WHITECAP RESOURCES INC

*Presented at the 24th Annual*
*$CO_2$ & ROZ Conference, Midland, TX*
*December 6, 2018*

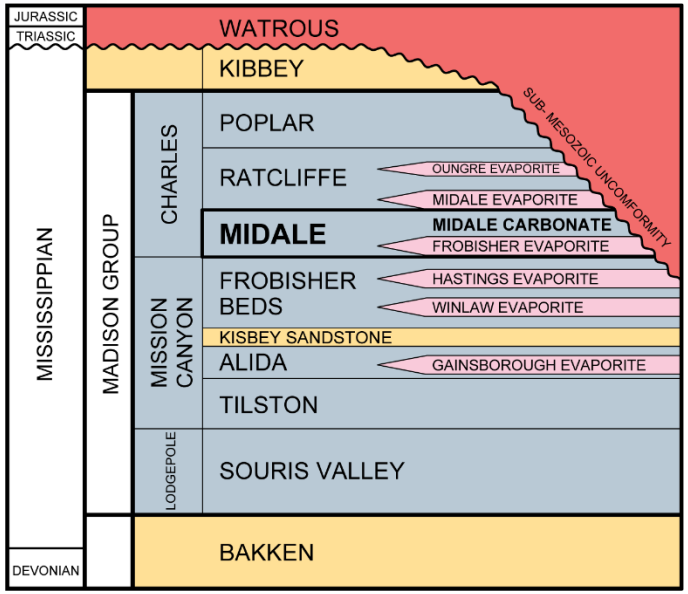
# Weyburn Unit
# Extending The Horizon

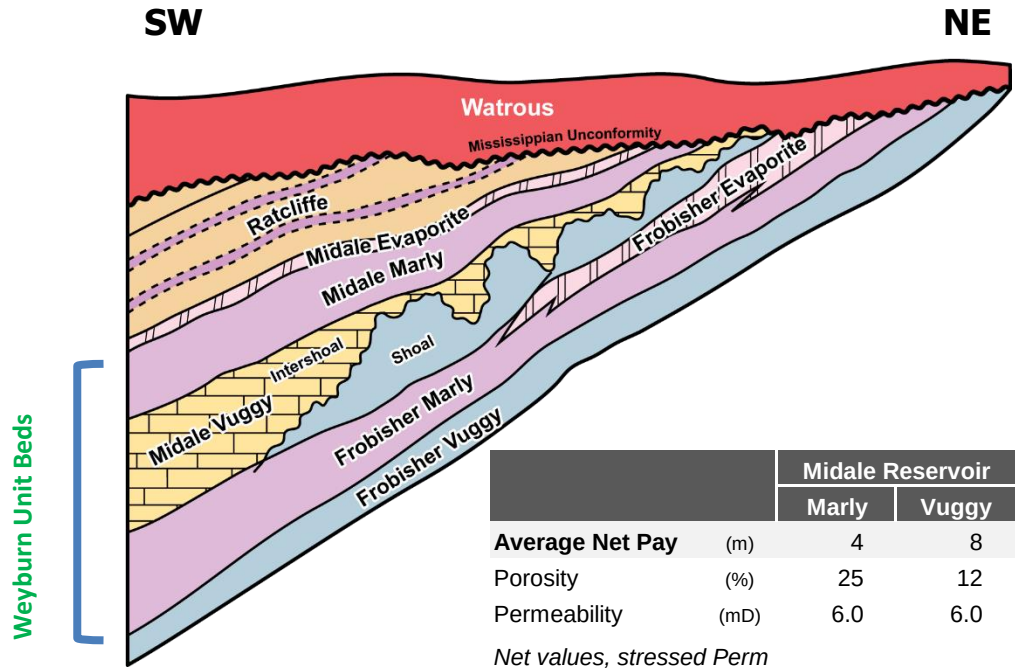

*Adlai Majer, Business Unit Manager*
*Bill Stoneman, Production Manager*
*Vladimir Vikalo, Senior Staff Reservoir Engineer*


# Weyburn Unit General Overview

- Significant and predictable base production
  - 24,000 bbls/d liquids (including NGLs) with <5% decline
- Large High Quality Resource on continuous land base
  - 1.4 B bbls OOIP in Midale
  - Weyburn Unit unitized lands total 22,000 ha
  - 30 API Oil (2-5% sulphur content)
- 18 years CO2 EOR Development
  - More than 80 CO2 EOR patterns rolled out to date
  - Over 400 horizontal wells drilled since 2000
  - Secure CO2 supply (2 suppliers)
  - Continuous improvement in CO2 EOR implementation and flood optimization are significantly extending the life of the field
- Whitecap Resources began operating the Weyburn Unit in 2018
  - Strong commitment to new EOR investment within Unit
    - New EOR Rollouts
    - Flood Optimization
    - Expanded NGL capture
  - Continue to investigate new CO2 EOR opportunities outside of the Unit to leverage existing CO2 supply, new carbon taxes, and our technical expertise

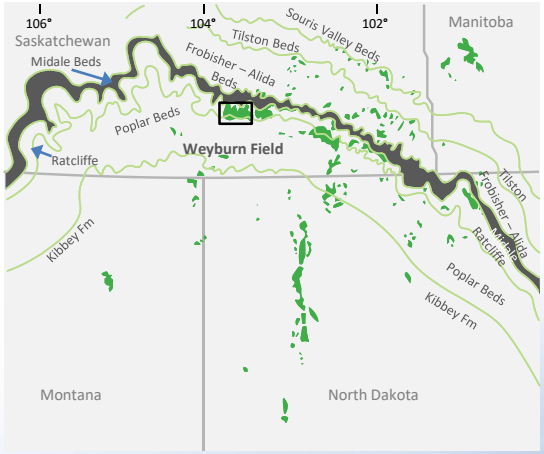
# Geological Overview



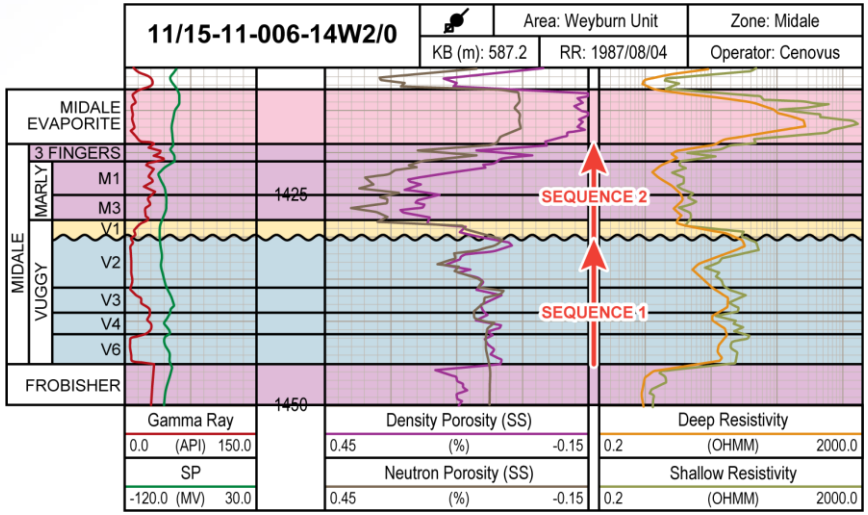

| | | Midale Reservoir | |
|---|---|---|---|
| | | Marly | Vuggy |
| **Average Net Pay** | (m) | 4 | 8 |
| Porosity | (%) | 25 | 12 |
| Permeability | (mD) | 6.0 | 6.0 |

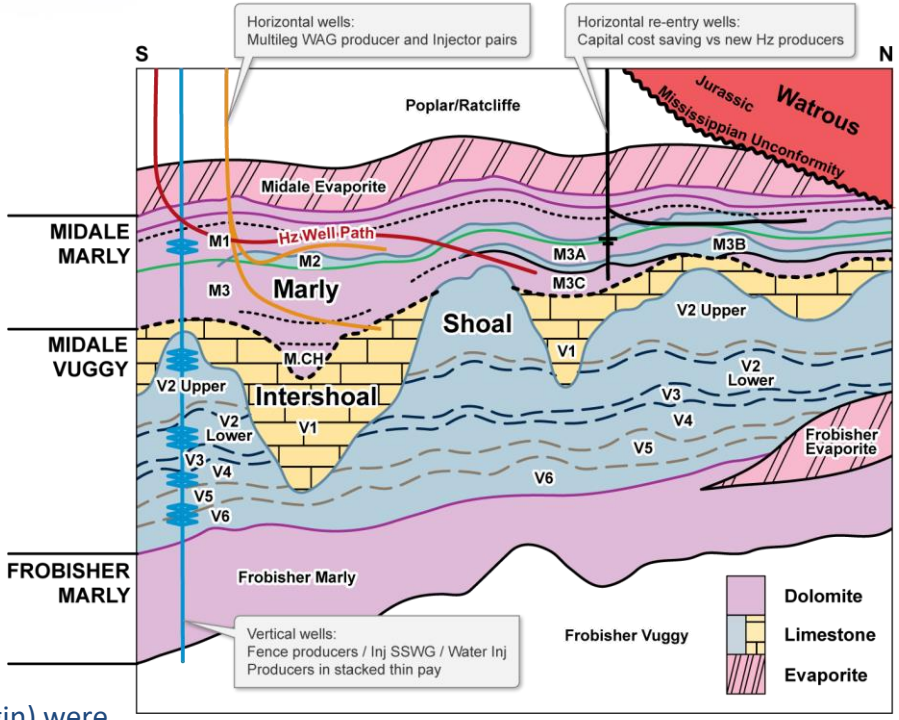
*Net values, stressed Perm*




- Capped by Midale Evaporite and regional Jurassic Red Beds
- Frobisher Marly + Evaporite form base seal

# Reservoir Characteristics



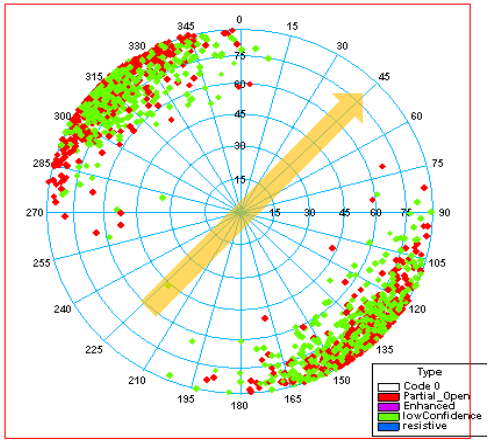

- Stacked, shallowing-upward cycles (subtidal to supratidal in origin) were deposited on a regionally extensive, gently dipping carbonate ramp
- Original drilling target = permeable Vuggy Shoal beds; today's $CO_2$ flood largely targets the relatively unswept Marly dolomite beds
- Local baffles and quality of reservoir rock controls sweep efficiency: strong focus on flood management and well configurations that promote good conformance in all Midale zones
- Effective sweep of tighter Marly zones achieved without overcapitalizing through use of multi-leg wells, Hz re-entries, and select vertical development

**Multi-zone reservoir with varied reservoir features are key to fluid dynamic optimization**

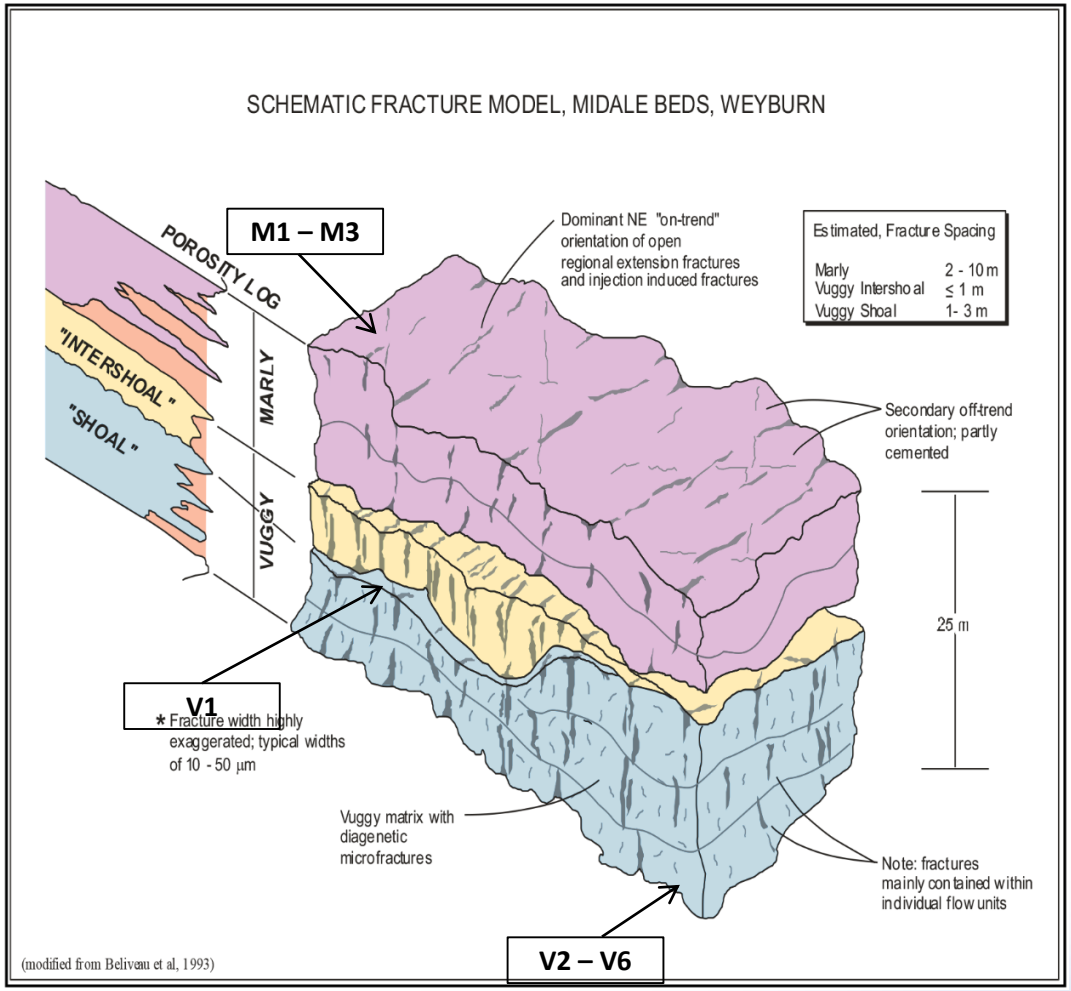
| Reservoir | | Marly | Vuggy Intershoal | Vuggy Shoal |
|---|---|---|---|---|
| Zone | | M1, M3 | V1 | V2-V6 |
| Porosity | (%) | 15-37% (26% avg.) | 2-15% (10% avg.) | 5-20% (10% avg.) |
| Permeability | (mD) | 1-100 (10 avg.) | 0.1-20 (1 avg.) | 1-500 (20 avg.) |
| Fracture Density | (m) | Low (2-10) | High (<1) | Moderate (1-3) |

# Schematic Fracture Model

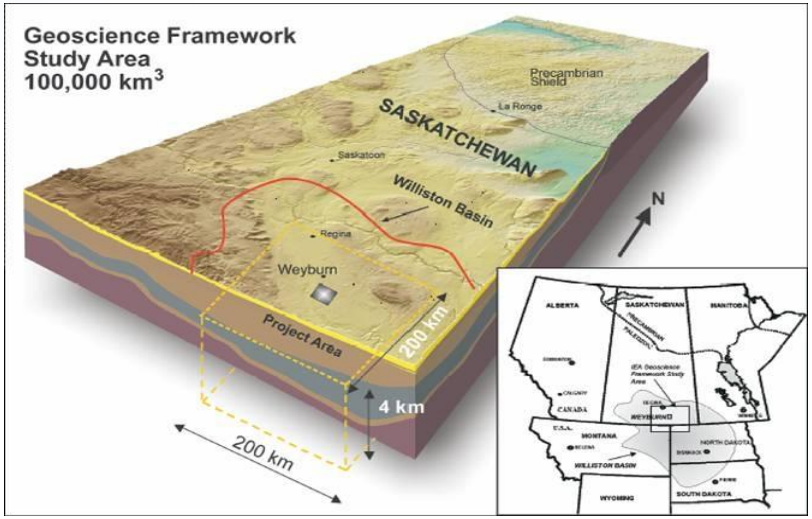
- Fracture style and intensity is dictated by timing & origin of stresses, bed properties & thickness (mechanical stratigraphy)
- Multiple sets of fracture scales and styles contribute to reservoir permeability and communication
  - Natural, injection induced, abandonment
- Natural and induced sets contribute to a dominant NE-SW anisotropy
- Most natural fractures are subvertical and terminate at bed boundaries
  - Contributes to both heterogeneity and homogenization of reservoir
- End product is a complex triple porosity system

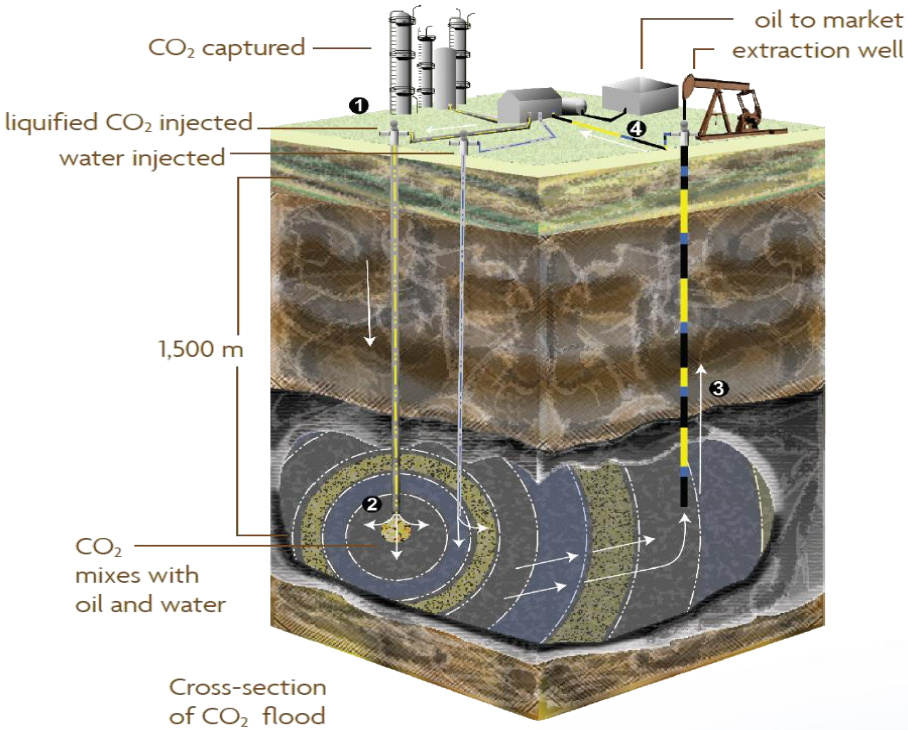



Stereoplot from Vuggy Image logs



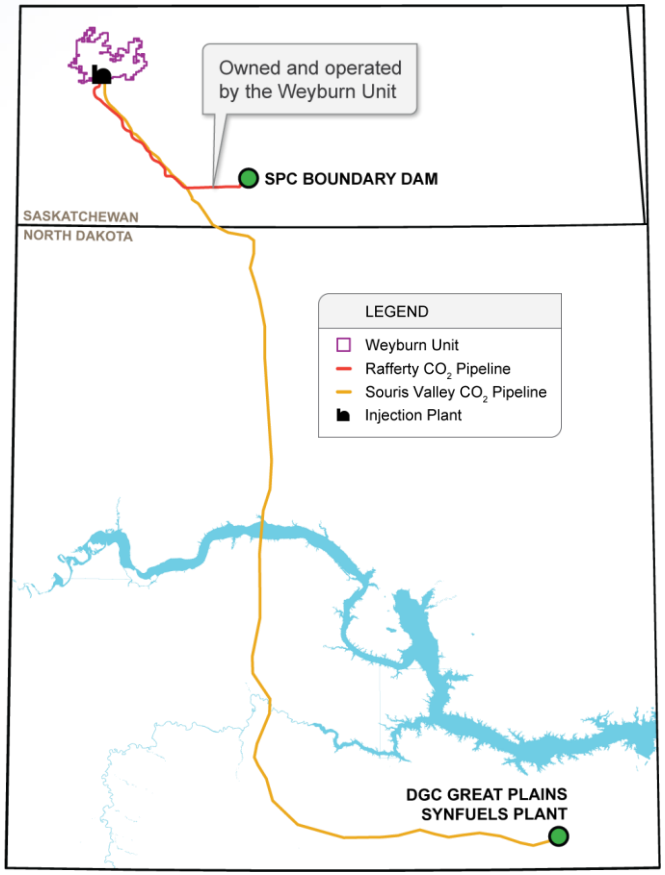
# Weyburn Unit Overview – Carbon Capture, Utilization & Storage




- Weyburn Carbon Capture, Utilization & Storage (CCUS)
  - Initiated carbon dioxide ($CO_2$) flood to enhance oil recovery (EOR) in Oct 2000
  - Have safely stored more than 30 million tonnes of $CO_2$
  - Store an additional two million tonnes of $CO_2$ each year
  - Site of an international research project, IEA GHG Weyburn-Midale CO2 Monitoring & Storage Project; led by the Petroleum Technology Research Centre (PTRC) in Regina
  - Estimate 55 million tonnes of potential $CO_2$ storage capacity
  - The Weyburn Unit has hosted over 250 groups from 20 countries

# Weyburn $CO_2$ Pipelines




$CO_2$ from SaskPower's (SPC) Boundary Dam Power Station

Rafferty $CO_2$ pipeline owned & operated by the Weyburn Unit

$CO_2$ from the Great Plains Synfuels Plant in Beulah, North Dakota

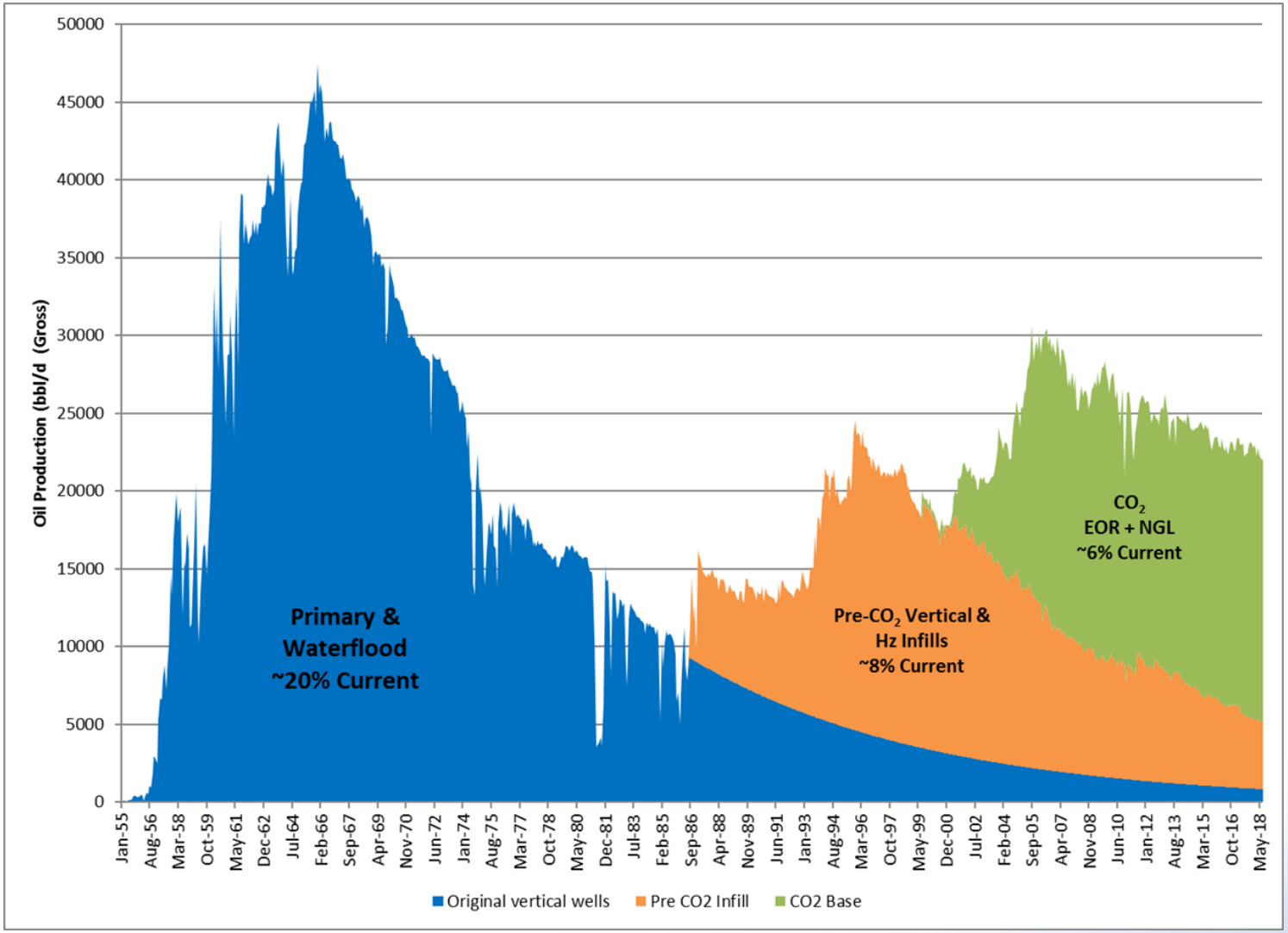
Pipeline and plant owned & operated by the Dakota Gasification Company (DGC)


Central Receiving Terminal

Both DGC & Rafferty $CO_2$ pipelines terminate at 06-34-06-13

$CO_2$ delivers directly into the $CO_2$ injection system at full pressure, blends with recycled $CO_2$ from Weyburn Plant

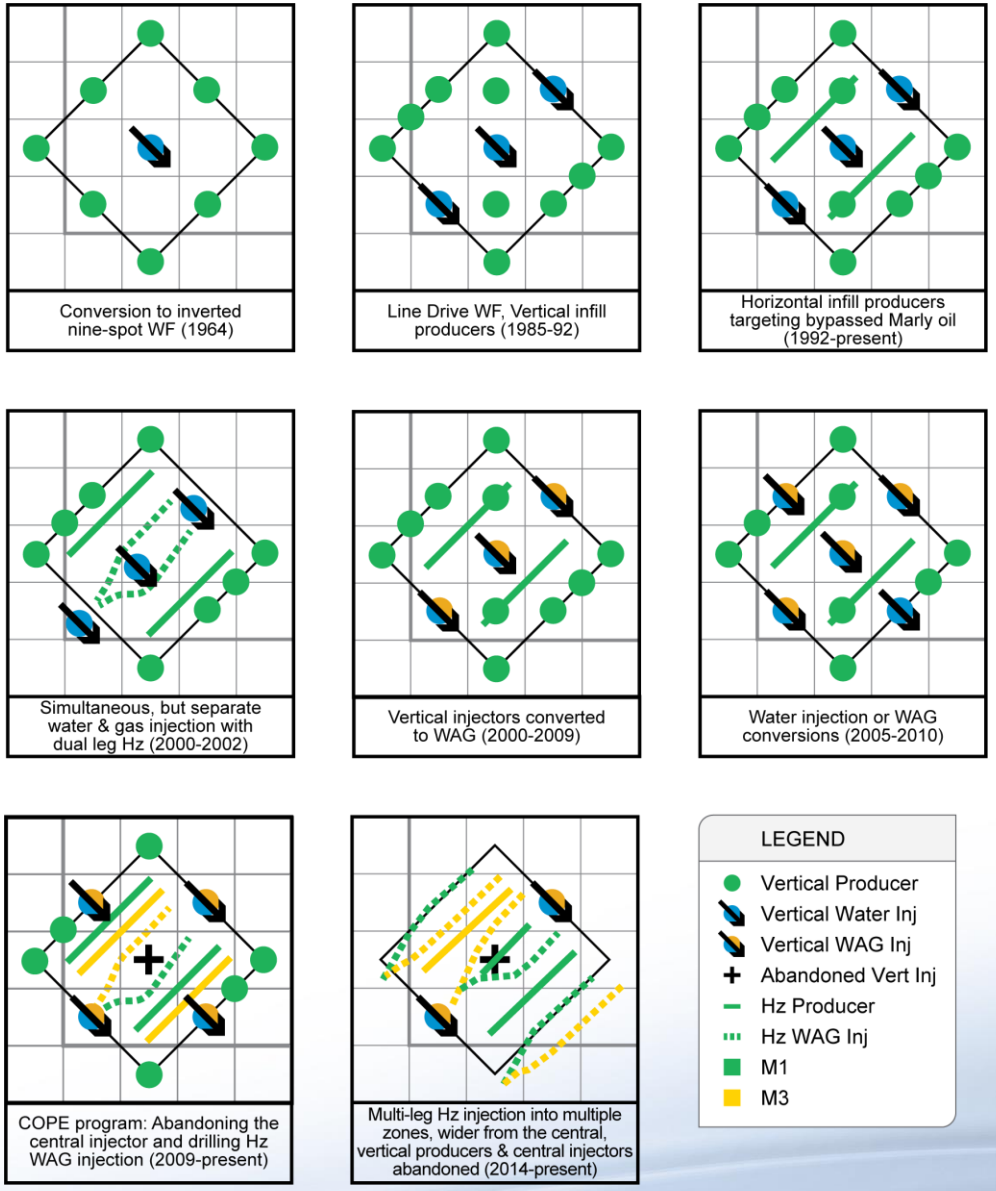
# Development and Production History and Recovery



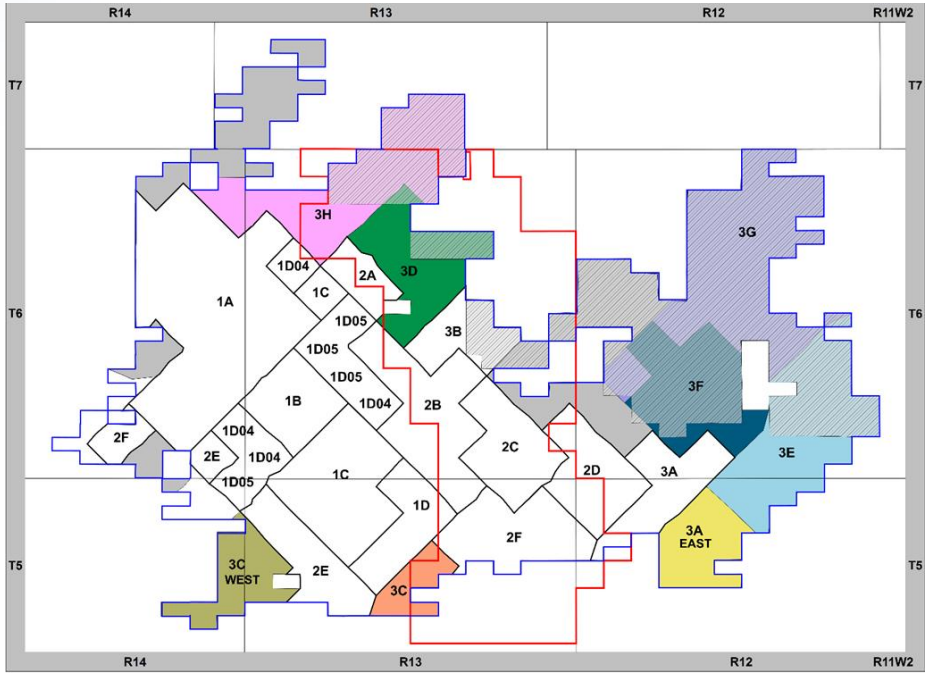
# Weyburn Flood Evolution

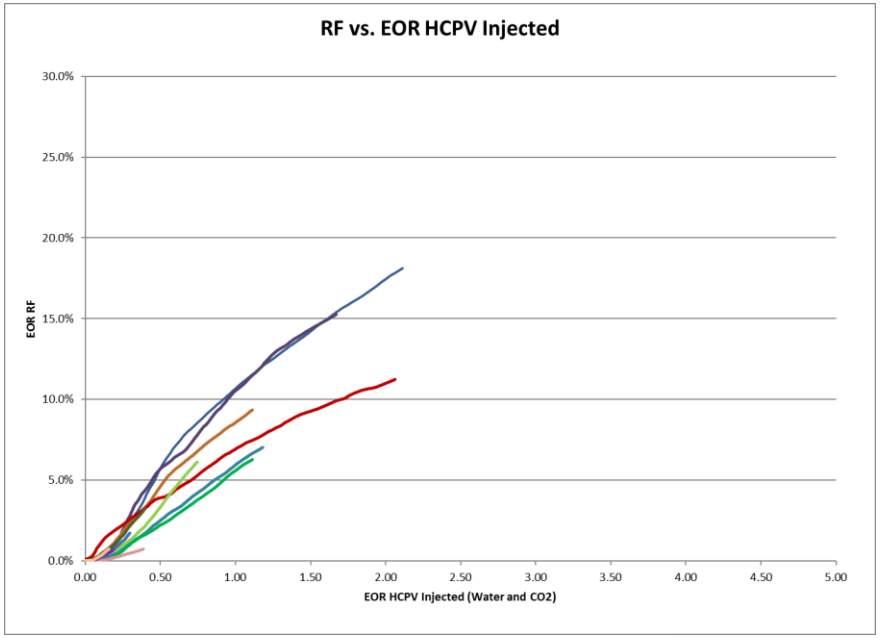
- **Waterflood**
  - Inverted 9 spot
  - Line drive
  - Vertical/Horizontal infill drilling
- **$CO_2$ Separate/Simultaneous Injection ("SSWG")**
  - Separate and simultaneous injection of water and $CO_2$
  - Central $CO_2$ injection into Marly with vertical injection in Vuggy to control mobility
  - Only used Phase 1A & 1B (shoal)
- **$CO_2$ Water Alternating Gas ("WAG")**
  - Alternating the $CO_2$ with the water injection
  - Initially central vertical injectors with horizontal Marly and vertical Marly/Vuggy producers
  - $CO_2$ Placement Enhancement ("COPE") program converts central injection to horizontal
  - Edge ½ pattern injectors in new rollouts now horizontal
  - Wide leg injectors

**Horizontal wells have improved injectivity and sweep in lower kH Marly in a cost effective manner**



# CO2 EOR Development

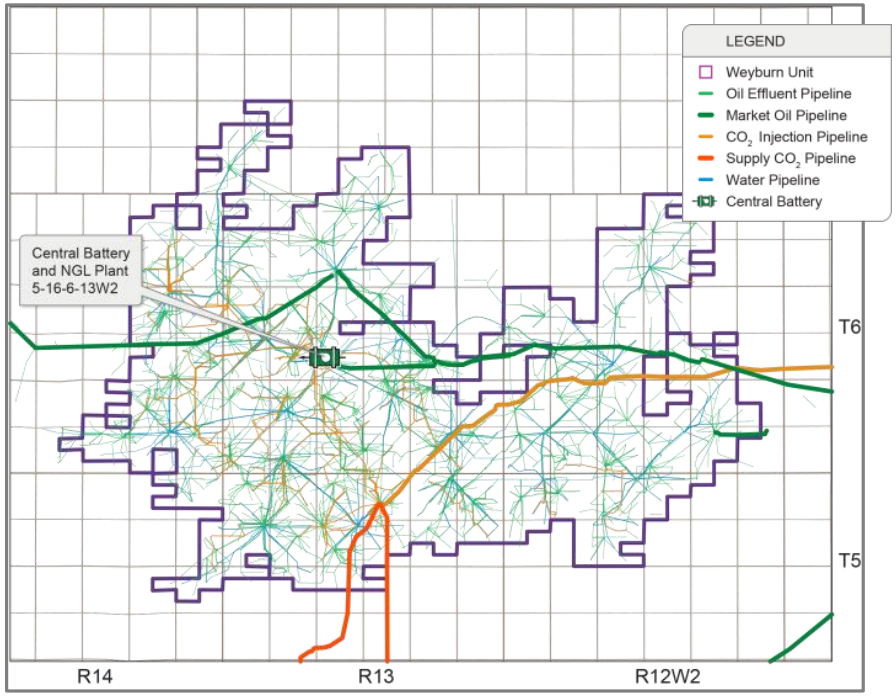


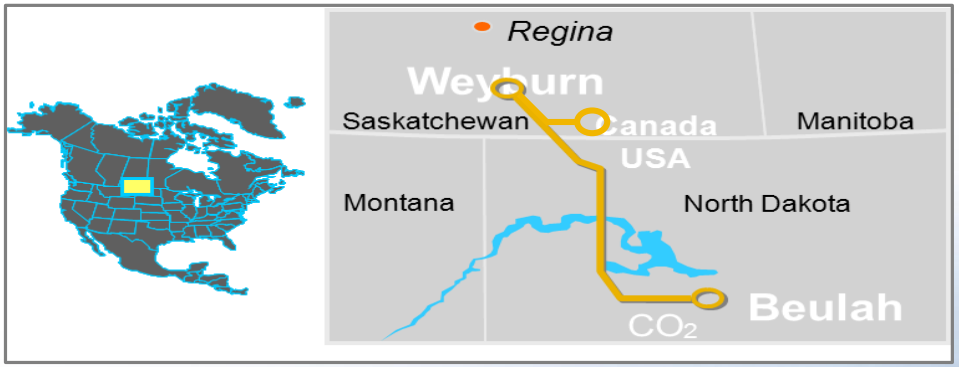

**Mature rollouts are performing better than expected and new rollouts have been successful in more challenging reservoir**

# Weyburn Unit Infrastructure Overview

| | |
|---|---|
| Producing Formation: | Mississippian, Midale |
| Depth: | 1,450 m |
| Discovered: | 1954 |
| Oil Quality: | 25-35 °API |
| Area: | 22,000 hectares (85 sq mi.) |
| # Production Wells: | 727 (435 Hz) |
| # Injection Wells: | 309 (100 Hz) |
| Pipeline: | 1,625 km |
| Oil Rate: | 23,000 bbl/d |
| NGL Rate: | 700 bbl/d |
| Water Injection: | 175,000 bbl/d |
| $CO_2$ Injection: | 350 mmcf/d |







# Weyburn Plant Facilities

- 2 free water knock out vessels, 4 treaters
- 20,000 bbl oil storage, 50,000 bbl $H_20$ storage
- 50,000 hp sour $CO_2$ gas compression
  - 2 x 100 mmcf centrifugal (2 section, 7 stage)
  - 2 x 25 mmcf recips, 3 stage machines
  - 2 x 12 mmcf recips, battery gas compressors
- 2 x 100 mmcf/d $CO_2$ dehydrators
- 14,000 hp water injection pumps (5 - 7 stage centrifugal pumps)
- 2 - 138kV to 4160V, 1 – 138 kV to 13.8 kV transformers
- NGL plant (~600 bbl/d C4, 200 bbl/d C3)
- Auxiliary systems: heat medium systems, instrument air, back up utility generators, $N_2$ generators, seal gas, lube oil, SaskEnergy fueled flare systems, etc,
- 100% electric drivers, no gas drivers
- Delta V DCS plant operation installed 2008 – 2010, independent SIS SIL level 3 designed system, separate F&G system (PLC)
- 24 hour control room monitors & operates plant equipment plus field production & injection wells and facilities

# Weyburn Field Facilities

- Approximately 530 pumpjacks, 100 ESPs, some flowing wells, 100% electric drivers
- 80 production and 54 injection satellites
- 24hr surveillance via SCADA
  - 99% of production
  - 100% of Water & $CO_2$ injection
- EOR production satellites are fully automated & able to do short duration statistical well testing & significantly more wells per test separator (up to 50 wells)
- 3250 km of flowlines in 85 sq miles (~50/50 active & abandoned)
  - Water injection – polylined steel & fibrespar
  - $CO_2$ Injection – bare steel
  - Emulsion gathering – fibrespar, fibreglass, polylined steel, bare steel
  - EOR Gas Gathering – polylined steel
- 68 km high pressure Rafferty $CO_2$ pipeline from Estevan

# Well Servicing

- Well control is critical
- Specialized well control techniques to deal with high reservoir pressures and liquid $CO_2$ present at production wellbore conditions
  - Access to variety of kill fluid densities is critical
  - Well Servicing activities require engineering support to manage reservoir pressures in order to minimize kill fluid costs
  - Routinely modify injection prior to downhole repairs or utilize coiled tubing or snubbing services.
  - Experienced consultants and rig crews are able to recognize potential well control issues before they become a problem
- Full time flushby unit deals with pumping/plugging issues by circulating with oil, flowing back to testers and or treating with chemical
- Wax/asphaltene deposits on rods and in tubing may require chemical treatment and occasionally removal by hand
- Wax and asphaltenes sometimes require specialized equipment (rod snubbers)

EOR service jobs require a line heater, portable separator and fuel supply ($C_3$) to enrich flared gas

# Operational Challenges - Problems

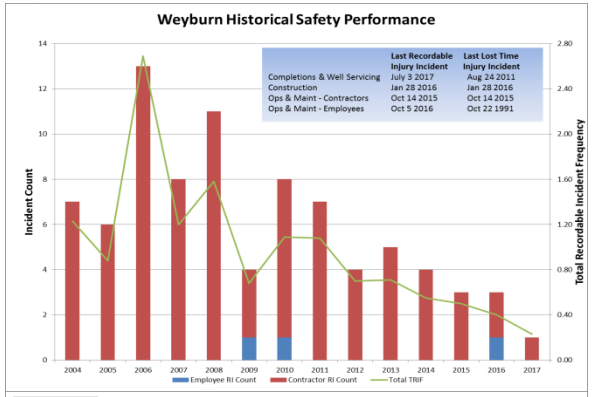
- Asphaltene/Wax (60%/20%)
  - Asphaltene more typical than Wax
  - Pump fouling/plugging
  - Rod hang-ups
  - Tubing/annular plugging

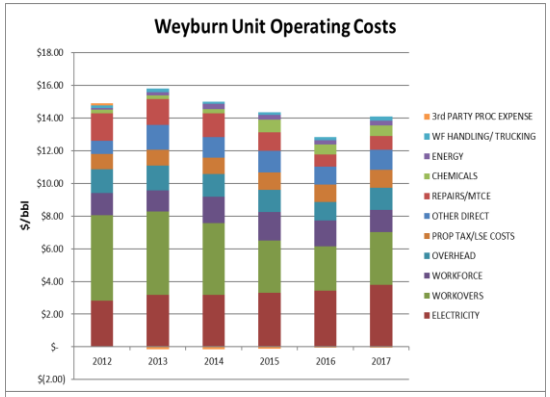
- Solids (20%)
  - Inorganic solids and scale
  - Formation fines up to large diameter rocks mobilized by gas and fluid
  - Inorganic fines combine with asphaltene and wax to form composite deposits
  - Hz section, tubing, and flowline plugging
  - Pump system wear/ destructive failure

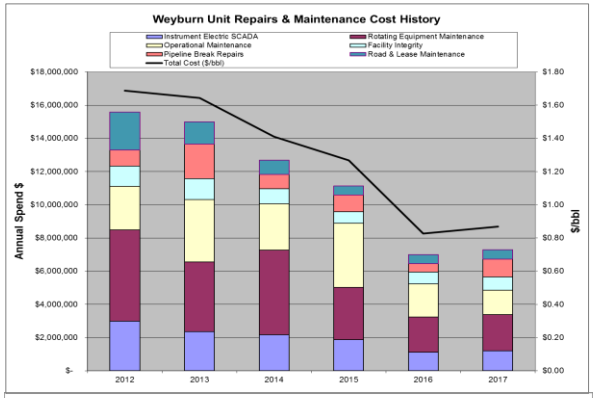
# Operational Challenges - Solutions

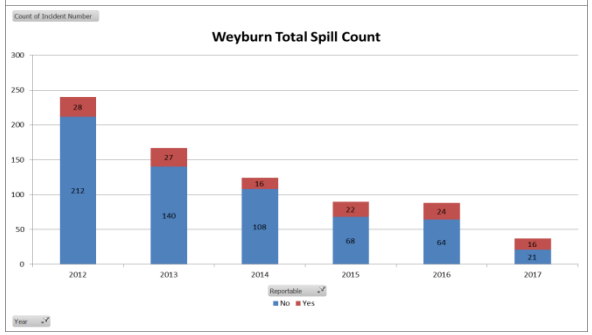
- Engineering
  - Artificial lift design improvements
  - Failure tracking and analysis & design revisions
  - Monitoring and verification, MTTF, pump tear-down findings
- Drillout program
- Chemical treatment
  - Pre 2014, wax dispersant from a single supplier was used in production wells
  - Since 2014, asphaltene inhibitors from multiple suppliers have been used, and oil samples are collected to monitor asphaltene stability and adjust dosages
  - Sample monitoring data are cross referenced with plugging events
  - Improved inhibitor formulations have been developed, such as dual asphaltene inhibitor/demulsifier
  - Reduced frequency of capillary line plugging through design & operation changes
  - Asphaltene inhibitor squeeze treatments appear to be effective, but more expensive than continuous treatment

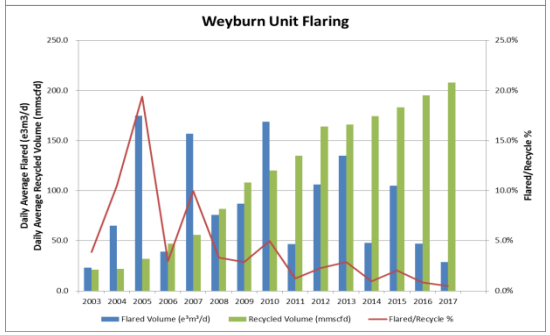
# Operational Summary

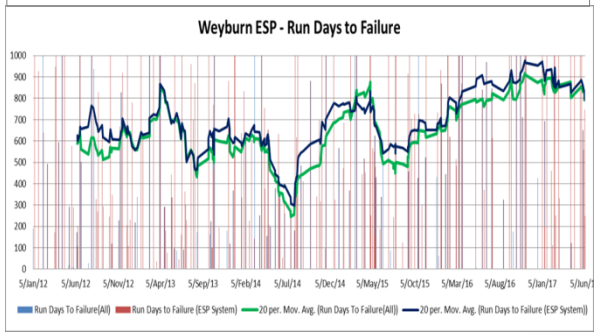


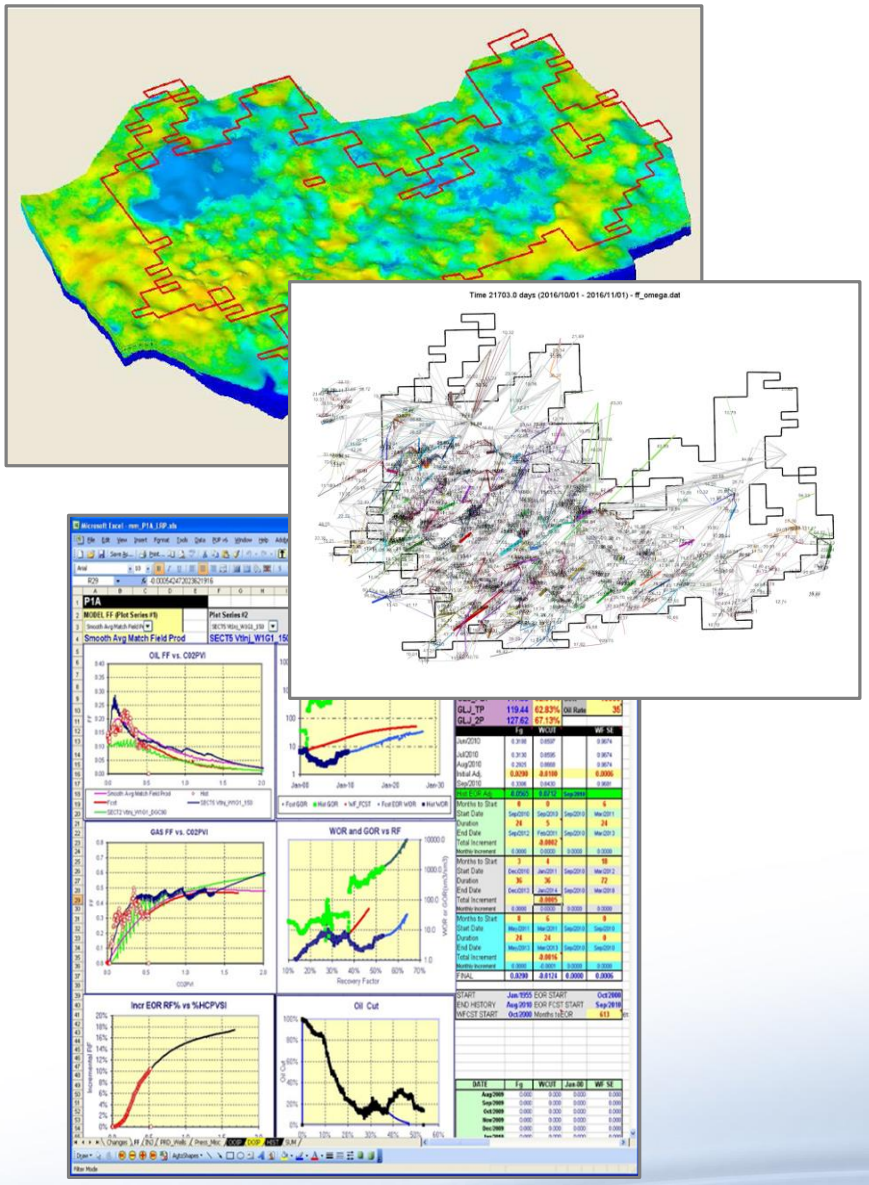

In spite of a challenging commodity price environment and a technically complex asset, the Weyburn Unit has been able to demonstrate continuous improvement in many areas of the operations

# Reservoir Simulation and Forecasting

- Importance of accurate forecasting
  - Base CO2 EOR predictions
  - CO2 EOR rollout Planning
  - Flood Optimization
  - Capital CO2 budget
  - CO2 recycle requirements

- Forecasting Tools
  - Historical Simulation Models
    - Older models 1976-2009
    - 2009 “Fine” Grid 2009 model
    - Course Grid Model
  - Streamline Model (3DSL)
  - Current Eclipse/IX Model
    - Fast and easy to use
    - Build close to geological grid
  - Analytical Forecasting Tools

**Simulation and analytical tools used in conjunction to make development planning and reservoir management decisions**

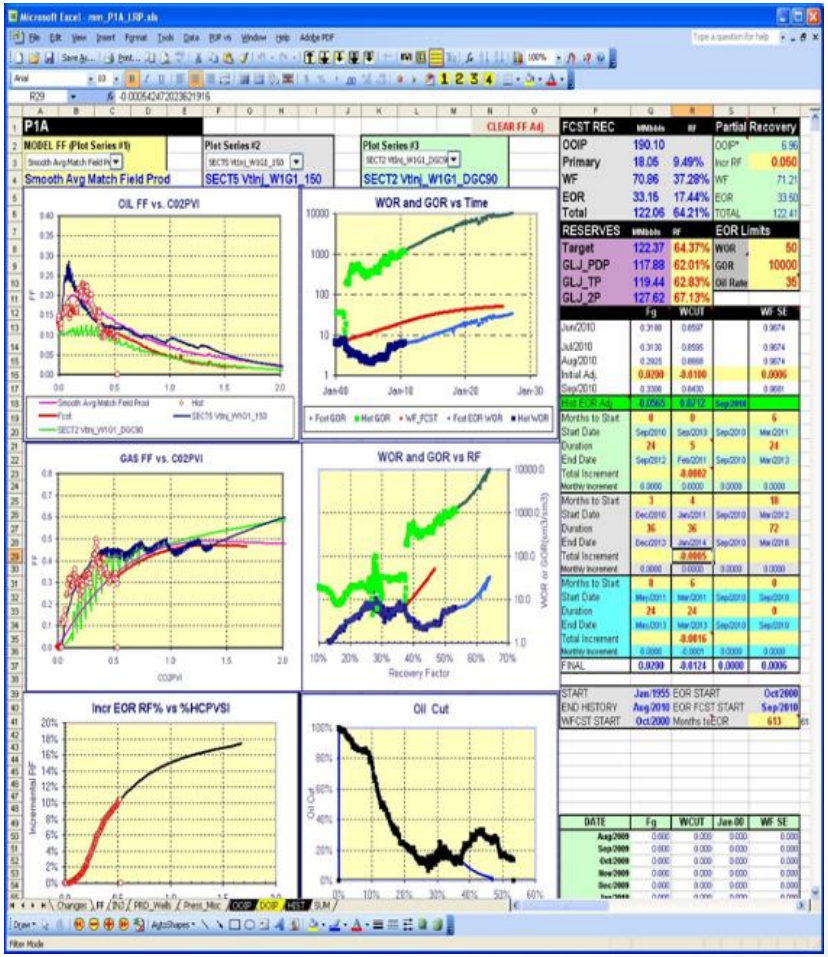


# LRP and Analog Tools (Excel Based)

WHITECAP RESOURCES INC

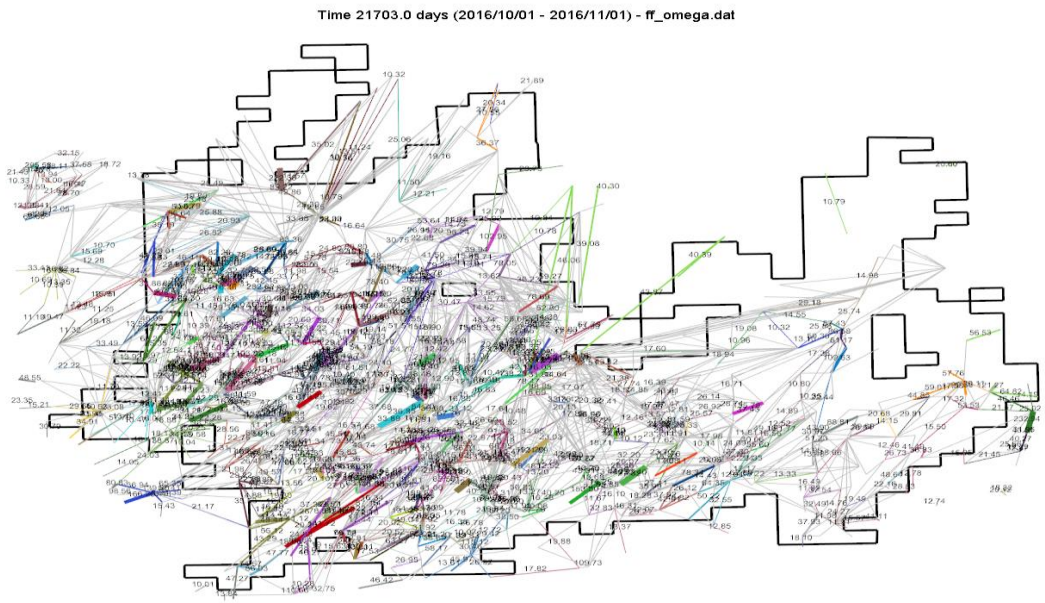
- "LRP Tool" provides a range of future field performance by combining history of both performance trends and operations with reservoir simulation driven scenarios
  - Uses fractional flow methods for forecasts, with future pattern processing rates and VRR as key inputs
  - Geological variability and miscibility differences handled through the results of simulation sector models
  - Forecasts generated for waterflood and EOR scenarios, allowing both short term (e.g. budget) and long term (reserves) objectives to be met and integrated
  - Easy to use, flexible, quantitative

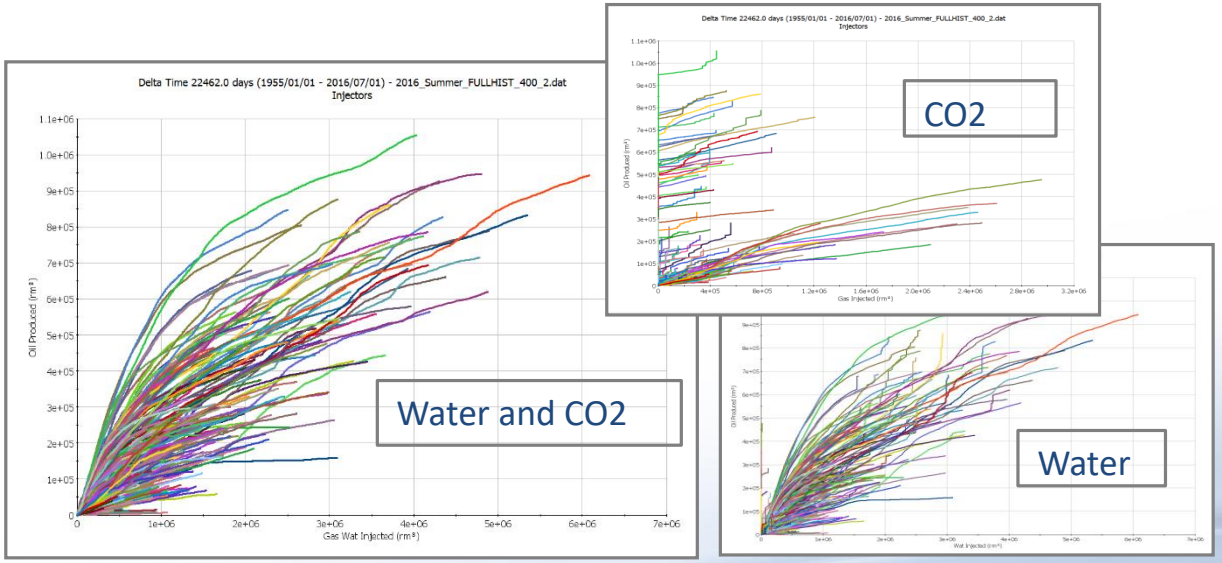
- Other Excel based analytical tools
  - Other similar tools have been developed in recent years to create incremental oil and CO2 purchase/recycle forecasts based on analog pattern behavior
  - Main purpose is to allow exploitation engineers to make quick, high level initial forecasts that can later be verified and refined by simulation



# Weyburn Streamline Model

- Streamline Model (3DSL)
  - Based on 2009 fine grid Eclipse model
  - Key pattern review tool
    - Easily integrated into Tableau surveillance tool
    - Helps to understand well level interactions
  - Reality check for simulation



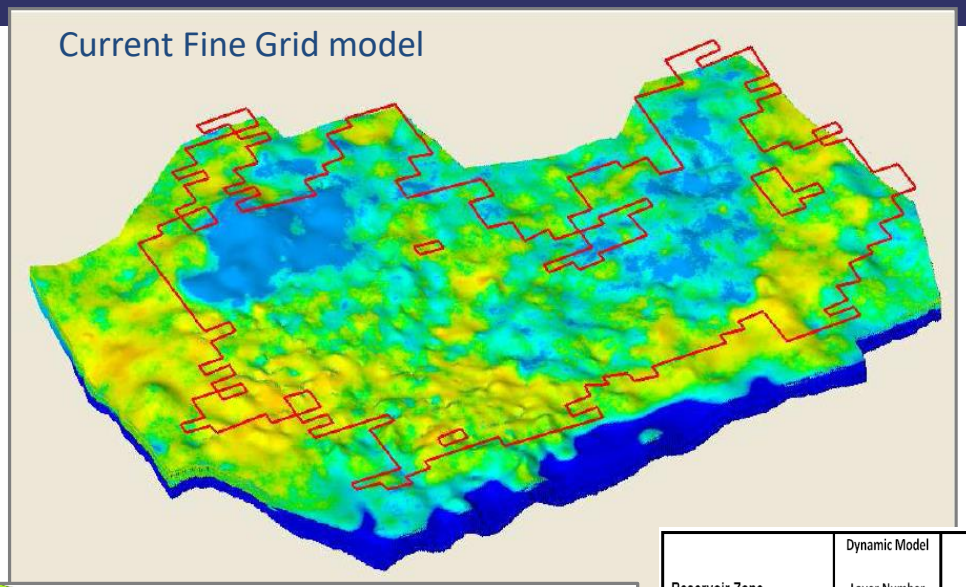
# Eclipse Simulation Models

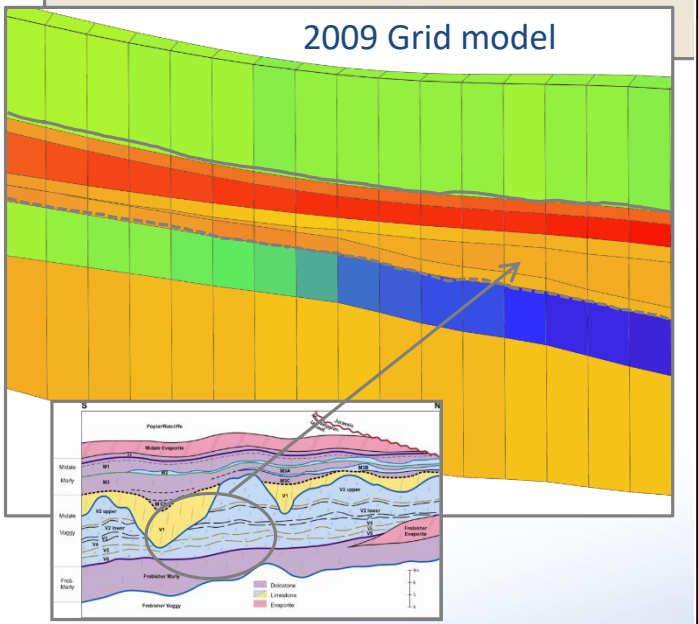
WHITECAP RESOURCES INC

- ***Current Eclipse/IX Model***
  - ***Fast and easy to use***
  - ***Integration with Petrel***
  - ***Build close to geological grid***

- Historical Simulation Models
  - Older models 1976-2009
    - Intercomp '76 (2 small areas)
    - 4 Area Models ('93-'97)
    - 2002 EOS Models
    - 2003-2005 New EOS larger area

  - 2009 "Fine" Grid model
    - 60x60m, 8 layer model
    - 1 million grid blocks
    - Single and dual porosity
    - 6 component EOS
    - Cut-outs from full field model used for rollout simulation
  - 2011 Course Grid Model
    - 400x400m, 2 layers
    - 3 pseudo wells/pattern
    - Dual porosity & dual perm
    - Upscaled to be flexible and fast

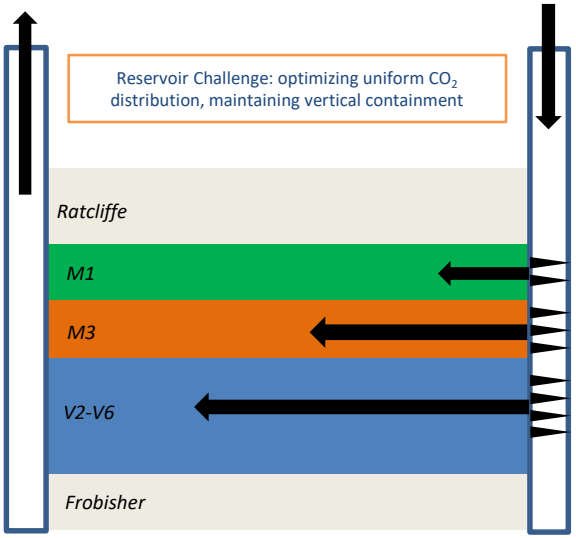


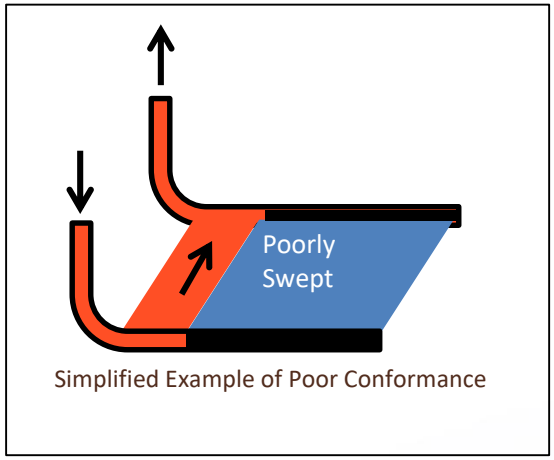




| Reservoir Zone | Dynamic Model Layer Number | Flow Barrier |
|---|---|---|
| Watrous | 1 | |
| Mississippi | | |
| Ratcliff | | |
| Ratcliff-A | | |
| Ratcliff-A_base | | |
| Ratcliff_por | | |
| Midale Evaporite | | |
| Three Fingers | | |
| M0 | | Total barrier |
| M1 | 2 | |
| M2 | | Partial barrier |
| M3 laminate | 3 | |
| M3a | | |
| M3b | | |
| M3c | | |
| V1 | 4 | |
| V2 | 5 | |
| V2 barr | | |
| V2 por | | |
| V3 | 6 | |
| V4 | | |
| V5 | | |
| V6 | | Partial barrier |
| Frobisher Evaporite | 7 | |
| Frobisher Midale A | | Partial barrier |
| Frobisher Midale B | 8 | |
| Frobisher Vuggy | | |

# CO2 EOR Conformance

- Conformance Challenges
  - Natural and induced fractures, most prominent in NE-SW direction
  - High $CO_2$ mobility → preferential perm to gas
  - Old vintage wells affect vertical containment
  - Tight well spacing leads to "short-circuiting" of $CO_2$ between injectors and producers
  - $CO_2$ in water affects carbonate composure over time, increasing permeability in limestone and leading to preferential Vuggy injection



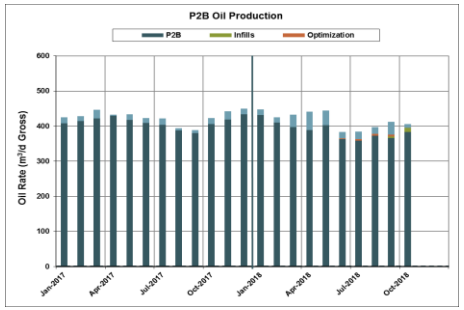

**Ideal reservoir conformance: uniform distribution of $CO_2$ sweeping oil towards producers at optimal rates under miscible pressure**

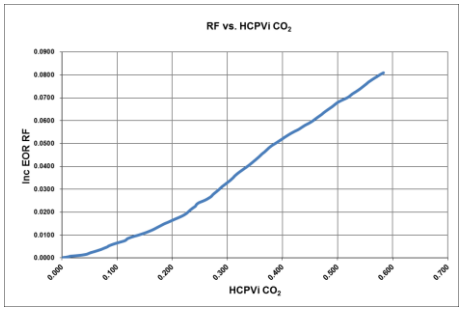
# Reservoir Surveillance

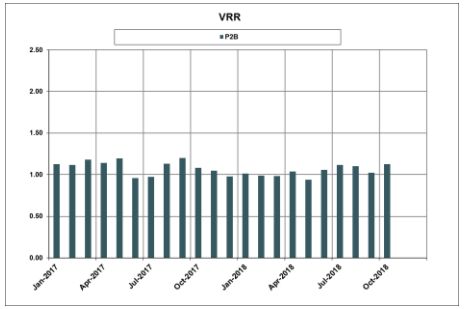
WHITECAP RESOURCES INC

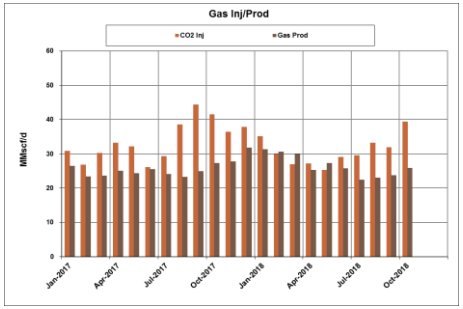
## Phase Level Monitoring (groups of 4-8 patterns)

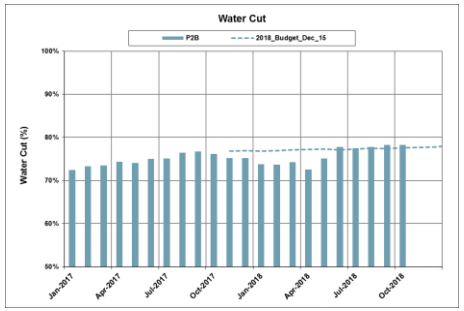
- Performance of EOR Rollout Phases reviewed monthly to determine if expectations are being met and to share new ideas and learnings from detailed pattern reviews
- Strong focus on phase level cash flow to ensure that CO2 usage is optimized and profit maximized across the field

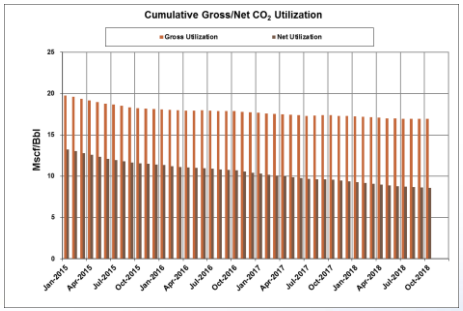


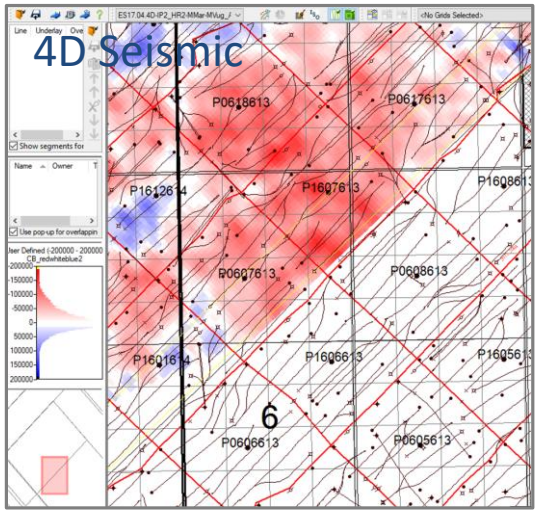

**Above CO2 rollout shows transition to positive cash flow with CO2 oil response**

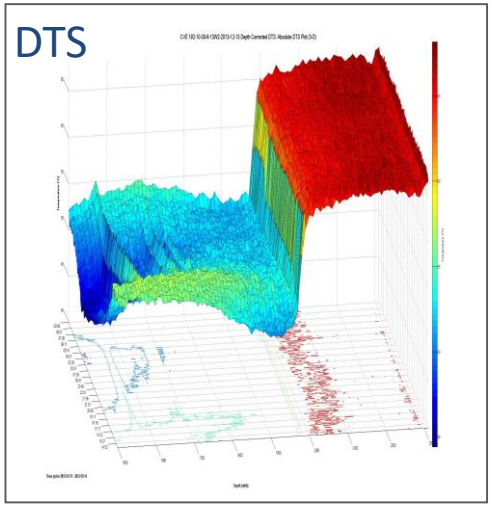
# Reservoir Surveillance – Pattern Reviews

WHITECAP RESOURCES INC

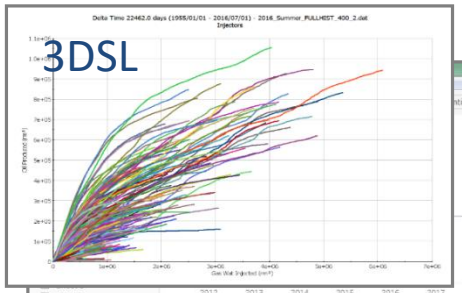
**Pattern Reviews**

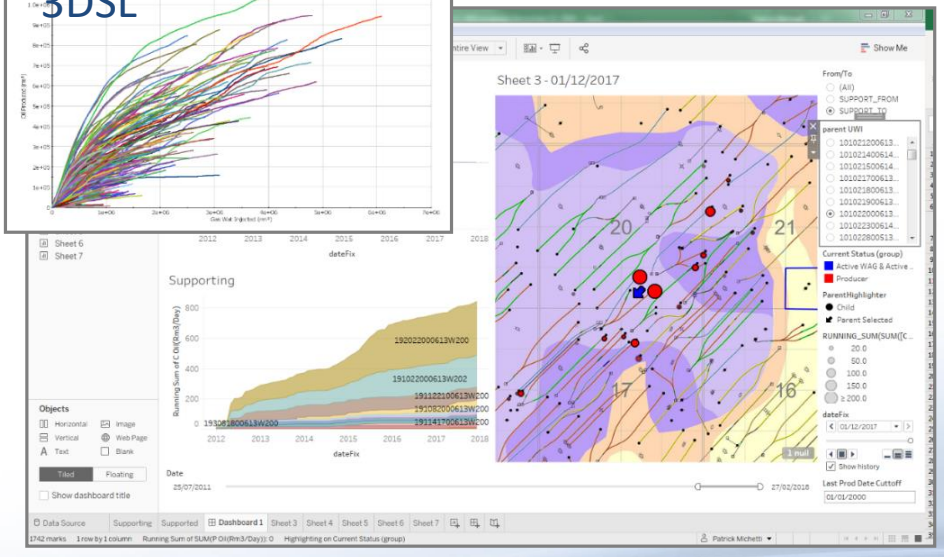
- Multidisciplinary teams meet weekly to review pattern and well performance
- Production and injection data are reviewed in conjunction with simulation, 4D seismic, spinner and DTS survey data to understand well interactions and identify optimization opportunities







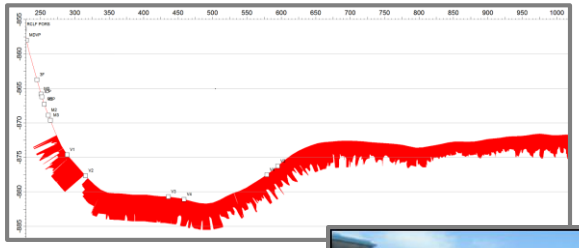



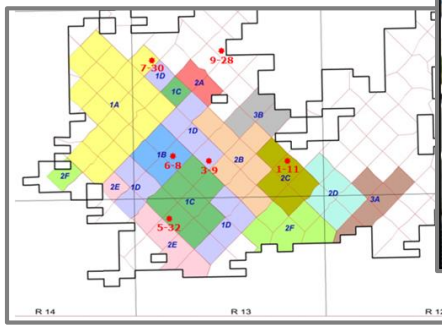
# MMV (Measurement Monitoring and Verification)

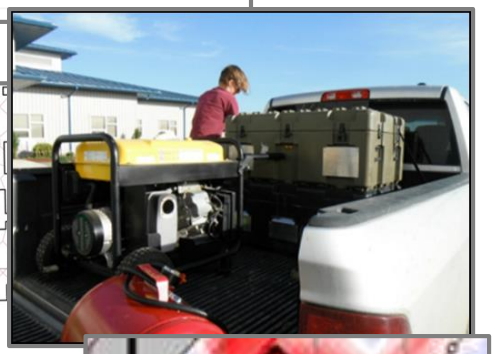
WHITECAP RESOURCES INC

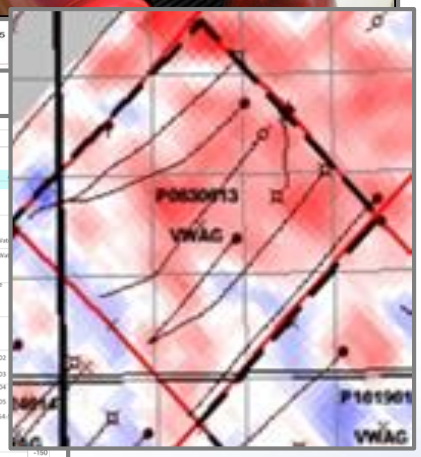
**Surveillance to Verify CO2 Containment**

- Mud Gas Logging
  - Pason gas concentration sampling in Vertical and Horizontal sections while drilling
- Pressure Observation Wells
- Shallow Aquifer Regional Fluid Characterization
  - Isotope and chemical water tests to confirm that Injected CO2 is not appearing in surface water
- Mobile Gas Detection
  - Equipment measured CO2, CH4, H2S and SO2 associated with wells and facilities and well service events
  - Surveyed fugitive emissions from 200 wells and compared to SCVF results
- 4D Seismic
  - Seismic used to evaluate CO2 in-zone conformance but also to verify that vertical migration is not occurring







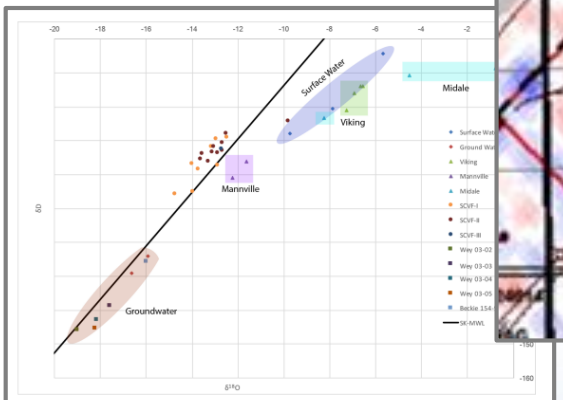




**Figure 1.** Plot of δD values versus $\delta^{18}O$ values. Included data: surface water, groundwater (2014 and 2017), the Viking Formation, the Mannville Group, the Midale, and 19 SCVF samples. The solid line represents the "Saskatchewan" Meteoric Water Line (SK-MWL) modified from McMonagle 1987.

# Flood Optimization

WHITECAP RESOURCES INC

**Surveillance**

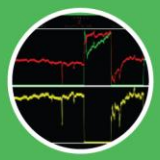
- Historical trends & data
- Production metrics & KPIs
- Communication behavior observed between wells
- 4-D Seismic

**Investigation**

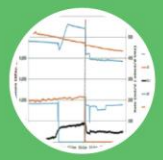
- Conduct fall-off tests to confirm suspected communication pathways
- Simulate possible scenarios (3DSL)
- Conduct surveys (Tracers, Spinners and DTS)

**Execution**

- Re-distribute injection (WAG)
- Producer modifications & infills
- $CO_2$ injection placement enhancement & WAG conversions
- Conformance treatment
- Well Abandonments



OFM/SCADA Trends



Falloff Tests

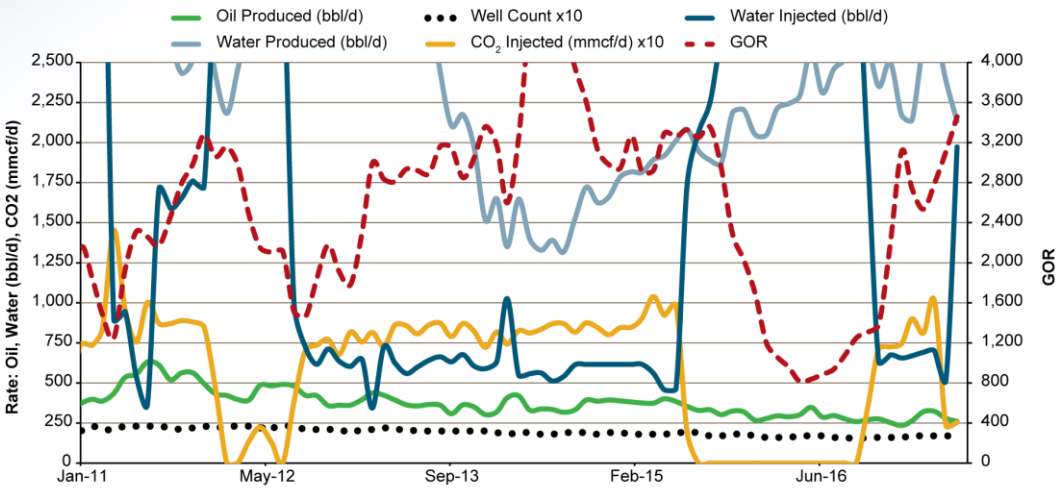
4D Seismic

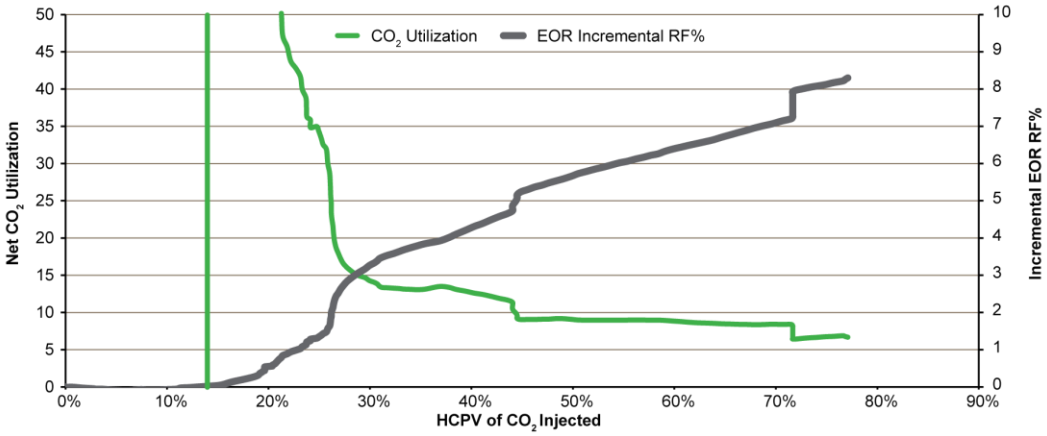
Simulation

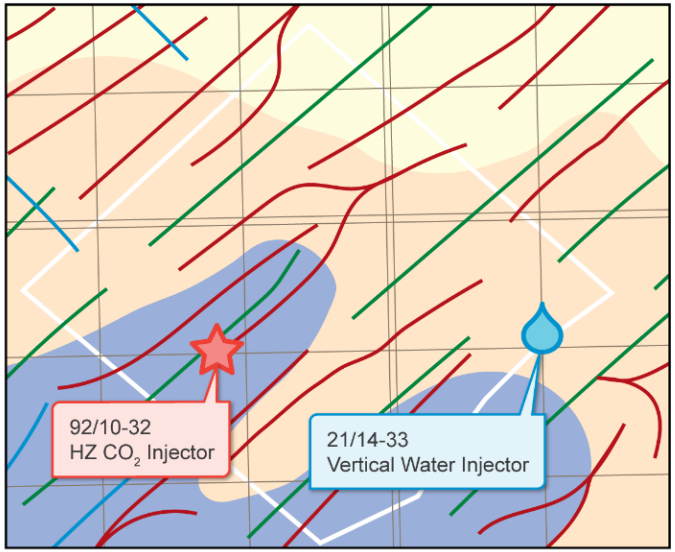
**Conformance Toolbox**

**Key Success Drivers: Injection Strategy and Efficiency → Reservoir Conformance**

# General WAG Management Case Study



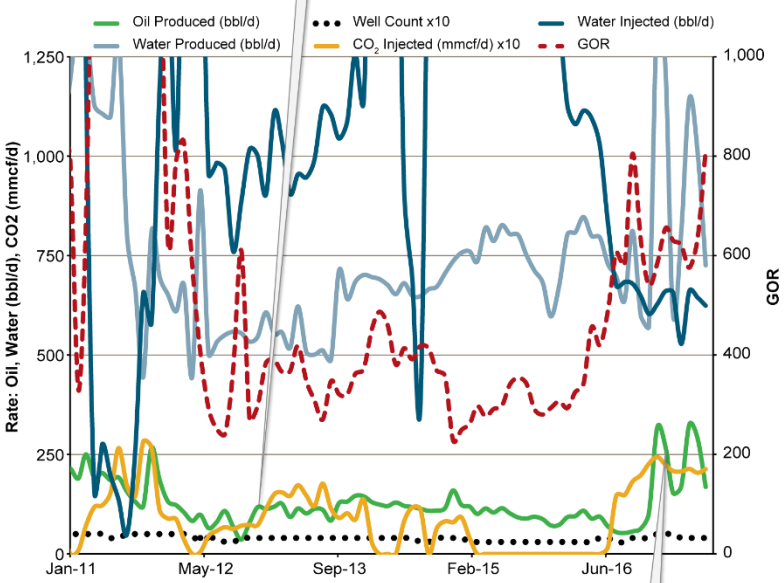

Monitor phase performance

- Turned central injector 92/10-32 over to $CO_2$ after long water cycle
- Improves $CO_2$ conformance and utilization
- Allows $CO_2$ and recycle capacity to be utilized in other areas (reducing total demand)
- $CO_2$ injection reduced over time by extending water cycles and suspending wells

**Water injection cycles used to enhance conformance and manage $CO_2$ purchase and recycle**

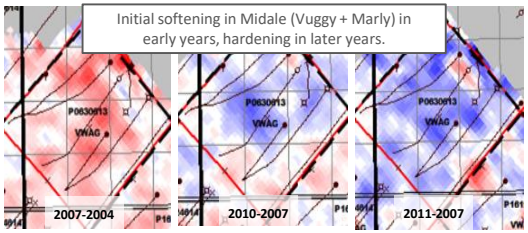
# Complex Conformance Treatment Case Study

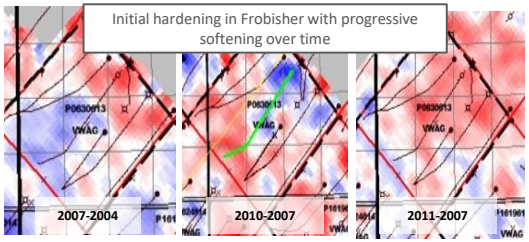
**Pre-conformance intervention:**
- Central horizontal drilled in 2011 with poorer EOR response than expected
- Low injection pressure and increasing rates at central injector (below miscible)



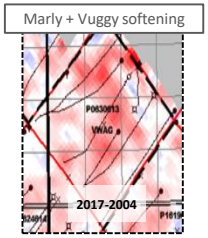

**Conformance re-abandonment of vertical in Nov 2015**
- Polymer gel treatment on vertical well used to block fracture communication from the horizontal injector into the Frobisher $CO_2$ injection resumed at central horizontal
- Higher injection pressures observed at lower injection rates
- ~189 bbl/d incremental oil response

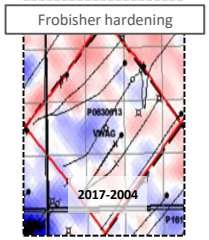
**4D shows $CO_2$ preferentially sweeping Frobisher Marly**

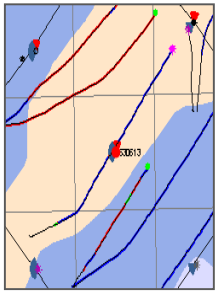


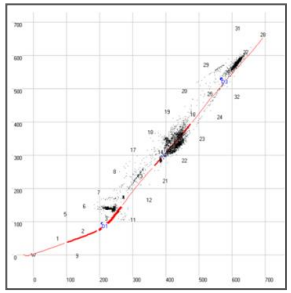




**2017 4D post treatment shows improved Marly sweep**

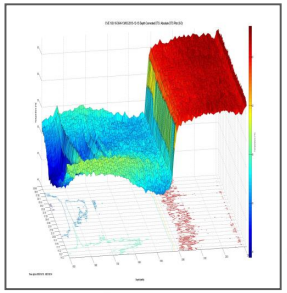




Acoustic survey indicates no injection downstream of intersection with abandoned vertical well



2014 distributed thermal survey supports 4D

**More advanced conformance treatments can provide very strong results but are very expensive**

# Complex Conformance Treatment Case Study

WHITECAP RESOURCES INC

## 93/07-12-006-14W2/0

- ❑ Mechanical shut-off of Wtr Prd
- ❑ Current Prd = 58 bbls/d (Gross)

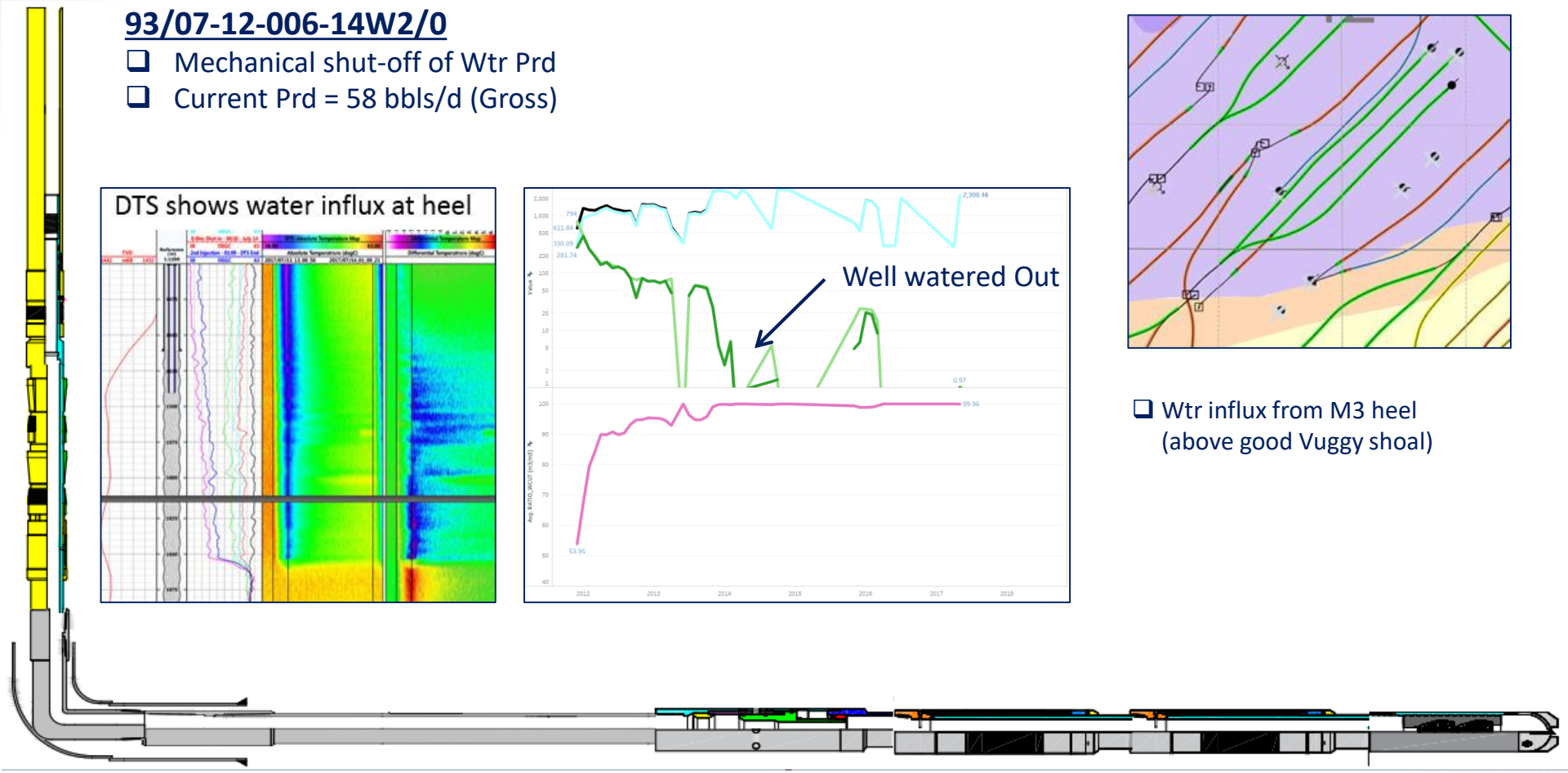








- ❑ Wtr influx from M3 heel (above good Vuggy shoal)



**Increasing investments Mechanical Conformance**

# Future of the Weyburn Unit

- Strong base cash flow to internally fund new opportunities
  - 24,000 bbls/d liquids with <5% decline
    - 30 API Oil (2-5% sulphur content)
    - High field gate price for Canadian crude
- Whitecap Resources acquired operatorship of the Weyburn Unit in 2018
  - Strong commitment to new Unit EOR investment
    - New EOR Rollouts
    - Flood Optimization
    - Expanded NGL capture
  - Continue to investigate new CO2 EOR opportunities in Western Canada and the US, leveraging
    - 18 years of CO2 EOR experience
    - Significant existing infrastructure investment
    - Excess CO2 supply
    - New carbon tax legislation