Large Scale CO_2 Flood Begins Along Texas Gulf Coast

(Technical Challenges in Re-Activating an Old Oil Field)

Darrell Davis, Mark Scott,
Adam Robinson, Kris Roberson, Bill Freeman
Denbury Resources Inc.

Presented at the 17th Annual CO_2 Flooding Conference

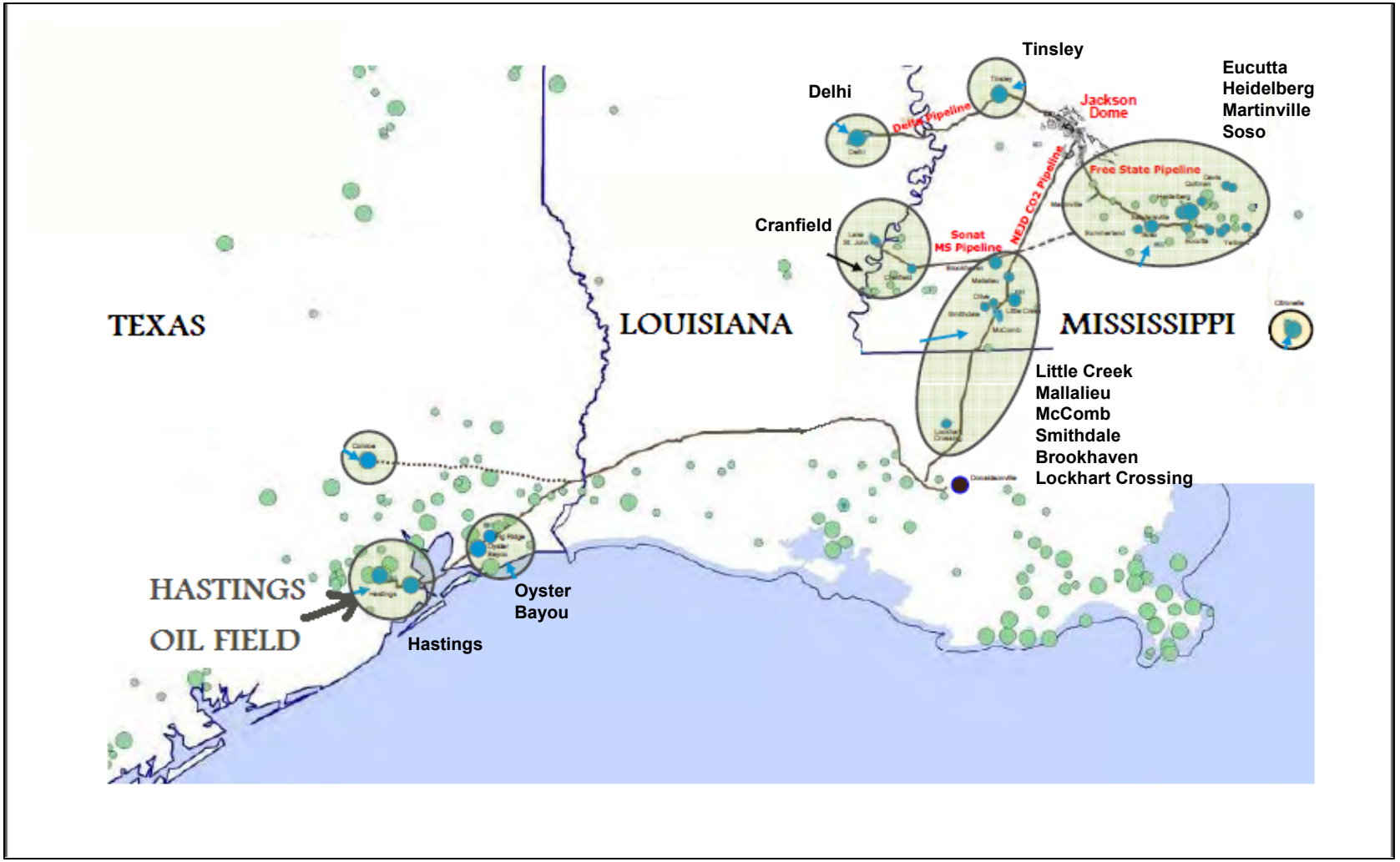
December 8-9, 2011

Midland, Texas

Denbury

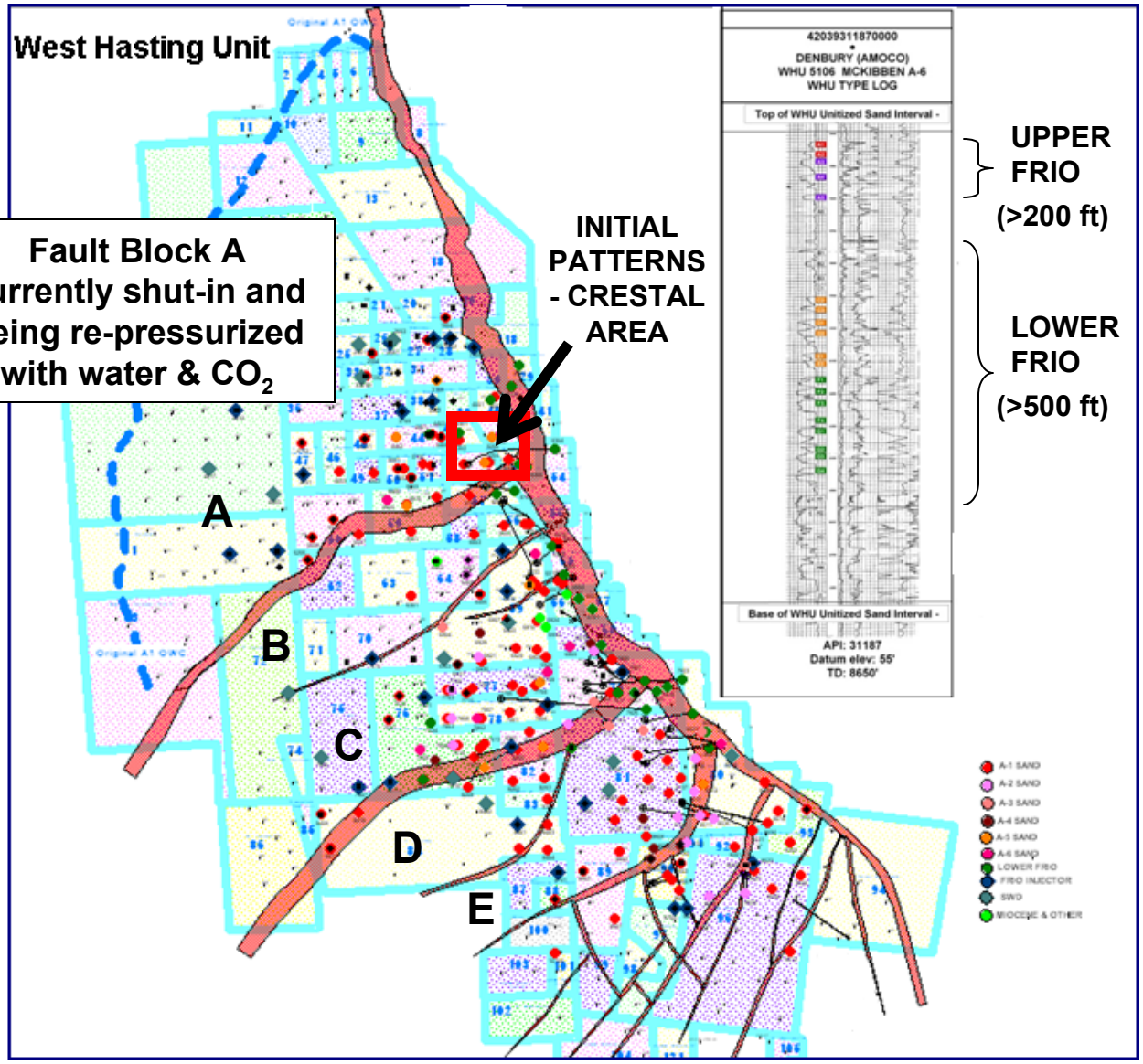
CO_2

CO_2 Supply & Oil Fields



323 Mile “Green” Pipeline

West Hastings Unit



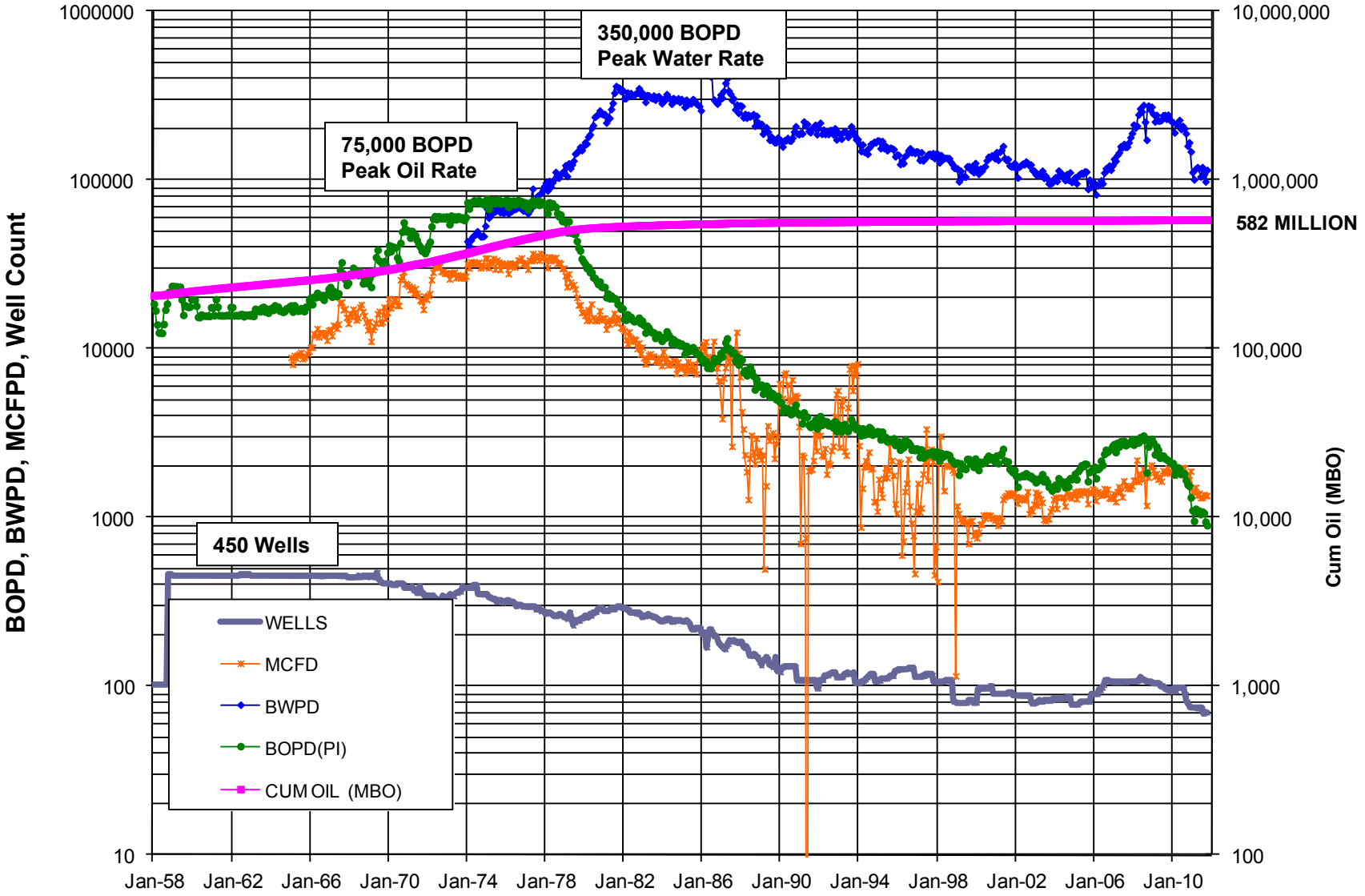
West Hastings Unit

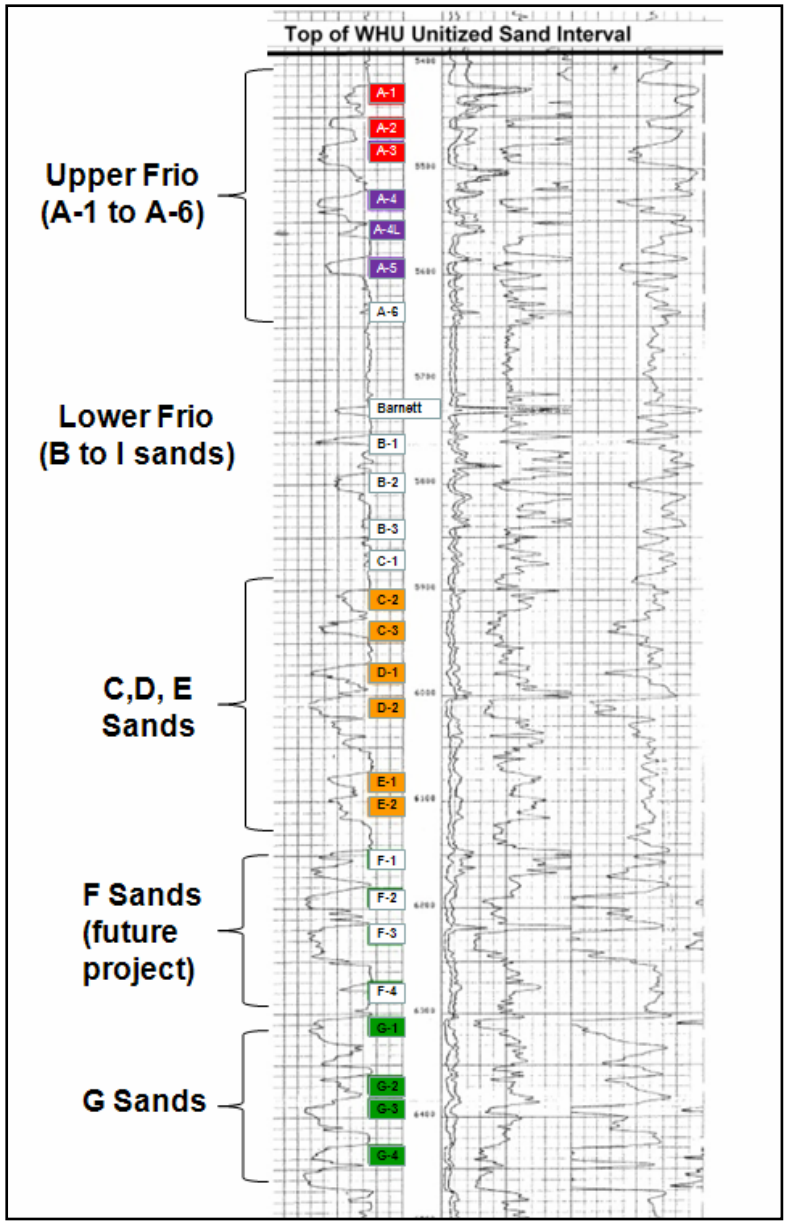
- Discovered by Stanolind Oil (Amoco) in 1934
- Frio sandstone reservoir at 6000 feet
- 30-33% porosity, 500-4000 md permeability
- 582 million barrels oil produced
- 2.7 billion barrels water production
- 10 acre development during primary
- 70% displacement efficiency with water
- 99.2% watercut (900 BOPD, 115,000 BWPD)

CO_2 Injection Initiated in Crestal Area

- Highest remaining oil saturation
- Largest concentration of remaining wellbores (all wells had to be addressed)
- Small original gas cap has been saturated above residual oil saturation and is not a concern for encountering low oil saturation
- Updip bounding faults allow for improved re-pressurization (no flow boundary)

West Hastings Unit Production History

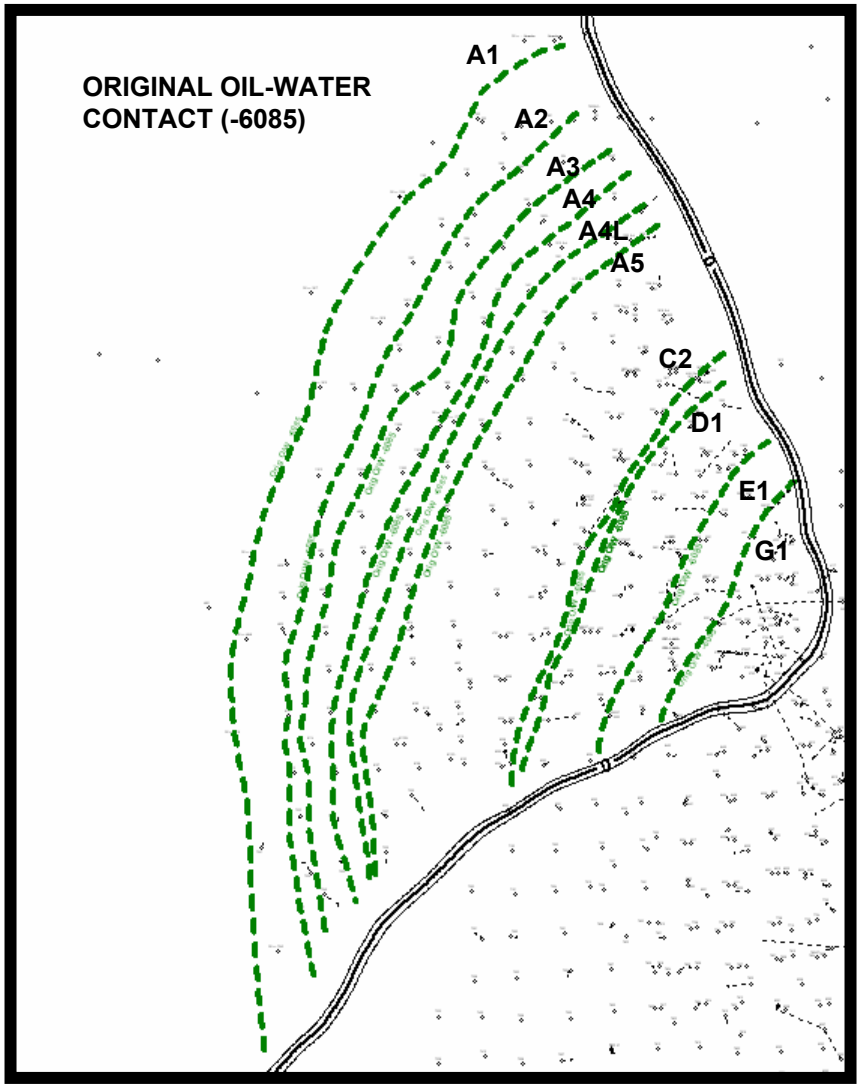


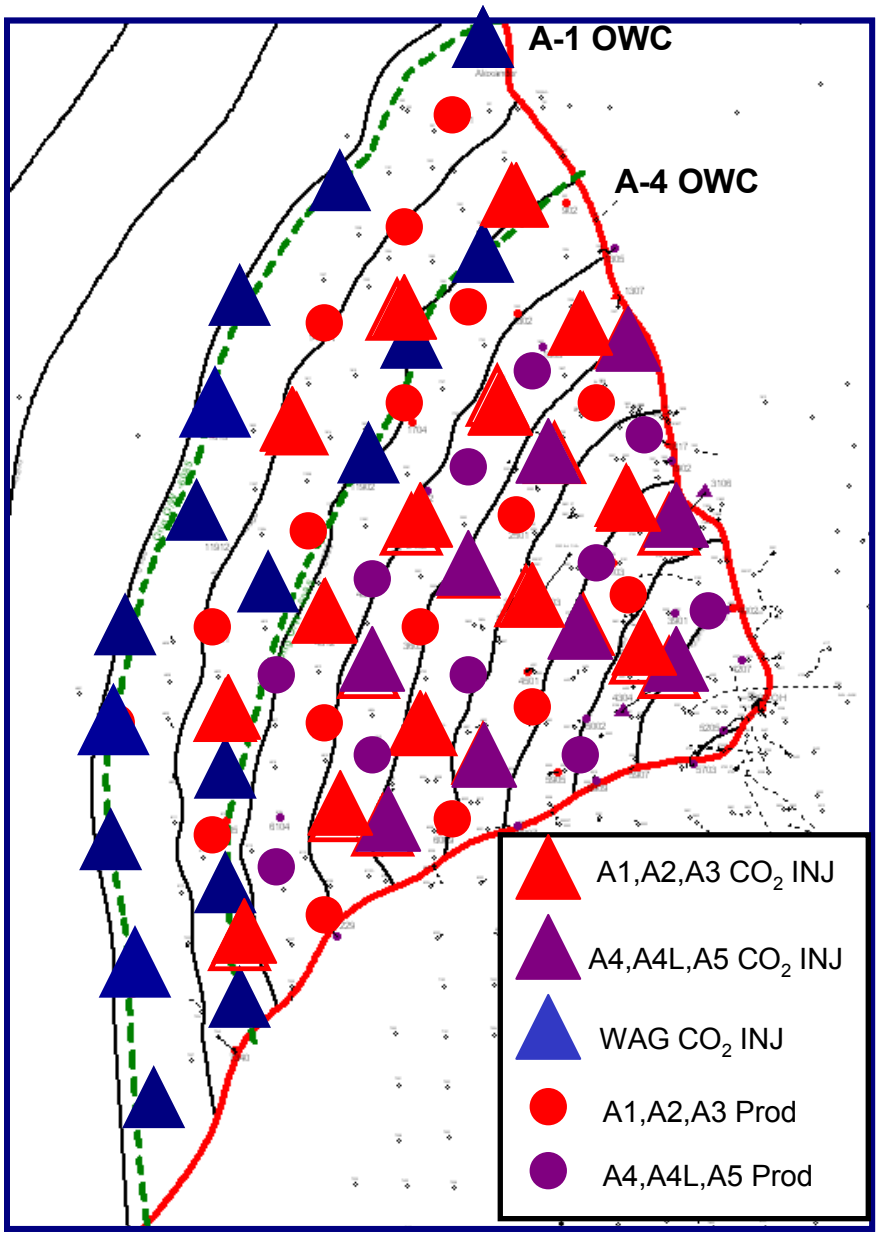


Multiple Sands to Consider

- 37 oil productive sands
- 15 fault blocks
- Approximately 1 billion barrels original oil-in-place
- Top 6 sands (Upper Frio A sands) contain 65% OOIP
- In Fault Block A, 34 Upper Frio and 4 Lower Frio patterns used. This includes F sand future development.
- 80 Acre 5-spot patterns utilized in Upper Frio A1-A5 sands
- Upper Frio sands are split between two different patterns (A1,A2,A3 and A4,A4L,A5) to improve areal and vertical sweep
- Limited perforations are used on injectors so that CO_2 will sweep all sands uniformly (each perforation capable of ~1 MMCF/D CO_2 injection, therefore 15-20 perforations are utilized in each well)

Original Oil-Water Contact – same for all sands (-6085 ft)



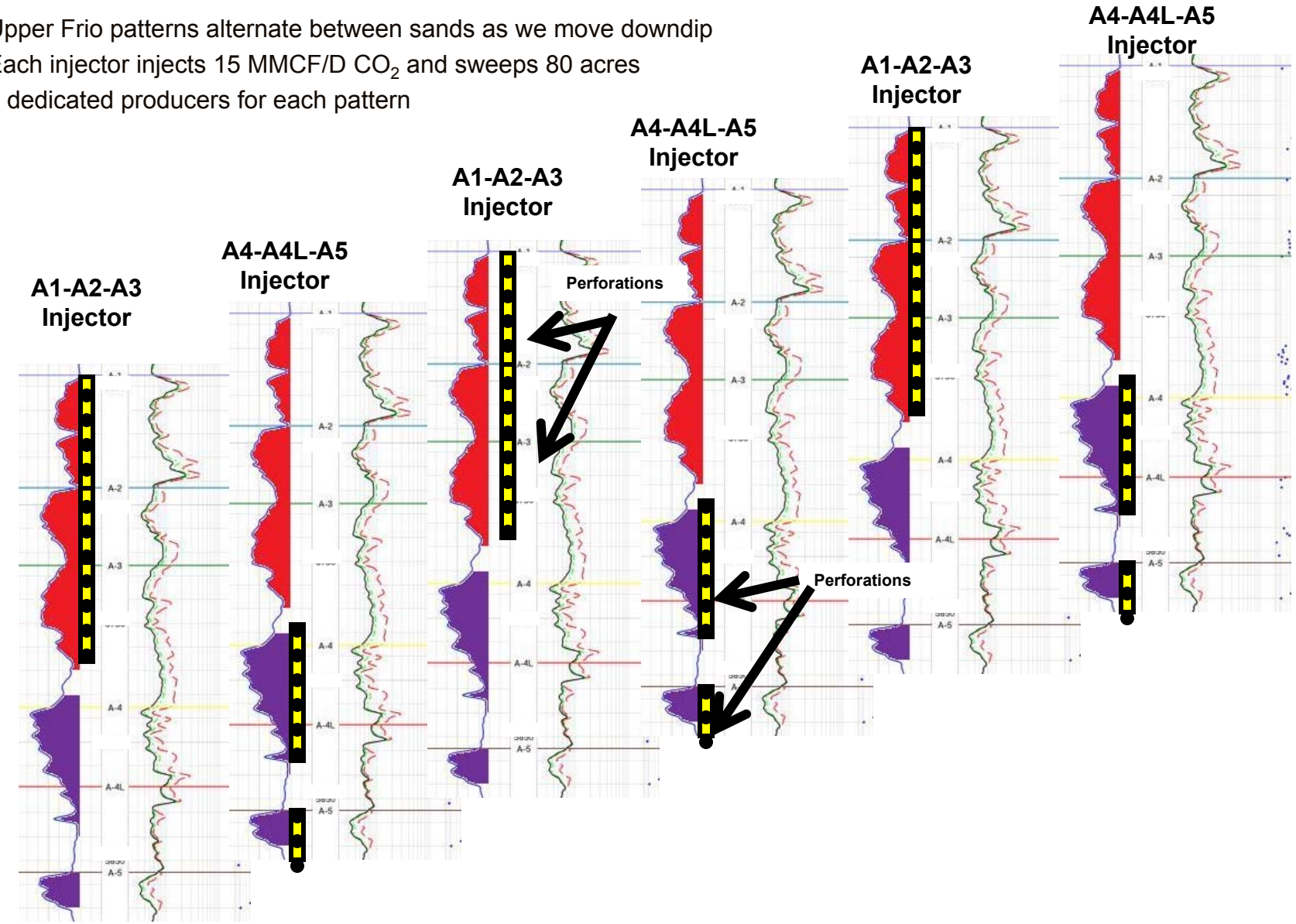


Project Design

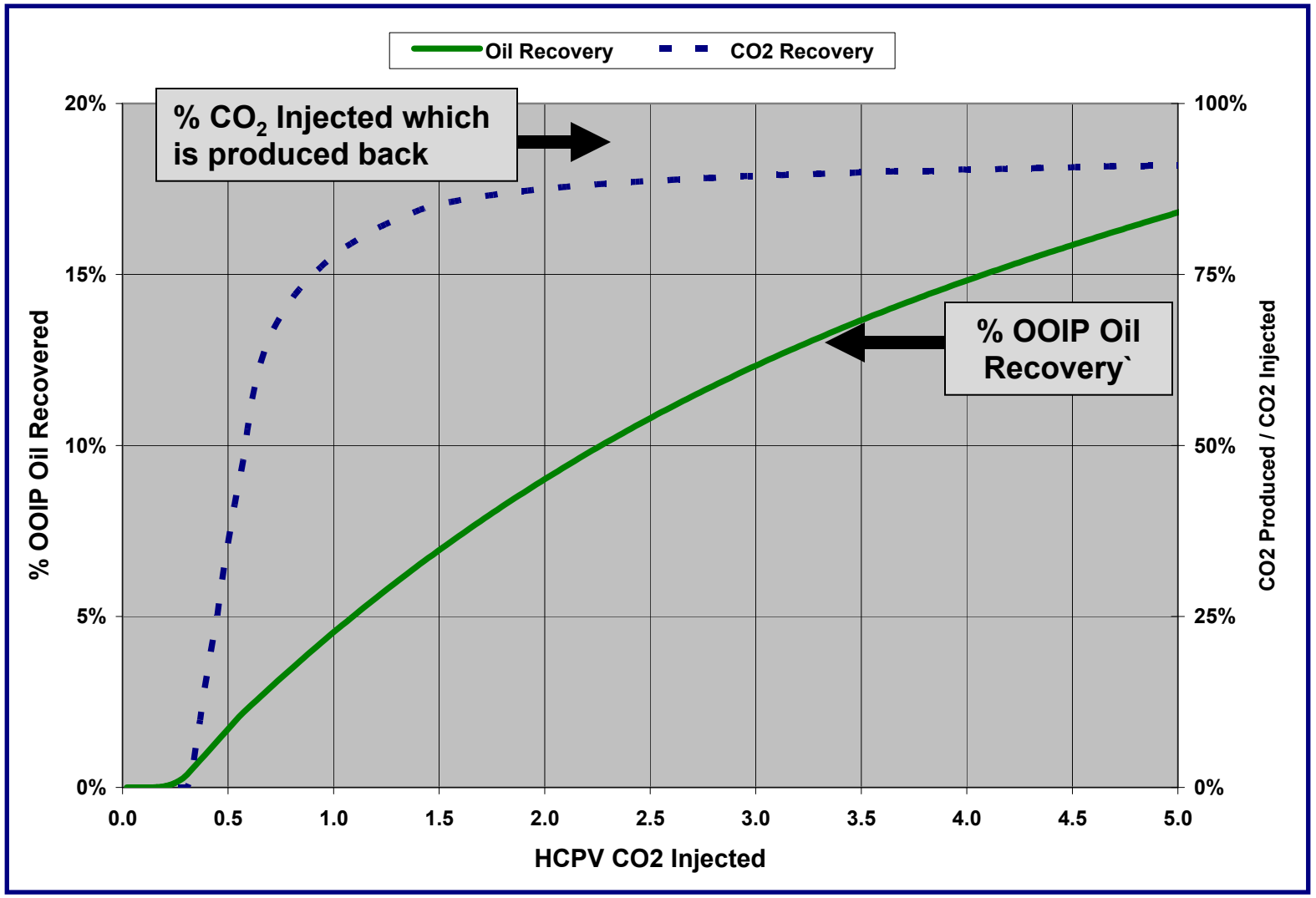
- Continuous (100%) CO_2 injection in main oil column.
- Injectors placed at original oil-water contact will initially be water only and then WAG.
- Injectors are staggered between A1,A2,A3 (red) pattern and A4,A4L,A5 (purple) pattern.

Design Basis to Improve Vertical Sweep

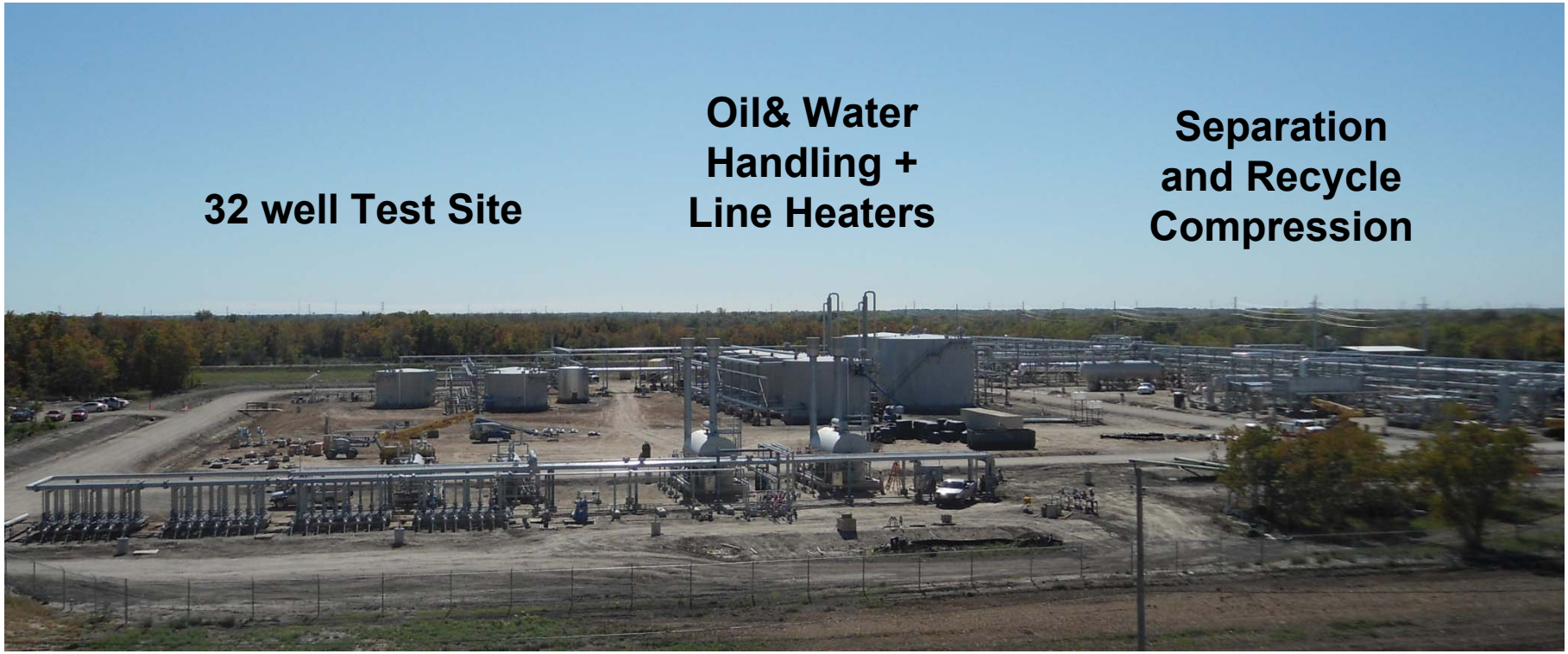
- Upper Frio patterns alternate between sands as we move downdip
- Each injector injects 15 MMCF/D CO_2 and sweeps 80 acres
- 4 dedicated producers for each pattern



Oil and CO_2 Production Forecasting



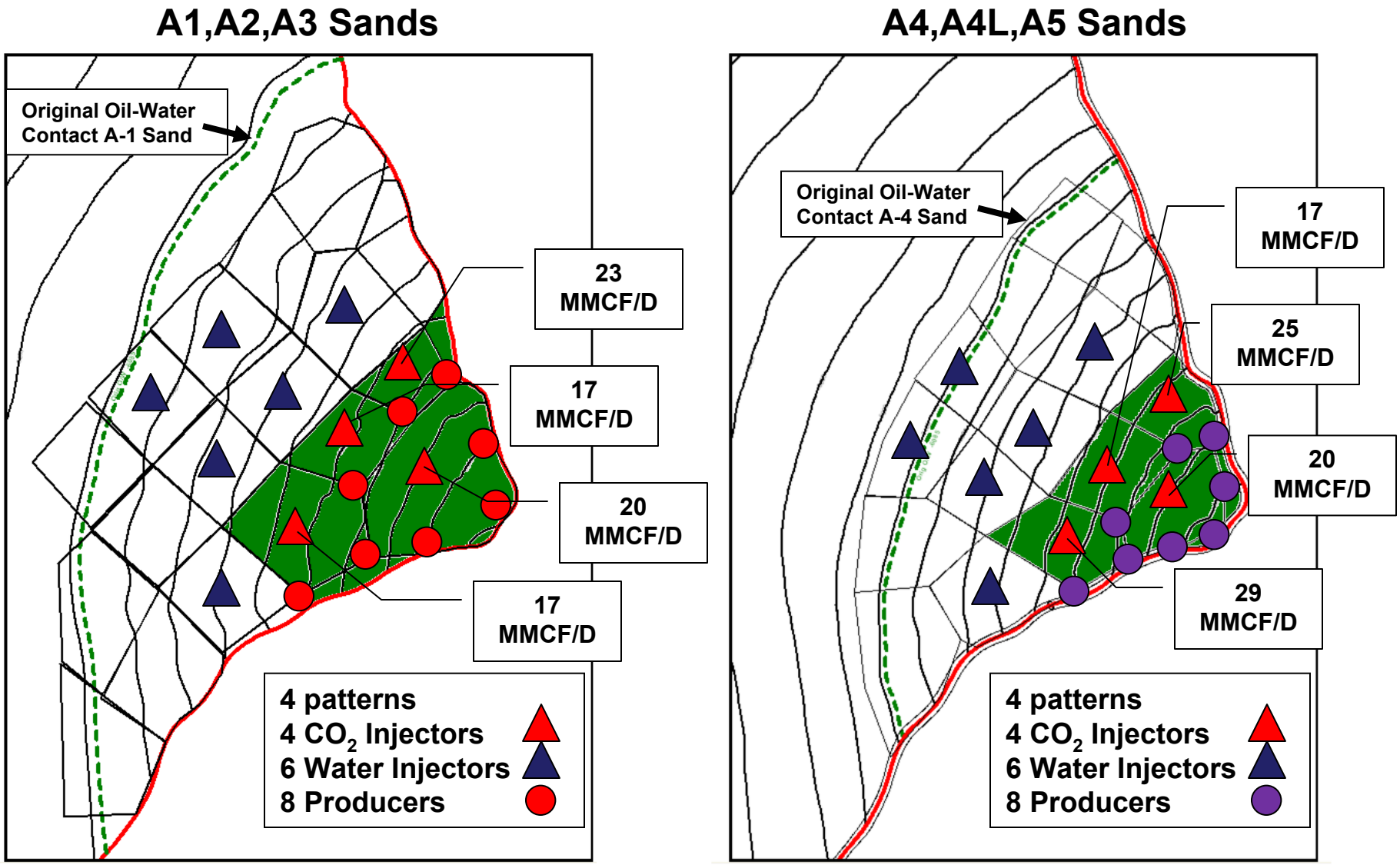
Hastings 550 MMCF/D CO_2 Facilities Site



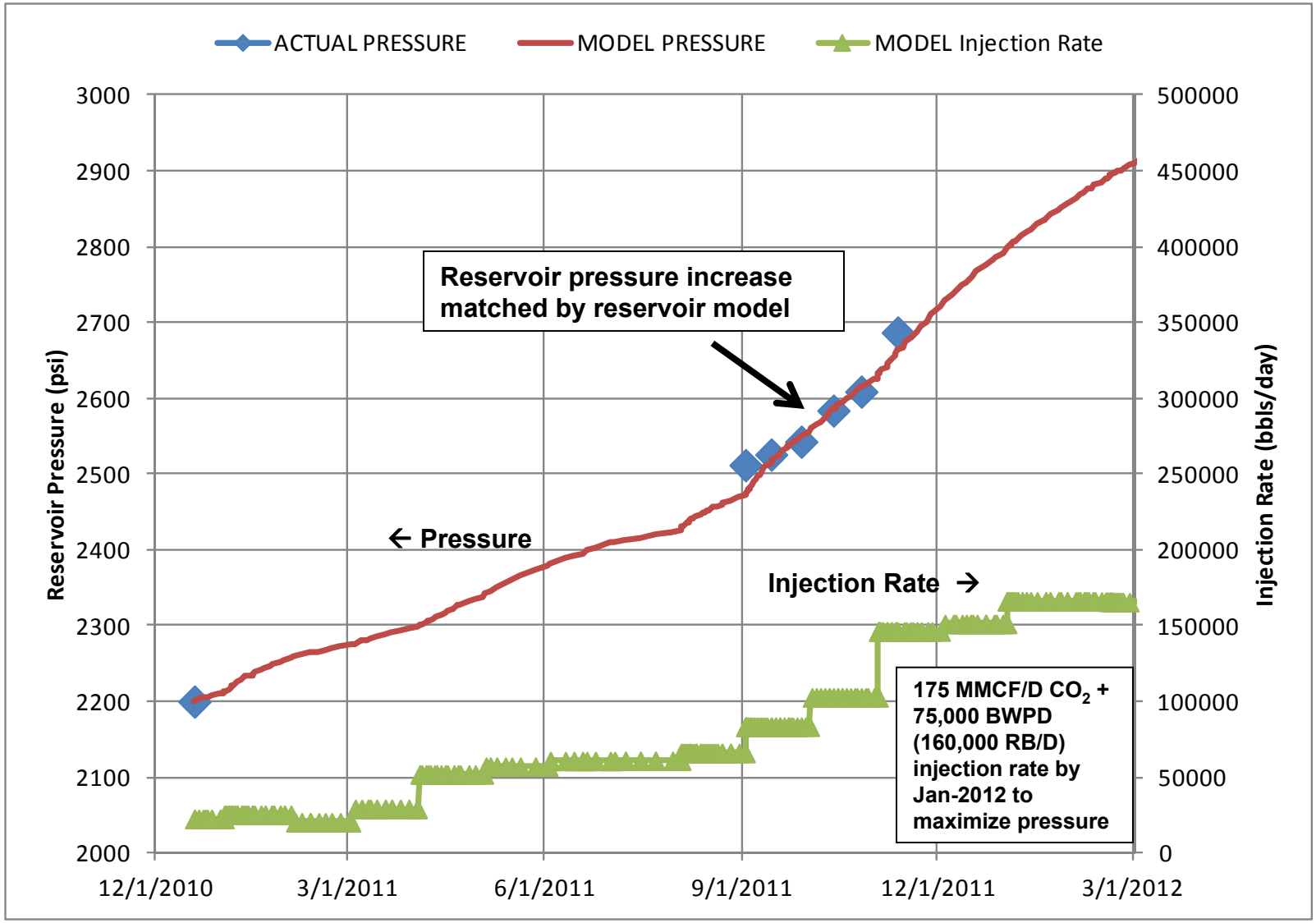
Planned Start-up January, 2012

Line Heaters at Test Site

Year-end 2011 (~175 MMCF/D CO_2 Injection)



Reservoir Re-pressurization

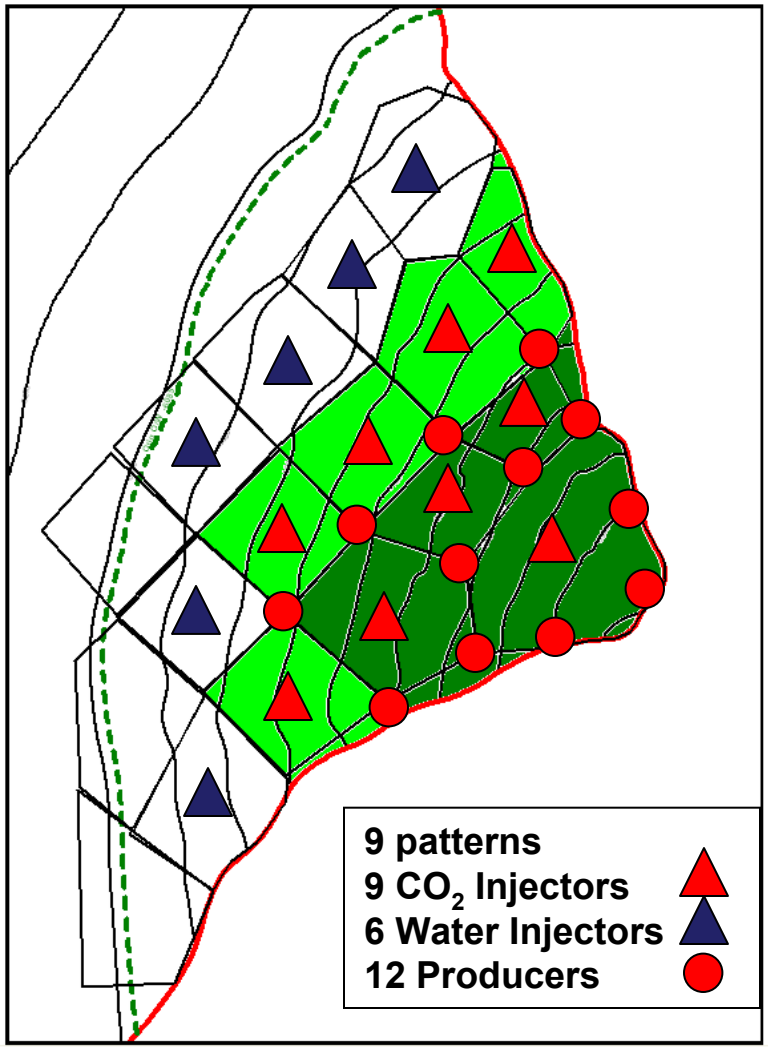


Key Learnings – Reservoir Re-pressurization

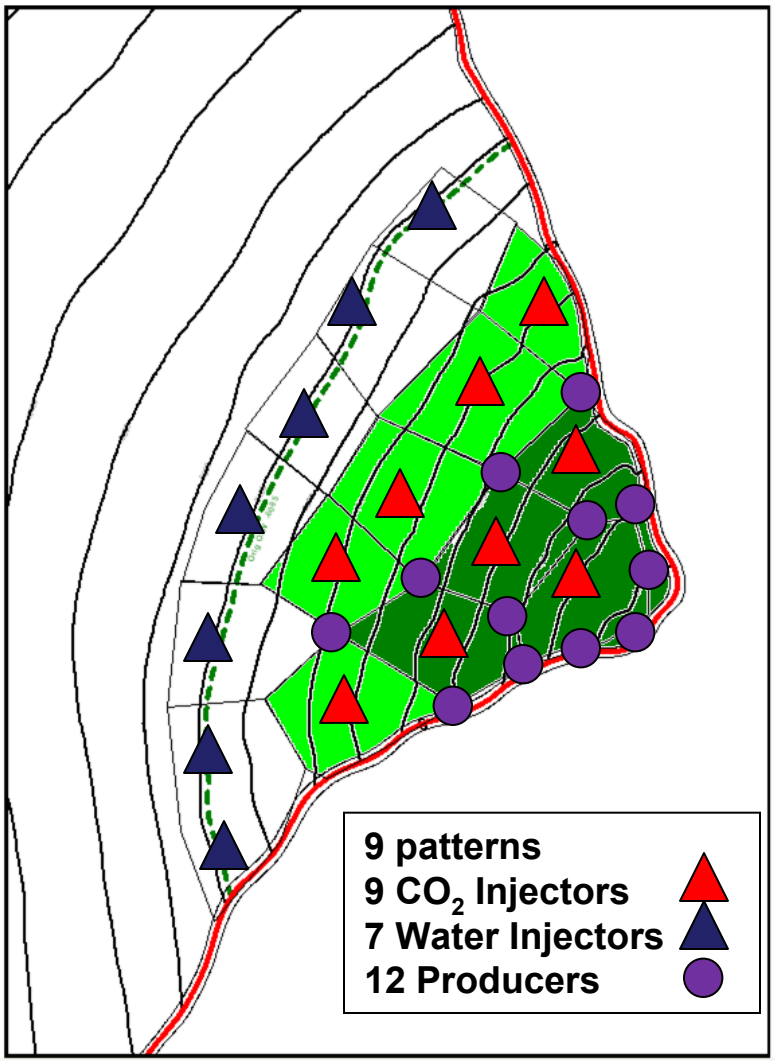
- Rock compressibility can be on the order of 30E-6 psi^{-1} (much higher than Hall plot)
- High permeability allows for pressure to leak-off faster (increased injection rate and volume required)
- By raising reservoir pressure above aquifer pressure, downdip water injection is required to minimize losses of CO_2 into the aquifer
- Large make-up water supplies are necessary
- Portions of the field must be shut-in to allow for re-pressurization (impacts production)

Year-end 2012 (~270 MMCF/D CO_2 Injection)

A1,A2,A3 Sands

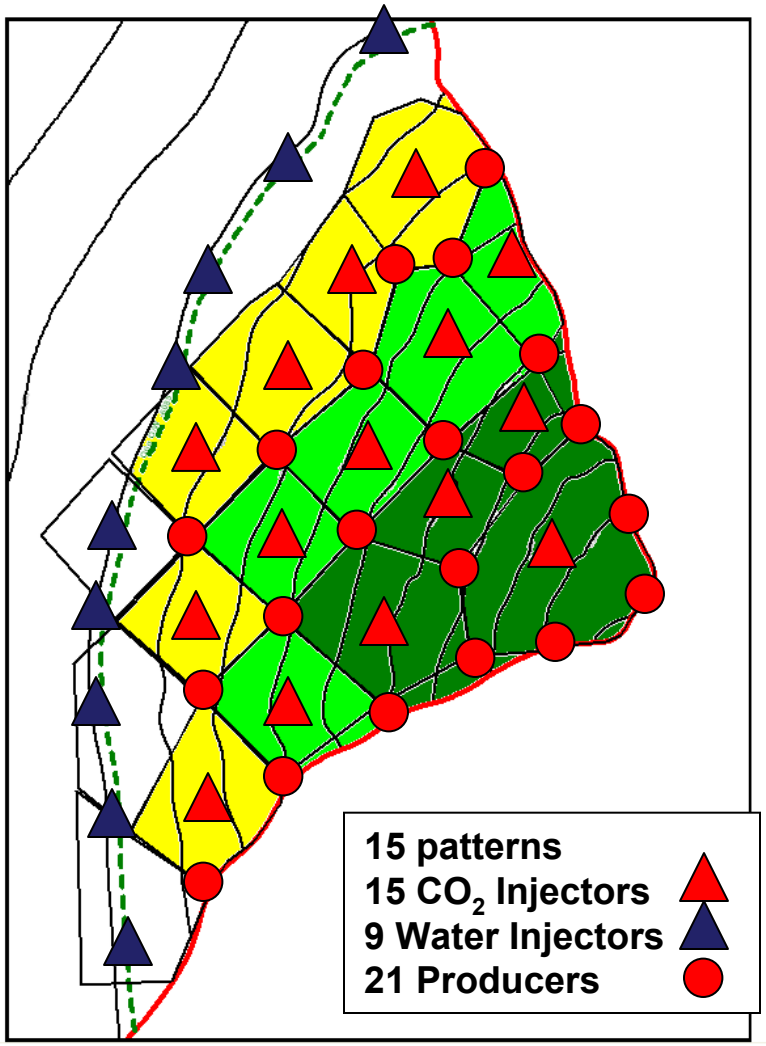


A4,A4L,A5 Sands

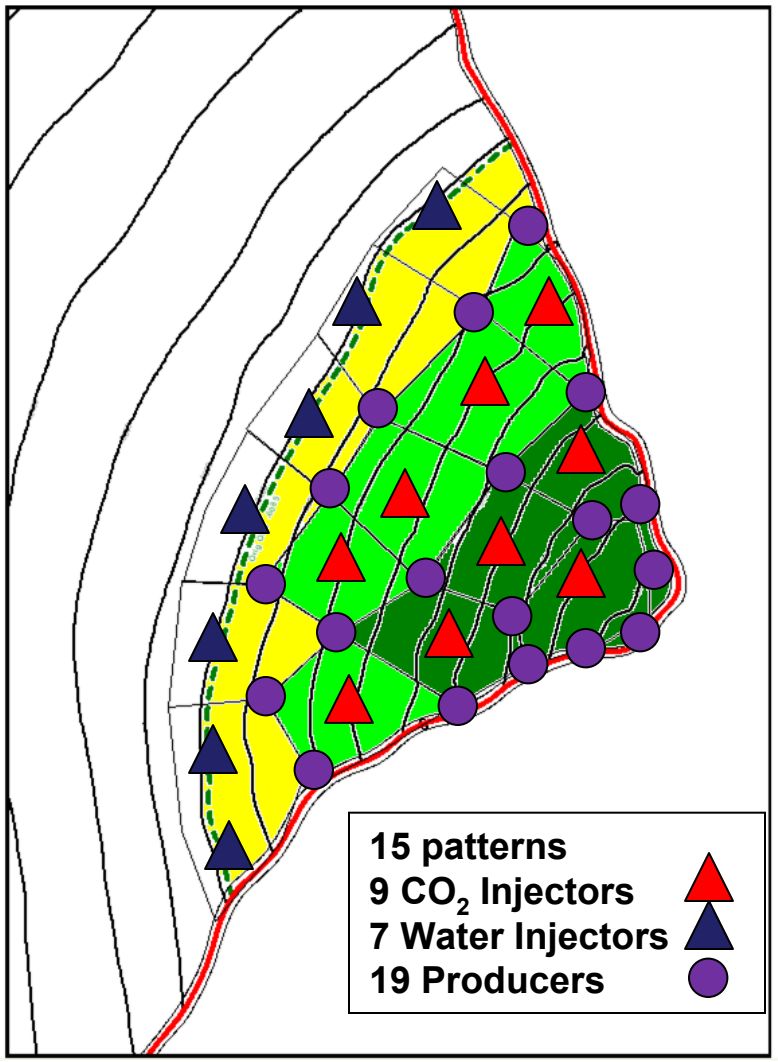


Year-end 2013 (~360 MMCF/D CO_2 Injection)

A1,A2,A3 Sands

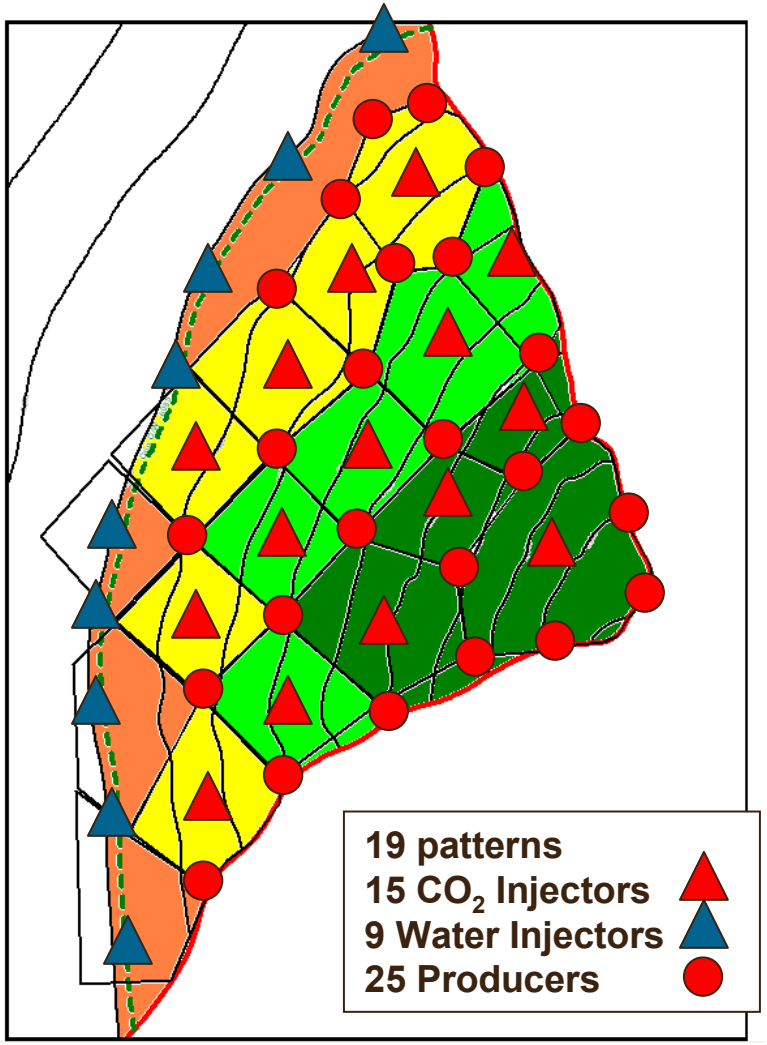


A4,A4L,A5 Sands

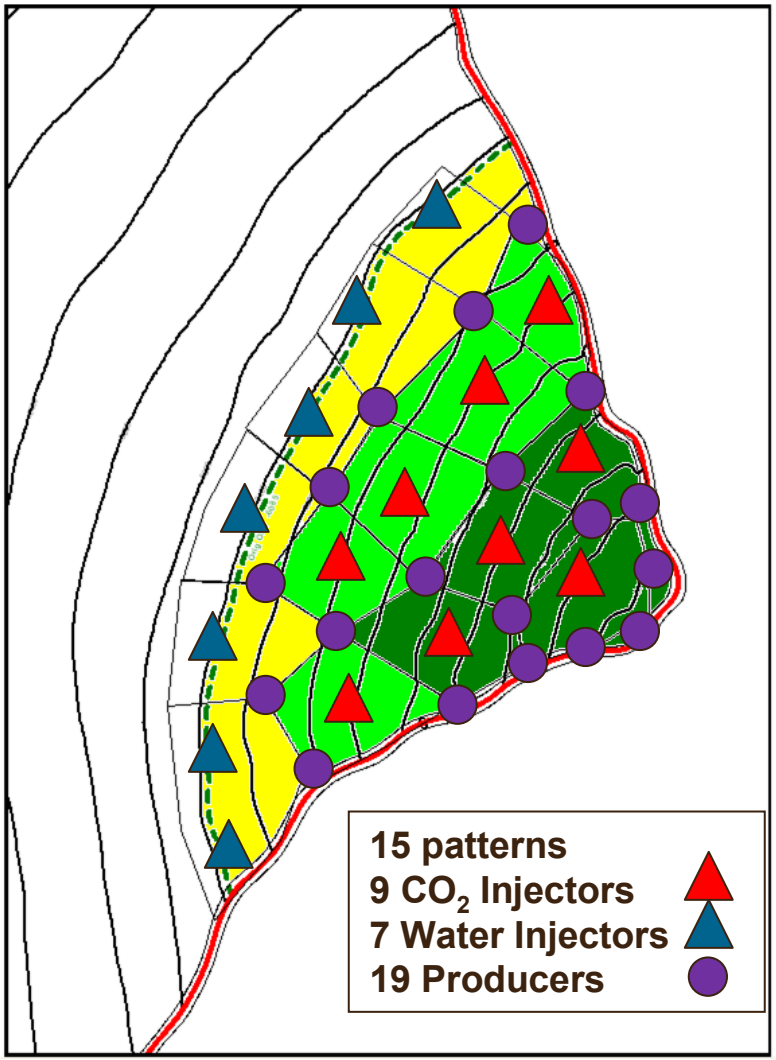


Year-end 2014 (~480 MMCF/D CO_2 Injection)

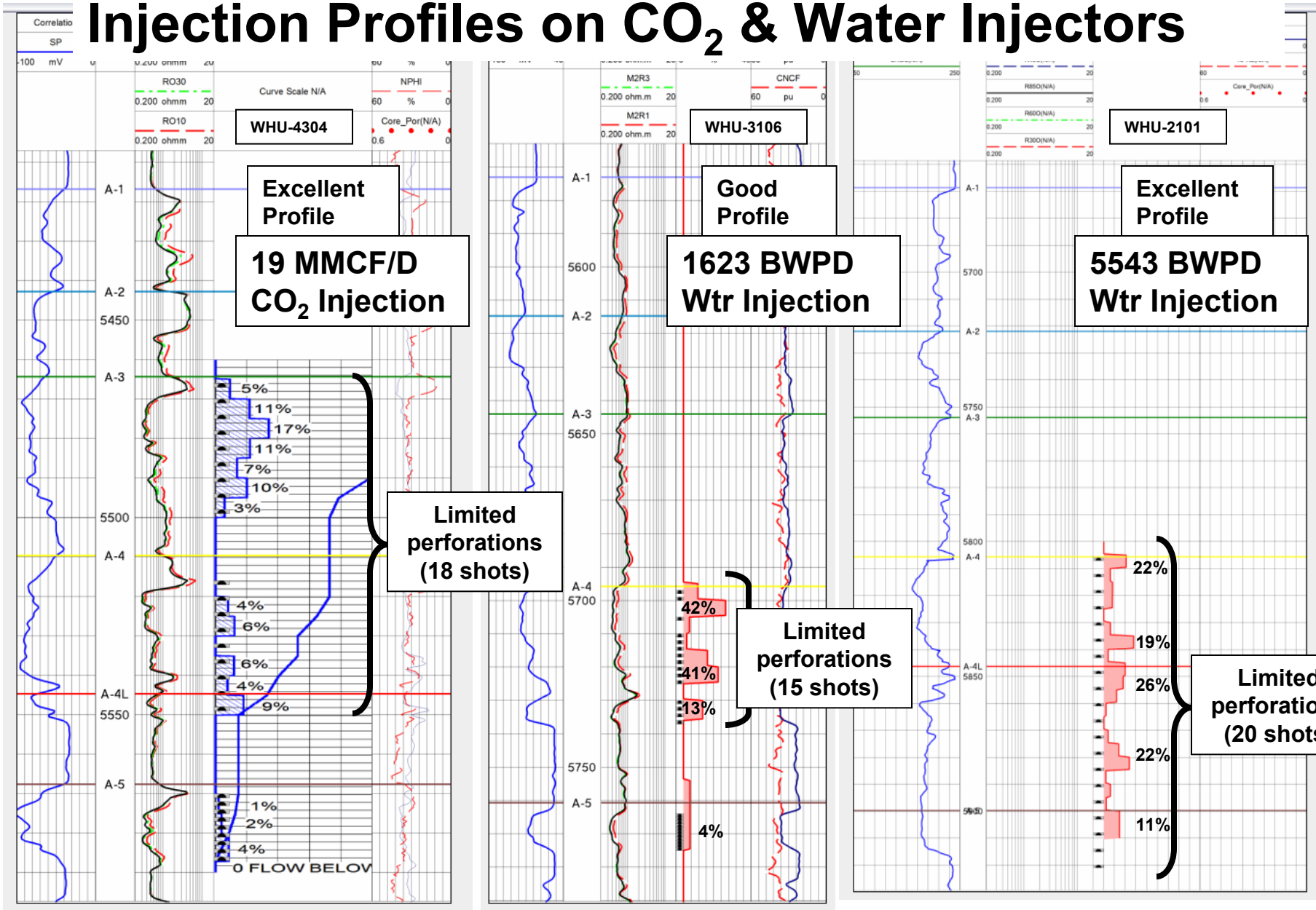
A1,A2,A3 Sands



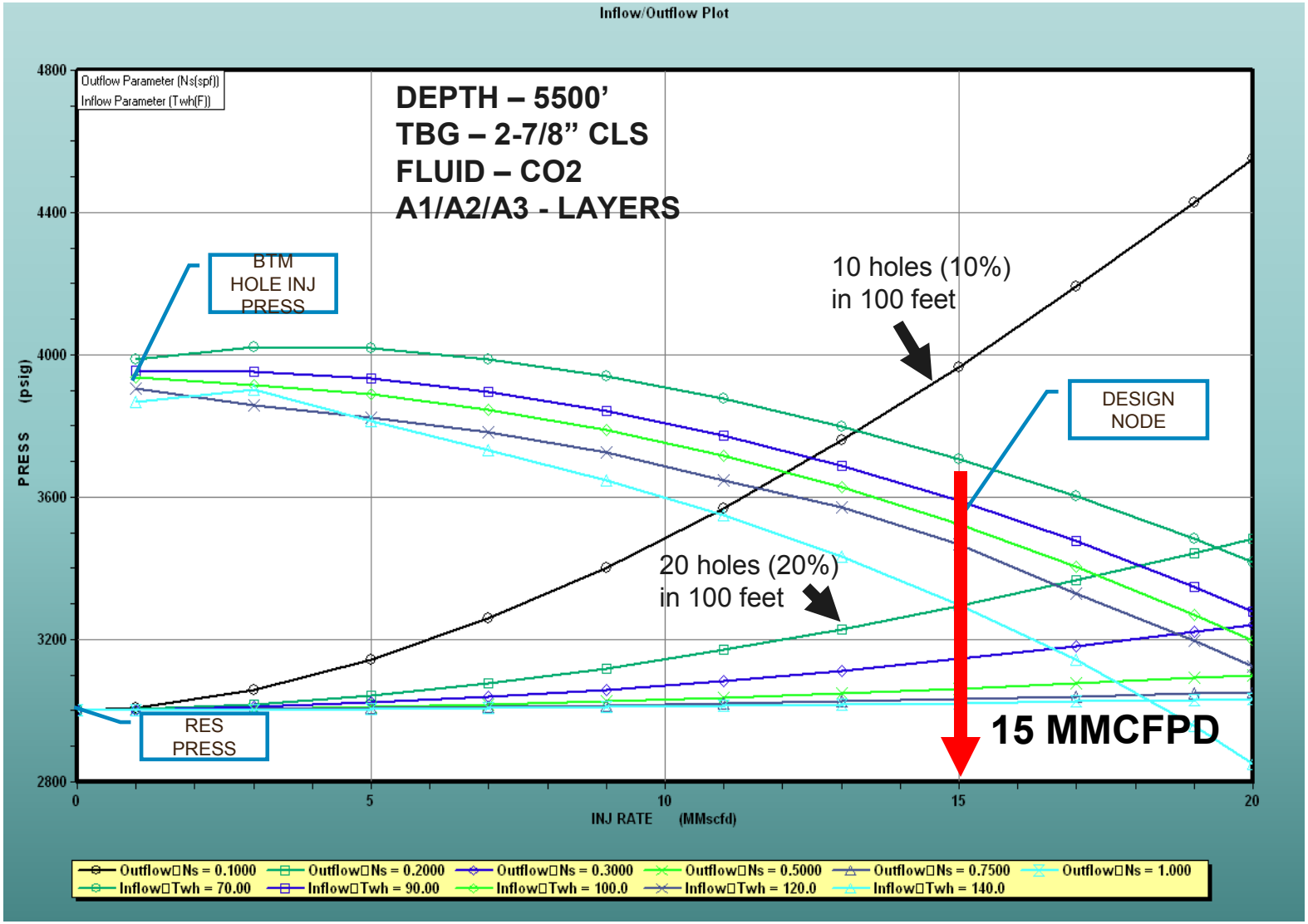
A4,A4L,A5 Sands



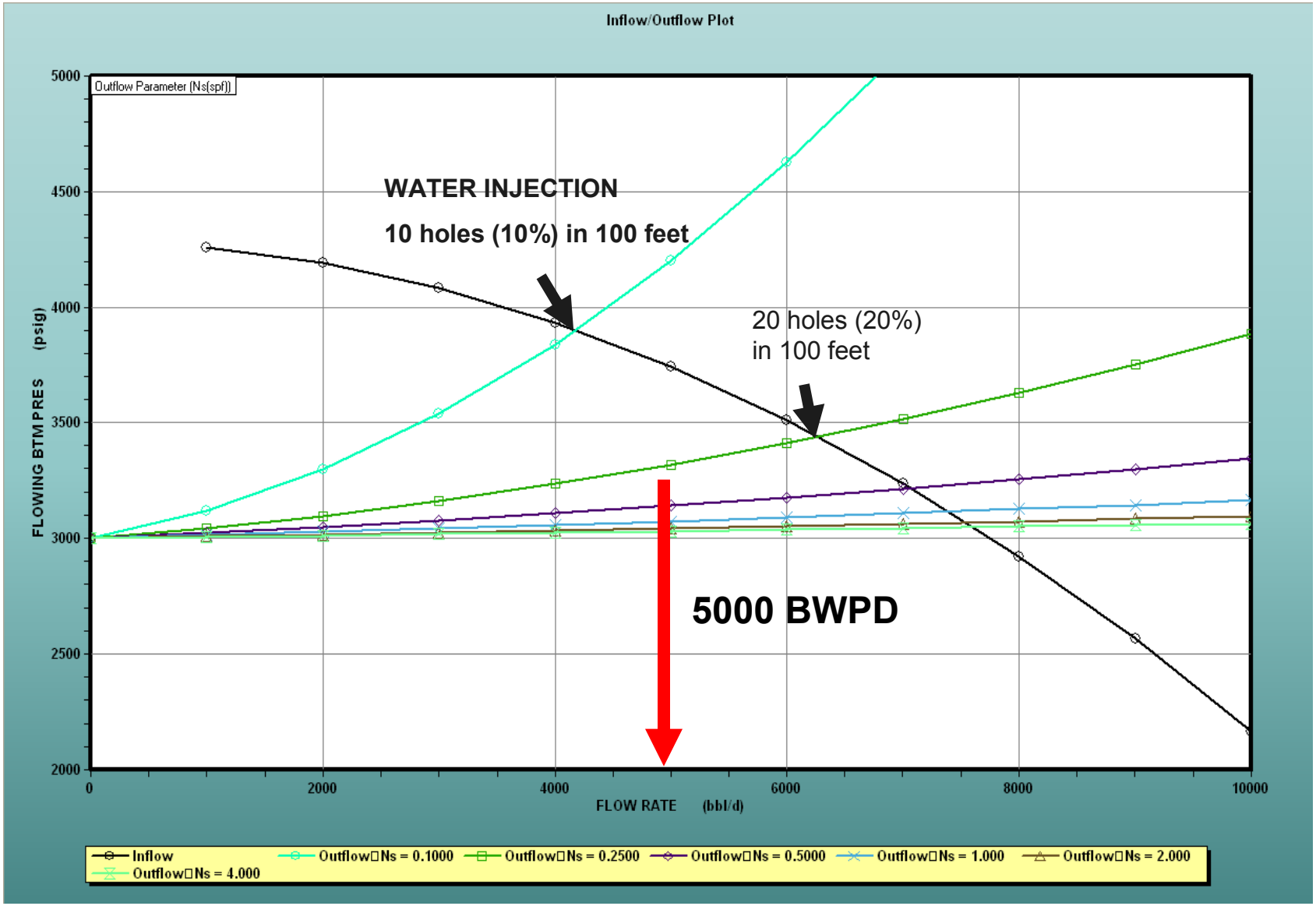
Injection Profiles on CO_2 & Water Injectors



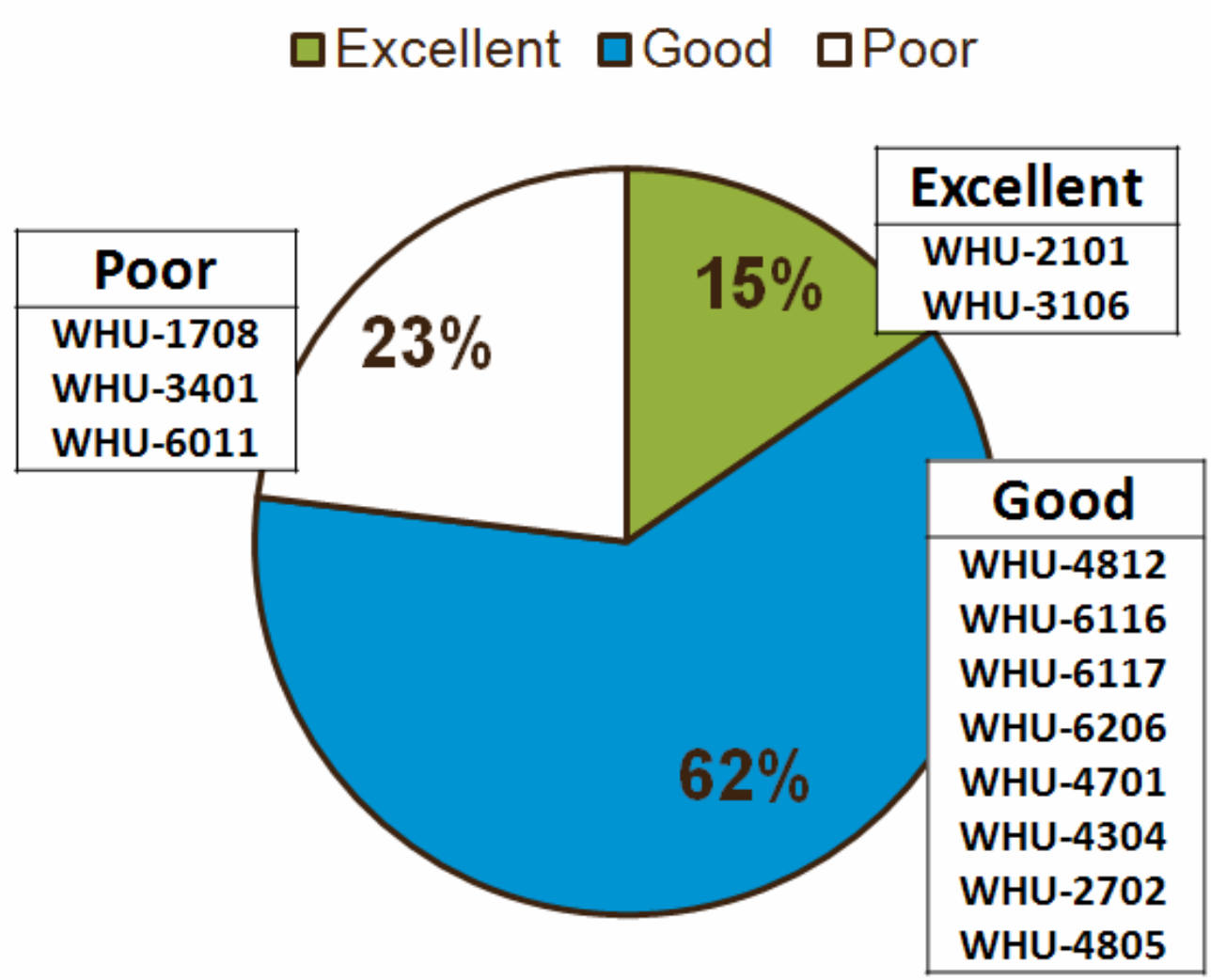
Perforation Shot Density for CO_2



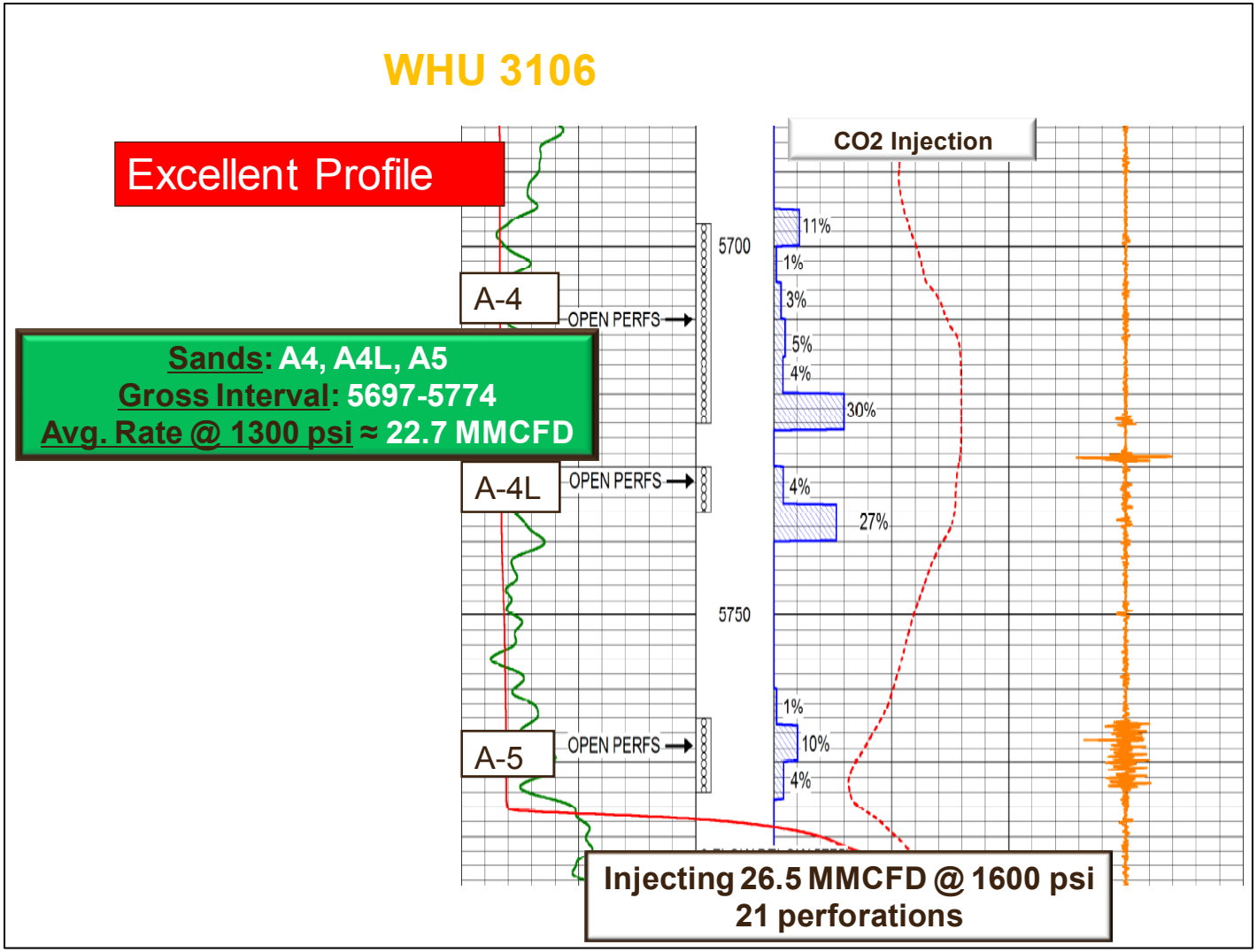
Reduced Shot Density Limits Water Injection



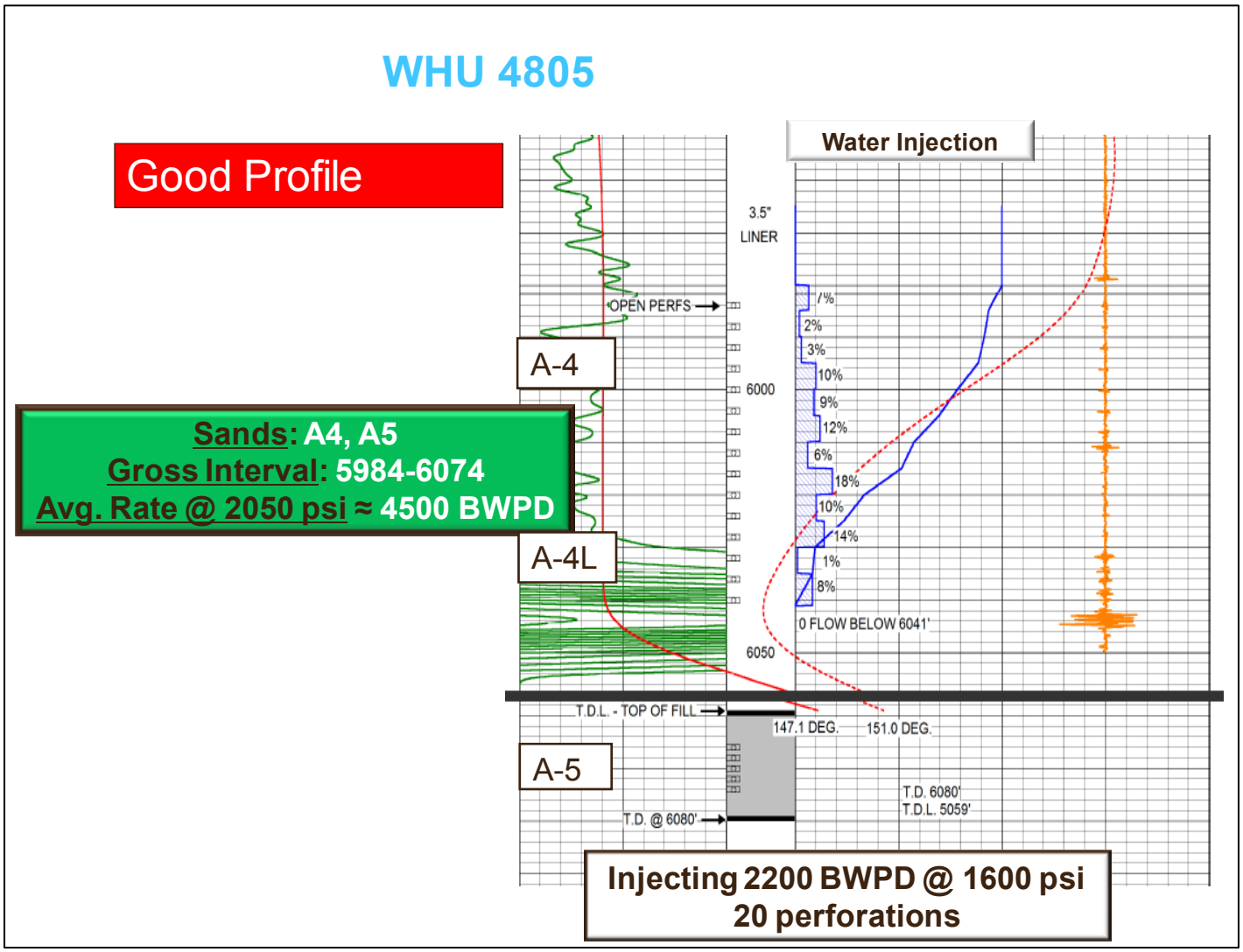
Injection Profiles – Limited Entry Perforations



Injection Profiles – Limited Entry Perforations



Injection Profiles – Limited Entry Perforations

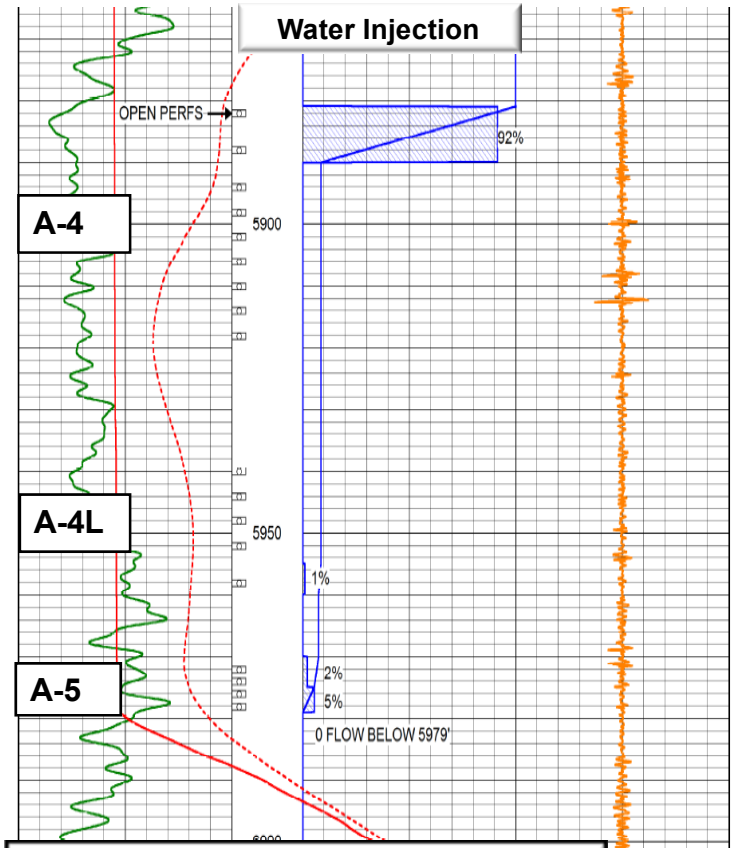


Injection Profiles – Limited Entry Perforations

WHU 3401

Poor Profile

Sands: A4, A5
Gross Interval: 5882-5978
Avg. Rate @ 2050 psi ≈ 6500 BWPD



Injecting 6800 BWPD @ 1850 psi
18 perforations

24

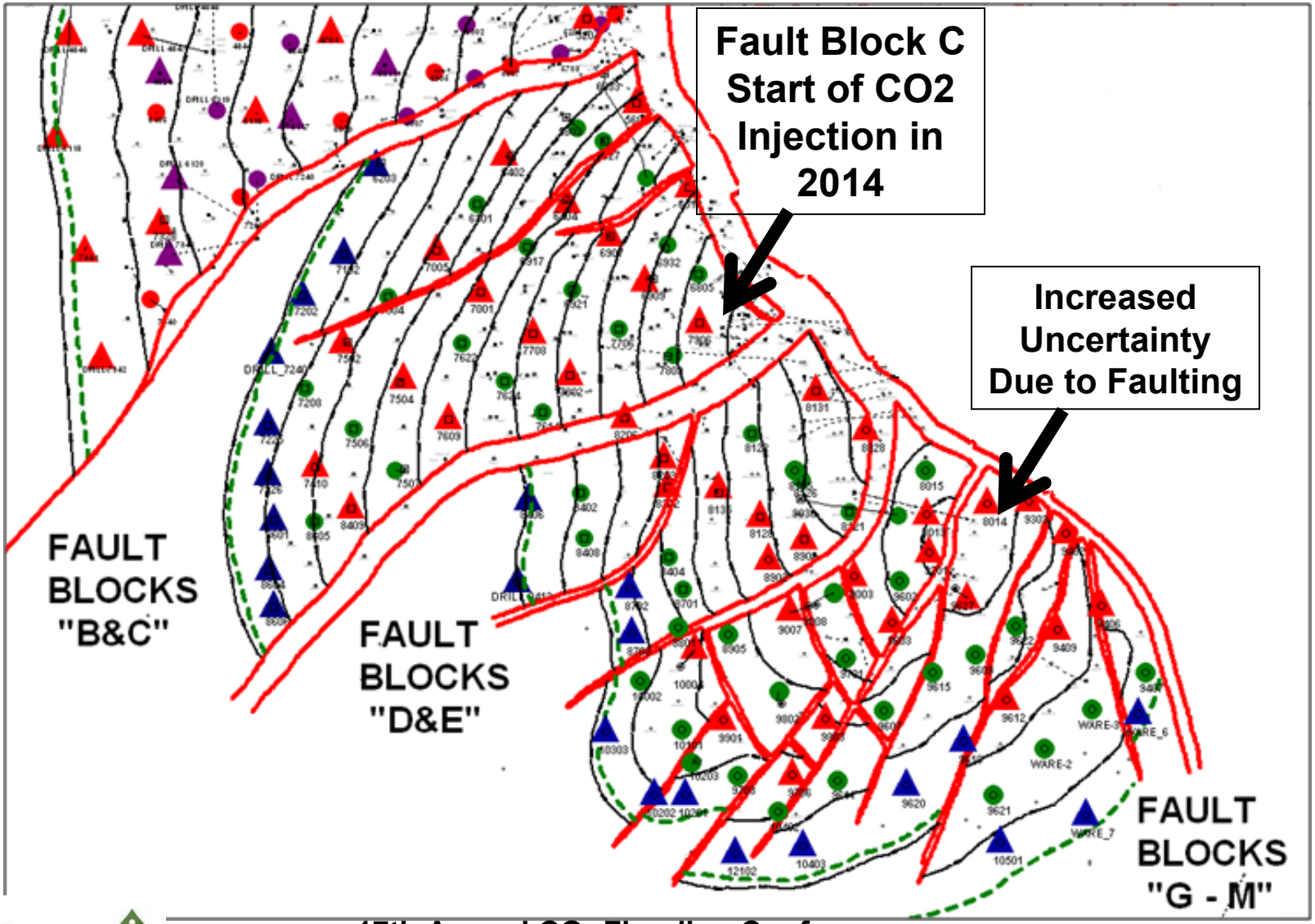
Challenges Faced By Activating Old Oil Fields

- Well files (and history) may be difficult to obtain
- P&A records filed with RRC are critical
- Additional pre-cautionary measures (casing inspection log, bond log, pressure test, etc.) are taken when P&A'd wells are re-entered and used as injectors or producers. (30 wells in Fault Block A)
- Production records (by well) may be limited, however since CO_2 recovers the residual oil, past production performance is not critical
- Urban development may require that houses be moved, real estate purchased, etc.

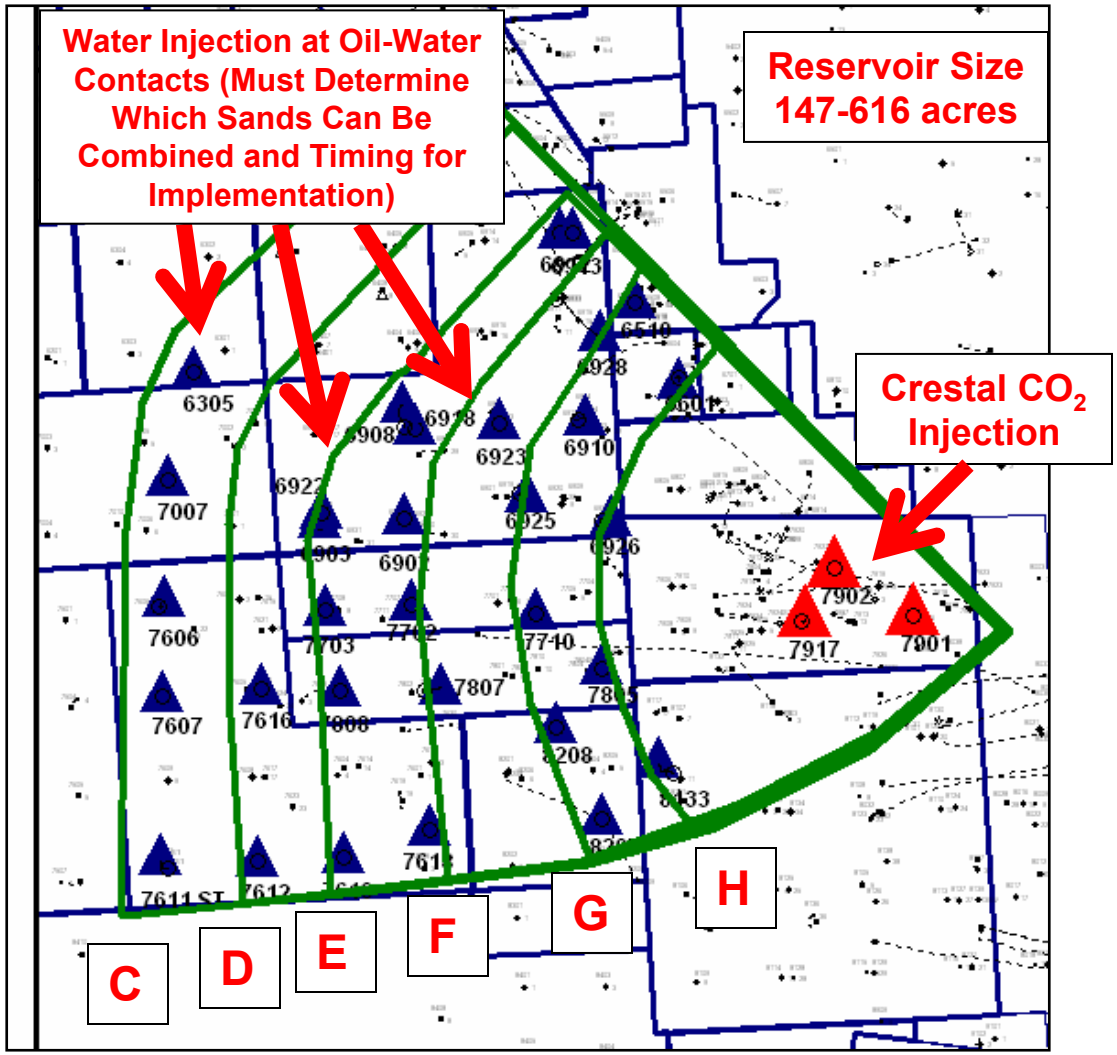
Work Scope Required to Develop Fault Block A

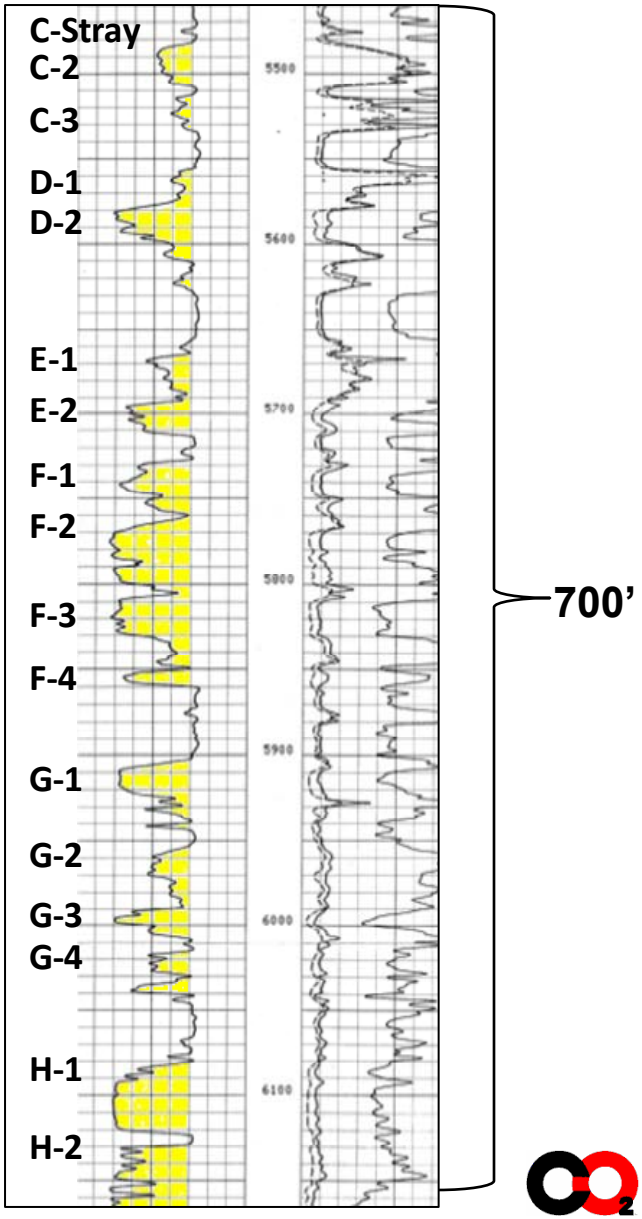
Well Type	2010	2011	2012	2013	Total
New Drill	1	9	15	7	32
Re-entry	8	7	5	10	30
Workover w/ sidetrack	7	10	0	0	17
Workover	15	9	0	0	24
Temporary Abandon	26	11	1	0	38
Plug & Abandon	4	4	3	0	11
Total	61	50	24	17	152
Unsuccessful	3	1			4

Technical Challenges
Sealing & Non-Sealing Faults



Technical Challenges
Development of Multiple Stacked Sands





Conclusions

- West Hastings Unit CO_2 flood is a significant, large scale EOR project along the Texas Gulf Coast
- Anthropogenic and natural CO_2 supplies will be used to recover incremental oil from Frio sands at 6000 feet
- Water injection is found to be a critical element in the design of the CO_2 flood due to the presence of a large aquifer and the requirement to raise reservoir pressure
- Technical challenges (multiple sands, faulting, depleted reservoir pressure) have been addressed using innovative approaches (dedicated patterns for groups of sands, limited perforations, downdip water injection, etc.)
- Success rate of re-entering plugged and abandoned wells has been high. Well histories and diagrams are critical.

Questions ?