SPE Aberdeen Section Meeting – 25th February 2015

Application of RESMAN's intelligent inflow tracers in long horizontal sand screen wells across Maersk Oil UK assets

MAERSK OIL

RESMAN®
WIRELESS RESERVOIR SURVEILLANCE

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Outline

- Monitoring requirements for Maersk Oil subsea assets
  - Data requirements, challenges, alternatives, solution
- RESMAN inflow tracer technology – how does it work
  - Project cycle and Technology fundamentals
  - Maersk UK applications: Tracer system design and Installation
- Maersk – RESMAN case studies
  - Confirmation of oil contribution
  - Determining shut in cross flow
  - Detection of gas and water producing zones
  - Onsite clean-up verification
  - Quantitative inflow distribution
- Application of acquired tracer data in asset management

Monitoring Requirements

Challenges

- Subsea – wet tree
- Long horizontal wells
- Cost constraints
- Commingled wells
- Flowline tieback

Monitoring Requirements

- Interventionless
- Cost effective
- No added risk
- Long monitoring life
- Capabilities:
  - Detecting oil and water production
  - Verifiction of clean-up
  - Inflow distribution along the wells

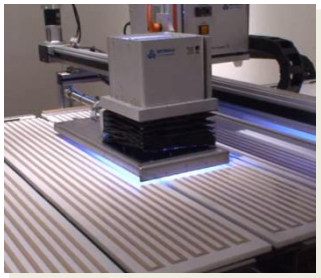
RESMAN Technology

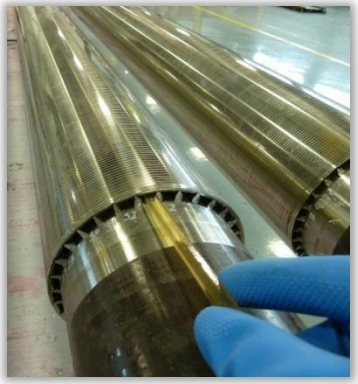
HOW IT WORKS

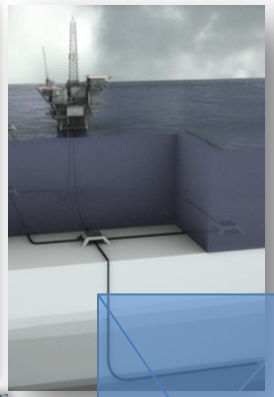
How it works – Project cycle

...up to 10 years!

Design and manufacturing → System integration → Well completion → Sampling → Lab analysis & interpretation

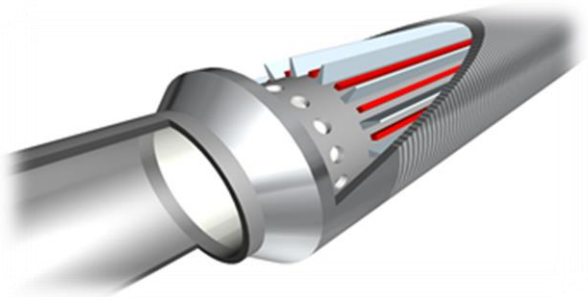


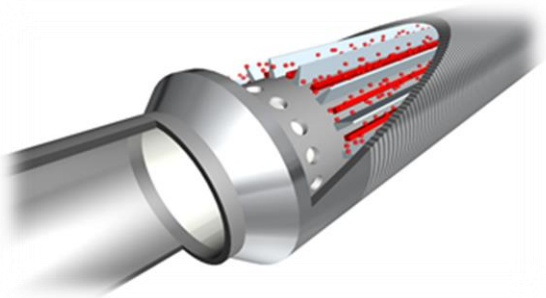


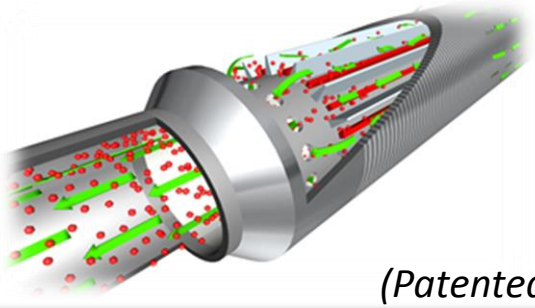


Polymer Matrix
70 oil
&
70 water
unique signatures

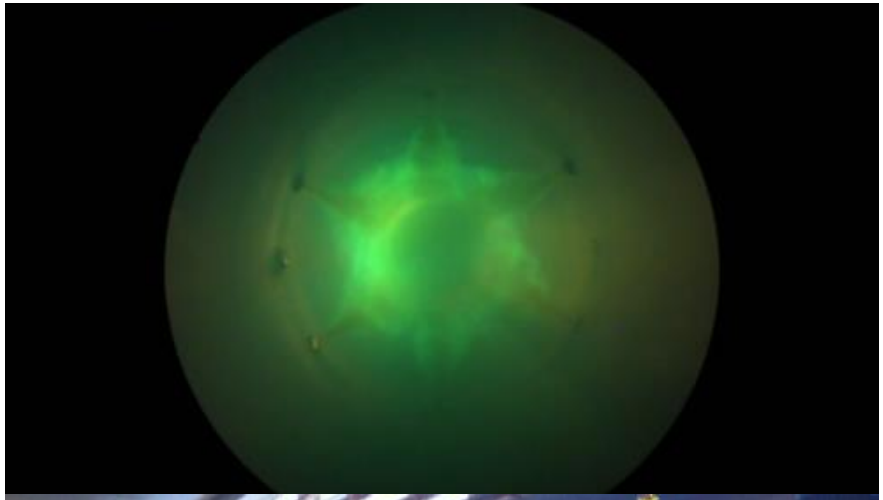
How it works – Technology basics

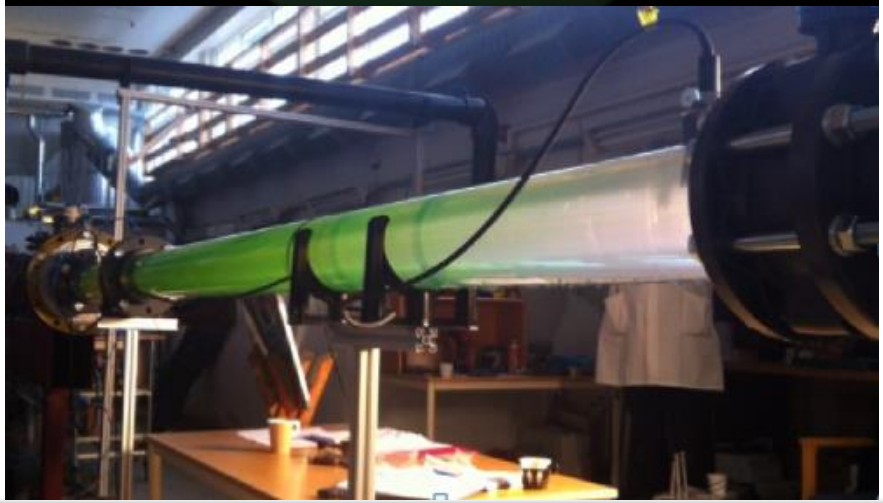






(Patented)





Tracer system design and Installation

MAERSK UK – RESMAN TRACER DESIGN AND INSTALLATION

Tracer system design

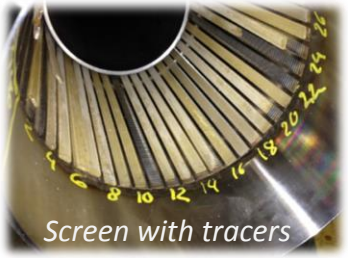
Long life tracer systems:

- Several oil and water tracers ordered
  - Flexibility to adjust deployment to needs
- Reservoir temperature of 65 – 85°C
- 36 months oil marking life
- 12 months water marking life after WBT
- Commingled sampling at up to 15,000bopd and 15,000bwpd

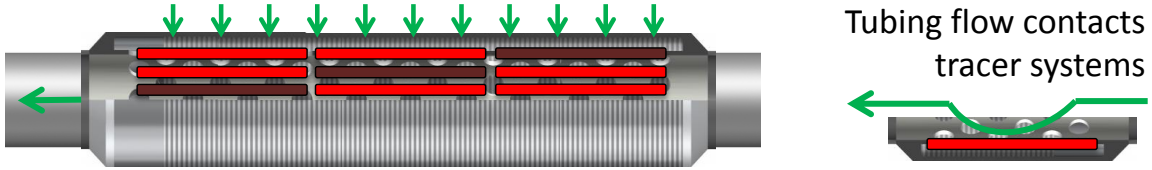
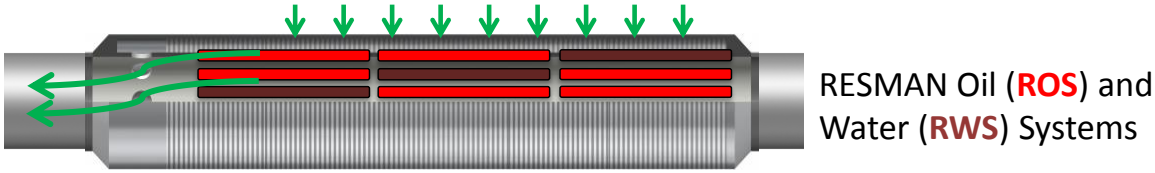
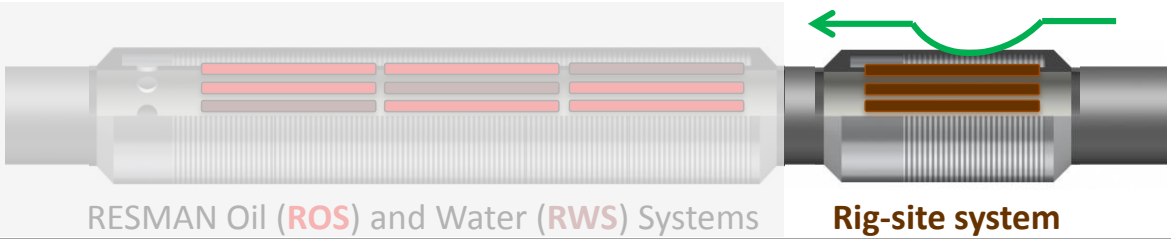
Rig-site tracer systems:

- Designed for same temperature and rates
- Shorter life (clean-up); detectable at rig-site by mobile lab

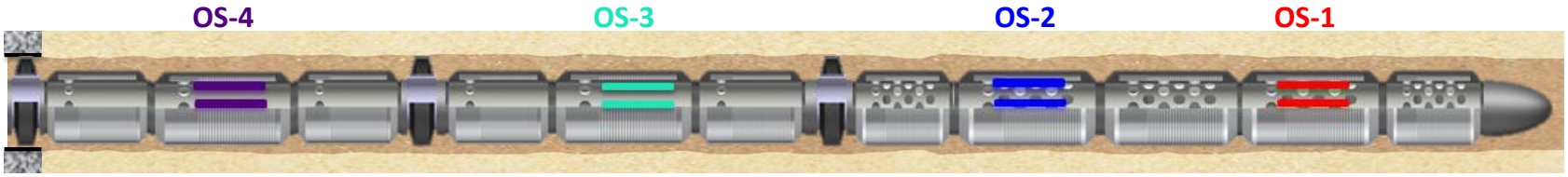
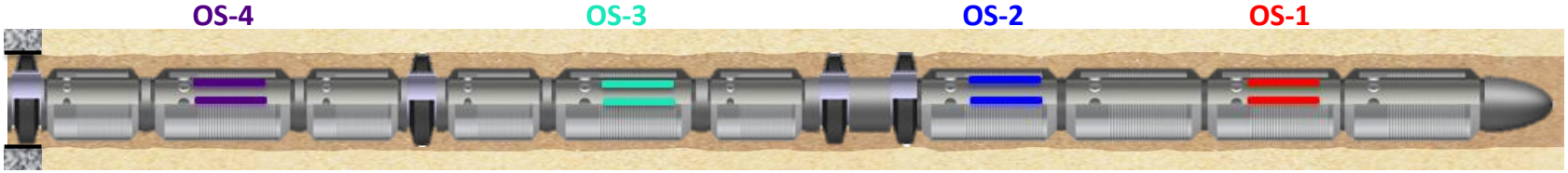
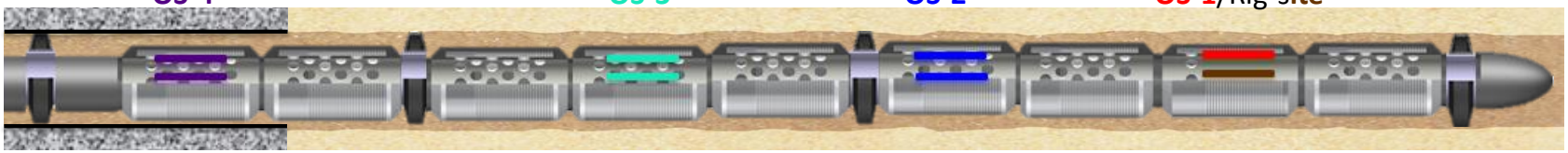
Tracer Carrier Screens



← *Oil and Water activated tracer rods installed into drainage layer of sand screens*

Baker Excluder (SAS) Perforated base pipe	
Baker Equalizer (ICD) Blank base pipe, ICD nozzles	
Baker Blank Screen (Rig-site) Blank base pipe, annular flow	

Completion Configurations

Well #	Completion schematic
1: ICD / SAS	
2: All ICD	
3: SAS*	
4 SAS*	

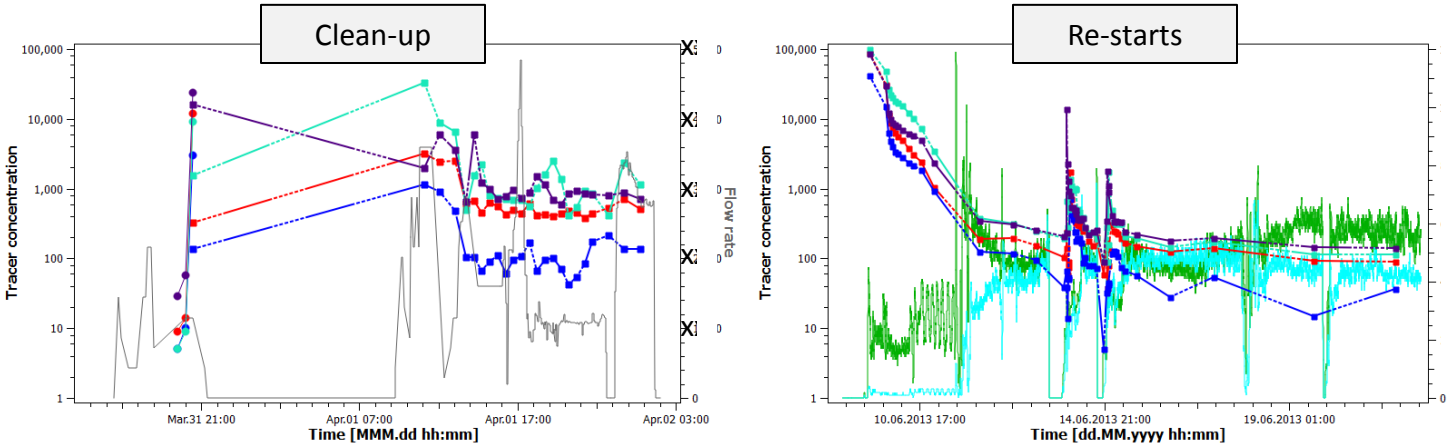
Intelligent Tracer Applications

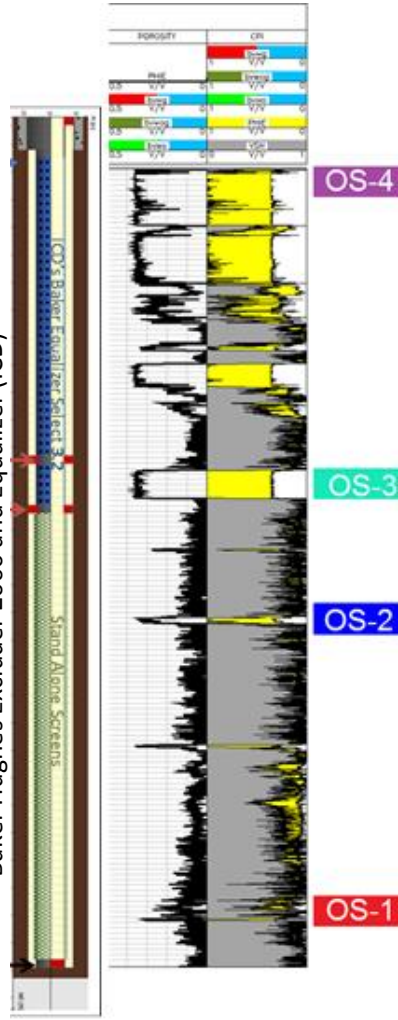
MAERSK OIL UK – RESMAN MONITORING CASE STUDIES

Confirmation of Oil Contribution

Well 1: Assess oil productivity

- Good sands choked back by ICD
- Tracers OS-1 and 2 in SAS to assess productivity from uncertain, lower sands and shale
- Clean-up to rig and re-starts to FPSO analysed



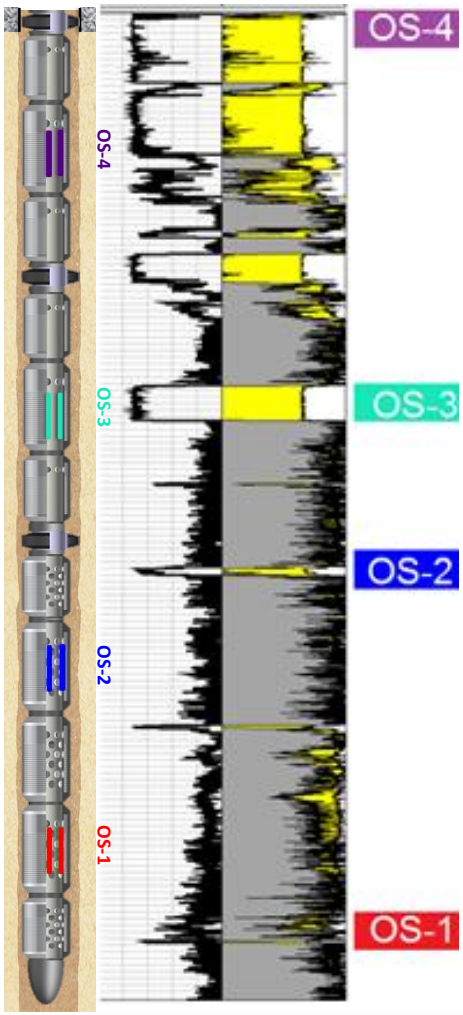


Confirmation of Oil Contribution

Clean-up

>80% of total production

<20% of total production



Re-starts

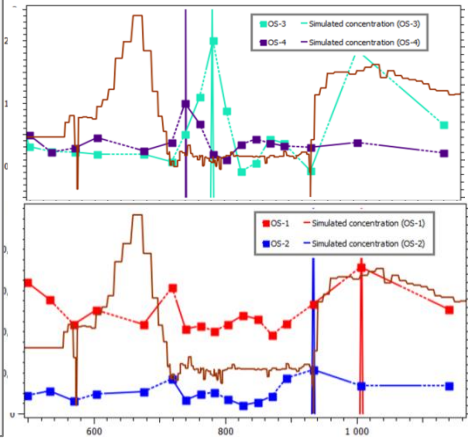
80-90% of oil production

5-10% of oil production. Potential gas and cross flow

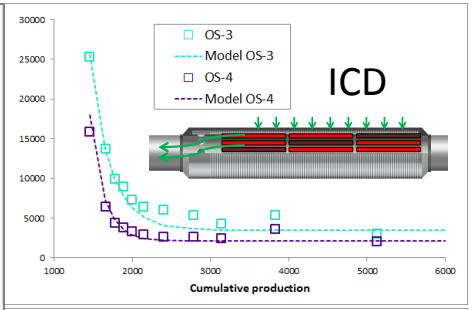
Little or no contribution to oil production

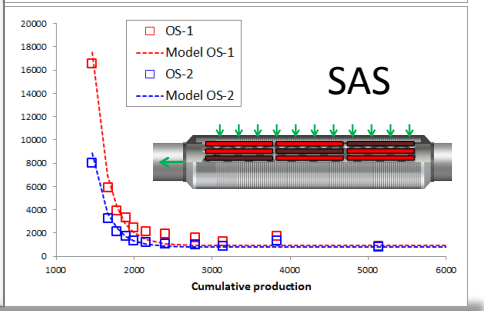
5-10% of oil production.

Clean-up: Arrival time model



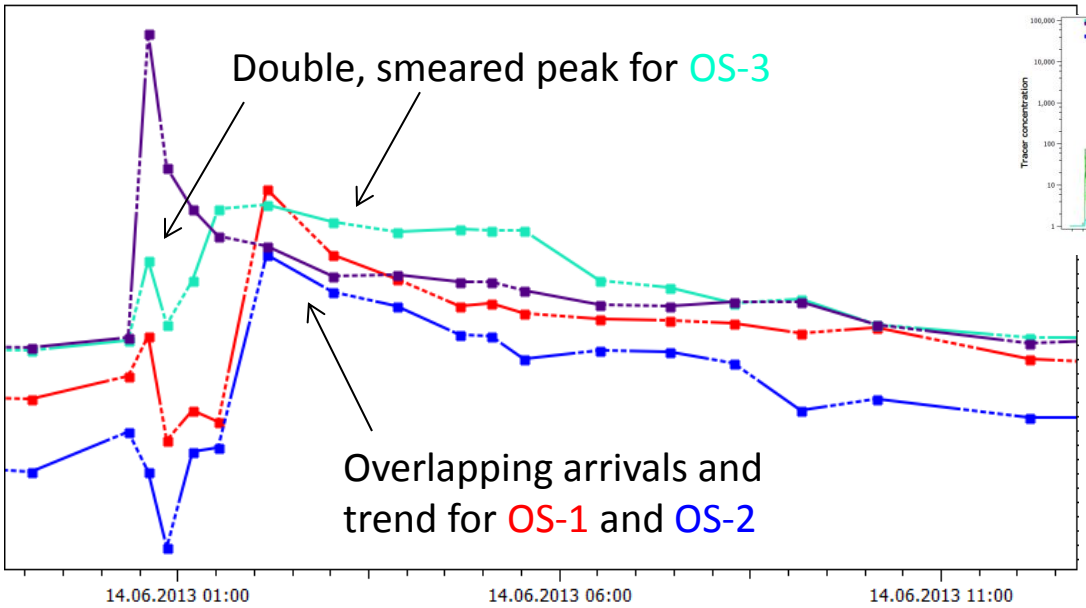
Re-starts: Flush-out model

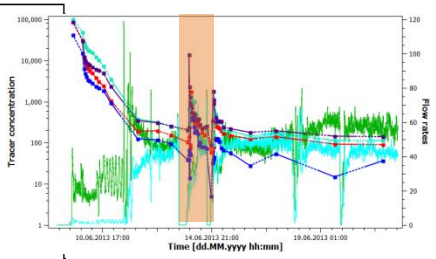


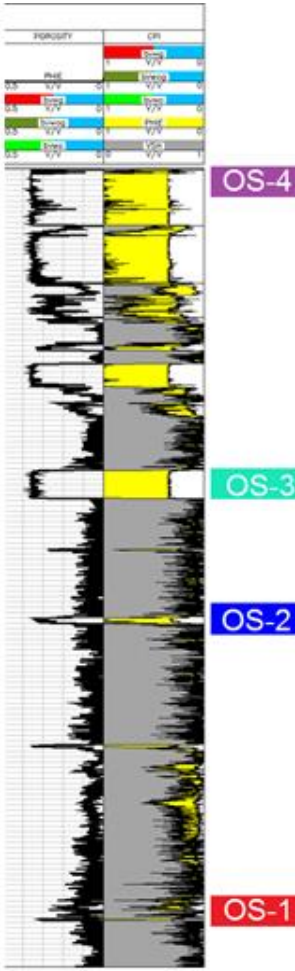


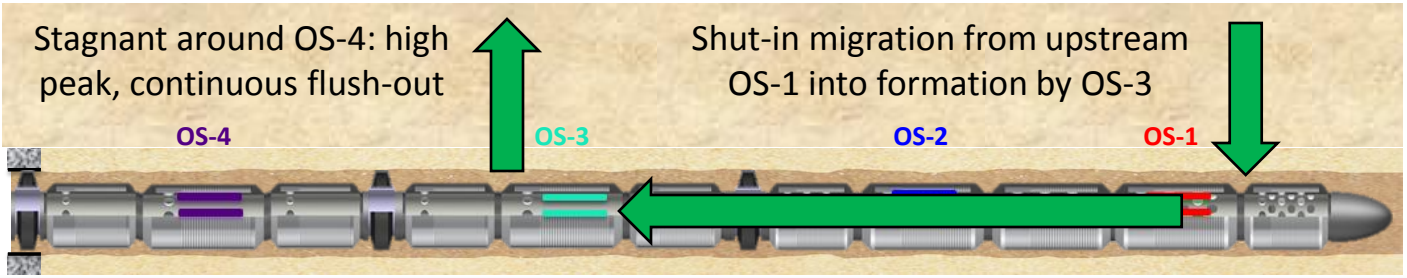
Determining Shut-in Cross Flow

Well 1: Tracers show dynamic shut-in conditions



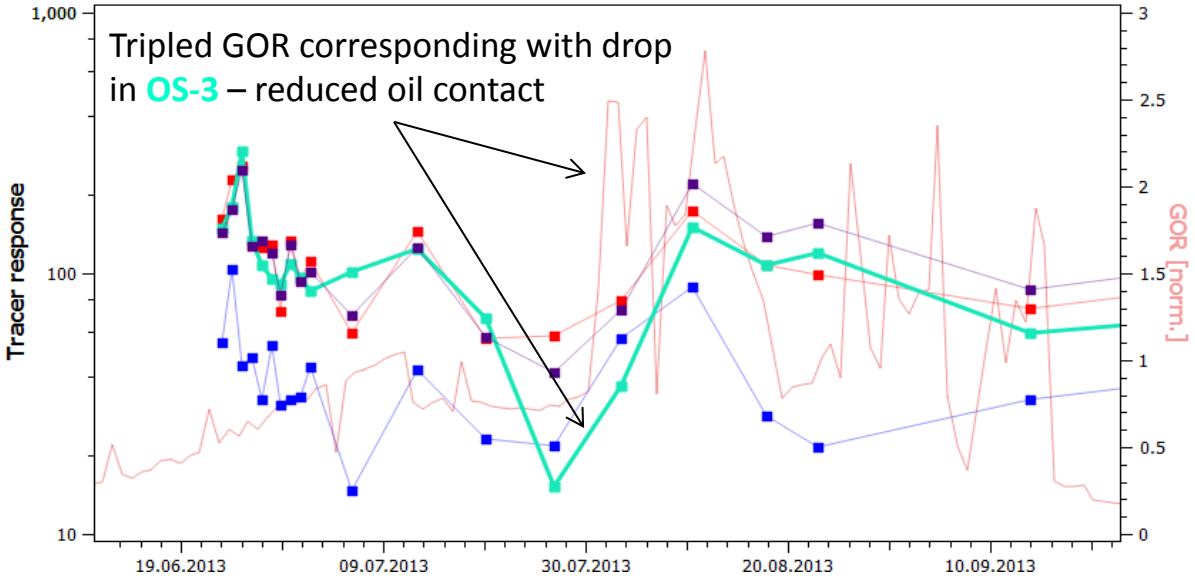




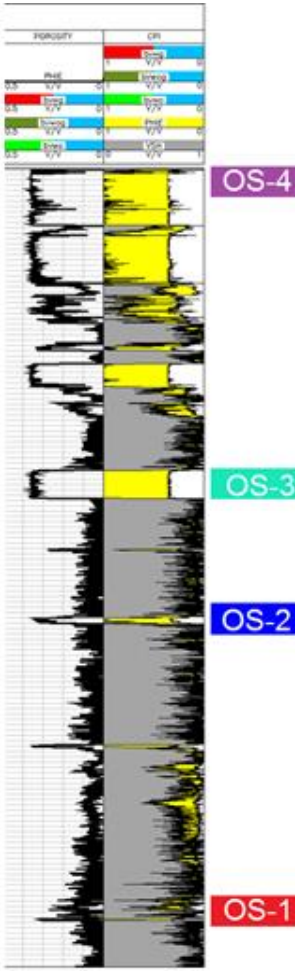


Gas Breakthrough Detection

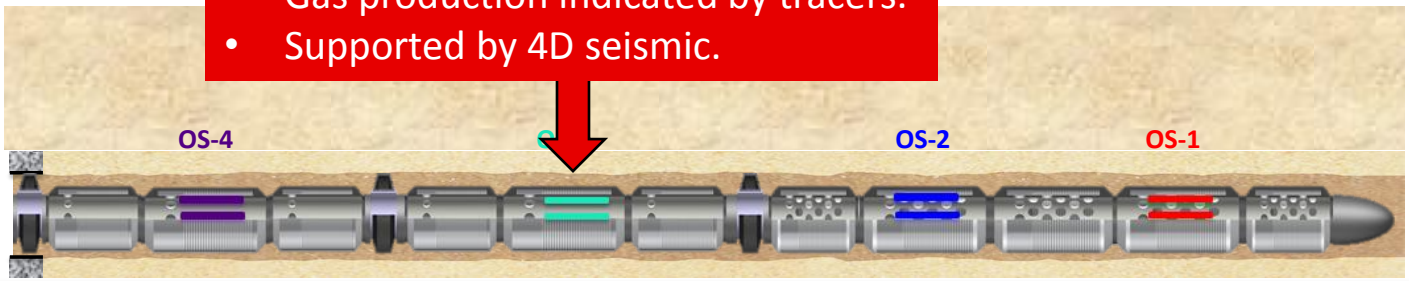
Well 1: Increased gas production



OS-3 response reduction recovered to some degree, but remains low compared to **OS-4** (reference)



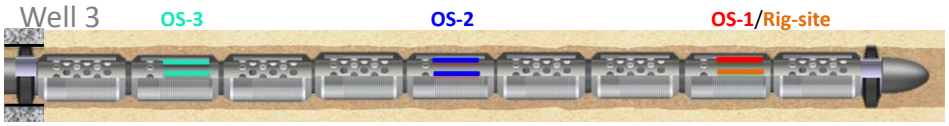
- Gas production indicated by tracers.
- Supported by 4D seismic.

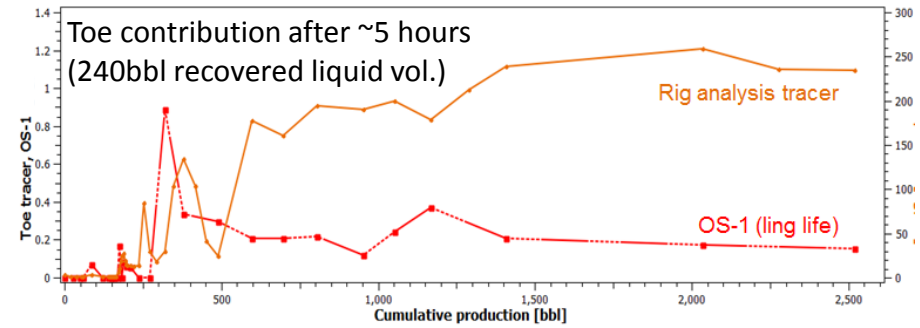


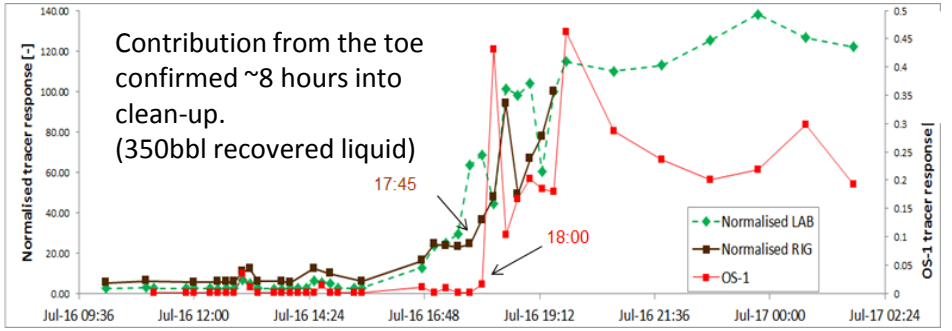
Rig-site Clean-up Verification

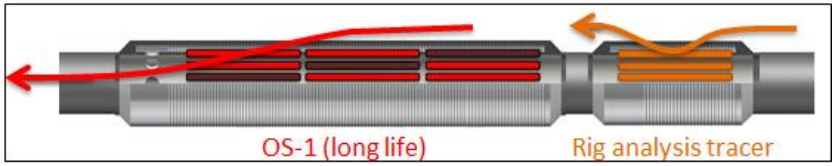
Wells 3 & 4: Verifying toe contribution with analysis on the rig

- Analysed on the rig with 2-4 hours turn-around time for results
- Similar timing for long life (OS-1) and rig-site tracer (offshore and onshore lab for Well 4)
  - Slow displacement of rig-site tracer pointing towards collapsed annulus









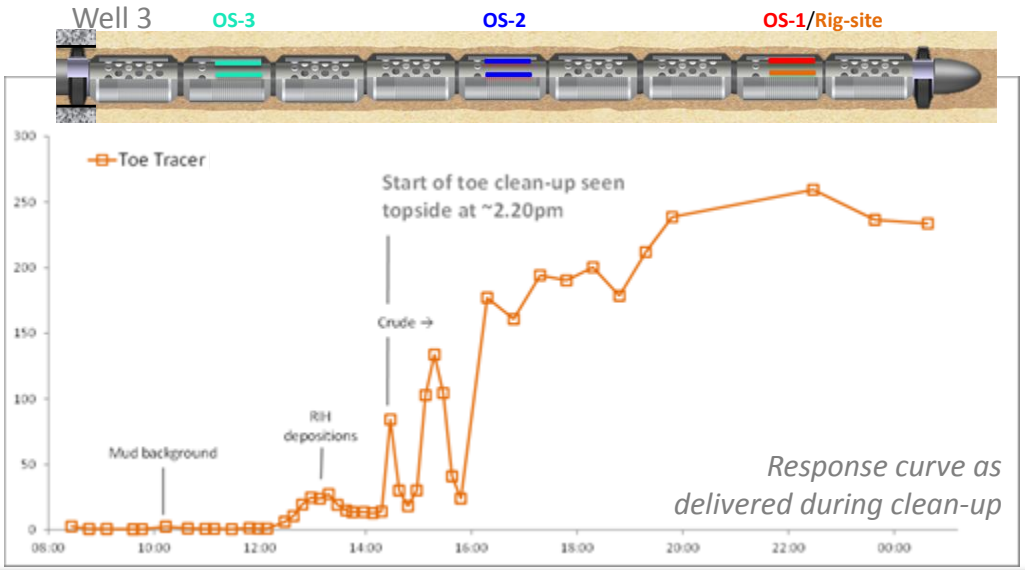
← Long life and rig-site systems installed on the same joint. Similar timing but different response trends due to tracer system design and flow displacement mechanism (ICD flush-out vs. annular flow driven)

Rig-site Clean-up Verification

Wells 3 & 4: Verifying toe contribution with analysis on the rig

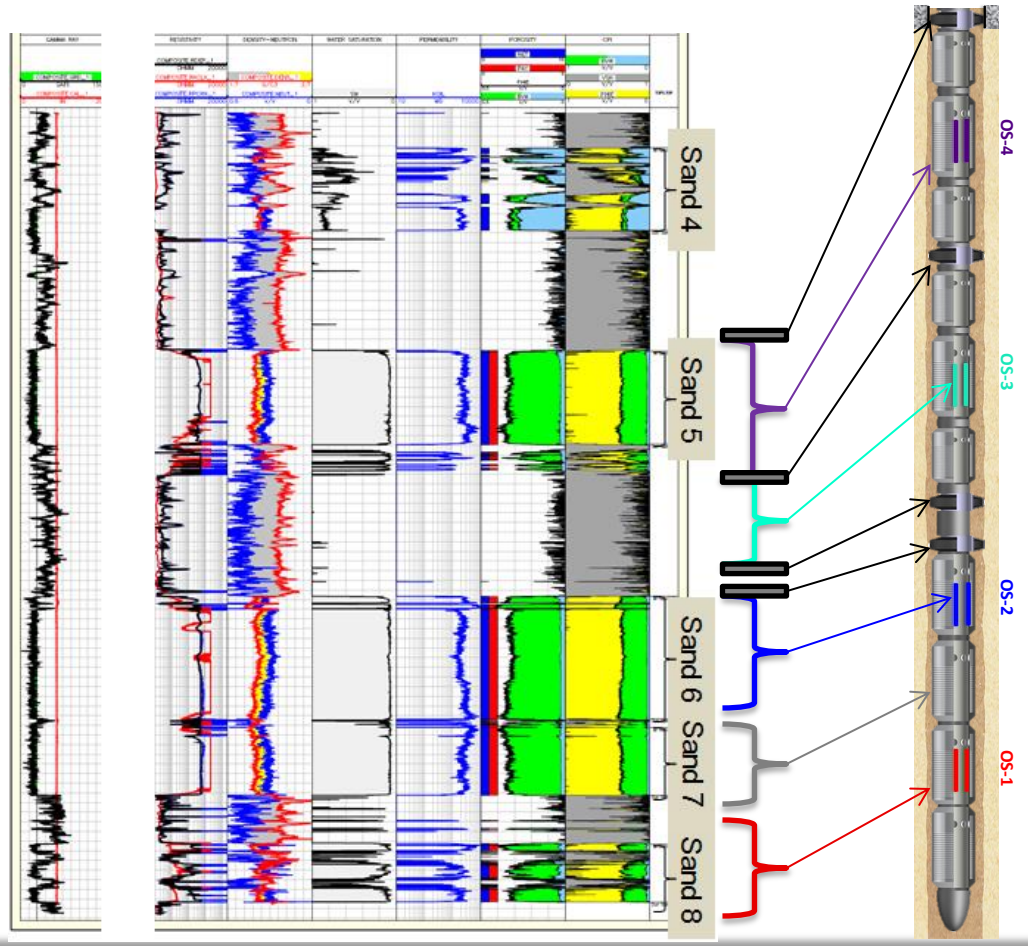
- Pilot version (2014): Bespoke tracer systems, analysis equipment set up in mud lab
  - Limited number of unique tracers (typically focus on toe)
  - Proof of concept and logistics
- Commercial version (2015): Use long life systems, analysis container on rig or beach
  - Multiple tracers available for full coverage of the well clean-up
  - Container lab available for North Sea assets

RESMAN offshore lab technicial for Well 3 clean- up



Quantitative Inflow Distribution

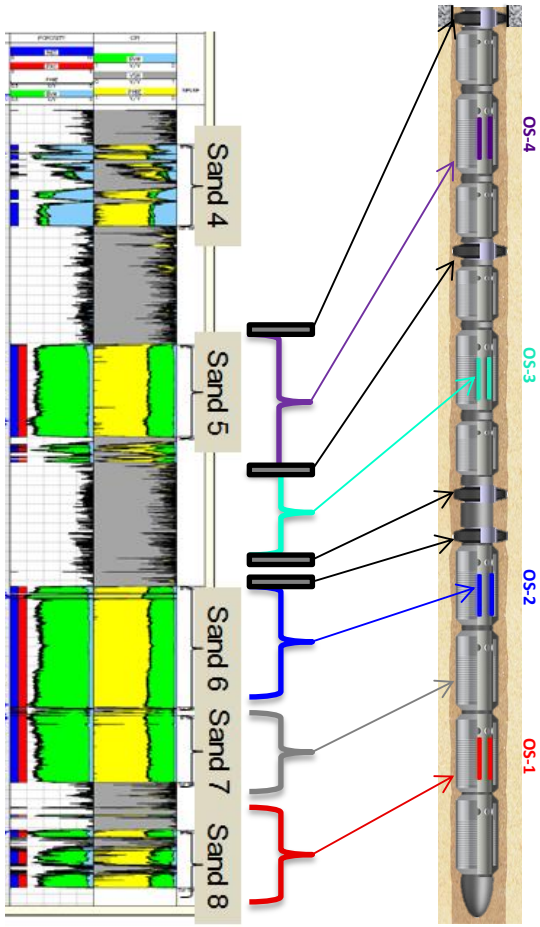
Well 2: Inflow distribution across multiple sands in an ICD well

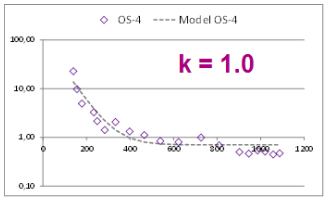
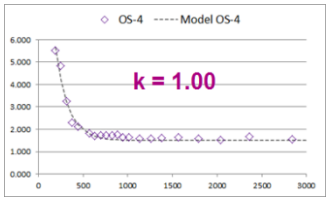
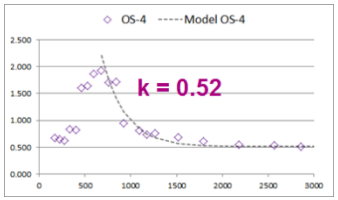
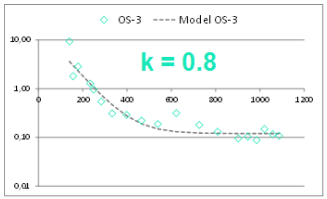
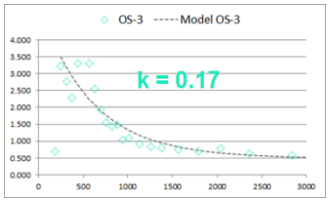
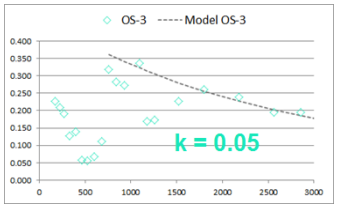
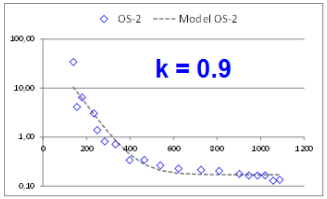
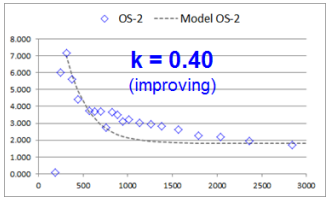
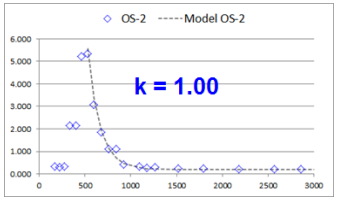
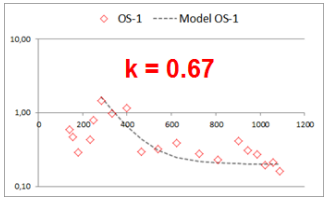
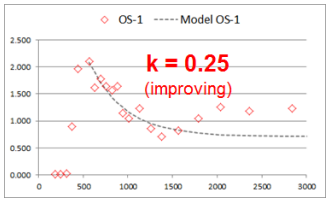
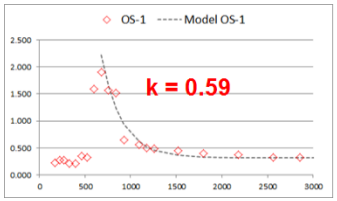


- **OS-4** monitoring Sand 5
- **OS-3** monitoring Shale between Sands 5 and 6
- Blanked off above Sand 6
- **OS-2** monitoring Sand 6
- No tracer in Sand 7
- Interpolating OS-1 and 2
- **OS-1** monitoring Sand 8

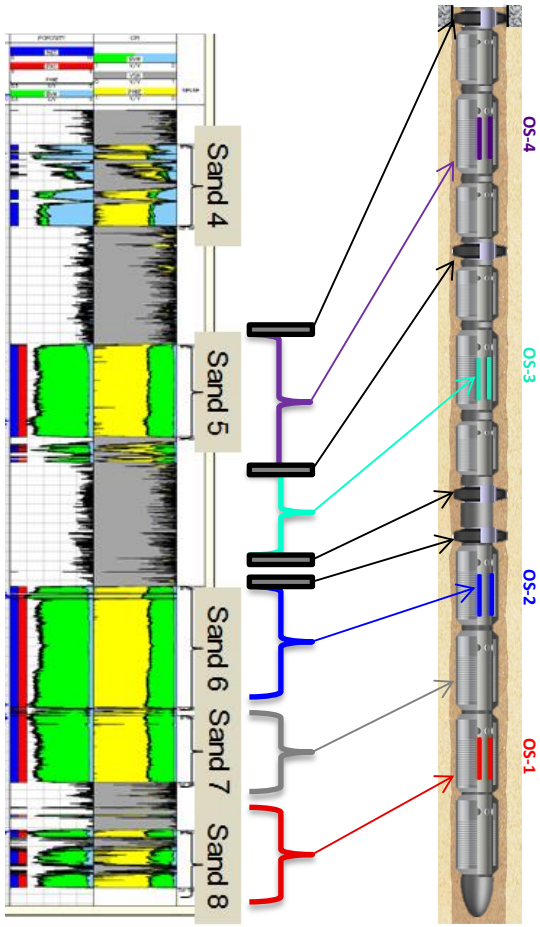
Quantitative Inflow Distribution

k = relative ICD performance factor



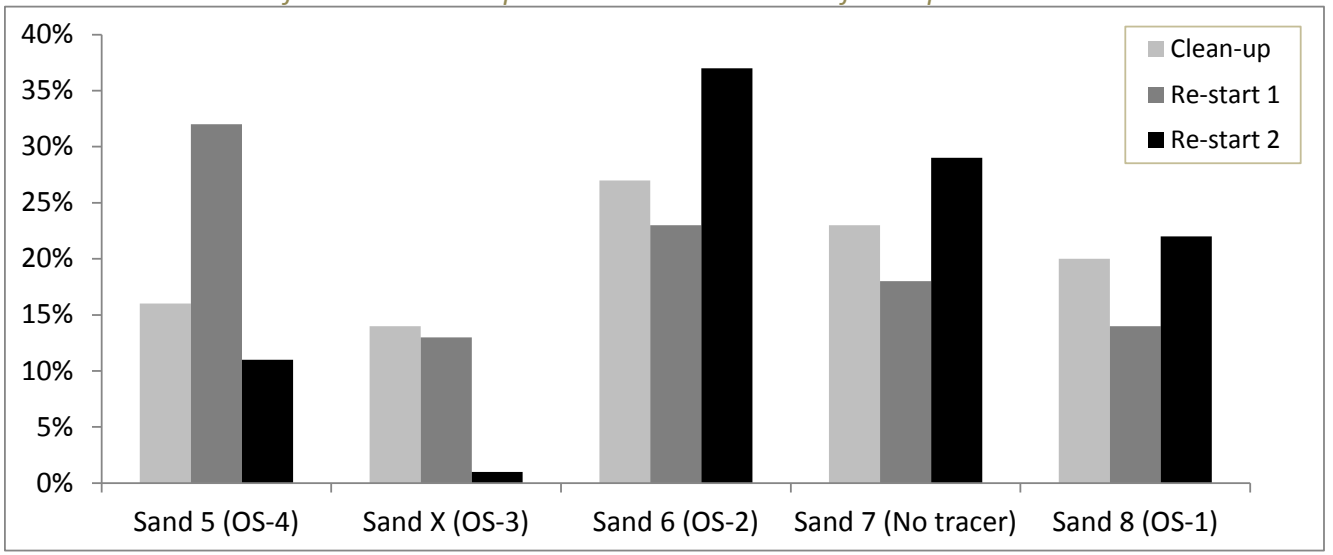
	Clean-up (rig)	**Re-start 1** (FPSO)	**Re-start 2** (FPSO)	
OS-4				Initially strongest. Reduced relative performance in Re-start 2
OS-3				Initially strong. Depleting rapidly.
OS-2				Seeing prolonged clean-up effects, ending up as strongest zone.
OS-1				Seeing prolonged clean-up effects, ending up as 2nd strongest zone.

Quantitative Inflow Distribution



- **Background**: LCM pumped during completion.
- **Observation**: Prolonged clean-up.
  - Noise in tracer responses and dynamic inflow distribution
- **Conclusions**: Mainly invasion or damage to Sands 6 to 8
  - Longer time required to clean up.
  - Prolific sands once LCM is displaced.

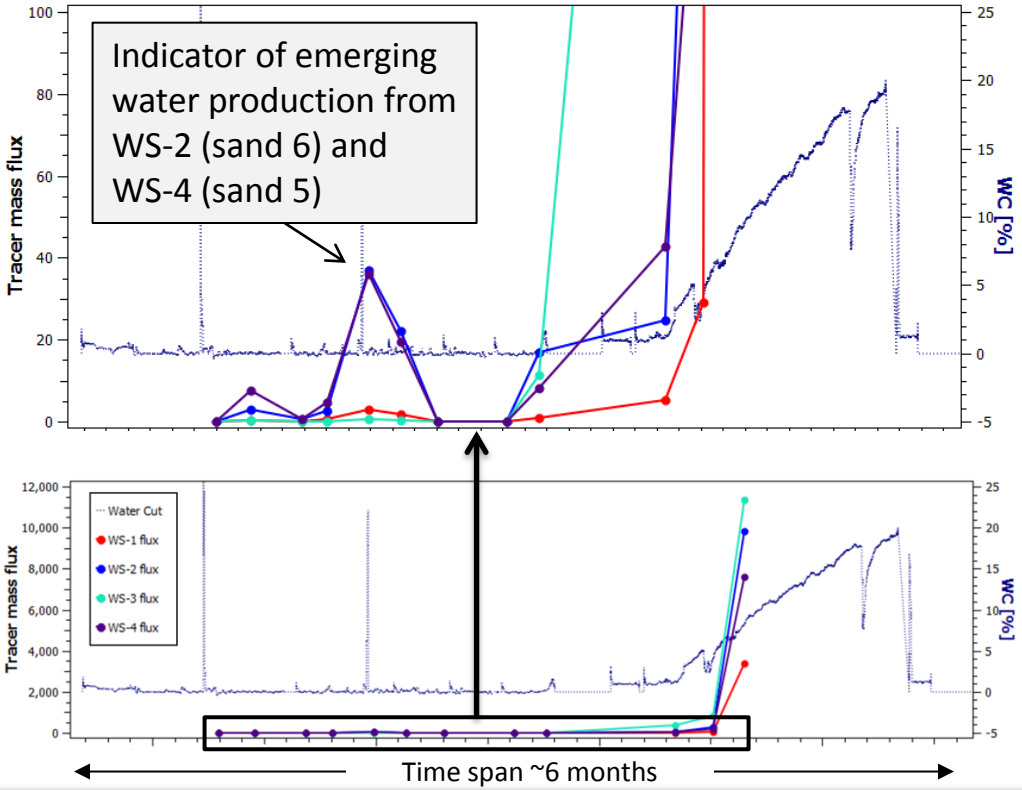
Inflow distribution per sand: % contribution of total production

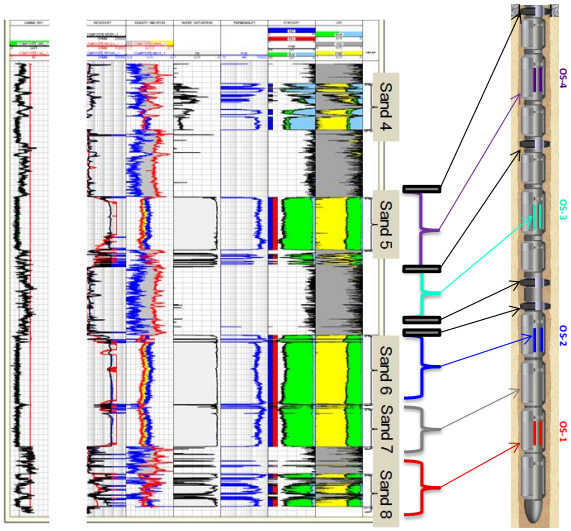


Water Producing Zones

Well 2: Water inflow detection in an ICD well

- Steady state water samples analysed around WC increase
- Early responses seen prior to WC increase (MPFM)





Significant response from all water systems at WC increase – Balanced water ingress?

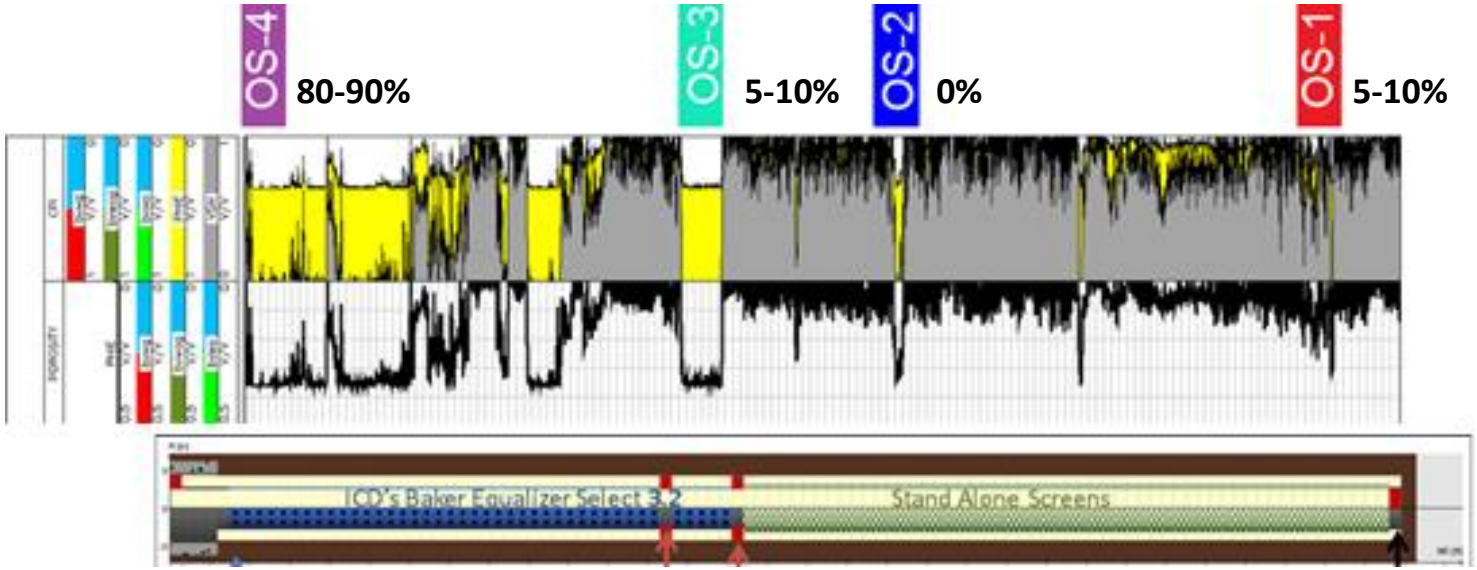
- Strongest for Sand 6 and above
  - In line with early indicator from WS-2 and WS-4
- Potential liquid loading creating response from WS-3 (well trajectory)

Continued sampling and analysis ongoing to further assess water production.

Application of RESMAN data

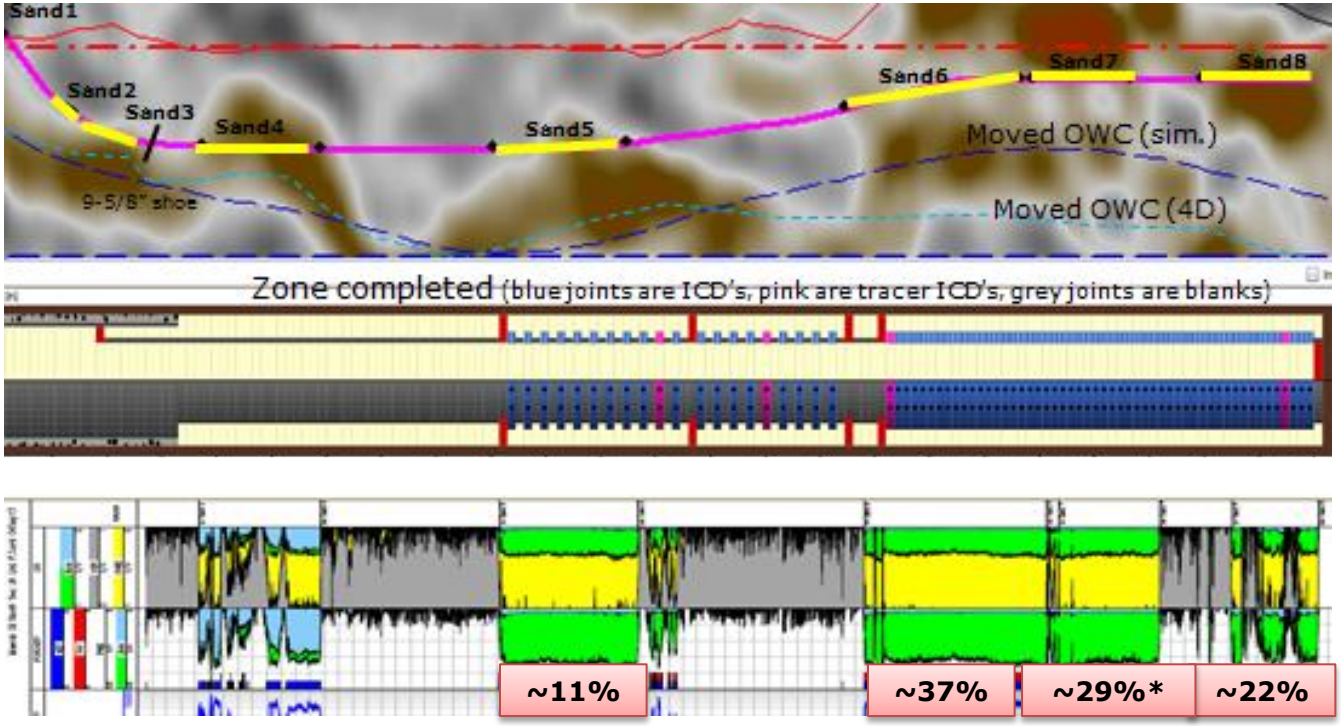
RESMAN RESULTS USED IN ASSET MANAGEMENT

Asset Management – Well 1



- **Drilling Injectites.**
  - **Question**: Should we bother completing zone 1 (~10ft of sand) separated by ~1500ft of shale?
- With the tracers we were able to convince management that we will be able to confirm flow from the toe if we completed it.
- Toe tracer (WIT 1) confirmed to produce ~5-10% of production
  - Production from this zone has paid for entire lower completion!
- Tracer Data also enabled us to make quality decisions in planning intervention.

Asset Management – Well 2



- Tracer Data confirmed completion is operating as designed.
- Tracer in shale confirmed shale is collapsed and/or packers are holding.
- Well recently has had water breakthrough:
  - Initial analysis (2 samples) of steady state water samples show potential in Sand 6.
  - Water loading in sump causing response from downstream tracers? (Sand 5 and Shale?).
- 'Transient' sampling planned to determine water production zone

Conclusions

- Intelligent inflow tracers were successfully installed in the wells at relatively low cost, without adding risk or rig-time.
- Monitoring campaigns provided insight into:
  - Qualitative verification of contribution
  - Quantified inflow distribution (alignment of models and log data)
- Campaigns conducted provided information on:
  - Individual well performance development
  - Completions design
  - Reservoir performance
- Continued monitoring of wells where RESMAN tracers are installed.

  - ***PLT on Demand!***