SPE-196161-MS
Application of Multiphase-Multilayer Pressure Transient Analysis (PTA) for Well Monitoring and Reservoir Management - A Case Study of deep-water offshore GoM reservoirs

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Outline

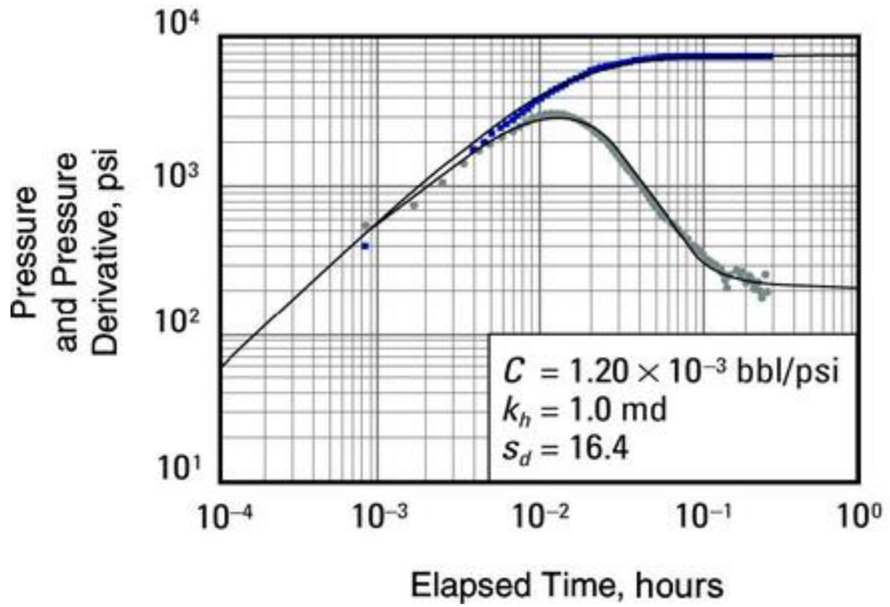
Introduction

Methodology

Case Description & Results

Conclusions

Acknowledgments



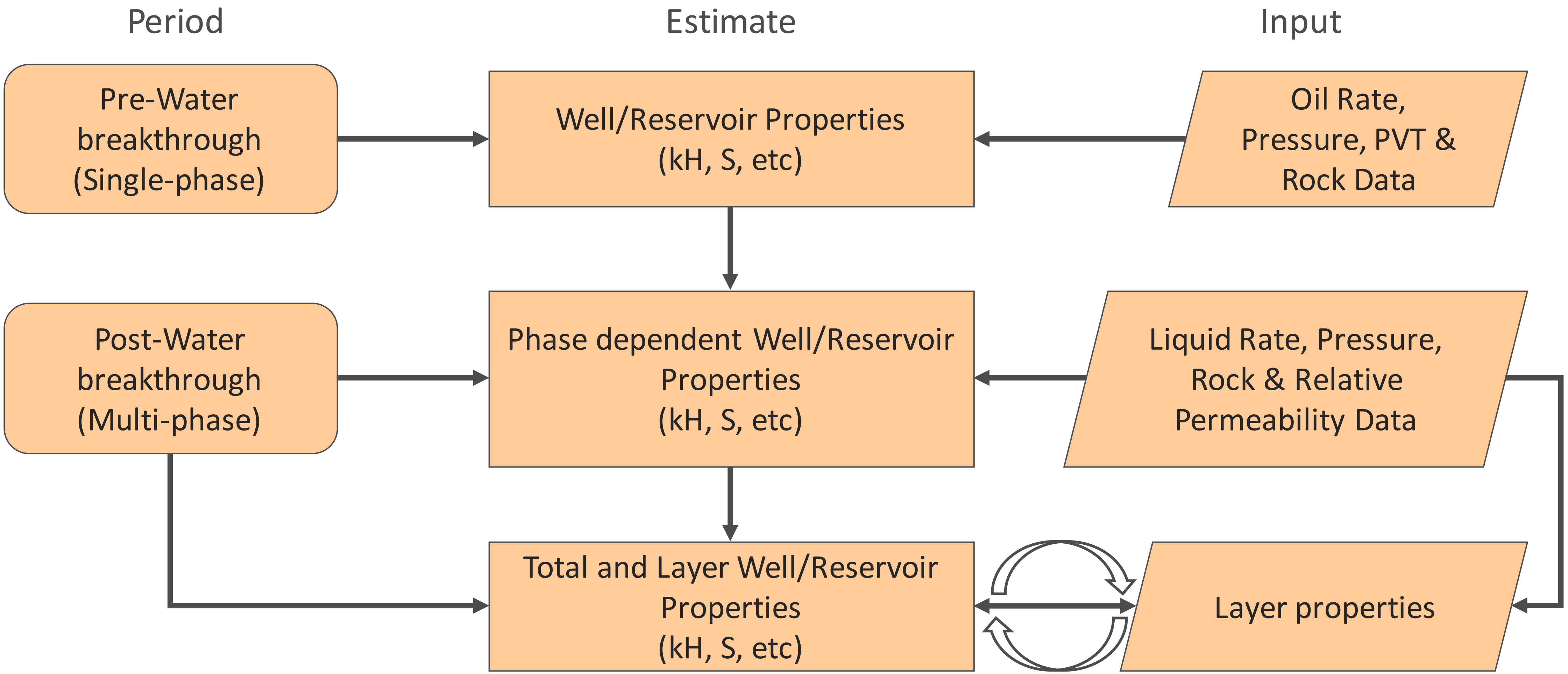
Paper Overall Objectives

- Develop integrated workflow that combines single and multi-phase PTA
  - Establish a reliable baseline for absolute and effective permeability using consistent relative permeability data
  - Identify causes of productivity decline and quantify their impact
  - Provide input for economic evaluation of remediation actions

Previous works on Multiphase PTA

- Perrine-Martin (1956)
  - Combined phase total mobility and compressibility
- Kamal and Pan (2010, 2011)
  - Incorporates relative permeability data consistent between PTA and reservoir model
- Contribution from this work
  - Consistent estimate of well/reservoir properties over well life
  - Estimate system scaled-up relative permeability curve consistent with reservoir facies
  - Decouple changes in kH due to effective stress and multiphase effect

Integrated PTA Workflow: Single- & Multi-phase-Multilayer



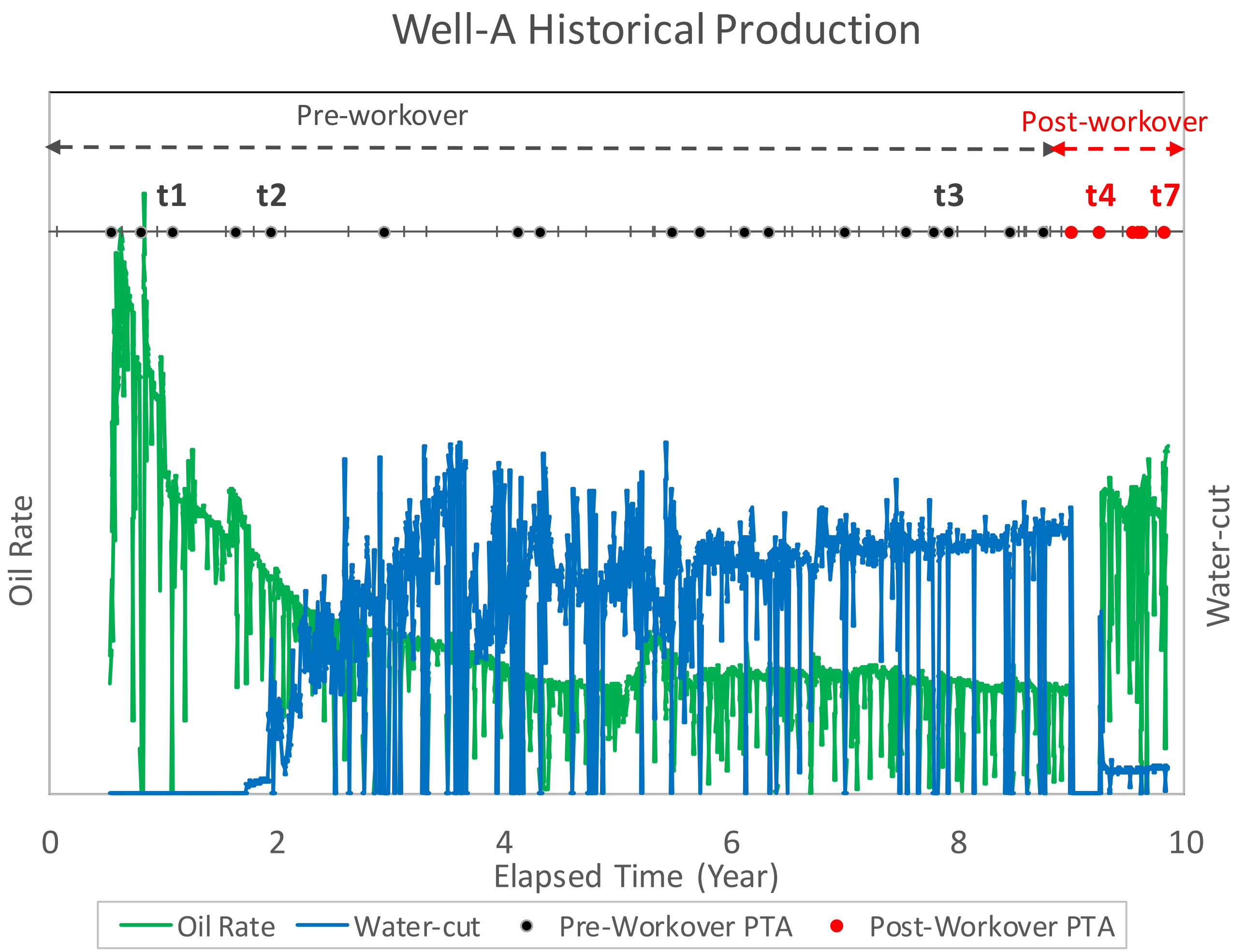
Case Study: Reservoir and Well data

- Undersaturated water-drive reservoirs (Deepwater GoM)
- Wells producing from three major reservoirs with depth between 25,000 – 30,000 ft. TVDSS
- Presentation focuses on Well-A

Property	Well-A	Well-B	Well-C1	Units
PVT Model	Dead Oil and Water			
Reservoir Temperature	212	193	177	°F
Oil Gravity	0.88	0.88	0.86	
Water Gravity	1.02	1.03	1.02	
Oil Formation Volume Factor	1.20	1.17	1.28	rb/stb
Oil Viscosity	2.70	1.94	1.40	cp
Water Viscosity	0.35	0.35	0.39	cp
Formation Thickness	103	374	53	ft
Porosity	0.18	0.21	0.21	fraction
Formation Compressibility	3.00E-06	3.00E-06	3.00E-06	1/psi
Total Compressibility	8.59E-06	7.40E-06	6.89E-06	1/psi
Wellbore Radius	0.35	0.51	0.52	ft

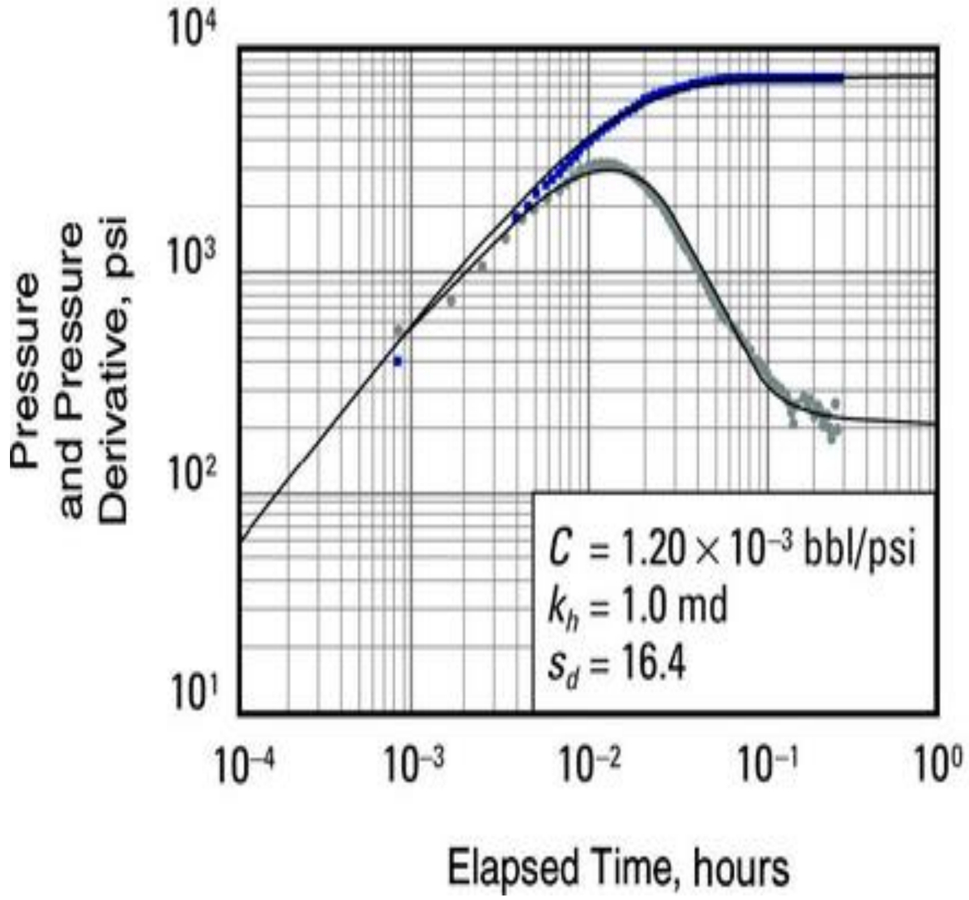
Case 1: Well Background

- Produced dry oil from single zone few years before water breakthrough
- Successful recompletion to add additional zone
- Post-workover performance
  - Well out-performed expectation
  - One zone developed skin leading to decrease in water-cut



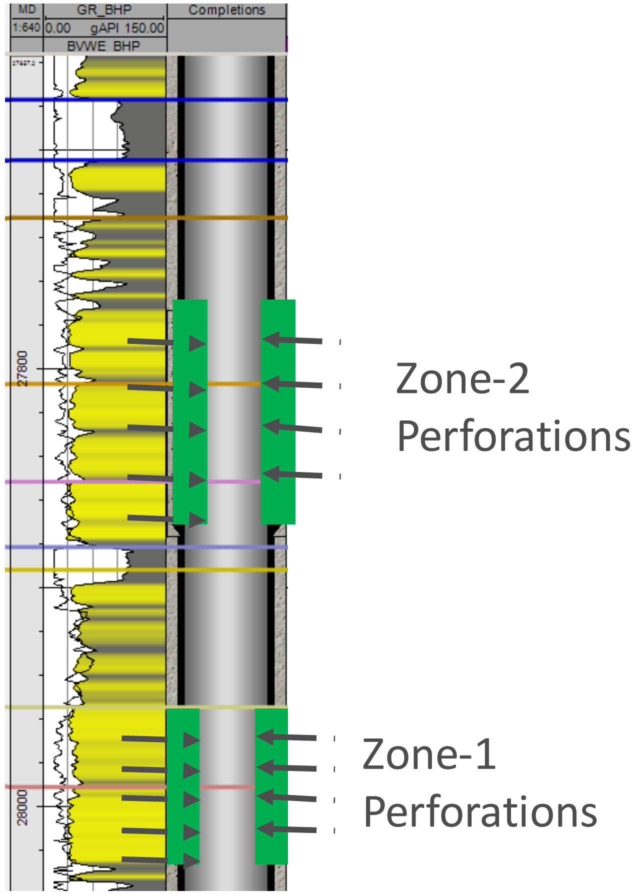
Case 1: Analysis Objectives

- Identify/validate damage zone
- Quantify the degree of skin development
- Make recommendations on remediation action
  - Perform economic analysis



Case 1: General PTA Model Set-up: Single & Multi-Layer

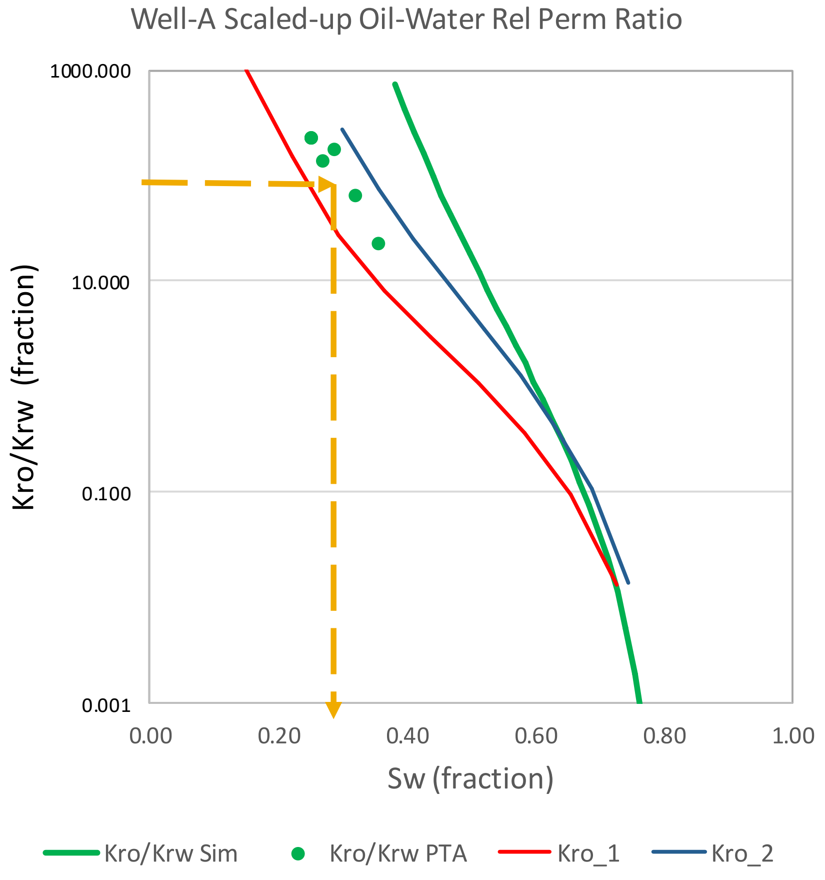
- Analytical Model Set-up
  - Constant wellbore
  - Vertical well with partial penetration
  - Homogeneous reservoir
  - Boundary:
    - Zone-1 : Faults with varying distances from well

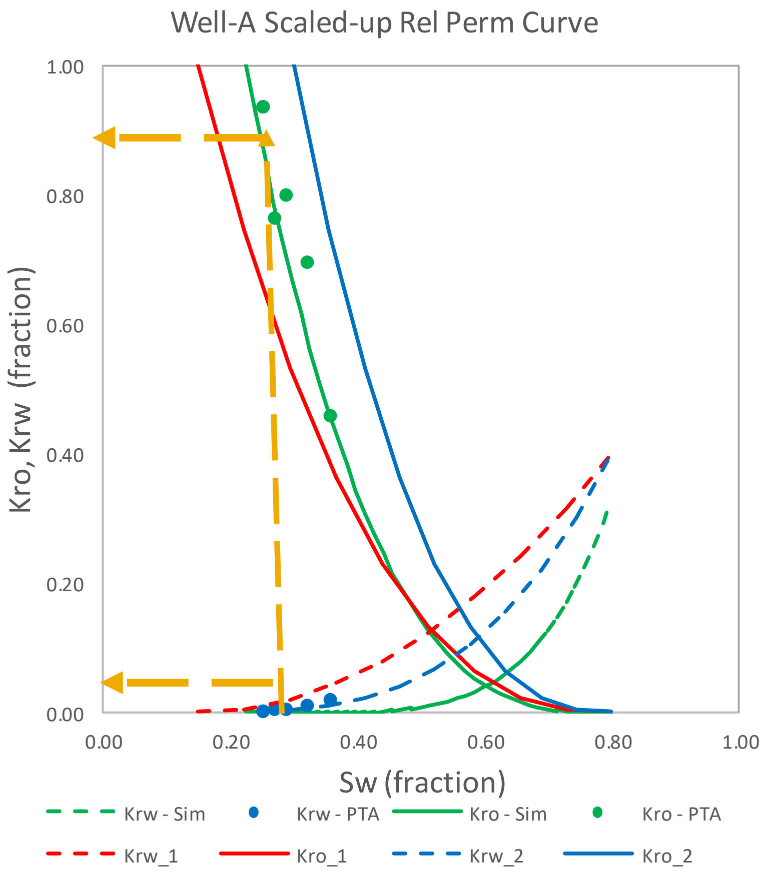


Case 1: PTA & Simulation Scaled-up Rel Perm Curves

- Simulation Scaled-up rel perm curves
  - Different facies with varying connate water saturation
  - Normalized curve with saturation end-point scaling
- PTA rel perm
  - Average of facies within test area
  - Constant fluid saturation
  - Ratio of fluid mobility equal to downhole production ratio

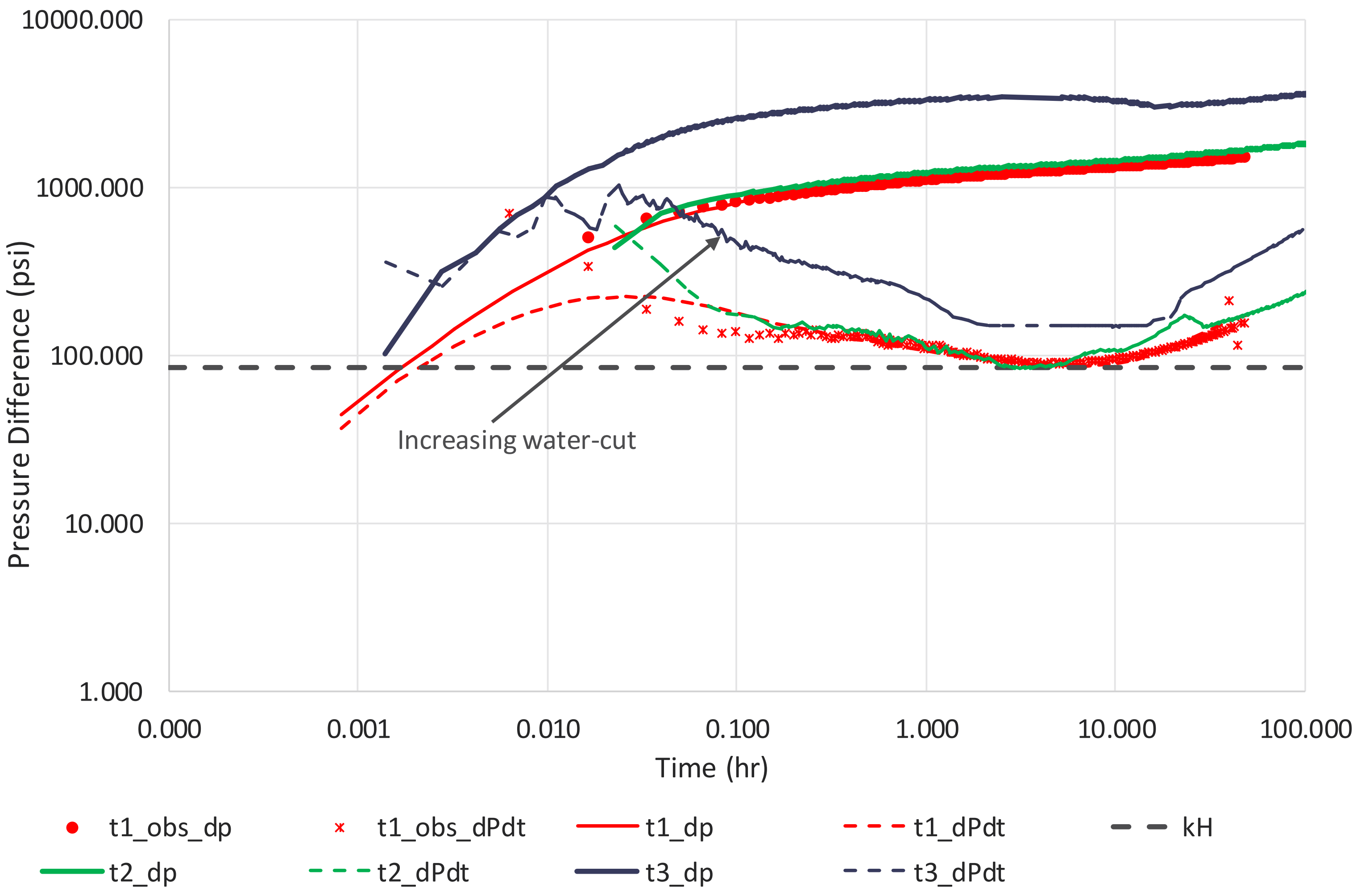
$$\frac{k_{ro}}{k_{rw}} = \frac{(qB\mu)_{oil}}{(qB\mu)_{water}}$$





Case 1: Single & Multi-phase PTA

- Single phase Analysis
  - Establish baseline kH
  - PTA/(Log kH) : 0.5
- Multi-phase Analysis
  - Water-cut conditions (10 – 27%)
  - Constrained by baseline estimates
  - Relative permeability data
    - Effective Oil permeability
  - Skin estimate



Case 1: Multi-Phase Multi-Layer PTA Model

- Model assumptions
  - Same multi-phase methodology
  - No crossflow between layers in reservoir
  - Commingled production in wellbore
  - Model response corresponds to equivalent single layer

$$(kh)_{total} = \sum_{i=1}^{n} k_i h_i$$

Input Layer Properties
- Static + Production

↓

Generate Model
- Combined Effect

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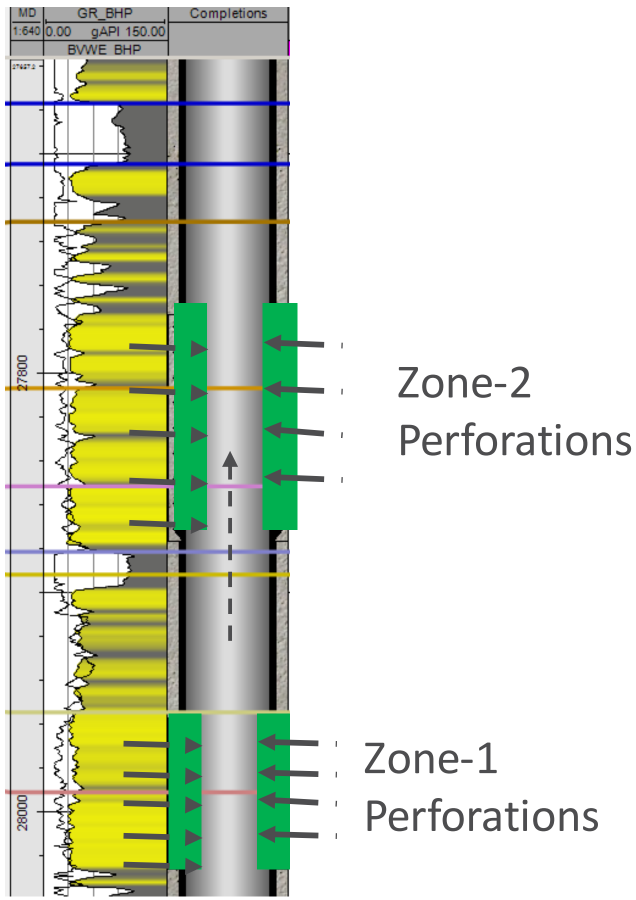
Adjust Parameters to Match Layer Rates
- Skin

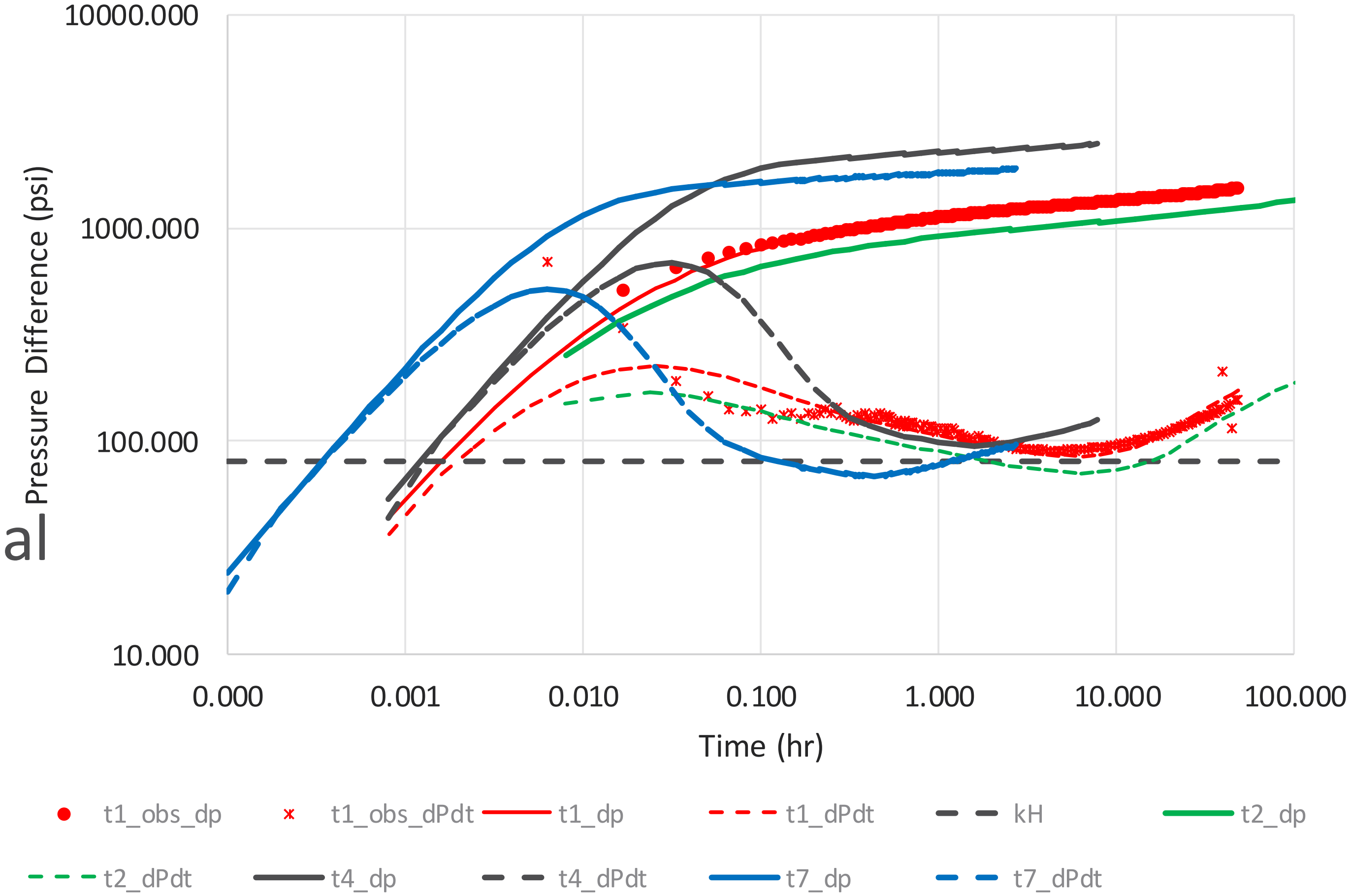
↓

Sensitivities on Alternate Solutions



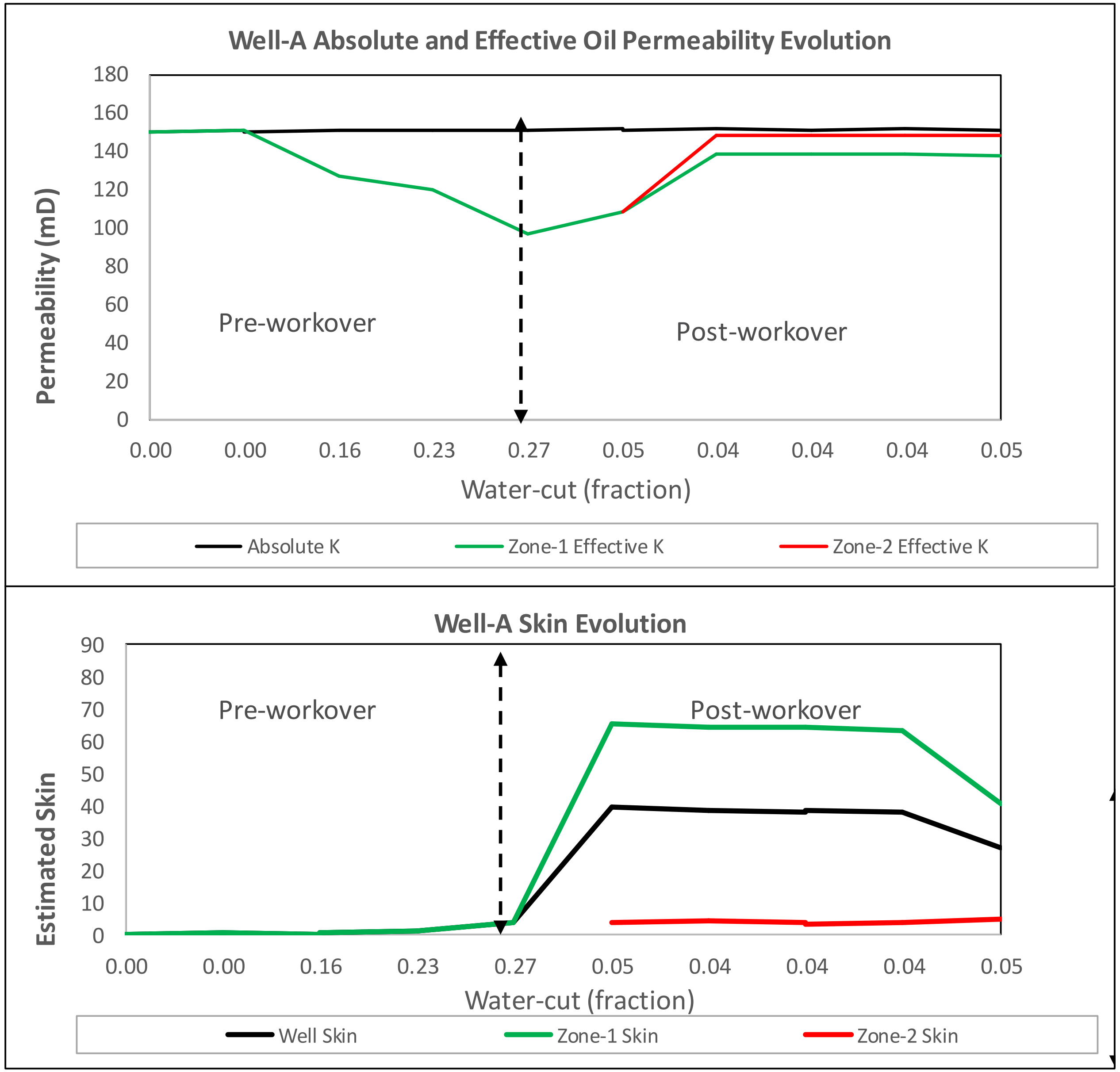
Case 1: Multi-phase Multilayer PTA

- Two zone production
  - Single zone: t1 - t2
  - Multi-zone: t4 - t7
- Model response is combination of layer behavior
- Requires knowledge of zonal rates
- Analysis results
  - Iterative non-linear regression



Case 1: Results

- Effective permeability trends with water-cut
    - Decrease attributed to multiphase effect
- Post-workover skin development
    - Mostly from Zone-1
    - Consistent with independent analysis
- Results used to design a focused potential remediation plan
    - Further improve well performance



Summary of Results for Case 2 & 3

Case 2

- Integrated PTA and Geomechanical study
- Decouple kH fluctuations due to effective stress and multiphase effect
- Quantify productivity loss contributors
  - Skin & Effective Stress
- Reservoir management to address effective stress
- Acid stimulation to address damage skin

Case 3

- Good agreement between PTA and simulation model relative permeability
  - Good match at low to mid water saturation
- Mismatch at high water saturation
  - Reflect heterogeneity and/or fluid property changes

Case Conclusions

- Established reliable baseline absolute and effective oil permeability consistent with scaled-up relative permeability data.
- Quantified different components of well productivity factors (skin).
- Estimated zonal skin distribution in commingled dual-zone multiphase production scenario.
- Provided information to generate forecast for economic evaluation of remediation actions.
- Decouple changes in kH due to effective stress and multiphase effect
- Provided a set of data that can support a reliable QA/QC process throughout the field life cycle.

Acknowledgement

- The authors would like to thank BHP management for the opportunity to publish this work.
- We also acknowledge the technical contributions from Ayuob Herris, Cem Ozan, Khalid Halabi, Doug Peck, Matt Honarpour, Doug Stewart, Carl Vreeling, Yen Dang, Trevor McClymont and Bill Begnaud.

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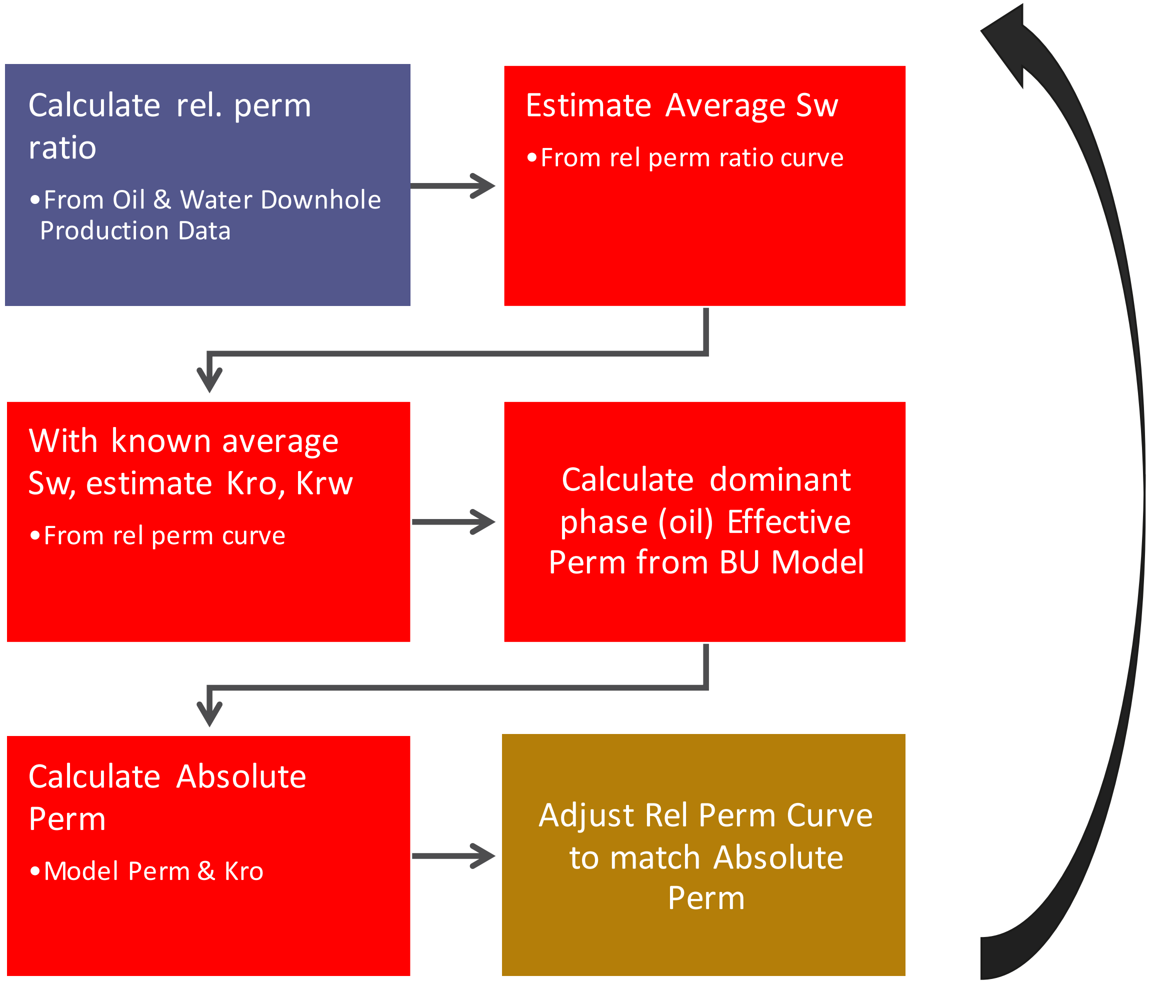
- Perrine-Martin (1956)
  - Earliest attempt on multiphase PTA
  - Combined phase total mobility and compressibility
- Kamal and Pan (2010, 2011)
  - Incorporates relative permeability data consistent between PTA and reservoir model
  - Consistent estimate of absolute permeability in single and two-phase conditions

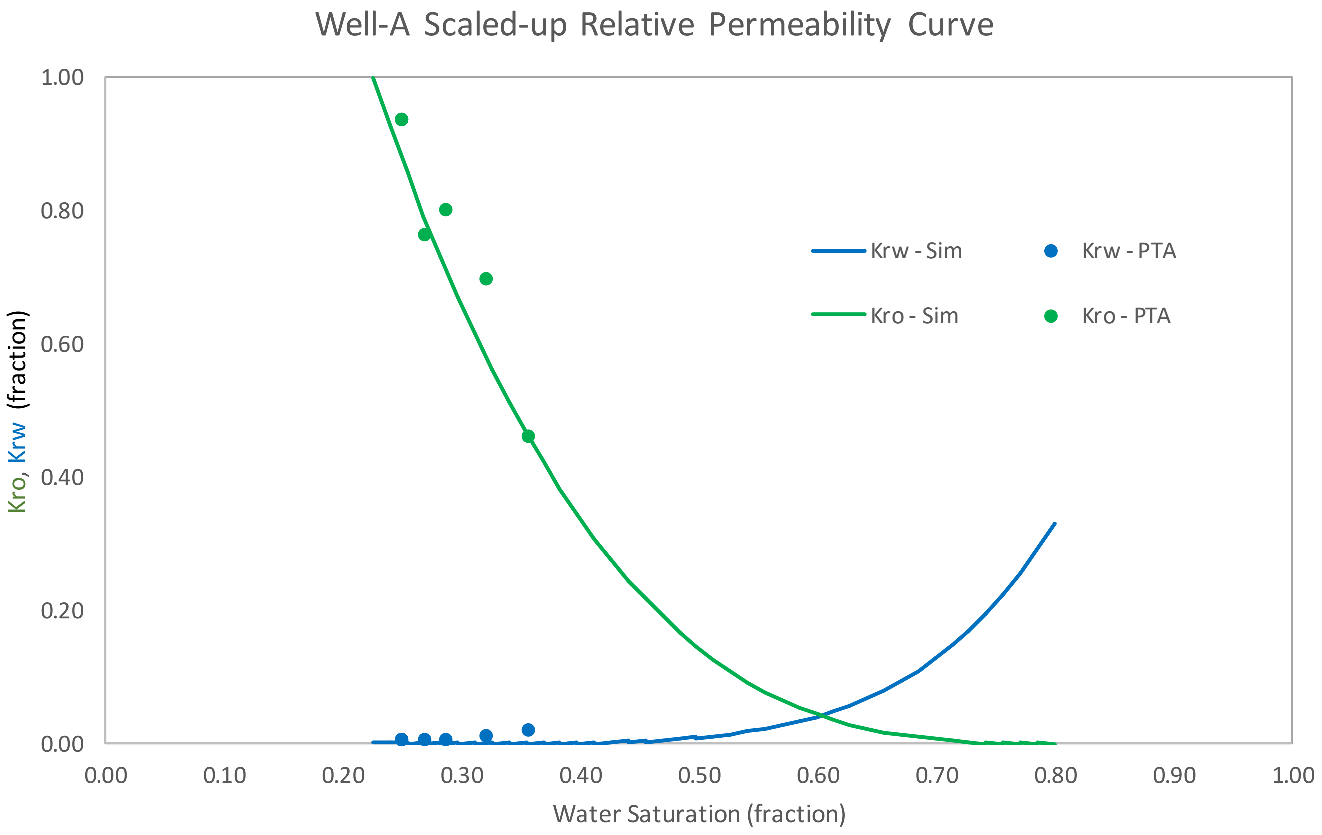
Case 1: Multi-Phase PTA Model

- Multi-phase assumptions
  - Single phase kH as baseline estimate
  - Constant fluid saturation in test area
  - Ratio of fluid mobility equal to downhole production ratio

$$\frac{k_{ro}}{k_{rw}} = \frac{(qB\mu)_{oil}}{(qB\mu)_{water}}$$



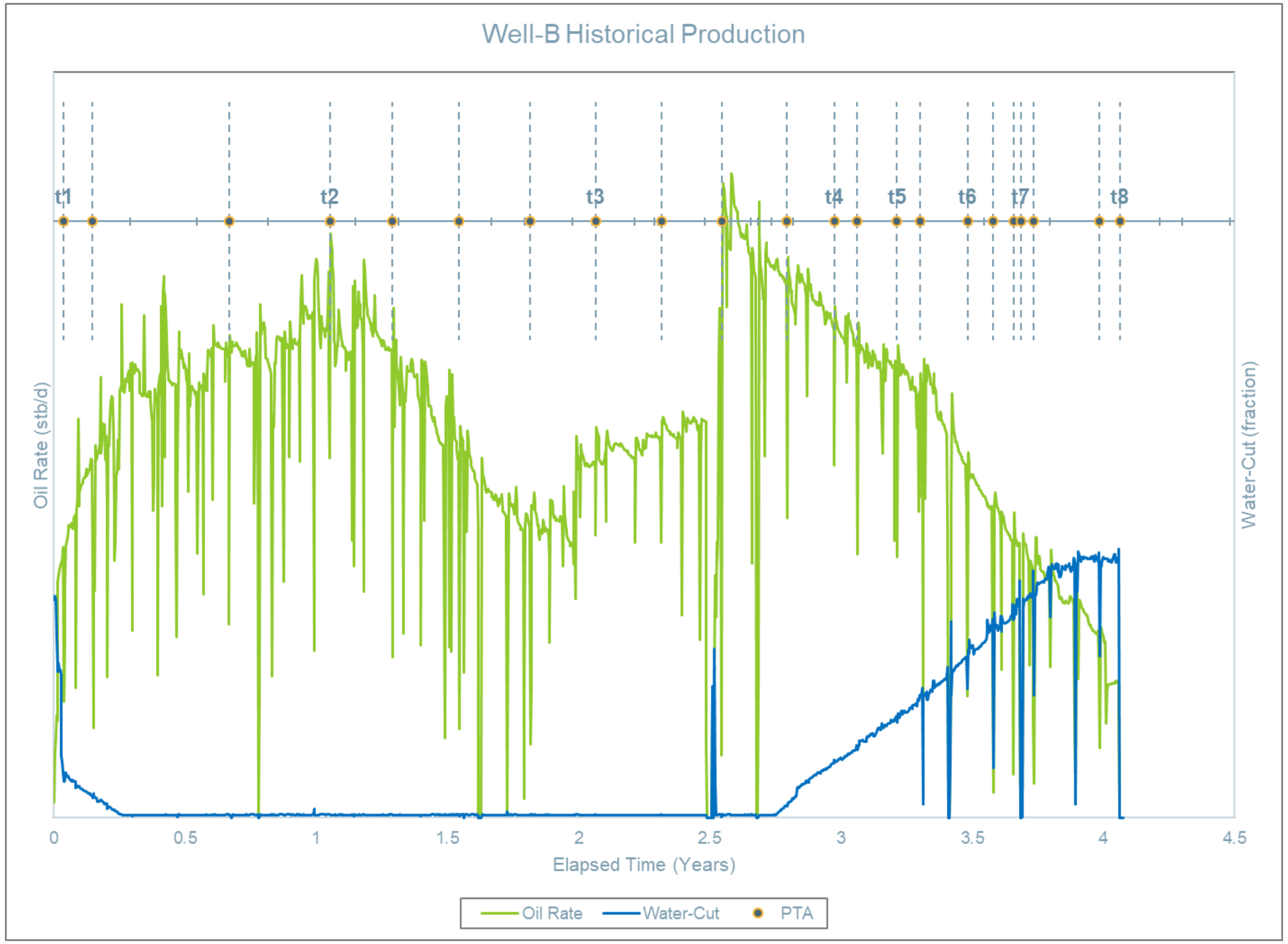
Case 1: Calibrated Relative Permeability Curves



- Scaled-up relative permeability family curves
  - Good match between simulation model history match and PTA data
  - Consistency between field performance and PTA

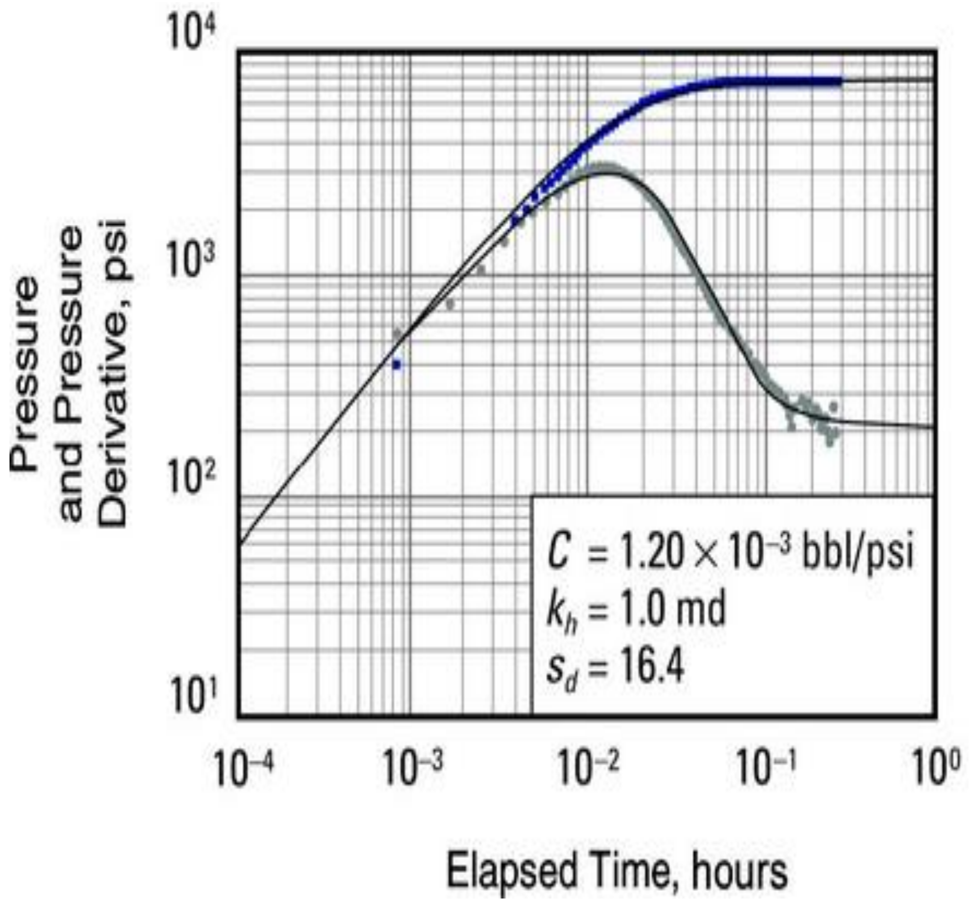
Case 2: Well Background

- Produced dry oil few years before water breakthrough
- Successful acid stimulation job shortly before water broke
- Production decline post water breakthrough
  - Increase in skin estimates from BU data
  - Decrease in absolute permeability on PTA



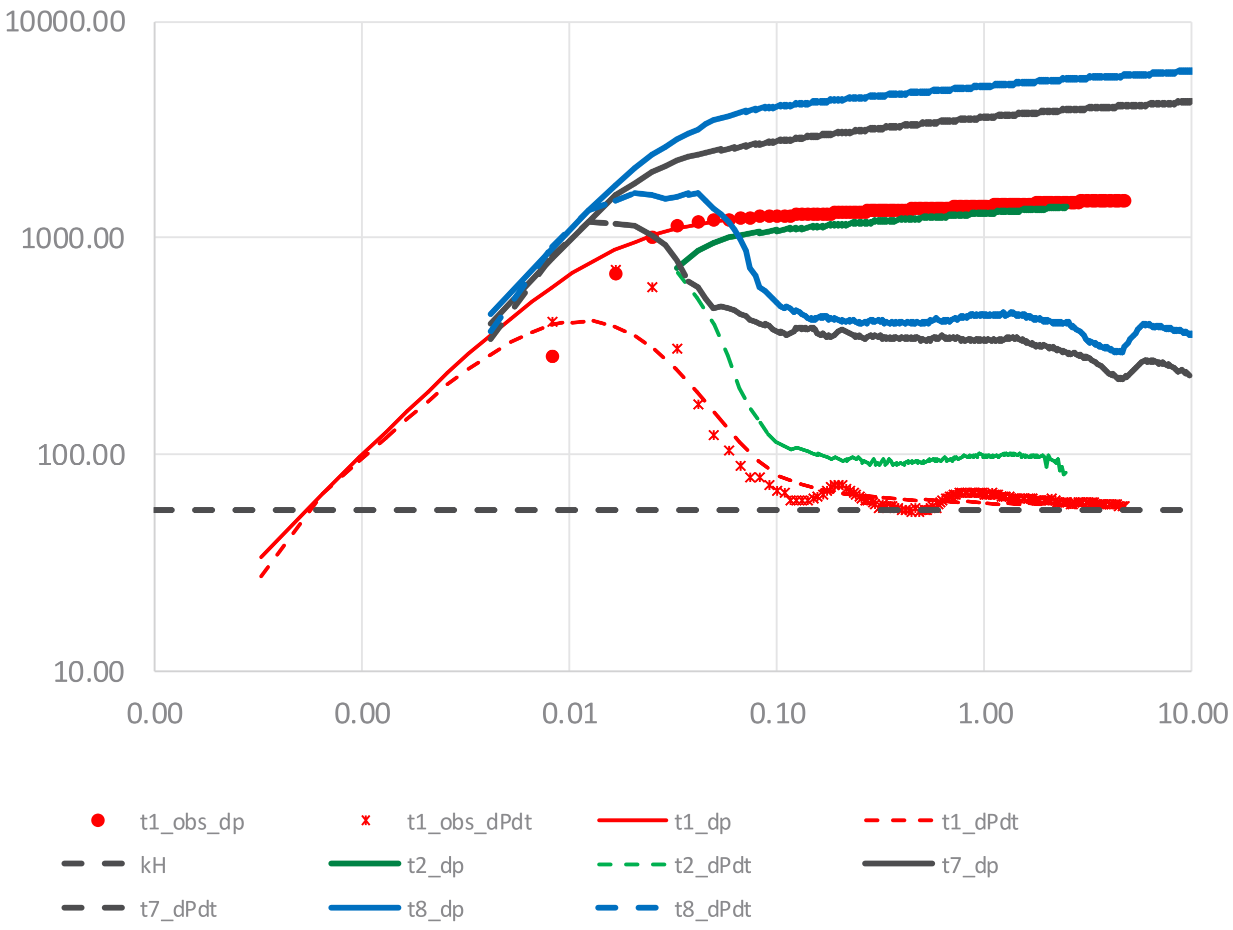
Case 2: Analysis Objectives

- Determine causes of productivity loss
  - List possible causes of productivity loss
  - Analyze available data and consult with specialists
  - Narrow down possible causes
- Decouple productivity loss factors
  - Multiphase effect (relative permeability)
  - Stress dependent permeability
  - Skin (damage)
- Evaluate economic viability of remediation for each factor



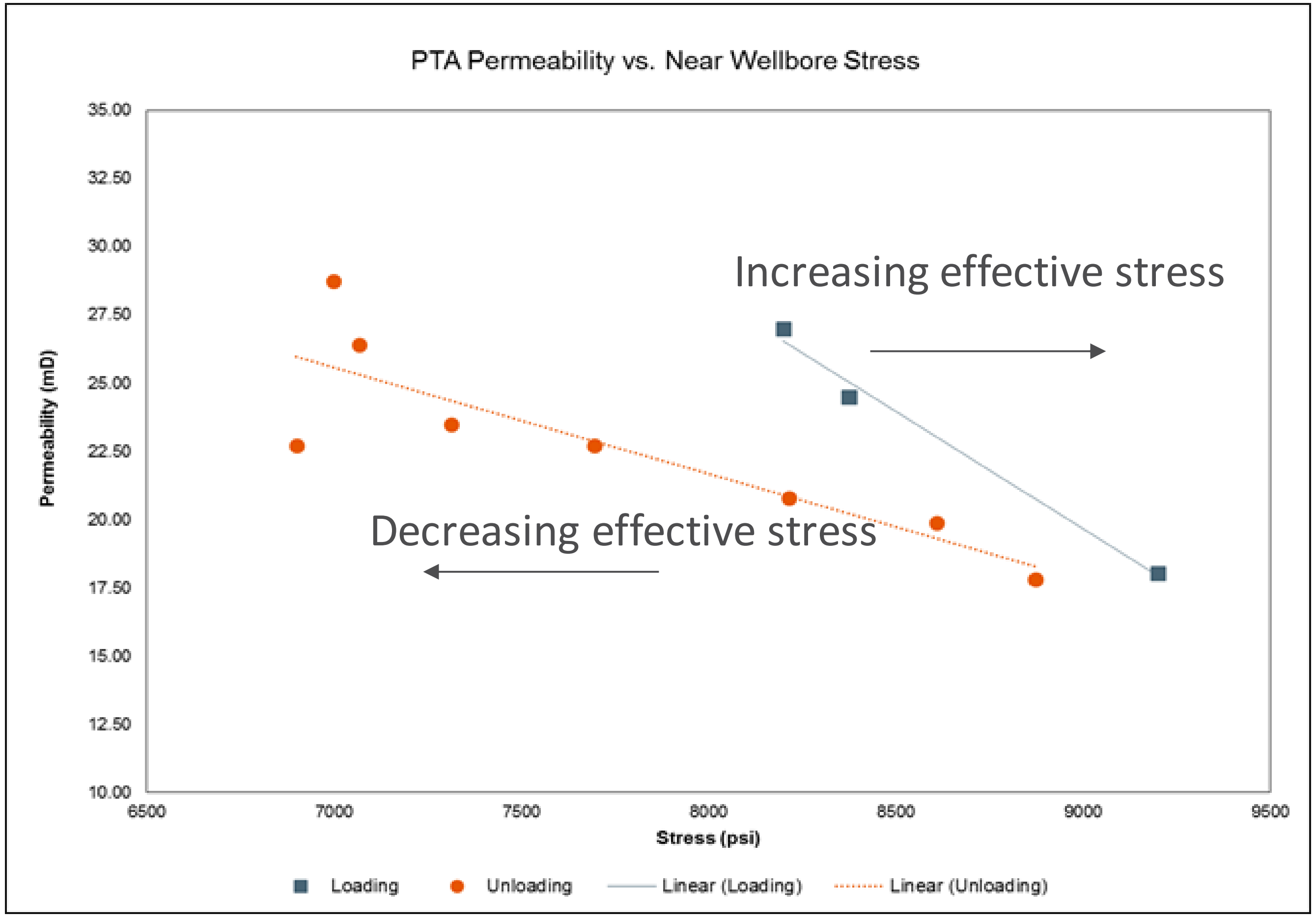
Case 2: Single & Multi-phase PTA

- Single phase analysis (t1 - t2)
  - Establish baseline kH
  - Observed fluctuations in kH
  - Geomechanical study to investigate potential causes
    - Fluctuations due to loading and unloading effective stress
  - Skin increase due to geomechanical effect (fines migration)
- Multi-phase (t7 - t8)
  - Decouple kH fluctuations from multiphase effect and geomechanical stress
  - Reliable and consistent Skin estimate



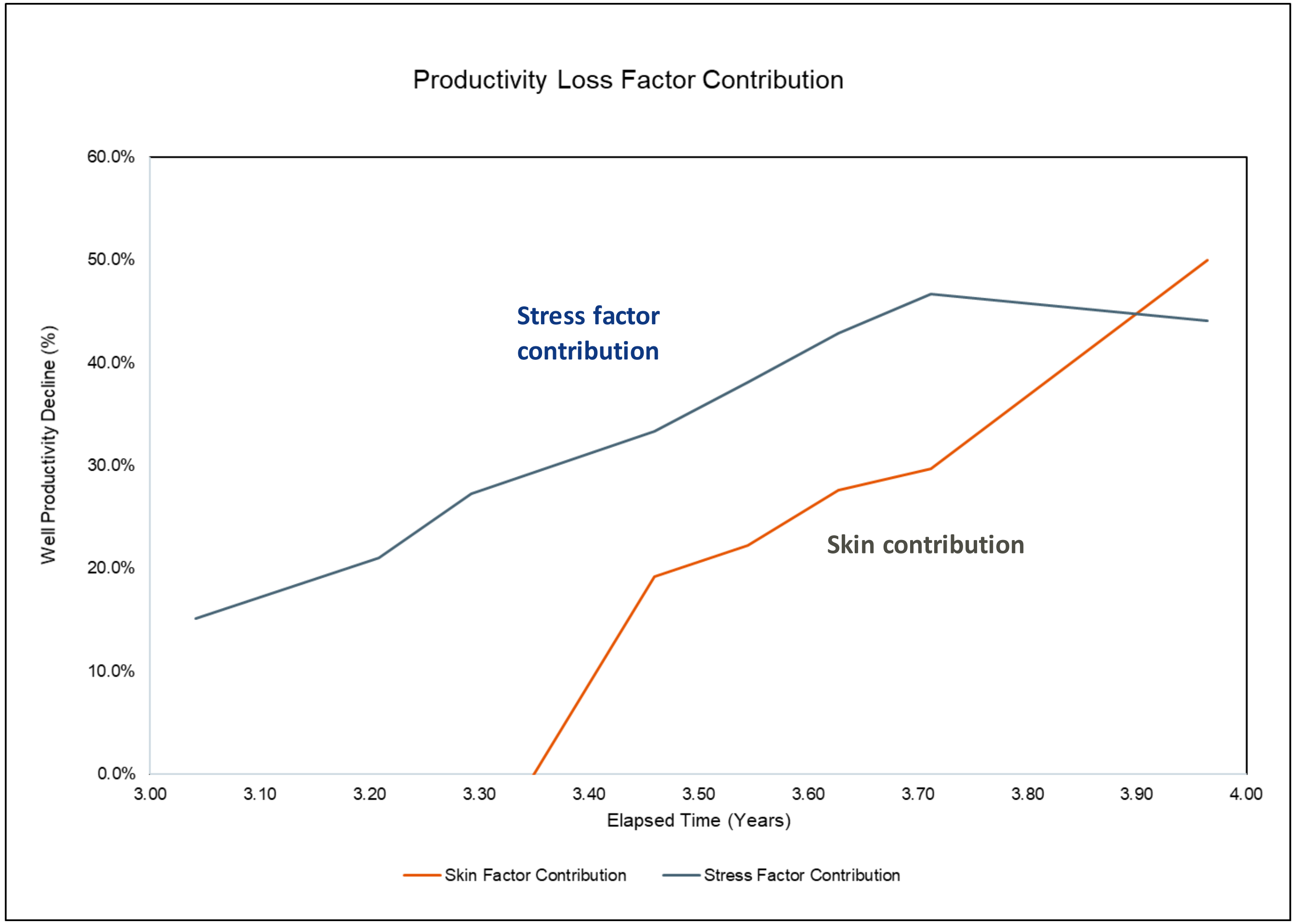
Case 2: Pressure-dependent Permeability

- Insight from geomechanical study
  - Inverse relationship between PTA permeability and near wellbore stress
  - Evidence for pressure dependent permeability



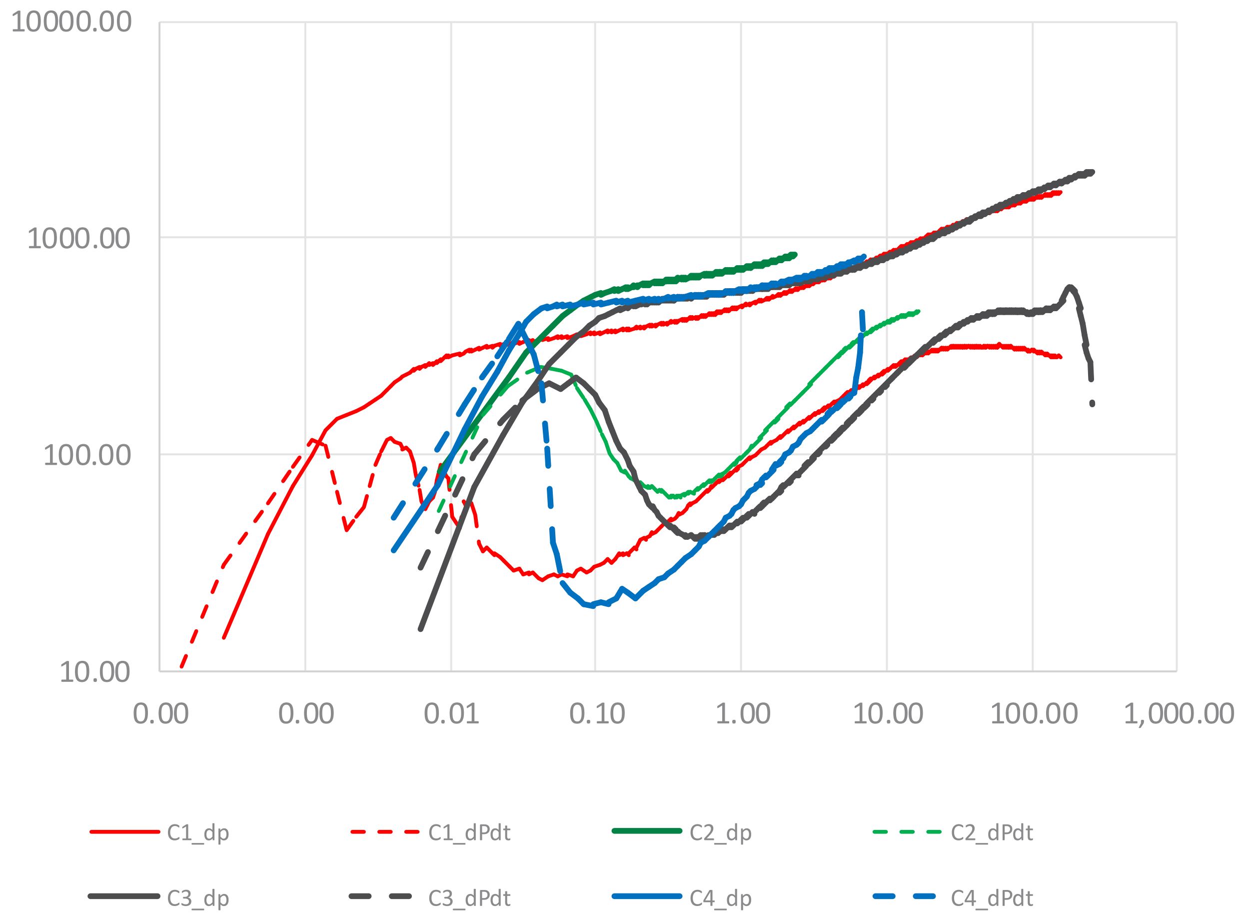
Case 2: Results

- Integrated PTA and Geomechanical study
  - Quantify productivity loss contributors
  - Establish a relationship between permeability and stress
  - Designed a trial to confirm stress – permeability relationship
- Economic Analysis
  - Acid stimulation to remediate skin
  - Reservoir management to address stress



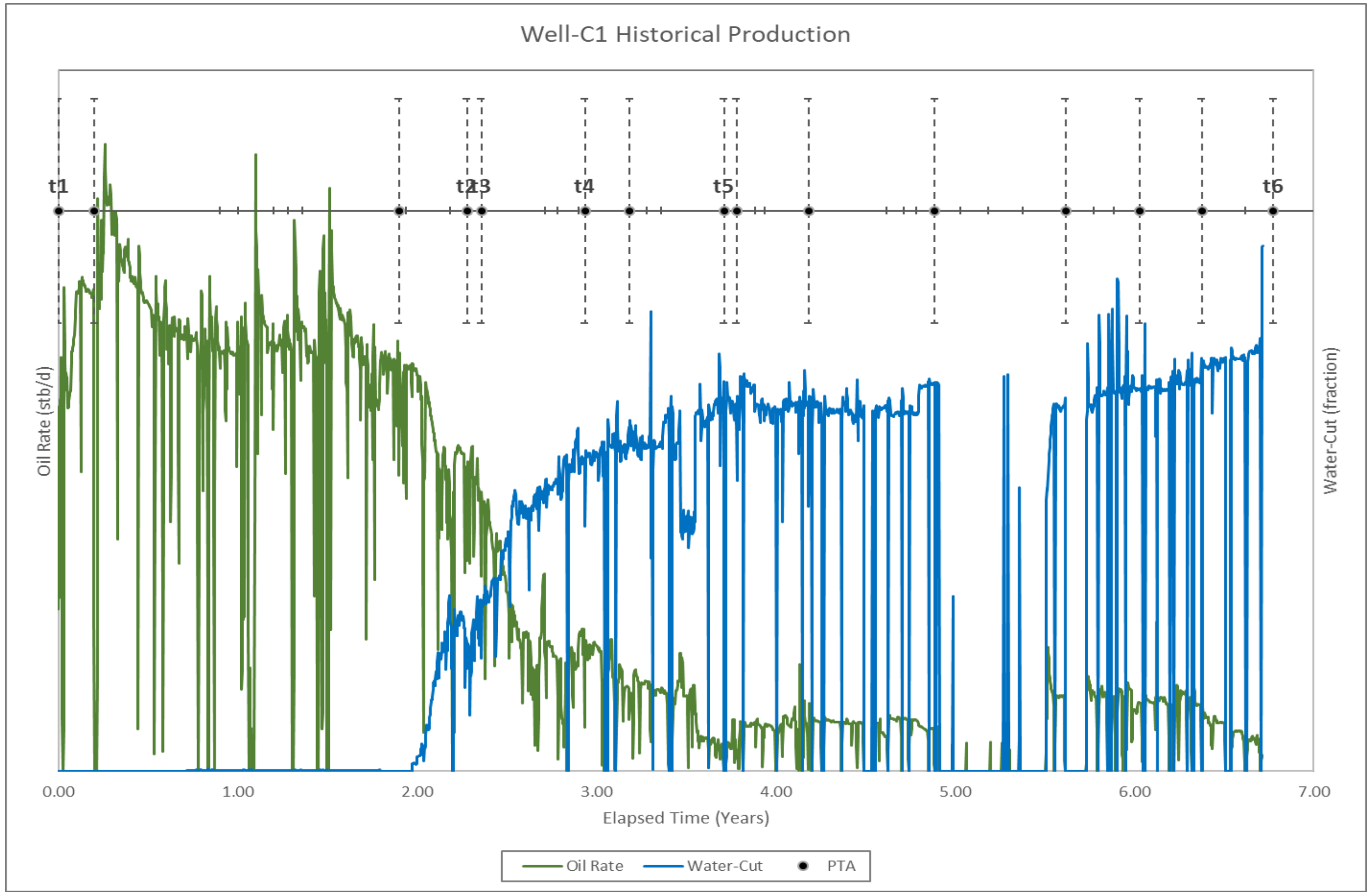
Case 3: Analysis Objectives

- Challenges in wells PTA signatures in this area
  - Wells have early close boundary signatures
  - Difficult to identify stable IARF
- Main Analysis objectives
  - Reduce uncertainty in relative permeability data used for history matching
  - Provide reliable basis for modeling of future targets



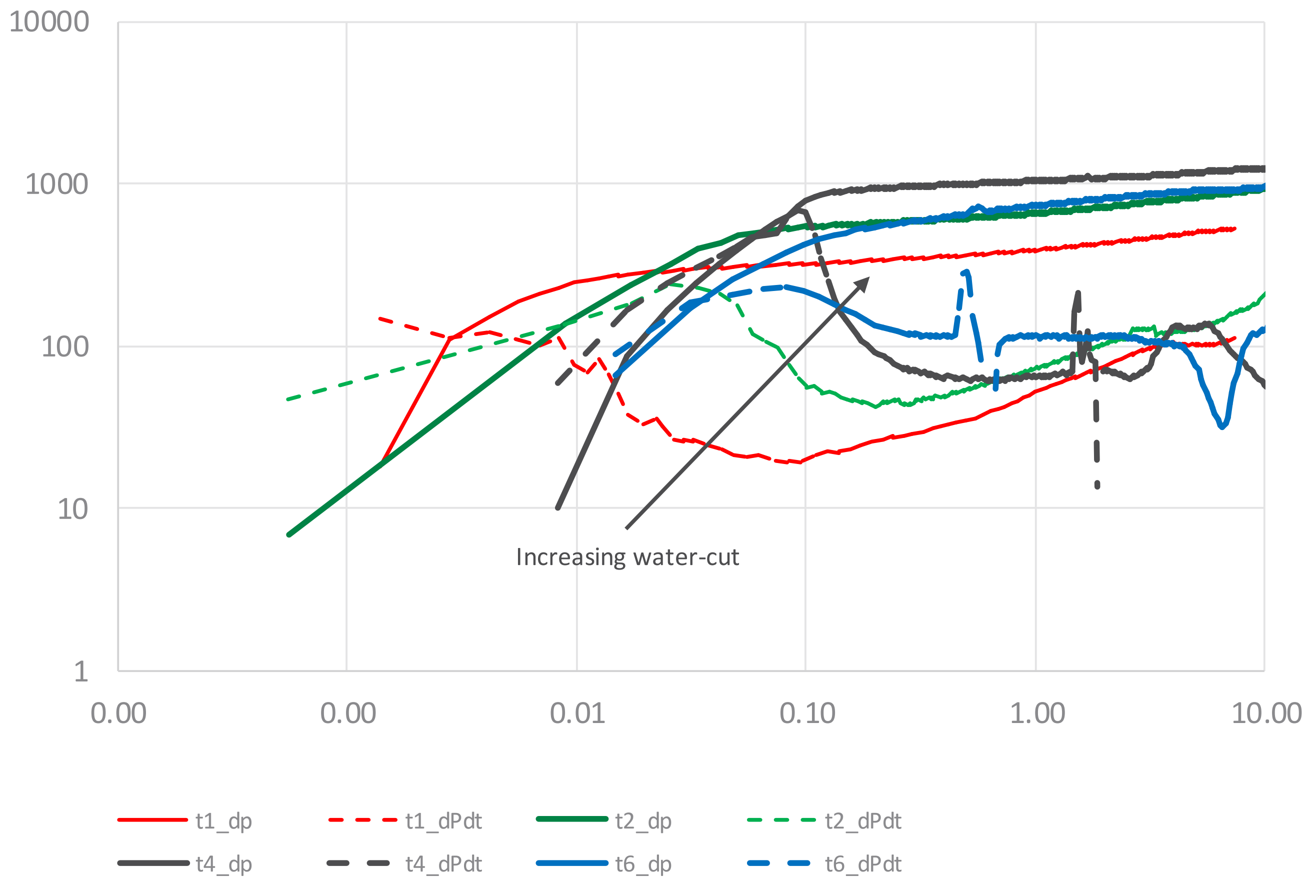
Case 3: Well C1 Background

- Well C1 as a case study example
  - Has highest quality dataset
  - Shut-ins covers several flow conditions and water-cuts
- Produced dry oil few years before water breakthrough



Case 3: Single & Multi-phase PTA

- Single phase analysis (t1)
  - Establish baseline kH
  - Consistent with area information
- Multi-phase (t2-t6)
  - Decrease in effective permeability with increase in water-cut



Case 3: Results

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  - Good match at low to mid water saturation
  - Inconsistency at high water saturation
  - Mismatch may reflect heterogeneity or fluid property changes