CLASS II DISPOSAL WELL
BEST MANAGEMENT PRACTICES
WORKSHOP

PREPARED BY: J. DANIEL ARTHUR, P.E., SPEC, THOMAS TOMASTIK, DAVID OVERSTREET, AND B. GREG CASEY, P.E.

Introduction

• Focus on understanding key aspects of Class II well disposal.
• Address the challenges facing the Class II disposal well industry.
• Demonstrate how Best Management Practices (BMPs) can help to reduce public concerns.

Source: ALL Consulting, 2015
Topics to be Covered

• Brief history of the Class II program
• Well siting consideration.
• USDWS, Area of review, ZEI, and corrective action
• Well and surface facility permitting
• Well construction and facility design
• Financial assurance

• Well drilling and completion practices
• Well testing requirements
• Operational considerations
• Well integrity and workovers
• Solid wastes disposal issues
• Risk considerations and Induced Seismicity
• Well closure
History of the Underground Injection Control Program

• 1930s – The first documented oilfield brine disposal by injection in Texas.
• 1950s – Many states establish the disposal of brine by injection.
• 1960s – The first documented cases of contamination of drinking water sources and induced seismicity due to injection.
• 1974 – Congress passes the Safe Drinking Water Act (SDWA).

Source: Tomastik, 2015
History of the UIC Program (continued)

- Early 1980s – Federal UIC regulations are passed under Parts 144, 145, 146 and 147.
- 1980 – Congress amends the SDWA to allow existing state oil and gas programs to regulate UIC.
- 1980s – Primacy is awarded to many states.
Class II Program

- There are approximately 151,000 Class II wells in the U.S.
- About 20% or 30,000 of these wells are Class II disposal wells.
- 33 states have Class II wells and 27 states and 2 Indian Tribes have primacy of their Class II program.
- Tennessee received primacy of their Class II program in April of 2015 and Michigan is seeking primacy.
- U.S. EPA shares regulatory responsibility for Class II in 6 states – IA, KY, MI, NY, PA, and VA.

Source: www.energytomorrow.org
Important Well Siting Criteria

• Ideally, away from populated areas
• Good road network and access
• Purchasing vs. leasing property
• Mineral rights issues and rights to inject
• Favorable geologic conditions for high capacity disposal

Source: www.be-novative.com
Location, Location, Location

• Try and avoid densely populated areas.
• Well siting in populated areas can lead to objections to applications, which can delay permit issuance.
• Permits in these areas can lead to complaints regarding noise, odors, truck traffic, etc.

Source: www.kcet.org
Good Access to a Road Network

• Again, location is critical in well siting if fluid wastes are transported to the site.
• Close proximity to state and Interstate highways allows easier access to the injection facility.
• Properly designed surface facility to allow for faster movement and unloading of trucks is very important.
Example of an Existing Class II Facility with Ideal Access

Source: Google Earth.com
Purchasing vs. Leasing Property

- Obviously, there can be a big advantage in purchasing the property for siting an injection well.
- If purchasing is not an option, then a lease agreement is the next step.
Mineral Rights Issues

• Many oil and gas lease agreements already have provisions that allow for enhanced recovery, saltwater disposal, and gas storage.

• Some leases do not and would require negotiating a separate agreement to allow for disposal operations.

• A title search of the property should be conducted prior to any agreement.

Source: Evrol, LLC, 2015
EXHIBIT "A"

ADDENDUM TO OIL AND GAS LEASE
(the "Addendum")

Attached to and made a part of that certain
Oil and Gas Lease, by and between
Mary A. Hagan, an individual as "Lessor," and
Antero Resources Appalachian Corporation, as "Lessee," dated August 4th, 2012 (the "Lease")

DEFINED TERMS: Any capitalized terms in this Addendum, which are not defined in this Addendum, shall have the meaning given to such terms in the Lease.

CONFLICT BETWEEN TERMS: In the event of a conflict or inconsistency between any of the terms and conditions contained in this Addendum and the other terms and conditions contained in the Lease, the terms and provisions contained in this Addendum shall be controlling.

NO STORAGE RIGHTS: Notwithstanding anything herein contained to the contrary, Lessee agrees the herein described Leasehold shall not be used for the purpose of gas storage as defined by the Federal Energy Regulatory Commission. Any reference to Lessee's rights to store gas within the Leasehold that are contained in this Lease is hereby deleted. If Lessor wishes to enter into an agreement regarding gas storage using the Leasehold with a third party, Lessor shall first give Lessee written notice of the identity of the third party, the price or the consideration for which the third party is prepared to offer, the effective date and closing date of the transaction and any other information respecting the transaction which Lessee believes would be material to the exercise of the offering. Lessor does hereby grant Lessee the first option and right to purchase the gas storage rights by matching and tendering to the Lessor any third party's offering within 30 days of receipt of notice from Lessor.

NO DISPOSAL OR INJECTION WELLS: Lessee is not granted any right whatsoever to use the Leasehold, or any portion thereof, for construction and/or operation of any disposal well, injection well, or the construction and/or operation of any other disposal facilities.

Source: ALL Consulting, 2015
Favorable Geologic Conditions

- Proper geological evaluation is critical to a successful large-scale disposal operation.
- Knowledge of local geologic conditions and regional variation is highly important in selecting optimal disposal intervals.
- With the advent of induced seismicity now playing a big role in Class II operations, avoidance of geologic structures and the proximity of a disposal zone to the Precambrian basement must be considered.

Source: ALL Consulting, 2014
Structural Geologic Evaluation

Source: ALL Consulting, 2015
Underground Sources of Drinking Water (USDWs)

- USDWs are defined broadly to include all fresh water aquifers unless they have been specifically exempted from protection.
- A USDW may be in current use as a source of drinking water, but that is not necessary.
- A USDW is simply any aquifer which contains fewer than 10,000 mg/L total dissolved solids (TDS) and is currently being used as a drinking water source or which is of sufficient volume and adequate quality to be a future source for a public water system (25 or more connections).

USDWs

While the U.S. EPA defines a USDW as containing less than 10,000 mg/L total TDS, some states, such as California and Texas, have adopted an injection well surface casing protection standard for fresh water aquifers that contain less than 3,000 mg/L TDS.

Source: ODNR, 1993
Underground Source of Drinking Water
Include: Drinkable Quality Water (<3,000 TDS)
And
Useable Quality Water (3,000-10,000 TDS)
Brine - Salt Water (>10,000 TDS)

Source: www.slideshow.net
Class II Regulatory Process

• Which agency or agencies have regulatory authority?

• An operator needs to understand Class II SWD state and federal regulations.

• Also needs to understand the well application preparation process.

Source: DOGRM, 2015
Area of Review (AOR)

- All primacy states or U.S. EPA uses either a fixed radius or equation for calculating an AOR for a Class II disposal well.
- Fixed-radius AORs range from ¼ to ½ mile.
- The equation is referred to as the “zone of endangering influence” or ZEI.

Source: ODNR, 2015
Zone of Endangering Influence (ZEI)

• ZEI can be calculated from site-specific data using a modified Theis equation defined in U.S. EPA regulations.

• Endangerment is defined as a pressure increase that has the potential to cause a column of formation fluid in a conduit to extend above the level of the base of a USDW.

• Some states may have modified the ZEI formula.
Computation of the zone of endangering influence may be based upon the parameters listed below and should be calculated for an injection time period equal to the expected life of the injection well or pattern. The following modified Theis equation illustrates one form which the mathematical model may take:

\[
r = [(2.25KHt) \backslash (S10x)]1/2\text{ where;}
\]

- \( x = (4\pi KH [hw-hbo (SpGb) ] ) \backslash 2.3Q \)
- \( r = \) Radius of endangering influence from injection well (length);
- \( K = \) Hydraulic conductivity of the injection zone (length/time);
- \( H = \) Thickness of the injection zone (length);
- \( t = \) Time of injection (time);
- \( S = \) Storage coefficient (dimensionless);
- \( Q = \) Injection rate (volume/time);
- \( hbo = \) Observed original hydrostatic head of injection zone (length) measured from the base of the lowermost underground source of drinking water;
ZEI Formula (continued)

– hw = Hydrostatic head of underground source of drinking water (length) measured from the base of the lowest underground source of drinking water;
– SpGb = Specific gravity of fluid in the injection zone (dimensionless); and
– π = 3.142 (dimensionless).

• The ZEI equation is based on the following assumptions:
  – (a) The injection zone is homogenous and isotropic;
  – (b) The injection zone has infinite area extent;
  – (c) The injection well penetrates the entire thickness of the injection zone;
  – (d) The well diameter is infinitesimal compared to “r” when injection time is longer than a few minutes; and
  – (e) The emplacement of fluid into the injection zone creates instantaneous increase in pressure.

Source: Ohio Administrative Code 3745-34-32
AOR Investigation

- Must identify potential conduits and ensure proposed measures are adequate to protect USDWs
- Must conduct an evaluation of all wells within the AOR
- Must determine the well types, which include: active production, other active injection, temporarily abandoned, and permanently abandoned

Source: DMRM, 2001
Corrective Action (CA)

- Corrective Action requires the identification of wells in the AOR in need of CA.
- Wells needing CA are likely vertical migration conduits that can cause potential contamination.
- Applicant must identify conduits and ensure proposed measures are adequate to protect USDWs.
- Requires an operator to develop and submit a plan for CA.

Source: DMRM, 2006
CA Options

• Monitoring of problem wells – more frequent testing, visual observations, or a systematic monitoring program
• Remedial cementing
• Plugging or re-open and replugging of inadequately plugged wells
• Need to be addressed with a plan prior to commencement of injection.
Permit Application Process

- The required forms vary from state to state.
- All agencies require basic well information, such as operator, location, injection zone, confining zones, well construction, proposed injection volumes and pressure, and types of injectate.
- The applicant needs to submit a surface facility design.

Source: Texas RR Commission, 2015
Location Information

- Regulatory agencies require location information.
- Location information requirement can vary from state to state.
- Some agencies require plat maps by a registered state surveyor.

Source: ALL Consulting, 2014
Proposed Injection Zone

- Required to identify the proposed injection zone/injection interval.
- Depths of the injection zone/interval.
- Type of completion method – Open hole or cased hole.
- Lithology of the injection zone.

Source: DOGRM, 2013
Confining Zones

• Some regulatory agencies require the identification of confining zones above the proposed injection zone.

• Confining zones are non-permeable zones that provide a barrier to upward migration of injected fluids.

Source: www.cypressenergy.com
Proposed Well Construction

- Applicant must submit a proposed casing and cementing proposal.
- Well design needs to ensure the casing and cementing proposal meets all applicable regulations.
- All Class II disposal wells must be cased and cemented to prevent movement of fluids into or between USDWs.

Source: ALL Consulting, 2015
Injection Pressures and Volumes

- All state Class II agencies and U.S. EPA require submittal of proposed injection volumes and pressures.
- Some agencies regulate injection volumes and some do not.
- All agencies set the maximum allowable surface injection pressure by either formula or by test methodology, such as step-rate testing.

Source: ALL Consulting, 2015
Types of Injectate

- Regulatory agencies require submittal of proposed fluids to be injected.
- Fluids must be associated with the drilling, completion, and production of oil and natural gas.
- Some agencies require lab analysis of fluid to be injected.

Source: DMRM, 2009
Surface Facility Design

• Application process requires submittal of a plan for the proposed disposal well surface facility.

• Typical plan has number of storage tanks, secondary containment design, and unloading pad.
Typical Surface Facility Plan

Source: ALL Consulting, 2015
Financial Assurance

• Financial assurance is required on all Class II disposal wells.
• Requirements vary by state or federal regulatory agency.
• Most agencies have acceptable financial options.
• Some of these options can include:
  – Surety bond;
  – Financial guarantee bond;
  – Performance bond;
  – Letter of credit;
  – Irrevocable trust; and
  – Financial statement.
Aquifer Exemption

• The definition is: “An aquifer or its portion that meets the criteria in the definition of a USDW but which has been exempted according to procedures in 40 CFR 144.7.”

• Aquifer exemption regulations went into effect in 1982.

• No exemption is final until approved by U.S. EPA as a program revision.

• Primacy states/tribes may recommend aquifer exemption, but U.S. EPA must concur.

• There are substantial vs. non-substantial exemptions.

• Some states have developed their own regulations.
Recent Aquifer Exemption Issues

• State of California has recently developed Aquifer Exemption Compliance Schedule Regulations.
• These changes will have an impact on Class II operations in California.
• The proposed regulations are necessary to ensure that the State’s federally-approved UIC program for Class II injection wells meets the requirements of the federal Safe Drinking Water Act, and protects public health, safety and the environment in an efficient manner.
Administrative Review

• The agency reviews the application for completeness.

• Some agencies issue “draft” permits and create a fact sheet or statement of basis.

• The public notice requirement will vary depending upon the state or federal regulations.

Source: ALL Consulting, 2015
Public Participation in Permitting Process

• All state and federal Class II programs allow for public participation.
• Each agency has public notice and public hearing requirements.
• There is opportunity for the public to provide written or oral testimony regarding the permit application during the public comment period.

Source: www.energyindepth.org
Example of U.S. EPA Public Hearing Notice

Source: www.epa.gov/region5/water/uic
Be Prepared for Opposition

- Opposition to saltwater disposal wells has increased dramatically in the last few years.
- Objections to applications can delay issuance of a permit.
- Applicant needs to be prepared to face these challenges.

Source: DOGRM, 2015
Permit Issuance and Fieldwork Preparation

• Select contractors and get MSA agreements.
• Prepare site specific H&S plan.
• Confirm scheduling and availability of contractors.

Source: DOGRM, 2015
Well-Designed Drilling and Completion Programs are Essential

• Experienced drillers and professionals reduce overall costs and ensure quality work.
• Proper well completion during drilling and cementing eliminates injection formation contamination and damage.
• Good internal and external well integrity reduces well workovers.
• Correct cement type and additives with proper placement reduce the possibility of inadequate cement jobs that can lead to groundwater contamination or stray gas migration.
Health and Safety Plan

- Hazard analysis
- Onsite training
- Hazard communication
- Worker awareness
- Emergency contingency
- Daily JSA before any work is performed

Source: ALL Consulting, 2015
Onsite JSA Meeting

Training Sign-In Sheet

Company Name: ALL Consulting, LLC
Instructor(s): Tom Tomastik and Chuck Lowe, ALL Consulting
Date: March 3, 2015
Course Name/Topic: Greens Run SWD well workover

Training Provider: ALL Consulting, LLC (in-house training)

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Source: ALL Consulting, 2015
Initial Well Drilling Operations

- Oversight and coordination of contractors
- Mobilization of drilling rig and equipment
- Evaluation of proposed well construction and cementing programs

Source: ALL Consulting, 2015
Equipment Mobilization

Source: ALL Consulting, 2015
Initial Drilling

Source: DOGRM, 2013
Class II SWD Well Construction

- The surface casing is set to protect all USDWs.
- Depending upon the depth of the injection well, intermediate casing(s) may be set.
- The production casing is set and cemented above the top of the injection zone.
- State regulations on production casing cement height in different states can vary from 100 to 300 feet.
- This construction provides multiple layers of USDW protection.

Source: DOGRM, 2013
Open Hole Geophysical Logging

• Open hole geophysical logging is conducted on Class II wells.
• Some states have minimum log requirements.
• Logging is used to identifying injection intervals.

Source: EnLink Midstream, 2015
Cementing Practices

- Regulations require cementing of multiple casing strings
- Surface or intermediate casing strings cemented to protect USDWs
- Production casing cemented to isolate injection zone and prevent movement of fluids into or between USDWs
Cementing of Production Casing

• Cementing of production casing demonstrates Part II of well integrity – External mechanical integrity.

• External well integrity can be demonstrated by cementing records or cement bond logging.

Source: ALL Consulting, 2014
Example of Adequate Cement on Production Casing

Criteria for Determining the Adequacy of Cement

Source: www.rrc.state.tx.us
Well Completion Practices

- Cased hole versus open hole completions
- Depends upon the injection interval and geologic conditions
- Cased hole correlation logging to ensure correct placement of perforations

Source: ALL Consulting, 2015
Cased Hole Completions

• Injection interval is selected from open hole logs.
• Correlate the open-hole log with the cased hole log to confirm depths.
• Production casing is perforated using a perf gun at those intervals.

Source: ALL Consulting, 2015
Checking the Perf Gun After Perforating

Source: ALL Consulting, 2015
Open Hole Well Completion

• Production casing is set and cemented in directly on top of the proposed injection interval.

• Open hole injection well completions allow for access to multiple formations for disposal.

• Since injection zones are not cemented on open-hole completions, it prevents cement invasion that can plug off potential injection zones.

Source: ODNR, 2012
Well Stimulation

- Class II disposal wells are normally stimulated by acid jobs or by hydraulic fracturing.
- Well stimulation increases the injectivity of the formations.
- Acidization and formation breakdown are common in Class II disposal.

Source: DMRM, 2008
Acid Stimulation

- Most common acids used are hydrochloric (HCl) and hydrofluoric (HF), and sometimes in various combinations.
- Acid jobs typically include surfactants to reduce surface and interfacial tension, prevent emulsions, water-wet the formation, and safeguard against other problems.
- To prevent damage to the injection formations, use additives such as corrosion inhibitors, iron inhibitors, scale inhibitors, and clay stabilizers (depending on the lithology of the injection zone).

Source: ALL Consulting, 2015
Acid Job Results

Source: ALL Consulting, 2015
Injection Well Testing Requirements

- Both federal and state regulatory agencies have specific disposal well testing requirements.
- Part I and Part II of (internal and external) mechanical integrity tests (MIT) have to be demonstrated prior to injection.
- Five-year MIT or continuous monitoring for mechanical integrity is a regulatory requirement.
- Other tests that are deemed necessary by regulatory agencies, such as temperature logs, tracer surveys, noise logs, or pressure fall-off tests can be required on a case-by-case basis.
Demonstration of Part I - Internal Mechanical Integrity (MI)

- Typically performed using a Standard Annulus Pressure Test (SAPT)
- Many procedural differences among states and U.S. EPA regions
- Differences in test pressure, duration of the test, and pass/fail criteria

Source: ALL Consulting, 2015
Example of a Packer

Source: ALL Consulting, 2015
Running Packer into Well

Source: DOGRM, 2013
Initial Internal MI

- Setting of tubing and packer
- Pressurization of the casing-tubing annular space
- Monitoring on pressure to confirm the disposal well has internal MI

Source: ALL Consulting, 2015
Conducting the MI Test

Source: ALL Consulting, 2015
Demonstration of Part II - External MI

• Accomplished with
  – cementing records;
  – Cement bond log; or
  – Other test methods acceptable under state regulatory guidelines

Source: ALL Consulting, 2013
Other Potential Test Requirements

• Temperature Log
• Noise Log
• Radioactive Tracer or Spinner Survey
• Pressure fall-off test
• Any other test deemed necessary by the regulatory agency
Example of a Pressure Fall-off Test

Source: DOGRM, 2015
Surface Facility Design

Source: ALL Consulting, 2015
“Best in Class” Design Features

- Continuous monitoring of pressures and injection rate improves compliance and efficiencies.
- Chemical additive systems programs reduce tank, equipment and well failures.
- Capturing skim oil increases profitability.
- Adequate loading bays and traffic control helps reduce truckers from taking their loads to other facilities and reduces wait time and accidents.

Source: ALL Consulting, 2014
“Best in Class” Design Features (Continued)

- Safety and grounding reduces fires and accidents.
- Pre-Treatment and filtration reduces well workovers.
- Baseline water sampling prior to well drilling and facility construction can reduce liability.
- Proper handling of solid wastes and addressing TENORM or NORM issues are crucial for operational efficiency.

Source: EnLink Midstream, 2015
Operational Considerations

• Environmental and Regulatory Compliance
• Spill Prevention, Control and Countermeasure Plan (SPCC)
• Emergency Response Plan
• Radiation Protection Plan

• Spill and Clean-up Remediation
• Routine and Preventative Maintenance
• Chemical treatment and filtering of injectate
Environmental and Regulatory Compliance

- Maintaining mechanical integrity of the well – by either continuously monitoring, other required testing, or by conducting a 5-year MIT

- Reporting requirements – submittal of injection pressures and volume reports – monthly, quarterly, or annually as required by the regulatory agency

Source: DOGRM, 2015
Spill Prevention, Control and Countermeasure Plan (SPCC)

- Required by federal regulations and some state requirements
- Must prepare and implement a plan to prevent any discharge of oil into or upon the navigable waters of the United States and adjoining shorelines

Source: ALL Consulting, 2015
SPCC Plan Objectives

• Identify designated personnel accountable for spill prevention
• Define specific SPCC procedures and practices – notifications, inspections, record keeping, training, and response actions
• Outline notification and response procedures for the early stages of a spill control effort
Emergency Response Plan (ERP)

- Describes incident management team
- Provide roles and responsibilities
- Requires notification and activation procedures
- Requires coordination with local first responders
- Develops communications – processes and procedures
- Addresses lessons learned
- Interfaces with other response plans
- Provides plan maintenance and review

Source: ALL Consulting, 2015
Spill and Clean-up Remediation

• Typical materials spilled at a disposal well – Condensate, crude oil, brine, antifreeze, hydraulic oil, diesel, acid, biocides, iron inhibitors, and scale inhibitors.

• Operator need to be aware of regulatory spill notification and response requirements.

• Most spills caused by: Valve left open, tank overflowed, or transfer hose dropped on the ground.

Source: ALL Consulting, 2015
Clean-up Remediation

Source: ALL Consulting, 2015
Routine and Preventative Maintenance

• Routine and preventative maintenance is a must at any Class II disposal facility.
• Routine inspections of all surface equipment (tanks, valves, injection pumps, treatment systems, etc.) and pipelines should be undertaken,
• Helps to ensure maintenance schedules and procedures are followed and equipment is performing as required.

Source: EnLink Midstream, 2015
Pre-Treatment and Filtering of Injectate

• Perhaps the most critical aspect of Class disposal operations is to ensure that the fluid to be injected is pre-treated and filtered to eliminate potential damage to the injection zone.

• Failure to properly address injection fluids by chemical pre-treatment, filtering, and solids removal can lead to serious downhole issues and expensive workovers.

• Use of an inline desilter/desander provides for separation and removal “on the fly” of solid (silt) particles.

• The desilter/desander dramatically reduces the reliance on conventional filter pods and sock filters.

• Use of these advanced technologies can lead to savings in labor and disposal costs.
Example of Desilter/Desander Solids Removal

**InLine DeSilter**

**Purpose:** Bulk removal of fine solids from flow. Common applications: to protect SWD formation; minimize sock filters; avoid erosion; etc.

Basic unit = 10K bpd

Source: FMC Technologies, 2015
Chemical Pre-Treatment

• Analysis of injectate is an important step in ensuring proper chemical treatment of injectate.

• With the advent of disposal of large quantities of flowback fluids from unconventional plays, chemical pre-treatment has become more important to a disposal operation.

• Lab results of injectate can provide insight into the type of chemical treatment that is warranted.

• Knowledge of injection formations and susceptibility to certain constituents in flowback fluids is critical to chemical treatment.

• Common chemical treatment can involve biocides, iron inhibitors, and scale inhibitors.
Example of Injectate Analysis

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<td>98,700</td>
<td>115,000</td>
<td>120,000</td>
<td>179,000</td>
<td>194,000</td>
<td>113,000</td>
<td>114,000</td>
<td>109,000</td>
<td>90,000</td>
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<td>109,000</td>
<td>131,000</td>
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<tr>
<td>Total Dissolved Solids</td>
<td>mg/L</td>
<td>105,000</td>
<td>130,000</td>
<td>173,000</td>
<td>161,000</td>
<td>191,000</td>
<td>179,000</td>
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<td>155,000</td>
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<td>173,000</td>
<td>155,077</td>
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<td>Total Organic Carbon</td>
<td>mg/L</td>
<td>439</td>
<td>376</td>
<td>319</td>
<td>960</td>
<td>2,220</td>
<td>996</td>
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<td>186</td>
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<td>1,510</td>
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<td>Total Suspended Solids</td>
<td>mg/L</td>
<td>205</td>
<td>1,070</td>
<td>344</td>
<td>275</td>
<td>217</td>
<td>426</td>
<td>201</td>
<td>183</td>
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<td>109</td>
<td>112</td>
<td>1,310</td>
<td>280</td>
<td>387</td>
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Source: ALL Consulting, 2015
Well Integrity and Well Workover

• The most critical aspects of Class II disposal is to maintain well integrity.

• Loss of internal or external mechanical integrity results in downtime and costly workovers.

• Well workovers can vary from simple to complex depending upon the issue downhole.

• Expensive well workovers can be avoided if BMPs for drilling, cementing, completion, and operations are followed.
Well Integrity

- 40 CFR 146.8(a) – “No significant leak in the casing, tubing, or packer and no significant fluid movement into USDW through vertical channels adjacent to injection wellbore.”

- All wells required to demonstrate external and internal mechanical integrity on a regular basis.

Source: GAO, 2014
Common Well Integrity Failures

- About 80% of internal MI failures are tubing and/or packer failures.
- The leak is contained within the production casing.
- This type of leak is easy to detect.
- Identified when pressure equalization occurs between the injection pressure and annulus pressure in the tubing/casing annulus.

Source: ALL Consulting, 2015
Repairing Internal MI Failures

• An internal MI failure is commonly fixed by pulling tubing and packer assembly.

• Common issues – tubing thread leak, bad tubing joint, holes in tubing, or packer rubbers not holding.

• Repaired by replacing bad tubing, replace rubbers on the packer, or replace the packer.

Source: ALL Consulting, 2015
Other Well Integrity Failures

- Casing or cement failure accounts for approximately 12 to 20% of all failures.
- These failures can be located using various methods, such as bridge plug, pump test with flag, or setting and testing areas with tubing and packer assembly.
- They can also be detected using case hole geophysical logging such as radioactive tracer survey, temperature, noise, or oxygen activation logs.
- Can repair these types of failures with liners, squeeze cement job, or other methods.

Source: ALL Consulting, 2015
Well Workovers

• Workovers can be fairly simple to rather complex depending on the downhole issue.

• Types of well workovers can include: acid jobs, replacing tubing or packer, casing repair, running in a liner, remedial cementing, plug back, and side tracking.

Source: ALL Consulting, 2015
Acid Job

• Acid treatments are fairly common for Class II disposal wells.
• Acid is used to clean-up the formation face and improve injectivity.
• Typically uses HCL or HF acids for treatment.
• Number of acid jobs on a well can be reduced by better pretreatment of injectate at the surface.

Source: ALL Consulting, 2015
Tubing and Packer Workovers

• Tubing and packer well workovers are the most common.
• These workovers can be relatively simple to rather complex depending on the downhole well conditions.
• Simple workovers can involve just the replacement of a few joints of tubing or changing out the rubbers on the existing packer.
• Complex workovers can involve isolation of the injection formation prior to pulling tubing and packer.
Example of a Simple Workover

• Pull tubing and packer and replace tubing string.
• Run in with new tubing and packer and set packer.
• Perform mechanical integrity test and put well back into operation.

Source: ALL Consulting, 2015
Example of a Complex Workover

- Injection formation is under high pressure.
- Pressure must be isolated prior to pulling tubing and packer.
- Need to address any containment issues prior to workover.
- Needed to develop a two-phase work plan.

- Isolation of injection zone was accomplished with inflatable packers.
- Then pulled existing tubing and packer.
- Reconfigured the wellhead to accept a snubbing unit.
- Pulled inflatable packers from the well.
- Ran into the well with new tubing and packer through free-standing snubbing unit.
- Set new packer, performed MIT, and put well back into operation.
Not an Ideal Location

Source: Google Earth, 2015
Preparation of Secondary Containment

Source: ALL Consulting, 2015
Isolation of the Injection Zone

Source: ALL Consulting, 2015
Pulling Existing Tubing and Packer

Source: ALL Consulting, 2015
Reconfigure Wellhead

Source: ALL Consulting, 2015
Pulling Inflatable Packers

Source: ALL Consulting, 2015
Running in New Tubing and Packer with Snubbing Unit

Source: ALL Consulting, 2015
Set Packer and Pass MIT

Source: ALL Consulting, 2015
Remedial Cementing

- Squeeze job or “remedial cementing” is a process of using pump pressure to inject or squeeze cement or additive into a void space behind a casing string.
- Squeeze jobs are commonly used for repairing casing leaks or remedy a deficient primary cement job.
- Additionally, can be accomplished using resins or other types of additives.

Source: ALL Consulting, 2014
Remedial Cementing Operation

Source: ALL Consulting, 2014
Plug Back Operations

- Sometimes an injection zone no longer accepts economic quantities of fluid.
- The well can be plugged and abandoned, or if shallower injection zones exist, the well can be plugged back to another zone for injection.
- This is common when converting existing oil and gas wells to disposal.
- Most regulations require a new permit through the normal application process.
Side Track Operations

• Occasionally, due to downhole issues, a disposal well may be side tracked to get back into the viable injection zone.

• Side tracking avoids abandoning the existing well and drilling a new well.

Source: www.slb.com
Solid Wastes at Disposal Wells

- Solid wastes associated with Class II disposal wells are NORM and TENORM.
- NORM is naturally-occurring radioactive material which commonly contains uranium, thorium, radium, or lead-210.
- TENORM (technologically enhanced radioactive material) is NORM that has been enhanced or modified by man-made actions.
- Radium-226 and Radium-228 are the main radionuclides that are the issue.

Source: ODH, 2015
Regulation of NORM and TENORM

• Federal government does not have regulatory authority of NORM or TENORM.
• Regulation of these materials is left to the States.
• At least 27 states have regulations that govern disposal of NORM/TENORM.

Source: www.slideshare.net
Types of NORM and TENORM Solid Wastes

- Spent frac sand
- Spent recycled drilling muds
- Pipe scale
- Tank bottoms
- Filter media
Examples

Source: www.boulderweekly.com

Source: www.bakken.com

Source: www.mpmews.org

Source: www.alertconsulting.com
Regulatory Standards

- U.S. EPA is responsible for setting federal radiation standards for exposure to TENORM.
- However, there is no single comprehensive TENORM regulation.
- Action levels for managing these wastes vary among the states.
- Operators need to be aware of state-specific NORM/TENORM regulations.

Source: www.ogj.com
Risk Considerations Associated with Class II Disposal

• Operators need to be aware of the inherent risks associated with Class II disposal wells.

• These risks can include:
  – Induced seismicity and seismic monitoring,
  – accidents and litigation,
  – public opposition, and
  – environmental activism.

Source: www.avoidbk.com
Induced Seismicity and Seismic Monitoring

- Induced seismicity associated with the oil and gas industry has become a national issue in the United States.
- Many states, including Arkansas, Kansas, Ohio, Oklahoma, and Texas, have developed or are developing regulations to address concerns regarding alleged induced seismicity related to oil and gas development.
- The main focus has been directed at Class II saltwater disposal operations (SWD).

Source: www.nap.edu
Induced Seismicity

The term “induced seismicity” is defined as earthquake events associated with man-made activities such as:

- surface and underground mining,
- geothermal energy,
- oil and gas operations,
- dams and artificial lakes,
- underground nuclear tests,
- groundwater extraction, and
- underground injection.
Increase in Seismicity Related to Oil and Gas Development

- U.S. Geological Survey (USGS) believes the rise in seismicity in the central and eastern U.S. since 2009 coincided with increased injection activities in Arkansas, Colorado, Ohio, Oklahoma, and Texas.

- USGS believes induced seismicity related to the energy industry occurs when there is a change in pore pressure or a change in stress, or both, near faults that are stable, but under critical stress.

Source: www.usgs.gov
Fundamental Questions of Induced Seismicity

• Are the events the first known earthquakes of this character in the region?
• Is there a clear correlation between injection and seismicity?
• Are epicenters near wells (within five kilometers)?
• Do some earthquakes occur at or near injection depths?
• If not, are there known geologic structures that may channel flow to the sites of earthquakes?
• Are changes in pore pressure at well depths and hypocenter locations sufficient to encourage seismicity?

Source: Davis and Frohlich, 1993
Recent Injection Induced Seismic Studies

- National Research Council’s 2013 Report on Induced Seismicity
- GWPC 2013 White Paper on Induced Seismicity
- U.S. EPA NTWG 2015 Class II Induced Seismicity Report

- And the IOGCC-GWPC States First Induced Seismicity Working Group Primer entitled:

“Induced Seismicity by Injection Associated with Oil & Gas Development: A Primer on Technical & Regulatory Considerations Informing Risk Management and Mitigation.”
Recent USGS Research

• USGS has identified 17 areas within 8 states with increased rates of induced seismicity.
• This is the first comprehensive assessment of the hazard levels associated with induced seismicity in these areas.
• The states include: Alabama, Arkansas, Colorado, Kansas, New Mexico, Ohio, Oklahoma, and Texas.

Source: www.usgs.gov
Induced Seismicity Working Group

• The management of risks associated with induced seismicity related to oil and gas rests with a state regulatory agency.

• The increase in seismic events has led to an increased level of public concern.

• The Primer will provide regulatory agencies with a guide to the causes and effects of induced seismicity events.

Source: www.statesfirstinitiative.org
EarthScope Array

EarthScope Stations Status as of June 2015

Source: EarthScope, 2016
Current Status Map of the EarthScope Array

Source: EarthScope, 2016
Induced Seismic Risk Assessment Plan

- Needs to identify and evaluate geologic structures located within the area of concern.
- Must evaluate risk impacts to public health, safety, and welfare associated with potential seismic events.
- Requires the development of a monitoring and mitigation plan.
- Addresses financial assurance with a proposal acceptable to the regulatory agency.
Objective of the Plan

To provide operators, regulators, and other stakeholders with a transparent and technology-based process for assessing and addressing actual and perceived risks.

Source: www.advtechconsultants.com
Seismic Monitoring and Mitigation

• ALL Consulting is actively involved in seismic monitoring for clients.
• ALL works in partnership with seismic experts in monitoring installation, software development, and real-time seismic monitoring and analysis.
• ALL conducts real-time seismic monitoring in our main office in Tulsa, OK.

Source: ALL Consulting, 2014
Passive Microseismic Monitoring

- Recommended deployment of a minimum of five seismic stations.
- Recommended using seismic units with three component (X,Y, and Z) velocity sensor.
- A minimum of 250 hertz (Hz) sampling rate for real-time data collection.

- Sensor response flat between 2Hz and 400 Hz and suitable for recording microseismic events at sampling rates of 1000 Hz.
- Data must be recorded using real-time automatic event detection and solution system such that event locations are published in real-time of an event being detected.
Portable Seismic Unit Placement

- Sensors should be deployed in shallow boreholes (6 to 9 feet below the surface) wherever possible to reduce surface noise and increase signal to noise levels.
- Placement of four seismic units 90 degrees in a radius around the wellhead at distances of the total depth of the well (+/- several 100 feet).
- Deployment of the fifth seismic unit within 500 to 750 feet of the wellhead for vertical to get vertical depth data on a seismic event.
- Using this arrangement, event surface location and event depth accuracy is +/- 250 meters.
Accuracy of Seismic Events

- Regional seismic network locations can lead to too much uncertainty to assess cause and effect.
- Location accuracy strongly depends on the distribution of seismic stations with respect to event locations.
- The farther the seismic event is from a monitoring station or array the larger the error in surface and depth location.
- Additionally, the velocity models developed for seismic event interpretation typically did not utilize existing oil and gas geophysical logs, which could provide more accurate velocities for the geological formations.

EW Event ID: 7

- Origin time: 2015.06.26 20:52:45 UTC
- Latitude: 40.6038
- Longitude: -81.0640
- Depth: -0.1 km
- Coda Magnitude: 0.7 Mr nobs=4
- Local Magnitude: 1.1 ±0.2 ML nobs=8
- RMS Error: 0.01 s
- Horizontal Error: 1.69 km
- Depth Error: 7.59 km
- Azimuthal Gap: 255 Degrees
- Total Phases: 4
- Total Phases Used: 4
- Num S Phases Used: 0
- Quality: D

Source: ALL Consulting, 2015
Seismic Monitoring System Design

Source: ALL Consulting, 2015
Seismic Monitor Installation

Drilling of boreholes for installation of seismic sensor and post for solar panel, receiver, battery, and modem for internet connection.

Source: ALL Consulting, 2014
Installation of PVC and Steel Pipe

Source: ALL Consulting, 2014
Installation of Seismic Monitoring Box and Solar Panel

Source: ALL Consulting, 2015
Seismic Sensor Installation

Source: ALL Consulting, 2014
Battery, Seismic Receiver, and Modem Installation

Source: ALL Consulting, 2014
Final Programming and Operational

Source: ALL Consulting, 2014
Seismic Data Processing

• Data is pushed from stations to Reftek RTPD software running on the server at ALL-LLC in Tulsa, where a continuous archive is retained as Reftek format files.

• Data is pulled from RTPD into an Enterprise Earthworm configuration, where earthquake detection is performed and waveforms are stored in a MySQL database for analysis.

• Automated alerts are sent out via email when an earthquake or other event (i.e., quarry blast) is detected by at a minimum of 4 stations.

• ISTI seismologists monitor the system for activity.
Example automated email

If the Earthworm system detected and located an event, it would have sent an email similar to the following:

Source: ISTI, 2015
Example of a Recorded Actual Seismic Event

Source: DOGRM, 2014
Example of a Recorded Mine Blast Event

Source: DOGRM, 2014
Monitoring and Mitigation Plan

- This plan would build upon the risk assessment and include both monitoring and mitigation elements.
- Monitoring would likely include additional forms of surface movement and seismic monitoring designed to identify events that might impact receptors identified in the Risk Assessment.
- Mitigation would likely involve a phased approach, like a traffic light system, to the resumption of operations and would include agreed-upon actions to be taken if triggering events are identified through enhanced monitoring.
Induced Seismicity Traffic Light System

- On a national level, regulatory agencies and the industry have been looking at the development of a traffic light system to address induced seismicity.
- This system would need to be reasonable and magnitude thresholds need to be based on risk associated with local conditions.
- Remote locations get a higher magnitude than an urban area with a higher density population.
Cooperation

• Even though induced seismicity is rare, it is a nationwide issue and it will not go away anytime soon.

• It is crucial for the oil and gas industry to approach induced seismicity proactively with sound science.

• Oil and gas industry will need to work in cooperation with regulatory agencies to address the issue of induced seismicity.
Accidents and Litigation

- The Bakken in North Dakota and Eagle Ford in south Texas have seen lightning strikes ignite hydrocarbons at brine disposal facilities.
- Several brine disposal sites have had accidents resulting in injury and costly litigation.

Source: ALL Consulting, 2015
Public Opposition and Environmental Activism

• Public opposition should be a significant consideration when siting and permitting a Class II brine disposal facility.

• Seismic events in areas of shale development has increased public concern and fueled environmental groups and media opposition to Class II injection wells.

Source: WKBN27
Opposition

• Opposition to Class II disposal wells has increased dramatically across the U.S.

• Objections to applications, protests, and demonstrations at operational sites are occurring more frequently.

• A Class II disposal operator needs to be prepared to address these challenges.

Source: www.slowdownfracking.wordpress.com
Well Closure

- Both state and federal regulations require that plugging of a Class II disposal well must occur in a way that will not allow movement of injected fluids into or between USDWs after plugging operations have been completed.

- Plugging methods and placement of plugs will vary among the states and federal agencies.

- Some states require an application and issuance of a plugging permit.
Conclusions

- Well planned and properly constructed Class II disposal wells will continue to be the best practice for managing flowback and produced water in the shale plays.
- ALL does not see a significant lessening in opposition to Class II well siting and use.
- ALL also believes these wells will continue to become more rigorously regulated.

Source: ALL Consulting, 2014
Questions?