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Strengthening Marginal and Mature Field Ecosystems: Technology, Innovation, and Collaboration

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Impact of Water Injection During Production Shut-In in a Mature Compartmentalized Oil Field: A Study Based on Reservoir Simulation and Field Performance Analysis

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Outlines

- Introduction
- Problem Statement
- Analytical Assessment
- Simulation Results
 - Unified model construction and calibration
 - Results analysis
- Conclusions and Recommendations



Introduction

Production Shut-In: Impact & Reservoir Management Approach

Production **shut-ins are routine in** oil & gas operations for maintenance, reservoir management, economics, regulatory, and safety purposes.

However, shut-ins can **negatively impact** overall field performance.

Key Points

The **effect** is especially **significant in reservoirs supported by water or gas injection** for pressure maintenance.

Impacts tend to be more severe in large, mature, compartmentalized fields with complex rock and fluid heterogeneity.

Implement a **robust Reservoir Management Plan (RMP)** to mitigate adverse impacts from operational disruptions.

Apply an **integrated, multidisciplinary workflow** that includes comprehensive data assessment, field performance evaluation, and dynamic simulation.

Mitigation Through RMP

Use **dynamic reservoir simulation** for forecasting, scenario testing, and quantifying shut-in impacts.

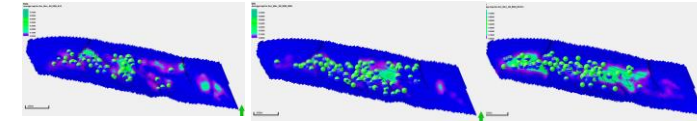
Leverage simulation insights to assess strategies such as **maintaining water injection (WI) during shut-ins** to preserve pressure and safeguard future production.



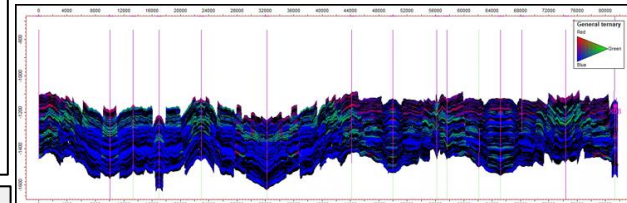
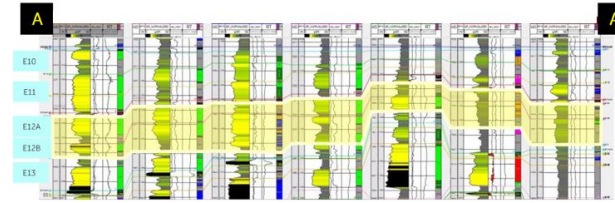
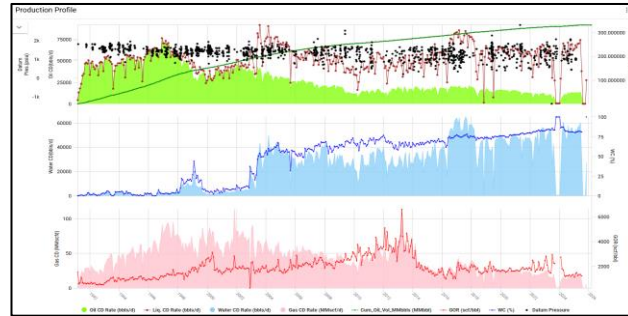
Problem Statement

Production shut-down for 4 months due to riser leak at FSO. This study aims to assess and optimize WI volume during production shut-ins to address:

- Cum VRR below target
- Uneven injection distribution



Avg. movable oil saturation maps

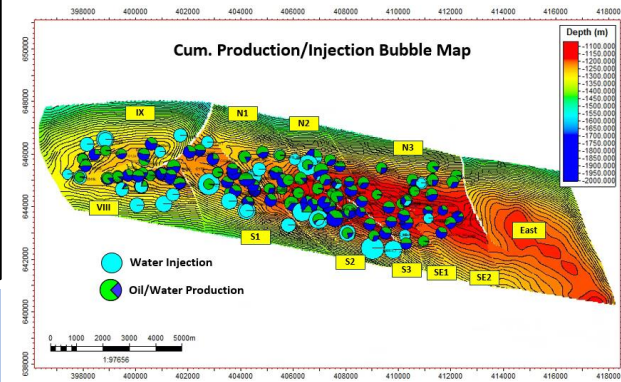
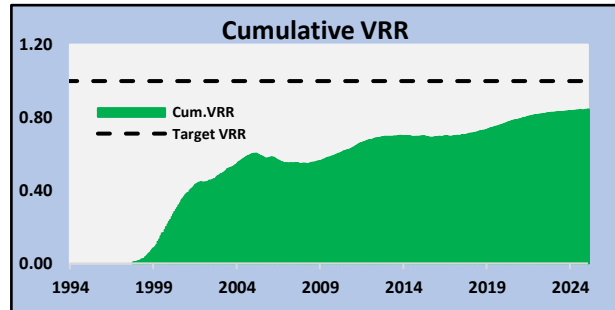
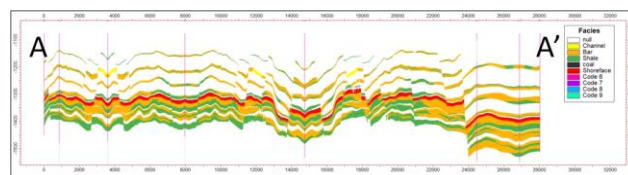
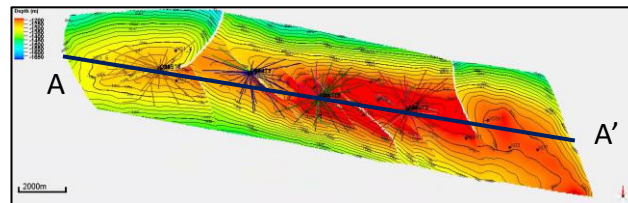


Cum. Oil Production (MMSTB)											
	IX	VIII	N1	N2	N3	S1	S2	S3	SE1	SE2	East
DL1/3	0	0	8.8	2.8	16.9	5.6	0.7	0	0	0	0
E1/2	2.1	6.4	1.2	1.2	2.1	11.2	4.2	0.4	0.1	0	0
E6/8	0	5.2	0	3.3	19.7	8.8	6.9	10.9	4.2	0	0
E10/14	25.2	30.6	8.6	6.1	17.5	20.2	25.9	5.9	5.1	1.5	0
E20/23	0	0	0.1	5.5	0.1	0	1.5	0.7	0.3	4.0	0
E32/34	0	0	3.1	0	12.7	0	5.0	0.9	1.2	1.7	0
E40/47	0	0	0	0	3.3	0	4.6	0	0	0.1	0
E51/55	0	0	0	0	0	0	0	0	0	0	0

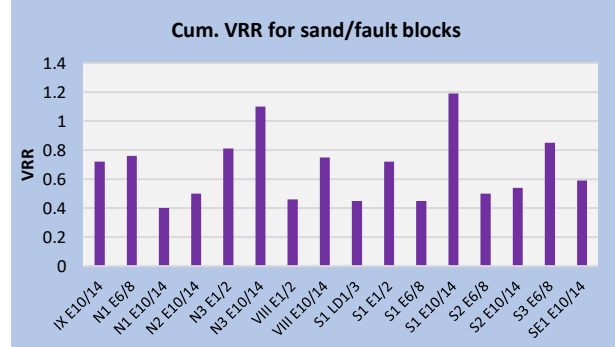
Cum. Water Injection (MMSTB)											
	IX	VIII	N1	N2	N3	S1	S2	S3	SE1	SE2	East
DL1/3	0	0	4.3	0	2.7	19.5	9.7	0	0	0	0
E1/2	3.3	9.9	0	0	2.7	19.5	9.7	0	0.5	0	0
E6/8	0.3	0.0	0	0	2.9	29.0	37.1	17.6	2.8	0	0
E10/14	52.5	58.7	23.0	6.9	45.4	77.5	79.1	5.1	0.5	0	0
E20/23	0	0	0	0	0	0	0	0	0	0	0
E32/34	0	0	0	0	0	0	0	0	0	0.2	0
E40/47	0	0	0	0	0	0	0	0	0	0	0
E51/55	0	0	0	0	0	0	0	0	0	0	0

Field Overview

Discovery Year/FOD	1981/Mar 1991
Reservoir Pressure (psi)	1600-1900
Reservoir Temp. (F)	200-210
Oil Gravity (API)	36-38
Major Oil Reservoirs	LD, E6-14
Minor Oil Reservoirs	F, E1-2, E20-50
Active WIs	23
Reservoir Thickness (ft)	10-66
NTG (%)	10-60
Porosity (%)	25-35
Sw (%)	20-70
Permeability (md)	70-180



- *Elongated elliptical structure* with dipping up to 10° (south) and 8° (north).
- *>20 major oil reservoirs*; three lateral compartments separated by three sealing faults (West, Main, East), each with multiple FBs.
- West/Main developed; East undeveloped due to limited economic viability.



- Low pressure in some of the target reservoirs/compartments. *Needs WI to compensate* pressure drop
- High pressure observed in some of the targets which *indicates over injection* in this reservoirs



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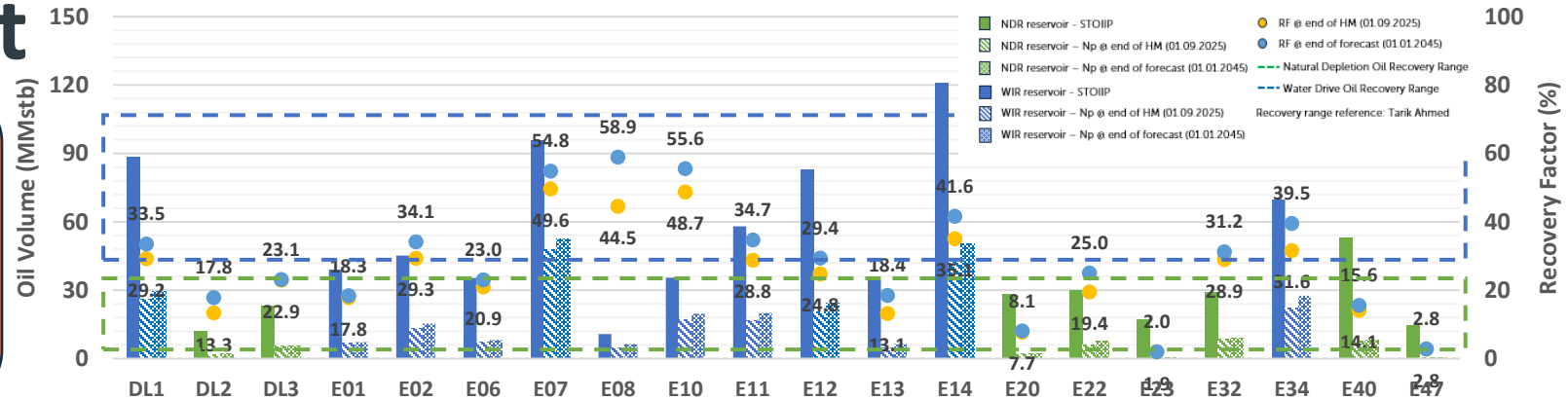


Reservoir Performance Benchmarking for NFA case (Dynamic Modelling)

Analytical Assessment

Summary of findings:

- Analytical assessment **flags wells needing adjustment** (over/under injecting/optimized).
- Further **optimization is required across the well set**.
- Maintain injection while tuning individual volumes.
- Injection optimization is linked to reservoir-wise recovery contribution.



Summary of Findings

Res.	No Inj., MMstb	Low Inj., MMstb	Current Inj., MMstb	Potential optimized MMstb	WI situation	Remarks	Way Forward	Active WI wells ID	Current WI rate, bwpd
N3-E1/2	0.13	0.13	0.18	0.18	Optimized	WI optimized. Resume injection since Mar 2023 & still under monitoring		1	3300
S1-E10/14	0.95	1.12	1.45	1.45	Optimized	Increasing current injection rate will not improve oil recovery due to water cycling.	To be validated with welltest data	2, 3, 4	7300, 3400, 2400
S2-E6/8	0.92	1.00	1.14	1.14	Optimized	WI optimized (S2 and S3 are sharing the same injector)		4, 5	5900, 7700
S2-E10/14	0.85	0.96	1.12	1.12	Optimized	WI optimized (S2 and S3 are sharing the same injector)		6, 7	3400, 7700
S3-E6/8	0.37	0.43	0.52	0.52	Optimized	WI optimized (S2 and S3 are sharing the same injector)		8	2800
VIII-E1/2	0.41	0.46	0.54	0.54	Optimized	WI optimized		9	1500
N3-E10/14	0.34	0.45	0.57	0.77	Under Injecting	To ramp-up injection by 1-2k bwpd	Study - part of the Redev 4/6	10	2800
S1-E1/2	0.77	0.91	1.14	1.28	Under Injecting	To ramp-up injection by 1-2k bwpd	To be validated with welltest data	11	4300
S1-E6/8	1.35	1.87	2.67	3.00	Under Injecting	To ramp up injection by 1-2k bwpd.	To be validated with welltest data	12	1700
IX-E10/14	0.88	1.15	1.82	2.52	Under injecting	To ramp up injection by 2-3k bwpd.	To ramp-up injection from 8k to 11k bwpd.	13, 14, 15, 16	500, 1800, 3200, 2800
N1-E10/14	0.78	0.85	0.88	0.88	Over injection	The volume of injection should be around 3000 instead of 5600 bwpd	To reduce WI from 5600 to 3000 bwpd	17	5600
VIII-E10/14	1.25	1.70	2.41	3.28	Over / under injecting	E10/11 under injecting. E12/13 over injecting	To close the intervals exposed to E12/13	18,19,20,21,22	1500, 3700, 1500, 4400, 6400
Total	8.99	11.02	14.44	16.68					



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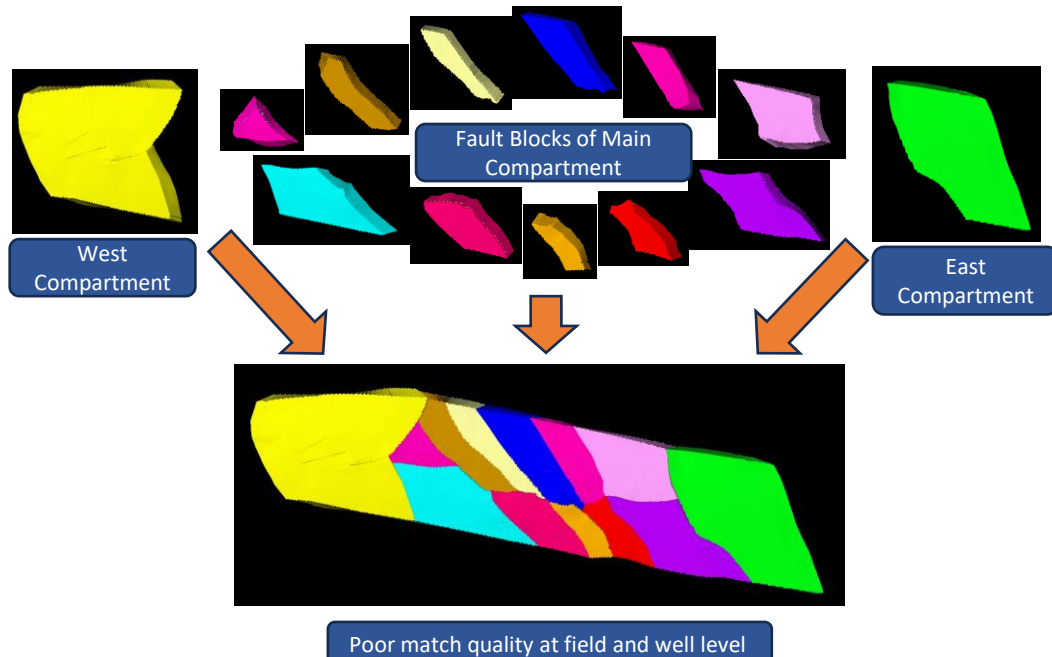
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Simulation Results



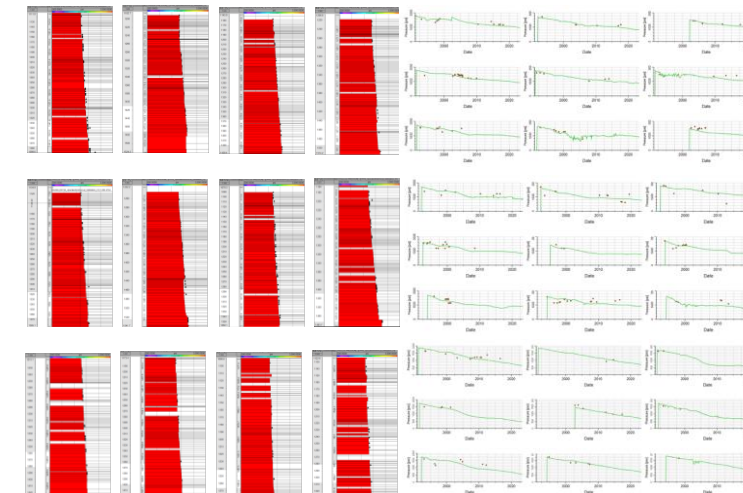
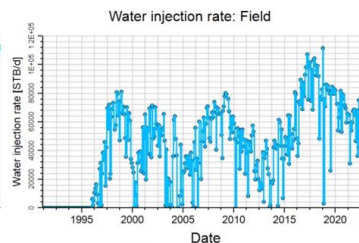
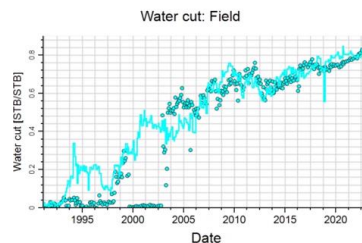
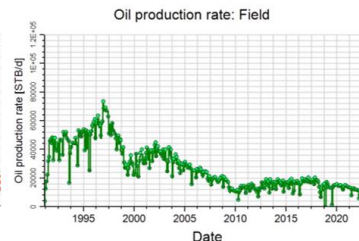
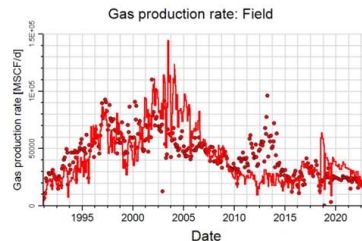
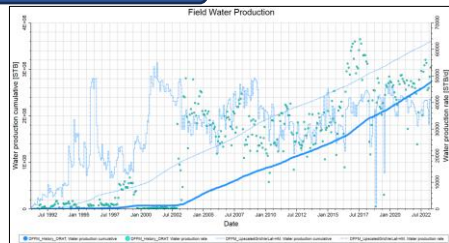
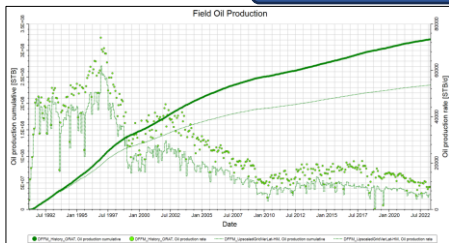
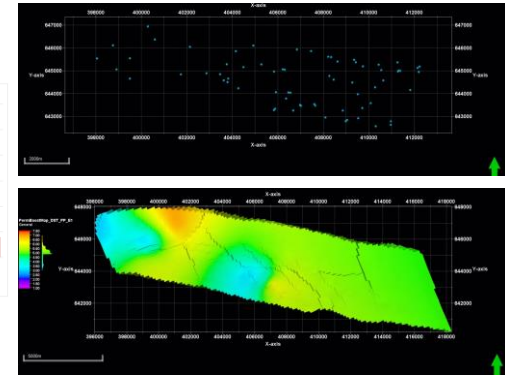
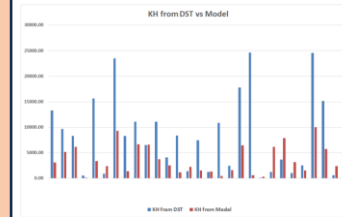
Building on analytical screening, team **developed a unified full-field model** to capture inter-fault block communication and **quantify shut-in and injection impacts** at field scale.

- **Previous models were sector models** with no-flow boundary assumptions; however, analytical **evidence suggests cross-fault pressure communication**.
- **A unified full-field model was constructed**, integrating all compartments and fault blocks **to capture production/injection-interferences** within the field.
- Performed **field and well-level history matching** using a **calibrated permeability map**, adjusted with permeability values derived from **DST data**.



Model Calibration:

- Compare model kh DST-derived kh and compute $kh(DST)/kh(Model)$ ratio
- Generate a KH-multiplier 2D map using isochore interpolation and **convert it to 3D grid property**
- Generate new permeability map using KH multiplier
- **Adjustment of fault** transmissibility to capture FB communications in Main compartment
- Adjustment of Saturation Function Tables (SFT) **end points and Corey exponents** to improve matching of ratio quantities



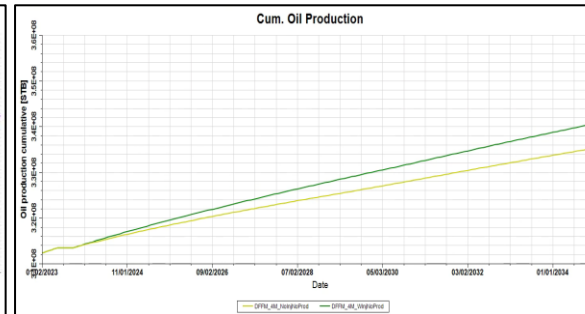
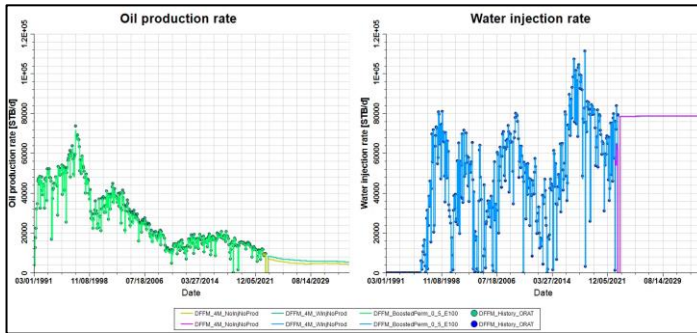


Simulation Results (Con't)

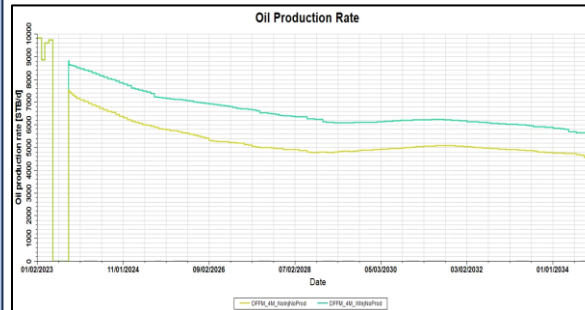
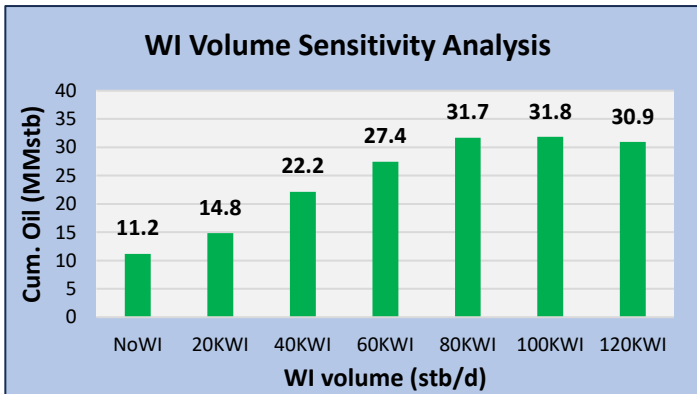


Below scenarios were investigated for analysis:

- Scenario 1: Four months production/injection shut-in and then resume production/injection as per previous scheme
- Scenario 2: Keep WI on during production shut-in period and try to optimise WI rate per well/reservoir based on production/injection performance analysis
- Sensitivity analysis to optimize injection water volume



More than 5 MMstb incremental oil for scenario 2



Field oil production rate, Scenario 1 vs 2

Summary of optimization applied for individual wells/FBs						
Well ID	FB	Res.	Current WI rate (STBD)	Proposed Res.	Proposed WI rate (STBD)	Remark
3	S2	E12/14	3400	E12/14	3400	
4	S2	E07	5900	E07	5900	
23	SE2a	E34A	1000	E34A	1000	
5,7	S2	E08/10/11/12/14	7700	E07/10/11/12/14	7700	
1	N3d	DL1, E01	3300	DL1, E01	3300	
8	S2	E14	2800	E14	2800	
10	S1c	E06/07/10/11	2800	E06/07/10/11	4000	Injection rate increased
17	N1	DL1, E10/11/12/13	5600	DL1, E10/11/12/13	3000	Injection rate decreased to control high WCUT
2	S1c	E06/07/10/11/12/13	7300	E06/07/10/11/12/13	7300	
6	S1b	E06/07/08/11	3400	E06/07/08/11	3400	
11	S1b	DL1, E02	4300	DL1, E02	5300	Injection rate increased
12	S1c	E06/07	1700	E06/07	2800	Injection rate increased
4	S1a	E11/12/14	2400	E11/12/14	2400	
18	VIII	E11/12/13/14	1500	E11/14	1500	E12/13 intervals are closed to prevent injection into this reservoirs
9	VIII	E01/02	1500	E01/02	1500	
19	VIII	E10/11/12/14	3700	E10/11/14	3700	E12/13 intervals are closed to prevent injection into this reservoirs
13	IX	E12/13	500	E12/13	2000	Injection rate increased
20	VIII	E11/12/13/14	1500	E11/14	1500	E12/13 intervals are closed to prevent injection into this reservoirs
21	VIII	E11/12	4400	E11	4400	E12/13 intervals are closed to prevent injection into this reservoirs
22	VIII	E10/11/12/13/14	6400	E10/11/14	6400	E12/13 intervals are closed to prevent injection into this reservoirs
14	IX	E12/13	1800	E12/13	2000	Injection rate increased
15	IX	E11	3200	E11	3500	Injection rate increased
16	IX	E01/11/12/13/14	2800	E01/11/12/13/14	3800	Injection rate increased

Note: wells with more/less WI compare with observed data and target reservoir changes are marked in Blue.

- Sensitivity analysis indicates that **80K volume of WI is the optimum** as oil recovery does not significantly increase beyond it.
- An additional sensitivity case tested shutting in injection to E12/13; the no-injection case delivered a marginally higher field oil rate (~150 STB/D), confirming over-injection in this interval.



Conclusions and Recommendations

- Increasing WI volume ***does not always improve oil recovery***. Excessive injection can ***channel through high-permeability streaks*** or thief zones, reducing sweep efficiency, accelerating water breakthrough and driving up WCUT in nearby producers.
- An ***effective waterflooding strategy*** requires establishing appropriate injector-producer connections, managing reservoir pressure distribution and optimizing injection volumes for each well or compartment to maximize sweep efficiency and recovery.
- Considering that the current VRR is below the target defined in the RMP, it is ***recommended to maintain WI*** throughout the 4-month production shut-in period. Continued injection will support ***reservoir pressure buildup***, which is expected to ***enhance well productivity*** and overall field performance when production resumes. At the same time, optimizing injection volumes for specific wells is necessary to improve ***sweep efficiency*** and avoid adverse impacts on nearby oil producers.



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Acknowledgement / Thank You / Questions

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All personnel who contributed to the data compilation

