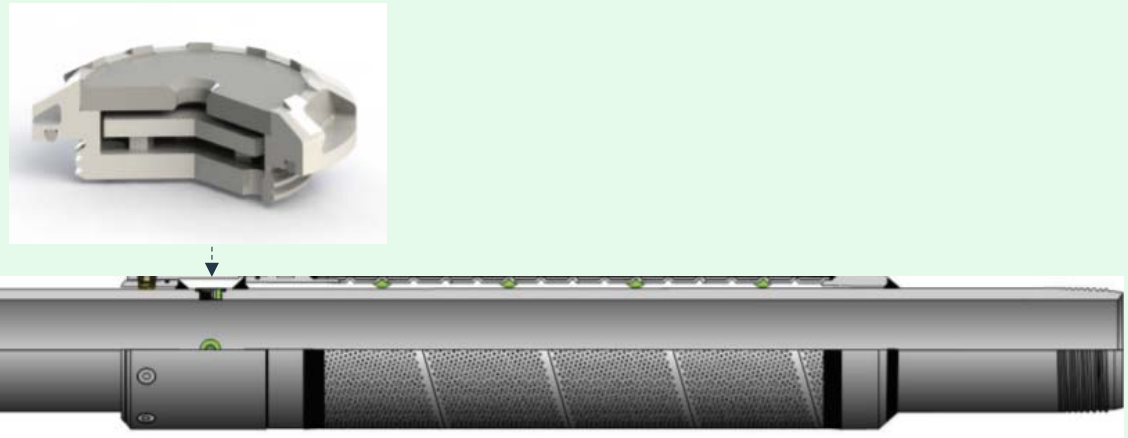
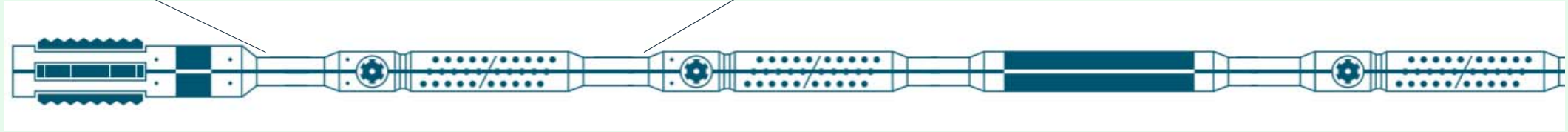


AICD masterclass
SPE DEVEX 2023

Arwin Nair ,Geir Elseth, John Costaschuk

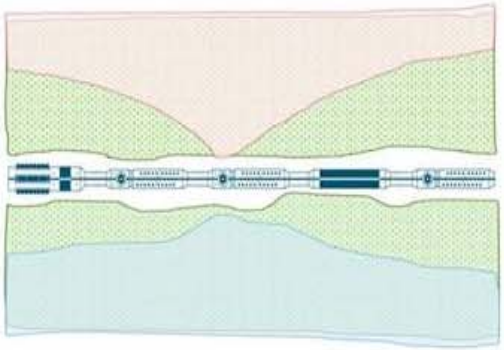


Source: Tendeka

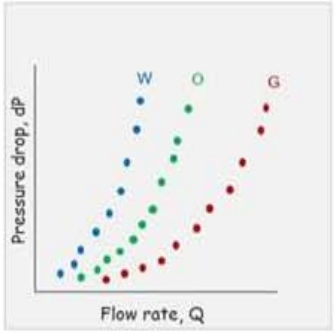
Challenge:
Excessive influx of gas/water

Possible solution:
Delay/restrict gas/water by inflow control technology

Asset Business Need



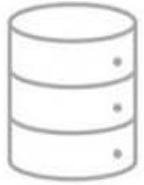
Hardware qualification incl. testing

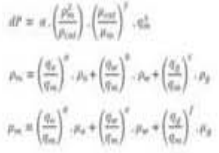


Modelling parameters

Test database

VaMoT®
Valve Modelling Tool

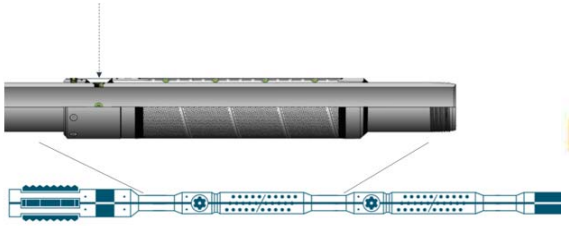


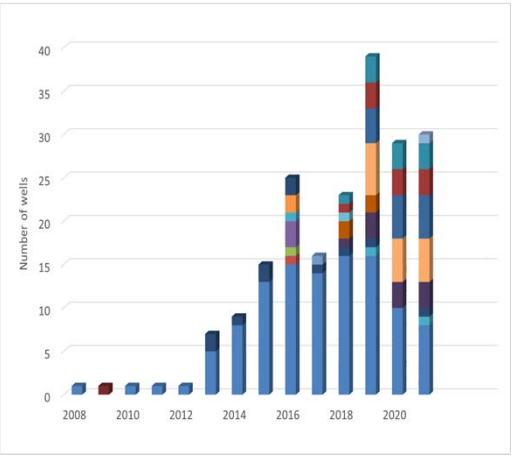


Modelling & Simulation

Completor

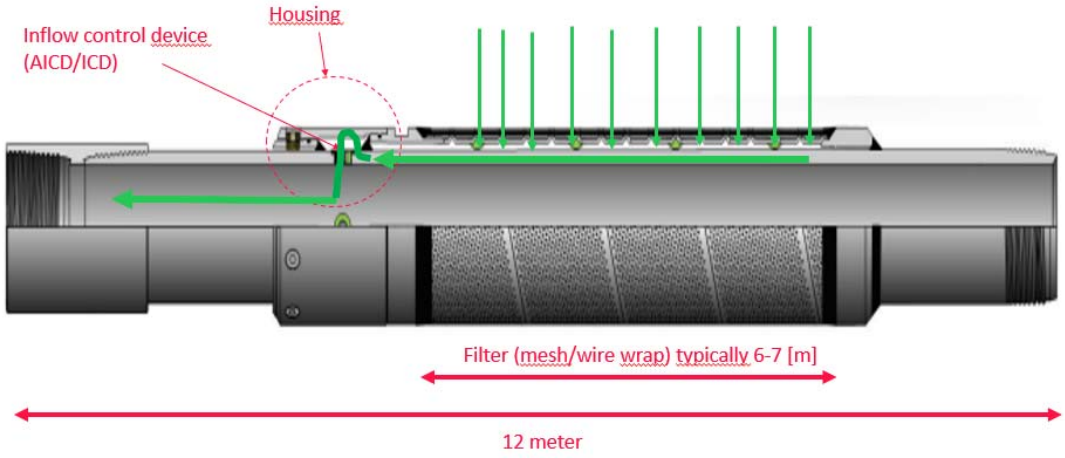
ECLIPSE

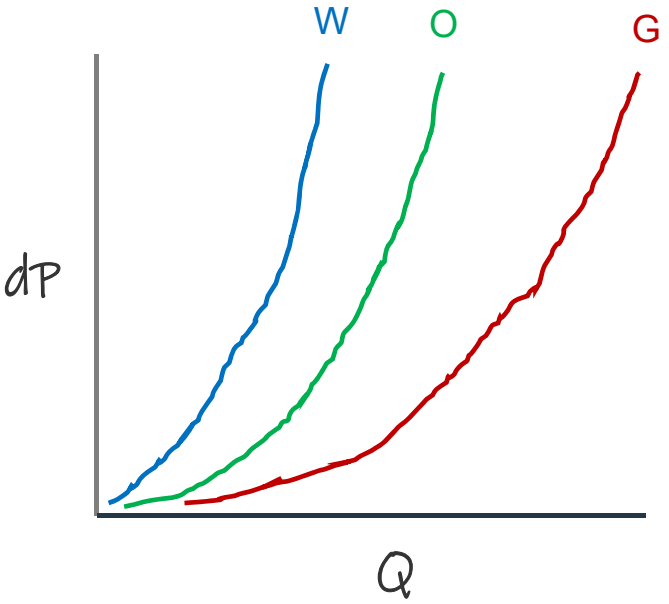




SOLUTION: Autonomous inflow control

- AICD based on different operating principles
- Input data to flow modelling
- Iterative process between supplier and operator

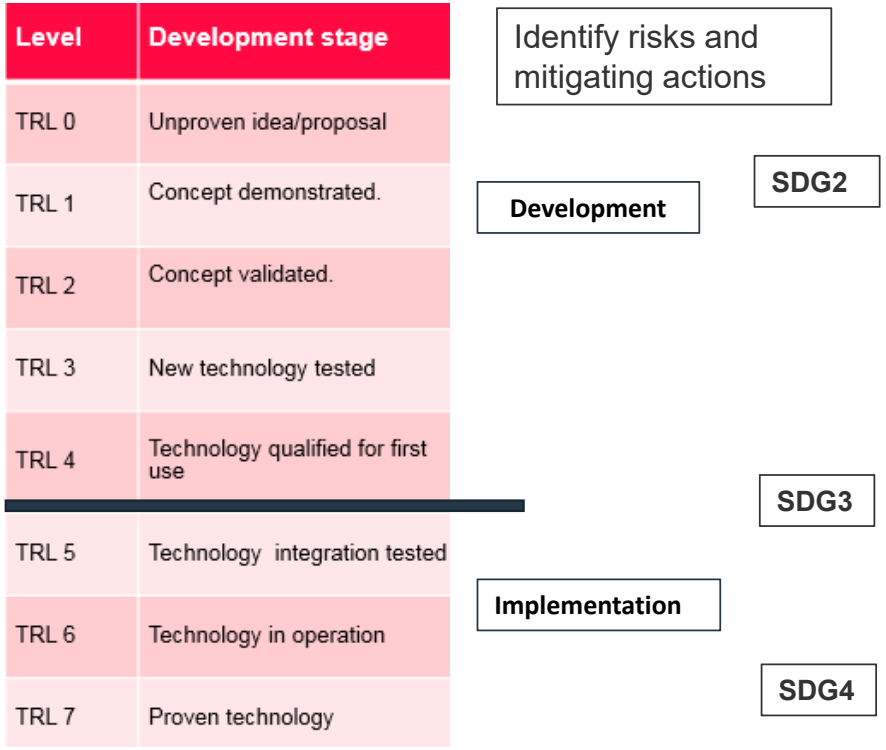




Souce: Tendeka

AICD Qualification – risk based approach

1. Risk assessment (FMECA)
2. Verification of final design - of AICD and Screen
3. Verification of plugging robustness
4. Verification of erosion resistance
5. Multi Lateral (MLT) compatibility
6. Bending of base pipe test
7. Factory acceptance test (FAT) of each individual inflow control device
8. Factory acceptance test (FAT) of each screen including inflow control device
9. Pressure Burst Test
10. Verification of flow performance for full-scale AICD
11. Scale and deposits
12. Bullheading
13. Longevity of moving parts

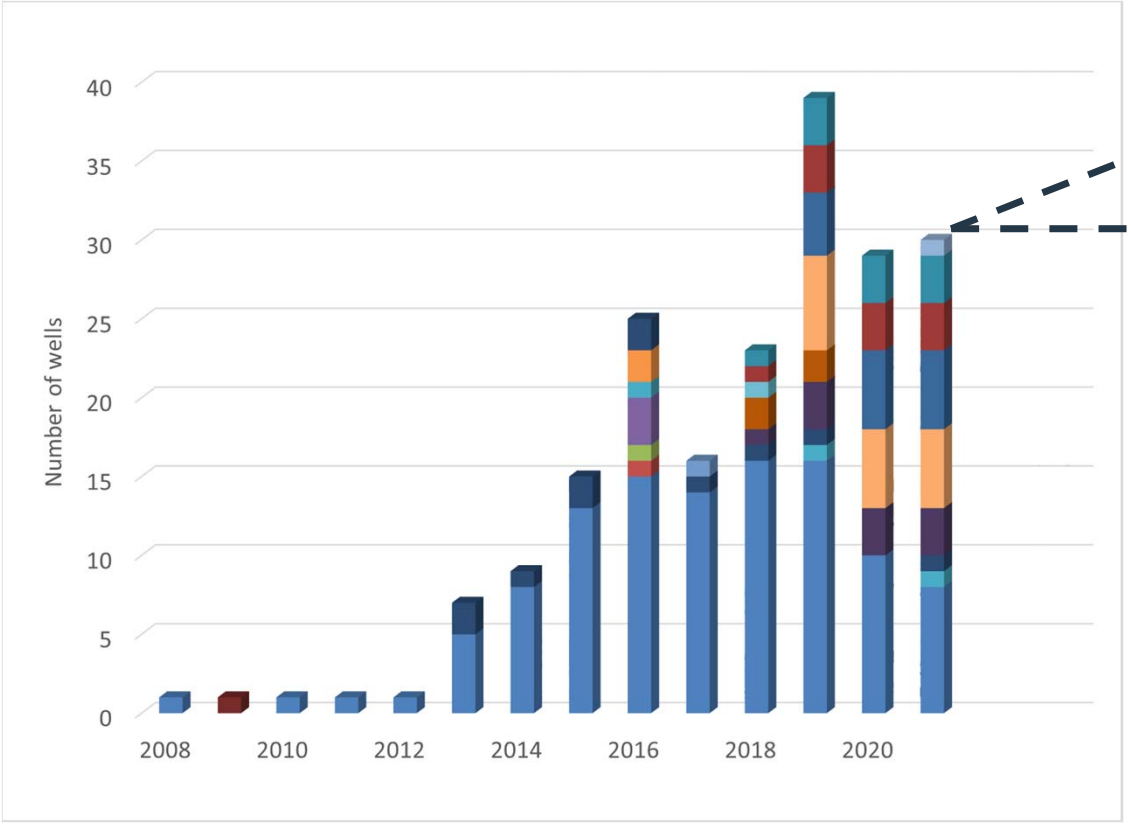


Benchmarking qualification study

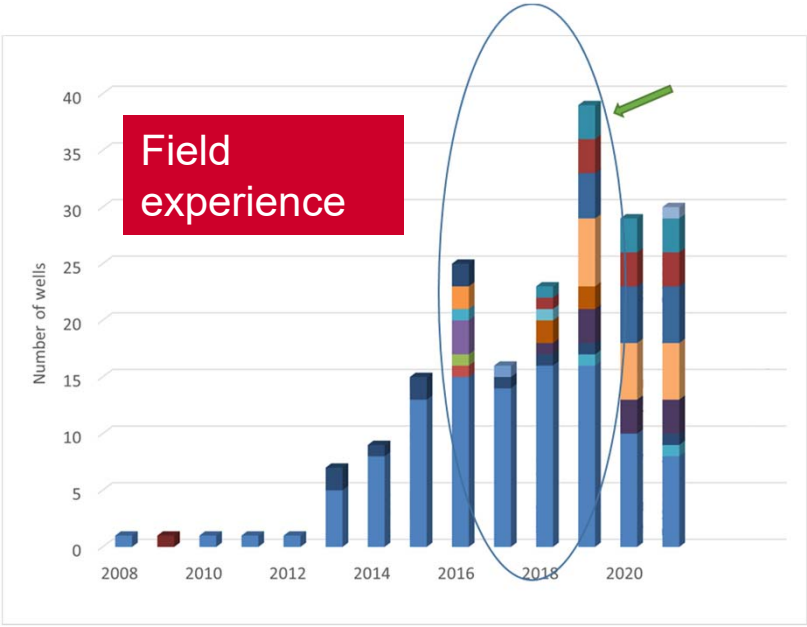
	AICD #1	AICD #2	AICD #3	AICD #4	AICD #5
Verification of design	+++	+++	+++	+++	+++
Well clean-up /plugging resistance	++	+++	++	+++	++
Erosion resistance	+	++	+	++	+
Mitigation of deposits - bullheading/injection solution	++	+++	++	+++	++
Full scale flow performance verification	+++	++	+++	+	+++

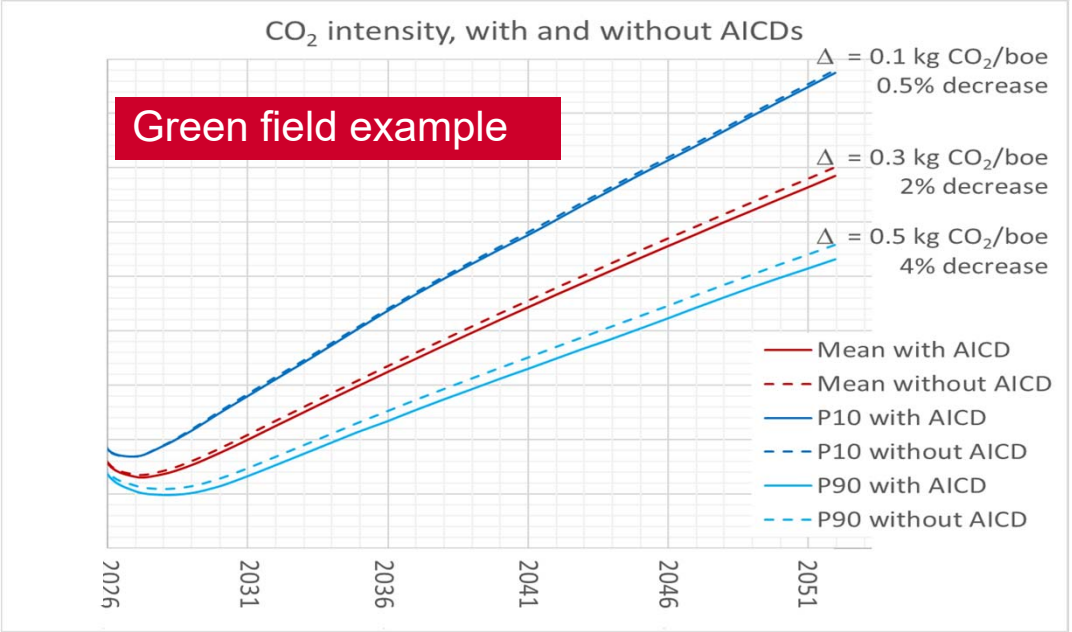
AICD implementation overview

- 15 years field experience
- More than 175 wells completed with AICDs
- 10 assets currently using AICD
- Several field development projects are evaluating use of AICDs
- 6 AICD technologies currently qualified for use (TRL 4-7)
- Several others in qualification process (TRL 1-4)



AICD as a CO2 intensity measure





- Equinor energy intensity target of 8 kg CO2/boe
- 20 wells from 3 NCS assets
- 1-5% increased recovery compared to reference wells

$$\text{CO}_2\ \text{intensity} = \frac{\text{cumulative CO}_2\ \text{emission (kg)}}{\text{cumulative barrels of oil equivalents of hydrocarbon export (boe)}}$$

Field case - Mariner

Heavy oil field (70-500 cP) with significant reservoir heterogeneity

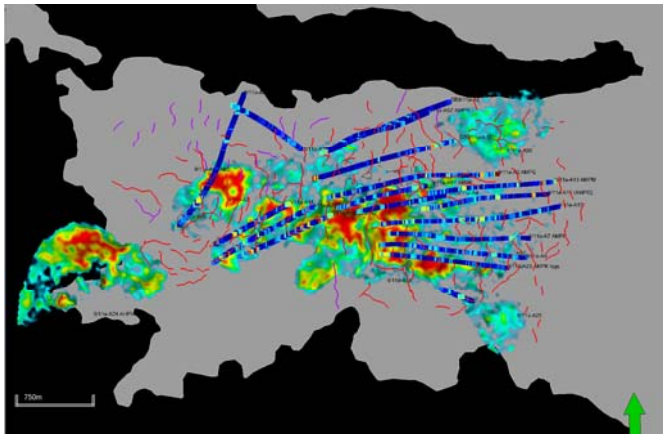
Multi-well inflow control programme and learning curve:

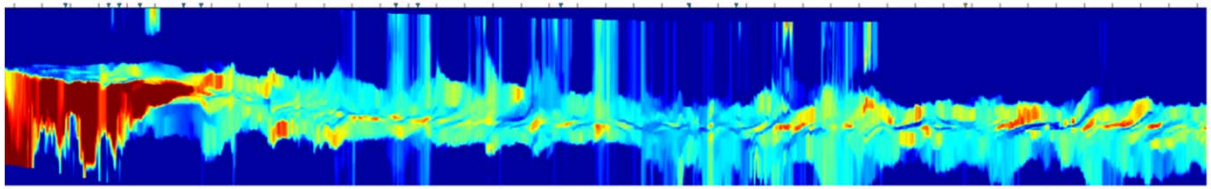
1. Stand Alone Screens (SAS)
2. ICDs
3. AICDs (4 vs 2 per joint)
4. AICDs + MGH

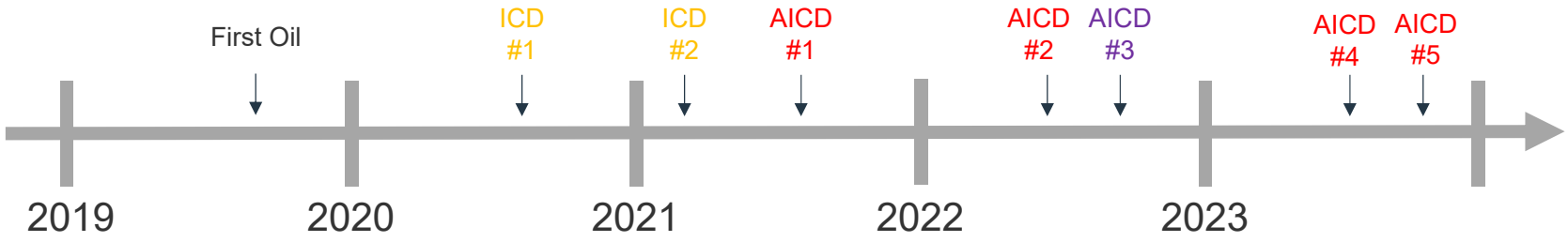
Objectives:

- Improve profile and recovery
- Improve Value of Water (VoW) and P:I ratio

Two inflow control learning wells per year

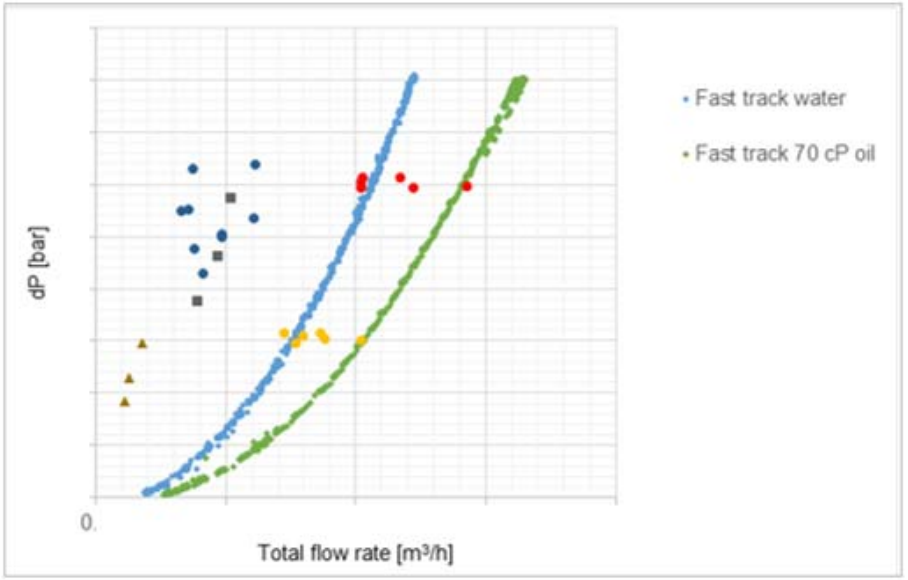


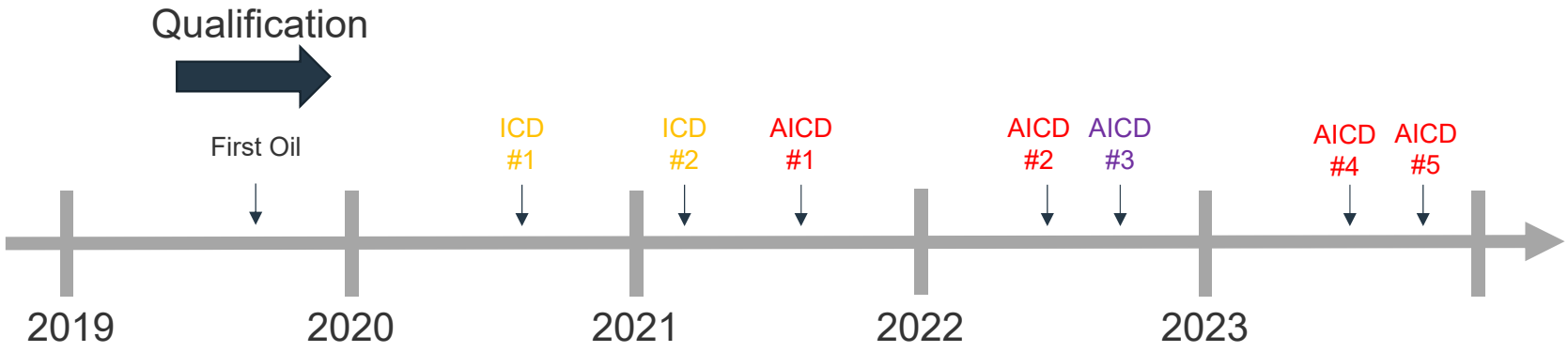




Mariner – Qualification of ResFlow

Feb-Mar 2019: Flow loop qualification and test results in Porsgrunn (Mariner)
June 2019 : TRL4 status meeting
Dec 2019 : Final test at Houston SWU
19 Dec 2019: TDG3 approval meeting

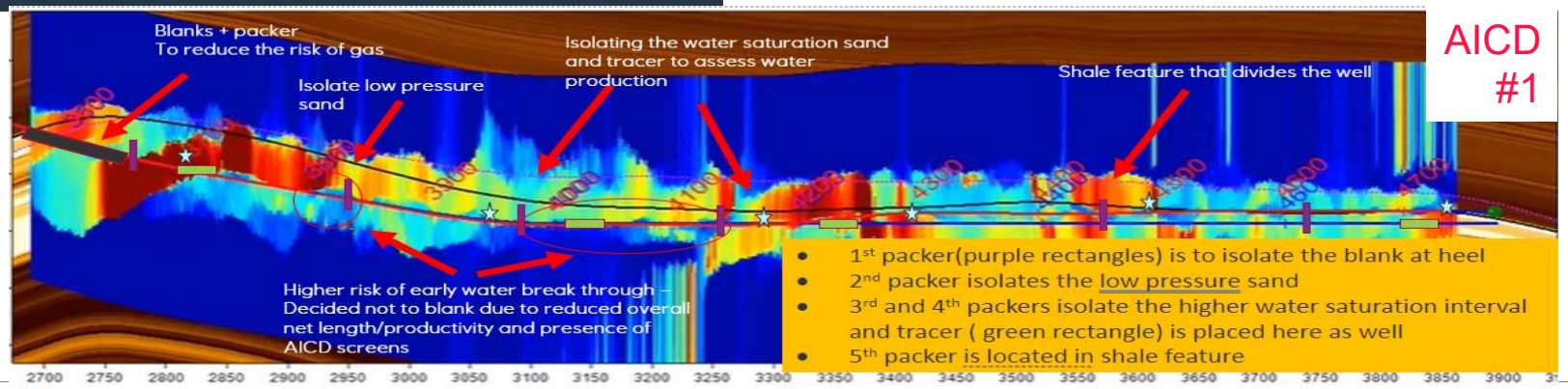




Mariner - Implementation

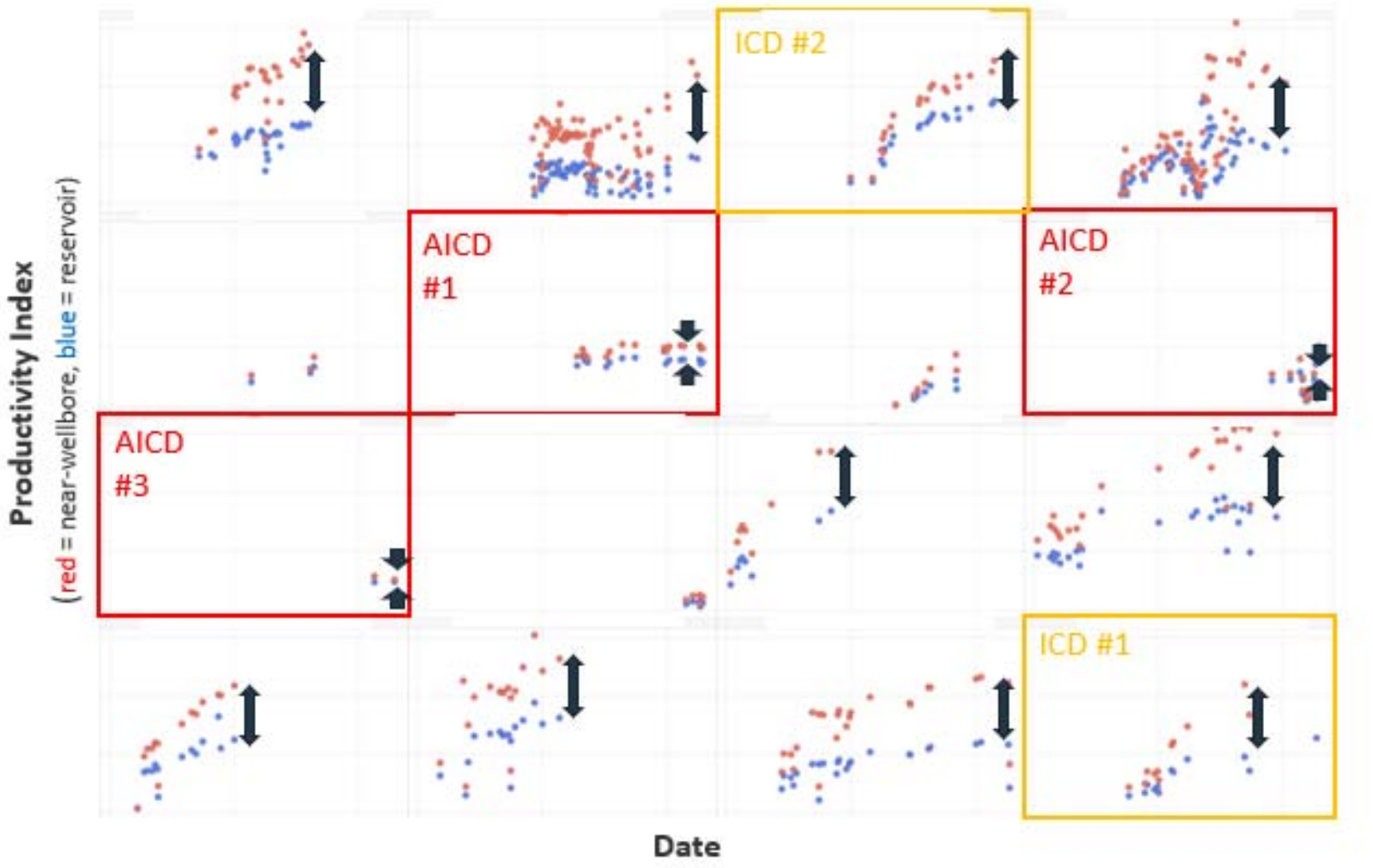
Well ID	Inflow Control
Well#1	4 × 2.5mm ICDs
Well#2	4 × 2.5mm ICDs
Well#3	2 × 2.5mm ICDs**
Well#4	2 × AICDs per joint**
Well#5	2 & 4 x AICDs per joint***
Well#6	2 & 4 x AICDs per joint***
Well#7	2 & 4 AICD per joint
Well#8	2 AICD per joint
Well#9	2 AICD per joint

**Revised based on experience on well#1
**ESP failure 01/08/2021 –following workover gauge failure has occurred
***combination of 2AICD/Joint & 4 AICD/Joint were installed to optimise inflow based on log data



Mariner – Learning #1 - Transient PI

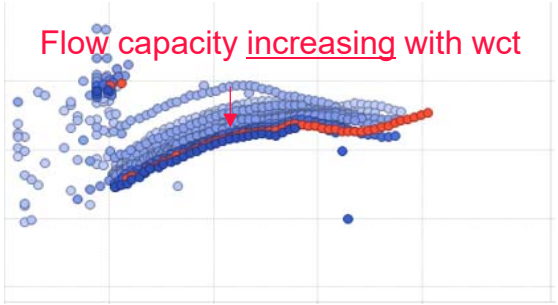
- SAS PI increases rapidly. Delta PI between near-wellbore and reservoir grows with watercut.
- ICD PI increases similar to SAS – no benefit
- AICD PI remains relatively low throughout water-cut development
- Additional variability due to gas



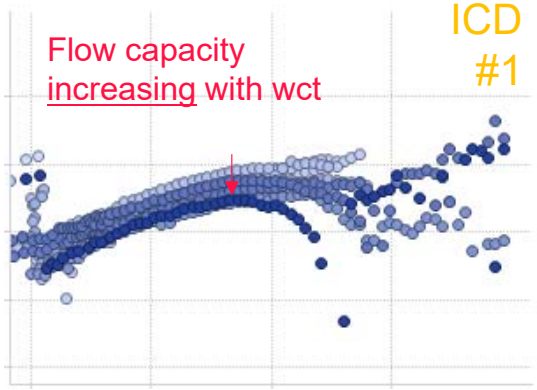
Mariner – Learning #2 – PTA

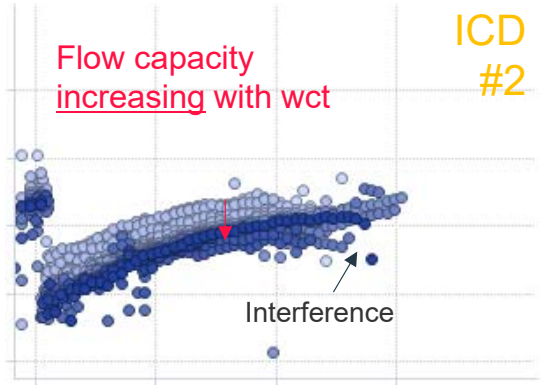
PTA comparison of SAS vs ICD vs AICD
Derivative vs dt shaded by date (dark=recent)

SAS

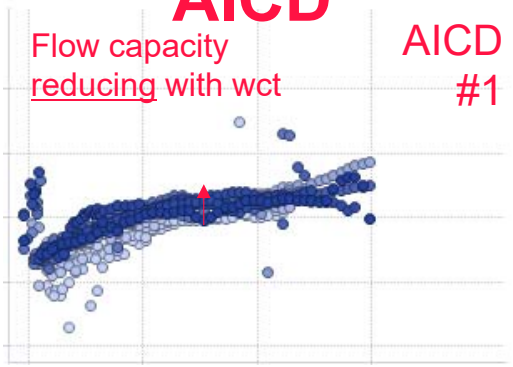


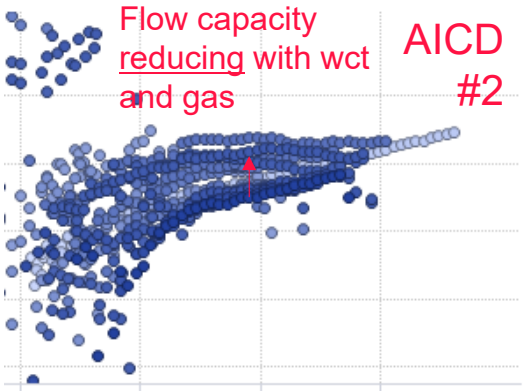
ICD

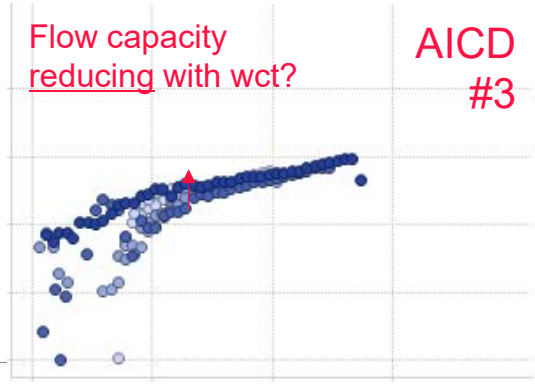




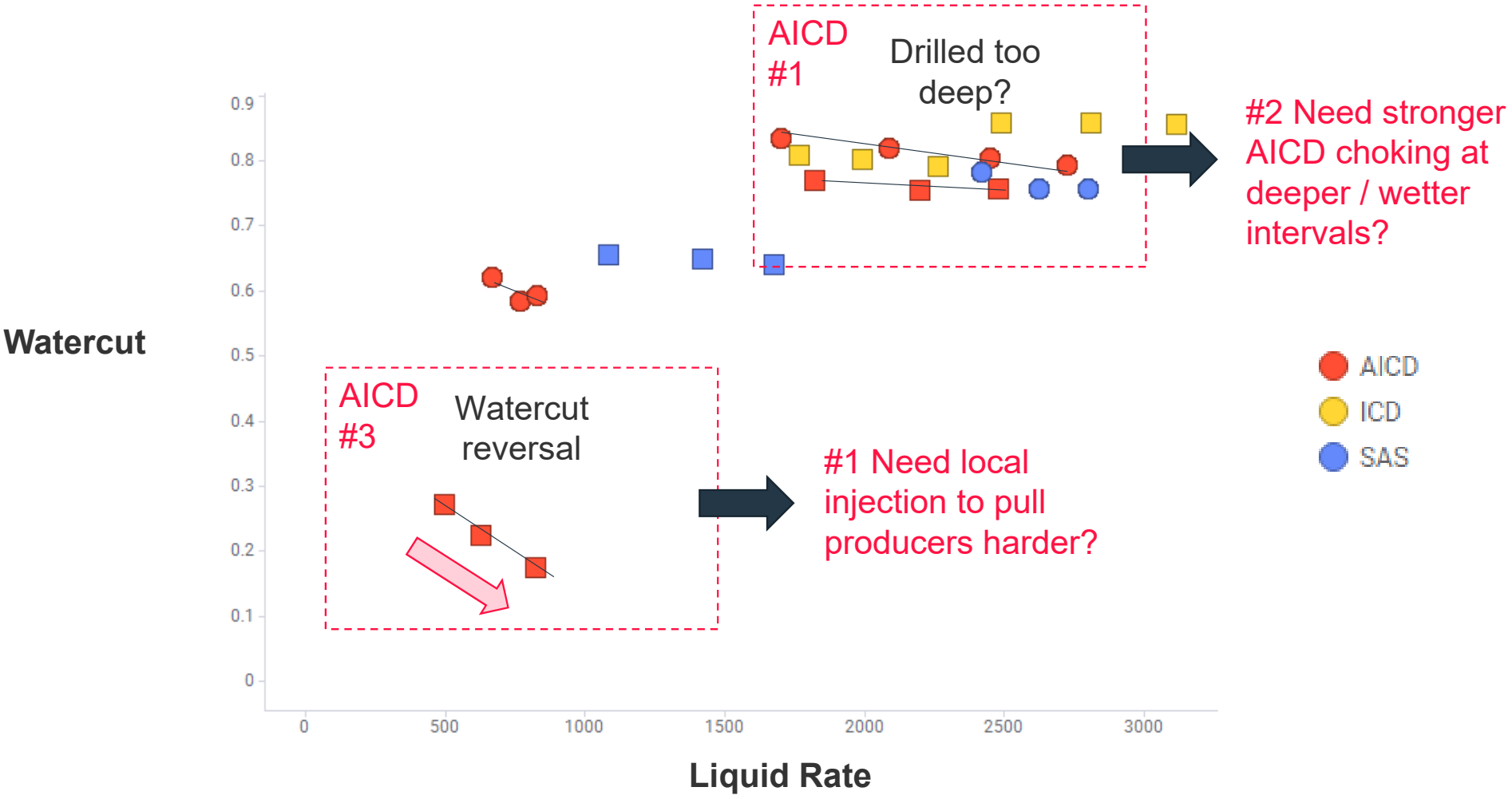
AICD



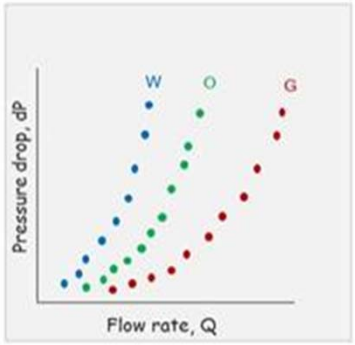


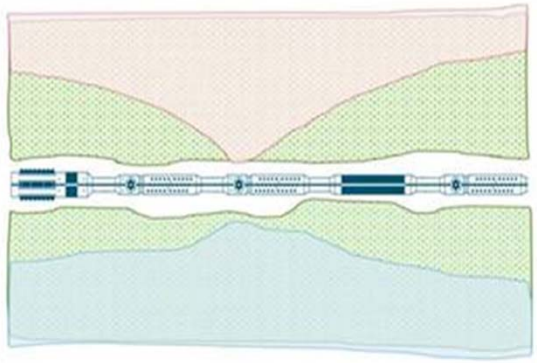


Mariner – Learning #3 - Multi-Rate Test (MRT)



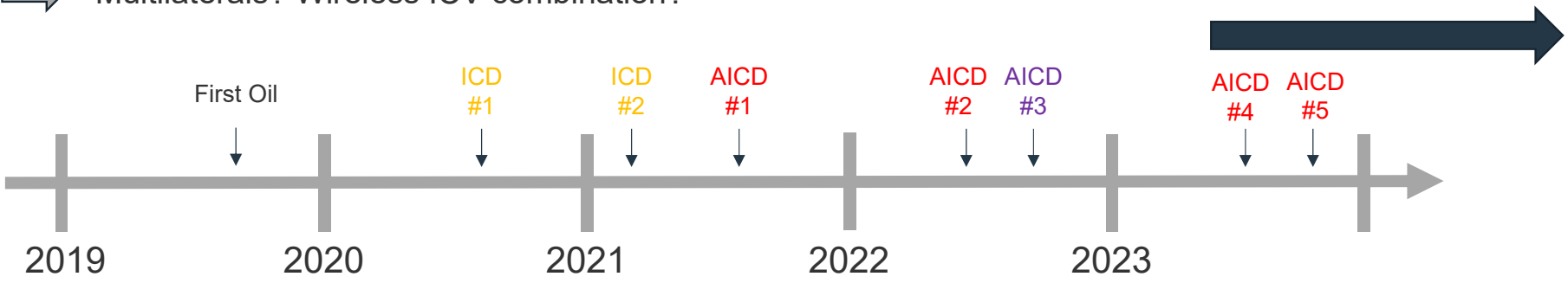
Mariner - Summary



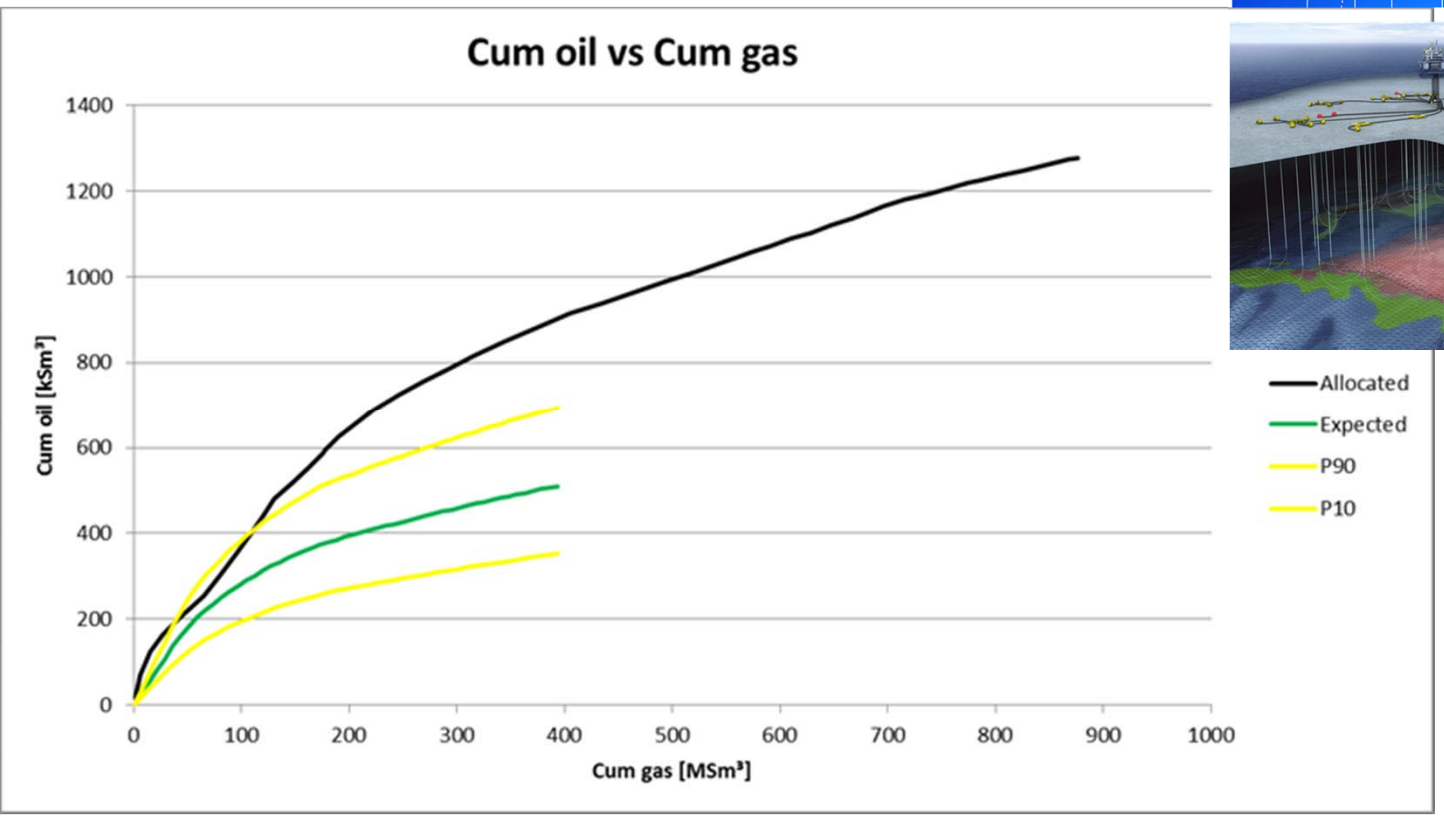


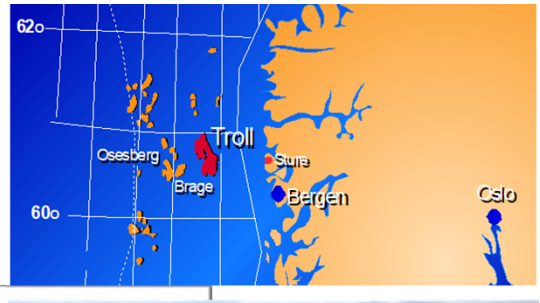
- Qualification – 9 months.
- Implementation – averaged two learning inflow control wells per year with tracers. Iterated from ICD to AICD.
- Optimizing AICD strategy with:
  1. Local water injection to pull AICD completions harder
  2. Stronger choking at deeper / wetter intervals
- Continuing to identify candidates and accelerate learning curve

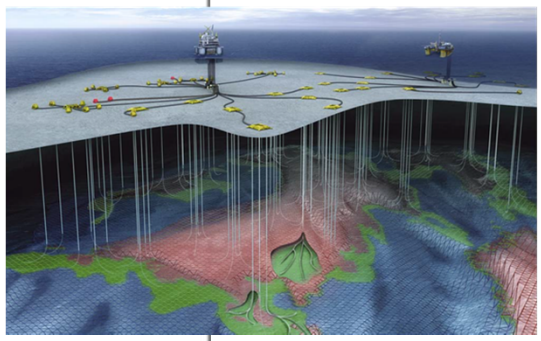
Multilaterals? Wireless ICV combination?

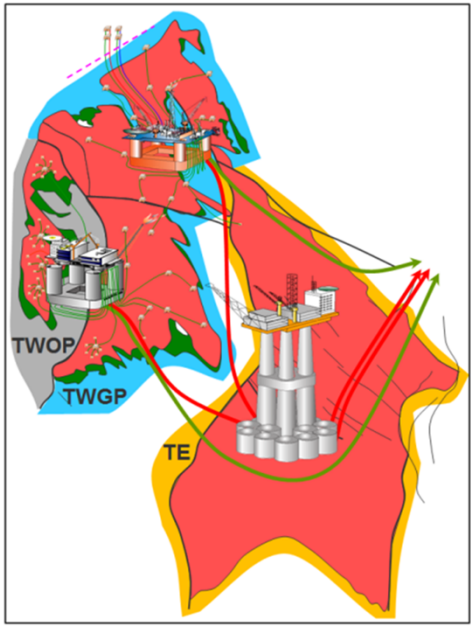


Field case - Troll



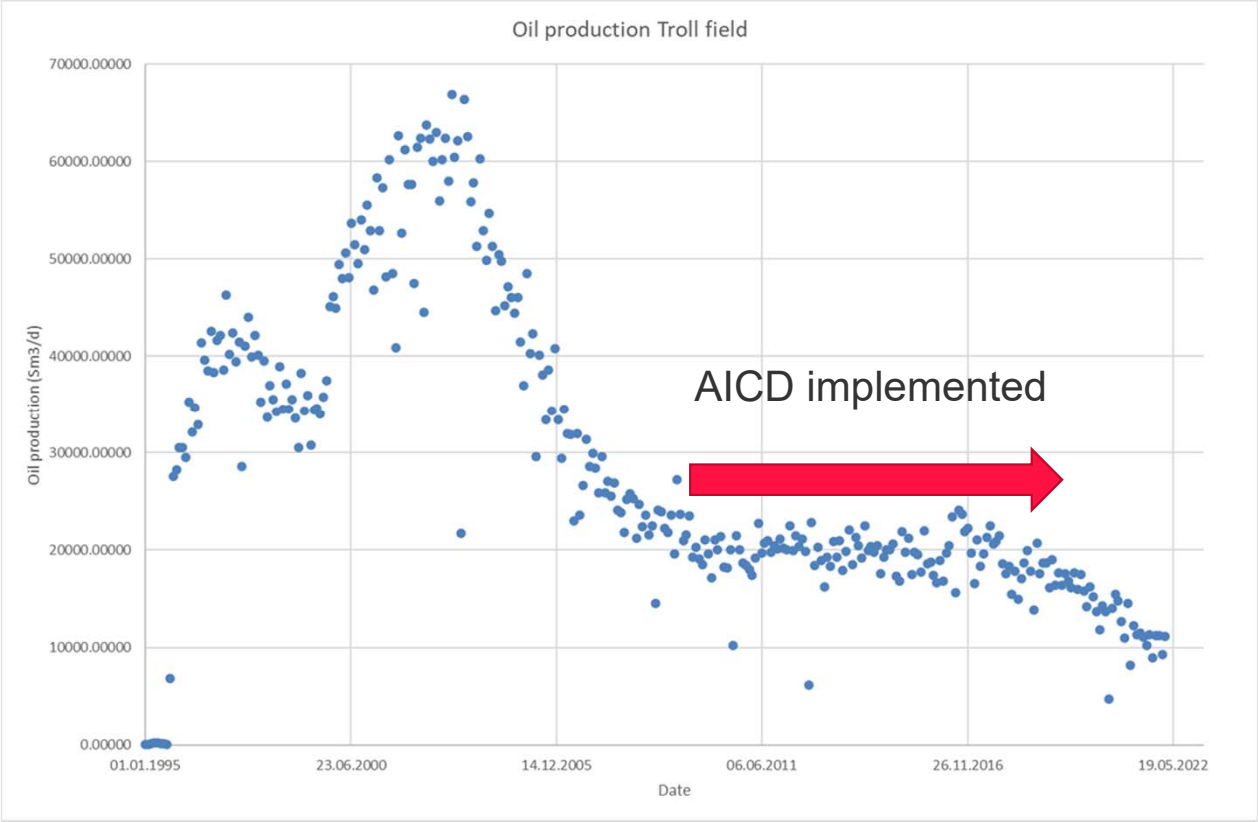






- AICD standard completion at Troll
- More than 100 AICD wells
- Focus on continuous AICD improvements

Troll -> Improved Recovery



Other applications

- Other NCS fields
  - Grane, 12 cP. Both gas and water choking
  - Oseberg, light oil. Gas choking
- Offshore UK
  - Mariner, heavy oil
  - 70-500 cP. Water choking
- Brazil
  - Peregrino, heavy oil
  - 13-15 API / 130-400cP.
  - Water choking

Completor® – simplified well modelling with inflow control

Internal developed software - Unix command line tool (Python 3.6)

Automatically generating well schedules WITH INFLOW CONTROL -> commercial/open-source reservoir simulators

Functionality for modelling:

- All passive inflow control technologies (ICD, AICD, including AICV and DAR)
- Open annulus with or without packers at user defined locations

Broadly implemented across Equinor assets -> extensively tested

Compatible with optimization tools (FMU/ERT, Mepo, Basra etc.)

Business value

- Increase oil and gas recovery - and reduce CO2 intensity
- Extend well lifetime
- Decrease erosion risk (safety)

- Smart solutions for our 3000 wells to come
  - Smaller & challenging reservoir targets
  - Connecting into existing infrastructure

- We need flexibility to choose the most optimal AICD's since this may depend on field conditions

- Increase collaboration with industry, suppliers and academia for efficient business descisions, standardization, qualification and implementations

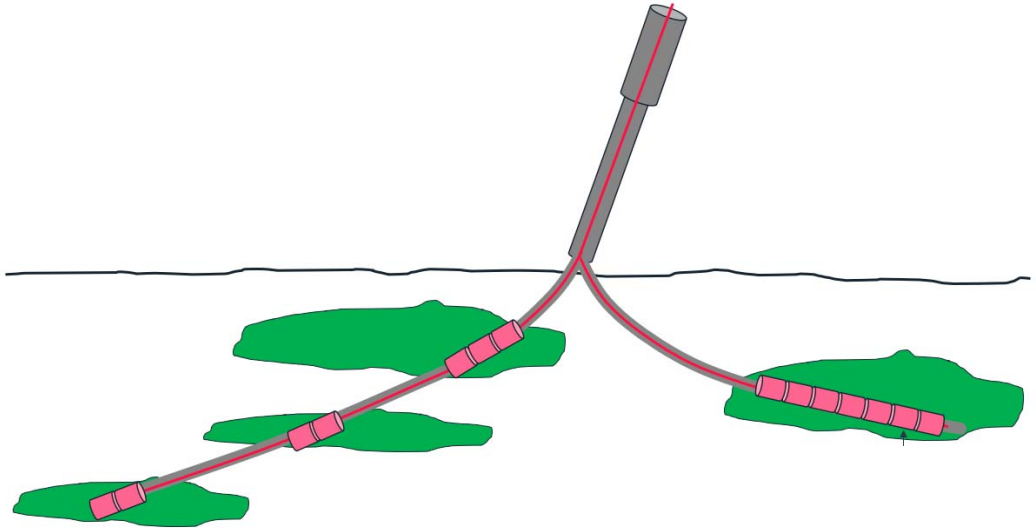
Future plans

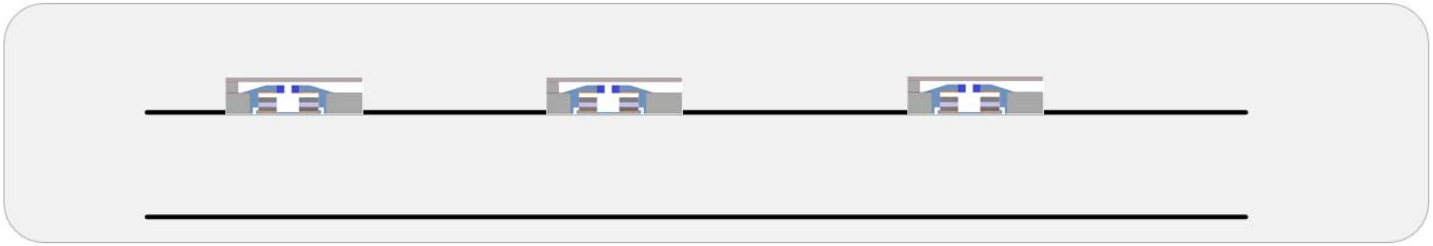
- Technology needs
  - Water shut-off in gas producers (low viscosity contrasts)
  - Increase performance, flexibility and reduce well cost
  - Efficient verification methods
  - Technology need: reaching more targets in one well

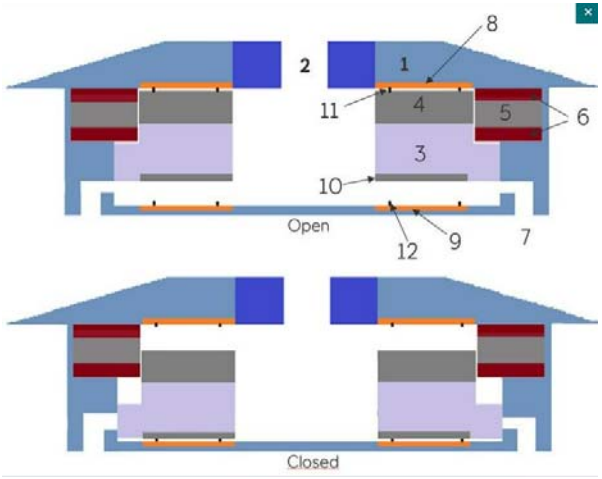
- New technologies – Operator/supplier collaboration
  - New AICDs and continuous improvements of existing AICDs
  - Density driven AICDs to choke back water
  - Wireless technology for ICVs
  - Retrofit solutions
  - Electrical ICD well concepts
  - Standardized work processes

Electric ICD well concept

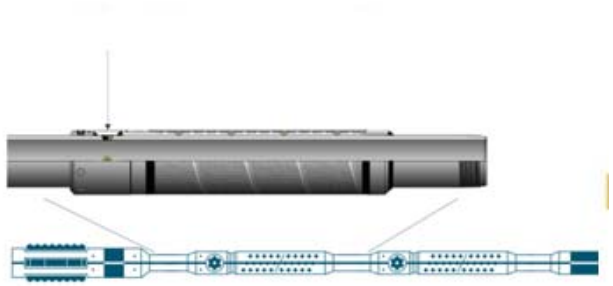
- Electrically operated valves in each screen
- Technology need: reaching more targets in one well
- Important, since many of our new wells will be tied into existing infrastructure
- Interval Control Valves vs electrical ICD's
- Supplier collaboration







Thank you!



Acknowledgements:

Partners at Mariner (Ithaca, One Dyas & Neo Energy) , Johan Sverdrup and Troll

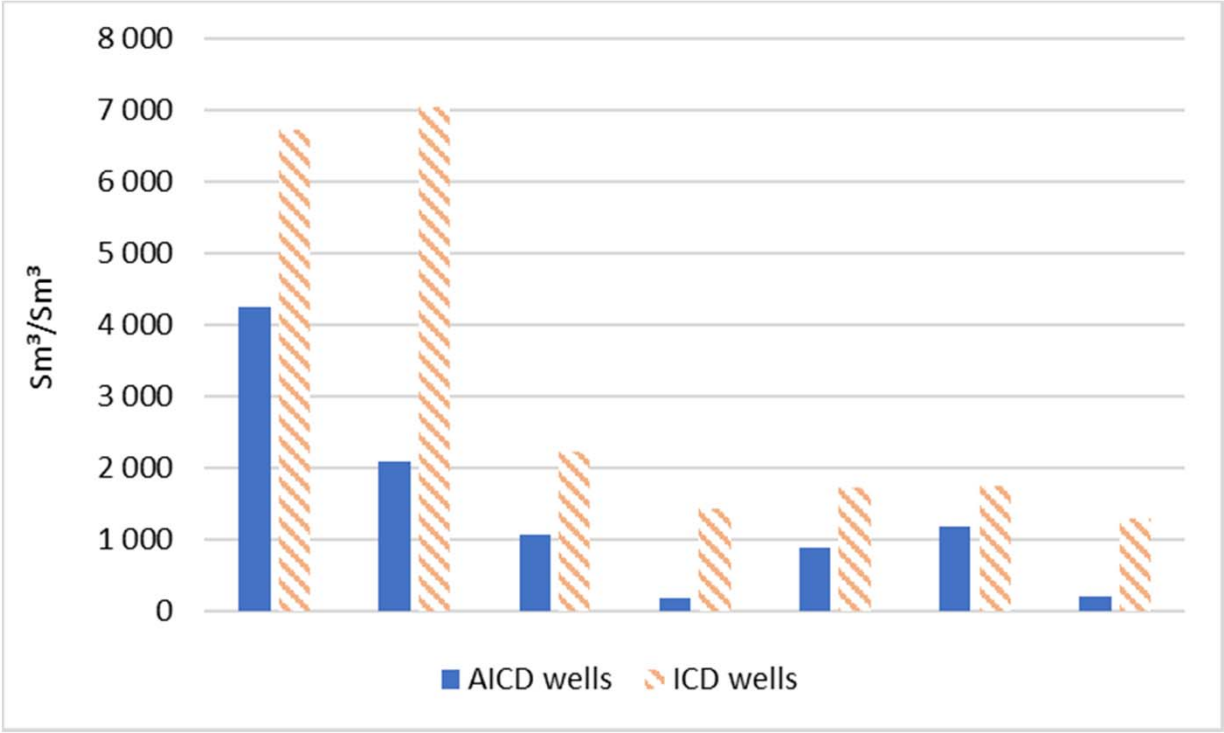
Contributor : Lene Amundsen

AICD masterclass - SPE DEVEX 2023

Arwin Nair, Geir Elseth, John Costaschuk

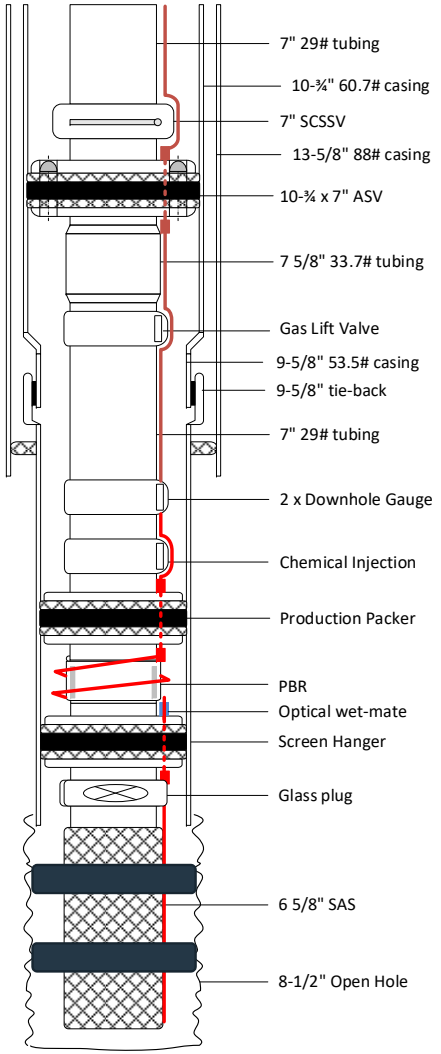
Field experience - comparison between wells with AICD and ICD

- Norwegian Continental shelf
- 7 wells with AICD compared to 7 wells with ICD
- Average GOR



Well design

- Run the lower ICD completion
  - Swell packers
  - Breakable glass plug
- Clean out down to lower completion, circulate in packer fluid
- Run the upper completion
  - Connect via wet-mate fiber
- Cycle pressure to break glass plug
- Ready for production



Field case - Johan Sverdrup

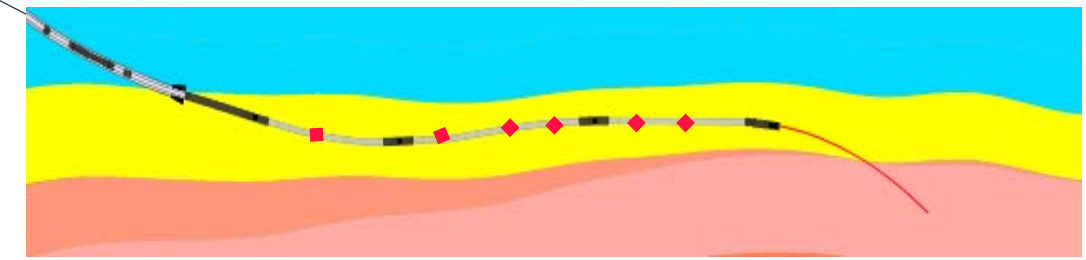
Real-time inflow profiling using fiber-optic sensing

DAS – Distributed **Acoustic** Sensing

DTS – Distributed **Temperature** Sensing

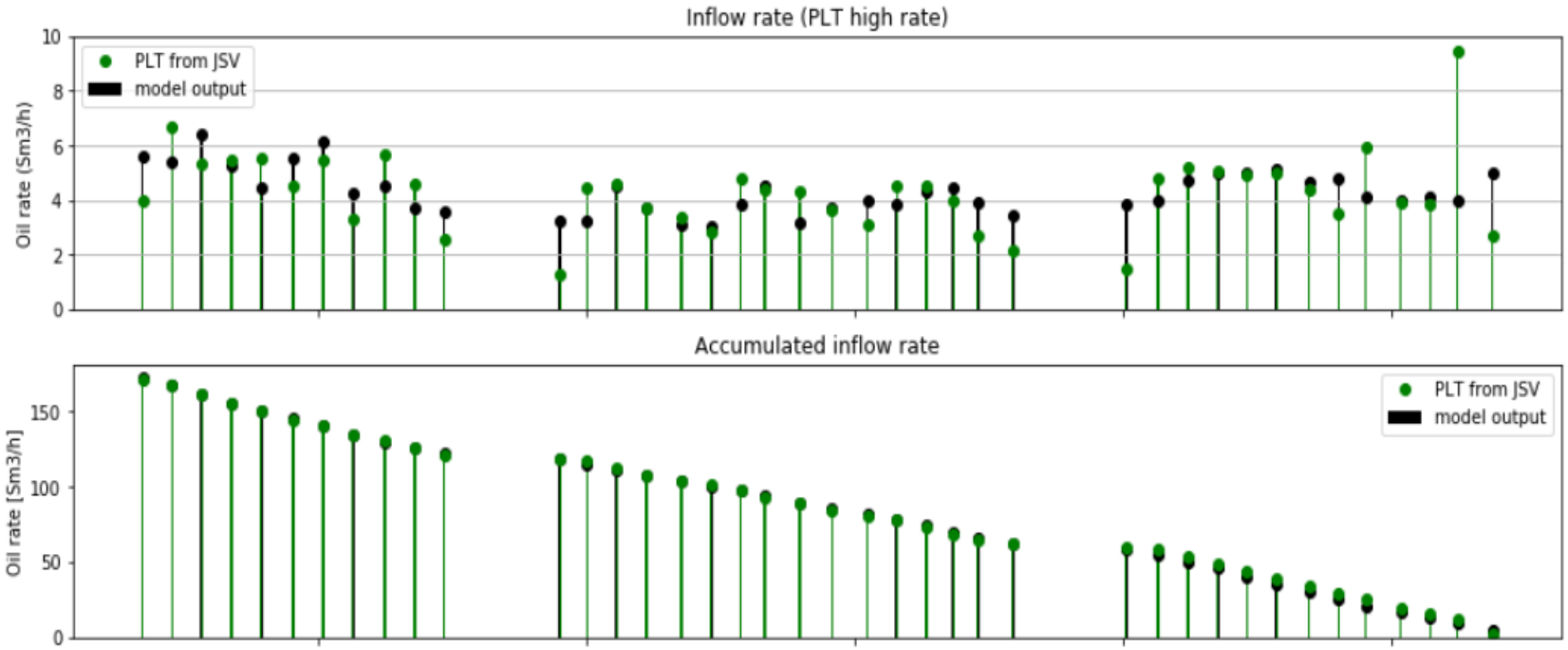
Interrogator
(Laser)

One 'Microphone **(DAS)** / Thermometer **(DTS)**' per meter



- Modified ICD screens with groove for the fiber optic cable
- 40 Nozzle ICDs
- 400m long reservoir section (almost horizontal)
- Three production zones separated by packers
- Single-phase oil inflow before June 2021
- Early signs of water production in June 2021, water production kept very low since then

Inflow profiling (Field case - Johan Sverdrup)



- PLT vs model DAS data
- The inflow profiler has been verified for single-phase (oil) inflow, ICD completion