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Integrated Historical Data Workflow: Maximizing the Value of a Mature Asset

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Schlumberger (retired)

Schlumberger

SPE International

APEGA

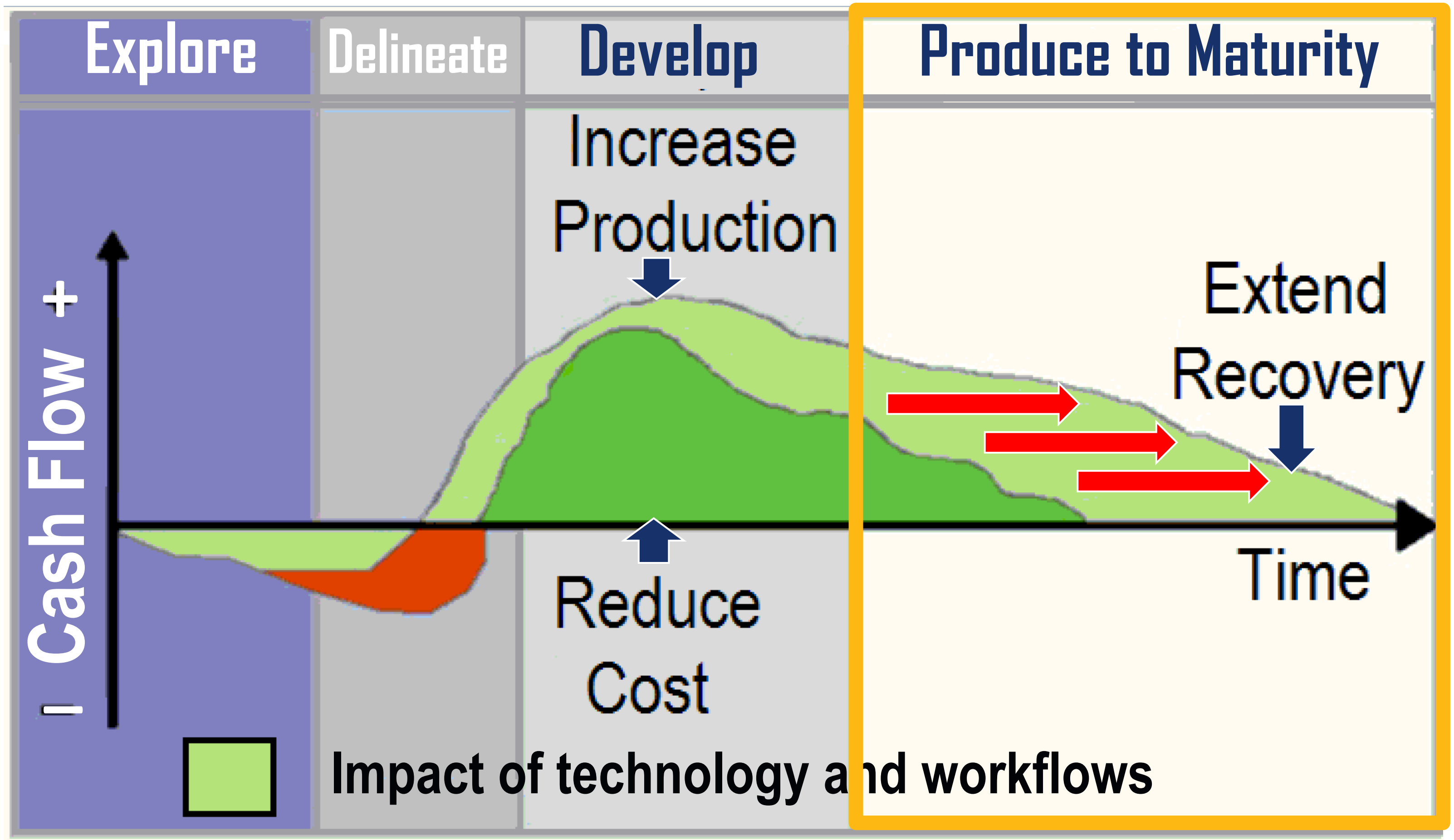
Outline

- Workflow
  - Data required
- Case Study
  - History
    - Initial underperformer identification
    - Water and formation damage indicators
    - Waterflood success
  - History Update
    - Results of interventions
- Summary and Conclusions

Opportunity identification more important than ever

- Low cost, quick techniques to identify opportunities, for example:
  - Well interventions: acid jobs, squeezes, recompletions, refracturing jobs
  - Wells to shut in or reactivate
  - Improved waterflood management
- Can be completed within a few days

Goal: Improve production / recovery at low cost

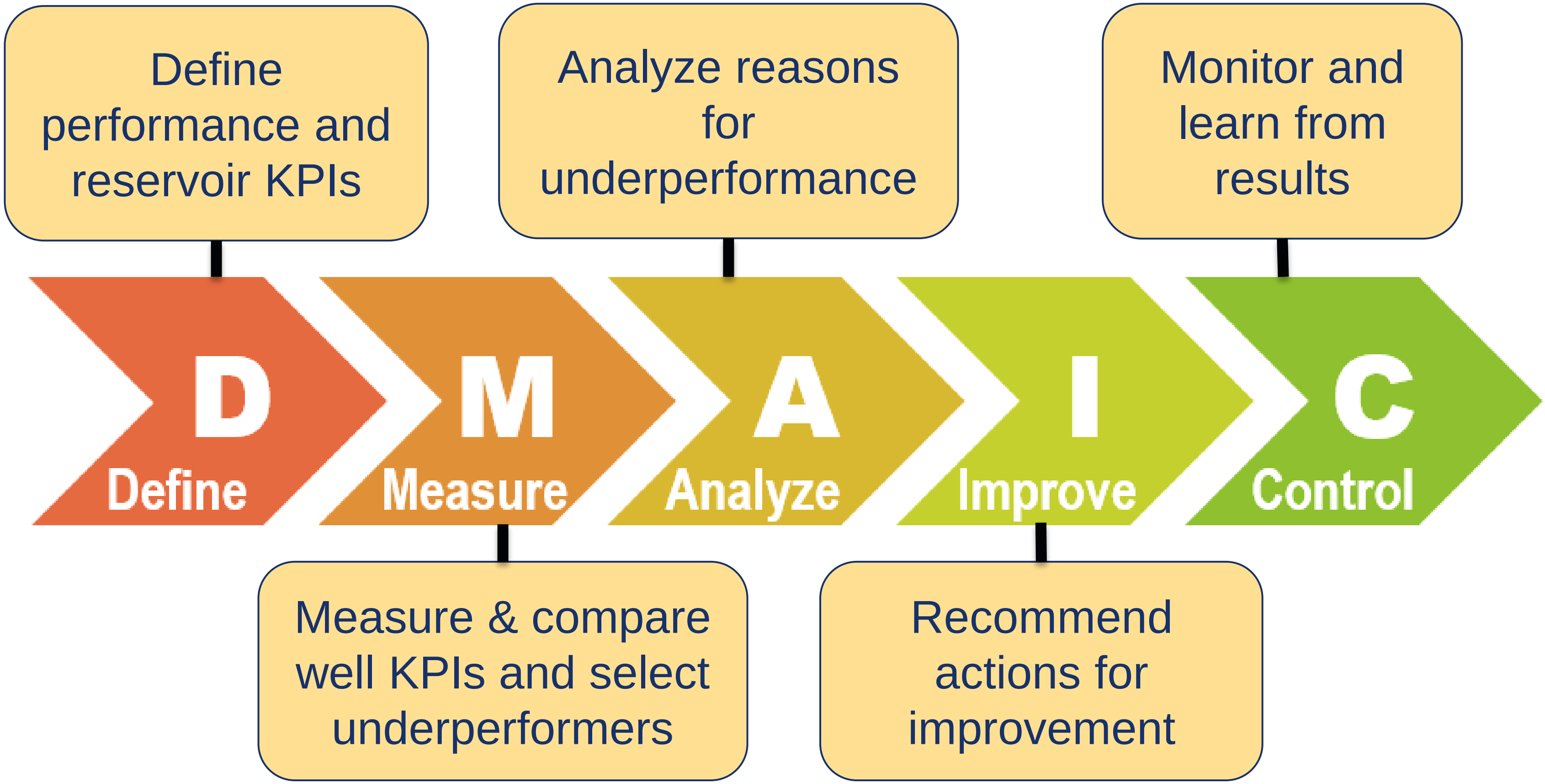


Source: The Digital Oil Field – Oil & Gas Investor – April 2004

What data do you need?

- Historical Dynamic Data
  - Monthly Production
  - Monthly Injection (if applicable)
  - Pressures
  - Well Events
- Static Data
  - Petrophysical: Permeability, Porosity, Net Pay, Initial Water Saturation
  - PVT Properties

The workflow approach



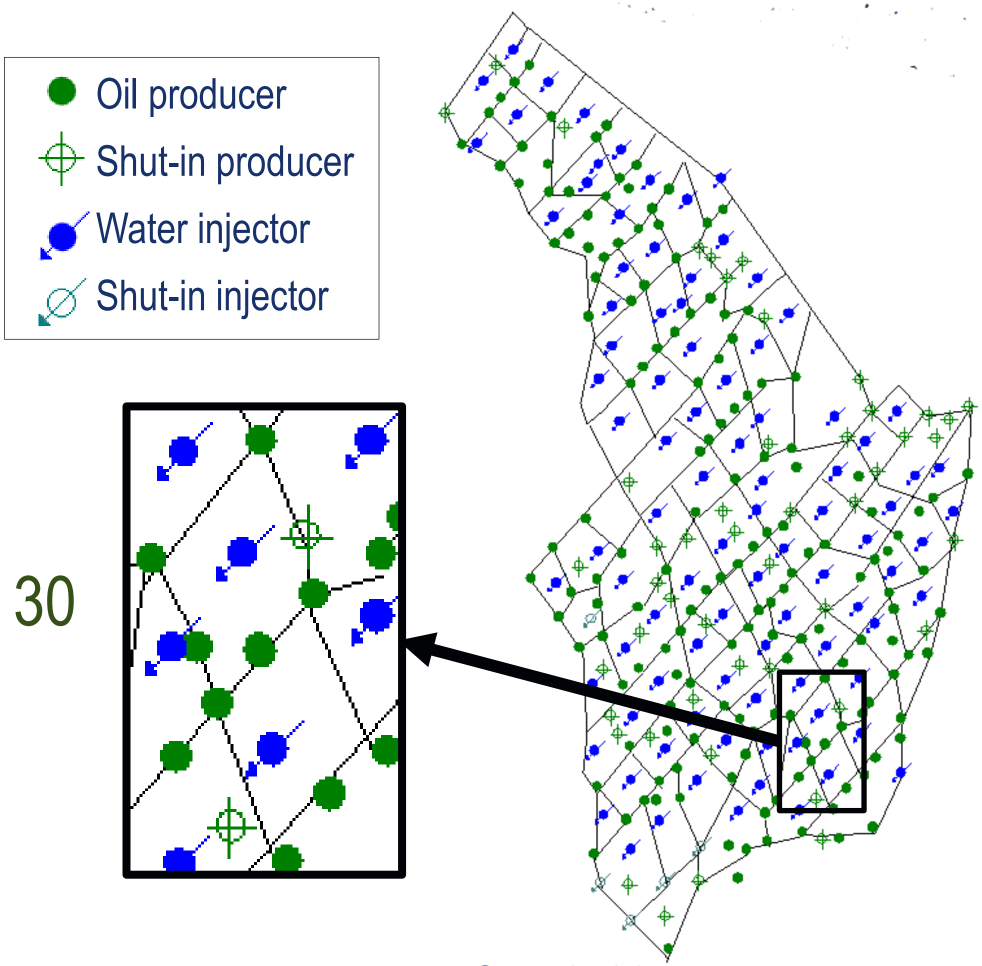
Buell, Turnipseed, “Application of Lean Six Sigma in Oilfield Operations”, 84434-PA SPE Journal Paper – 2004

Case study:
A large waterflood

Ferrier field, Alberta, Canada

- Upper Cretaceous Cardium sandstone
- Low permeability
- Main waterflood area (303 wells)
- Original oil in place (OOIP) ~ 30 million m^3
- Recovery factor (RF) ~19%

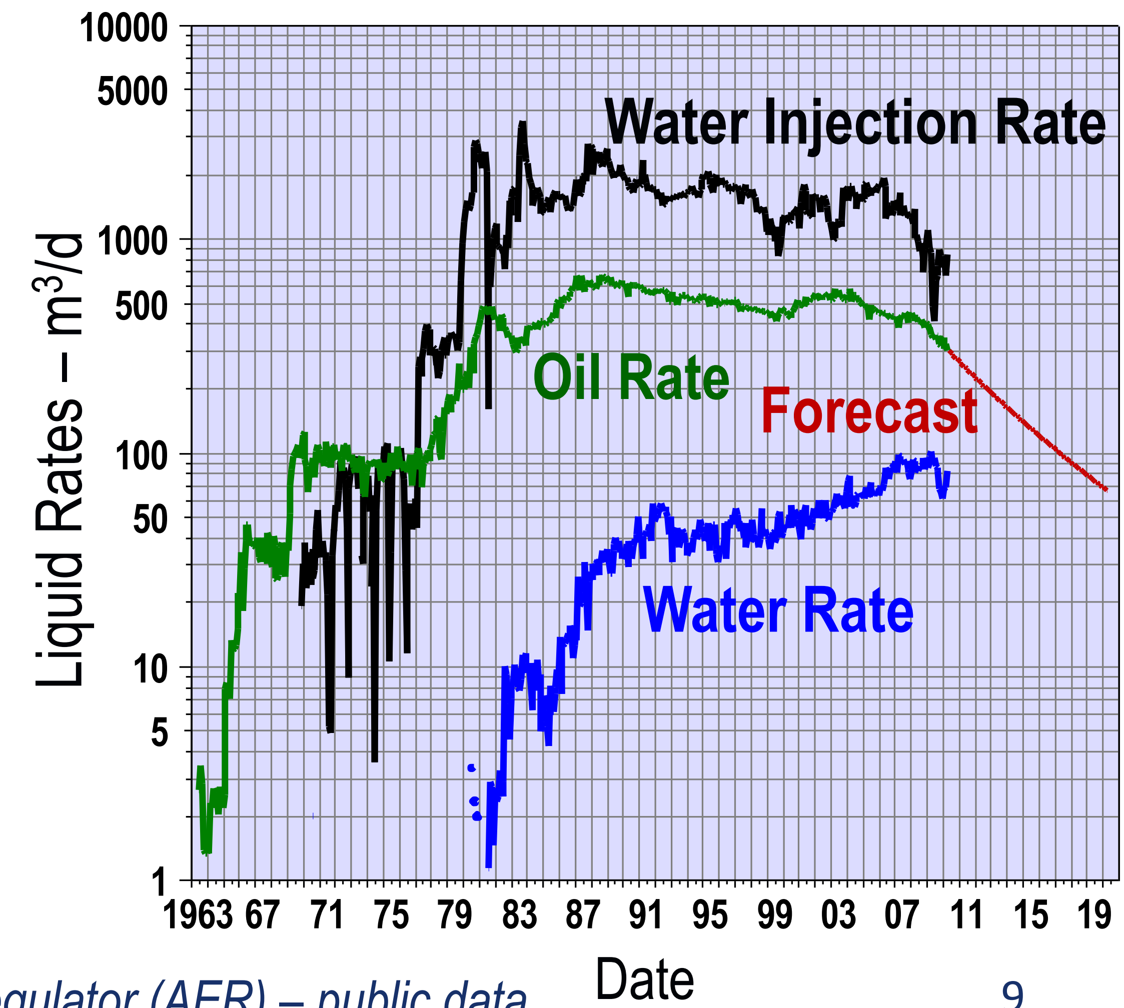
An outsider's "look-back"



Jones, McCord, Cummer, "Reservoir Simulation Pays Big Dividends", SPE 2428
Geological Atlas of the Western Canadian Sedimentary Basin – Chapter 23

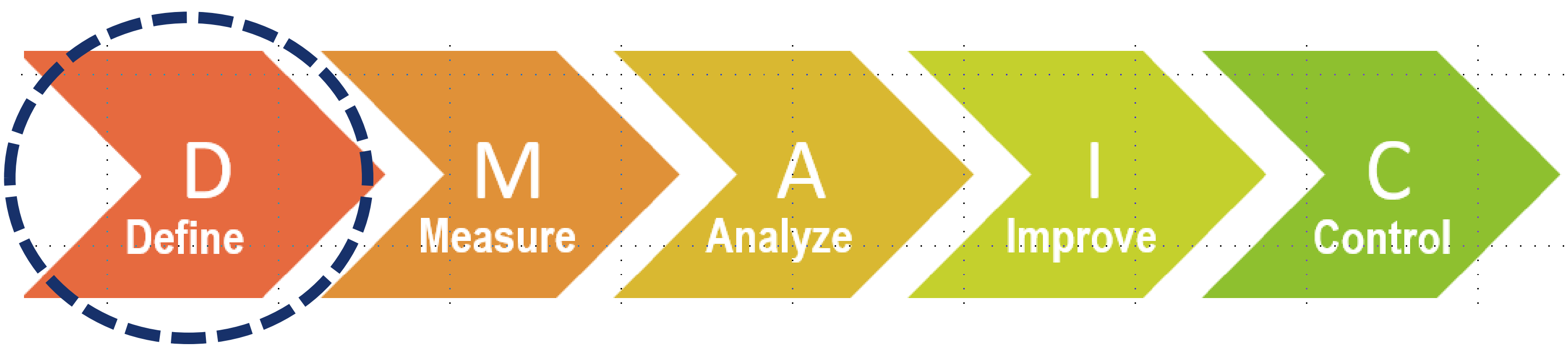
Historical production

- Date: May 2010
- Base 10-year forecast
- Expected ultimate recovery (EUR) → 6.33 million m^3 ~ 21% recovery factor
- Goal: optimize production at a low cost



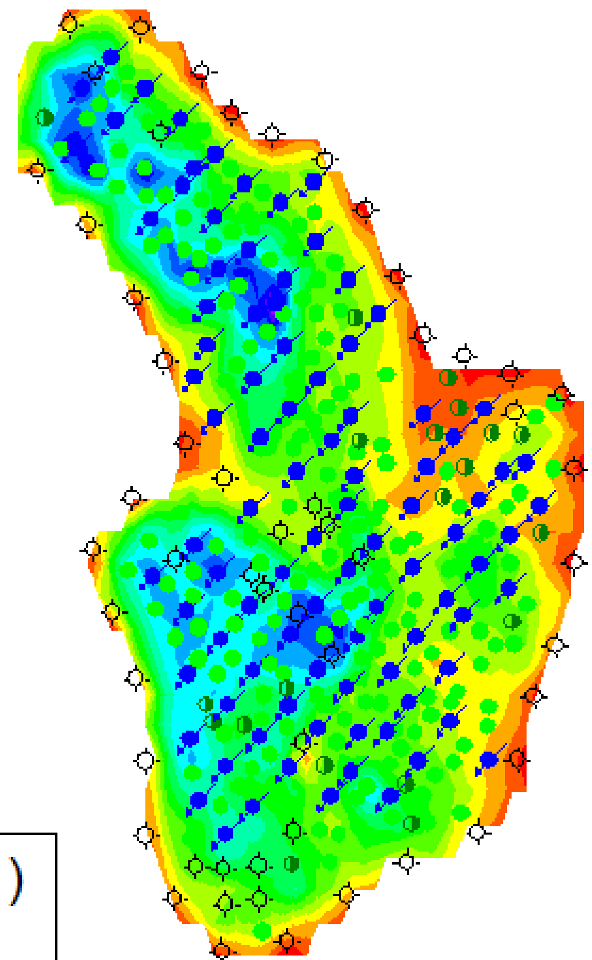
Alberta Energy Regulator (AER) – public data

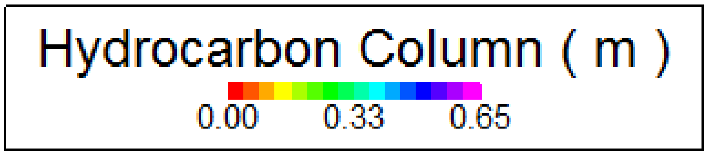
DEFINE KPIS



Fundamental assumption

- Performance should be a function of reservoir quality
- How to define “reservoir quality”?
  - Flow capacity (kh) = Permeability x Net pay
  - Original oil in place (OOIP): proportional to hydrocarbon column (per well) = Net pay x Porosity x (1 – Initial water saturation)





Definition of “performance”

- Oldest well: 48 years of production
- Newest: 2 years of production
- An old well, even a poor one, normally has higher cumulative oil than a new well.
- For this field, cumulative oil is not a good indicator of “good performer” versus “bad performer”.

Other options:

- Current rate (if same age)
- Lifetime average rate
- Peak rate
- Cum prod at x years
- Cum prod / Cum prod days
- EUR *(uncertain)*
- Combination of above

Selected indicator of "performance"

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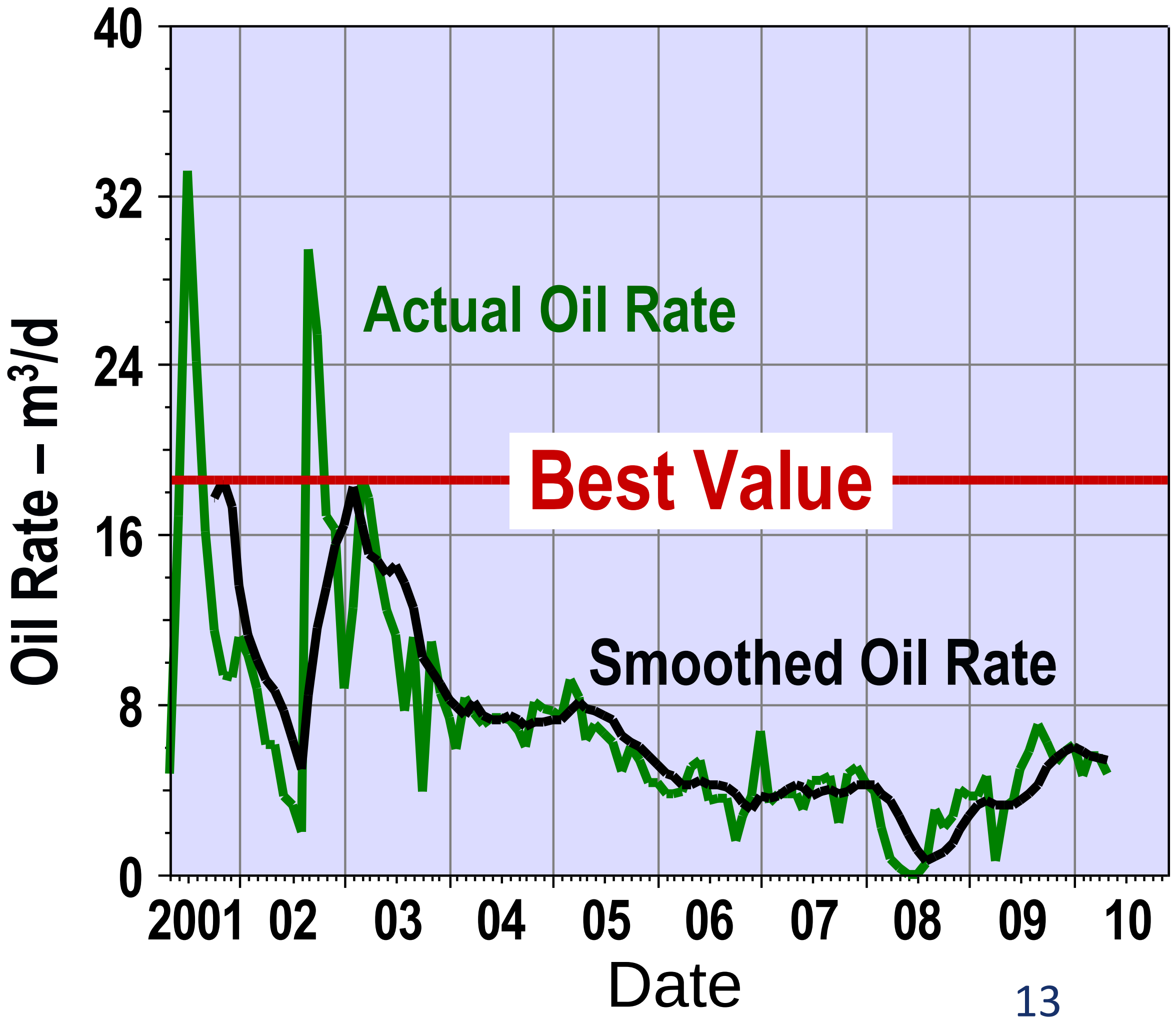
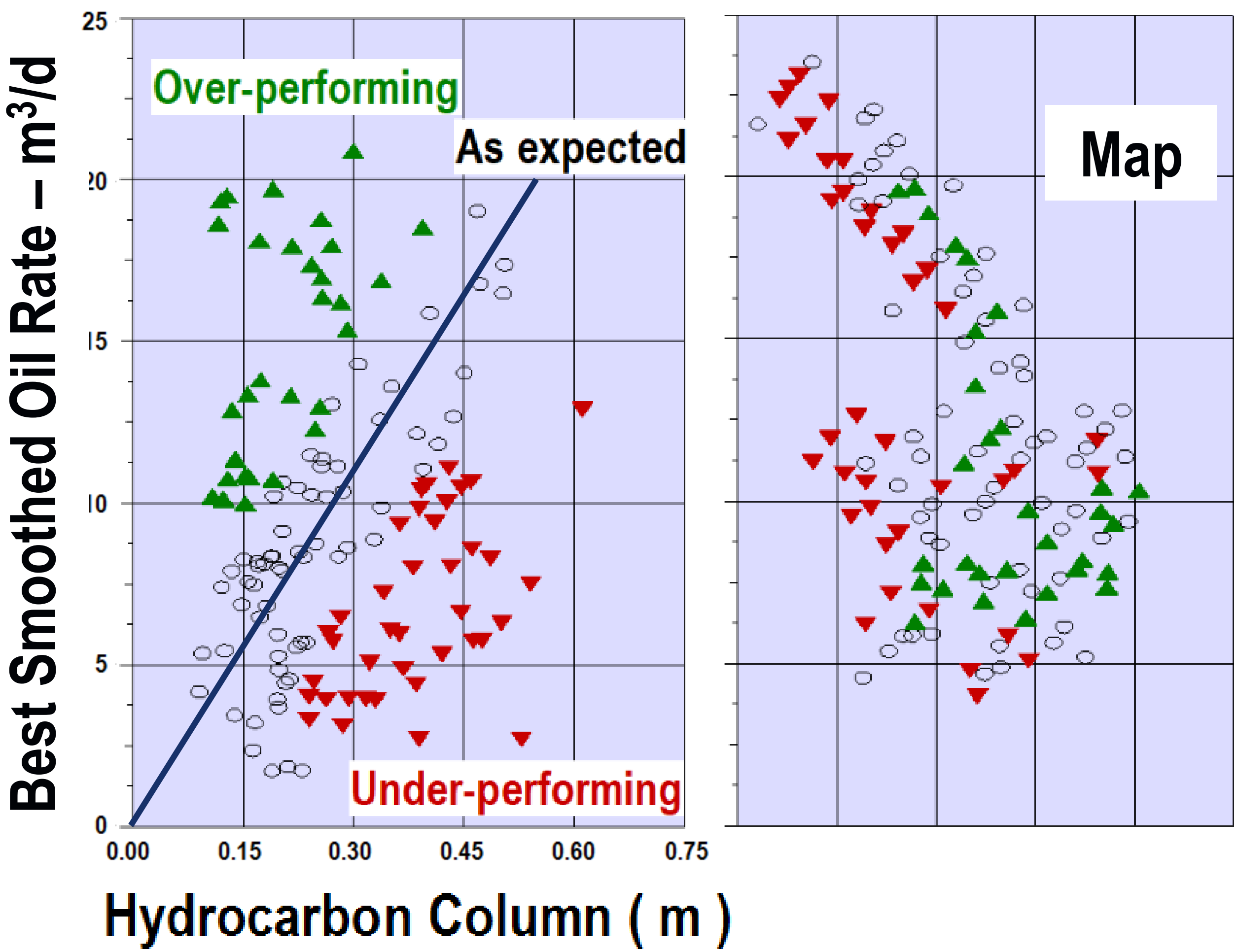
- Smooth (moving average) oil rate and select best value
- Data quality control
  - removes noise and anomalous points



MEASURE KPIS, SELECT UNDERPERFORMERS

Initial underperformance identification

- Plot performance indicator vs. reservoir indicator
- Categorize wells and view on map



ANALYZE REASONS FOR UNDERPERFORMANCE

Possible under-performance reasons

Individual wells:

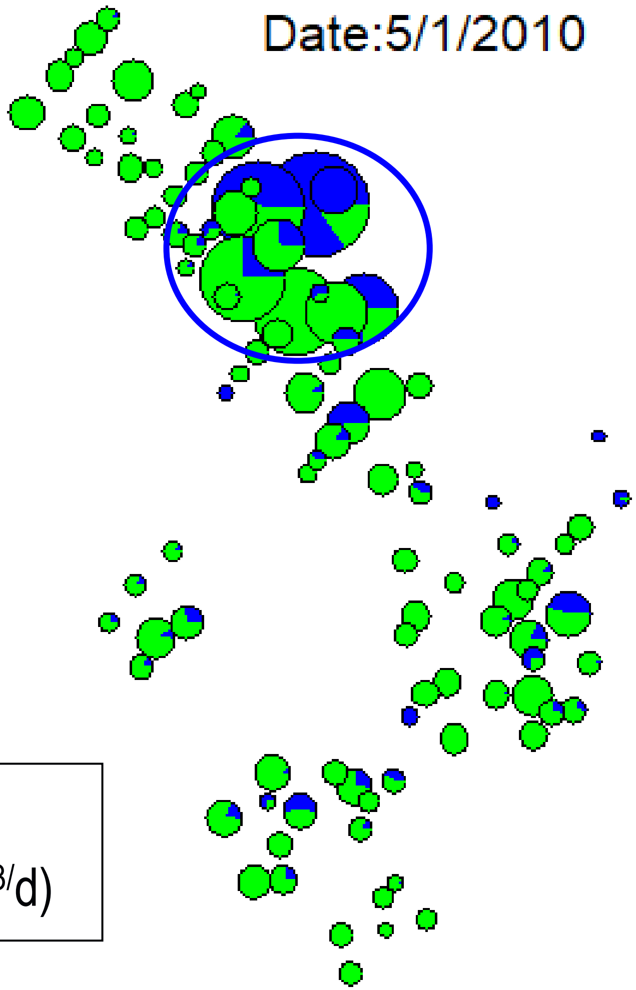
- Water production (overall water cut = 18%)
- Formation damage
- Wellbore or completion problems *
  - Perforations inadequate
  - Artificial lift restrictions
  - Surface constraints

Overall:

- Waterflood management

Water distribution

- Water production not generally a big problem
- Some individual wells - increasing water cuts



Oil Rate (m^3/d)

Water Prod (m^3/d)

Identify wells with above average water production

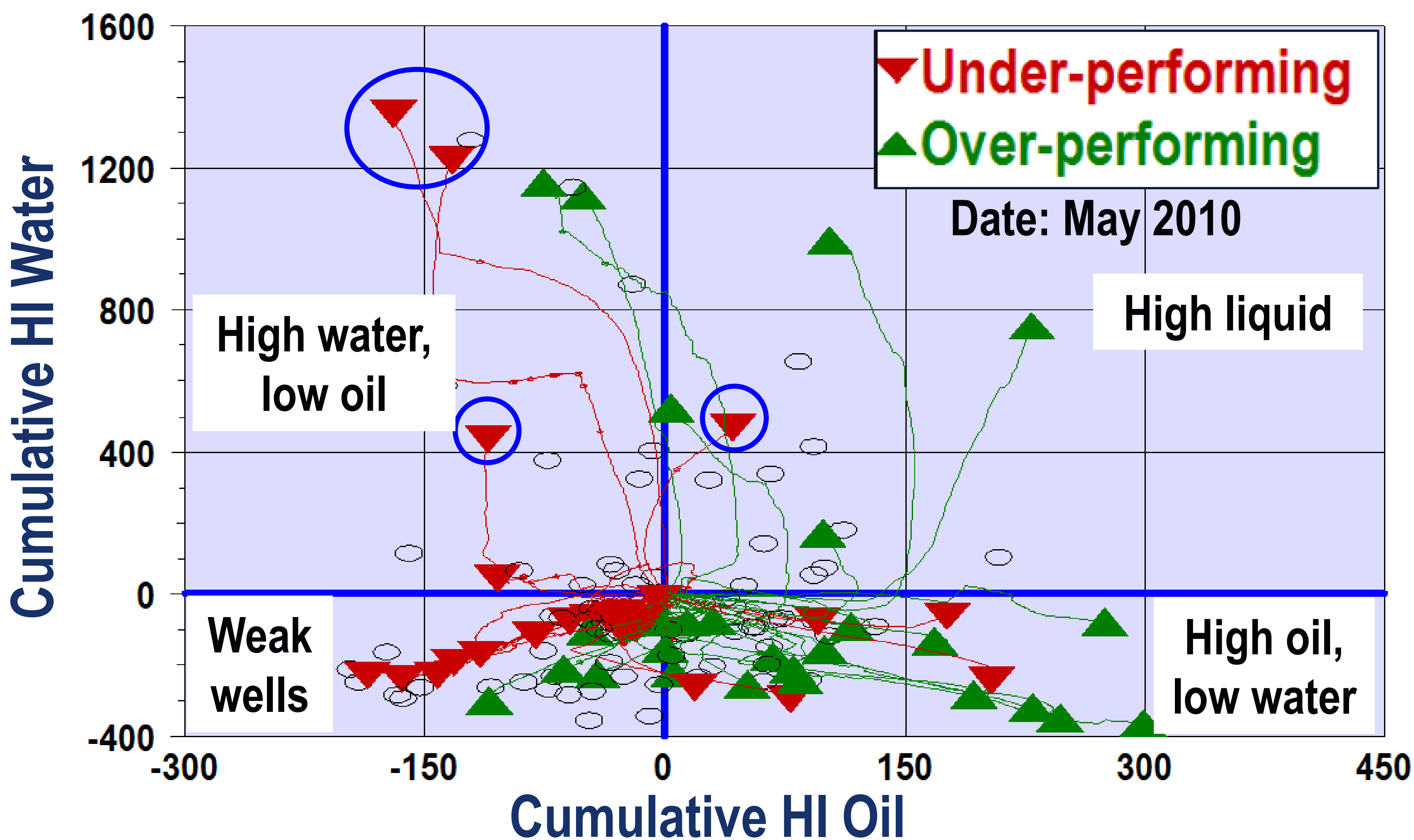
- Heterogeneity index (HI) compares each individual well with the group average

$$HI = \frac{VALUE_{WELL}}{VALUE_{GROUP.AVERAGE}} - 1$$

- HI = 0 for a well that behaves like the average
- Above average > 0, below average < 0
- Calculate a running sum to see long-term trends
- Plot of two HI values shows trends

SPE 36604: Completion Ranking Using Production Heterogeneity Index
SPE 138229: Performance Model Analysis for Candidate Recognition

Underperformers with higher water production



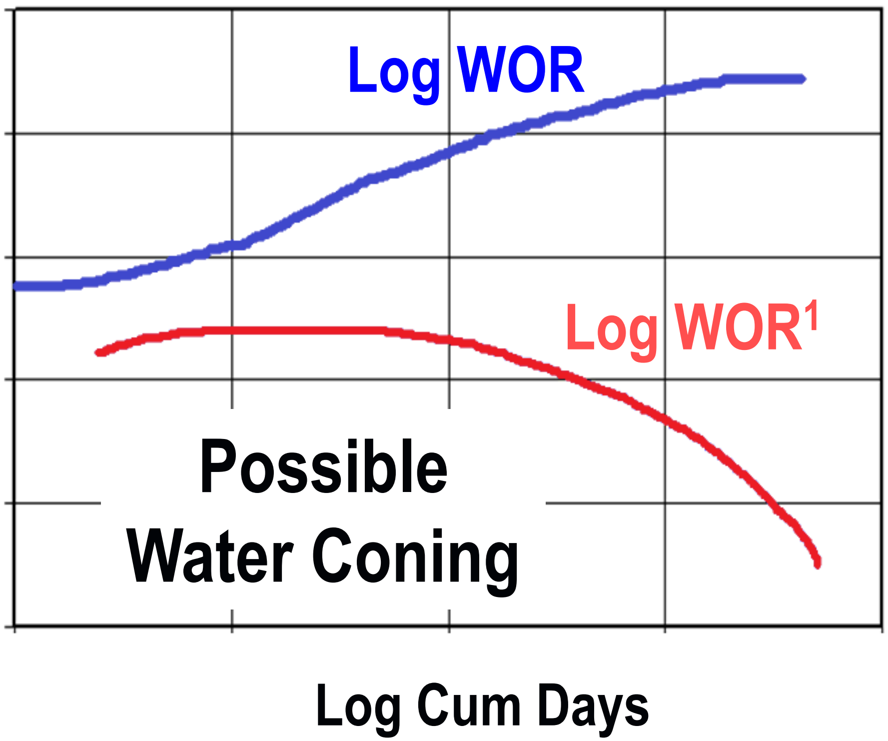
Water control diagnostics

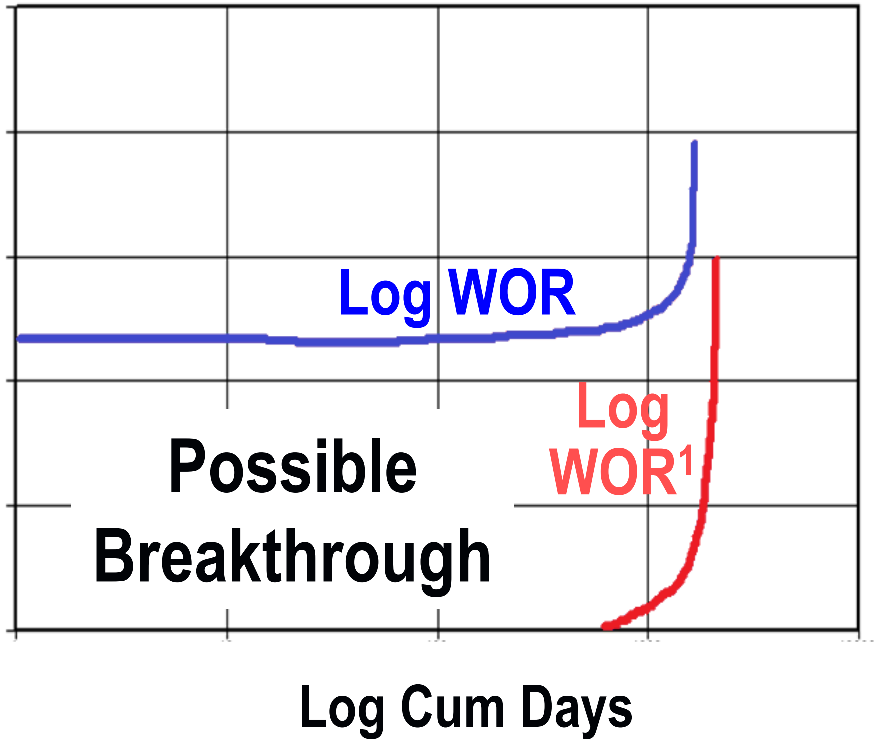
- Technique to diagnose water production behavior
- "Chan plot":
  - WOR (water-oil ratio)
  - WOR[1] (first derivative of water-oil ratio)
  - Versus cumulative days on production
  - Log-log scales
- Widely used
- Also applicable for WGR or GOR

SPE 30775: Water Control Diagnostic Plots
Plus many later papers based on this

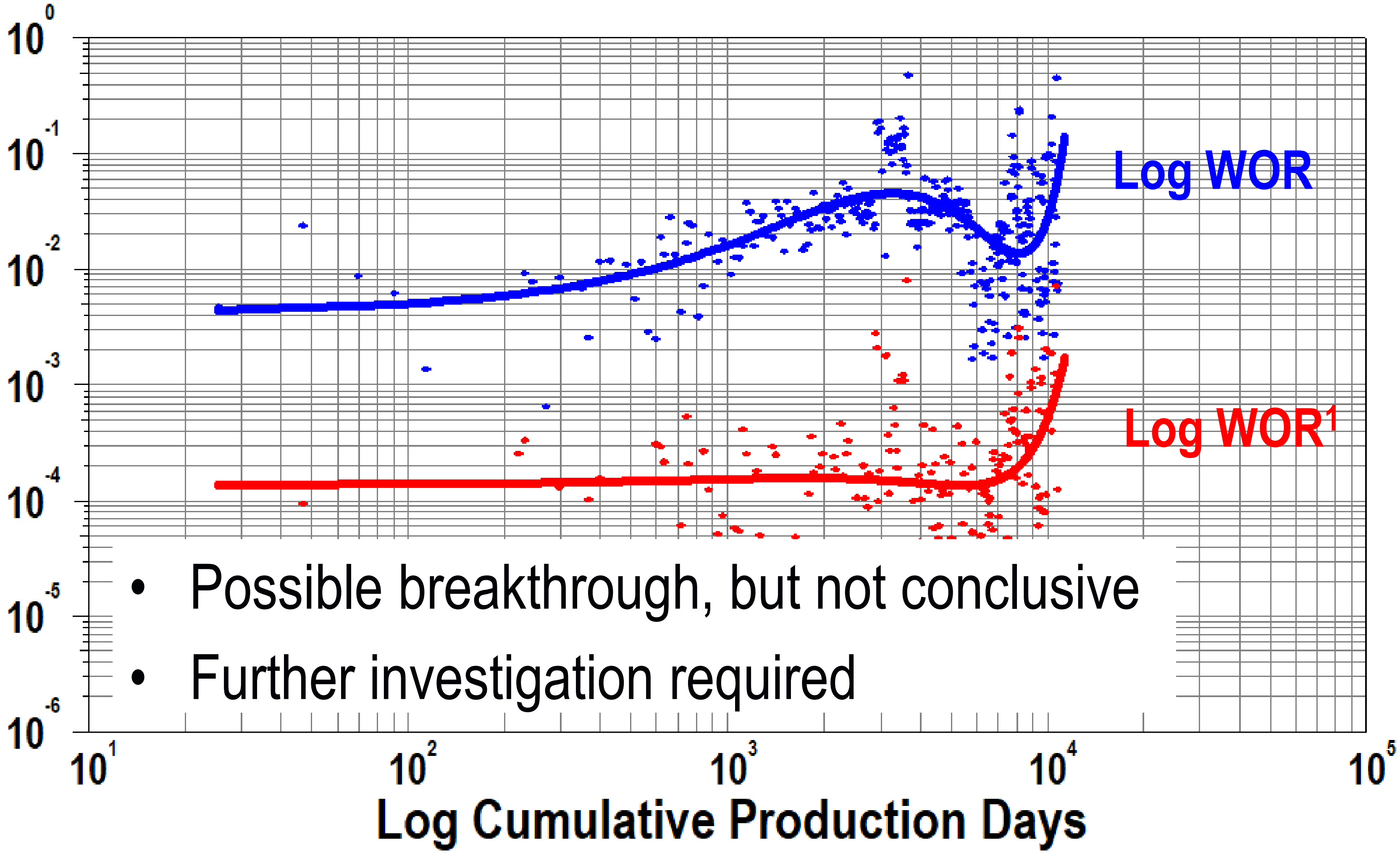
Water control diagnostics - Theory

- Possible insight into water problems



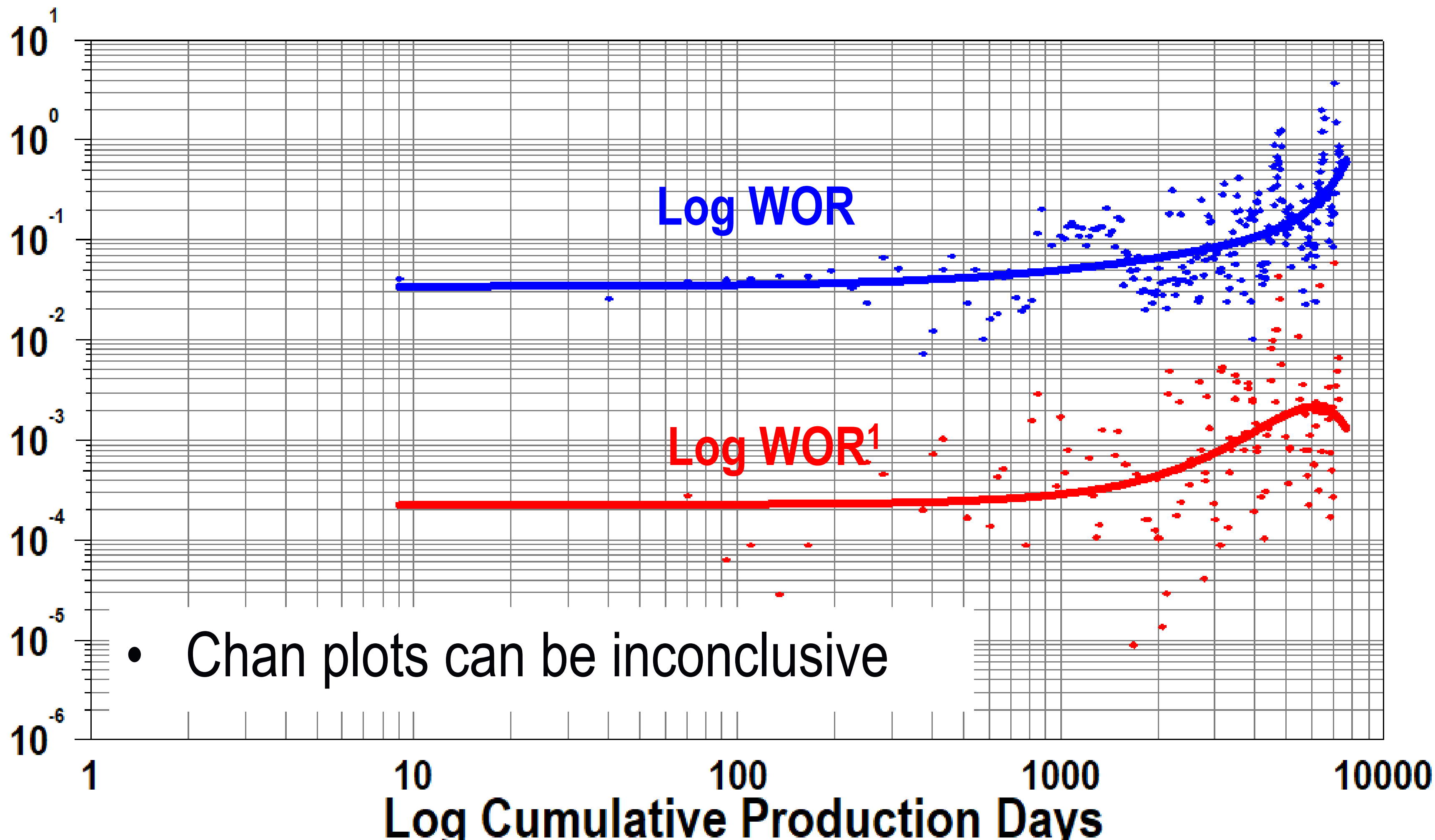


Diagnosis of possible water source



- Possible breakthrough, but not conclusive
- Further investigation required

Avoid misleading conclusions



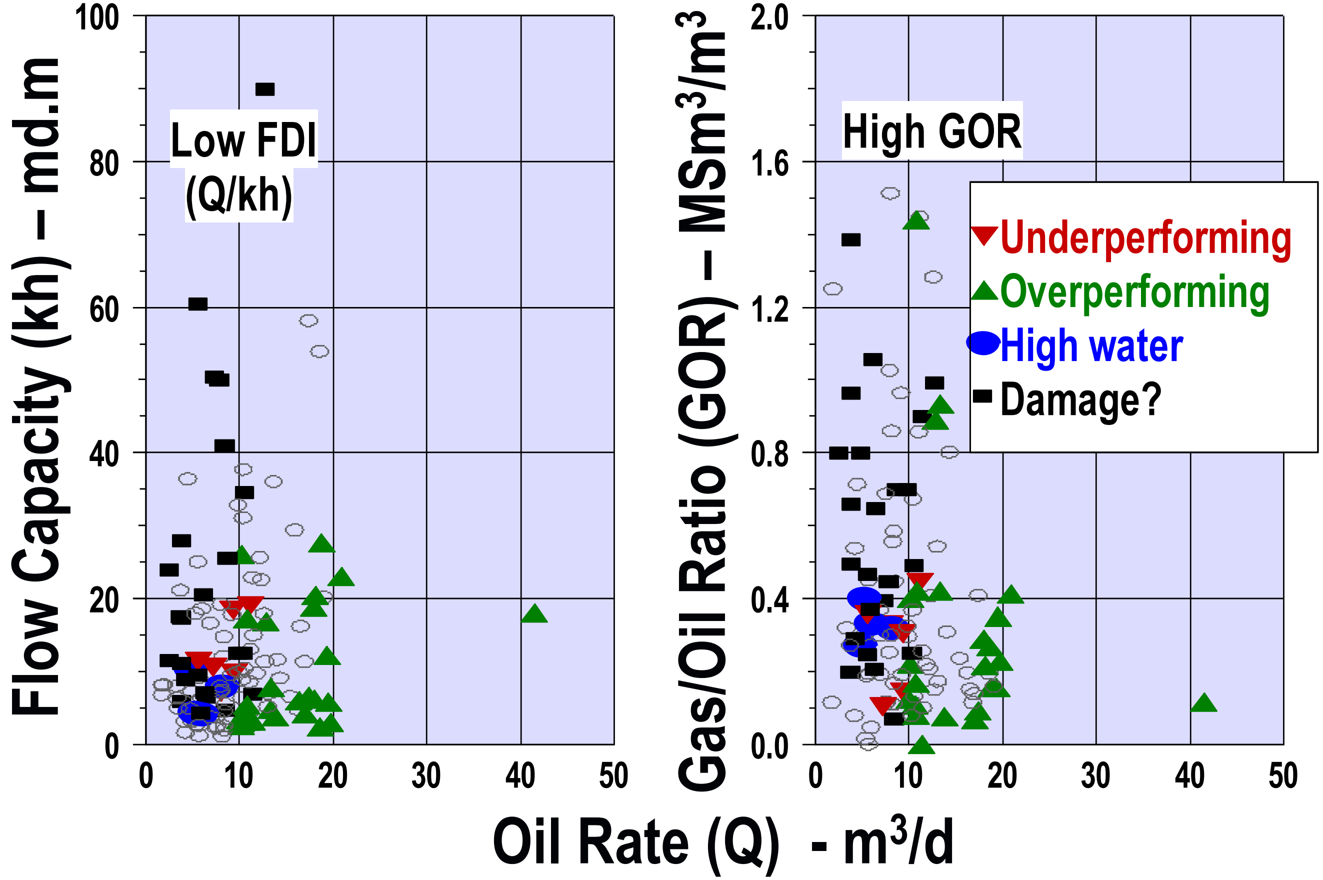
- Chan plots can be inconclusive

Signs of formation damage

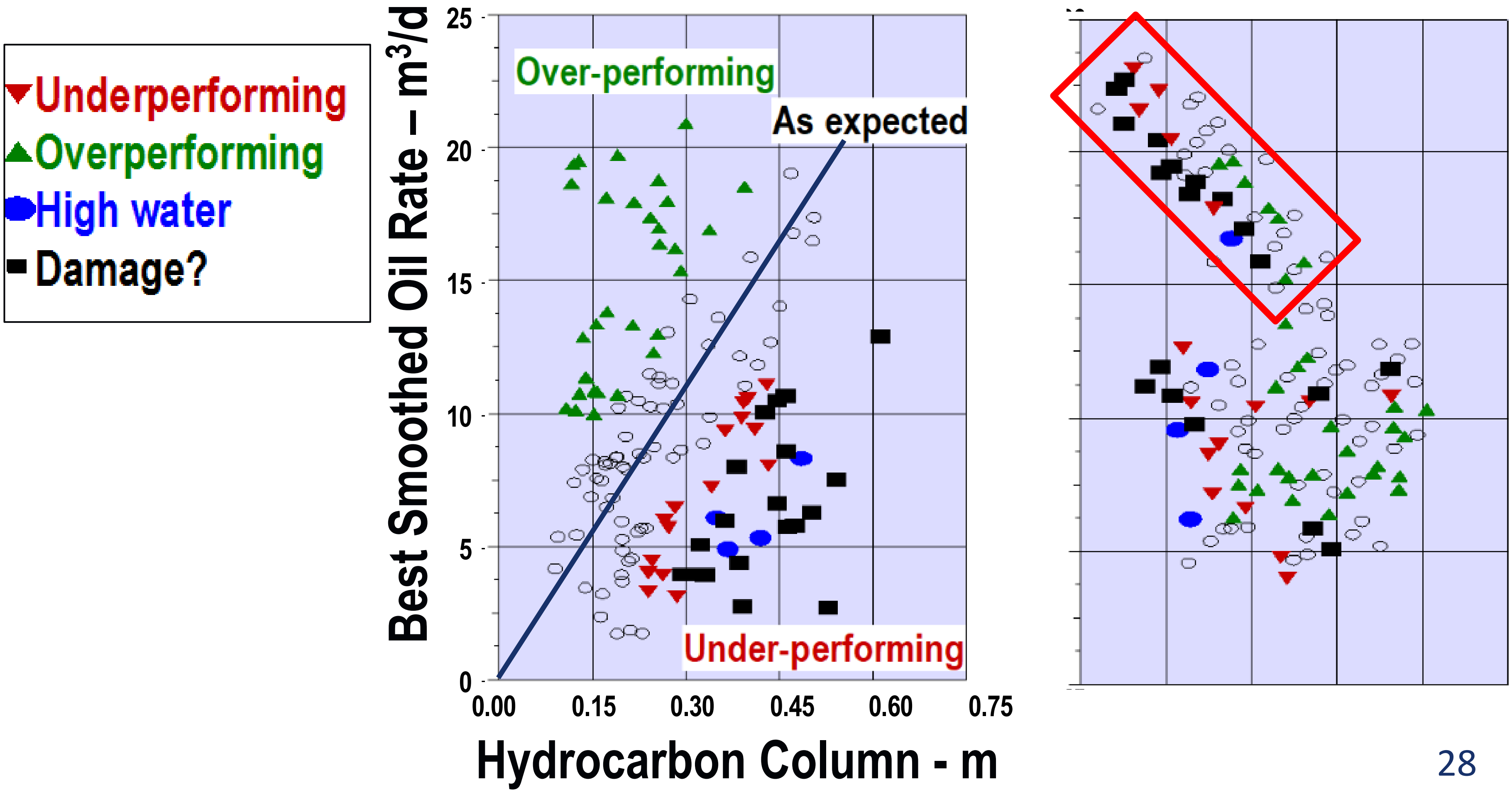
- For damage during drilling or completion
  - Formation damage index (FDI) may be low
    FDI = Q / kh = oil rate / flow capacity
- For damage anytime
  - Gas/oil ratio (GOR) may be high due to pressure drop across damaged zone
  - Gas comes out of solution in the wellbore

Formation damage indicators

- Previous colour coding
- Potentially damaged wells marked



Locations of damaged wells



Other reasons for underperformance

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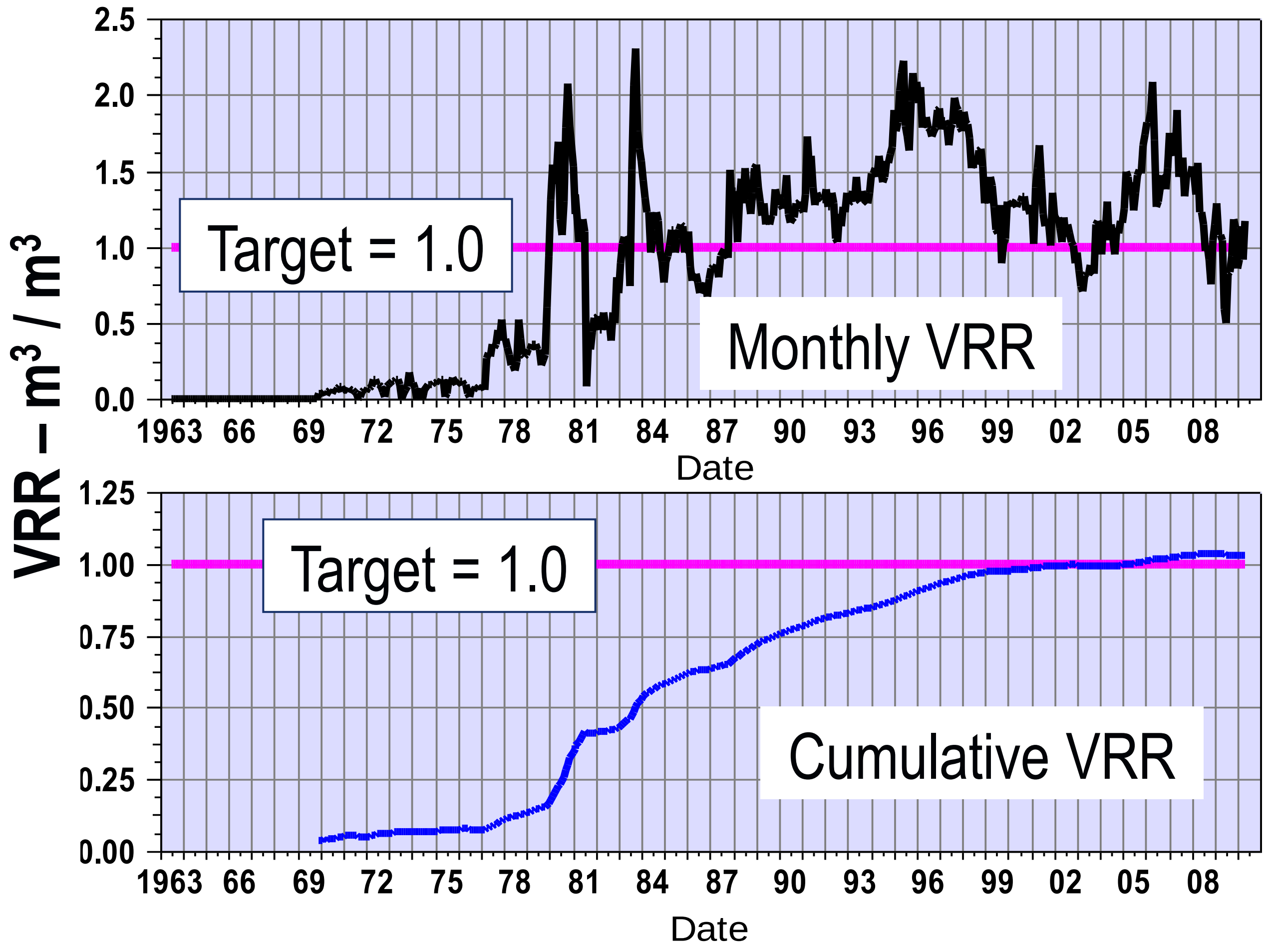
- Waterflood management is crucial
- Voidage replacement ratio (VRR)
  = injected volume / produced volume
  - Volumes include oil, water and gas and are expressed at reservoir conditions
  - Target VRR = 1.0

Voidage replacement ratio

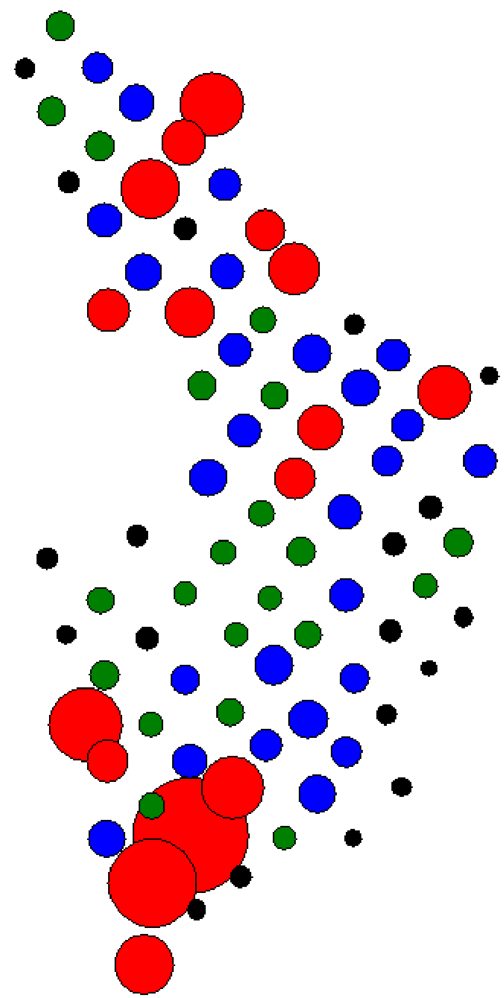
- Waterflood as a whole is quite well balanced
- May 2010:
  - VRR = 1.17
  - Cum VRR = 1.03



Pattern voidage replacement ratios

Decrease injection rate

Possibly stop injection



Increase injection rate

Well balanced

Cumulative VRR

- 0.2 – 0.8
- 0.8 – 1.2
- 1.2 – 2.0
- 2.0 – 8.0

Injector analysis – Hall plot

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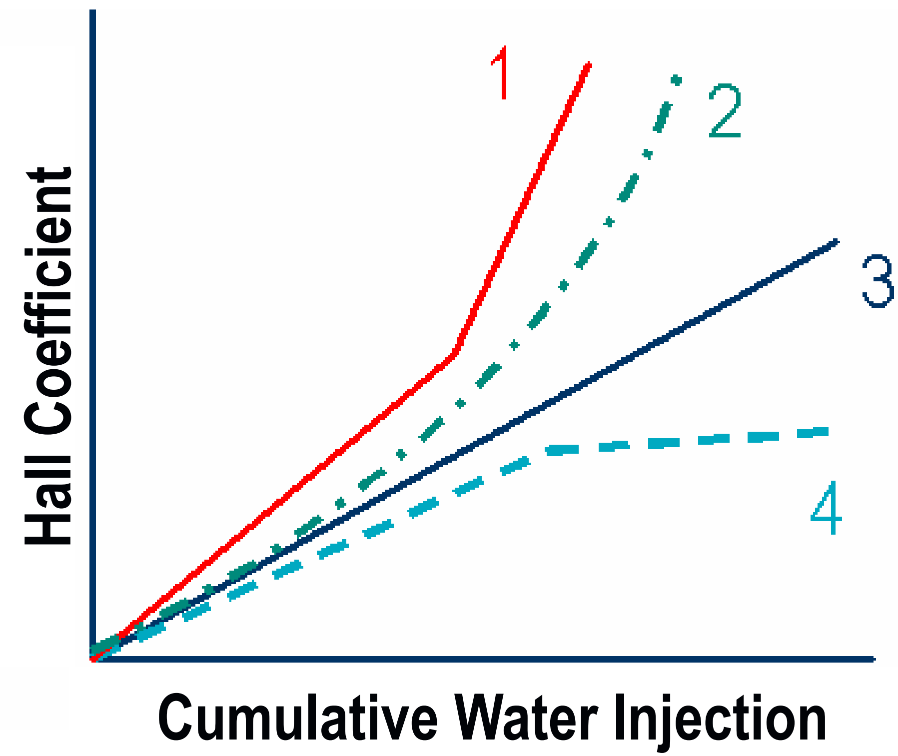
- Skin analysis technique for injection wells
- Y-axis = Hall coefficient
  = ∑ (Δpressure x Δdays)

  1 = Damaged well

  2 = Gradual plugging in well

  3 = No change, no plugging, no damage

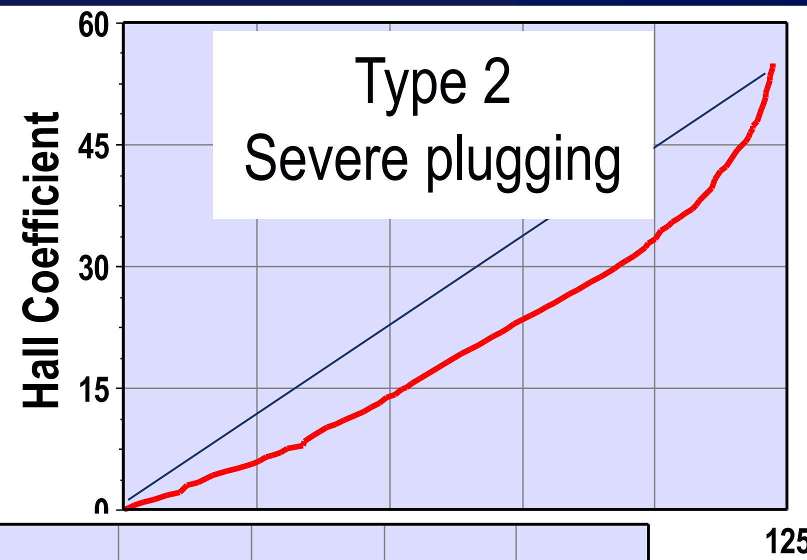
  4 = Stimulated well or sudden channeling

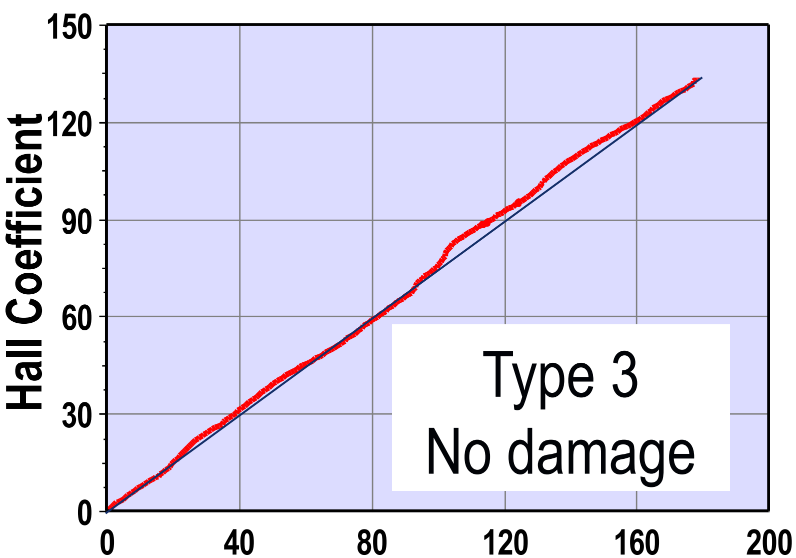


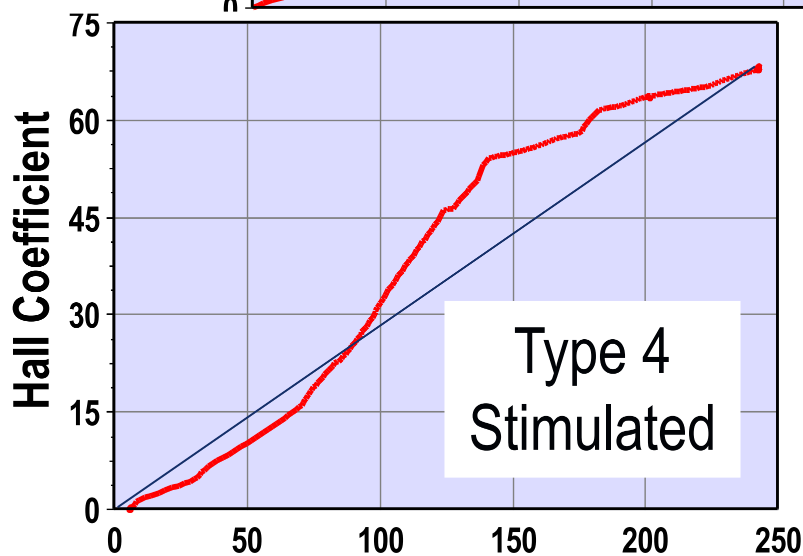
Hall, H.N. "How to Analyze Waterflood Injection Well Performance", World Oil (Oct. 1963) 128-130

Example injectors

- All types are commonly found, particularly type 2

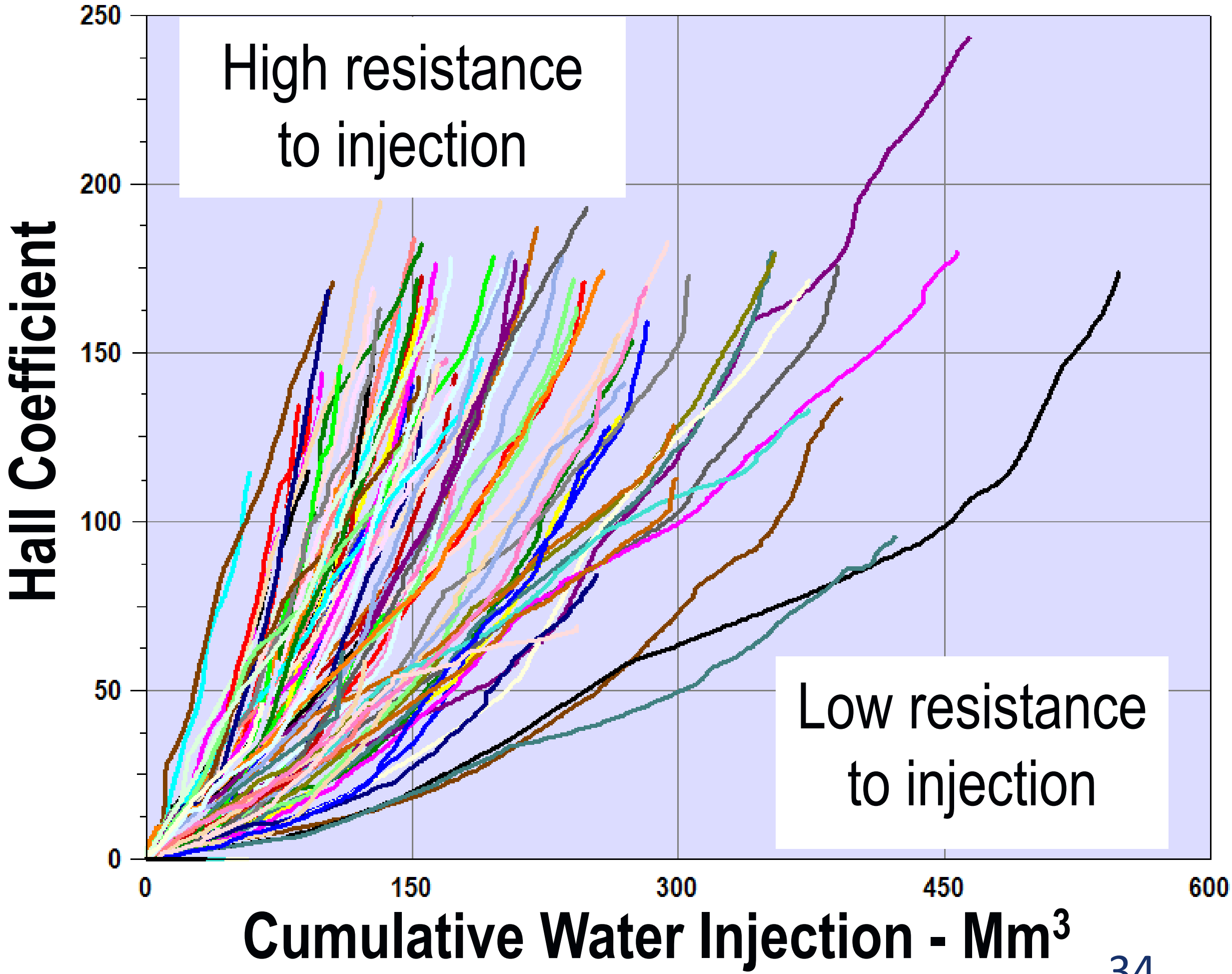






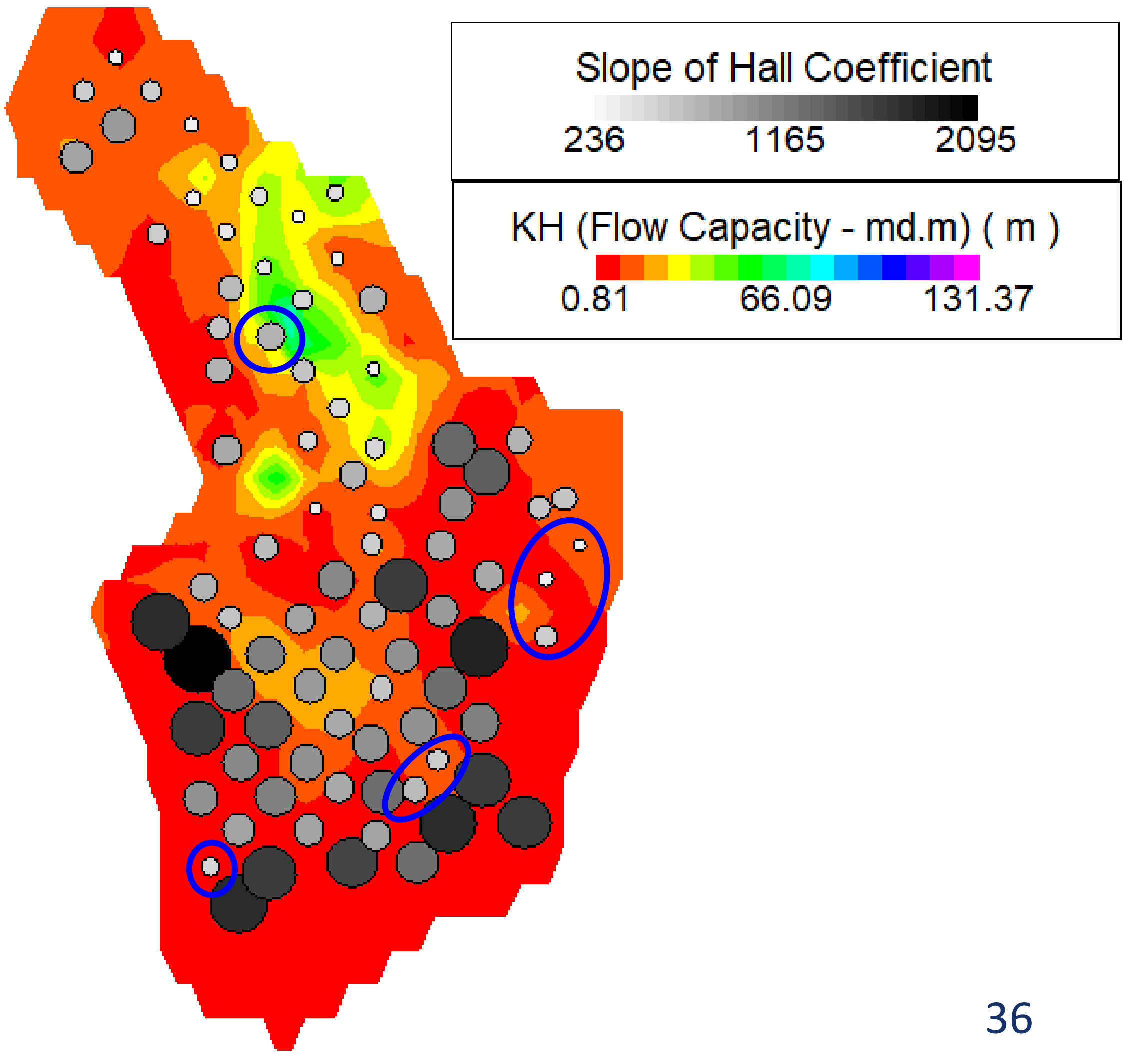
Hall plot slopes

- All injectors are shown
- Steeper slopes mean more resistance to injection



Injectivity relationship to flow capacity

- We expect injectivity to be related to flow capacity
- Overlay resistance to injection on KH grid map
- Not always related – investigate further



TAKE ACTIONS,
MONITOR, LEARN FROM RESULTS

Three years later: May 2013

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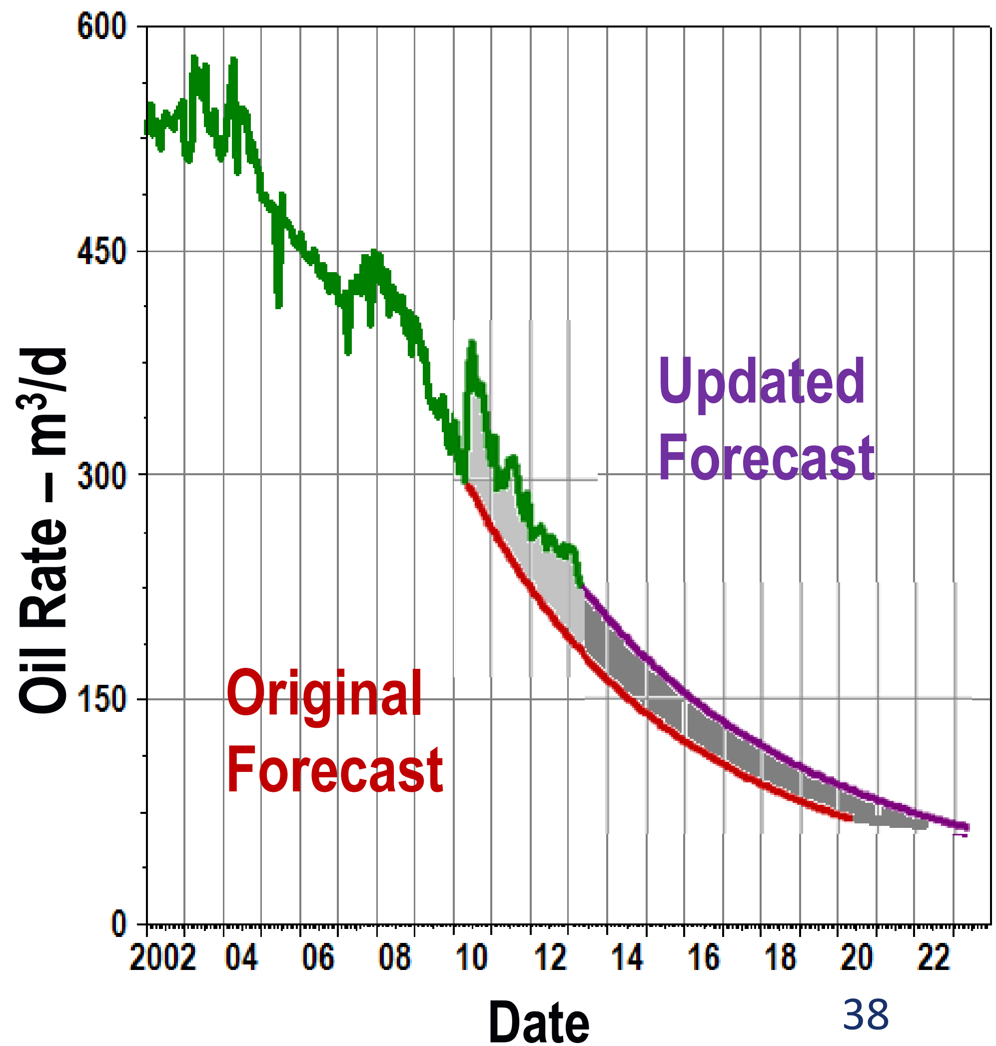
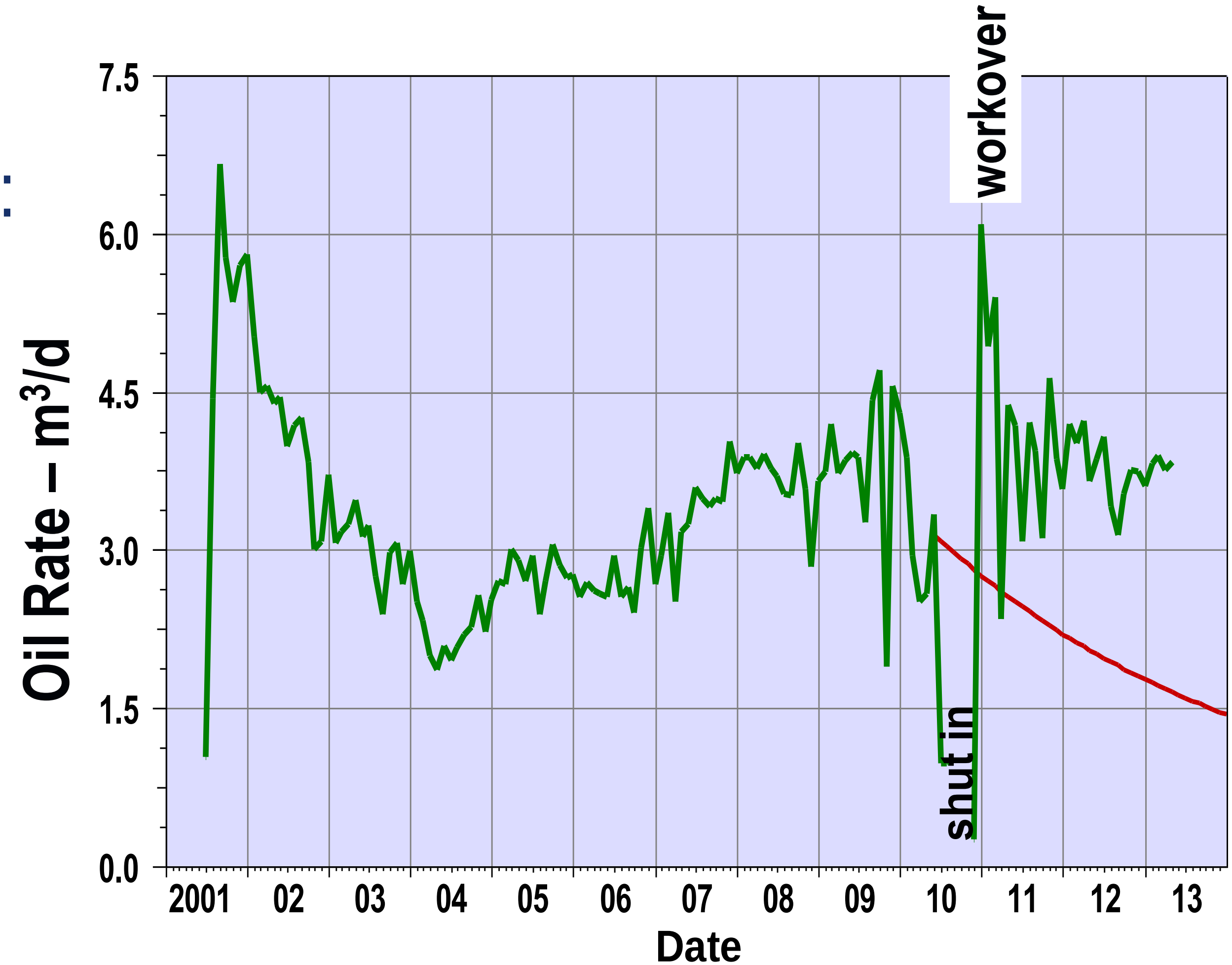
- Interventions done in 2010 – 2011 in 40 wells identified here as underperforming
- Impact on field total to date → gain of ~ 60,000 m^3 compared to original forecast = rate increase of 57 m^3/d
- Increase in EUR → ~ 220,000 m^3
- Projected recovery factor ~21% → ~22%



Formation damage candidates

- Example well with intervention: gain ~1150 m^3

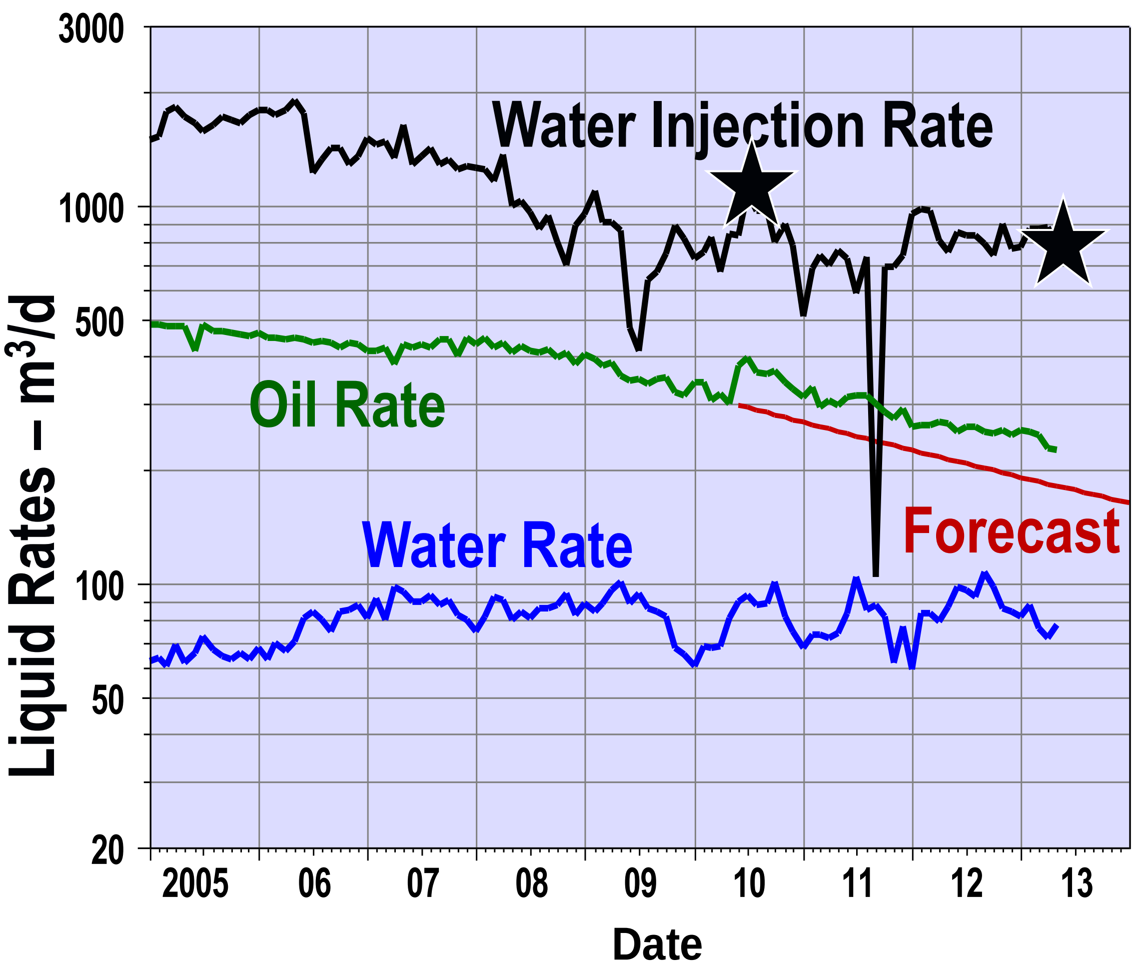


High water candidates

- No squeezes were carried out
- Higher cost intervention
- Problem was not severe

Injection changes – Balance waterflood

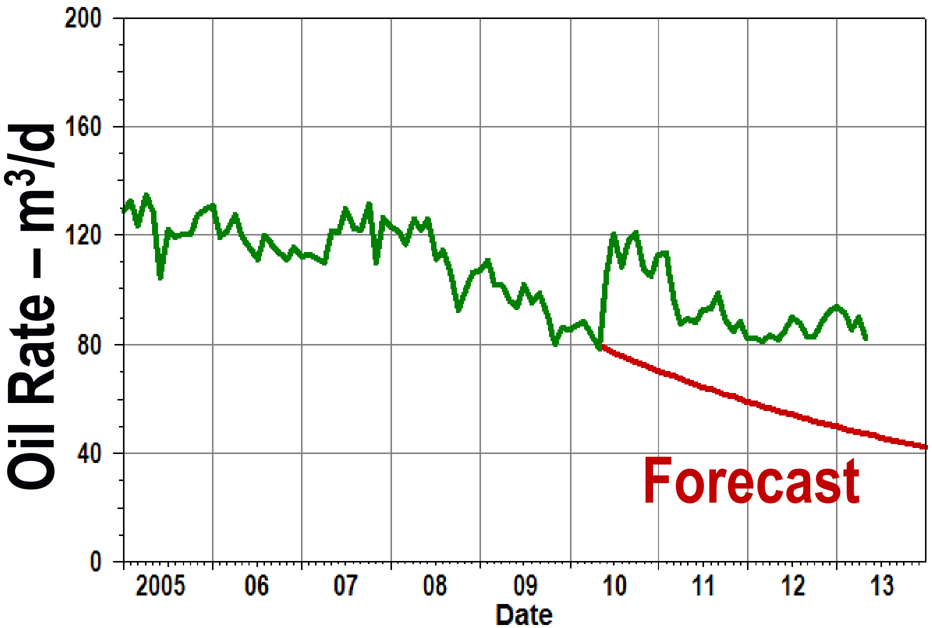
- Injector interventions unknown, field VRR changed little
- Some injection rates were decreased
  - 2010: 1082 m^3/d
  - 2013: 768 m^3/d

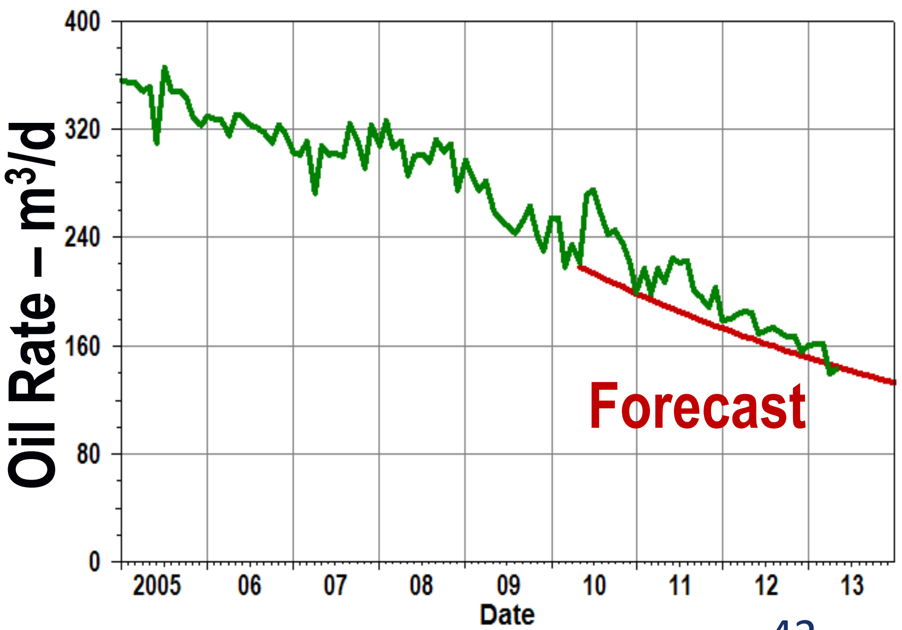


Results with vs without interventions

- Producers with interventions (40)
- Gain ~ **40,000 m³**

- No interventions (95)
- Gain (maybe due to waterflood balancing) ~ **20,000 m³**





Results

- Underperforming wells identified in a short time (2 to 3 days)
  - Producers – potentially damaged wells
  - Injectors – plugging and/or resistant to injection
  - Patterns – where to increase / decrease injection?
- Action taken on 40 underperforming wells
- Some injection rate adjustments
- Gain in reserves ~ 220,000 m^3 (1.4 million bbl)
- **Cash flow improved, life cycle extended**

Conclusions

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- This workflow is
  - Simple and effective
  - Flexible, can be adapted to multiple reservoir / field types
  - Able to handle huge amounts of data
- Key is to determine appropriate performance indicators with built-in quality control
- Demonstrates value of historical data
- Can result in production gains

Your Feedback is Important

Enter your section in the DL Evaluation Contest by completing the evaluation form for this presentation Visit SPE.org/dl

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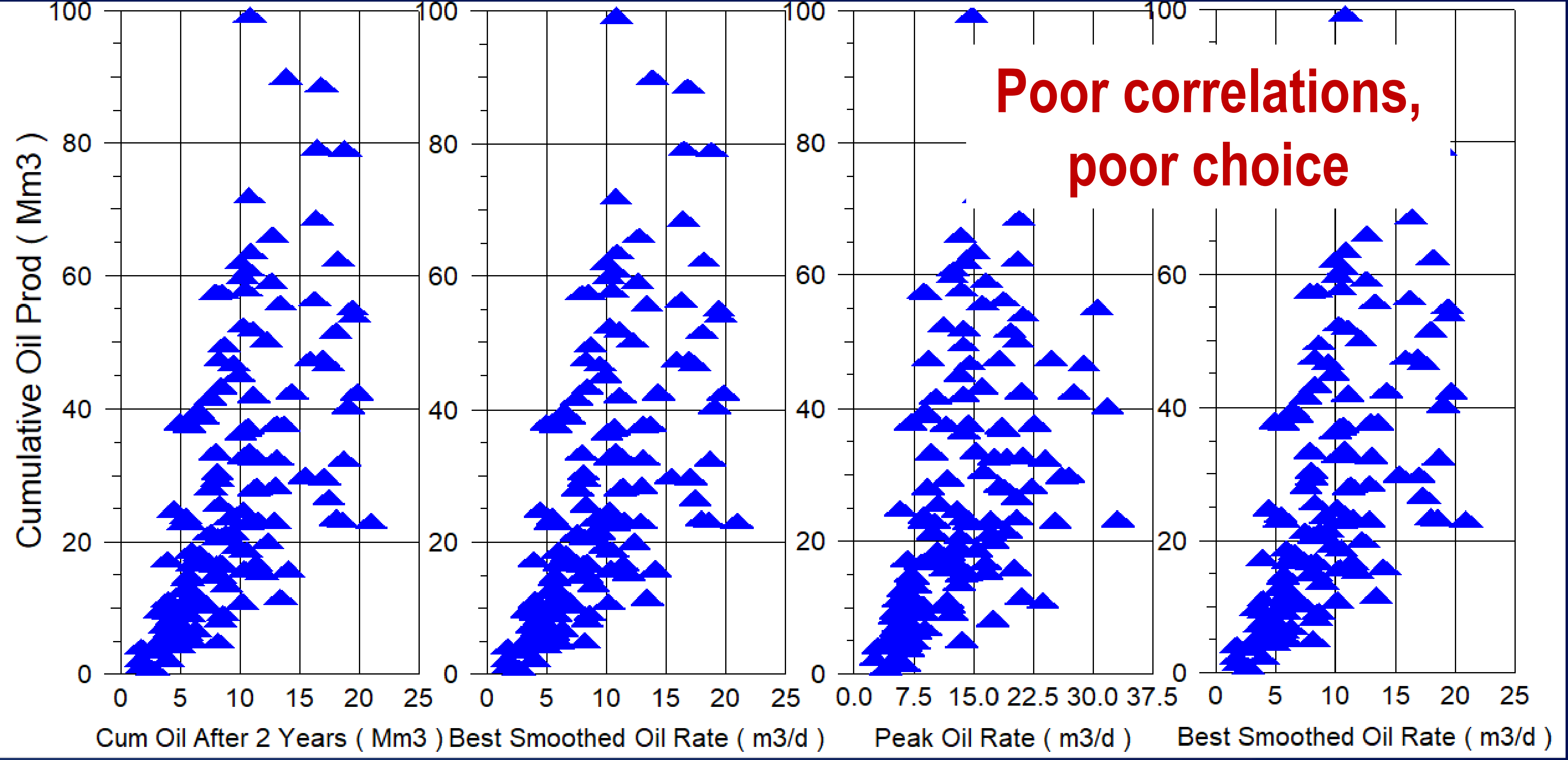
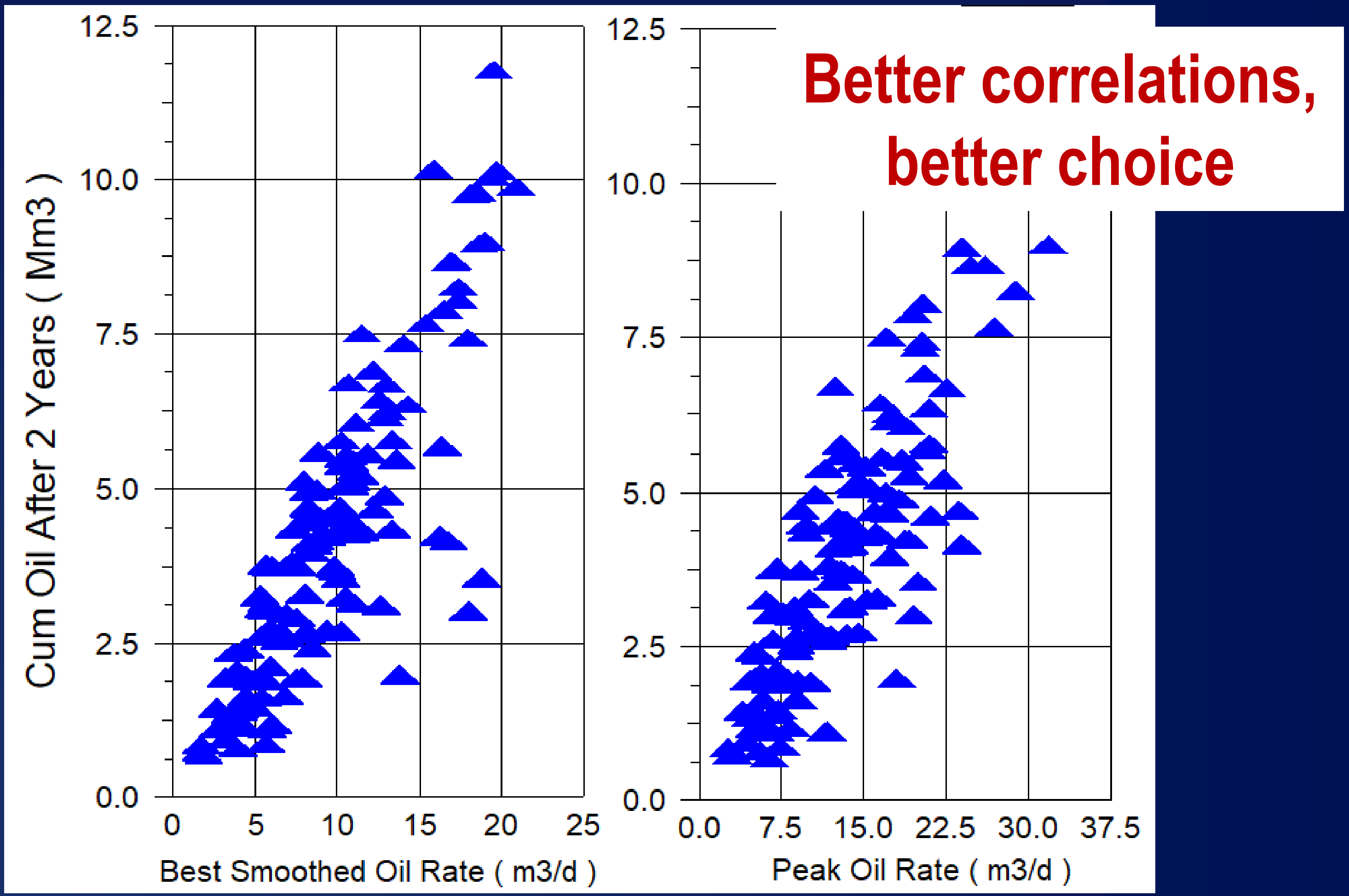
Backup

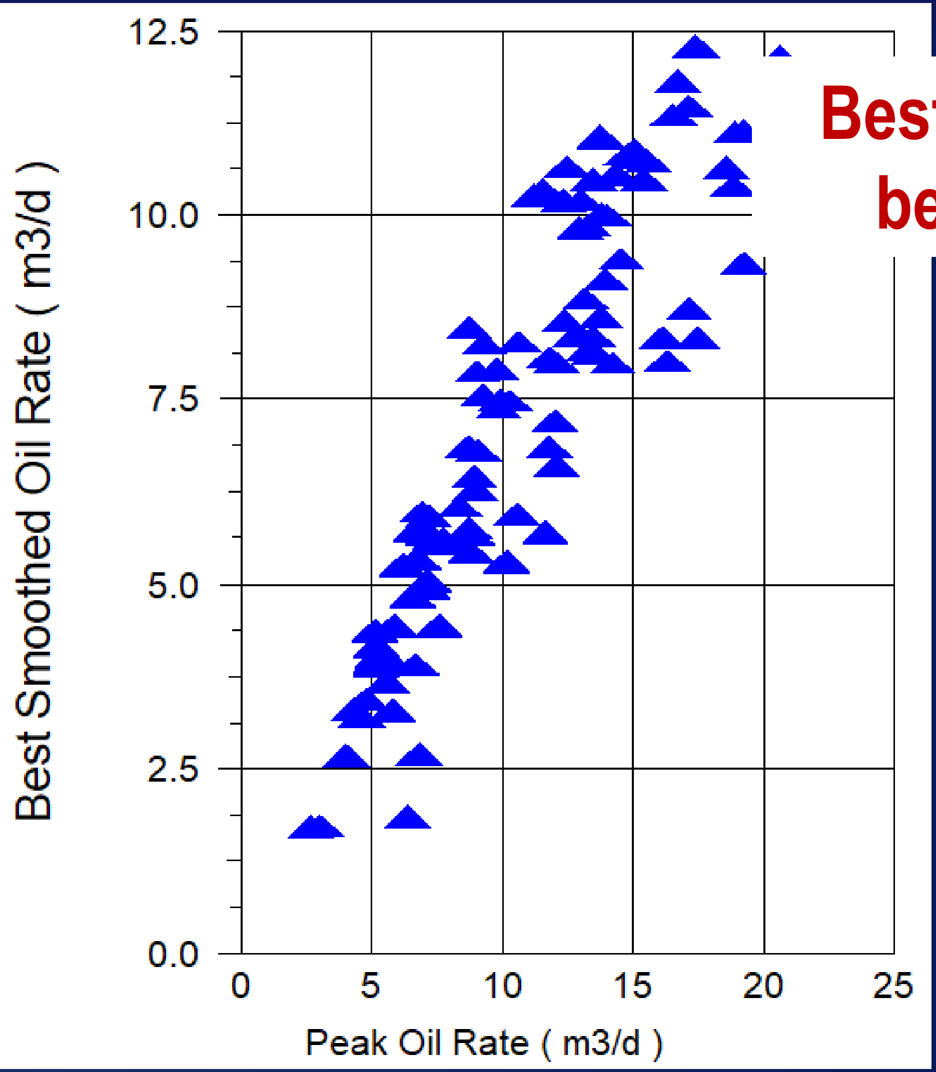
Selection of performance KPIs – test Cum Oil



Selection of performance KPIs – test Cum Oil at 2 yrs



Selection of performance KPIs – test peak rates



Best correlation, best choices

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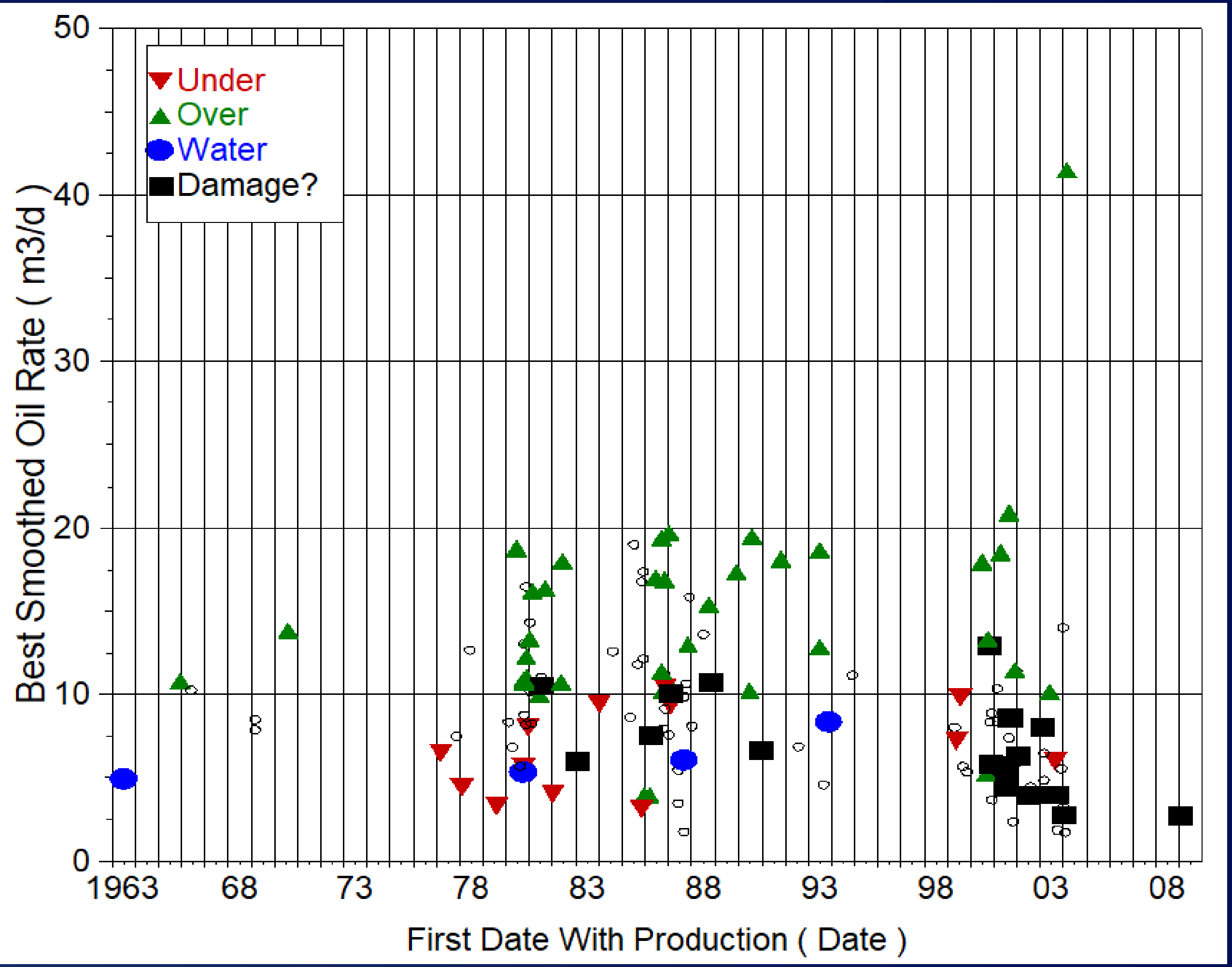
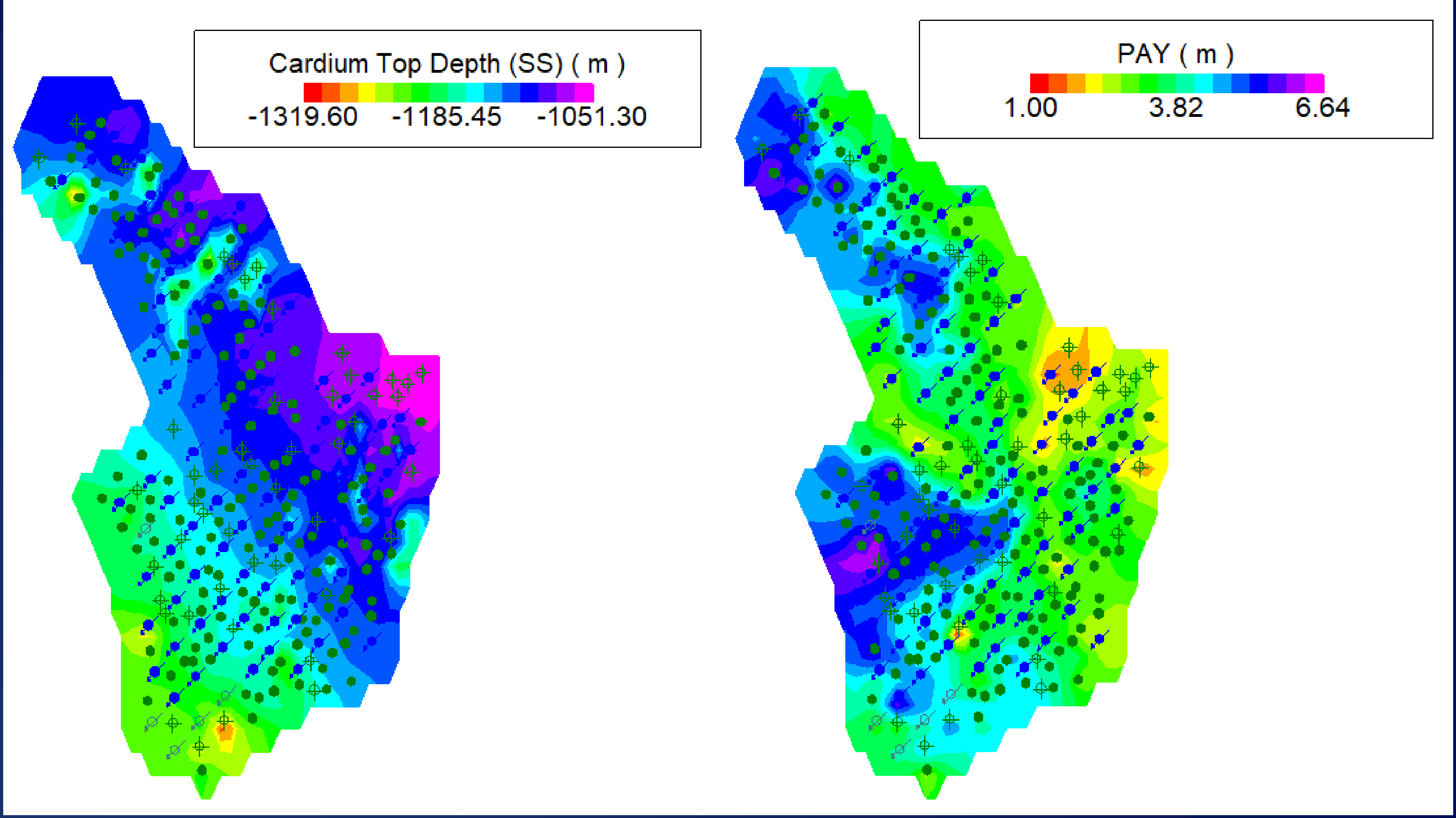
When did marked wells start production?

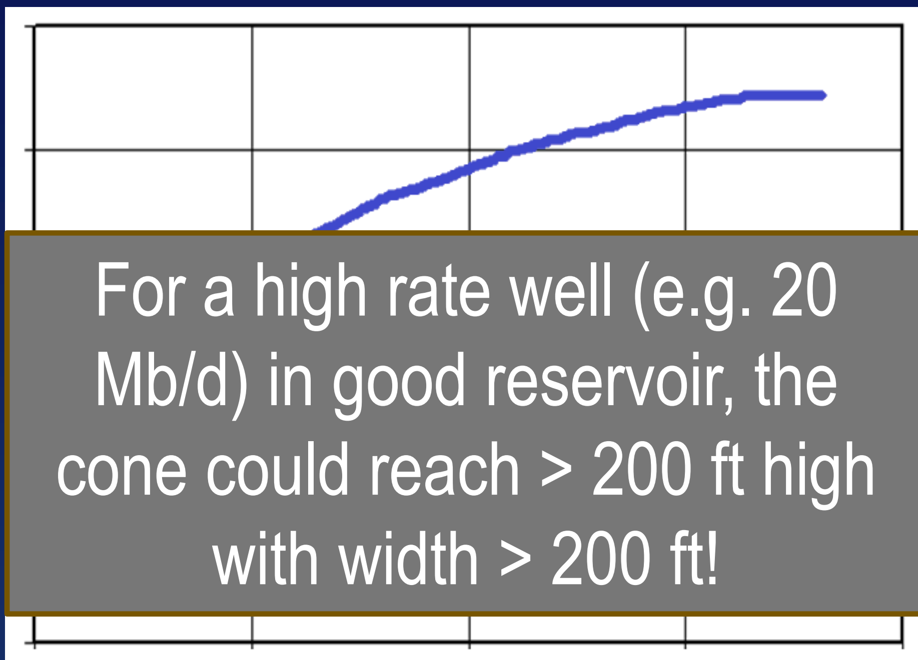
- Wells still producing in 2010 only
- Note most possibly damaged wells are recent



Downdip, vintage, net pay



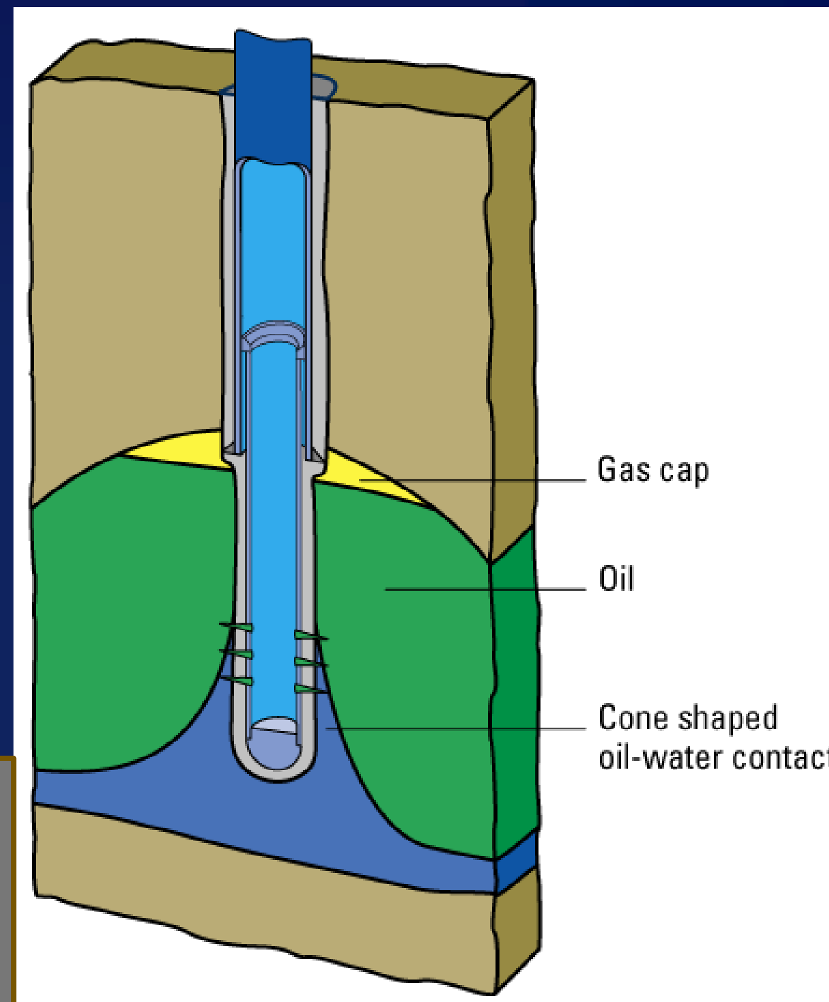
Water control diagnostics - Theory



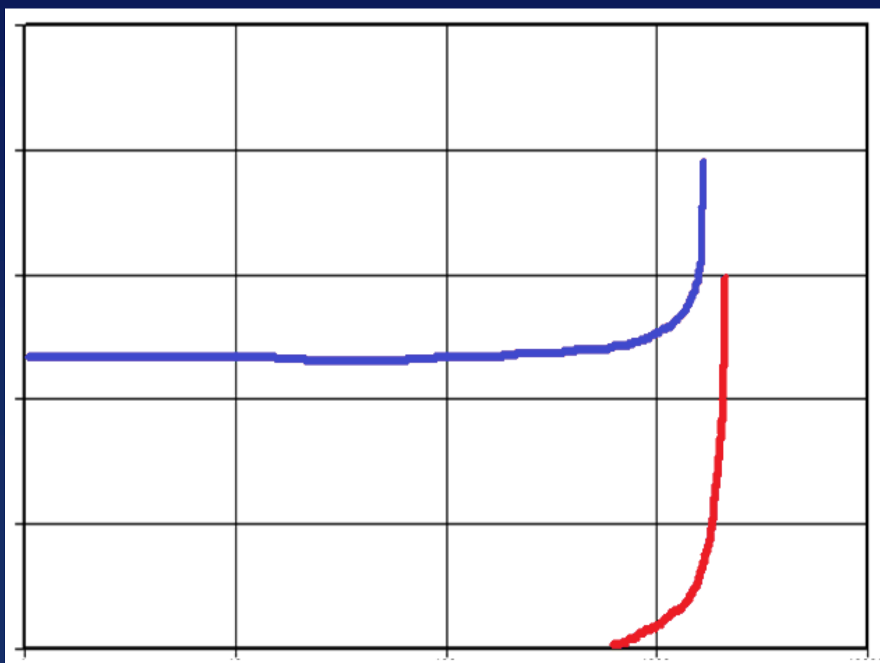
For a high rate well (e.g. 20 Mb/d) in good reservoir, the cone could reach > 200 ft high with width > 200 ft!

Possible Water Coning

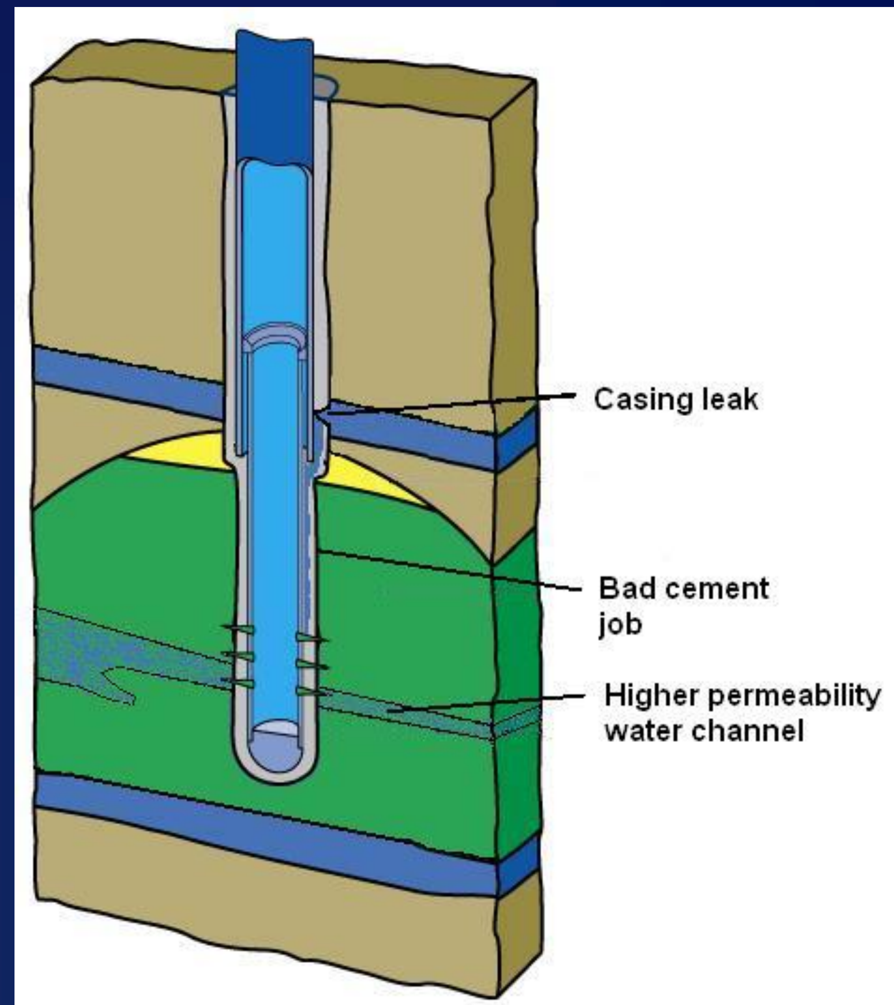
Further evidence of coning:
When liquid production rate drops, WOR also drops.



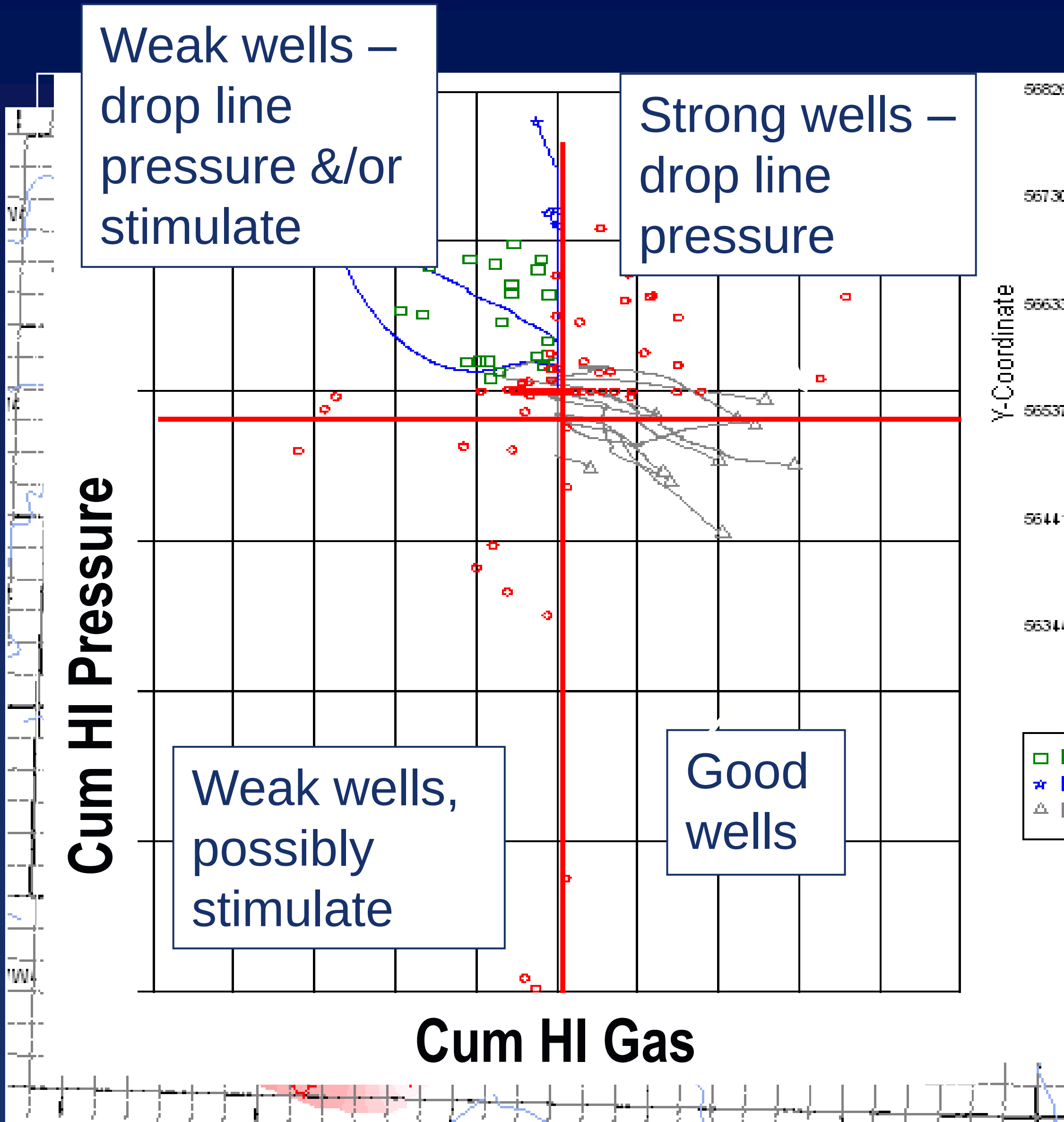
Water control diagnostics - Theory

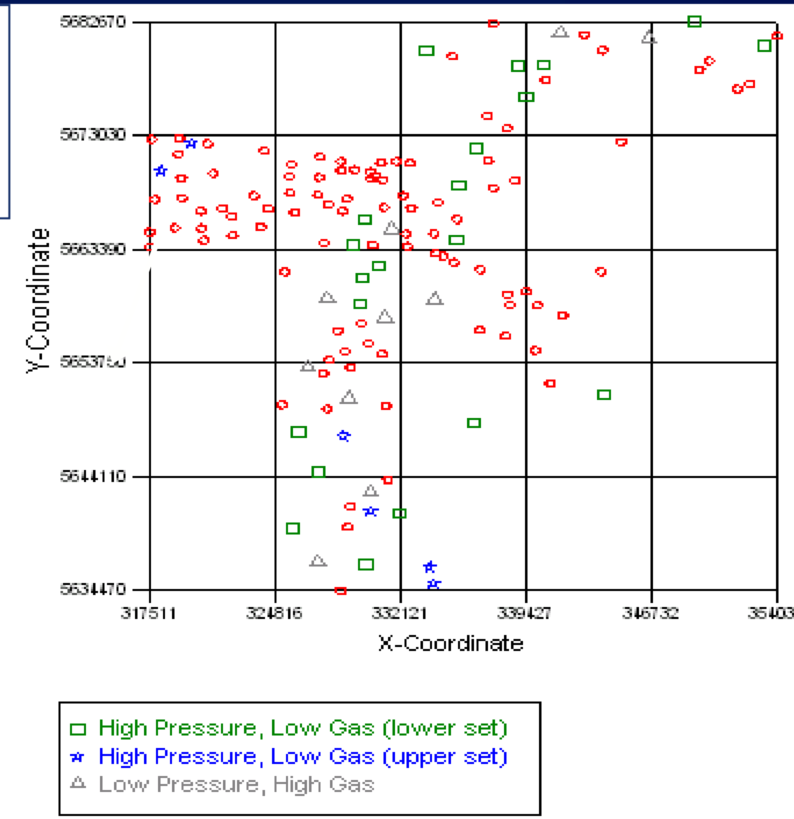


Possible Breakthrough

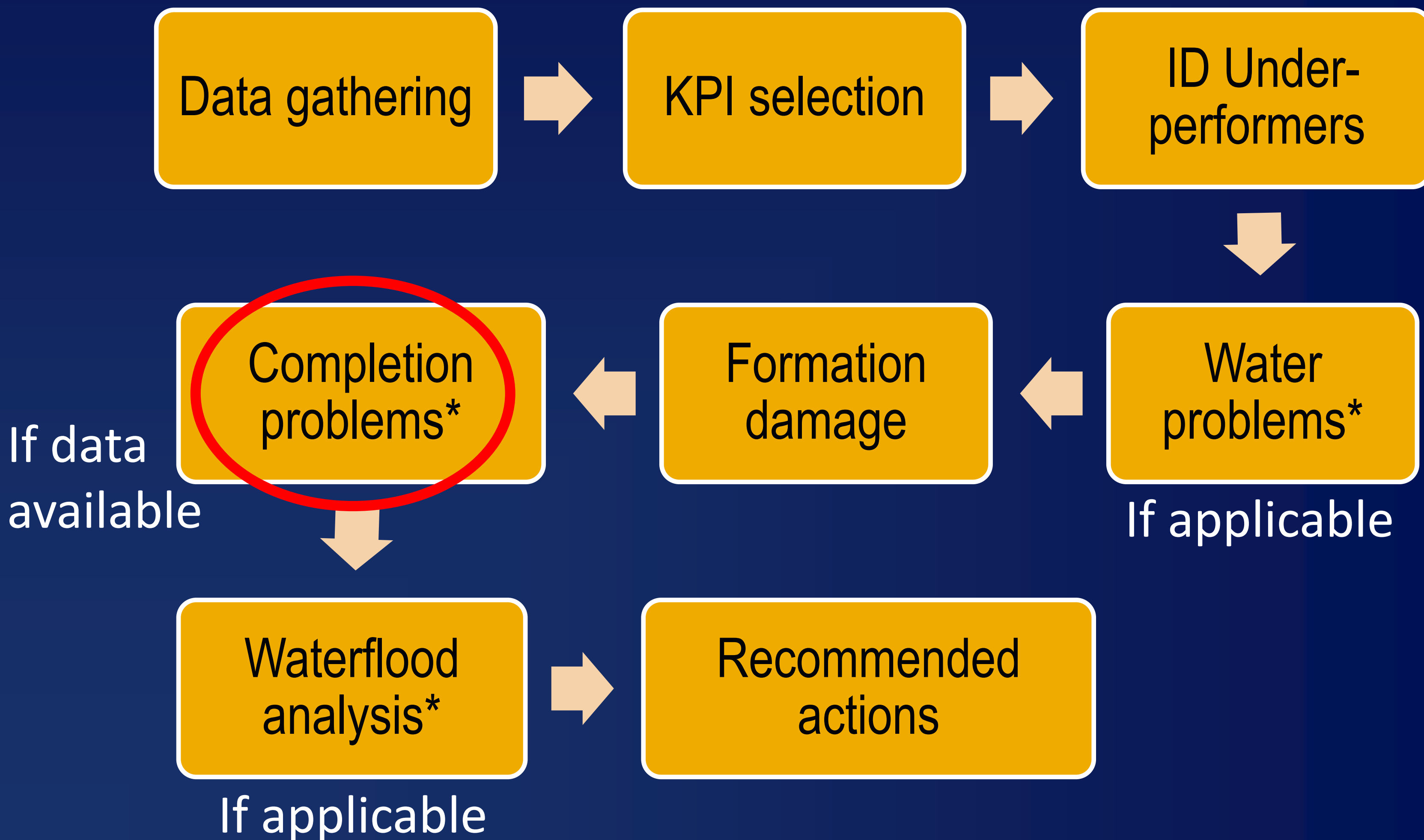


HI - Gas field example





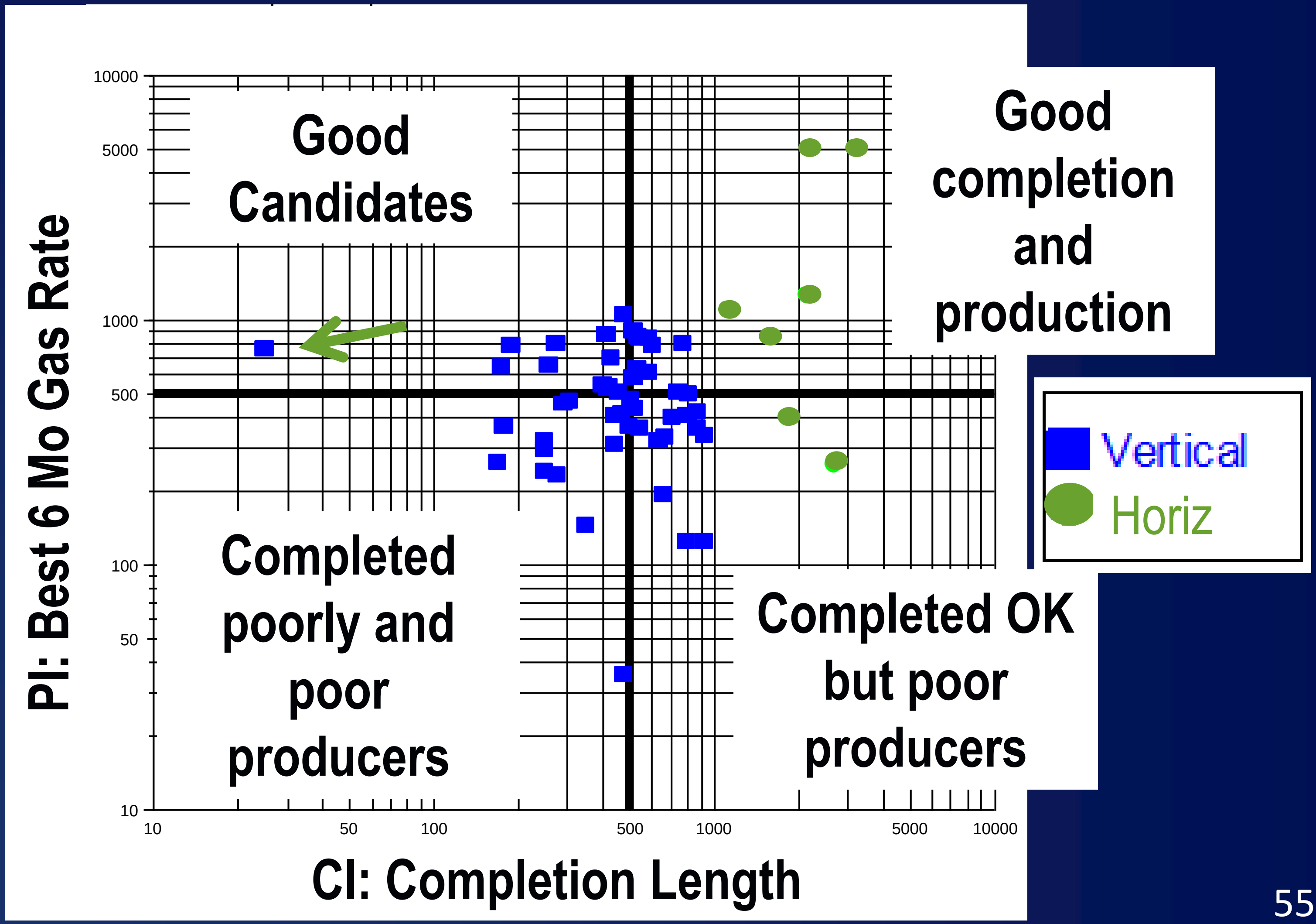
Workflow – Define, Measure & Analyse stages



Selection of completion KPIs

- Two wells, same reservoir quality – we expect better performance from “better completion”
- Completion indicator depends on data available
- Vertical / deviated / horizontal
- Meters perforated / open
- Frac job data (e.g. fluid volume)
- A combination (e.g. fluid volume / completion length)
- *NOTE: not analyzed for case study due to lack of data*

Shale gas example – completion KPI



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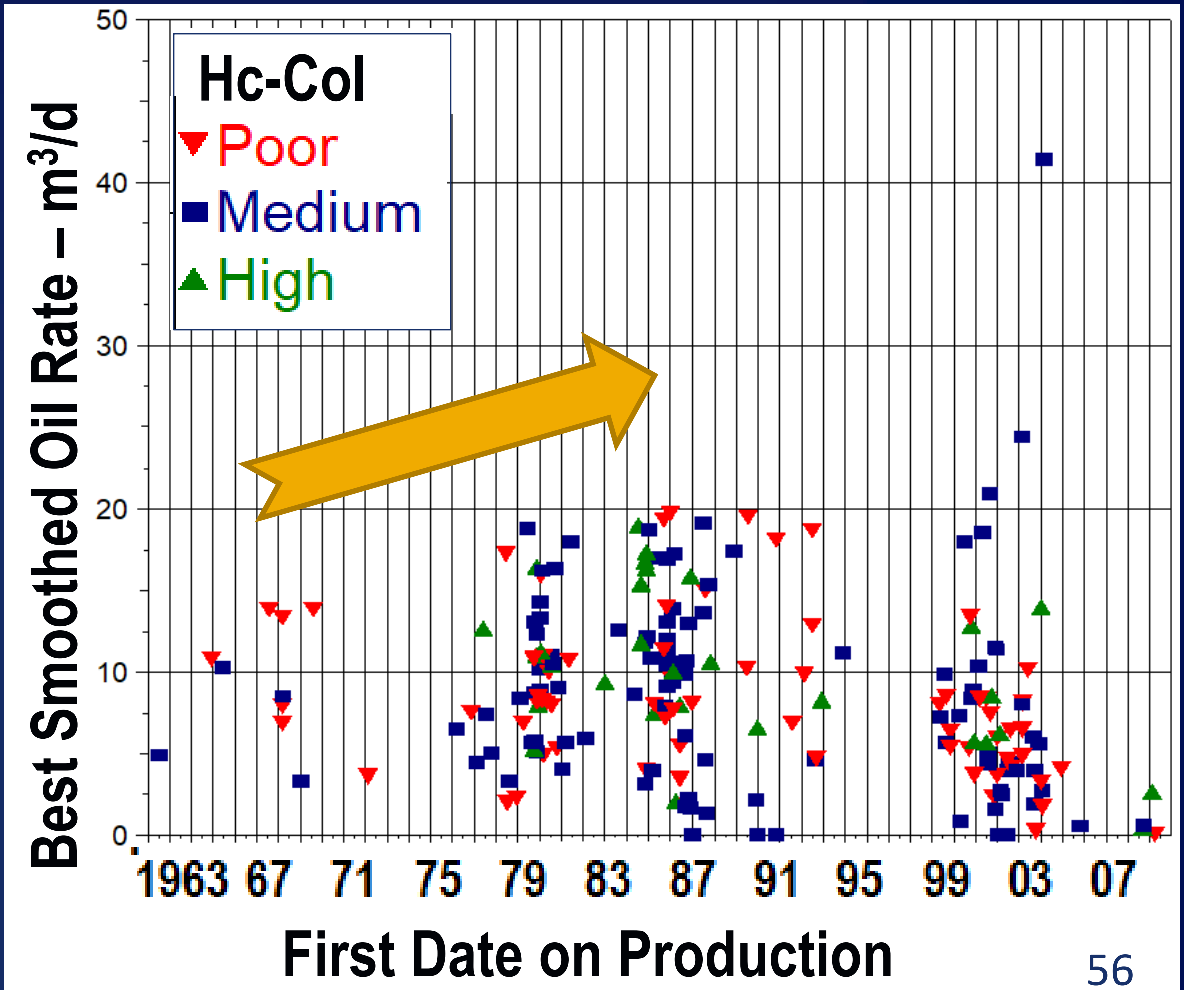
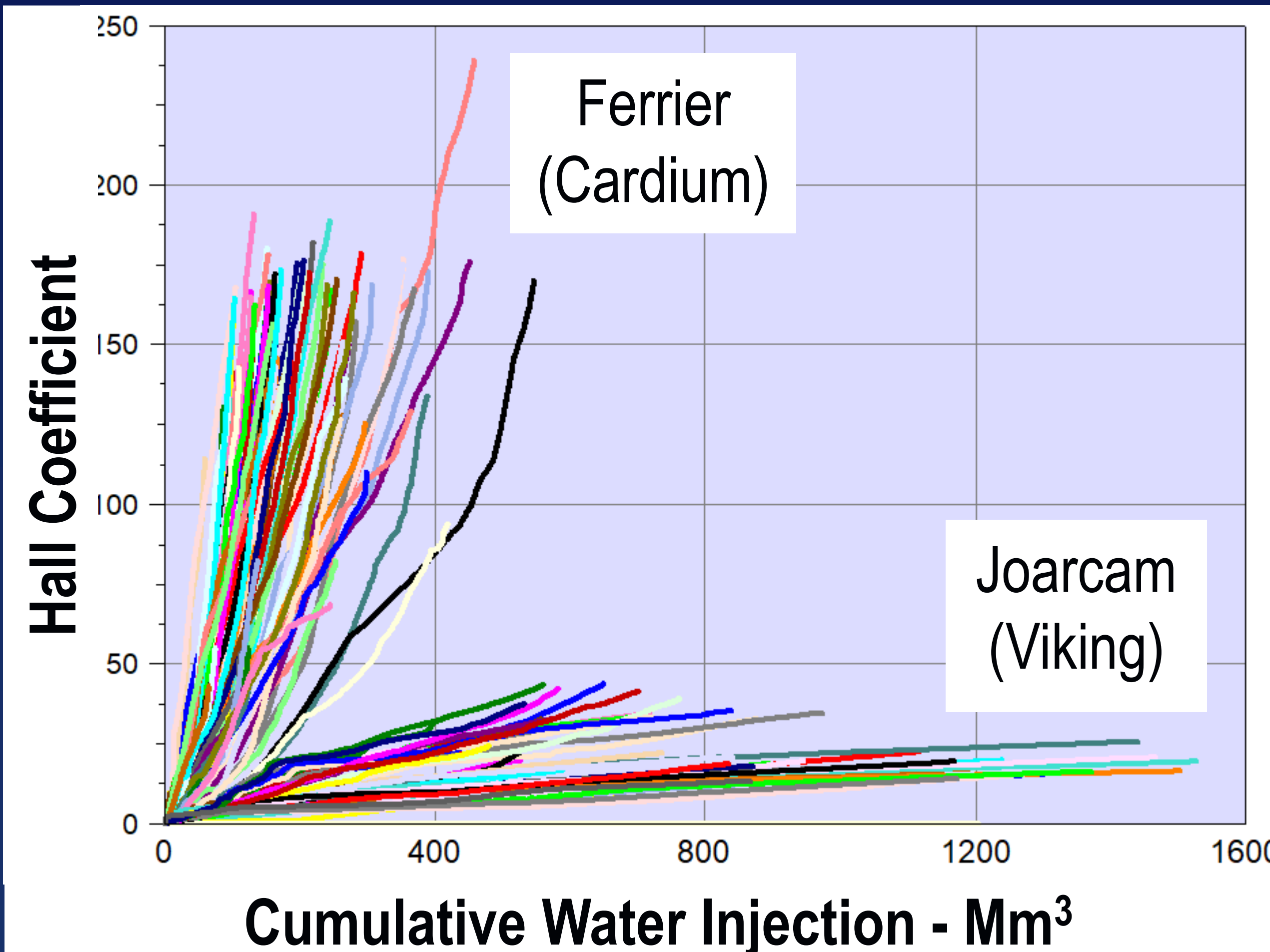
How performance indicator changed with time

- What could cause performance to be better with newer wells?
- Usually - Better technology (drilling or completion)



Compare Cardium Injectivity to Another Formation

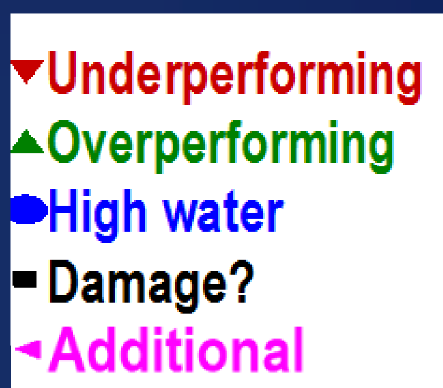


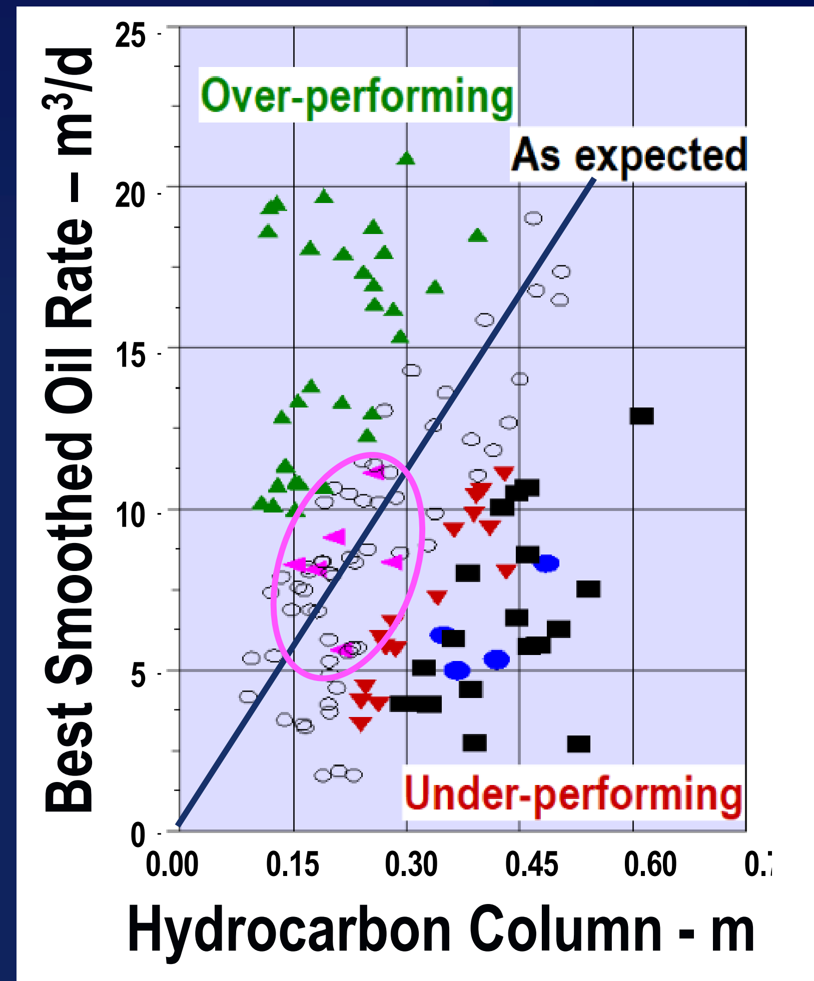
Field	Avg Cum Oil @ 10 Yrs (Mm3)
Ferrier	17.5
Joarcam	19.4

- Reservoir quality or waterflood effiency?

Additional workovers done

- Six workovers done among the Expected group
- Results: rate increases with fastèr declines





Example well