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Jonah Field H_2S Mitigation Strategy

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10/26/16

Agenda

- Background
  - Personal
  - Jonah Field Overview
- Water Management Strategy
  - Production & Flowback phases
  - Transportation & Treatment
- H_2S Source
  - Sulfate-Reducing Bacteria (SRB)
  - Historical Mitigation Strategy
  - New Mitigation Strategy
- Conclusions
  - Treatment Performance
- Questions

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Background

- Personal
  - BS Chemical Engineering 2008 - Colorado School of Mines (CSM)
  - MS Chemical Engineering 2009 - CSM
    - Focus on Palladium-Silver Membranes for Hydrogen Separation
  - 4 years in Alaska with ConocoPhillips
    - Seawater Treatment Plant
    - Potable and Waste Water Treatment
  - 3+ years in Denver with Jonah Energy & Encana

Background – Jonah Field

- Located in Sublette County, WY
- 1,700+ gas wells within 11,700 acres
- 510 MMSCFED Production*
- 9,000 BPD Produced Water*
- Initially developed by McMurray Oil in 1993 then Encana in 2000
- Jonah Energy LLC formed in 2014 after divestiture by Encana

*Approximate Gross Jonah Energy LLC daily volumes

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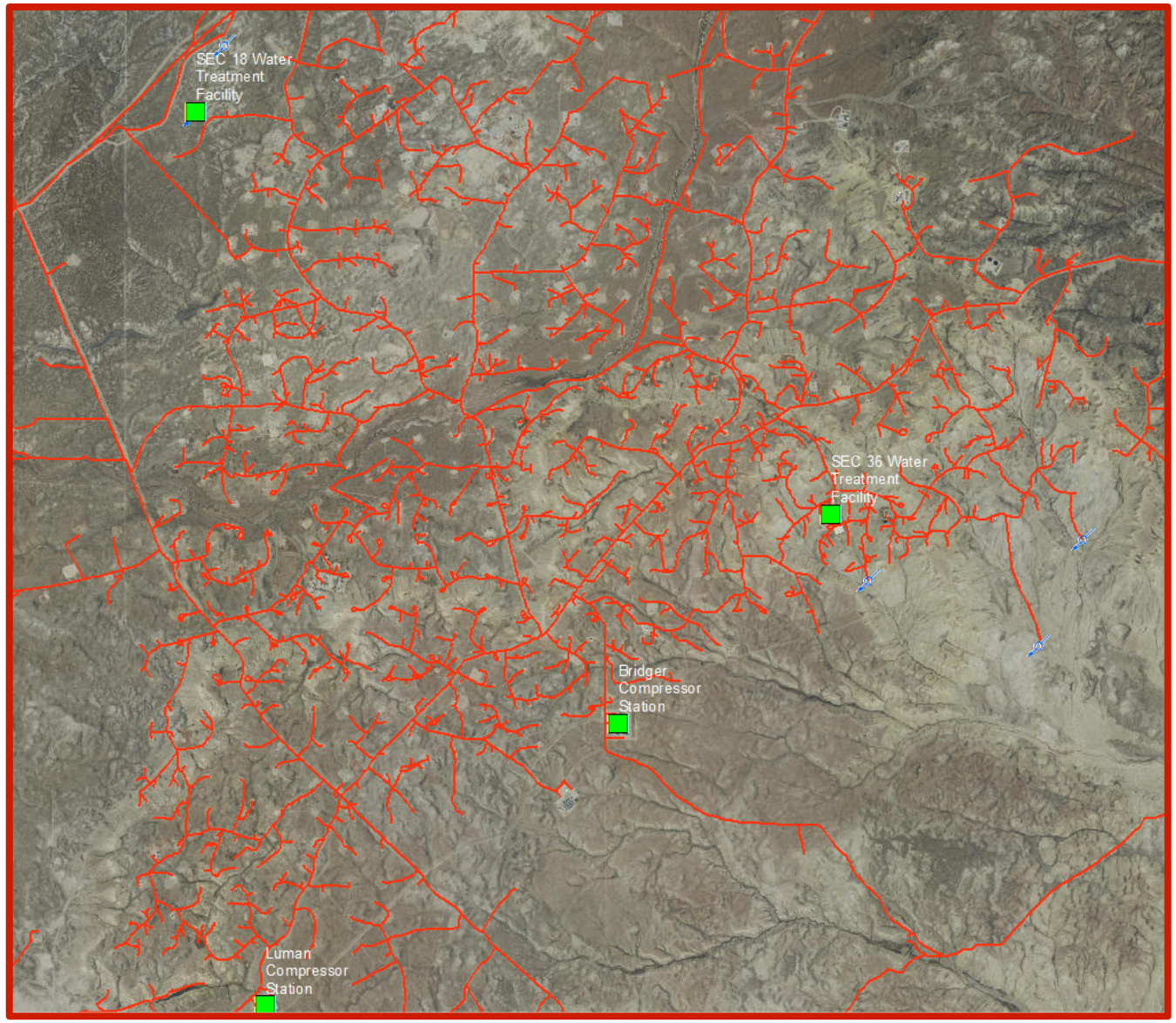
Background – Jonah Field



- Extensive road network due to the development of the field
- Individual production units for each well were used for initial field development
- Consolidation to Central Delivery Points (CDP's) has reduced equipment footprint
- Due to a number of factors, water is trucked throughout the field

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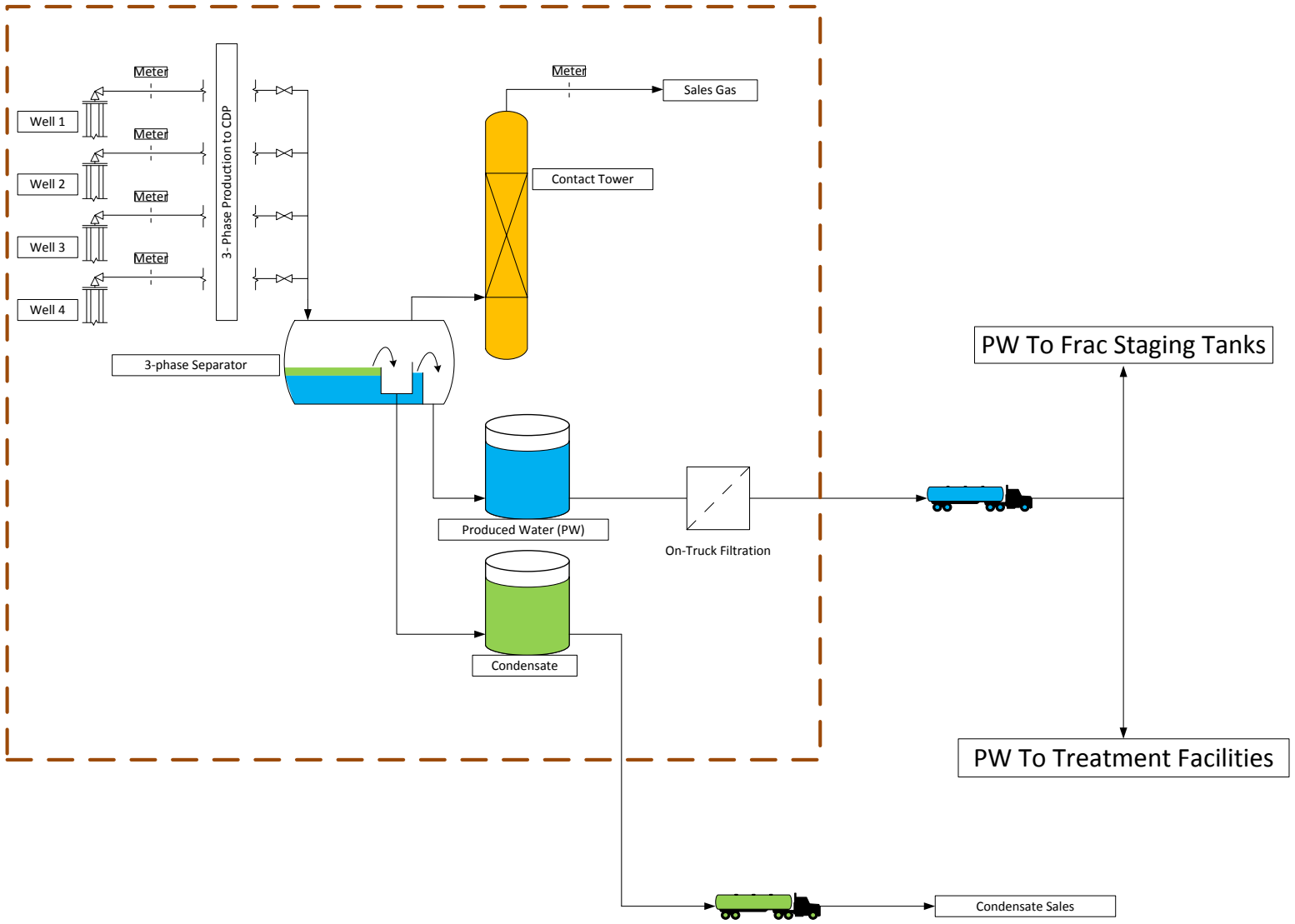
Water Management Strategy – Production Phase



- Three-phase (3-ph or 3φ, a stream with condensate (AKA oil), water, and gas) production flows from individual wells
- 3-ph Separator at CDP separates water, oil, and gas
- Gas is dehydrated using tri-ethylene glycol (TEG)
- Oil and water are stored in tanks
- PW trucked either to treatment facilities or directly to completions

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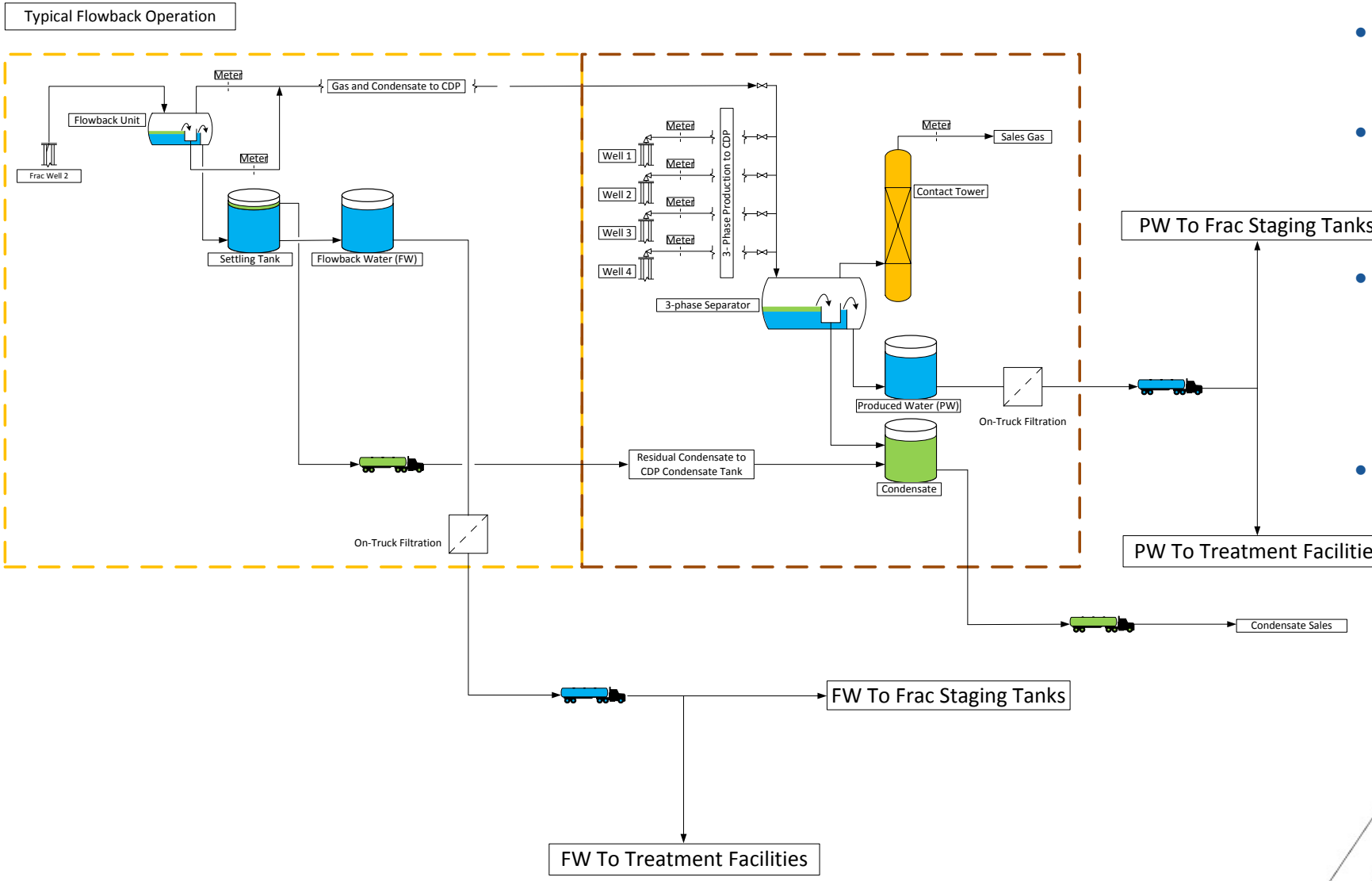
Water Management Strategy - Flowback



- Slickwater completions primarily used
- Flowback sites typically handle 100+ bbls/hour of fluids
- Flowback Water (FW) trucked to water treatment facilities or to another completion
- Typically achieve 30% recovery of water from completions

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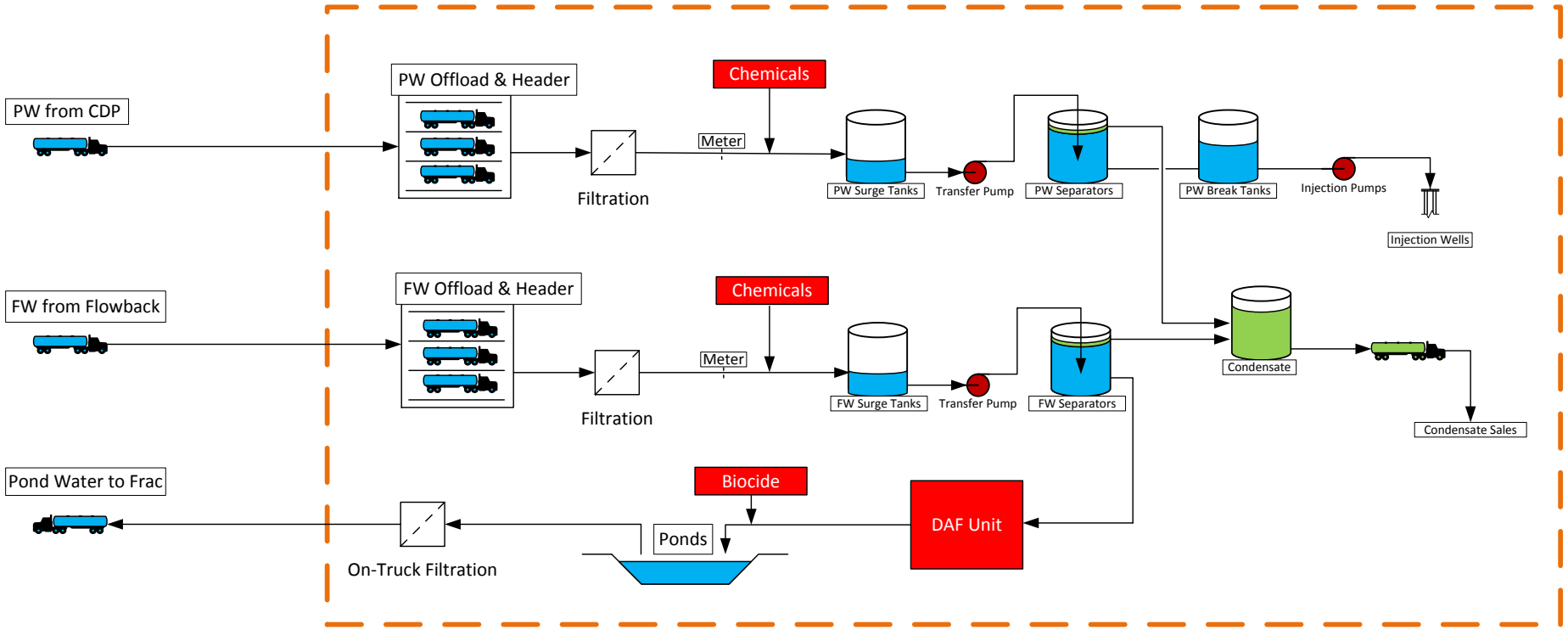
Water Management Strategy



- Process-flow diagram (PFD) for the Section 36 Water Treatment Facility
- Separate process trains for PW and FW
- FW additionally treated by a Dissolved-Air Flotation Unit (DAF)
- FW stored in Ponds for future completions
- PW can be sent to Ponds for storage if necessary

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H_2S Source

- Primarily Sulfate-Reducing Bacteria (SRB)
  - Sulfidogen - reduces sulfate (SO_4^{2-}) to sulfide (S^{2-})
  - Anaerobic respiration
  - "Inhales" sulfate instead of oxygen, "exhales" H_2S
  - Consumes organic compounds as "food"
  - Known to "sour" fields due to improper water treatment (especially water-floods)

- Small H_2S concentrations in water = large H_2S concentrations in air
- Sulfide Stress Cracking/Corrosion
- Generates FeS (plugging agent)

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H_2S Source

- Section 36 Water Treatment Facility upgraded in 2010
- Several ponds have been closed
- FW stored in covered ponds to control emissions and comply with MBTA
- Pond covers installed in 2012
- Light color chosen to reduce solar heating impact
- Warm ambient temperatures result in SRB population blooms

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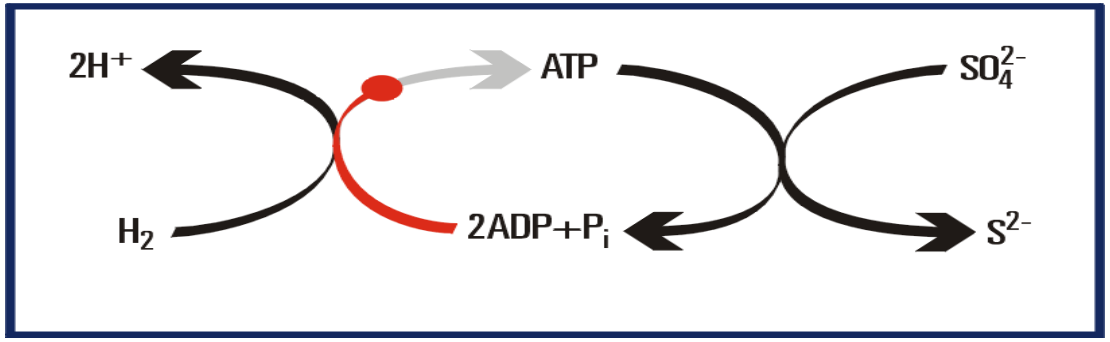
Historical Mitigation Strategy

- Utilize bio-stat chemical batch treatment to suppress SRB growth ($$)



- Occasional H_2S breakout still occurred in pond water loading tanks and at staging tanks during hot summer months
  - Pond water not accepted for completions
  - Pond required to be treated with additional biocide and/or disposed
- Single pond pump could not keep up with completions demand

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New Mitigation Strategy

Objectives

- Protect personnel from H_2S exposure at pond water loading tanks, staging tanks, and frac sites
- Improve water deliverability for recycling
- Reduce chemical costs
- Reduce trucking costs
- Customize water storage volumes based on completion demand
- Provide flexibility for future operations
- Extend life expectancy for ponds

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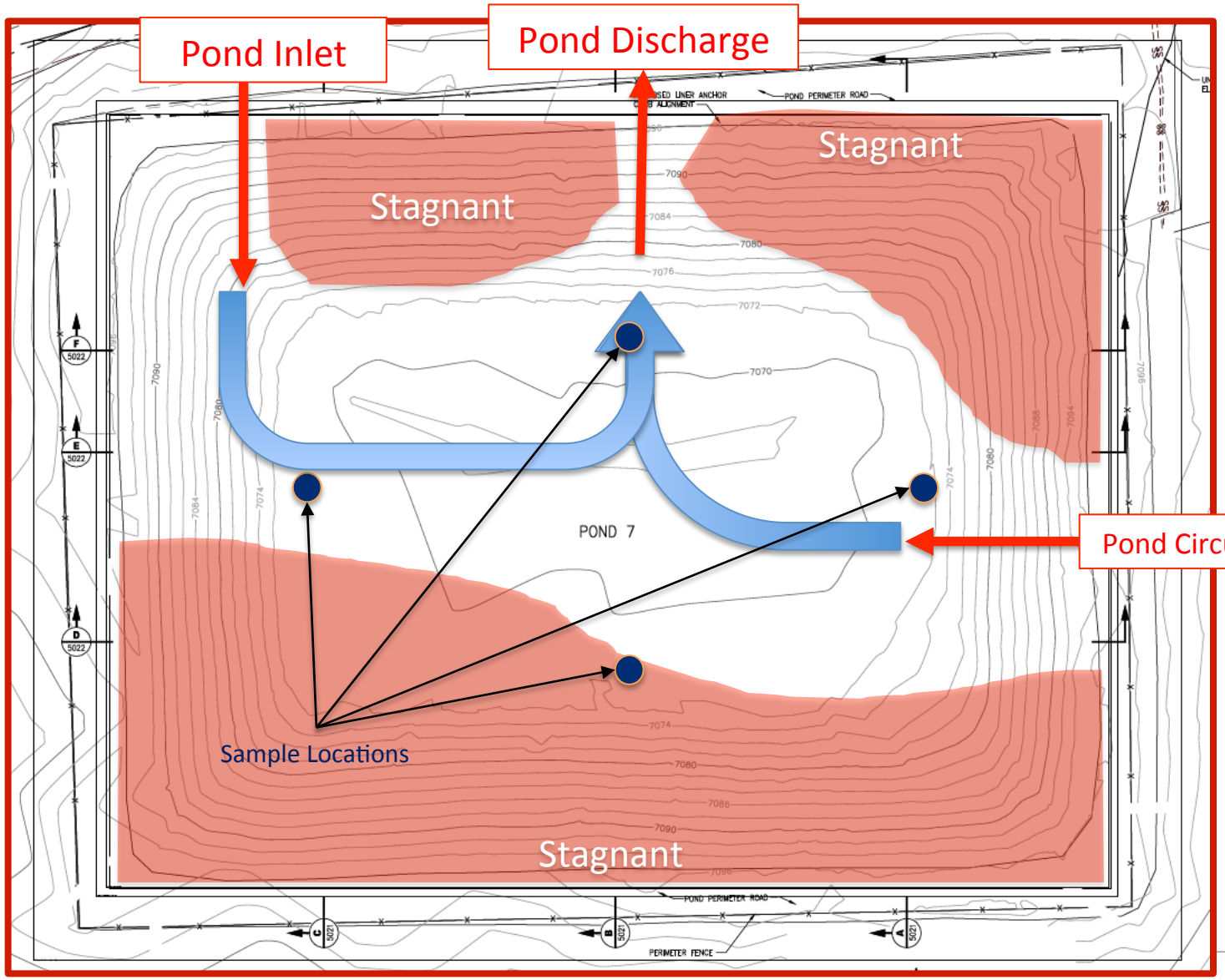
New Mitigation Strategy – Existing Pond Configuration



- Address stagnant water in pond
  - Poor dispersion of chemical = ineffective treatment
- Stagnant water allows for sessile bacteria growth
- Sample probes encountered 1 to 3.5 ft of loose slurry
- Analysis confirmed presence of DRO and GRO

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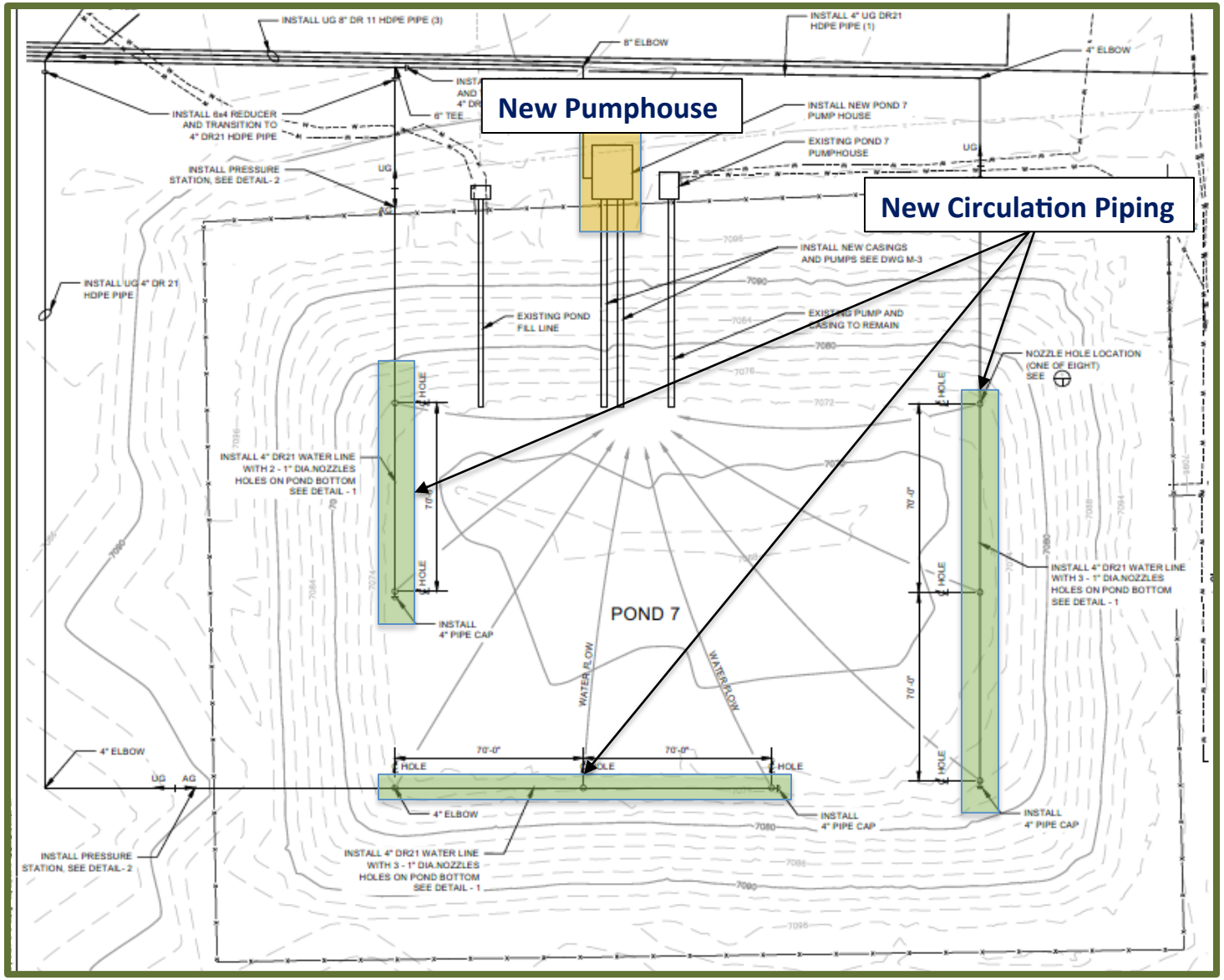
New Mitigation Strategy – Pond Modifications



- Installed new circulation piping at pond bottom
- Installed new pond pumps to improve water deliverability rates and circulation
- Intended to move slurry at bottom of pond to pond discharge line for in-situ processing
- Chemical delivery accomplished through new circulation lines for better dispersion
- Utilized shop-fabricated skids to minimize field construction activity

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New Mitigation Strategy – Pump Modifications

- Grundfos 475S200 Multi-stage submersible pump previously used
  - Rated for 475 gpm @ 100 ft H but never delivered on curve
- Consistent failure due to solids (mainly biofilm)
- Pump replacement was difficult and expensive
- New centrifugal pumps installed to handle solids
- Capable of delivering 1000 gpm with two pumps

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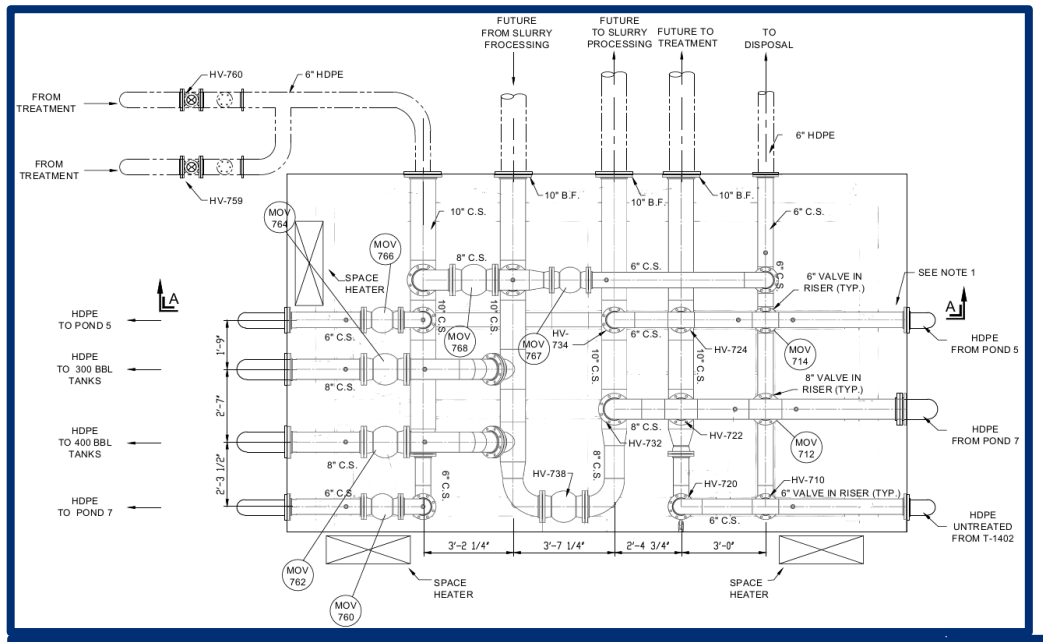
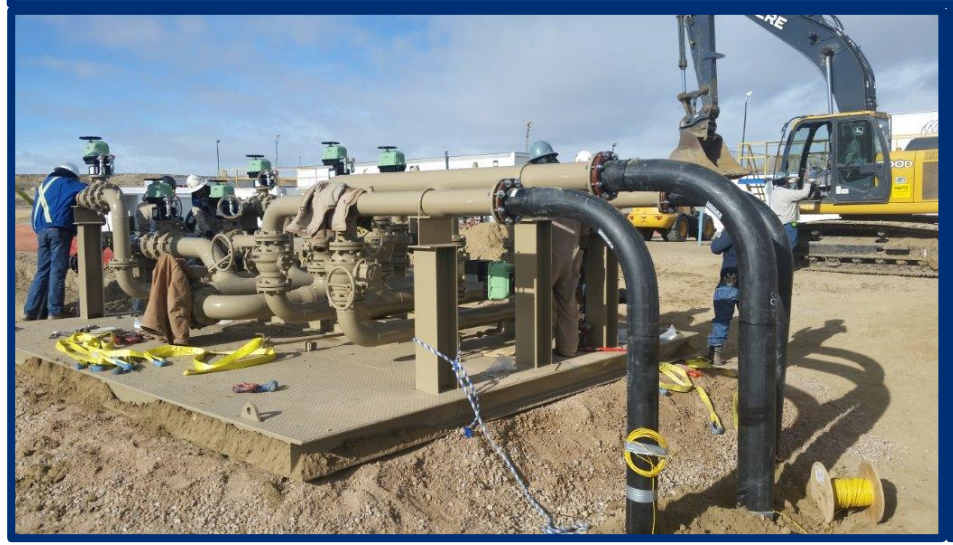
New Mitigation Strategy – Control Change



- Installed Valve Manifold with Motor-Operated Valves (MOV)
- MOV's direct water to loading tanks, circulation, between ponds, and to disposal
- Eliminates trucking of water between ponds or to disposal
- Provides single injection point for chemical delivery
- Designed for future expansion or modifications
- Eliminated unnecessary loading tank battery



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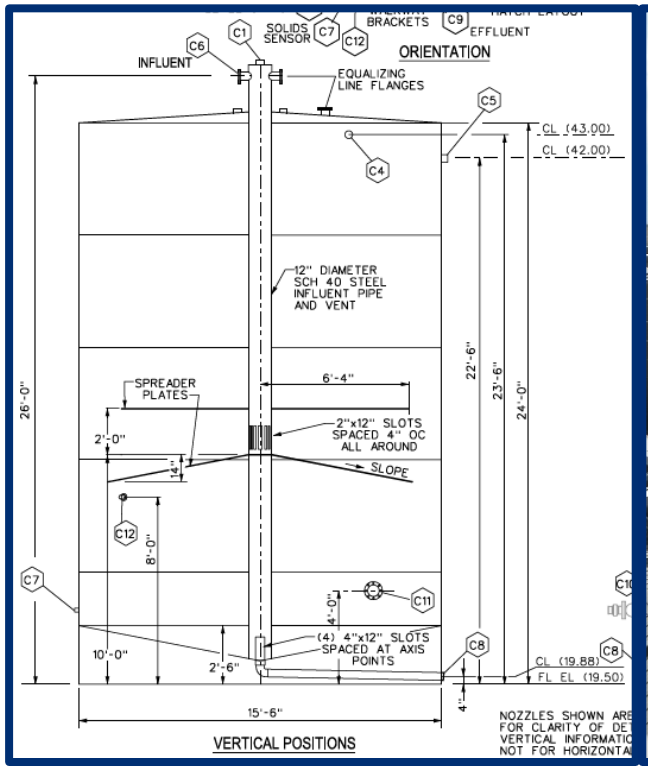
New Mitigation Strategy – Separation Efficiency



- Front End of water treatment facilities designed to separate residual hydrocarbon from water
- Gunbarrel separators for oil-water separation
- Emulsion in FW separators leads to oil carryover to DAF process
- Emulsion breaker injected upstream of separators unable to break emulsion
- Emulsion caused by high polymer content in water from drilling rigs mixing with FW
- Established rig water recycling program to eliminate problem
- Increased condensate recovery

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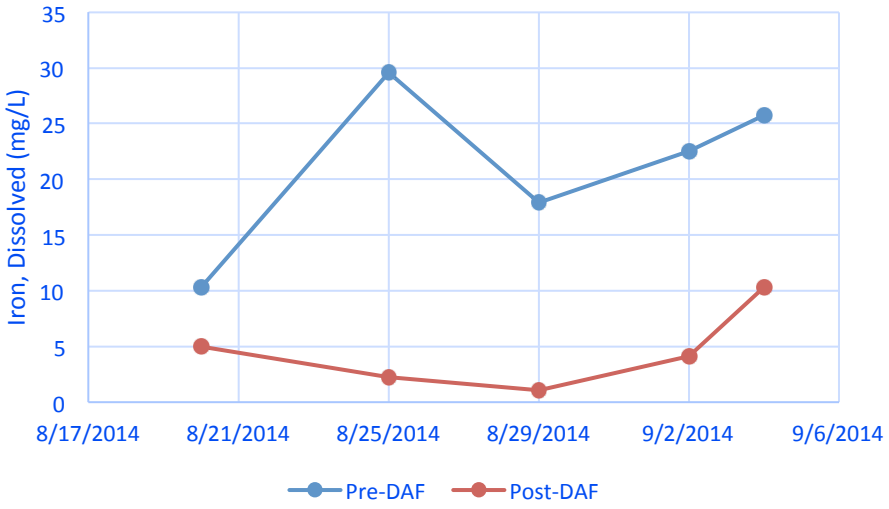
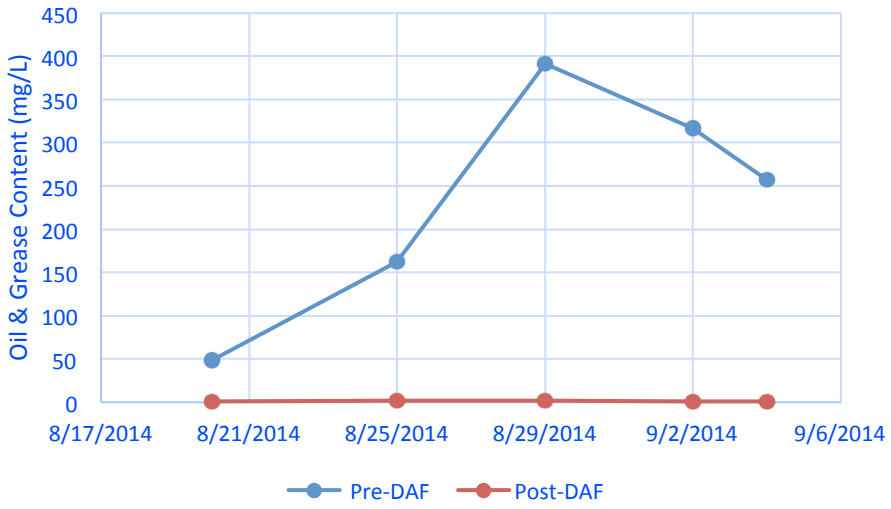
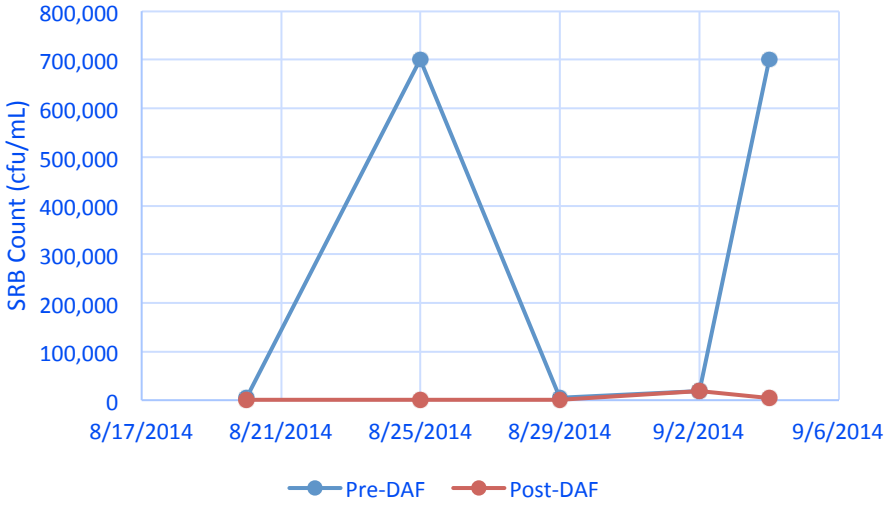
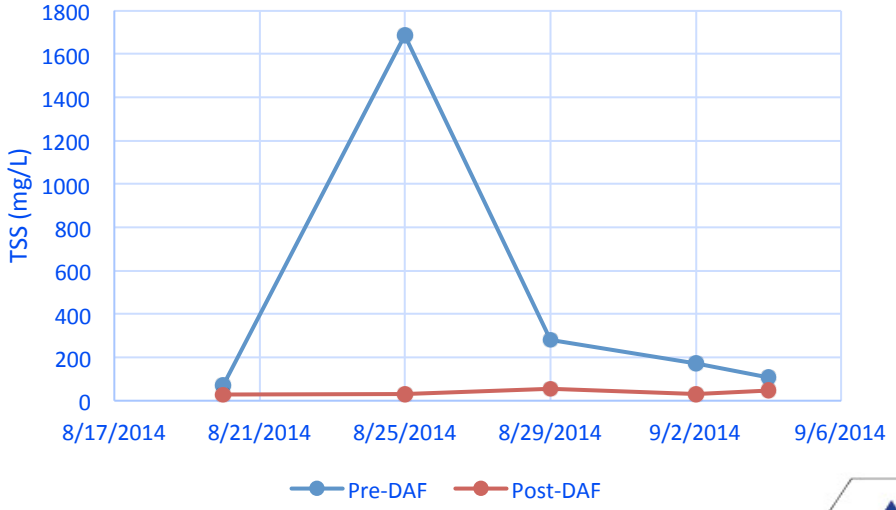
New Mitigation Strategy – DAF Treatment Efficiency





- DAF treatment essential for removing TSS and residual hydrocarbon
- Relatively inexpensive treatment
- Improved front-end separation = Improved water quality from DAF





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New Mitigation Strategy – Biocide Treatment

- Performed biocide kill studies
  - Matrix of different biocides & concentrations
- Iterations of biocide treatment programs
  - Glutaraldehyde/quaternary amine at 50 ppm
    - Continuously injected upstream of DAF to treat FW
    - Implemented before facility modifications
    - Not ideal treatment location, but only place to get continuous injection
  - DDAC quaternary amine at 50 ppm
    - Implemented after facility modifications
    - 50 ppm dosed only to weekly **added** pond volumes
    - Injected into circulation lines
  - DDAC quaternary amine at 10 ppm
    - Implemented after SRB counts stabilized
    - 10 ppm dosed only to weekly **stored** pond volumes
    - Injected into circulation lines

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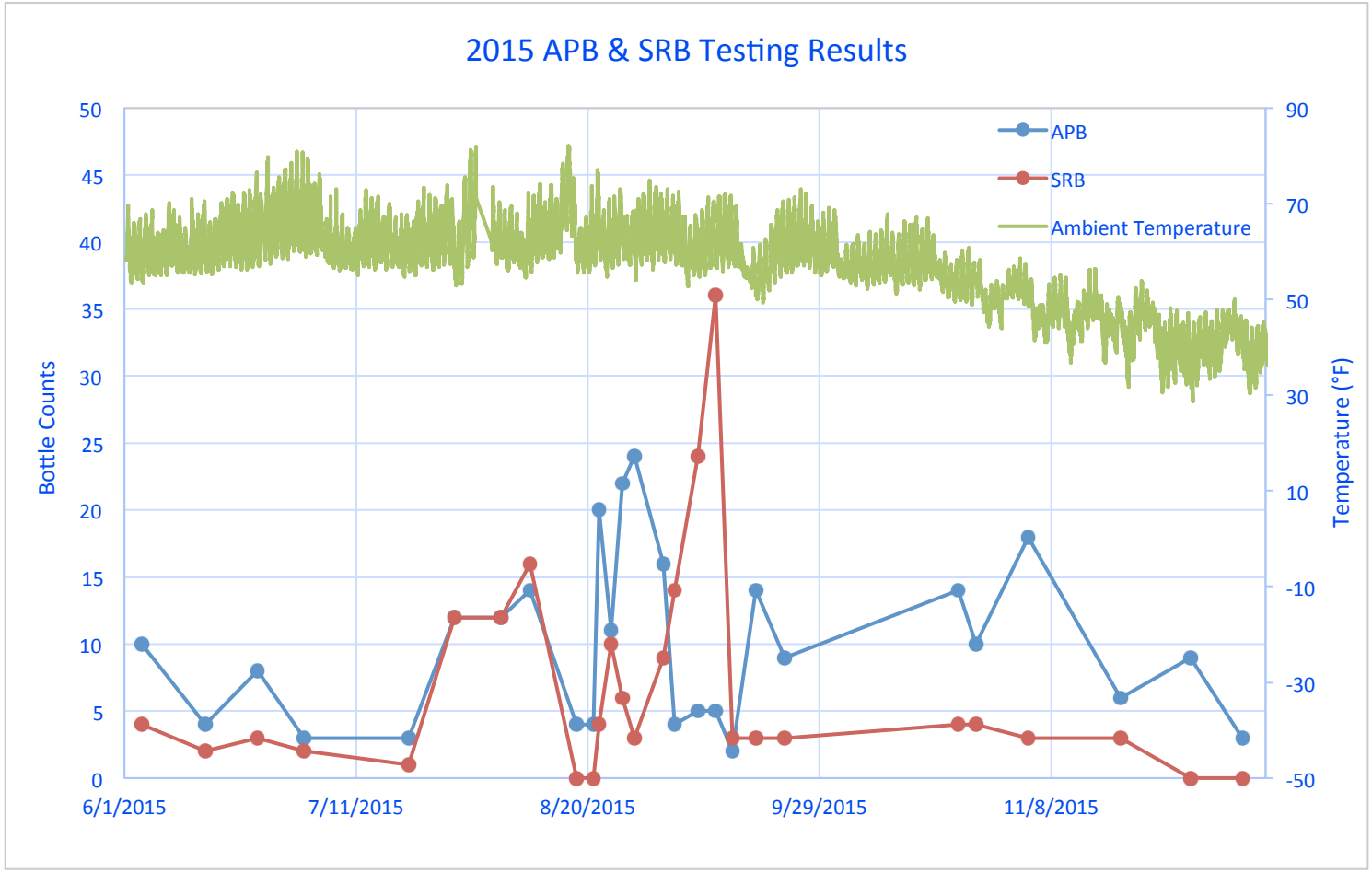
Conclusions – Historical Performance



- Chemical vendor change in June 2015
- Continuous injection of glutaraldehyde/ quaternary amine (glut/quat) upstream of DAF at 50 ppm
- Batch treatment of glut/quat utilized to suppress SRB explosion in September (50 ppm)
- SRB growth resulted in occasional H_2S detection events at pond water loading tanks and frac sites
- Delivered approximately 13,000 bbls of pond water per completion

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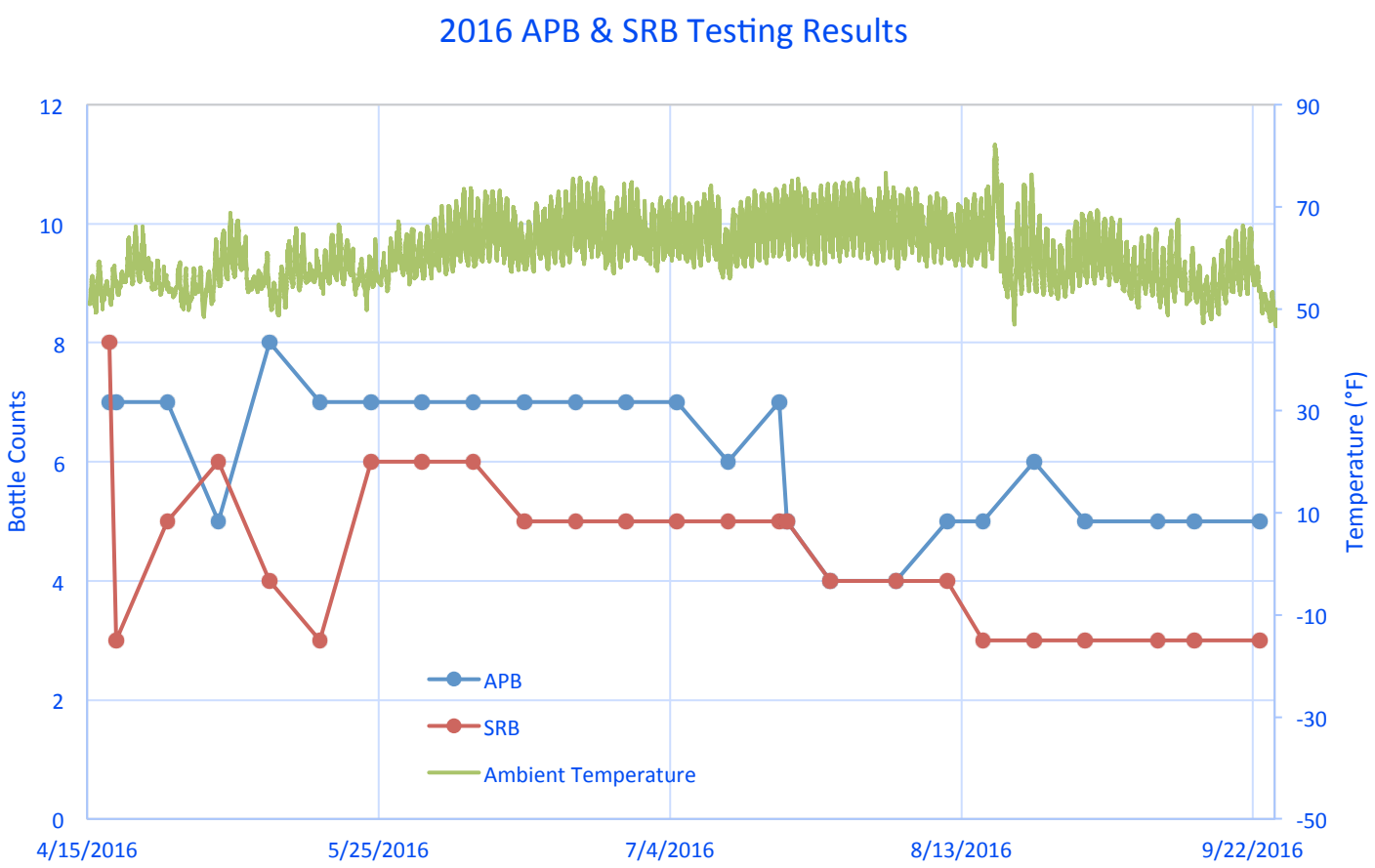
Conclusions – 2016 Performance



- Changed chemical vendors again in January 2016
- System operational March 2016
- DDAC quaternary amine injected in circulation system at 50 ppm for new volumes, 10 ppm for storage volume
- Stable SRB and APB counts
- No H_2S detection events
- Reduced drilling program still resulted in only approximately 13,000 bbls of pond water per completion
- Significant cost savings compared to historical bio-stat treatments

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Conclusions – System Performance

- Key Takeaways
  - Several aspects of water treatment affect H_2S generation
    - Hydrocarbon removal
    - TSS removal
    - Circulation
    - Biocide
  - Effective SRB management in storage = Effective treatment during completions
- System changes resulted in 90% reduction of chemical costs
- Recycling system better prepared for future development

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Questions?

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