# An operational plan for safe and effective CO2 injection at Wellington Field, Kansas (DE-FE0006821) in perspective of recent, nearby seismic activity

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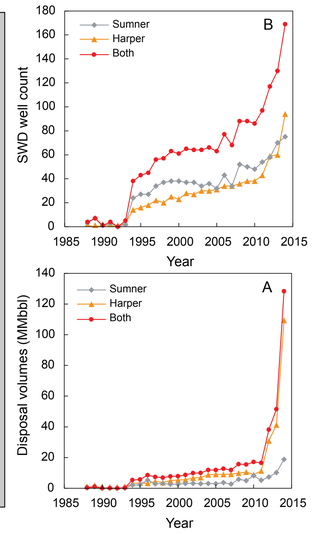
KANSAS GEOLOGICAL SURVEY
The University of Kansas

## Kansas Seismic Activity - An Update of Kansas Geological Survey Research

An operational plan will be used to ensure that CO2 injection at Wellington is conducted in a safe manner, in part, addressing recent concerns about the increase in shallow seismicity in the central micontinent and south-central Kansas, the location of Wellington Field. The presentation is three-fold, 1) summary of the seismic activity and recent large volume brine disposal, 2) geologic conditions associated with the seismicity, and 3) summary of key elements in the operational plan for safe CO2 injection at nearby Wellington Field.

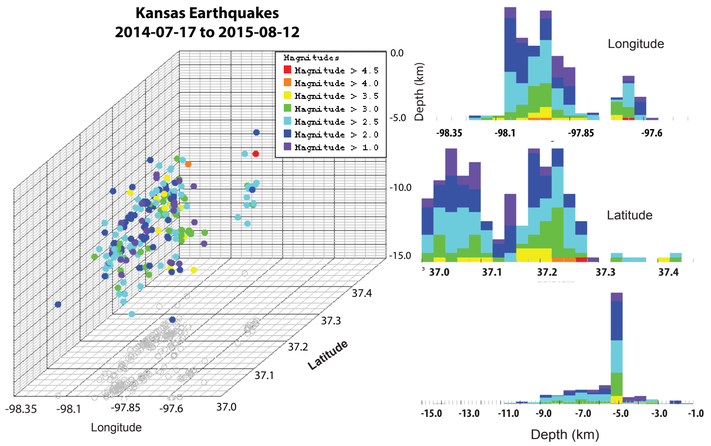
### Current Research

- Seismic monitoring
- Fault mapping and stress field analysis
- Geologic and simulation models
- Operational plan for safe CO2 injection at Wellington field




## Brine Disposal

Recent earthquakes in south-central Kansas dramatically increased since 2013 to 108 events above 2 magnitude in 2014 compared to, on average, less than 2 events per year state-wide prior to 2014. Coincident with the increase in seismicity that began in 2013, a notable increase in high capacity (volume, rate, and injection pressure) Class II brine disposal wells began injection into the Lower Ordovician Arbuckle Group saline aquifer, the same unit to be tested at Wellington field.

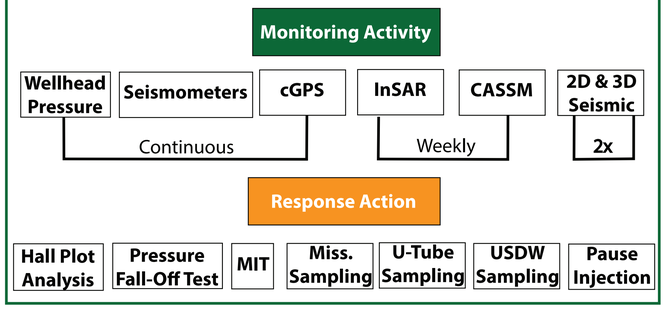



## Operating Plan for Safe and Efficient Injection (OPSEI)

The Wellington OPSEI is designed to ensure that CO2 injection operations are conducted in a safe manner that does not endanger life or property and is no more intrusive than normal oilfield operations in Kansas. The plan integrates activities outlined in the Class VI permit document that relate to testing, monitoring, safety controls, and operation of the injection well. It consists of four sub-plans that provide a) an electronically programmed and controlled workflow for safe day-to-day operations, b) instrumentation based monitoring checks to provide early warning of CO2 plume and pressure front deviations, and associated activities to maintain safe injection, c) limits injection to levels below those that could potentially induce detrimental seismic activity, and c) an emergency rapid response plan to prevent damage in the unlikely event of a natural disaster, equipment failure, or escape of the CO2 from deep within the subsurface.

- **Injection Control Plan**
- **Wellington Seismic Action Plan**
- **Monitoring-based Rapid Response Plan**
- **Emergency Remedial Response Plan**

## Monitoring based Rapid Response Plan



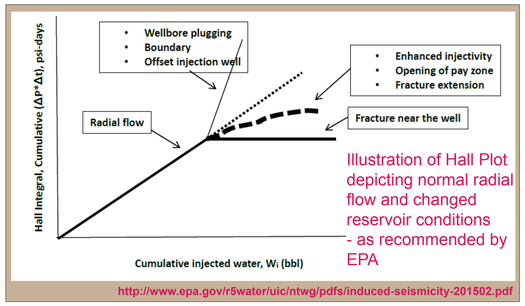
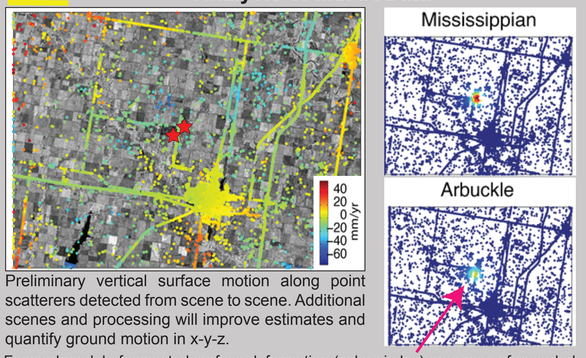




Illustration of Hall Plot depicting normal radial flow and changed reservoir conditions - as recommended by EPA

http://www.epa.gov/r5water/uic/ntwg/pdfs/induced-seismicity-201502.pdf

## Analysis of InSAR Data




Preliminary vertical surface motion along point scatterers detected from scene to scene. Additional scenes and processing will improve estimates and quantify ground motion in x-y-z.

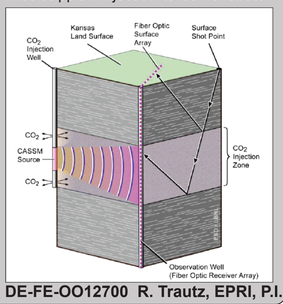
Forward model of expected surface deformation (color circles) on a map of recorded point scatterers. Deformation is simulated for the planned CO2 injection into each reservoir. Deformation is higher and more focused due to the shallower injection into thinner Mississippian. Reservoir pressure during injection is also greater than in the Arbuckle. Calibration will be done during the Mississippian injection to demonstrate effectiveness of method.

### CASSM, Crosswell, Fiber Optics*

Fiber Optic Array may be used with CASSM and Crosswell Tomography for imaging CO2 during the injection. Multiple seismic shots will create a pseudo-3D volume to help image the CO2 plume.

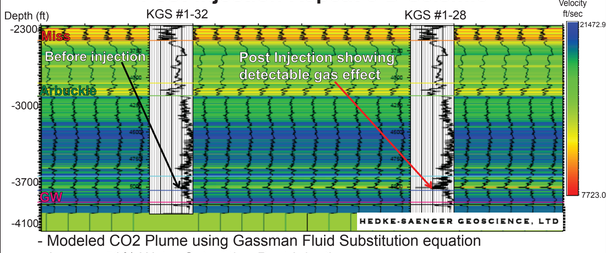
*Prospect remains to secure distributed Fiber Optic Arrays with VSP for monitoring

High Resolution Vibroseis source for VSP, R. Miller, KGS




DE-FE-OO12700 R. Trautz, EPRI, P.I.

## Post-injection Repeat 3-D Seismic




- Modeled CO2 Plume using Gassman Fluid Substitution equation
- Assume 50% Water Saturation Post Injection

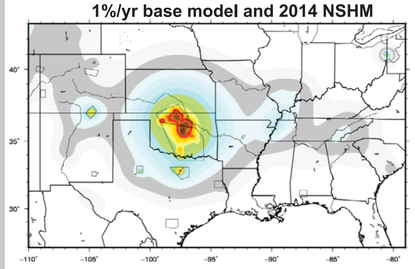
AVO analysis to date suggest certain offset range (source-receiver distance) could detect fluid changes to aid the acquisition design. Far offsets (>30 deg) are expected to contain more information about pore fluids than near offsets, but far offset reflections from deep targets are more noisy so subtle changes are difficult to detect with confidence. – *G. Tsoflias, personnel com.*

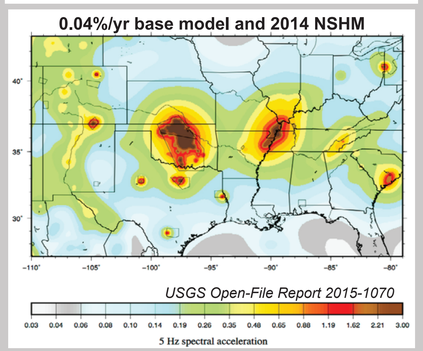
Related references on CO2 detection: http://library.seg.org/toc/leedff/29/2

**Acknowledgements**

- KGS colleagues in Energy Research Section who generously shared their research include; Tandis Bigdoli, Mina Fazelalavi, Eugene Holubnyak, and John Doveton
- Bittersweet Energy – Tom Hansen with Paul Gerlach and Larry Nicholson; Dennis Hedke, Martin Dubois and SW Kansas CO2-EOR industry consortium, John Youle, George Tsoflias and students at KU, Gene Williams, and KGS staff supporting the acquisition of data, stratigraphic correlation, regional mapping, and interpretations
- Dana Wreath, Berexco, LLC for access and participation in drilling and testing at Wellington and Cutter fields and small scale field test at Wellington
- The DOE-CO2 project supported by the U.S. Department of Energy (DOE) National Energy Technology Laboratory (NETL) under Grants DE-FE0002056 and DE-FE0006821, Jason Rush, Joint-PI, Jennifer Raney, Project Coordinator
- Rick Miller and Shelby Petrie, Wellington seismometer array, high resolution seismic
- Induced Seismicity Task Force -- Rex Buchanan, Chair

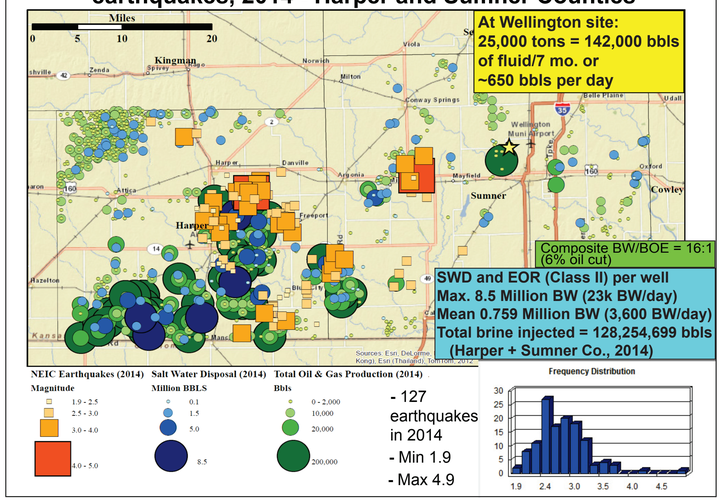
## Seismicity Hazard Map



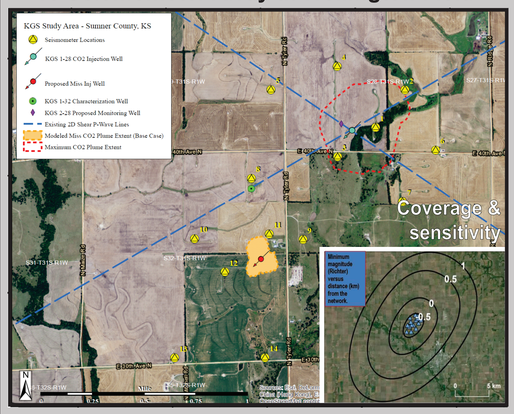




2014 NSHM combined with induced seismicity hazard. Uniform hazard maps for 1-percent (top) and 0.04-percent (bottom) probability of exceedance in 1 year. This base case model uses a 2014 nondeclustered catalog with magnitudes greater than minimum magnitude (Mmin) 2.5, b-value equal to 1.0, 5 kilometers (km) smoothing, 8 National Seismic Hazard Model (NSHM) ground motion models (GMM), and NSHM craton maximum magnitude (Mmax) model (mean M7). Five-hertz (5-Hz, 0.2 seconds) spectral accelerations are in units of acceleration of gravity (g).

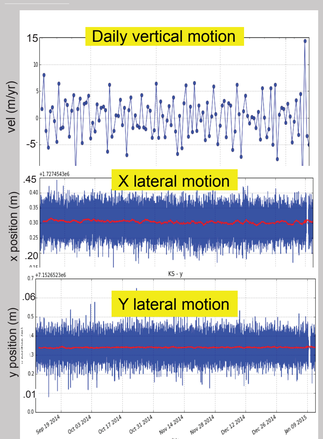
## Total salt water injected by well, BOE by lease, and earthquakes, 2014 - Harper and Sumner Counties




## 18 Seismometer Array at Wellington Field




## cGPS




Raw cGPS Data (Recorded 9/14 - 2/15)

-- a steady baseline for calibration of InSAR

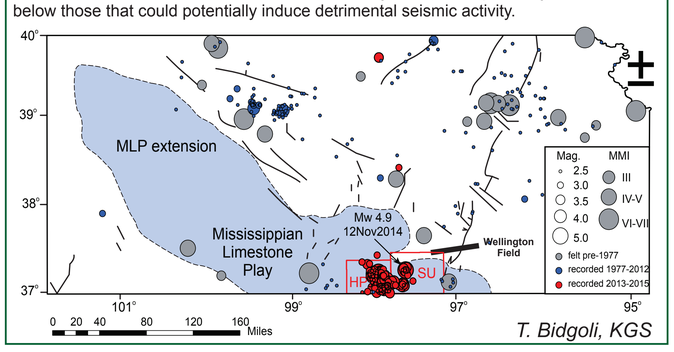
-- Data processed at KU under the direction of Leigh Stearns using GIPSY-OASIS

-- Noise is primarily due to tidal effects

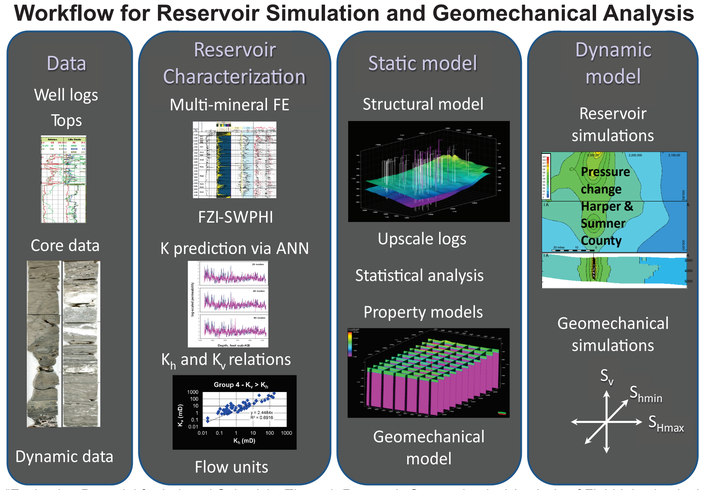
*D. Schwab, KGS*

## Historical Seismicity in KS

Regional geologic maps accessed from http://maps.kgs.ku.edu/co2/ developed under DE-FE0002056 provide context for the seismicity, brine disposal and permit comparison with the Wellington Field site. These tools were used in part to develop an operation plan for CO2 injection at Wellington Field with objectives to 1) permit safe day-to-day injection, 2) monitoring checks to provide early warning of CO2 plume and pressure front deviations, and associated activities to maintain safe injection, and 3) limit injection to levels below those that could potentially induce detrimental seismic activity.




## Workflow for Reservoir Simulation and Geomechanical Analysis




"Evaluating Potential for Induced Seismicity Through Reservoir-Geomechanical Analysis of Fluid Injection in the Arbuckle Saline Aquifer, South Central Kansas" Annual Meeting AAPG 2015, Denver
-- T. Bidgoli, Y. Holubnyak, M. FazelAlavi