

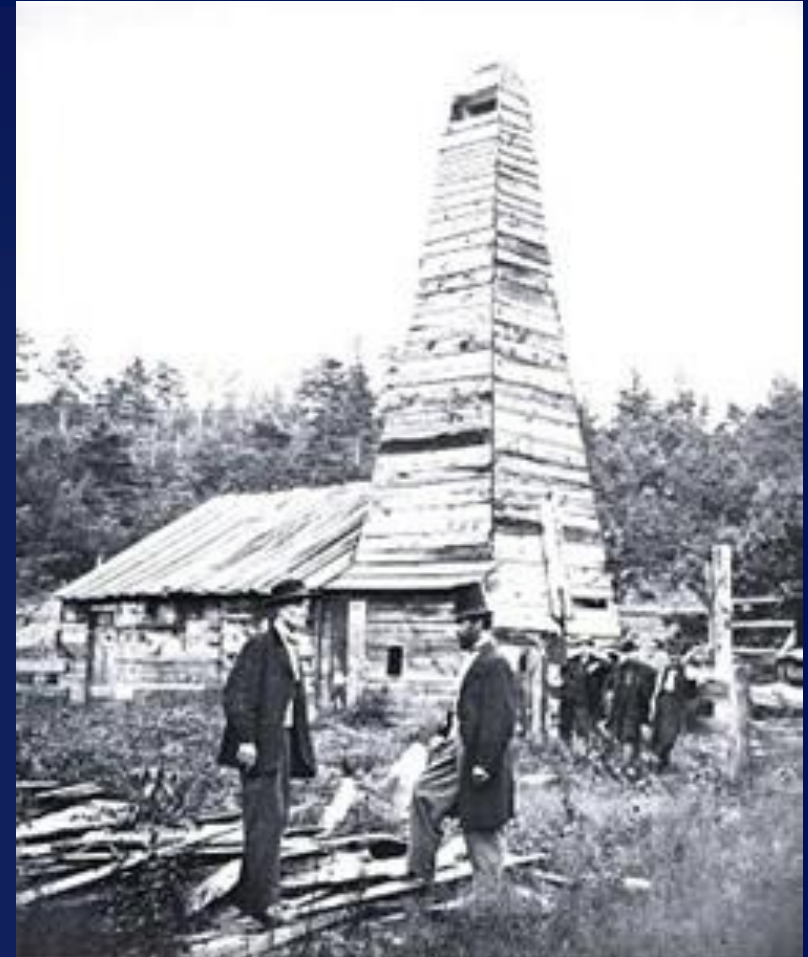
Water Management for Shale Plays

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Water Management Began With Oil and Gas Production

- Water is produced along with oil and gas from nearly every well
- Water is the most common and heavily used fluid in the petroleum industry
- Water is used as a base fluid in drilling, completion, and production operations
- Water is mixed, produced, cleaned, recycled, and injected
- **Water's use, protection, and disposal are emotionally charged subjects in many communities**



Drake Well 1859

Source: PA Department of
Conservation and Natural Resources

History of Water Disposal

- Into the middle of the 20th century produced water was flowed:
 - Onto the ground
 - Into lakes and streams
 - Into unlined evaporation pits (Lined evaporation pits are still in use today)
- Today in the US over 98% of produced water is disposed of in disposal wells or used for waterflooding
- Waterflooding
 - The first waterflood in the US was at Pithole City, PA in 1865
 - Started in Oklahoma and Texas in 1930's
 - Became wide spread in the 1950's



A well in the Oklahoma City Field flowing waste oil and water down a stream. Photo taken 1/1/1939
Source: Library of Congress

Introduction to Shale Water Management

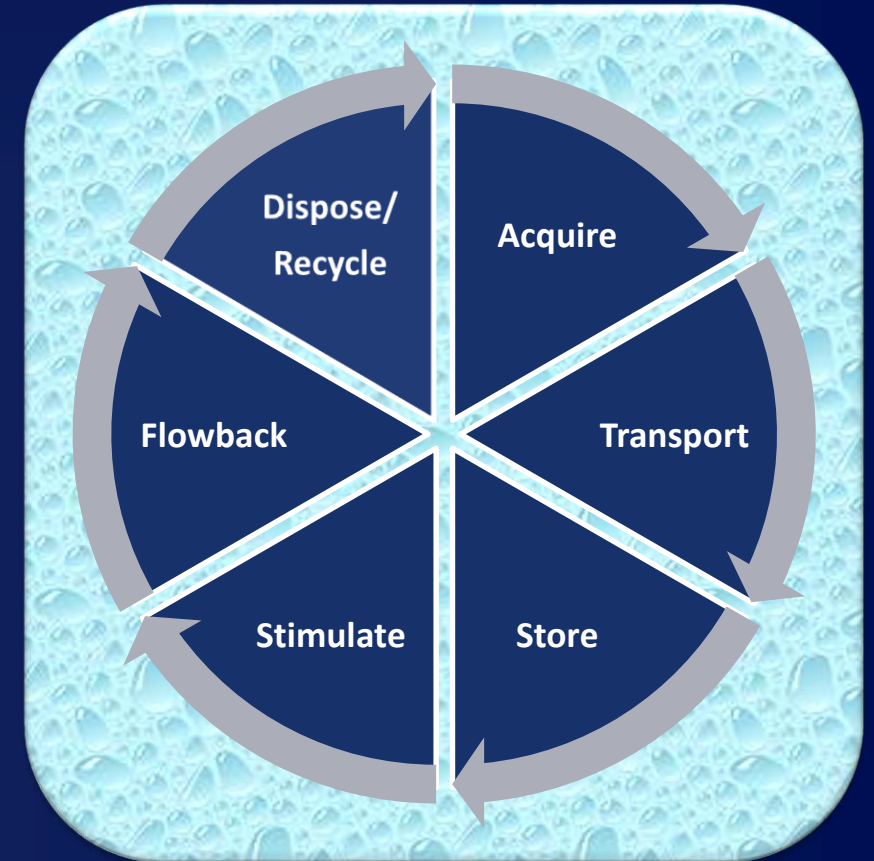
- Water Management Planning and Infrastructure Considerations:
 - Move from exploration to development
 - Pad drilling w/longer laterals
 - Move to mostly slickwater fracs
 - Increased demand for water for completions
 - Water availability
 - Induced seismicity
 - States limiting disposal capacity
 - Environmental concerns



Source: ALL Consulting, 2016

Water Management Cycle

- Water source
 - Subsurface aquifers
 - Rivers, lakes or ponds
 - Rural or urban water supplies
 - Gray Water
 - Acid Mine Drainage
- Water transport
 - Pipeline
 - Trucking
- Water storage
 - Frac Tanks (500 BBLS)
 - Modular Tanks (up to 60,000 BBLS)
 - Portadam (size as required)
 - Pits or ponds (100,000+ BBLS)
- Water treatment and reuse
 - Biocides
 - Aeration
 - Aerobic bacteria
 - Settling
 - Filtration
 - Flocculation
 - Distillation
 - Crystallization
- Water disposal
 - Evaporation
 - Water disposal wells
- Dispose/Recycle



Significance of Water to Shale Completions

More than ever, water is an integral part of the success of oil and gas operations in Shale Plays.

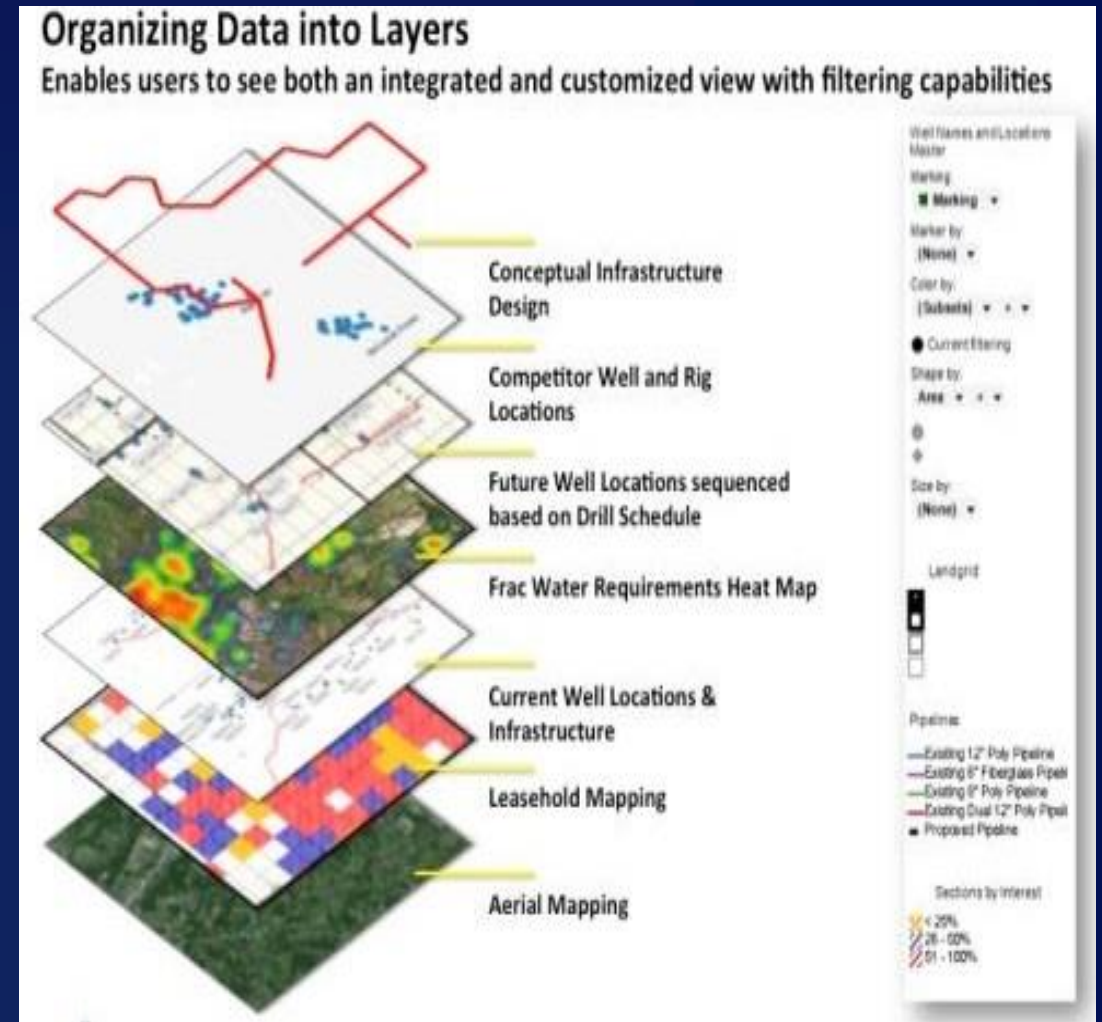
Consider this:

- No Water
- No Hydraulic Fracturing
- No Oil and Gas Resource Plays



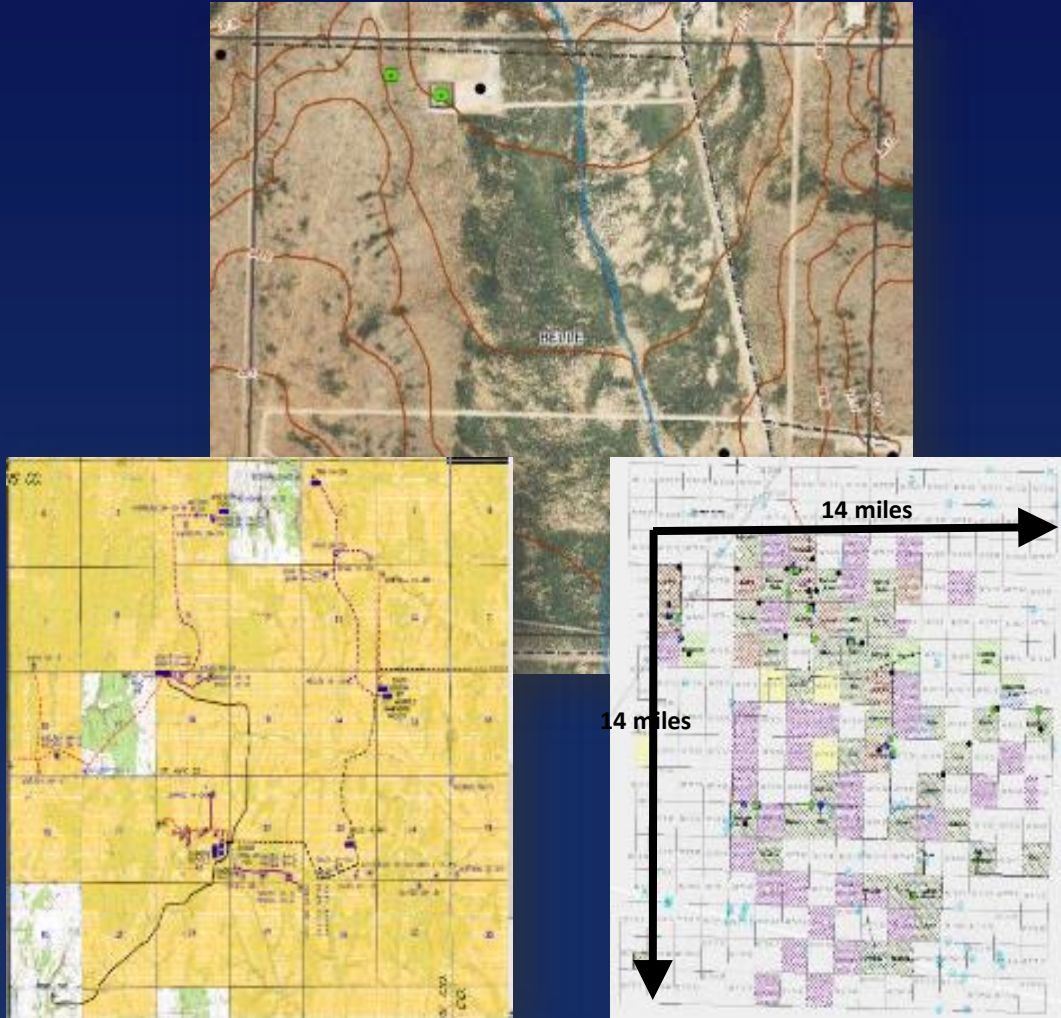
Water Management Plan Components

- Water Management Plan
 - Company's acreage position
 - Water sources
 - Regulatory constraints
 - Environmental constraints
 - Cultural constraints
 - Fracturing fluids
 - Water volumes required
 - Storage capacity required
 - Refill time required
 - Layout infrastructure
 - Geotechnical investigation
 - Design facilities
 - Construction plan



Source: B. Pribish, 2015 private communication

Infrastructure



- Infrastructure planning
 - Plan placement of
 - Fresh water storage
 - Produced water treatment facilities
 - Disposal facilities
 - Buried HDPE pipelines
 - Practical limit of lay-flat is about 3 miles
- Flexibility
 - Move fresh water to any storage facility
 - Move treated and produced water from any treatment and disposal facility to any other facility
 - Delivery to and from each facility by both pipelines and trucks

Primary Water Sources

- Subsurface Aquifers using water wells
- Ground Water from naturally occurring or man made ponds



Water Needs and Costs

- Increased water demand due to
 - Drilling extended lateral lengths to 12,000 ft. or longer
 - Pad drilling
- Fracture fluid volumes
 - 300,000 to 1,000,000 BBLs per well
- Fresh water cost
 - Permian Basin
 - \$0.50 to \$0.75 per BBL
 - Anadarko Basin
 - \$0.25 to \$0.50 per BBL
- Costs for produced water treatment
 - \$1.00 per BBL using aerobic bacteria and aeration
 - Other treatment costs may be higher



Source: ALL Consulting, 2016

Produced Water Storage Facilities

- Preferred designs - 1 to 6 lined 300,000 to 500,00 BBL impoundments
- Recommended Produced Water Impoundment liners:
 - Gas vent strips made of geotextile material
 - Geotextile layer
 - Secondary 40 mil black liner
 - Geotextile layer
 - Leak detection system (sump)
 - Geocomposite layer
 - Washed pea gravel
 - Perforated Pipe
 - Primary 40 mil white liner
- Pits connected by 12” HDPE equalization pipes
- Suction pipes installed in the clean brine impoundment



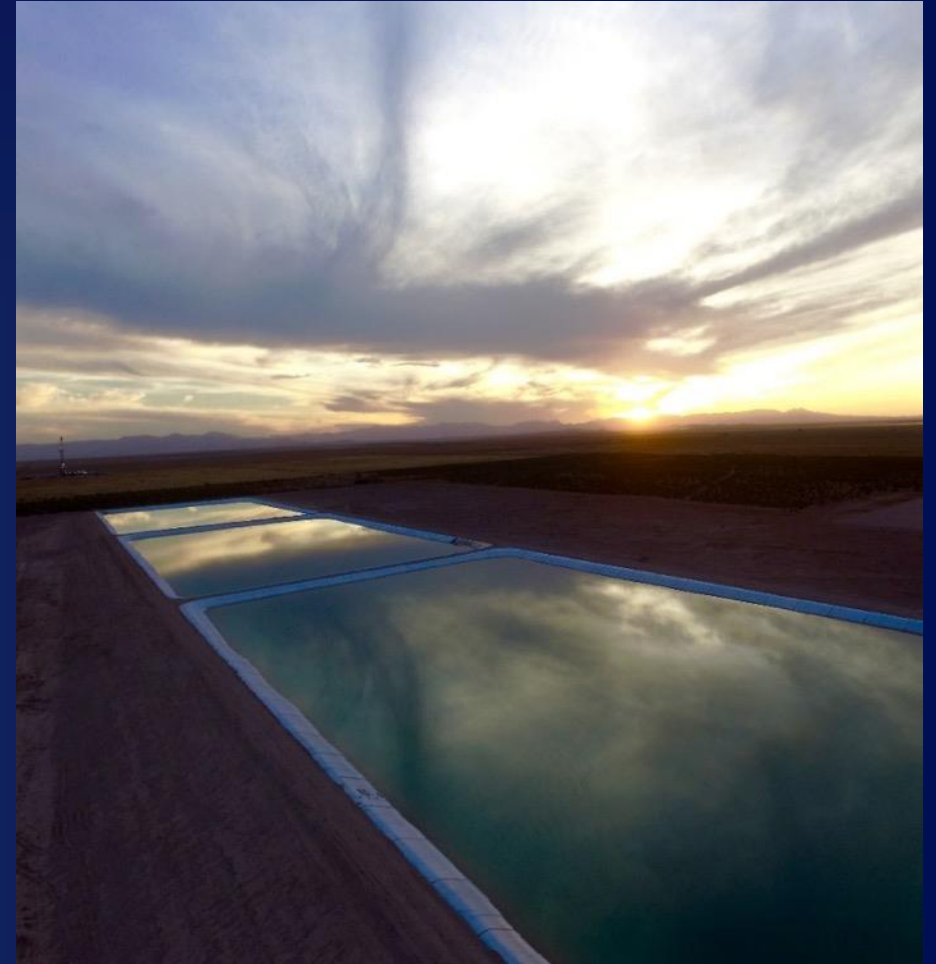
Source: ALL Consulting, 2018



Source: ALL Consulting, 2018

Impoundment Sizing and Design

- Impoundment designs based on operators needs:
 - Type of water stored
 - Completion schedule/water forecast
 - Water volume from production
 - Water recycling/treatment plan
 - Disposal capacity
- Ideal Design:
 - Can store fresh or produced water
 - Effective solids and bacteria removal
 - Designed for lowest cost
 - Combined storage volume from 300,000 to 2 million BBL



Source: ALL Consulting, 2018

Impoundment Construction



Source: ALL Consulting, 2018

Source: ALL Consulting, 2018

Water Pit Liner Installation



Source: ALL Consulting, 2018

Source: ALL Consulting, 2018

Liner Installation/Completed Pits



Source: ALL Consulting, 2018



Source: ALL Consulting, 2018

Typical Completed Recycle Facility



Source: ALL Consulting

Pipeline Design and Installation

- Water transport by pipeline to or from
 - Water source(s)
 - Existing water storage
 - Planned storage and treatment facilities
 - Salt water disposal wells
- Multidirectional water flow is a necessity
 - To move either fresh or salt water
 - To transport water from multiple facilities
- Benefits of developed pipeline systems
 - Reduced trucking
 - Decreased long-term costs
 - Increased safety & reduced risk of spills
- Automation
 - Allows control of water remotely
 - Decreases in-field man power



Source: ALL Consulting, 2018

Pipeline Installation



Source: ALL Consulting, 2018

Source: ALL Consulting, 2018

Frac Water – Recycling Objectives

- Economically produce clean brine water from produced water that can be used as a base fluid for hydraulic fracturing
 - Process must be able to remove hydrocarbons, gelling agents, metals, H₂S, iron sulfide, bacteria, boron, and suspended solids
 - Process must be able to handle variable qualities and quantities of inlet water
 - For most operations equipment must be mobile and have a compact footprint
 - Water treatment must be economical when compared to the acquisition and disposal of fresh water

Before Recycling Water

- What Do We Need to Know
 - Type of fracturing fluid that is being used
 - Slickwater
 - Linear gel
 - Cross linked gel
 - The chemical analysis
 - For fresh water
 - For flowback/produced water
 - For treated water
 - Regulations governing
 - Produced water transportation
 - Produced water storage
 - Treated water storage
 - Waste stream disposal
 - Economic constraints
 - Cost of water storage (approximately \$2.00/BBL for initial installation)
 - Cost of water transportation (\$0.50/BBL to move water from storage to frac)
 - Cost of water processing
 - Cost of waste stream disposal

Drivers for Recycling

- Reduce demand on limited freshwater resources
- Reduce injection volumes
 - Reduce injection costs
 - Limited disposal zones for salt water disposal wells
 - Induced Seismicity concerns
- Reduce water costs



Source: ALL Consulting, 2018

Recycling Challenges

- Produced water
 - Treatment must be economically feasible
 - Minerals can interfere with friction reducers or frac gel
 - Quality varies widely
 - Minerals can cause scale
- Environmental regulations
 - Have become more stringent
 - In most states flowback, recycle or produced water pits have to be permitted in some fashion
 - Oklahoma requires design, certification, permitting, and construction supervision by a registered professional engineer

Naturally Occurring Radioactive Materials (NORM)

- Many shales contain low levels of NORM
- NORM generally remains in drill cuttings or scale
- NORM Radiation levels are generally low
- NORM scale deposits in production tubing and equipment result in concentrated radiation levels.
- NORM poses little practical risk to general public who normally would not be exposed to oilfield equipment for extended periods of time



Source: ALL Consulting 2009

A Basic Approach that Works



Source: ALL Consulting, 2017

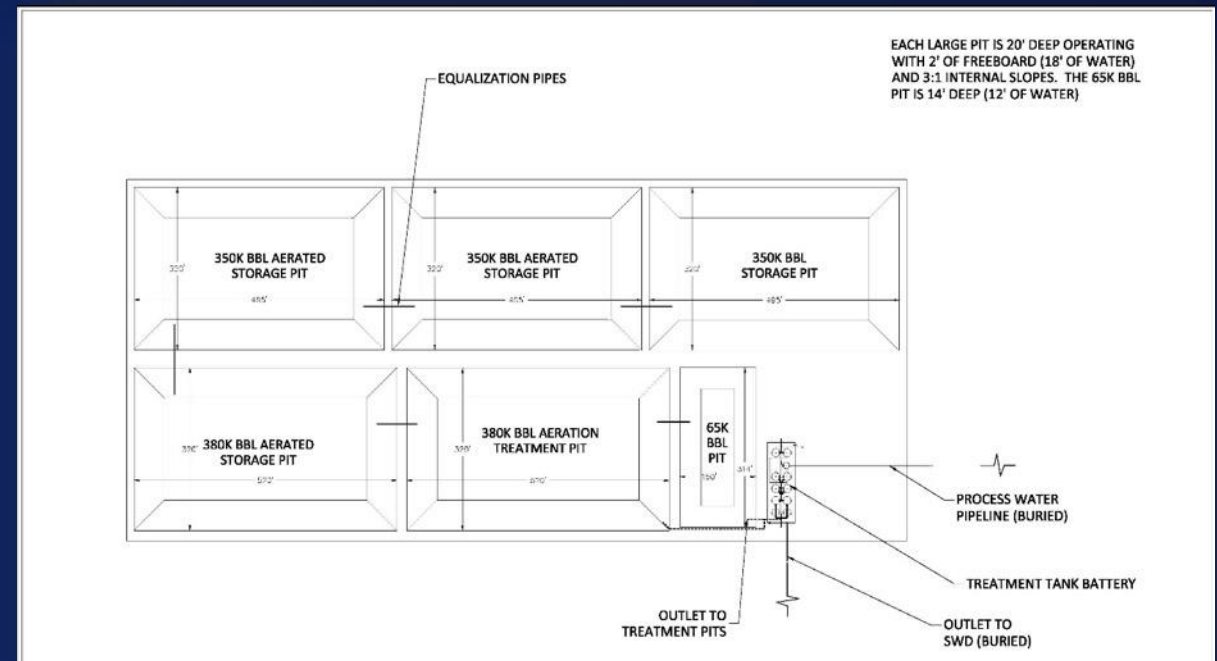


Source: ALL Consulting, 2017

- Combine at the same facility
 - Produced water treatment
 - Water storage
 - SWD well
- Separate pipelines
 - For fresh water
 - For produced water
 - For clean brine
- Tank battery to remove solids and separate oil
- Treatment system to provide a clean brine
- Injection well for produced water that cannot be recycled
- Multiple facilities strategically placed

Treatment System

- Treatment system consists of:
 - A tank battery
 - A series of lined impoundments
 - Improves treatment
 - Provides ample storage
 - Aeration and microbial treatment
 - Equalization pipes
- Results in a clean brine suitable for reuse



Source: ALL Consulting, 2016

Treatment/Disposal Tank Battery

- Located adjacent to
 - Injection wells
 - Treatment pits
- Removes
 - Solids
 - Oil (down to 30 ppm)
- Automated to send water to
 - Treatment pits
 - Injection well
 - Both
- Typically coupled with 2 H-pumps controlled by variable speed drives (VSDs)



Source: ALL Consulting, 2017



Source: ALL Consulting, 2017

Impoundment Aeration / Biological Treatment

- Aeration
 - Increases dissolved oxygen levels in water
 - Sustains aerobic bacteria
 - Eliminates hydrocarbons and other organics from the water
 - Prevents water from “Flipping”
 - Reduces the proliferation of Anaerobic Bacteria
- Aerobic bacteria
 - Control anaerobic bacteria
 - Managed with biocides during frac operations
- Anaerobic bacteria
 - More problematic (e.g., SRB’s - H₂S producing bacteria and APB’s - acid producing bacteria)
 - More expensive to manage with biocides



Source: ALL Consulting, 2017

Salt Water Disposal Considerations

- Increase in seismicity
 - Decreased injection allowables
 - Operators are choosing to limit injection
 - Alternate disposal zones are limited
 - Operators are exploring recycling as a way to reduce injection volumes
- Trucking produced water for disposal
 - Expensive
 - Can create adverse community impacts
- Transporting produced water through pipelines
 - Cost effective
 - Environmentally sound



Source: ALL Consulting, 2017

Typical Water Disposal Facility



Source: D. Steven Tipton, 2014

Source: D. Steven Tipton, 2014

Benefits of Good Water Management Plan

- Ensures adequate water for completions
- Allows for
 - Unexpected changes in the completion schedule
 - Changes in frac water volumes
- Reduces fresh water demand
- Provides options for managing produced water
- Provides options for water treatment
- Reduces SWD well injection volumes
- Limits trucking for produced water disposal



Source: ALL Consulting, 2018

Keys to Success

- Provide a cost-effective approach to water management that
 - Supplies sufficient water supply for completions
 - Reduces fresh water demand
 - Recycles produced water
 - Disposes of excess water
- Provide flexibility to respond to unexpected changes in
 - Schedules
 - Need to move water from one facility to another
 - Injection well use or problems
 - Equipment
- Provide simple operations using
 - Automated controls
 - Uncomplicated treatment systems
 - Limited operator involvement in day-to-day operations
 - Minimal operator training
- Provide a process that recovers capital investment in three years or less.

Questions?



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