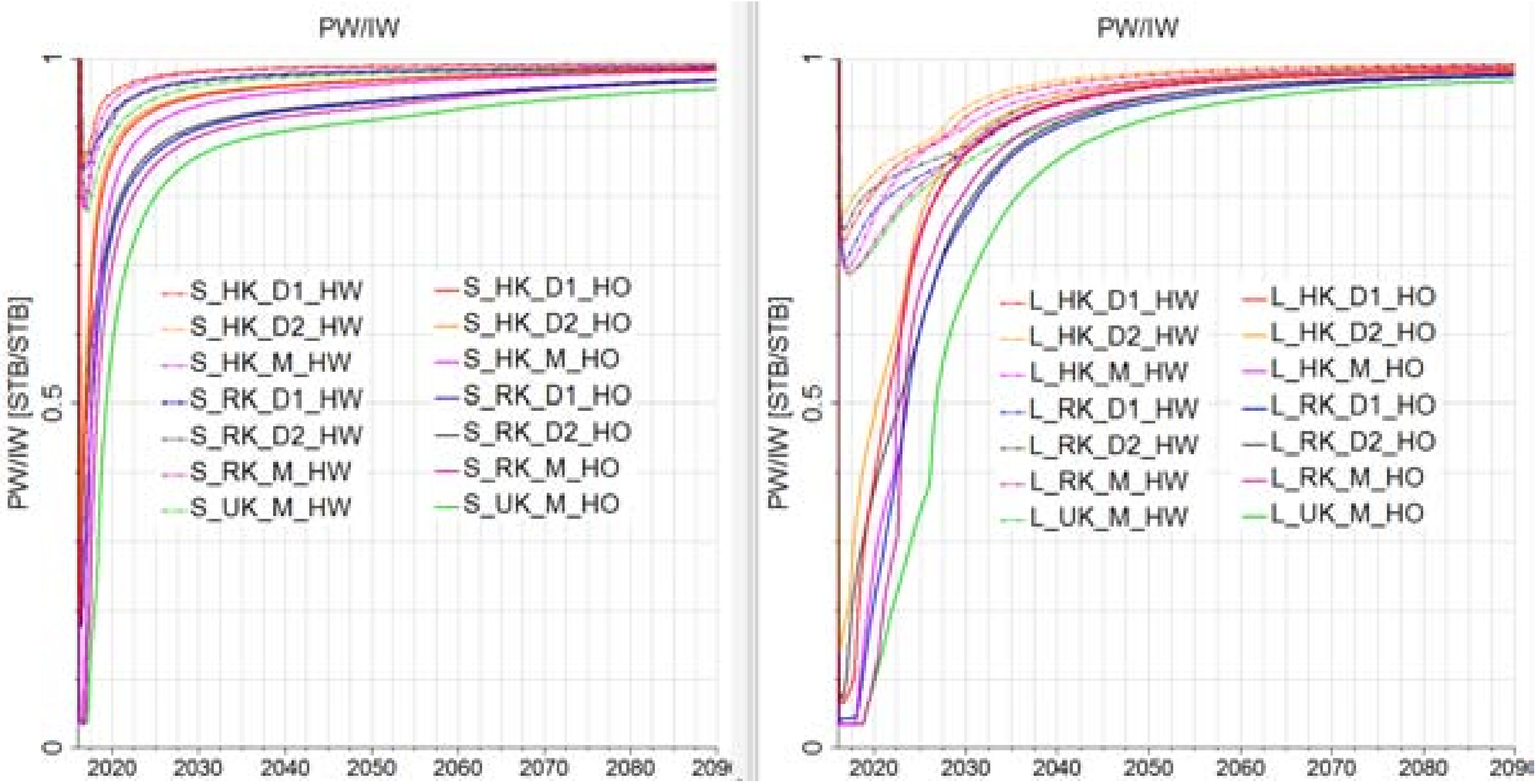


Injection Efficiency: Produced Water Rate /Injected Water Rate

HO,S: HK-high, RK-middle, UK-low; L: HK-high, RK-middle, UK-low

HW,S:HK-high, RK-middle, UK-low; L: HK-high, RK-middle, UK-low

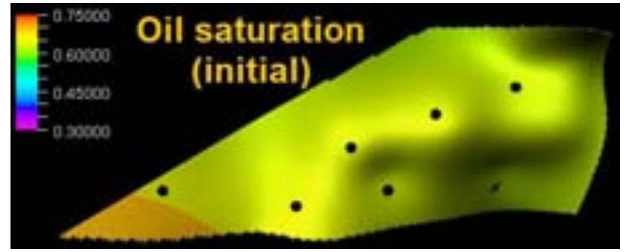
HO cases low vs. HW cases high; S cases high vs. L cases low

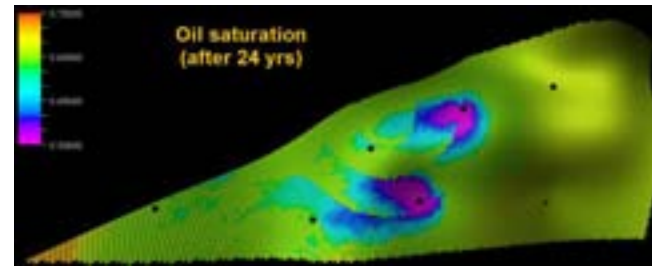


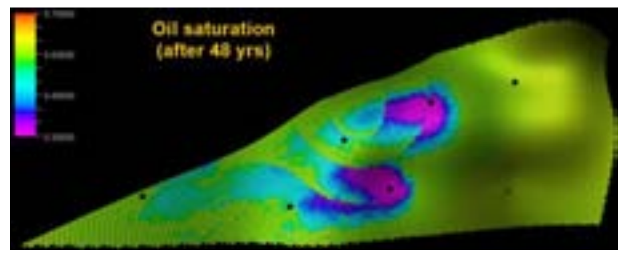
Sweep Efficiency (SE)

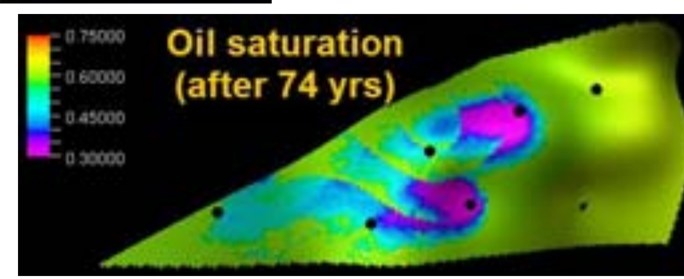
Definitions:
Swept cell: oil saturation decreasing at least 5%
Sweep efficiency (%):
  swept cells*100/total cells

Cell size: 50’ x 50’ x 1’
Number of cells: 190,718









Sweep Efficiency after 24 Years of Production (2040)

HO,S: HK-high, RK-middle, UK-low; L: HK-middle, RK-low, UK-high
HW,S: HK-high, RK-middle, UK-low; L : HK-high, RK-middle, UK-low
HO cases high vs. HW cases low; S cases high vs. L cases low

S-HO	HK	RK	UK
M	36.6	33.9	33.7
D1	37.2	33.7	33.7
D2	36.8	32.5	33.7

L-HO	HK	RK	UK
M	36.3	35.7	39.4
D1	35.9	34.9	39.4
D2	36.4	34.7	39.4

S-HW	HK	RK	UK
M	17.2	13.7	13.2
D1	19.8	15.3	13.2
D2	20.9	16.0	13.2

L-HW	HK	RK	UK
M	16.4	13.9	12.6
D1	21.3	16.1	12.6
D2	23.4	18.2	12.6

Sweep Efficiency after 48 Years of Production (2064)

HO,S: HK-high, RK-middle, UK-low; L: HK-middle, RK-low, UK-high
HW,S: HK-high, RK-middle, UK-low; L : HK-high, RK-middle, UK-low
HO cases high vs. HW cases low; S cases high vs. L cases low

S-HO	HK	RK	UK
M	48.3	46.2	45.9
D1	50.0	46.4	45.9
D2	50.1	45.3	45.9

L-HO	HK	RK	UK
M	40.9	40.8	45.1
D1	40.0	39.3	45.1
D2	40.5	39.4	45.1

S-HW	HK	RK	UK
M	23.8	20.1	19.5
D1	27.1	22.4	19.5
D2	28.4	23.6	19.5

L-HW	HK	RK	UK
M	24.1	21.7	22.7
D1	28.2	24.1	22.7
D2	29.8	26.1	22.7

Sweep Efficiency after 74 Years of Production (2090)

HO,S: HK-high, RK-low, UK-middle; L: HK-low, RK-middle, UK-high
HW,S: HK-high, RK-middle, UK-low; L : HK-high, RK-middle, UK-low
HO cases high vs. HW cases low; S cases high vs. L cases low

S-HO	HK	RK	UK
M	55.9	53.8	54.6
D1	57.5	54.6	54.6
D2	57.6	54.5	54.6

L-HO	HK	RK	UK
M	43.8	44.0	48.6
D1	42.8	42.5	48.6
D2	43.3	42.4	48.6

S-HW	HK	RK	UK
M	29.0	25.6	24.9
D1	32.6	28.0	24.9
D2	34.1	29.5	24.9

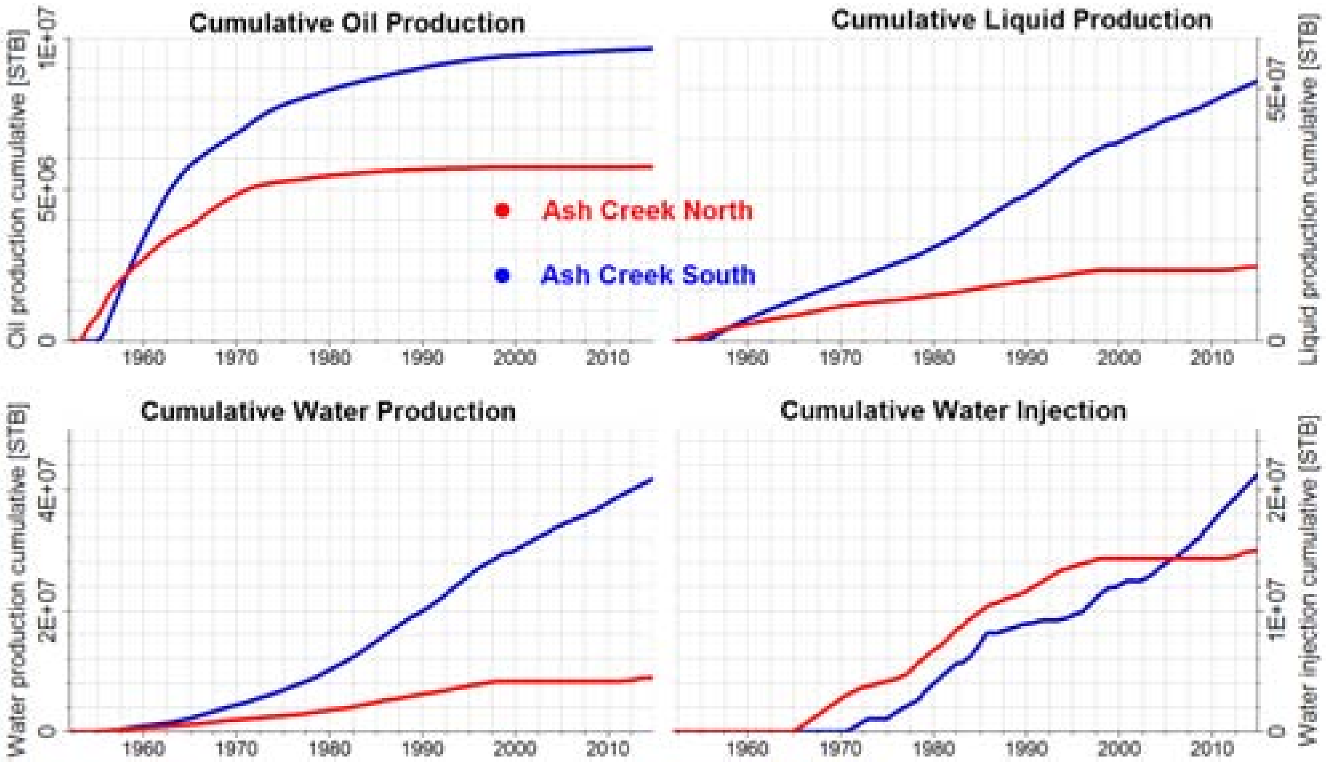
L-HW	HK	RK	UK
M	28.8	26.6	28.8
D1	31.7	28.4	28.8
D2	33.1	30.1	28.8

Primary Analysis of Ash Creek Data

Basic Cumulative Data

North: low oil production
low water production
high water injection (<2010)
weak water drive

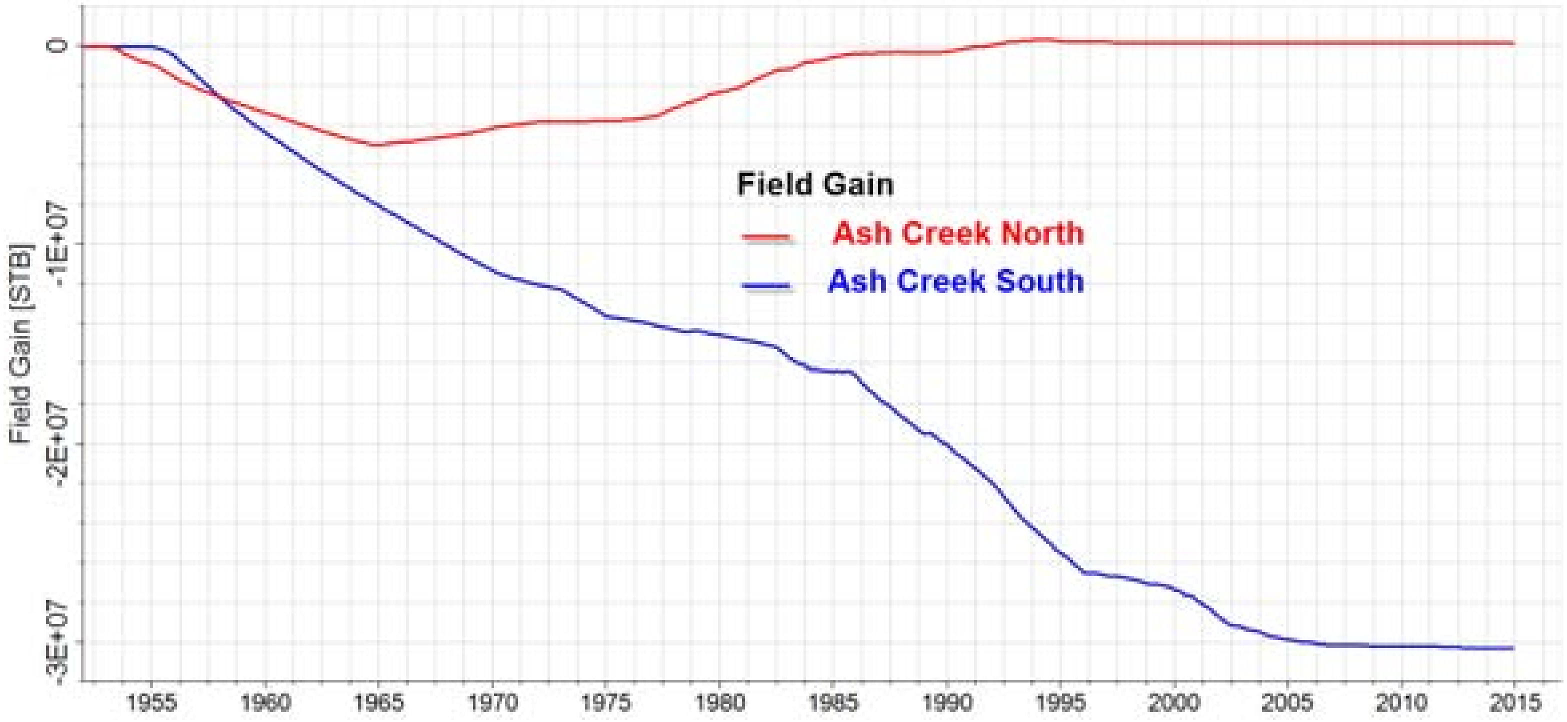
South: high oil production
high water production
low water injection
strong water drive



Field Liquid Gain from Injection and Production

Definition: cumulative injection – cumulative liquid production

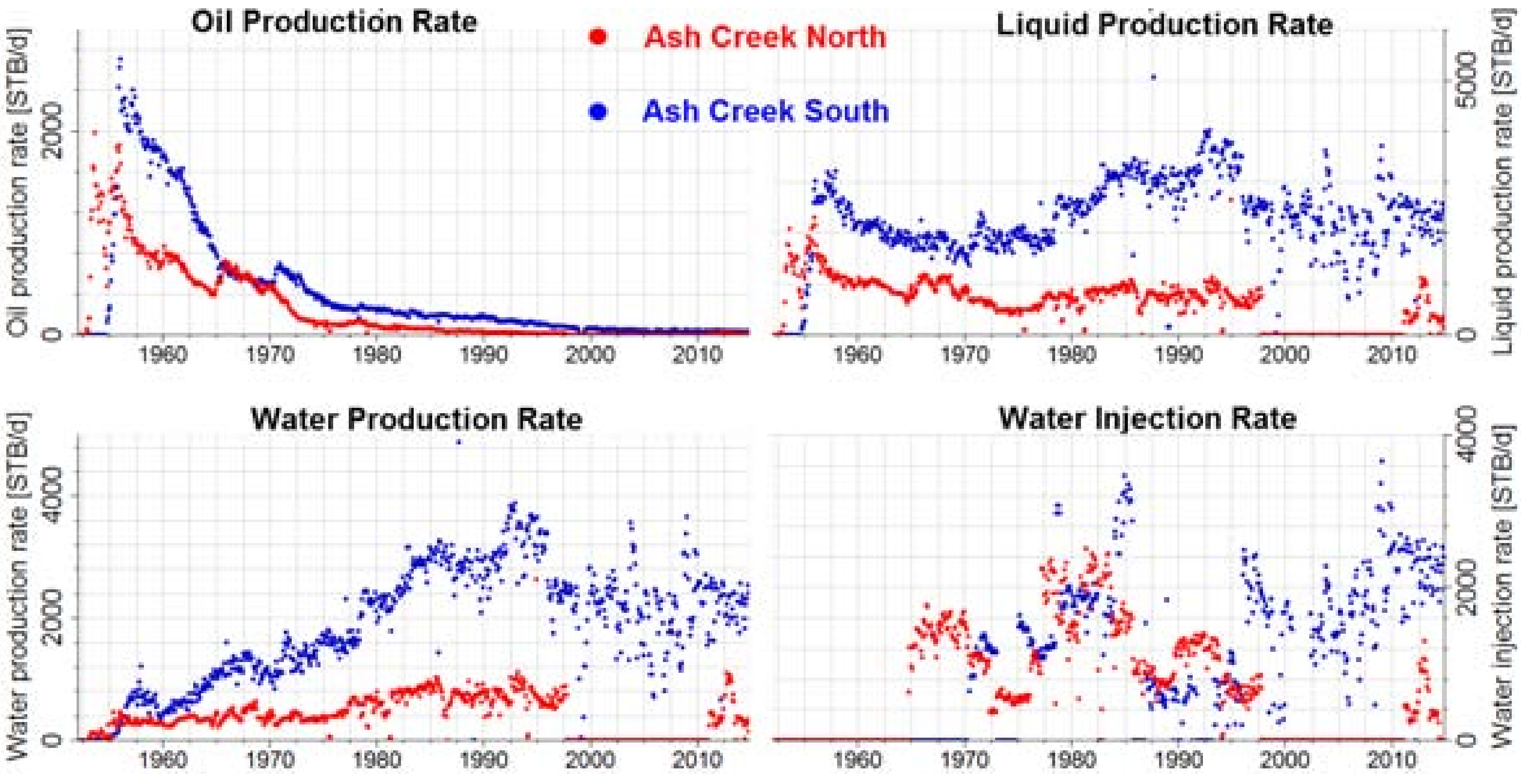
North: small South: huge aquifer water



Basic Rates

North: low oil production rate
low water production rate
high water injection rate early

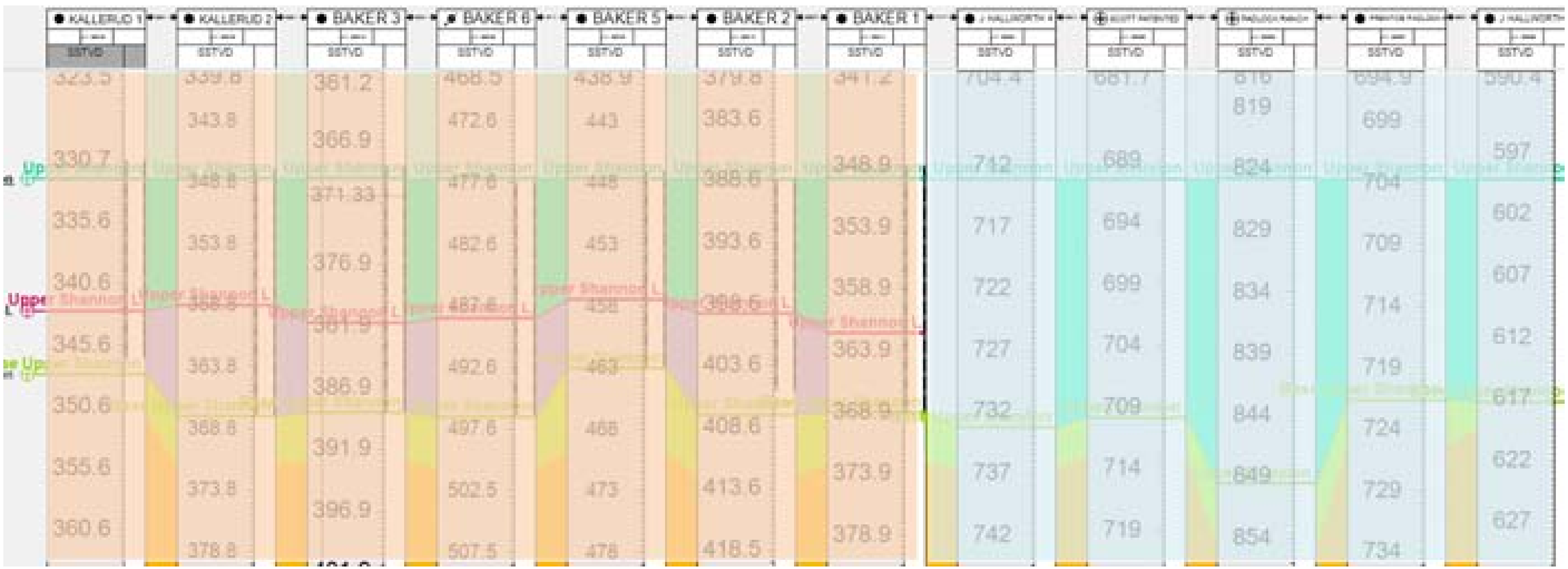
South: high oil production rate
high water production rate
low water injection rate early



Formation Depth

North: shallow
weak water drive
possible high oil saturation

South: deep
strong water drive
possible low oil saturation



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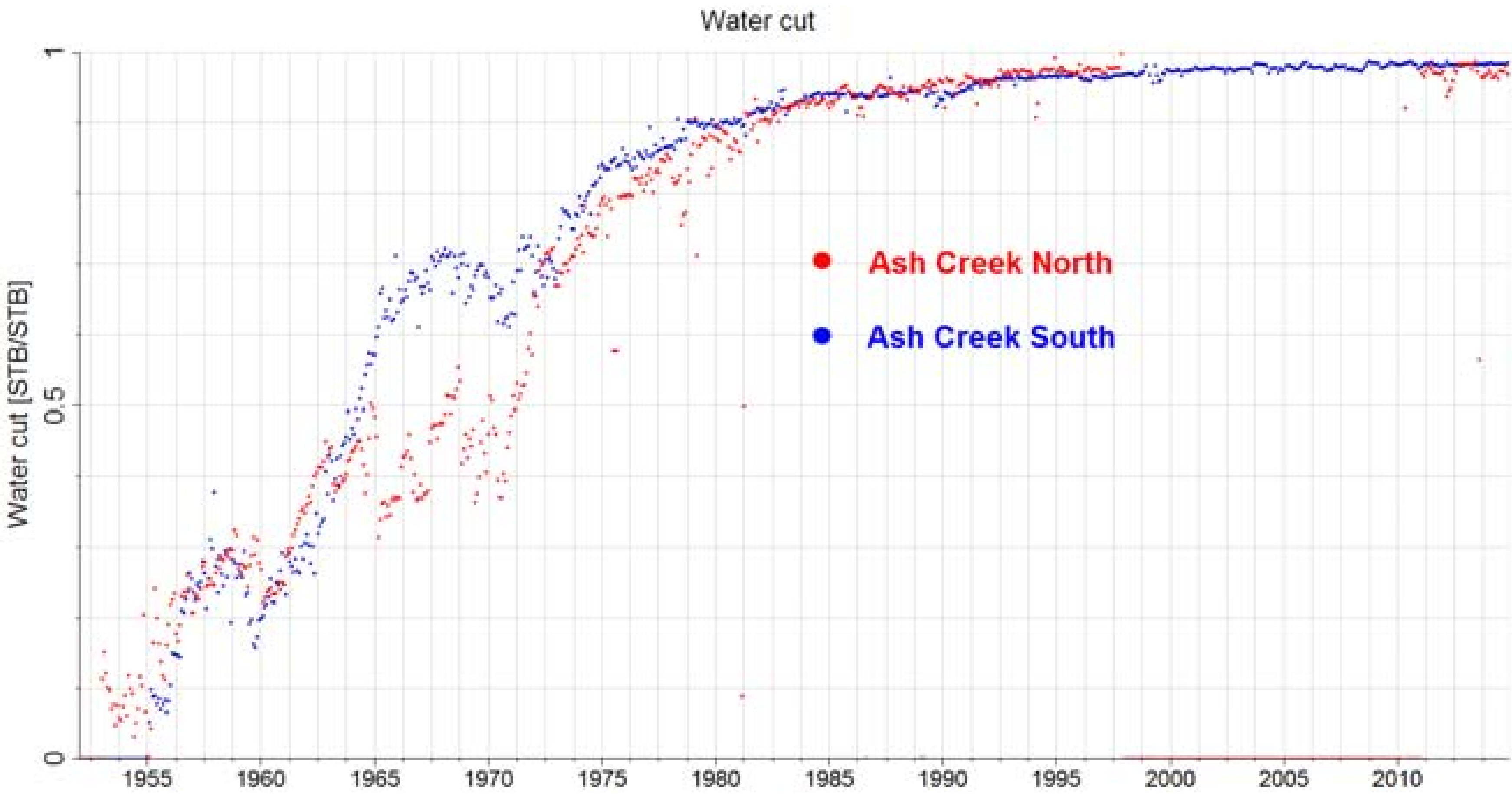
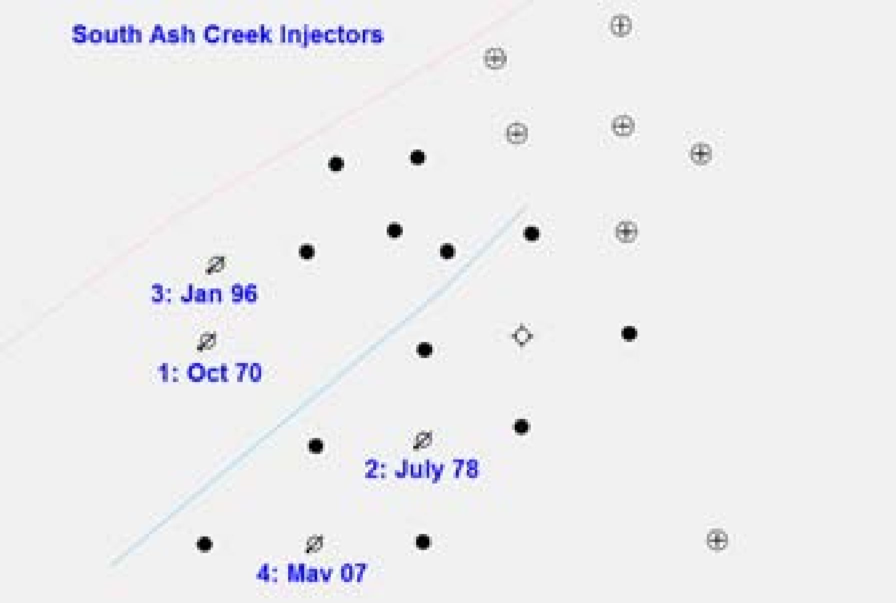
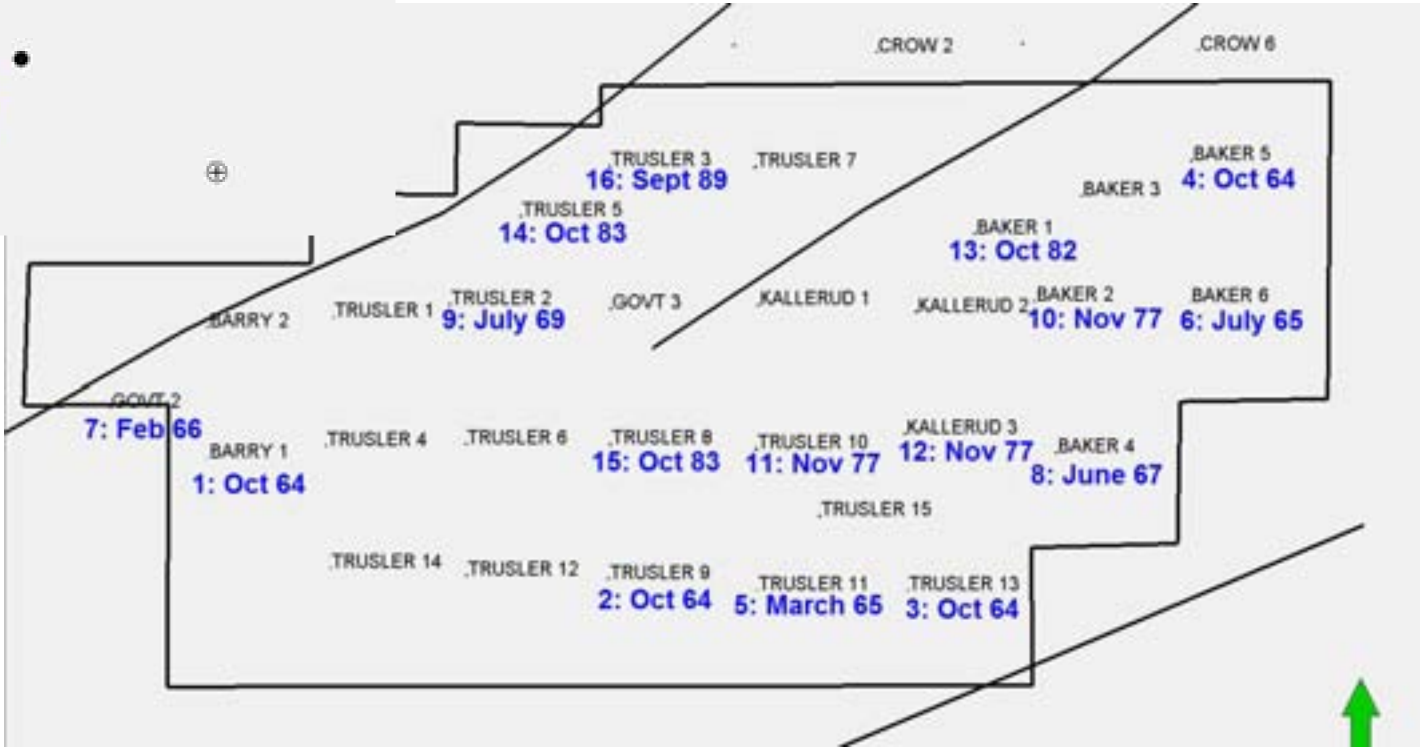
Water cut

North: low water cut **South**: high water cut



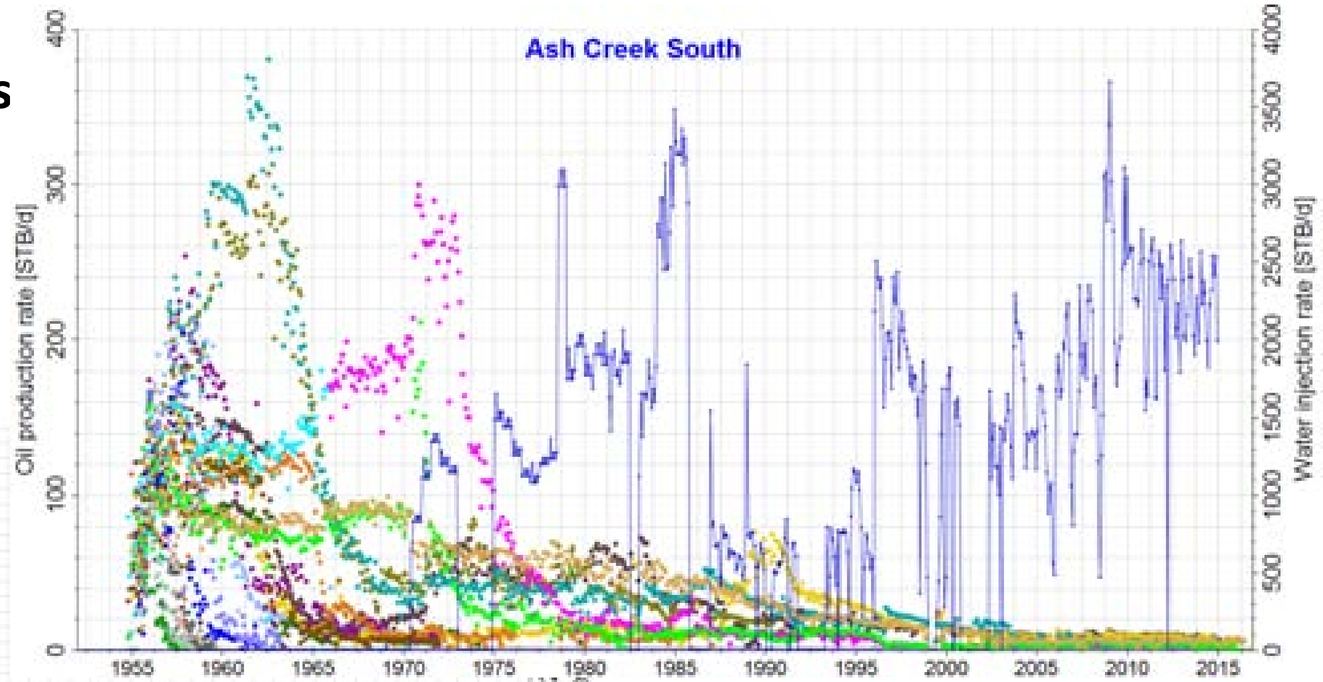
Water Injection Sequence and Locations

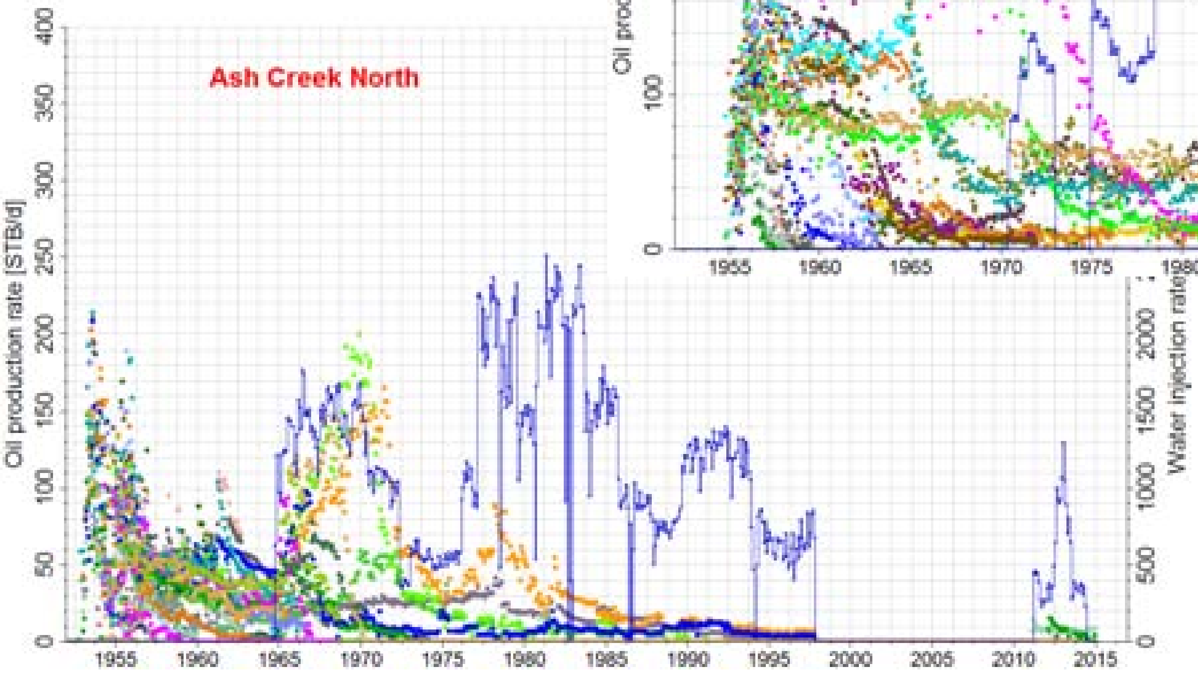




Oil Production Responses to Water Injection

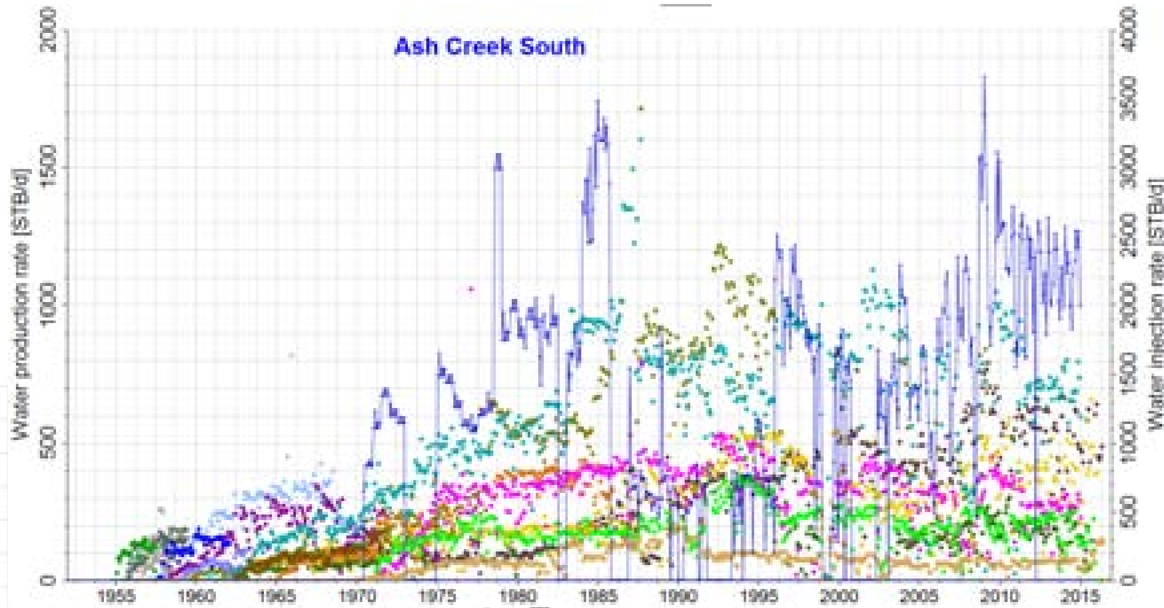
North:
strong and instantaneous

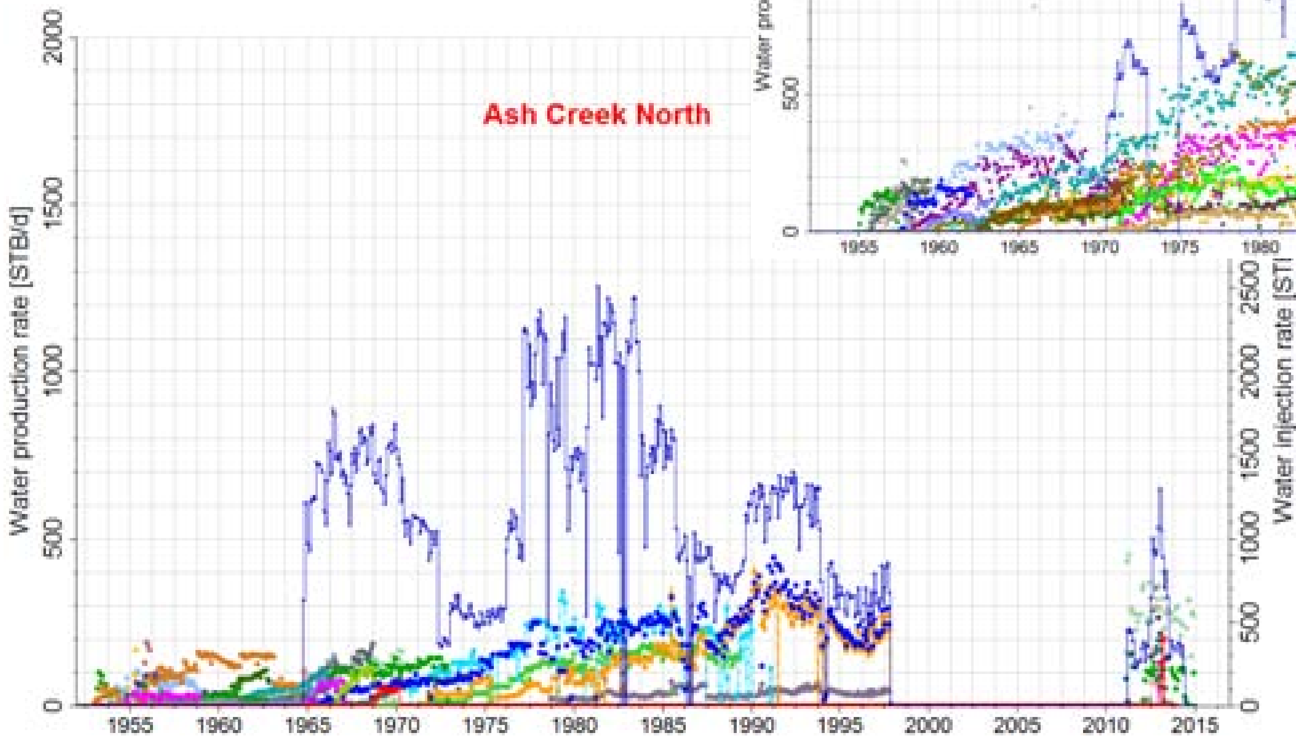




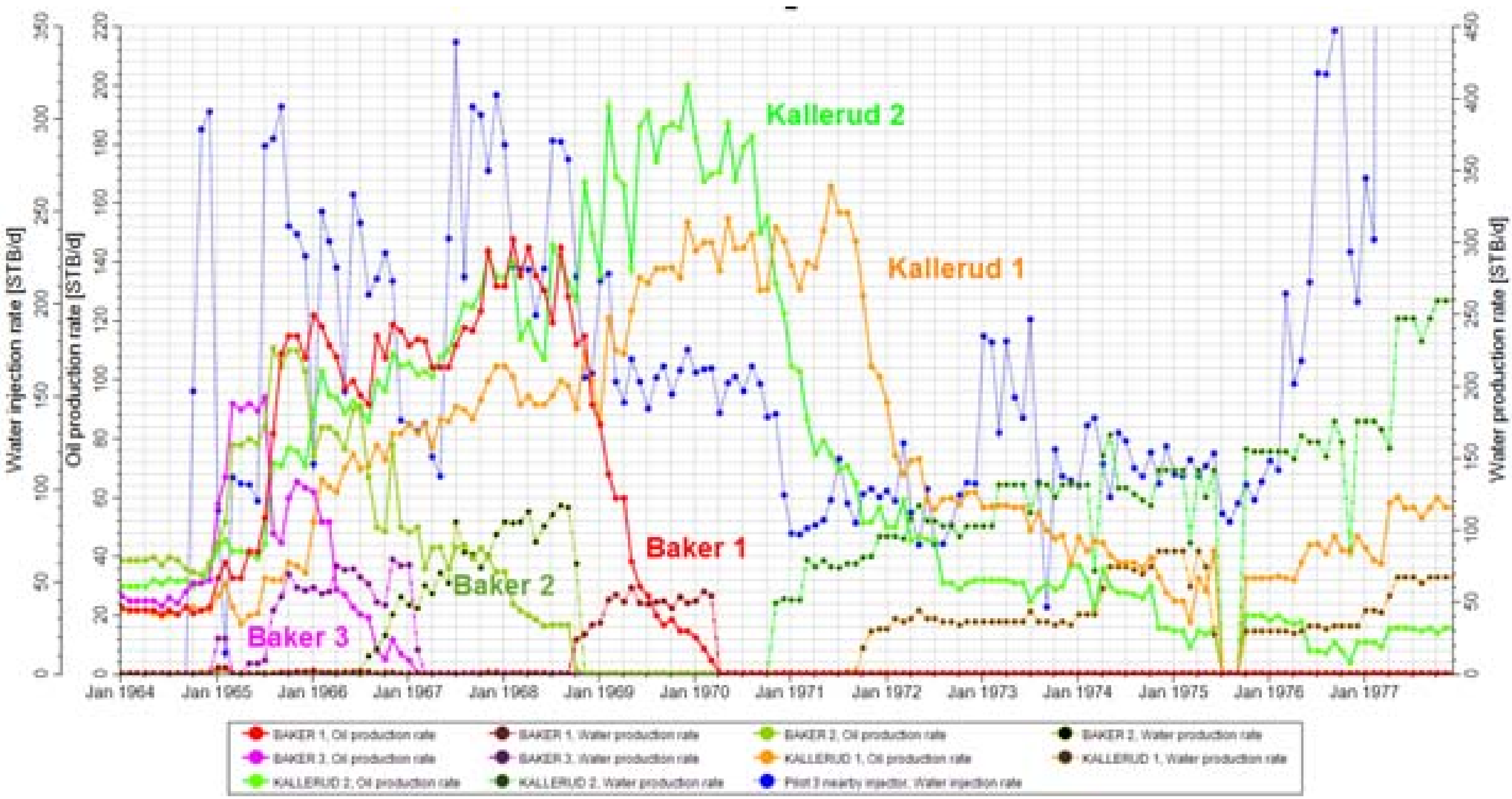
South:
One well strong and instantaneous

Water Production Responses to Water Injection





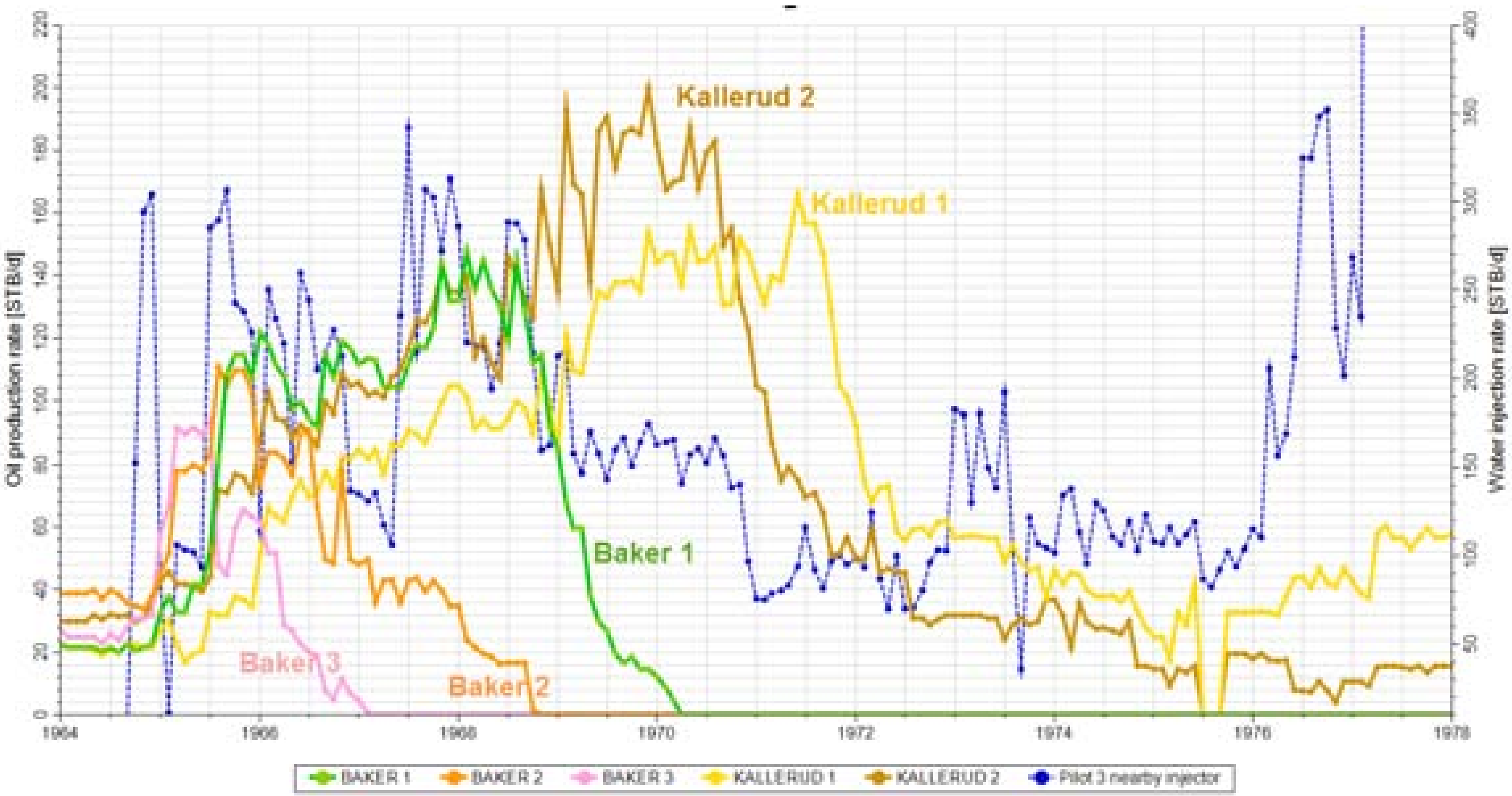
Well Responses to the Injections at Baker 4, Baker 5, Baker 6, Trusler2



Well Responses (Oil) to the Injections at Baker 4, Baker 5, Baker 6, Trusler2

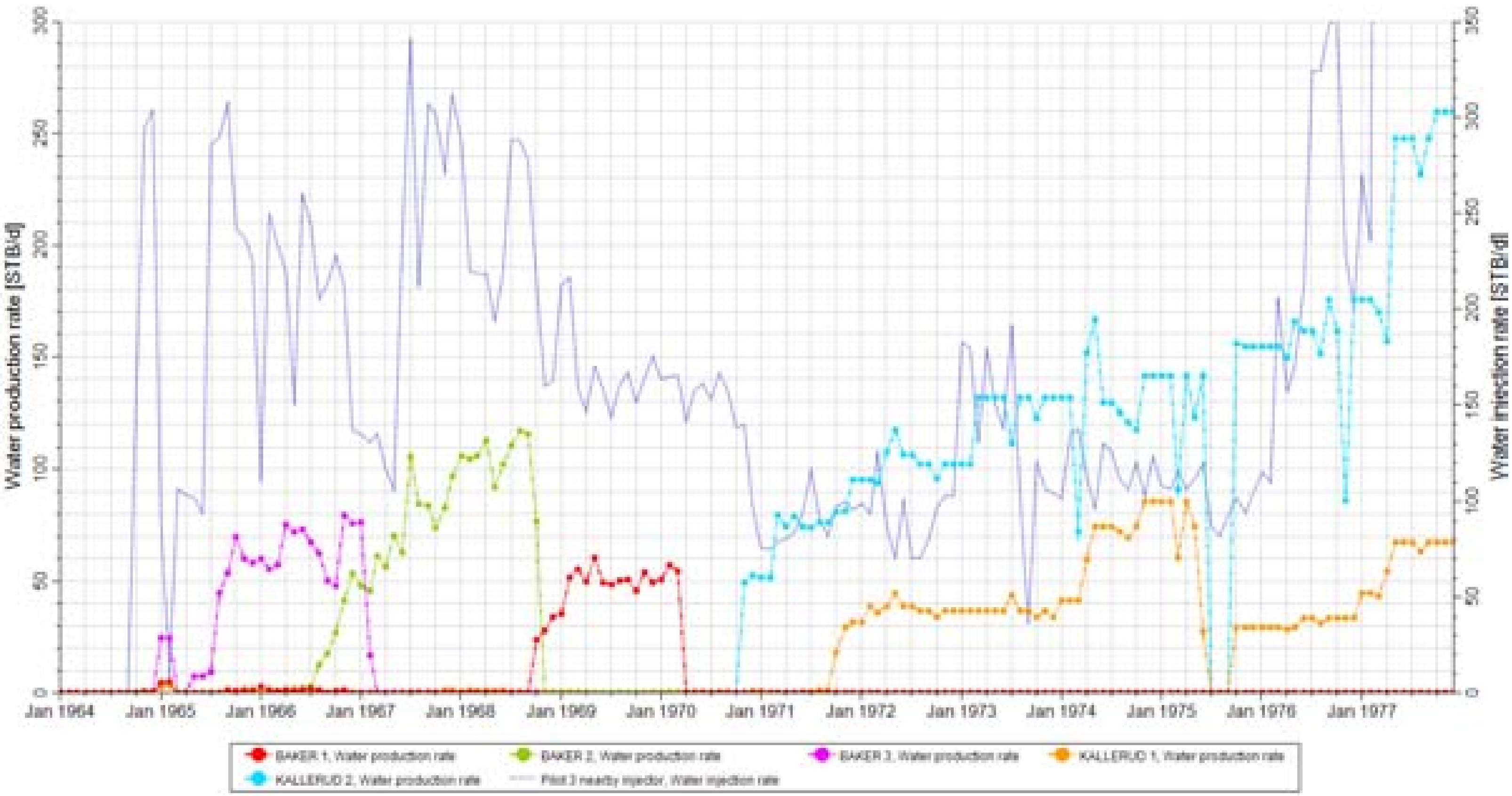
Baker 2 and Baker 3 have responses at almost same time; Baker 3 stronger than Baker 2

Baker 1 and Kallerud 2 have response at almost same time; Baker 1 stronger than kallerud 2



Well Responses (Water) to the Injections at Baker 4, Baker 5, Baker 6, Trusler2

Water breakthrough sequence: Baker 3, Baker 2, Baker 1, Kallerud 2, Kallerud 1



Conclusions

1. The synthetic models of Pilot 3 area are generated and the simulations are completed.
2. The high values of core permeability do impact the production, injection efficiency, and sweep efficiency.
3. In general, an uniform permeability distribution over the entire field is better for high production, high injection efficiency, and high sweep efficiency over the entire field.
4. However, in a small local area, cells having high permeability seems better for production.
5. High heterogeneity of the field made a high remaining oil in place, and a high homogeneity field will produce a high amount of oil.

Thank You or Questions, Comments, Suggestions

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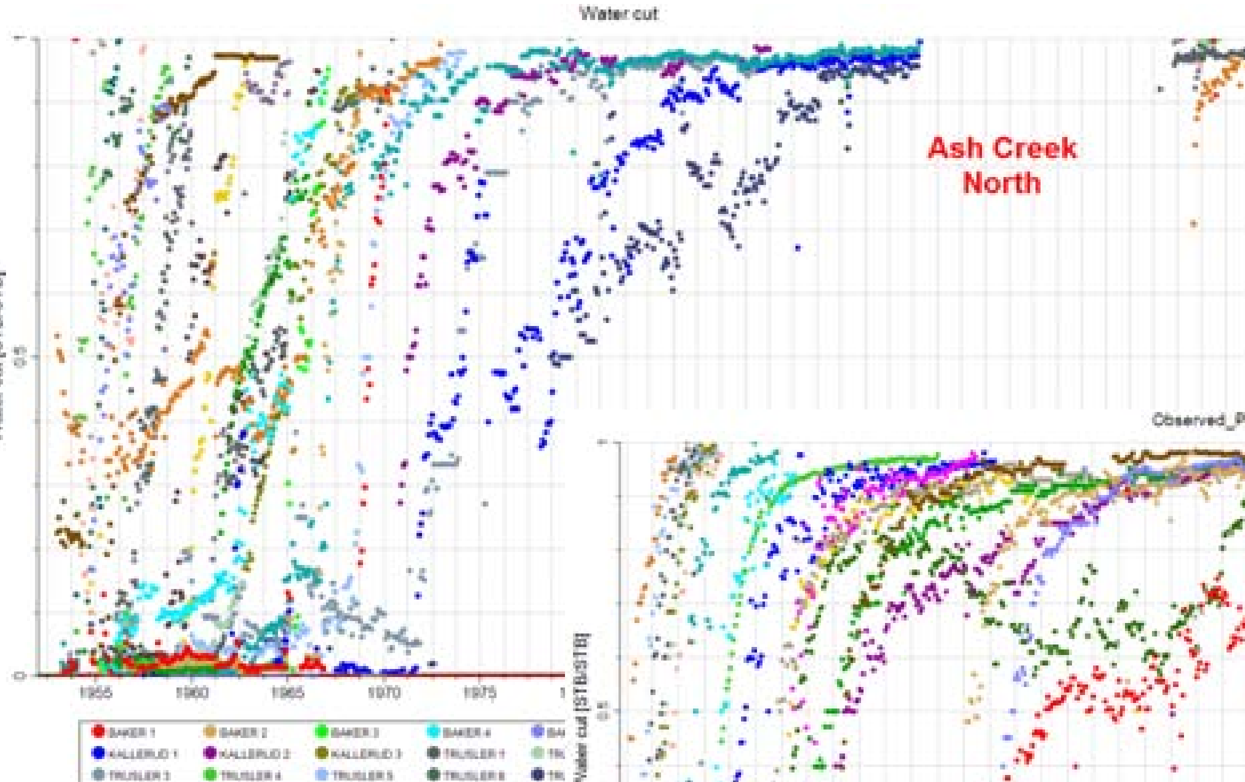
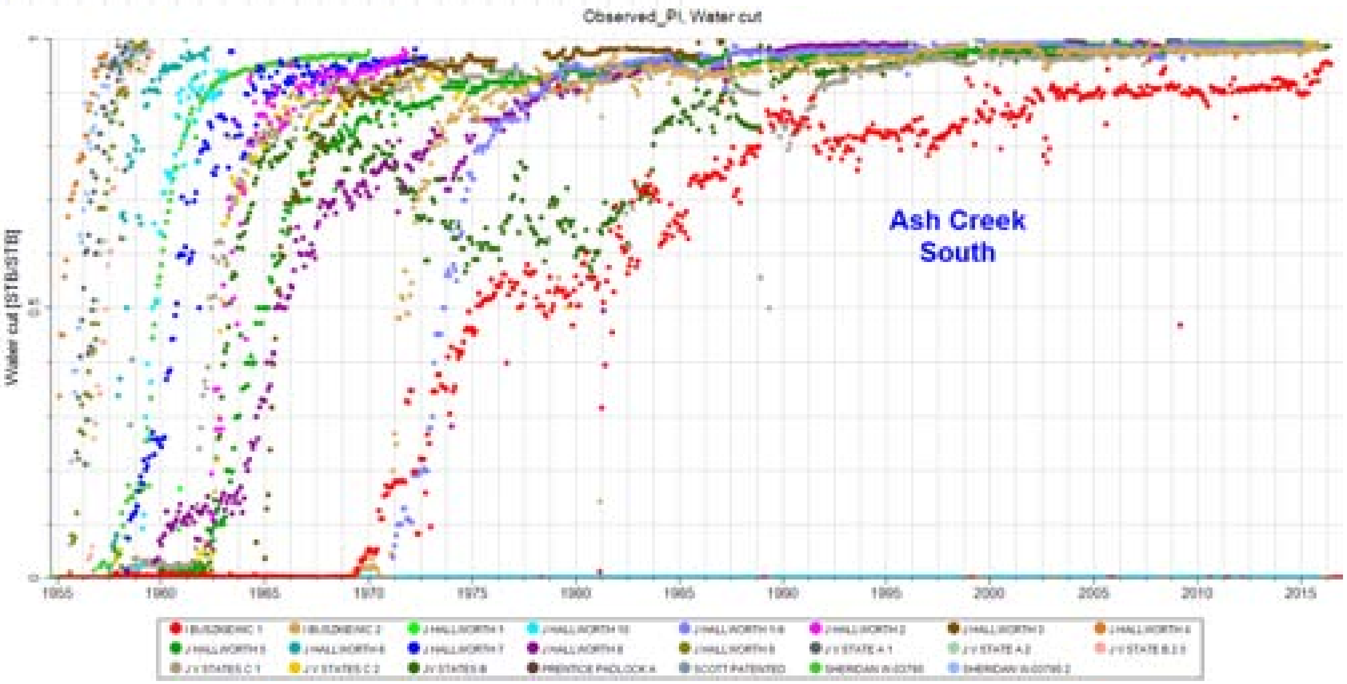
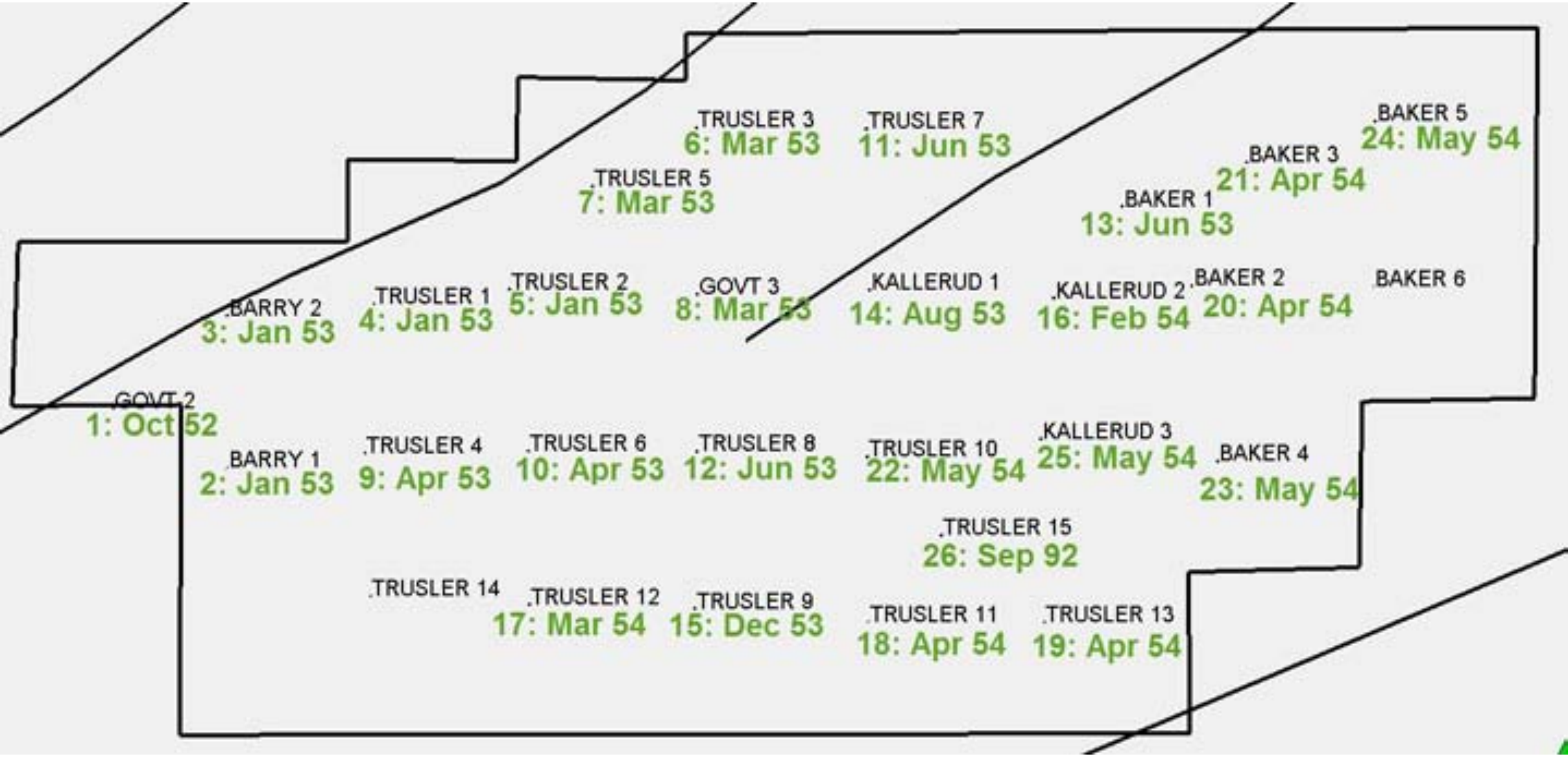
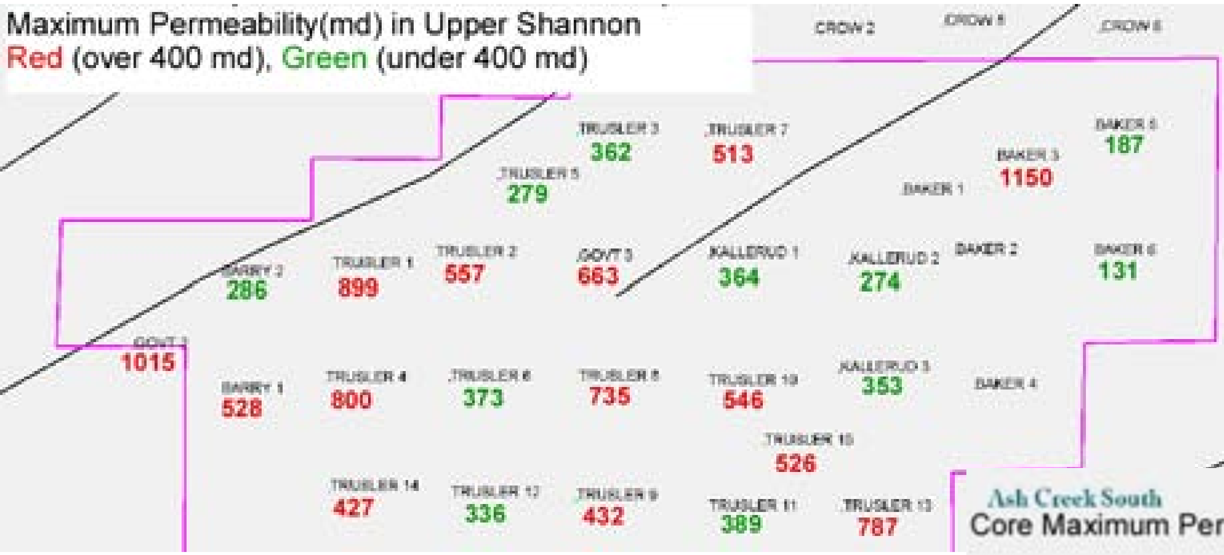

Water cut
Ash Creek
North
1955
1960
1965
1970
1975
BAKER 1
BAKER 2
BAKER 3
BAKER 4
KALLERUD 1
KALLERUD 2
KALLERUD 3
TRUSLER 1
TRUSLER 3
TRUSLER 4
TRUSLER 5
TRUSLER 6

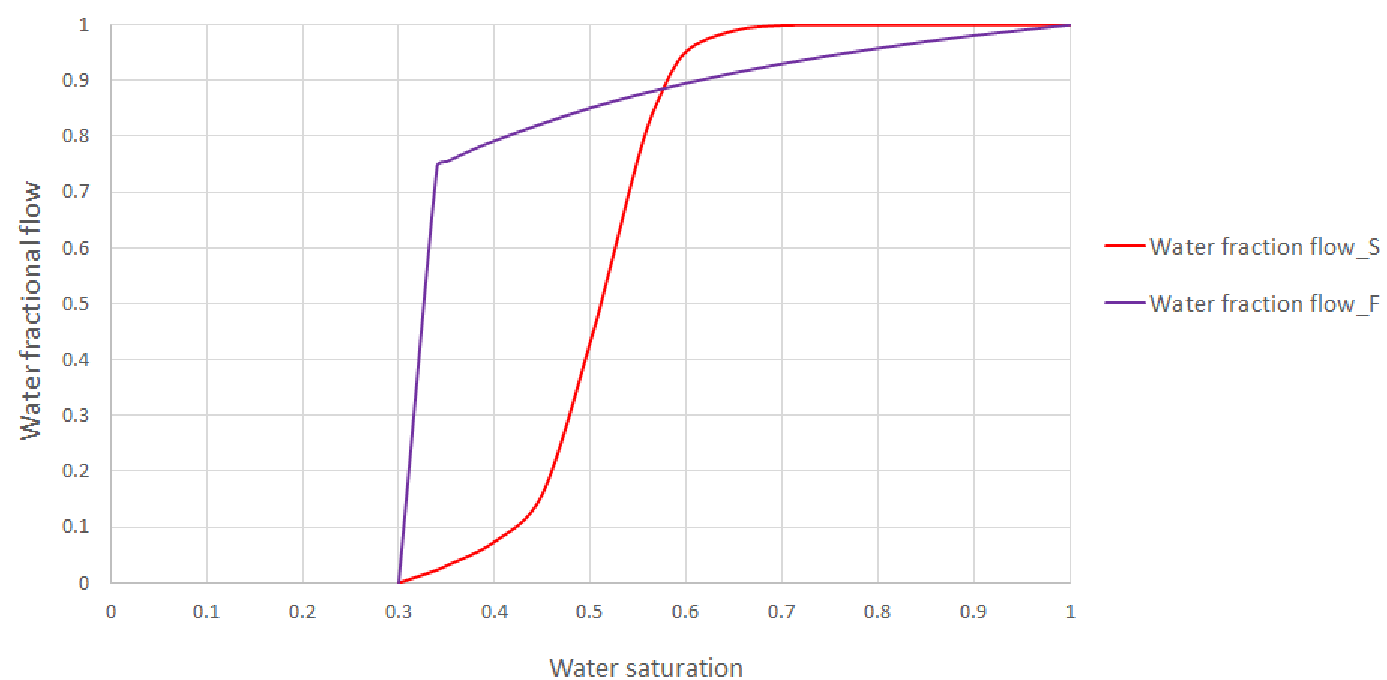

Observed_PI, Water cut
Ash Creek
South
Water cut [STB/STB]
0.5
0
1955
1960
1965
1970
1975
1980
1985
1990
1995
2000
2005
2010
2015



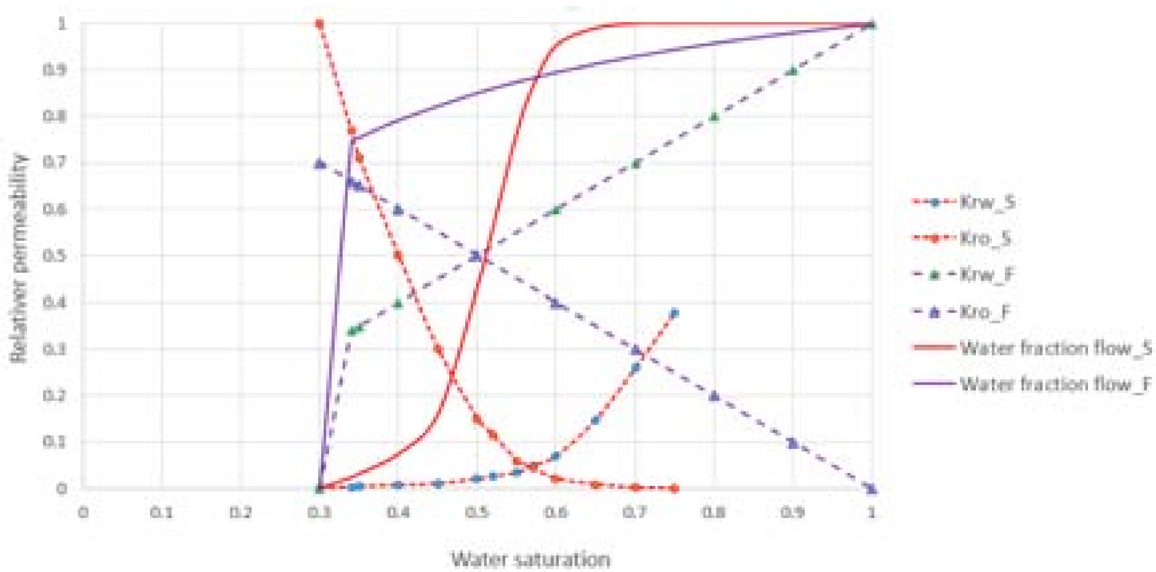
TRUSLER 3
6: Mar 53
TRUSLER 7
11: Jun 53
BAKER 5
24: May 54
BAKER 3
21: Apr 54
TRUSLER 5
7: Mar 53
BAKER 1
13: Jun 53
BARRY 2
3: Jan 53
TRUSLER 1
4: Jan 53
TRUSLER 2
5: Jan 53
GOVT 3
8: Mar 53
KALLERUD 1
14: Aug 53
KALLERUD 2
16: Feb 54
BAKER 2
20: Apr 54
BAKER 6
GOVT 2
1: Oct 52
BARRY 1
2: Jan 53
TRUSLER 4
9: Apr 53
TRUSLER 6
10: Apr 53
TRUSLER 8
12: Jun 53
TRUSLER 10
22: May 54
KALLERUD 3
25: May 54
BAKER 4
23: May 54
TRUSLER 15
26: Sep 92
TRUSLER 14
TRUSLER 12
17: Mar 54
TRUSLER 9
15: Dec 53
TRUSLER 11
18: Apr 54
TRUSLER 13
19: Apr 54



Core Permeability Data



Water fractional flow
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
Water saturation
Water fraction flow_S
Water fraction flow_F



Relativer permeability
Water saturation
Krw_S
Kro_S
Krw_F
Kro_F
Water fraction flow_S
Water fraction flow_F