Vertical Conformance, the Challenge at Rangely

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Agenda

- The Rangely Weber Sand Unit (RWSU).
- The geology of the Weber Sand.
- The pace of development and completion strategies.
- The Water Flood project development.
- Preparation for the CO$_2$ project.
- Conformance improvement.
- Lessons Learned / Summary.
# Rangely Statistics, 2014

## Daily Average 2014

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Oil Production</td>
<td>11,200 B/D</td>
</tr>
<tr>
<td>NGL Production</td>
<td>1,200 B/D</td>
</tr>
<tr>
<td>Water Production</td>
<td>250,000 B/D*</td>
</tr>
<tr>
<td>Gas Production</td>
<td>153 MMCF/D*</td>
</tr>
<tr>
<td>CO₂ Purchases</td>
<td>35 MMCF/D</td>
</tr>
</tbody>
</table>

*All produced gas and water is re-injected.

## Cumulative as of 2014

<p>| | |</p>
<table>
<thead>
<tr>
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<tbody>
<tr>
<td>Oil Production</td>
<td>897 MMB</td>
</tr>
<tr>
<td>NGL Production</td>
<td>12.9 MMB</td>
</tr>
<tr>
<td>Water Production</td>
<td>4.7 BB</td>
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<tr>
<td>CO₂ Purchase</td>
<td>573 BCF</td>
</tr>
<tr>
<td>Gas Production (since CO₂)</td>
<td>1.2 TCF</td>
</tr>
<tr>
<td>CO₂ Injection</td>
<td>1.8 TCF</td>
</tr>
<tr>
<td>Well Data, 2014</td>
<td></td>
</tr>
<tr>
<td>----------------</td>
<td></td>
</tr>
<tr>
<td><strong>Average Elevation</strong></td>
<td>5300 FT</td>
</tr>
<tr>
<td><strong>Average Perf Depth</strong></td>
<td>6000 FT</td>
</tr>
<tr>
<td><strong>Active Producers</strong></td>
<td>415</td>
</tr>
<tr>
<td><strong>304 Electric Submersible Pumps</strong></td>
<td></td>
</tr>
<tr>
<td><strong>46 Flowing Wells</strong></td>
<td></td>
</tr>
<tr>
<td><strong>65 Rod Pumps</strong></td>
<td></td>
</tr>
<tr>
<td><strong>Active Injectors</strong></td>
<td>277</td>
</tr>
<tr>
<td><strong>Total Wells, including P&amp;A and SI</strong></td>
<td>954</td>
</tr>
</tbody>
</table>
# Reservoir Properties

<table>
<thead>
<tr>
<th>Producing Horizon</th>
<th>Weber</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lithology</td>
<td>Aeolian SS w/fluvial stringers</td>
</tr>
<tr>
<td>Unit Area</td>
<td>19,153 Acres</td>
</tr>
<tr>
<td>Average Gross Thickness</td>
<td>526 FT</td>
</tr>
<tr>
<td>Average Effective Thickness</td>
<td>189 FT</td>
</tr>
<tr>
<td>Average Effective Porosity</td>
<td>12%</td>
</tr>
<tr>
<td>Average Effective Perm.</td>
<td>8 md</td>
</tr>
<tr>
<td>Average Initial Swi</td>
<td>35.8%</td>
</tr>
<tr>
<td>Reservoir Temperature</td>
<td>160 deg. F</td>
</tr>
<tr>
<td>Initial Reservoir Pressure</td>
<td>2750 psi</td>
</tr>
<tr>
<td>Fractures</td>
<td>Some faulting &amp; natural fractures</td>
</tr>
</tbody>
</table>
Rangely Field Top Weber Structural Contour Map

Top Weber Ss structure map of the Rangely Field (Mendeck, 1986)

DISCOVERY WELL: RAVEN A1, 1993
ORIGINAL GAS-OIL CONTACT -330 ft MSL
ORIGINAL OIL-WATER CONTACT -1150 ft MSL

CI = 50’
Rangely Weber Sand Unit

Aeolian Sandstone

Sandstone w/ Fluvial deposits

AVG PERMEABILITY (Geom. Avg)
(Core data - 1 md cutoff)
CI = 2 md

24 md

4 md
The pay is in the odd numbered zones.
Rangely Weber Sand Unit Development History

- '33: Discovery - Raven A1
- '43: Start 40 Acre Development
- '58: Unitize, pilot Water Flood
- '66: Start 20 Acre Development
- '86: Initiate CO2 Project
RWSU - Field Development History

- Discovered the Raven A1 well in 1933, idle for ten years.
- 40-acre development 1943 – 1948, in five years.
  - 470 - wells completed as open hole producers in the Weber sand.
    - 51% shot with Nitro Glycerin (East End).
    - 49% braden head sand oil squeezes (West End).
    - Many 40-Acre producers were fracture prior to conversion to injection.
- Unitized in 1957 and initiated the Water Flood in 1958.
  - 37% of 40-acre open hole producers were converted to water injection.
  - Installed 5” and 5-1/2” liners across the Weber Sand in 53% of these open hole producers.
RWSU- Field Development History

- 20-acre development, 1966 – 1992 ~
  - 400 wells, typically cased to Total Depth.
  - 40% were drilled and completed as injectors.

  - A single string of tubing with multiple packers and side pocket mandrels with an orifice to control the rate of injection into each zone.
  - SIE installed in 260 injectors, plugging and corrosion has reduced the effectiveness.
  - Removing SIE is very difficult and costly in old wellbores.

- RWSU has 343 Injection wells
  - 38% of all RWSU wells are designated as an injector with 277 active.
Selective Injection Equipment (SIE)
RWSU Projects and Opportunities

- 10-acre infill pilots implemented and under review.
  - Three 10-acre pilot projects drilled from 1984-85, 23 10 Acre wells.
  - Two 10-acre producers drilled in 2010 and one 10-acre injector drilled in 2013.

- Sweep improvement
  - Areal conformance by realignment.
    - 3 successful pilots and a larger project under review in the middle of the field.
  - Vertical or zonal conformance.
    - A large opportunity, challenging to wellbore equipment and condition.
    - Piloted a side track project to evaluate mechanical conformance improvement.
    - Considering a foam CO₂ trial and re-evaluating gel and foamed gel projects.
Side Track Project for Vertical Conformance Improvement

Description:
Increase production and ultimate recovery with a conformance improvement project, using recently acquired experience in sidetrack technology.

Opportunity:
After successfully drilling the Weber section on several 20-acre new drills and a sidetrack using a work-over rig, we initiated a pilot project to sidetrack and enhance injection into under-processed zones, generating a positive response in the offset producers.
Project Scope:

- Side-track existing injection wells w/ problems across the Weber, i.e. broken injection profiles, failed SIE, poor casing, etc.

Alternative Selection Criteria:

- Area with the potential for zonal conformance improvement.
- Wells close together to impact a project area.
- An area of high processing rate to see an early impact.
- At least 3+ zones present.
- Data to access the base line vs. the response.
- No additional work in area that may influence the project, i.e. new drills, 10-acre pilot, realignment and expansions
Rangely Weber Sand Unit
Vertical or Zonal Conformance

Injection history shows zones 5, 7 and 9 under-processed...

...with very little of current CO2 injection going in those zones

Here is an example of opportunity in lower zones (5, 7 and 9). These zones are estimated at 1.7 MMB OOIP, but are largely unprocessed with CO2.

Assuming a CO2 recovery of only 5%, would result in 85,000 Bbls of additional oil through improving conformance.
Rangely Weber Sand Unit
Vertical Conformance Improvement Project Area

AVG PERMEABILITY (Geom. Avg)
(Core data - 1 md cutoff)
CI = 2 md
Vertical Conformance Improvement Project Area
Well Work Procedure

- **Pre work:**
  - Enlarged the location to accommodate additional equipment.
  - Pull injection string, run work string & cleanout SIE w/ 1-1/4” drill pipe.
  - Pre-cut tubing w/ wireline between packers to expedite fishing SIE.
  - P&A'd the Weber section and set the base for the whip-stock.

- **Set whip-stock, cut window and drill side track wellbore:**
  - Required larger pump and 3-1/2” power swivel.
  - Install 5” L80 Hydril liner from 100’ above window to TD.
  - Install 5-1/2” L80 LT&C liner from hanger to surface.
  - Complete the lower zones, install packers and fiber-lined tubing.
Injector with SIE & broken profile

- Over processed in Zones 1 & Zone 3
- Plug back, Side track & process lower zones
Conformance Improvement Project

WE CI - All

Up 100+ bopd
Conformance Improvement Project

WE CI - North Area

Up 70 bopd
Conformance Improvement Project

WE CI - East Area

Slow to respond
Conformance Improvement Project

WE CI - South West Area

Oil
Gas
Wtr
Wnj
Gnj

Active Producers
Active Injectors

Up 40 bopd

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West End Conformance Improvement Project Lessons Learned

- We worked closely with experienced personal from the work-over rig, fishing and tool companies to develop a successful procedure.

- Coil tubing cleanouts through packers and mandrels (SIE) are difficult. We drilled out with 1-1/4” drill pipe and then made wire-line cuts to fish SIE.

- Fishing SIE in old wellbores is unpredictable. The minimum objective was to fish at least to the bottom of zone 3 and plug zones 1 & 3.

- Cutting the window and drilling the side track was executed well at 130’/day.

- Extra lead time was required for the 5” Hydril connections for handling tools, the cement shoe, float collar and the hanger.

- Liner were run in two stages: The 5” Hydril liner was installed and cemented in the sidetracked wellbore, then the 5-1/2” liner was installed to surface. To ensure cement to surface in this low reservoir pressure area of the RWSU.

- Ran cased hole logs, PNL or CNL with CBL to pick perforations.
West End Conformance Improvement Project Lessons Learned

- Scoping future conformance improvement projects:
  - Continue to utilize an integrated technical team (Tenant #10)
    - Project selection: Earth Scientist, Reservoir, Production & Completion Engineering

- Optimizing for the Future.
  - Manage injection target rates, monitor BHP, keep above MMP.
    - Be aware of the logistics for shut-in of CO₂ Trunks to Install WAG skids.
  - Run injection profiles, before & after on both water & CO₂.
  - Be aware of production loss from plugging back over processed zones.
  - Schedule a sequence of side track jobs to optimize the operation.
Summary

- A large opportunity exists to improve the ultimate recovery at Rangely through vertical conformance improvement.

- Plugging and corrosion of equipment in the injection wells has reduced the effectiveness. Removing SIE is very difficult and costly in old wellbores.

- Where selective injection equipment has been removed, there is no mechanical control of injection fluids within the Weber Sand formation.

- We can side-track and drill a wellbore parallel to the P&A’d wellbore and re-completed in the under-processed zones.

- The plug-back and side-track is one alternative to improve vertical conformance.

- A 10-acre injector may be required to achieve vertical conformance in certain areas of the Rangely Weber Sand Unit.
Thank You
BACK UP SLIDES
Current Wellbore

Plug Bushing

2-7/8" 6.5#/ft EUE 8rd Fiberlined tubing

Calculate Packer fluid @ 10,000 psi (KNI-12) in to the bigbore Annulus.

To maintain Underground Injection Control (UIC) the Colorado Oil & Gas Conservation Commission (COGCC) requires a Mechanical Integrity Test (MIT) from the isolation packer to surface every 5 years.
1200 psi for 15 min w/ less than 10% loss.
We report casing pressure and injection rate montly to the COGCC.

Isolation Packer: Hydraulic set Packer or TAM FreeCap packer in bad casing

On/Off tool

Hydraulic set Packer or TAM FreeCap packer in bad casing

Side pocket Mandrel w/ orifice to adjust rate

1.0" Repeated plug set

Tubing below isolation packer is externally fiberglass wrapped.
### Geologic Section at Rangely

#### Stratigraphy of the Rangely Anticline
Rio Blanco County, Colorado

<table>
<thead>
<tr>
<th>ERA</th>
<th>PERIOD</th>
<th>FORMATION</th>
<th>LITHOLOGY</th>
<th>THICKNESS</th>
</tr>
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<tbody>
<tr>
<td></td>
<td>Upper</td>
<td>Mancos Shale</td>
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<td>2700 ft.</td>
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<tr>
<td>Cretaceous</td>
<td>Dakota Sandstone</td>
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<td>Upper</td>
<td>Morrison Formation</td>
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<td>Jurassic</td>
<td>Curtis Formation</td>
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<tr>
<td></td>
<td>Entrada Sandstone</td>
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<td>150 ft.</td>
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<td></td>
<td>Carmel Formation</td>
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<td>50 ft.</td>
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<tr>
<td></td>
<td>Lower</td>
<td>Navajo Sandstone</td>
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<td>Jurassic</td>
<td>Chinle Formation</td>
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<td></td>
<td>Shinarump Congl.</td>
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<td>30 ft.</td>
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<td></td>
<td>Lower</td>
<td>Moenkopi Formation</td>
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<td>Permian</td>
<td>Phosphoria Formation</td>
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<tr>
<td></td>
<td>Weber Sandstone</td>
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<td>1100-1200 ft.</td>
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<td>Maroon Formation</td>
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<tr>
<td>Pennsylvanian</td>
<td>Morgan Formation</td>
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<td>1500 ft.</td>
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<td>Molas Formation</td>
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<tr>
<td></td>
<td>Madison LS</td>
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<td>500 ft.</td>
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<td>Mississippian</td>
<td>Chaffee Formation</td>
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<td>Manitou LS</td>
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<td>Devonian</td>
<td>Lodore Formation</td>
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<td>(Silurian)</td>
<td>Uinta Mtn. Group</td>
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<td>Cambrian</td>
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<tr>
<td>Pre-Cambrian</td>
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