Digital, Data Analytics, and Automation: Value Creation Through Digital E&P

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Optimizing Waterflood Management in Offshore Field: A Comprehensive Reservoir Management Study Using the Capacitance-Resistance Model (CRM)

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Agenda

Part 1: Background and CRM theory

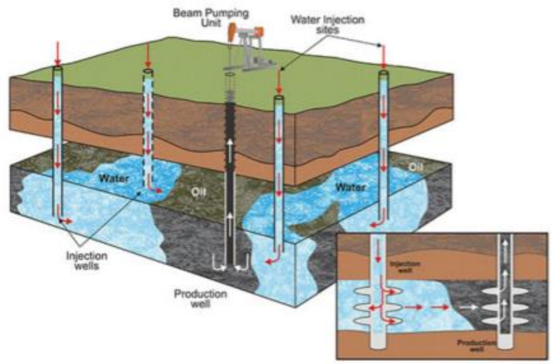
Part 2: In-house software development: Flood Sight

Part 3: Field case study on offshore oil field

- Reservoir diagnostics and surveillance
- CRM model analysis and reservoir connectivity
- Reservoir management remedial plan and way forward
- Scenario 1: subblocks with partially-sealed fault
- Scenario 2: subblocks with sandwiched reservoir (aquifer encroachment and gas cap)

Results and Conclusions

Problem & Study Objective



Secondary and Tertiary recovery mechanism: Oil is displaced by injected fluids

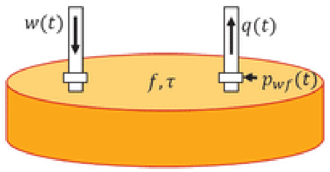
Lower IOR/EOR performance from brown field development is caused by:

- Reservoir complexity
- Poor understanding of inter-well connectivity
- Vertical heterogeneity
- Insufficient production and injection control

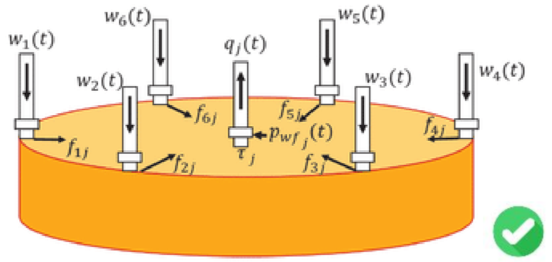
Goal	**Enable routine use of this analytical workflow by the asset team for continuous optimization.**
Solution	**Apply the Capacitance-Resistance Model (CRM) along with fundamental reservoir diagnostic for rapid waterflood recovery modeling.**
Need	**Integrate fast and effective reservoir management techniques.**
Challenge	**Optimize oil production and minimize bypassed oil in mature oilfields.**

Background and CRM Theory

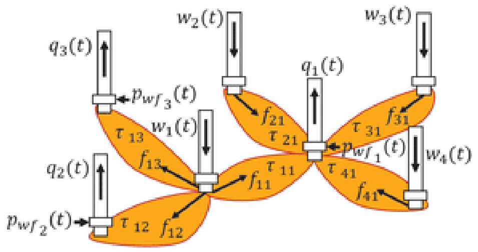
Single tank (CRMT)



Producer-based (CRMP)



Producer-Injector Pair-based (CRMIP)



Capacitance-Resistance Model (CRM) serves a fast analytical tool designed for modeling waterflood recovery processes, including history match and forecast with optimization.

CRM is a physics-based model, requiring only production, injection and well pressure data to provide information of

- Injection contribution from each injector f_{ij}
- Connected volume for each producer τ_j
- Producer productivity index J_j
- Optimized water injection rate $q_{j,\max}(f_{ij}, \tau_j, J_j)$

$$q_j(t_k) = q_j(t_{k-1})e^{-\frac{\Delta t_k}{\tau_j}} + \left(1 - e^{-\frac{\Delta t_k}{\tau_j}}\right)\left(\sum_{i=1}^{N_i} f_{ij}\, i_i^k - J_j \tau_j \frac{\Delta P_{wf_j}^{(k)}}{\Delta t_k}\right)$$

Primary recovery | Fluid injection | Bottomhole pressure change

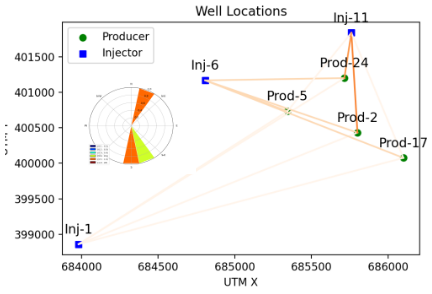
For this study, **CRMP will be implemented** via the FloodSight software.

Source: A State-of-the-Art Literature Review on Capacitance Resistance Models for Reservoir Characterization and Performance Forecasting

In-House FloodSight Application

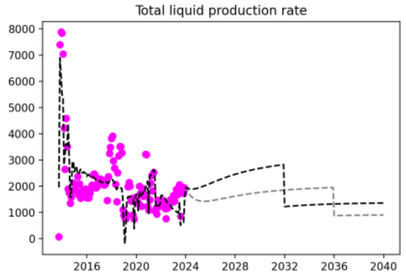
Step 1

Input Preparation
- Historical production rate
- Historical injection rate
- Bottom hole pressure reading
- Well coordinate and well grouping



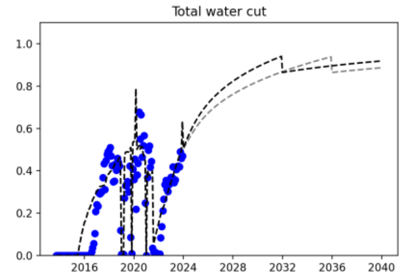
Step 2

CRM liquid rate modeling
- Inter-well connectivity
  - Injection contribution
  - Magnitude and direction
- Reservoir and well property
  - Connected pore volume
  - Productivity
- Liquid rate history matching



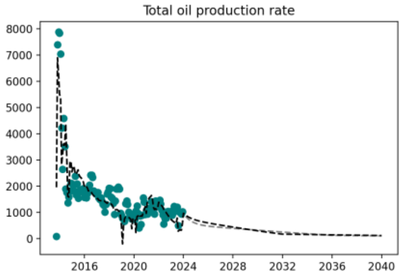
Step 3

Koval water cut modeling
- Reservoir heterogeneity index
- Water cut modeling
- Oil rate history matching



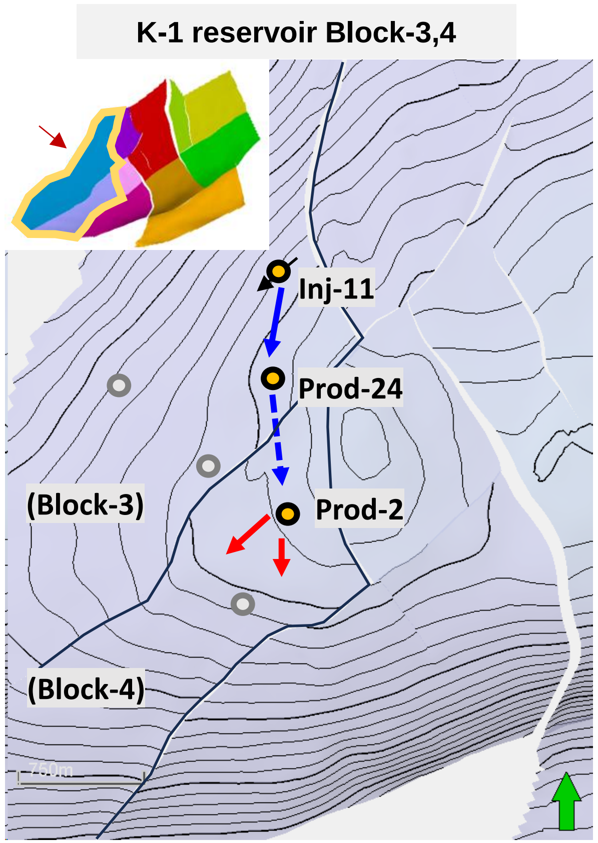
Step 4

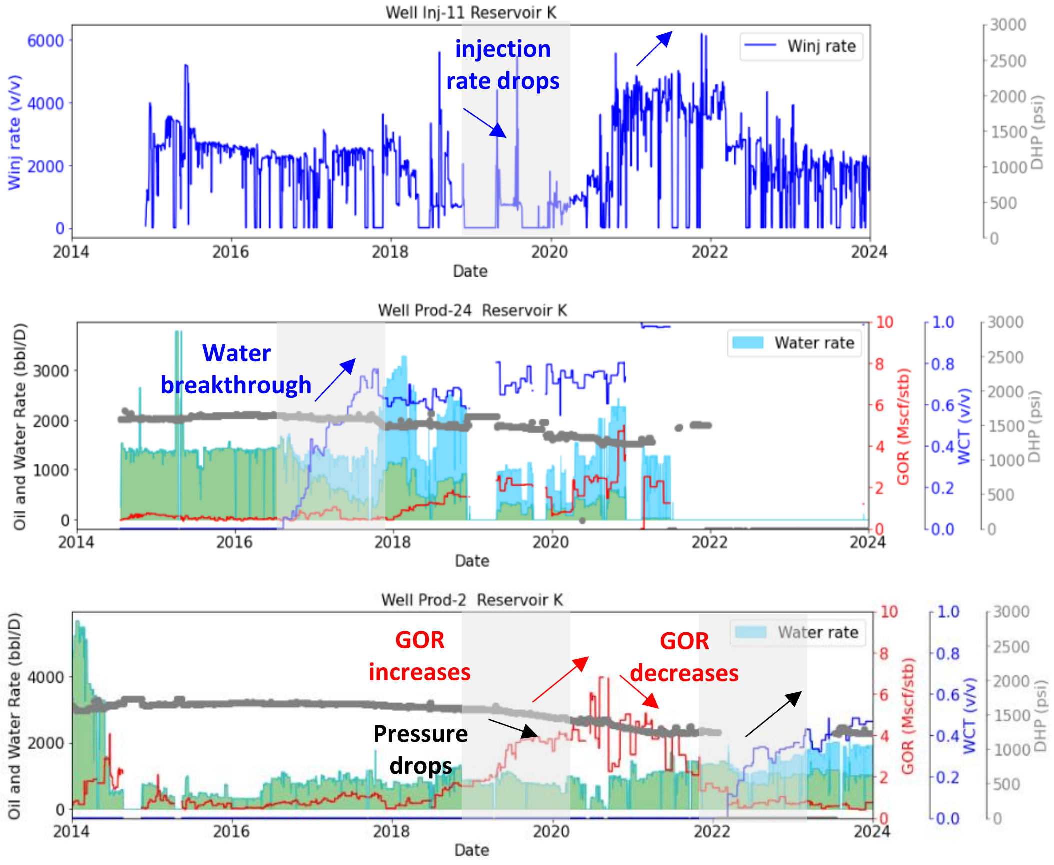
Forecast model
- No forward activity forecast (NFA)
- Optimized injection scheme
- Estimated waterflood gain
  - Volumetric and profile



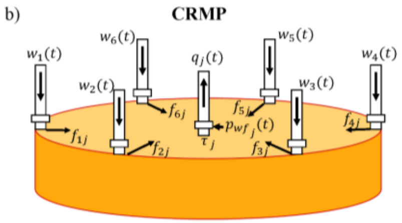
History and forecast
Forecast with optimization

Scenario 1: subblocks with partially-sealed fault



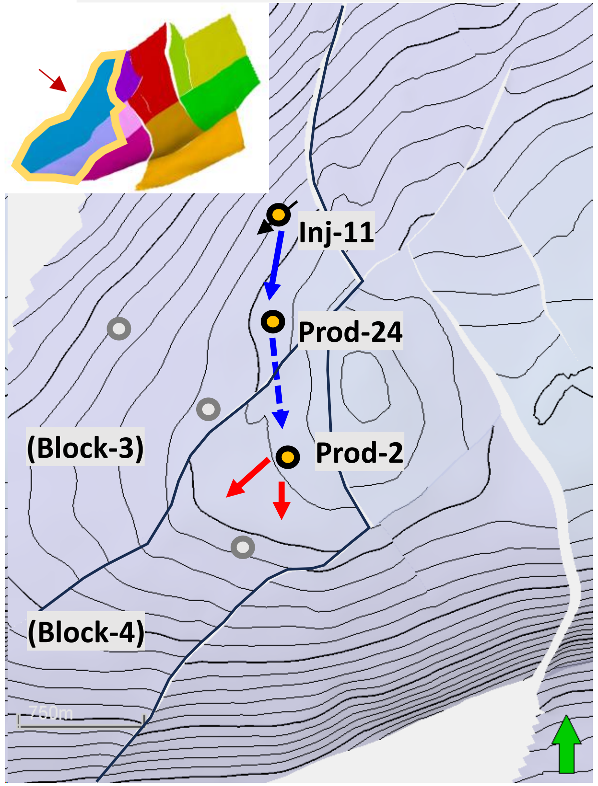


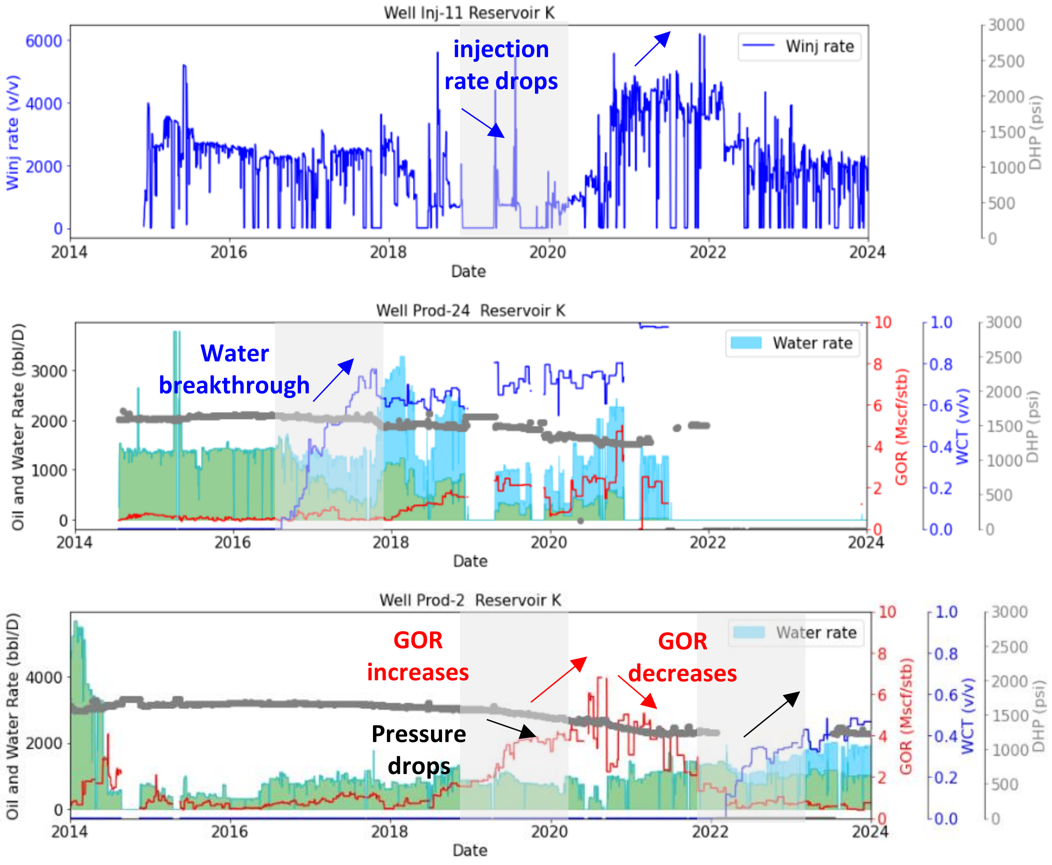
- In K-1 reservoir, Block-3: Prod-24 experienced water breakthrough from Inj-11
- In K-1 reservoir, Block-4: No active injector, but GOR of Prod-2 increased when Inj-11's injection dropped, and GOR of Prod-2 decreased after ramping up Inj-11's injection.
- Suspected inter well connectivity between Prod-2 and Inj-11 via a leaky fault, confirmed by pulse testing.
- Group all producers in Blocks 3 and 4 for CRM modeling → need to increase VRR (Inj-11) to maintain waterflood support at Prod-2



Scenario 1: subblocks with partially-sealed fault

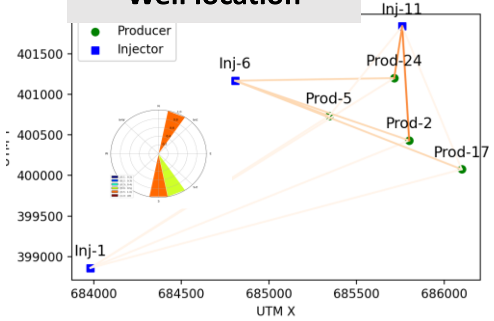
K-1 reservoir Block-3,4



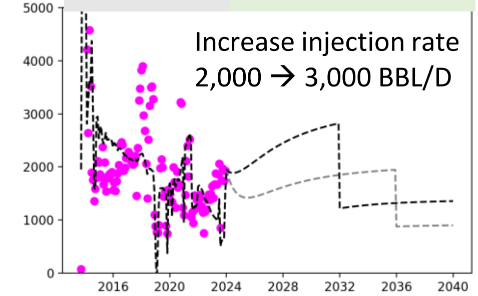


History and forecast
Forecast with optimization

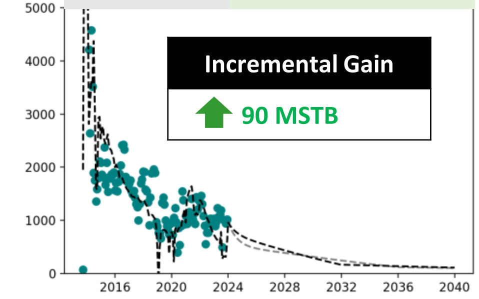
Well location



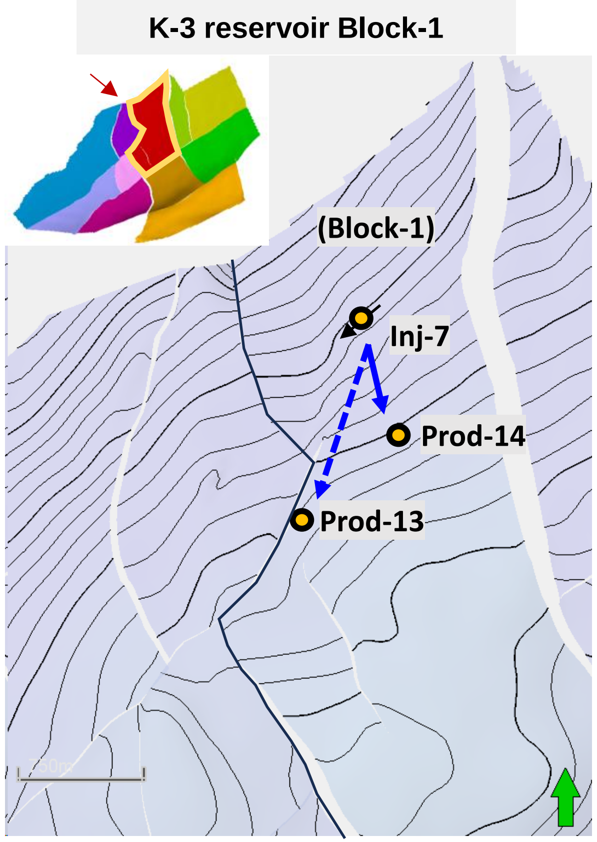
History	Forecast

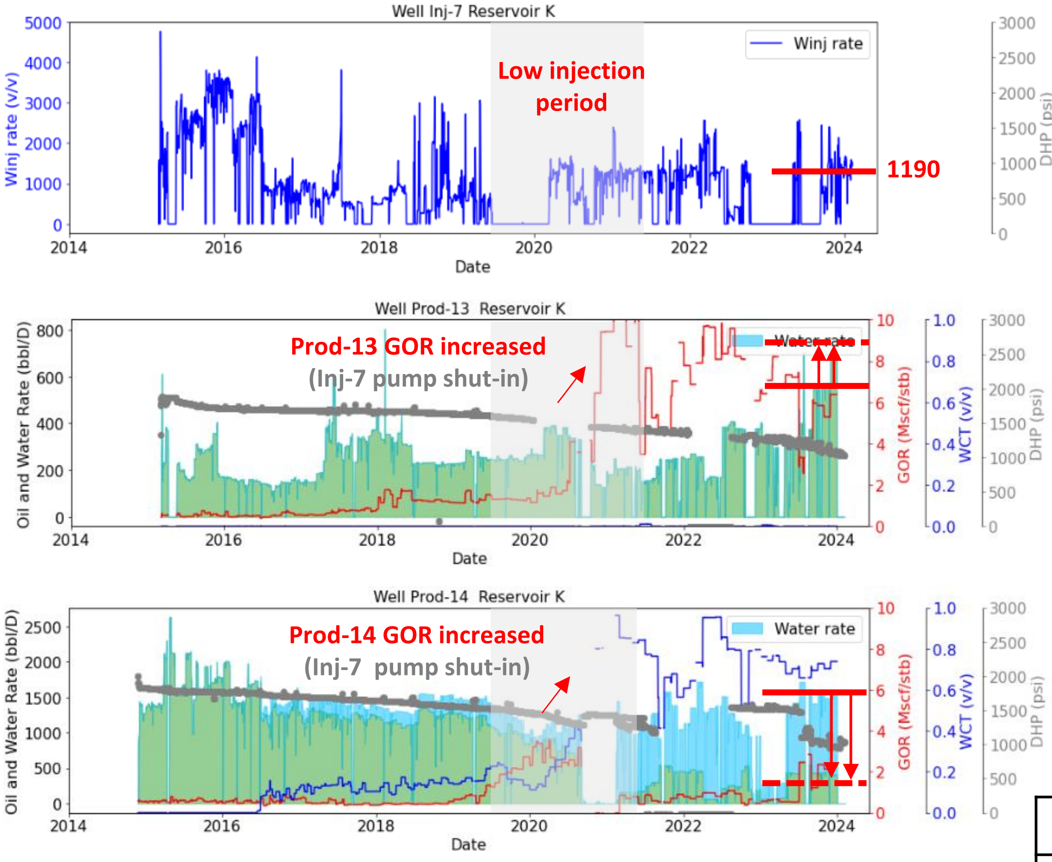


History	Forecast



Scenario 2: subblocks with sandwiched reservoir





- In K-3 reservoir, Block-1: Prod-14 experienced water breakthrough from Inj-7
- Prod-13 experienced high GOR due to gas cap expansion, with insufficient pressure support from Inj-7. Waterflood response at Prod-13 is blocked by Prod-14.
- Calculate instantaneous VRR (iVRR)

q_L (Prod-13) = 570 BBL/D, WCT < 0.1%
q_L (Prod-14) = 1,500 BBL/D, WCT = 72%
q_{inj} (Inj-7) = 1,190 BBL/D

$$iVRR = \frac{\sum q_{inj} B_w}{\sum (q_o B_o + q_w B_w)}$$

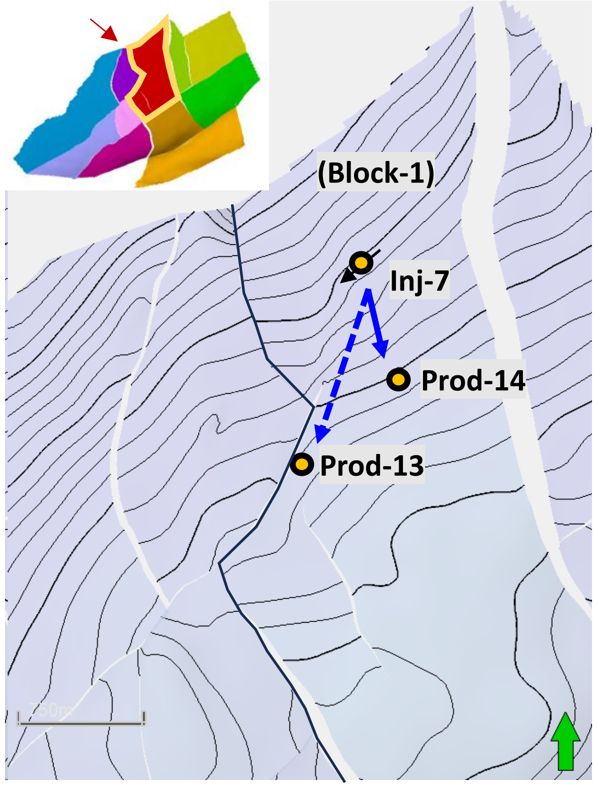
$$= \frac{1190 \times 1}{1500 \times 0.72 + [1500 \times 0.28 \times 1.3 + 570 \times 1.3]} = 0.5$$

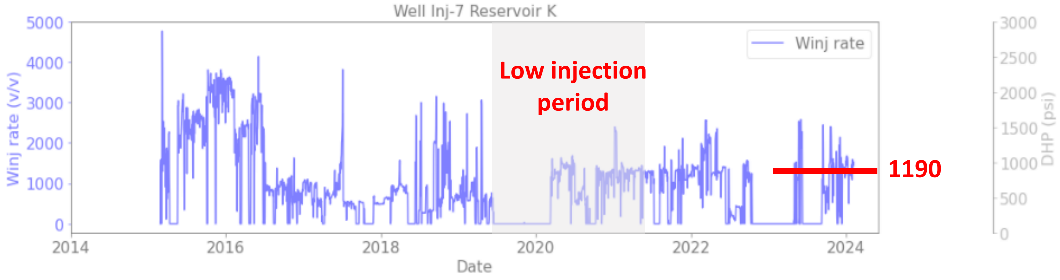
- Set iVRR = 1 and fix q_{inj} (Inj-7) at 1,190 BBL/D
- cut back gross at Prod-14 since it already sees high water cut and divert water to Prod-13

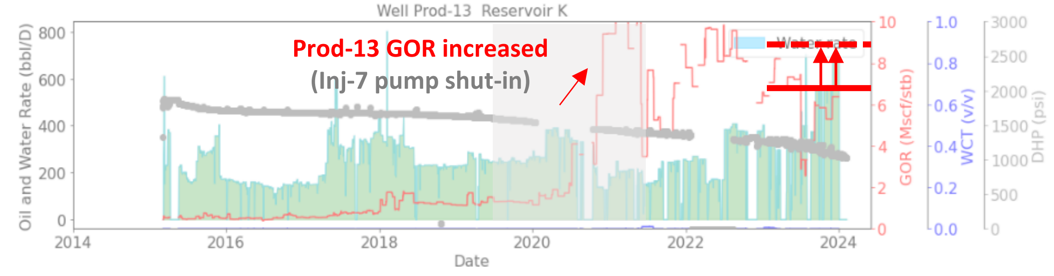
q_{inj} (Inj-7)	q_L (Prod-13)	q_L (Prod-14)	iVRR
1,190	570	1,500	0.5
1,190	743	207 ↓	1.0

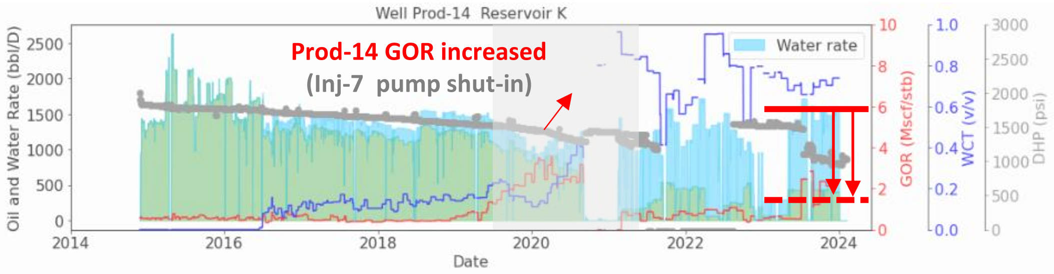
Scenario 2: subblocks with sandwiched reservoir

K-3 reservoir Block-1



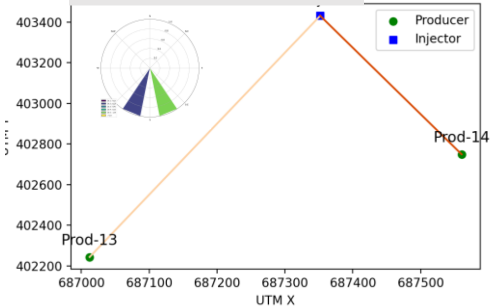


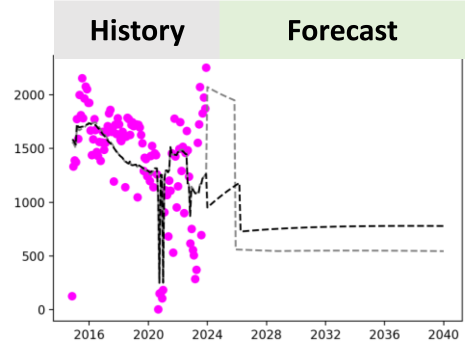


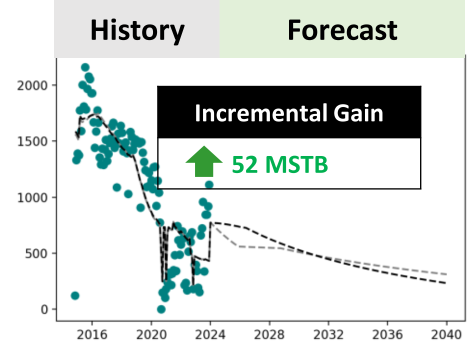


History and forecast
Forecast with optimization

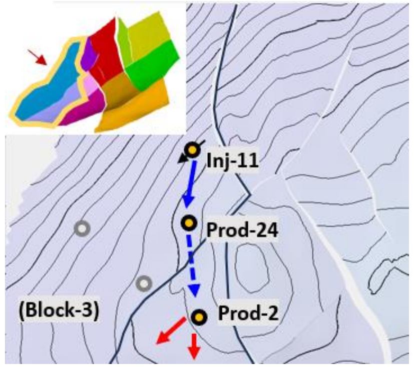
Well location

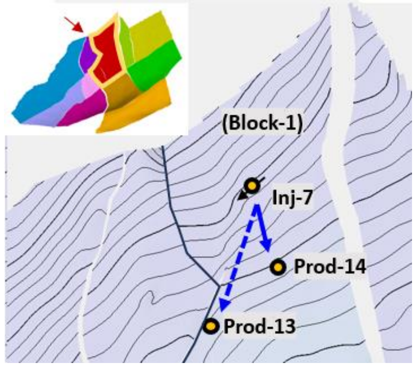


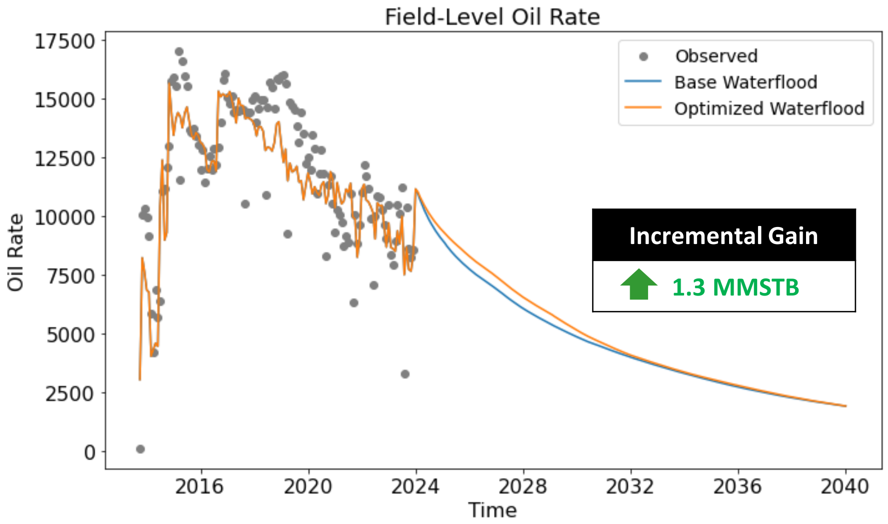




Results and Conclusions







Key deliverables: New water injection requirement

- New injection requirement is proposed by CRM optimizer.
- For scenario 1, increase **injection rate to boost oil production** in the adjacent subblocks with transmissible faults.
- For scenario 2, cut gross rate at high water-cut producer to **avoid water recycling** and support waterflood to more updip wells.

Conclusions and Key take aways

- Field water injection rate remains at 20,000 BBL/D but gets redistributed among injectors to maximize oil gain.
- **Repeat CRM workflow for all subblocks → Oil Gain + 1.3 MMSTB**
- This study examines the implementation of the PTTEP in-house capacitance-resistance model, Floodsight, The incorporation of the CRM model is recommended due to its speed, repeatability, and low computational resource requirement.