Rangely Weber Sand Unit WAG Management Optimization

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Key messages

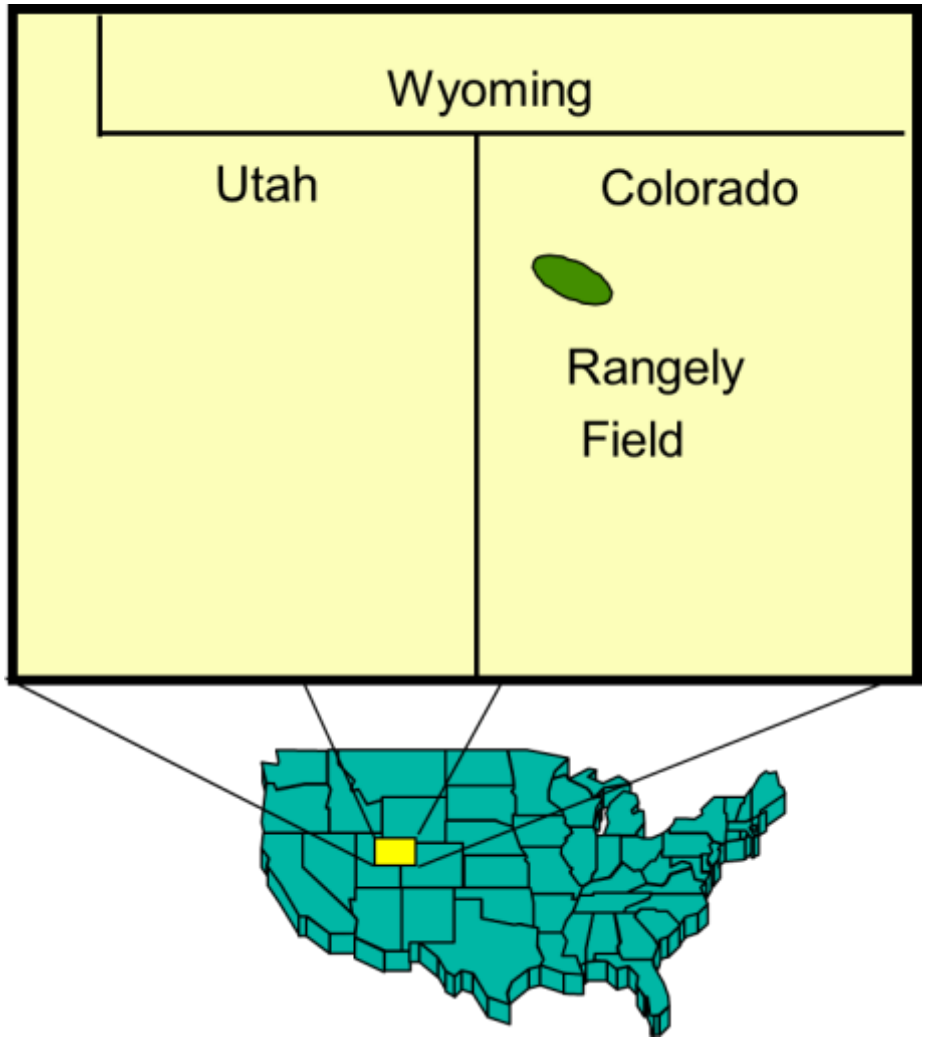
- Rangely has produced over 900 MMBO.
- Current recovery is focused on CO_2 EOR.
- Successful conformance control is an important piece of flood management.
- Water Alternating Gas (WAG) management is the ongoing focus on conformance control at Rangely.
- Planning and execution of the WAG program at Rangely is intensive and complex for both the technical staff and operations.
- Starting in 2012 new injection equipment, WAG skids, were installed across the field to improve the WAG program.
- Benefits of installation of new WAG skids:
  - Enhancing conformance and improving production
  - Supplying better data to enhance decisions
  - Improving control of the WAG process
  - Lowering safety and environmental risks

Outline

1. Field overview
2. Conformance control and WAG management
3. WAG management history
4. Yearly WAG management planning
5. WAG plan execution
6. Legacy WAG equipment vs. new WAG skid
7. WAG optimization with new WAG skids
8. Results of WAG optimization

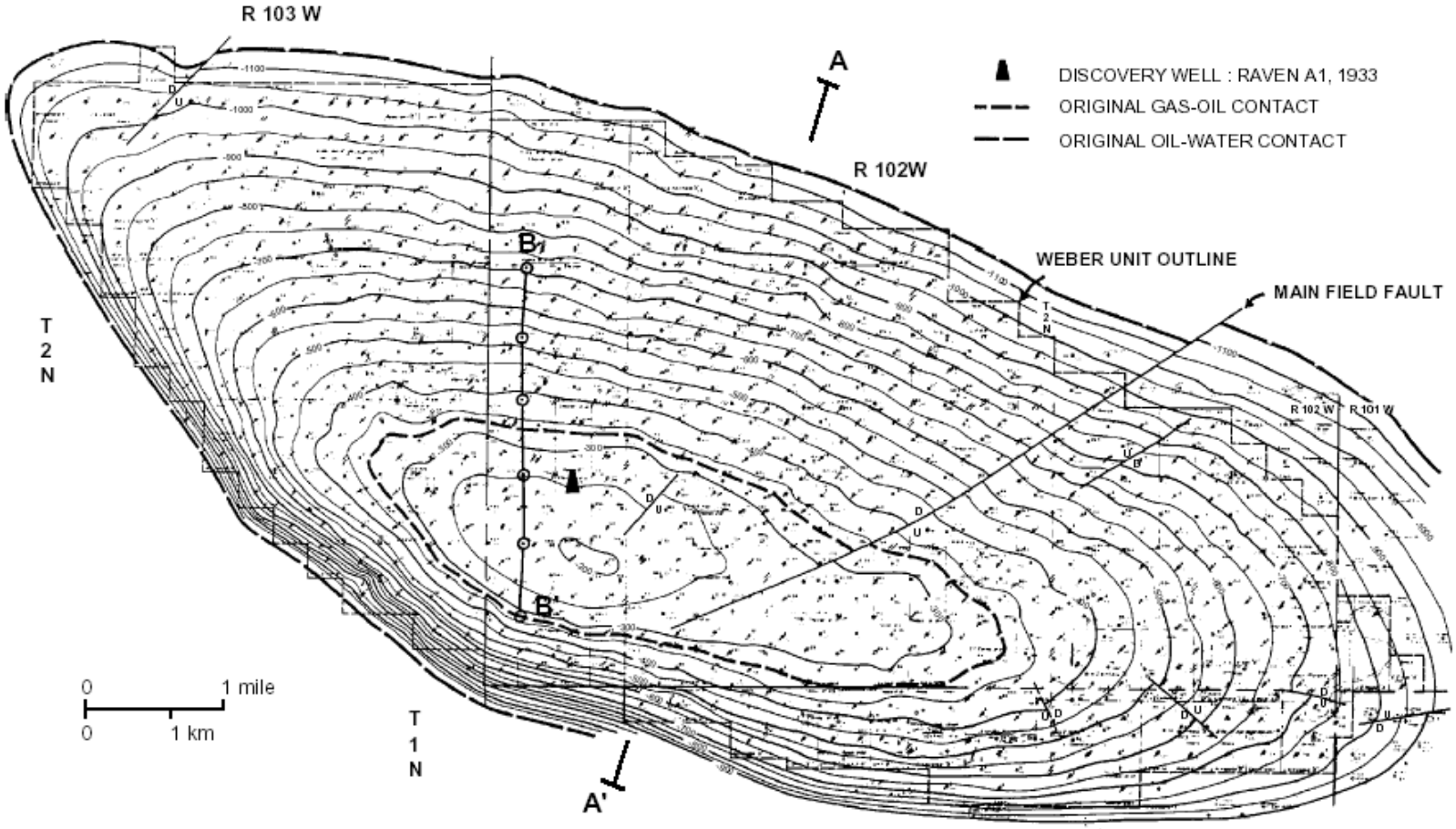
Rangely Weber Sand Unit (RWSU) location

Northwest Colorado near the town of Rangely



RWSU top structural contour map

Faulted anticline with four-way closure



RWSU type log

Six productive zones in the Weber

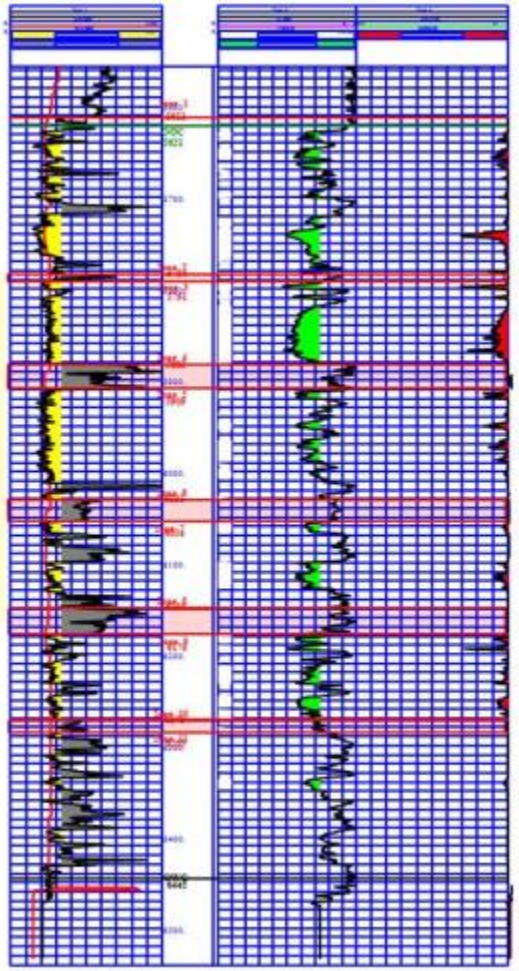
TYPE WEBER LOG
RANGELY FIELD
U.P. 139Y-28

Odd Zones = Aeolian

PAY

Even Zones = Fluvial

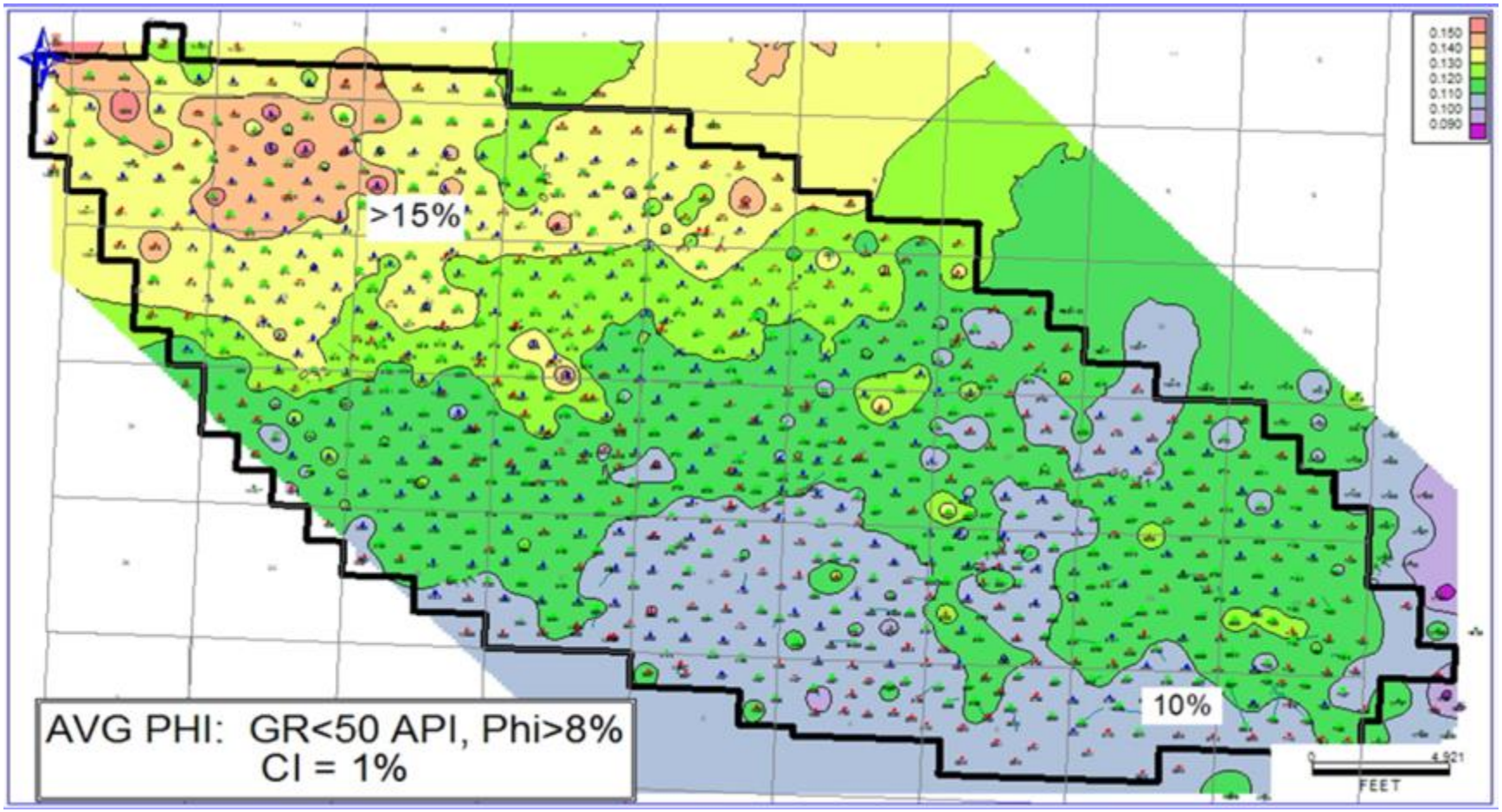
NON-PAY



TOP WEBER
ZONE 1
ZONE 2
ZONE 3
ZONE 4
ZONE 5
ZONE 6
ZONE 7
ZONE 8
ZONE 9
ZONE 10
ZONE 11

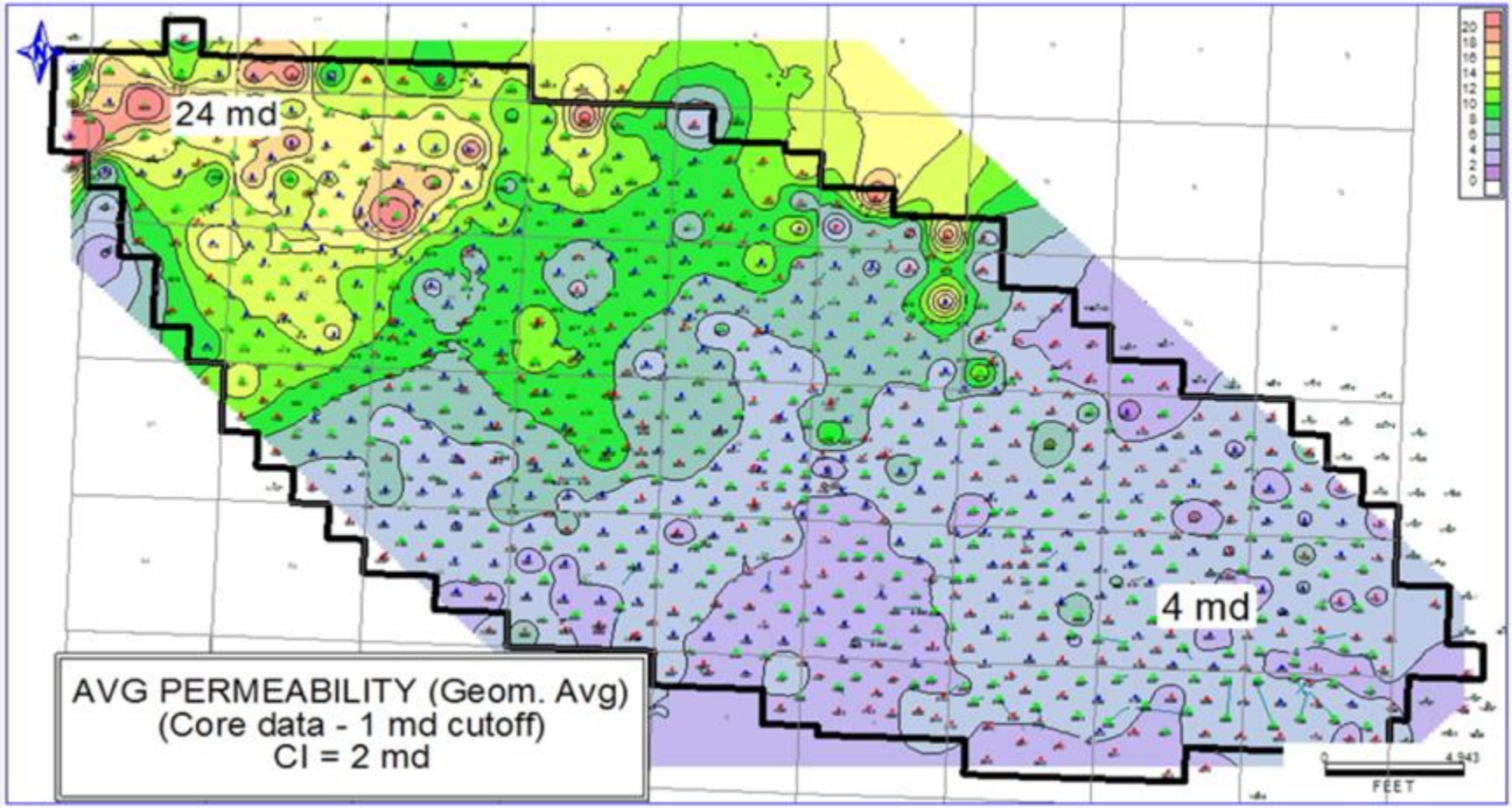
Porosity map

Varied sandstone lithology across the field



Permeability map

Varied sandstone lithology across the field



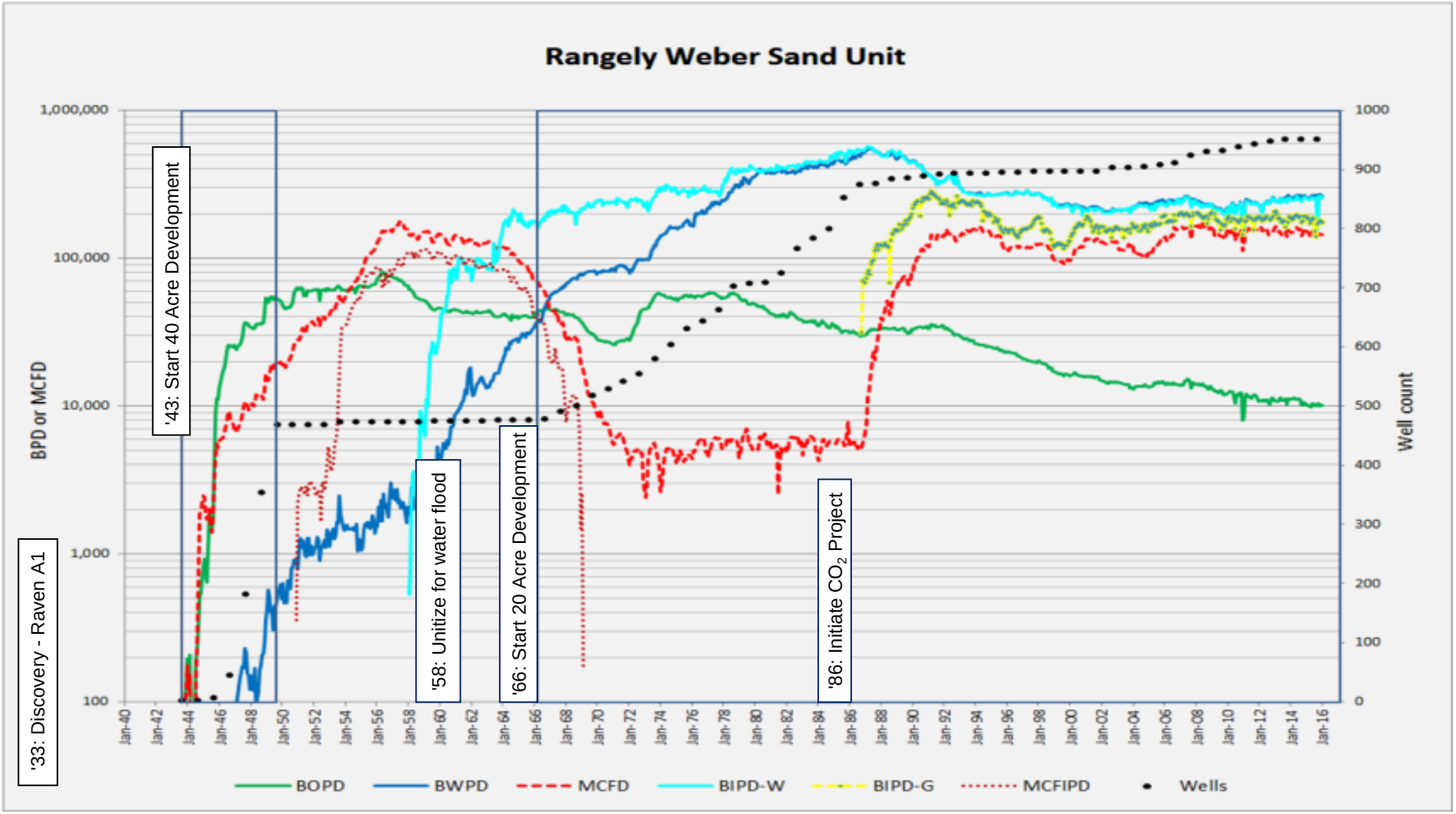
Average reservoir properties

- Average porosity: 12%
- Average permeability: 8 mD
- Reservoir temperature: 160 ^{o}F
- Oil gravity: 35^{o}
- Oil viscosity: 1.7 cp
- OWC: -1150 ft (SS)
- Initial reservoir pressure: 2750 psia
- Current reservoir pressure: 2500-4000 psia
- Minimum miscibility pressure: 2750-3000 psia

Development history

Weber sand discovered	1933
40-acre development started	1944
HC gas injection	1950-1959
Unitized	1957
Waterflood expansions	1958-1983
20-acre infill development	1963-1985
10-acre infill pilots	1983-present
CO_2 flood starts	1986
Edge CO_2 expansions & targeted infills	1999-present

Development history



Well data – 2016

Wide range of well and completion types

Active producers	**418**
Electric submersible pumps	309
Flowing wells	42
Rod pumps	67
Active injectors	282
Total active wells	**700**

Conformance control

Challenging but key to success

- Effective CO_2 EOR flood management at Rangely requires good pressure maintenance and **conformance control.**

- Conformance control consists of methods devised to evenly and thoroughly process the reservoir, to maximize hydrocarbon recovery and minimize waste of injection fluids.

- Conformance can be vertical, areal, or both.

- Methods at Rangely:
  - Pattern realignment
  - Targeted sidetracks
  - Selective injection equipment
  - Chemical treatments
  - **WAG management**

WAG management

Favored conformance control method with strong results

WAG = Water Alternating Gas - the process of injecting water and gas in alternating periods

WAG management is a favored form of conformance control due to:

- Ease of implementation
- Controllable, non-permanent, and reversible
- Quick results – success or failure seen within weeks or months
- Low cost

Good WAG management should:

- Optimize and possibly reduce gas production – minimizing compression costs
- Optimize makeup volumes – water and CO_2 purchases
- Maximize oil recovery

WAG management history at RWSU

Reservoir response and other factors drive continuing changes

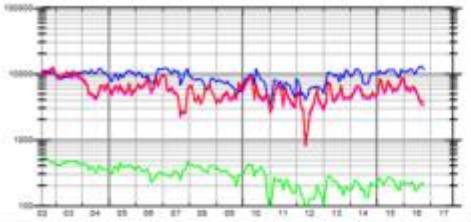
	Initial Design	Current
WAG ratio	1:1	Tapered
Half cycle slug size	1.5% HCPV	Varies
HCPV CO_2 slug size	30%	55% (current)
Compression capacity	120 MMCFD	165 MMCFD
Peak CO_2 makeup rate	200 MMCFD	150 MMCFD
Ultimate CO_2 makeup	670 BCF	600 BCF
NGL recovery	NO	YES

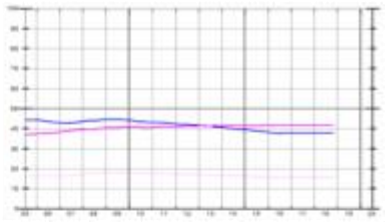
WAG management planning

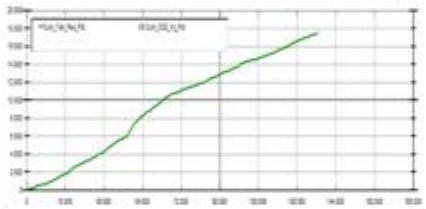
Large data set (with uncertainties) driving decisions

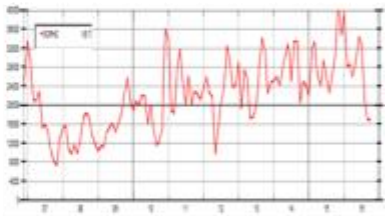
Yearly process to design the optimal schedule based on recent performance

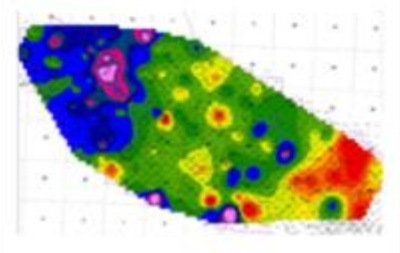
- Data reviewed includes:
  - Production/injection trends
  - Dimensionless recovery curves
  - Gas produced to gas injected ratio
  - Voidage replacement ratio
  - Gas oil ratio
  - CO_2 utilization
  - Reservoir pressure
  - System constraints
    - Injectivity
    - Injection lines
    - Flowlines
    - CO_2 plant
    - Water plants
    - CO_2 makeup
    - Disposal capacity
    - Wellbore availability
    - Org. capability (e.g. manpower)











WAG management planning

Large data set (with uncertainties) driving decisions

Yearly process to design the optimal schedule based on recent performance

Results focused on efficient CO_2 utilization

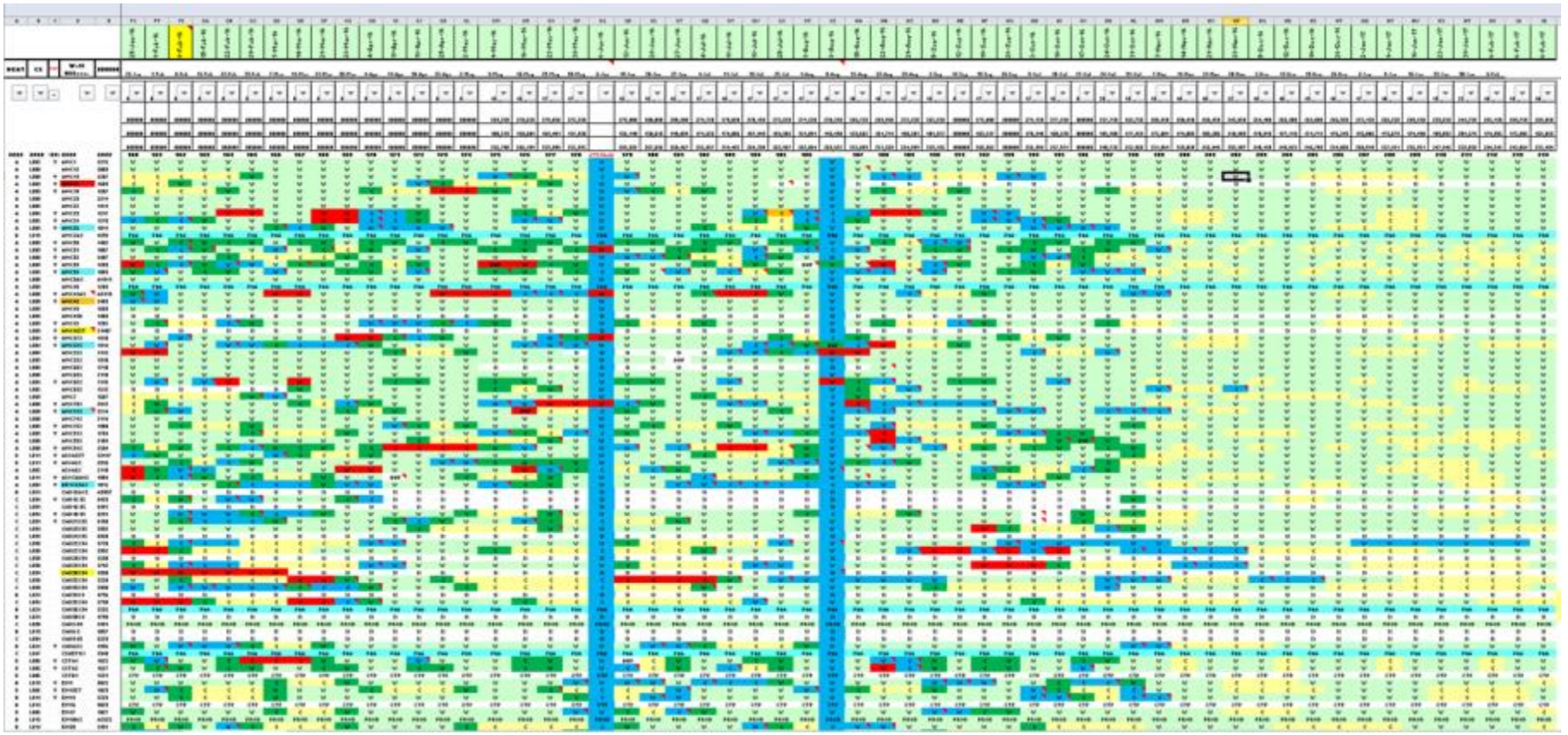
Outputs for each pattern:

- CO_2 slug size
- WAG ratio
- Target injection rate
- **Weekly WAG schedule**

WAG plan execution

Time intensive process, teamwork is key to success

- WAGs occur on an ongoing basis, ~2400 completed year-to-date in 2016!
- The planned WAG schedule requires weekly updating to maintain system balance with ongoing operations



WAG skid installation project

Summary

- Two long standing opportunities:
  1. Enhanced data acquisition on injectors
  2. Operational improvement of the WAG process
- A project was started in 2012 to ensure both opportunities were addressed in an optimal way.
- The goal of the WAG skid project is to improve the production and ultimate recovery of the Rangely field through implementation of an improved WAG process and data acquisition from the injectors.

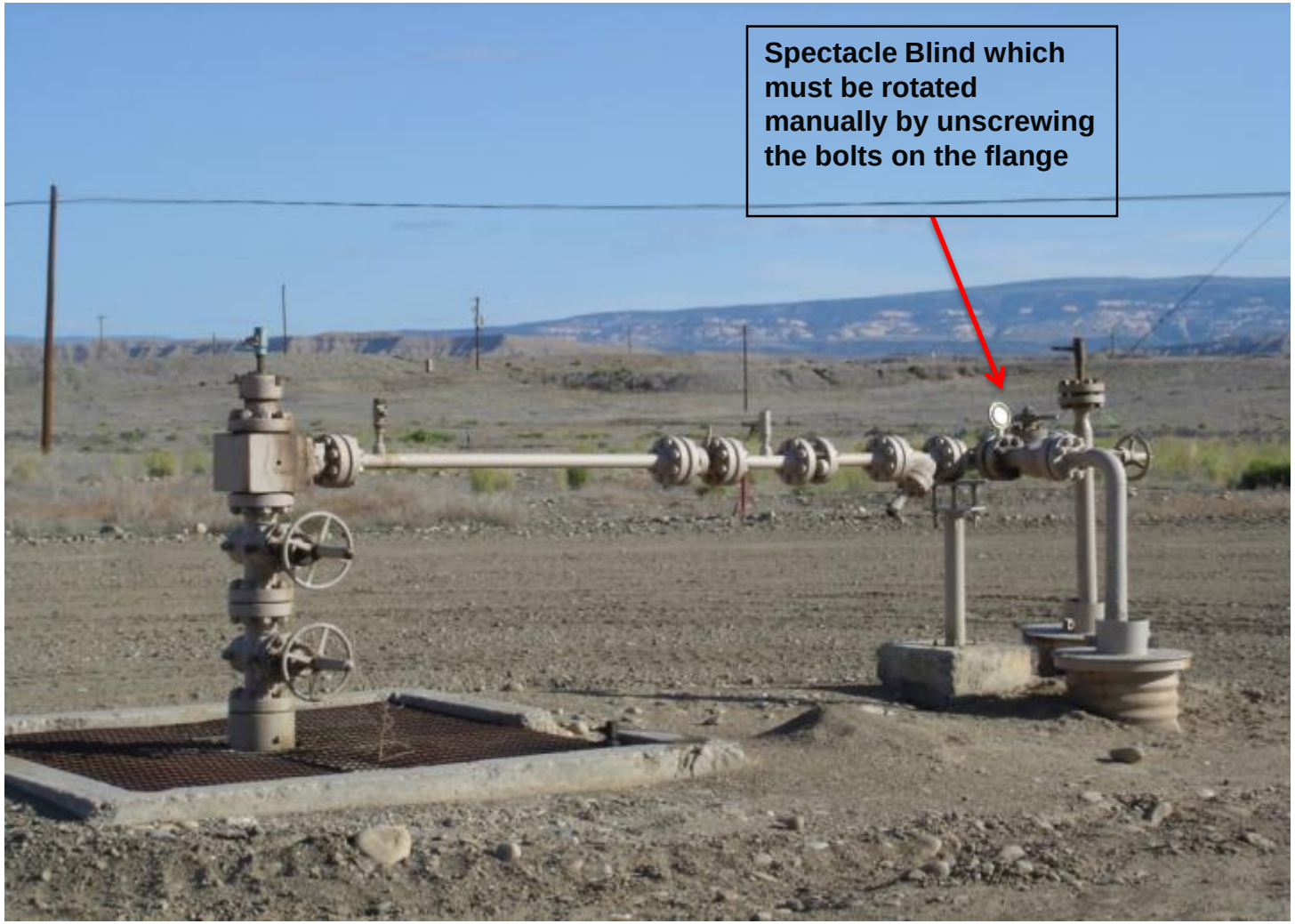
WAG skid installation project

Operational significance

- Enhanced ability to increase the number of WAGs per week above the current capabilities as needed for reservoir management
- Access to real time data to provide the ability to make more timely decision in regards to reservoir management i.e. injection rates, cycles, VRR, line maintenance, casing pressures, leak detection, etc.
- Ensured standardization of injection well upgrades
- Leverage expertise currently in place from FE, Ops, EIS & Technical Team
- Lowering safety and environmental risks

Legacy WAG equipment

Labor intensive, limited data

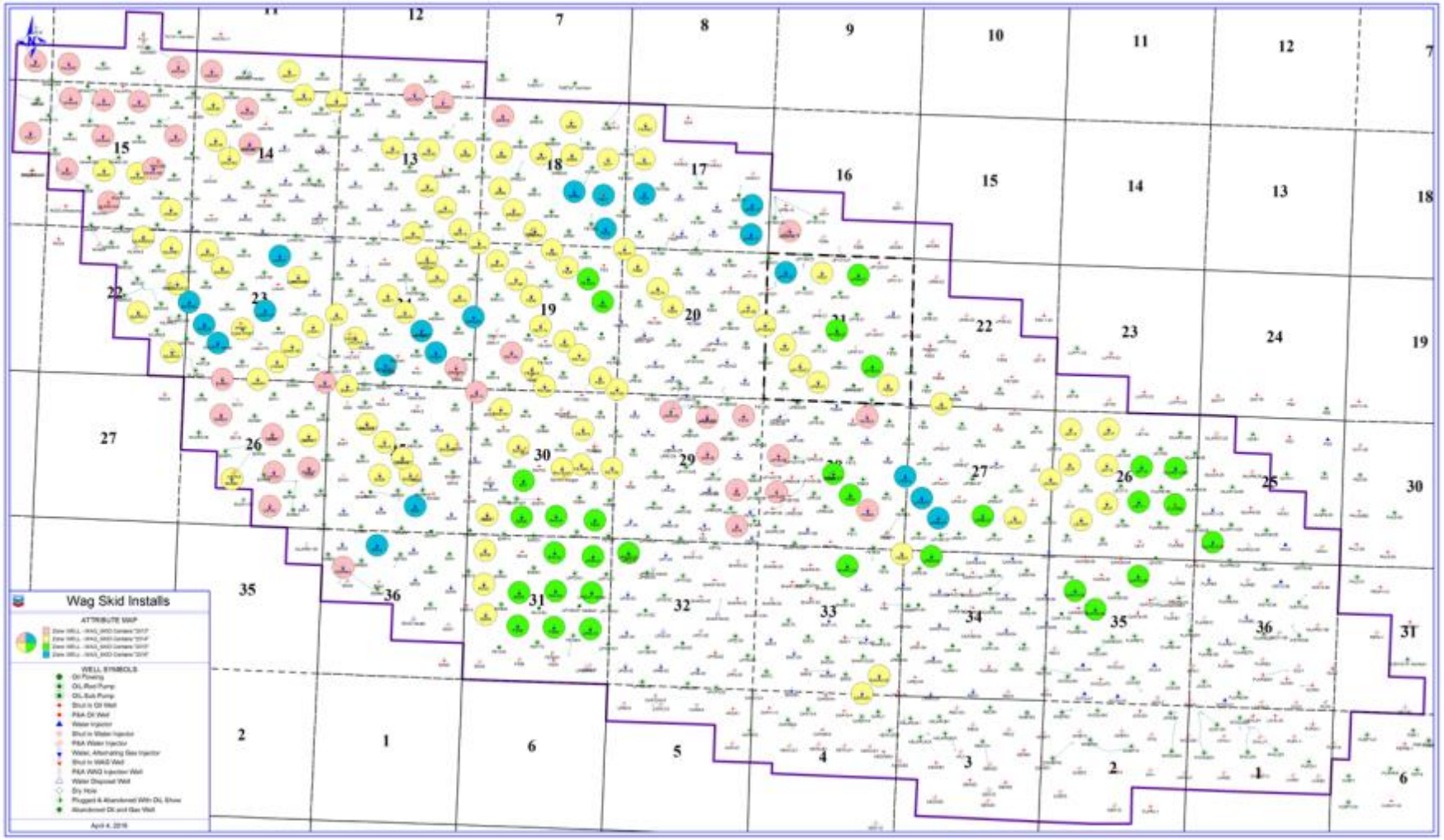


New WAG skid design

Streamlined operation with increased data and limited automation

Current WAG skid installations

Yearly bulk installations gain from manufacturing efficiencies



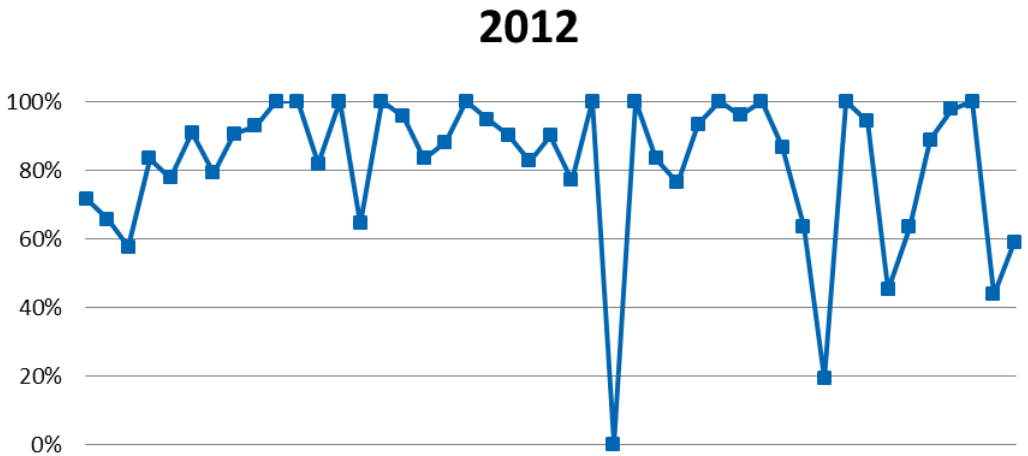
Changes to WAG management

More WAGs in less time with better control

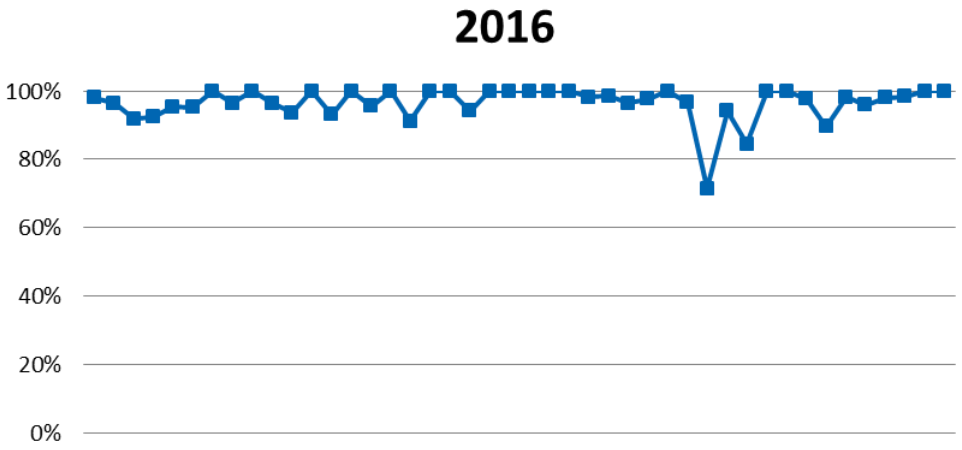
- Time to WAG a well went from ~45 minutes (possibly 2 operators) to less than 10 minutes
- Auto choke capability – rates are managed through a controller with a rate set point, requiring less operator intervention
- Decreased reliance on WAG ratio tapering to manage gas control
  - Slug sizes are can be reduced down to ~0.25 HCPVi CO_2
  - Some areas were successfully reverse tapered
- 2,450 WAGs in 2011 to 3,300 WAGs in 2016
- Increased WAG execution efficiency
- Increased target rate compliance

WAG execution efficiency

Maintaining schedule consistently with all injectors

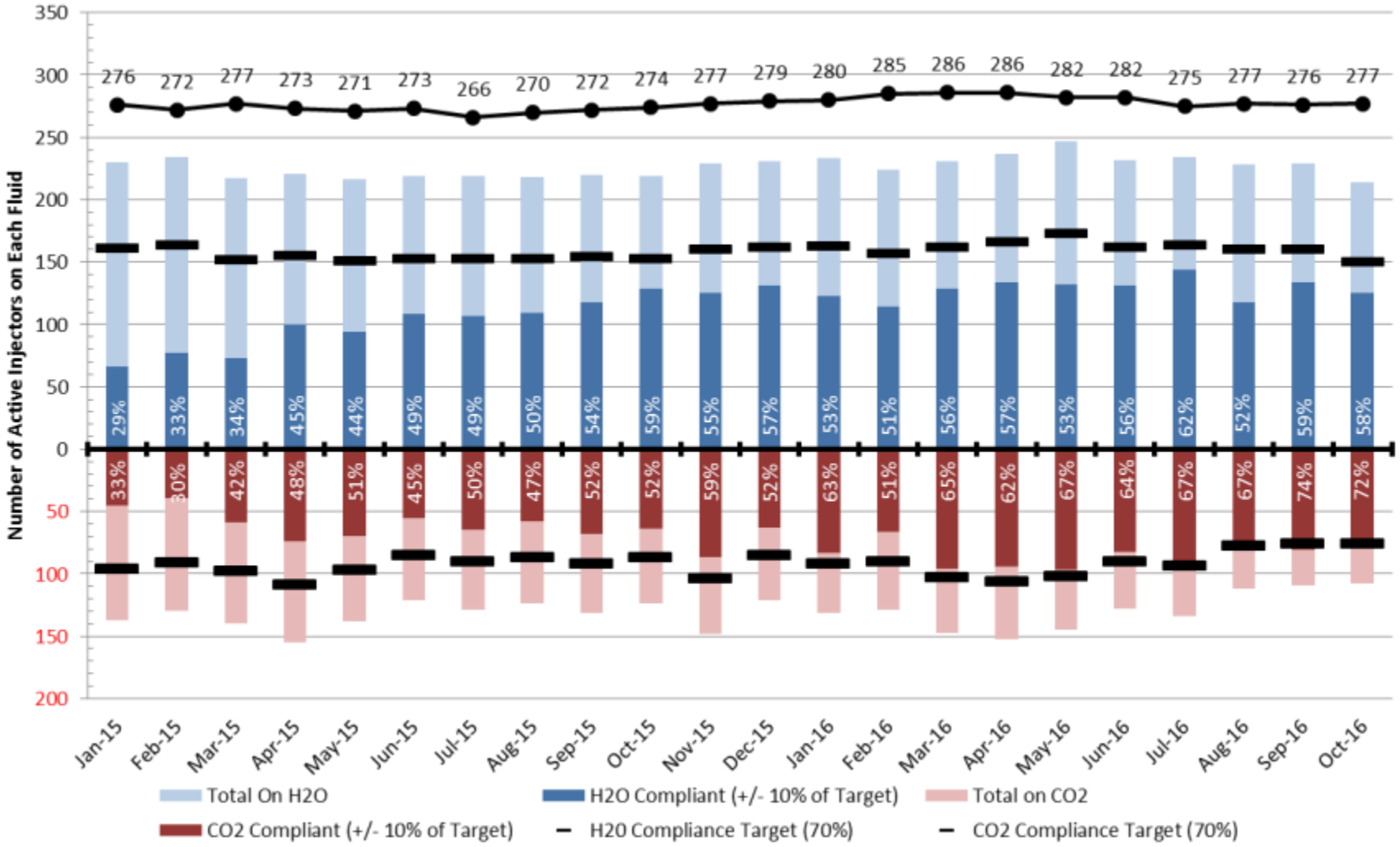


Percent of scheduled WAGs completed each week



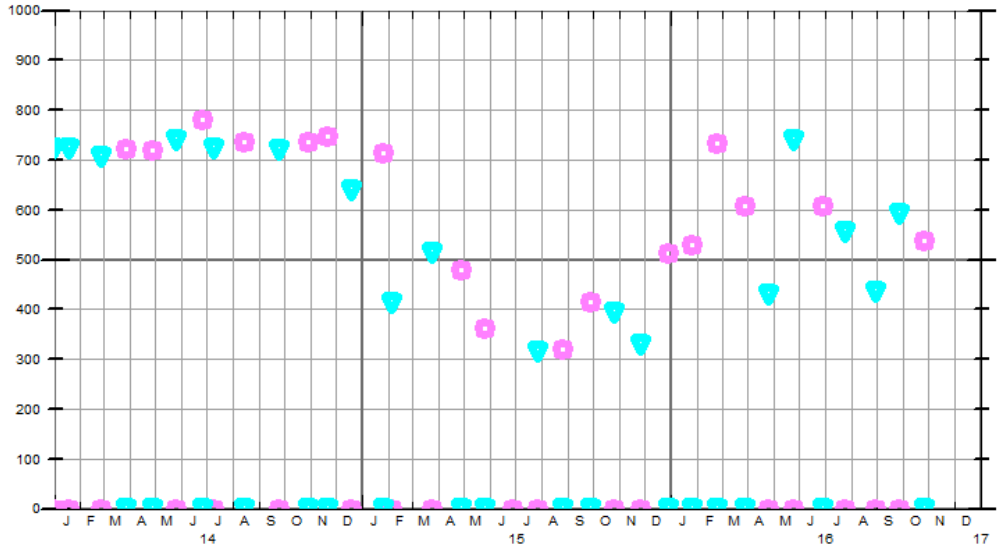
Target rate compliance

New metric – significant gains since 2014



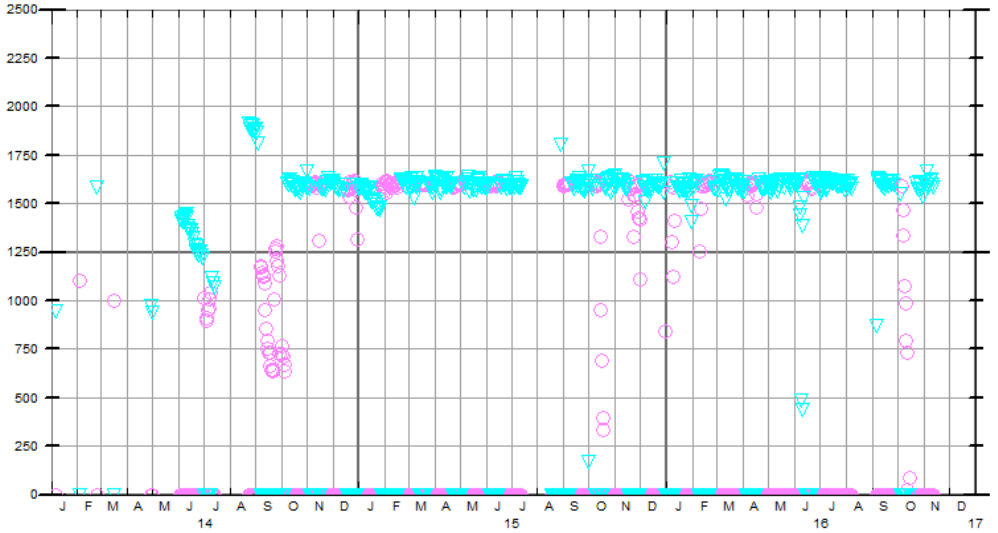
WAG well injection rate charts

More data, better rate control with new equipment



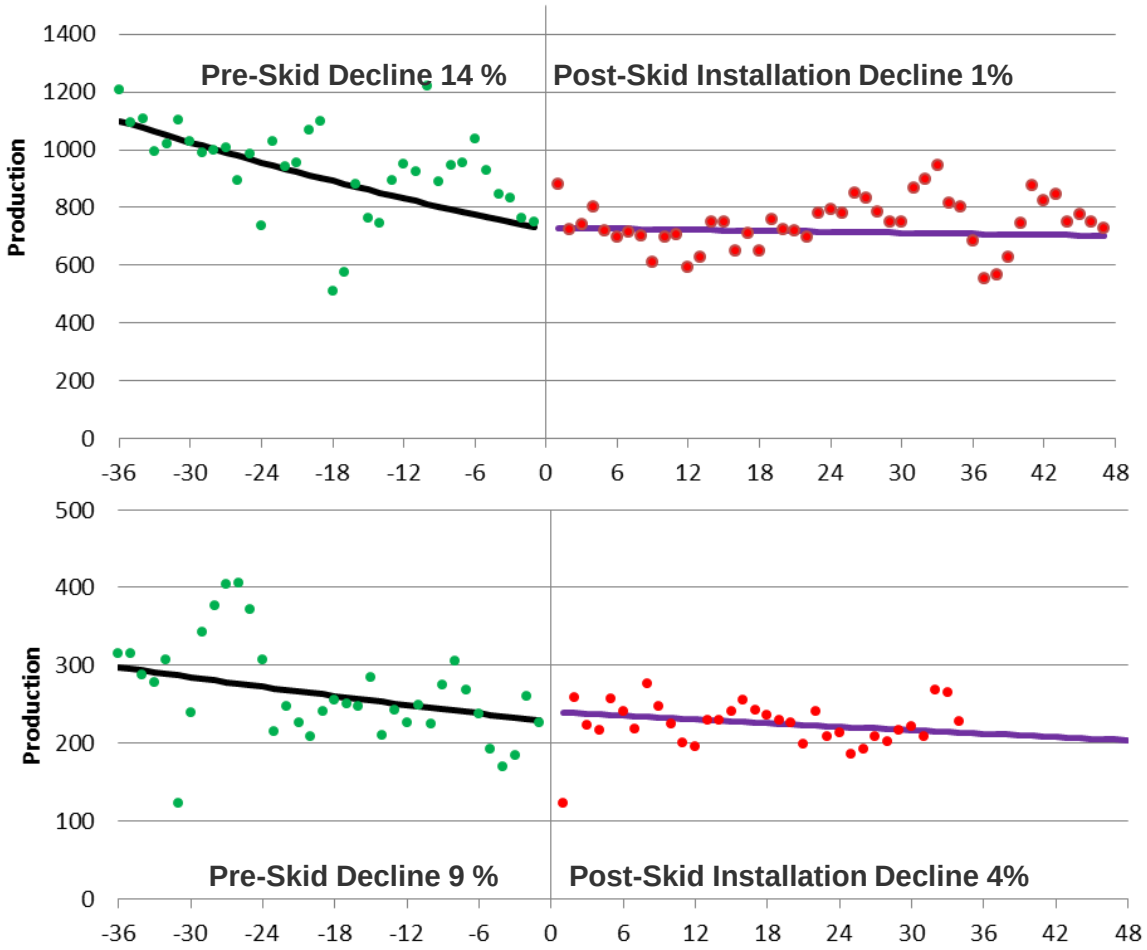
Legacy WAG equipment

New WAG skid



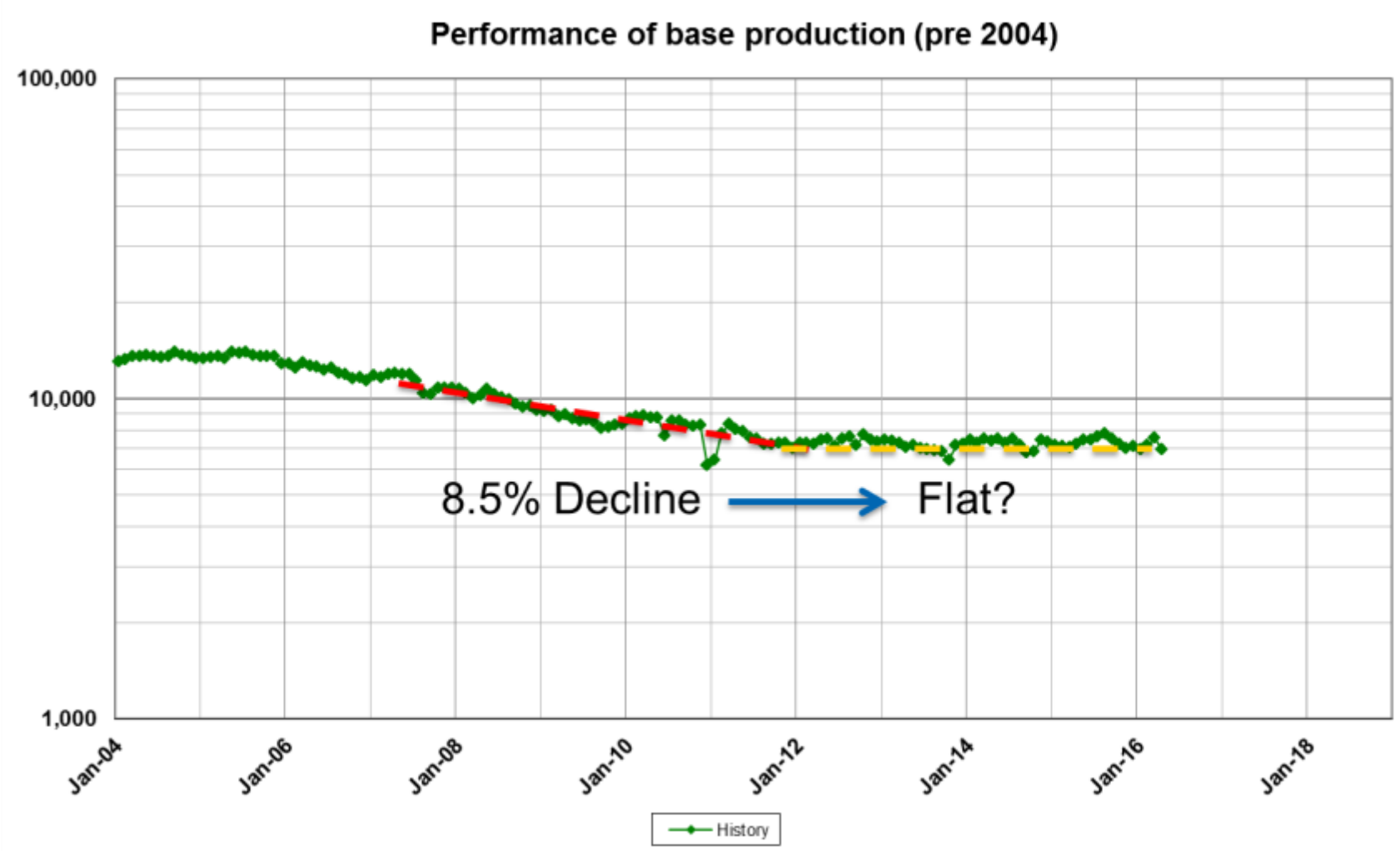
Normalized production impact

Enhanced WAGs are adding incremental barrels in the tank



Current base impact

Significant full field production impact



Questions