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U.S. Department of Energy
FEDERAL ASSISTANCE REPORTING CHECKLIST
AND INSTRUCTIONS FOR RD&D PROJECTS

1. Identification Number: **DE-FE0006821**	2. Program/Project Title: **Small Scale Field Test Demonstration CO2 Sequestration**
3. Recipient: **University of Kansas Center for Research, Inc.**	

4. Reporting Requirements:	Frequency	Addressees
A. MANAGEMENT REPORTING		
☒ Research Performance Progress Report (RPPR)	Q	FITS@NETL.DOE.GOV
☒ Special Status Report	A	FITS@NETL.DOE.GOV
B. SCIENTIFIC/TECHNICAL REPORTING		
(Reports/Products must be submitted with appropriate DOE F 241. The 241 forms are available at www.osti.gov/elink)		
Report/Product — Form		
☒ Final Scientific/Technical Report — DOE F 241.3	FG	http://www.osti.gov/elink-2413
☒ Conference papers/proceedings* — DOE F 241.3	A	http://www.osti.gov/elink-2413
☐ Software/Manual — DOE F 241.4		
☐ Other (see special instructions) — DOE F 241.3		
** Scientific and technical conferences only*		
C. FINANCIAL REPORTING		
☒ SF-425 Federal Financial Report	Q, FG	FITS@NETL.DOE.GOV
D. CLOSEOUT REPORTING		
☒ Patent Certification	FC	FITS@NETL.DOE.GOV
☒ SF-428 & 428B Final Property Report	FC	FITS@NETL.DOE.GOV
☐ Other		
E. OTHER REPORTING		
☒ Annual Indirect Cost Proposal	O	See block 5 below for instructions.
☐ Audit of For-Profit Recipients		
☒ SF-428 Tangible Personal Property Report Forms Family	A	FITS@NETL.DOE.GOV
☒ Other – see block 5 below	A	FITS@NETL.DOE.GOV

FREQUENCY CODES AND DUE DATES:

A - Within 5 calendar days after events or as specified.
FG- Final; 90 calendar days after the project period ends.
FC- Final; End of Effort.
Y - Yearly; 90 calendar days after the end of the reporting period.
S - Semiannually; within 30 calendar days after end of project year and project half-year.
Q - Quarterly; within 30 days after end of the reporting period.
Y180 – Yearly; 180 days after the end of the recipient's fiscal year
O - Other; See instructions for further details.

5. Special Instructions:

Annual Indirect Cost Proposal – If DOE is the Cognizant Federal Agency, then the proposal should be sent to FITS@NETL.DOE.GOV . Otherwise, it should be sent to the Cognizant Federal Agency.

Other – The Recipient shall provide all deliverables as contained in Section D of Attachment 2 Statement of Project Objectives.

QUARTERLY PROGRESS REPORT
To
DOE-NETL
Brian Dressel, Program Manager
Award Number: DE-FE0006821

SMALL SCALE FIELD TEST DEMONSTRATING CO_2 SEQUESTRATION IN ARBUCKLE SALINE AQUIFER AND BY CO_2-EOR AT WELLINGTON FIELD, SUMNER COUNTY, KANSAS

Project Director/Principal Investigator:
W. Lynn Watney
Senior Scientific Fellow
Kansas Geological Survey

Ph: 785-864-2184, Fax: 785-864-5317
lwatney@kgs.ku.edu

Joint Principal Investigator:
Jason Rush
Assistant Project Manager
Jennifer Raney
Prepared by Lynn Watney, Jennifer Raney, and Tiraz Birdie with contributions by Eugene Holubnyak, Jason Rush, George Tsoflias, Brandon Graham, Alex Nolte, John Victorine, John Doveton, Brent Campbell, Jason Bruns,

Date of Report: October 2, 2015
DUNS Number: 076248616

Recipient: University of Kansas Center for Research &
Kansas Geological Survey
1930 Constant Avenue
Lawrence, KS 66047

Project/Grant Period: 10/1/2011 through 9/30/2016
Sixteenth Quarterly Report
Period Covered by the Report: July 1, 2015 through September 30, 2015
Signature of Submitting Official:

Willard Lynn Watney

Digitally signed by Willard Lynn Watney
DN: cn=Willard Lynn Watney, o=University of Kansas, ou=Kansas Geological Survey, email=lwatney@kgs.ku.edu, c=US
Date: 2015.10.12 16:31:37 -05'00'

EXECUTIVE SUMMARY

Project Objectives

The objectives of this project are to understand the processes that occur when a maximum of 70,000 metric tonnes of CO_2 are injected into two different formations to evaluate the response in different lithofacies and depositional environments. The evaluation will be accomplished through the use of both *in situ* and indirect MVA (monitoring, verification, and accounting) technologies. The project will optimize for carbon storage accounting for 99% of the CO_2 using lab and field testing and comprehensive characterization and modeling techniques.

CO_2 will be injected under supercritical conditions to demonstrate state-of-the-art MVA tools and techniques to monitor and visualize the injected CO_2 plume and to refine geomodels developed using nearly continuous core, exhaustive wireline logs, and well tests and a multi-component 3D seismic survey. Reservoir simulation studies will map the injected CO_2 plume and estimate tonnage of CO_2 stored in solution, as residual gas, and by mineralization and integrate MVA results and reservoir models shall be used to evaluate CO_2 leakage. A rapid-response mitigation plan will be developed to minimize CO_2 leakage and provide comprehensive risk management strategy. A documentation of best practice methodologies for MVA and application for closure of the carbon storage test will complete the project. The CO_2 shall be supplied from a reliable facility and have an adequate delivery and quality of CO_2.

Scope of Work

Budget Period 1 includes updating reservoirs models at Wellington Field and filing Class II and Class VI injection permit application. Static 3D geocellular models of the Mississippian and Arbuckle shall integrate petrophysical information from core, wireline logs, and well tests with spatial and attribute information from their respective 3D seismic volumes. Dynamic models (composition simulations) of these reservoirs shall incorporate this information with laboratory data obtained from rock and fluid analyses to predict the properties of the CO_2 plume through time. The results will be used as the basis to establish the MVA and as a basis to compare with actual CO_2 injection. The small scale field test shall evaluate the accuracy of the models as a means to refine them in order to improve the predictions of the behavior and fate of CO_2 and optimizing carbon storage.

Budget Period 2 includes completing a Class II underground injection control permit; drilling and equipping a new borehole into the Mississippian reservoir for use in the first phase of CO_2 injection; establishing MVA infrastructure and acquiring baseline data; establishing source of CO_2 and transportation to the injection site; building injection facilities in the oil field; and injecting CO_2 into the Mississippian-age spiculitic cherty dolomitic open marine carbonate reservoir as part of the small scale carbon storage project.

In Budget Period 3, contingent on securing a Class VI injection permit, the drilling and completion of an observation well will be done to monitor injection of CO_2 under supercritical conditions into the Lower Ordovician Arbuckle shallow (peritidal) marine dolomitic reservoir. Monitoring during pre-injection, during injection, and post injection will be accomplished with MVA tools and techniques to visualize CO_2 plume movement and will be used to reconcile simulation results. Necessary documentation will be submitted for closure of the small scale carbon storage project.

Project Goals

The proposed small scale injection will advance the science and practice of carbon sequestration in the Midcontinent by refining characterization and modeling, evaluating best practices for MVA tailored to the geologic setting, optimize methods for remediation and risk management, and provide technical information and training to enable additional projects and facilitate discussions on issues of liability and risk management for operators, regulators, and policy makers.

The data gathered as part of this research effort and pilot study will be shared with the Southwest Sequestration Partnership (SWP) and integrated into the National Carbon Sequestration Database and Geographic Information System (NATCARB) and the 6th Edition of the Carbon Sequestration Atlas of the United States and Canada.

Project Deliverables by Task

1.5 Well Drilling and Installation Plan (Can be Appendix to PMP or Quarterly Report)
1.6 MVA Plan (Can be Appendix to PMP or Quarterly Report)
1.7 Public Outreach Plan (Can be Appendix to PMP)
1.8 Arbuckle Injection Permit Application Review go/no go Memo
1.9 Mississippian Injection Permit Application Review go/no go Memo
1.10 Site Development, Operations, and Closure Plan (Can be Appendix to PMP)
2.0 Suitable geology for Injection Arbuckle go/no go Memo
3.0 Suitable geology for Injection Mississippian go/no go Memo
11.2 Capture and Compression Design and Cost Evaluation go/no go Memo
19 Updated Site Characterization/Conceptual Models (Can be Appendix to Quarterly Report)
21 Commercialization Plan (Can be Appendix to Quarterly Report).
30 Best Practices Plan (Can be Appendix to Quarterly or Final Report)

Accomplishments

1. Class VI Progress

Decision was made in July to build a compositional simulation of the Arbuckle saline aquifer in STOMP, the software used by EPA evaluate the AoR to facilitate the conversion from CMG simulation used by KGS to software platform used by EPA. After consultation with the developer of STOMP at Pacific Northwest National Laboratory, a methodology was developed to import the domain built in the Petrel geomodel into STOMP. The conversion process that was creating difficulties in sharing the CMG model to STOMP was subsequently solved and confirmed with EPA. Employing STOMP at the KGS will facilitate future updates.

CMG is now uses the parameters, processes, and rock properties to confirm the AoR with a conservative model. The same domain and input parameters will be used in STOMP.

Table 6 *Testing and Monitoring* containing questions from EPA was completed during this quarter. The table includes testing and monitoring including above confining zone, CO_2 plume, and pressure front monitoring. A geomechanical model was built evaluate the extent of surface deformation associated pressure exerted by the CO_2 injection.

Table 7, *Emergency and Remedial Response Plan*, questions was completed during the quarter. The questions from EPA were satisfactorily addressed by specific answers to questions and submittal of an *Operating Plan for Safe and Efficient Injection (OPSEI) (See Appendix A)* that conveys how and to what extent the monitoring would be used to avoid leakage and earthquakes. The success of the Operating Plan is based on prioritizing the monitoring technologies:

- Reliability of the data and approaches used to analyze the data
- Frequency that the data is acquired during injection
- Sensitivity and precision of the monitoring method and its ability to detect small changes in CO_2 plume behavior
- Location and therefore resolution from which the data is collected
- Spatial resolution and coverage of the CO_2 plume
- Ability to detect movement out of the injection zone both above and below the injection zone.

A summary of the monitoring techniques and responses are included in **Figure 1**.

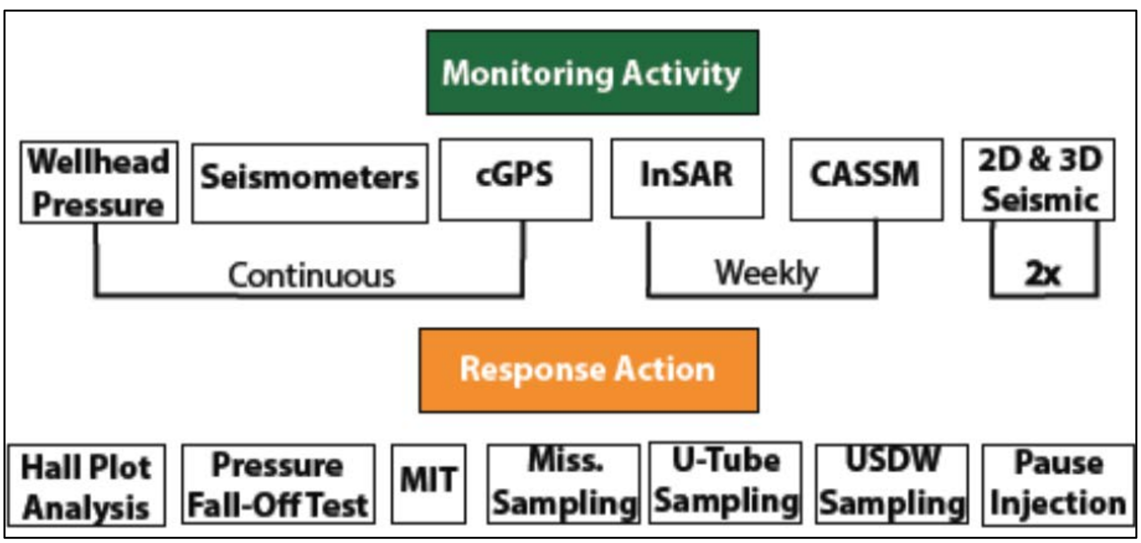


Figure 1. Operating plan for safe injection.

Appendix B titled, "KGS's Opinion Regarding Likelihood of Inducing Earthquakes Due to CO2 Injection in the Wellington Oilfield," was also presented on the topic of induced seismicity.

The QASP (Class VI Injection Well: Quality Assurance and Surveillance Plan) was also being finalized during this quarter and a final signed copy is included in Appendix C.

2. Hydrogeology evaluation

Appendix D. is a report on hydrogeology of the area in and around Wellington Field. The report was submitted to EPA to provide a perspective of the variable yield and water quality of shallow unconfined groundwater in the vicinity. The title of Appendix D is "Brief review of the hydrogeology of the shallow unconfined aquifer in north-central Sumner County, Kansas."

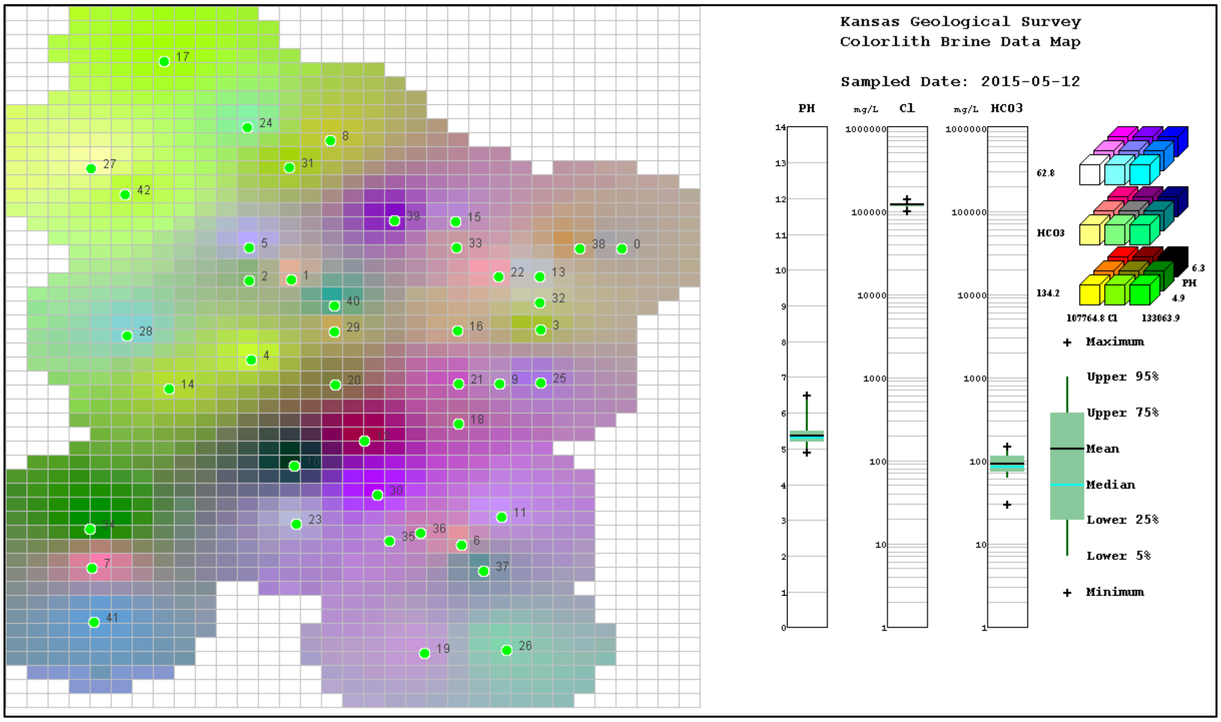
The summary of findings as reported in Appendix D. –

> *The shallow geology at the Wellington CO2 injection site is reflective of general conditions in Sumner County, KS, with alternating thin loess/clay deposits in the uplands and relatively thick sand/gravel deposits in the lowlands formed by modern drainage. The alluvial deposits in the lowlands favor local infiltration from precipitation and are likely to be hydraulically connected with perennial creeks in the area. On the other hand, the terrace deposits in the uplands are composed of the clayey/loess Bethany Series, which, with the underlying Wellington Shale provides impedance to infiltration, and due to the thick underlying salt (halite) beds, results in brackish water in shallow wells lying between the incised valleys in the area.*
>
> *It is demonstrated through geologic cross sections and maps that the three shallow highly brackish monitoring wells at the Wellington site (SW-1, SW-2, and SW-3) are located in the uplands and that the two (relatively fresh) domestic wells (Shepherd and Blubaugh), that are to be sampled for water quality, are located in the incised valley along the perennial Slate Creek. This explains the cause for the sharply varying water quality at the Wellington site and the two domestic wells southwest of the site.*

3. Completed baseline chemistry of produced brines from Mississippian oil reservoir

Existing and new samples of brine from the Mississippian oil reservoir were completed in August and results and displays using java applications are now online with a methodology to normalize the data to account for systematic changes so the results can be mapped. Systematic error of the major constituents, while within the analytical tolerance of +-5%, can assignment of either spatial or temporal anomalies that could be within the real changes in the brine as the reservoir is swept by CO2.

An example of the baseline map is shown in **Figure 2** that depicts the distribution of pH, Cl, and HCO3.



List of samples shown on the map

	API Number	Well Name	Latitude	Longitude	PH	Cl	HCO3
0	15-191-21179	COLE 2	37.3186181	-97.4222009	5.4	116779.0	85.8
1	15-191-19005	WELLINGTON UNIT 36	37.316789	-97.4404585	5.0	115677.0	91.5
2	15-191-10077	WELLINGTON UNIT, was J. C. FRANKUM 6 35	37.3167567	-97.4427281	5.6	115351.0	103.7
3	15-191-43889	WELLINGTON UNIT, was F. BARLOW 4 51	37.3131677	-97.4267918	5.4	113642.0	128.1
4	15-191-10078	WELLINGTON UNIT, was J. C. FRANKUM 5 53	37.3113174	-97.4427614	5.2	107742.0	122.0
5	15-191-43814	WELLINGTON UNIT was W.H. Neel 4 28	37.3189958	-97.4427138	5.3	116275.0	61.0
6	15-191-10270	Wellington Unit 108	37.2985459	-97.4314147	5.0	118434.0	91.5
7	15-191-10295	Wellington Unit 110	37.297249	-97.4518072	4.9	121009.0	85.4
8	15-191-10049	WELLINGTON UNIT was CURTIS 2 13	37.3262015	-97.4380895	5.2	113183.0	122.0
9	15-191-10119	WELLINGTON UNIT, was BARLOW 'B' 2 67	37.3095437	-97.4291032	5.3	118795.0	79.3
10	15-191-43882	WELLINGTON UNIT, was MURPHY 3 82	37.3040974	-97.4405362	6.5	128012.0	128.1
11	15-191-10257	Wellington Unit 102	37.3004292	-97.4291577	5.2	118622.0	61.0
12	15-191-10107	WELLINGTON UNIT, was ERKER 17 73	37.3057345	-97.4366087	5.4	139549.0	115.9
13	15-191-20789	Wellington Unit 144	37.3167935	-97.4267498	5.3	113276.0	73.2
14	15-191-10093	WELLINGTON UNIT, was MURPHY 1 60	37.3094396	-97.4473117	5.3	110894.0	122.0
15	15-191-10054	WELLINGTON UNIT was Kamas 7 25	37.3206206	-97.4312801	5.3	119798.0	73.2
16	15-191-10131	WELLINGTON UNIT, was ERKER 3 49	37.3131714	-97.4313305	5.2	116055.0	97.6
17	15-191-10066	WELLINGTON UNIT, was LUDWIG 6	37.331713	-97.4471575	5.4	107441.0	134.2
18	15-191-10112	WELLINGTON UNIT, was ERKER 10 75	37.3068262	-97.431404	5.3	122869.0	91.5
19	15-191-10262	Wellington Unit 128	37.291225	-97.433637	5.2	118172.0	73.2
20	15-191-11442	WELLINGTON UNIT, was ERKER 7 63	37.3095512	-97.4381806	5.6	120744.0	115.9
21	15-191-10100	WELLINGTON UNIT, was ERKER 9 66	37.3095456	-97.4313725	5.2	125396.0	79.3
22	15-191-10104	WELLINGTON UNIT, was PEASEL 2 38	37.3167954	-97.4290191	4.9	117952.0	85.4

23	15-191-10281	Wellington Unit 100	37.3000928	-97.4405128	5.3	114512.0	73.2
24	15-191-10074	WELLINGTON UNIT, was LUDWIG 2 11	37.3271537	-97.4426522	5.6	108781.0	85.4
25	15-191-10126	WELLINGTON UNIT, was BARLOW 'B' 1 68	37.3095419	-97.4268338	5.4	122212.0	67.1
26	15-191-11325	Wellington Unit 129	37.2913664	-97.4291	5.6	111867.0	85.4
27	15-191-21608	Wellington Unit 149	37.3244862	-97.4512991	4.9	104796.0	85.4
28	15-191-10096	WELLINGTON UNIT, was FRANKUM 2 44	37.3130335	-97.4495591	5.6	112224.0	73.2
29	15-191-10134	WELLINGTON UNIT, was ERKER 1 47	37.313177	-97.4381385	5.2	116258.0	109.8
30	15-191-10261	Wellington Unit 94	37.3020297	-97.4359747	5.3	133276.0	30.5
31	15-191-10061	WELLINGTON UNIT, was W. I. GASKILL 2 14	37.3244208	-97.440403	5.4	112096.0	134.2
32	15-191-21180	Wellington Unit 145	37.3149806	-97.4267708	5.2	112734.0	85.4
33	15-191-10045	WELLINGTON UNIT, was KAMAS 6 32	37.3188077	-97.4312801	5.2	117735.0	91.5
34	15-191-10294	Wellington Unit 99	37.2998989	-97.4518557	6.5	118856.0	152.5
35	15-191-10259	Wellington Unit 106	37.2988754	-97.4353874	5.3	119951.0	73.2
36	15-191-10255	Wellington Unit 107	37.2993815	-97.4336889	5.2	120956.0	85.4
37	15-191-10271	Wellington Unit 114	37.2967687	-97.4302689	5.8	118592.0	91.5
38	15-191-21000	Cole 1	37.3186655	-97.4244707	5.2	118516.0	112.2
39	15-191-10055	WELLINGTON UNIT, was FRANK KAMAS 9 24	37.3206917	-97.4346848	5.6	132569.0	79.3
40	15-191-10136	WELLINGTON UNIT, was PEASEL 2 41	37.3149899	-97.4381175	6.1	116674.0	91.5
41	15-191-10290	Wellington Unit 123	37.2935546	-97.4517973	5.8	117231.0	73.2
42	15-191-10059	WELLINGTON UNIT, was RIDDELL 2 16	37.3226624	-97.4494956	5.3	99927.5	122.0

Data Statistics

MNEM	Description	Minimum	5%	25%	Mean	Median	75%	95%	Maximum
PH	PH	4.9	4.93	5.2	5.3	5.36	5.5	6.37	6.5
Cl	Chloride	99927.5	107764.79	112479.0	116779.0	116650.62	119874.5	133063.9	139549.0
HCO3	Bicarbonate	30.5	62.83	73.2	85.4	91.81	114.05	134.19	152.5

Gridding Parameter & Calculated Data

Grid Area Parameters

Minimum X in feet: 509357.4	Minimum Y in feet: -1369.6
Maximum X in feet: 520657.6	Maximum Y in feet: 16128.6
Number of Columns: 34	Number of Rows: 52
Minimum Grid Spacing: 342.4	

Search Parameter Selection

Inverse Distance Weighting Exponent:	2.0	Maximum Distance to Nearest data point, ft:	1884.0
Number of Nearest Neighbors:	8	Maximum Search Radius, ft:	3767.0

ColorLith Plot Limits

			Minimum		Maximum	
MNEM	Description	Color	BrineData	Color Value	Brine Data	Color Value
PH	PH	RED	4.9	255	6.3	0
Cl	Chloride	GREEN	107764.8	255	133063.9	0
HCO3	Bicarbonate	BLUE	62.8	255	134.2	0

Figure 2. Gridding and mapping of baseline brine data using a new Java application.

4. Updated Mississippian model for CO_2 injection design

The Mississippian reservoir was revisited and updated in July and August to incorporate new data from the KGS #2-32 drilled in the previous quarter. The core obtained and the log data made a compelling case for slightly inclined stratification of high-frequency depositional cycles. Seismic was reexamined to trace this cyclicity and confirm that the small dip of a few degrees was depositional dip, not structure.

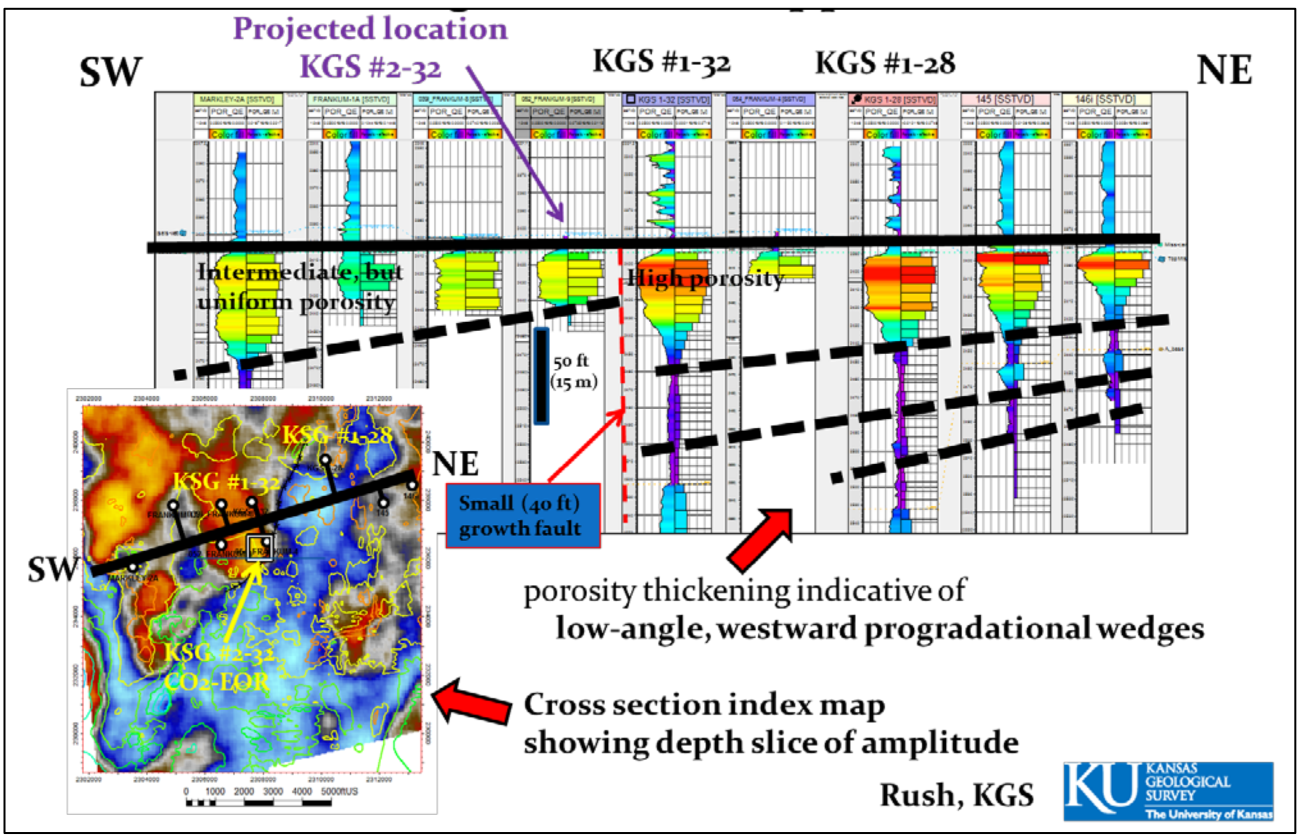


Figure 3. SW-NE stratigraphic cross section using well logs illustrates the progradational wedge geometries that clearly distinguish the west and east sides of Wellington Field. The

west side has a uniform porosity profile (colors of yellow and green), while the porosity on the east side exhibits a notable gradient with the porosity highest at the top. The location of the CO2 injection is located on the index map that is inset and on the cross section. Thus, the CO2 injection well is located in a more optimal location with more uniform matrix porosity profile.

5. Identification of nearby seismicity events

The team of Tsoflias, Graham, Nolte, Raney, and Victorine has made considerable progress since January when the operation, processing, and interpretation were turned over to them. The critical threshold for seismic events is 2.5 magnitude, since this is the levels of magnitude that is commonly felt and is the level at which an event is reported to EPA. Events as low as 1.0 are being routinely recognized.

Milestone Status Report

Project Schedule

Task 2 – Site Characterization of Arbuckle Saline Aquifer System - Wellington Field

July 1

Area of Review Computational Modeling submission made to EPA GS Data Tool. This included an updated export of the grid as an attempt to repair conversion errors in the files.

July 1 – Overview presented of seismic activities by Brandon Graham

> *"For approximately the past month, Alex Nolte and myself (Brandon Graham) have been assigned to process the 15 Mark Products L-22 3-component seismometers with IRIS Ref-Tek R-130 Data Acquisition Systems (DAS), as well as install 3 broadband, high sensitivity Nanometrics Trillium Compact Posthole seismometers to record data concurrent with 3 of the Ref-Tek seismometers. The new Nanometrics systems have been configured for continuous data collection into an onboard recoding medium (SD card) at maximum sensitivity of 2 volts peak to peak with a sampling rate of 250 Hz. This should allow for adequate acquisition of local high frequency micro-seismic events. During the time period of a high resolution 2 dimensional survey to be performed by the Geophysics group at the KGS, the Nanometrics systems' sampling rate will be increased appropriately to allow for adequate sampling of the high frequency chirp from the vibroseis. This will allow for*

increased control of the velocity model linked with known source location, timing, and approximate energy.

Processing the seismometer data is non-trivial. The current choice of processing software is the Seisan Earthquake Analysis Software package, Version 10.3, developed and maintained by Lars Ottemöller and Jens Kavskov of the Department of Earth Science at the University of Bergen, Norway and Peter Voss of the Geological Survey of Denmark and Greenland. This software was chosen based upon: recommendation from KGS employees, IRIS backing/associated program support, the multiple operator system platforms supported (Windows, Solaris, Linux, and MacOSX) and interoperability of data, processing capabilities, and plotting location features. Various processing tools include: location based upon arrival times, back azimuth determination from multi-component stations, magnitude, hypocenter location, velocity model flexibility and updating, focal mechanism estimation, spectral analysis, particle motion based on instrument correction, and more.

The process of accessing the data in Seisan required an understanding of the Seisan software and data structure. Seisan utilizes several databases and file types to represent data. An .S file is the file type used to organize the relevant data into a standard format (NORDIC format) for an event. The file contains WAV file names associated with the event, phase information picked from the WAV files, magnitude calculations, calculated location of the event, hypocenter information, etc. The .S files can be stored in a database structure associated with the data of the event. WAV files are the response or waveform files recorded from a seismometer. WAV files can be of various formats, including SEED and MiniSEED, however there are words of caution in the documentation about the preservation of header information/metadata with the use of SEED and MiniSEED data. The documentation does note successful use of SEED and MiniSEED data formats, but warns it is not fully supported yet. Upon initial testing of MiniSEED data recorded from the Nanometrics seismometers, there does not appear to be any loss of data however. An option however would be to convert the WAV file into another format which is more adequately supported. For the time, we will maintain use of the response file in the Miniseed (.mseed) format.

The recorded raw waveform data from the Ref Tek R-130 seismometer is collected through an RTP server and archived at the KGS. This data is saved in several formats that need to be reconstructed through a series of UNIX based programs to become a usable format. The data is in a Ref Tek file format that is very similar to a year/day directory format. All data that was not sent to the KGS server, but was stored in the cards on the seismometers, must be added into the correct days to ensure proper formatting. Once all the data is formatted, it is compiled into special ZIP files of approximately 2 GB each, through a program IRIS developed called NEO. These files are then sent through a second program (RT2MS) which converts this Ref Tek file format to MiniSEED format. This process is unfortunately very slow, taking approximately three hours for each of the 2 GB ZIP files. Since there is already over 200 GB of data from the Ref Tek seismometers, this process can become very time consuming. More testing of the RT2MS program is underway but currently only one of *these ZIP files can be processed without error, so the program must be rerun for each file.*

The recorded raw waveform data from the Nanometrics is saved to an SD card that is manually retrieved and swapped out with a fresh card to continue recording. The data is natively saved in MiniSEED format, and is directly readable by Seisan. All data is continuously recorded, and triggered event file creation is not utilized because the level of detection for micro-seismic events would not consistently register.

The data is currently planned to be formatted into SEED/MiniSeed, however as further testing of Seisan is performed, it may be transformed into a different format such as Seisan format or SAC for data processing purposes. This may be necessary as other formats are more compatible with signal processing while the SEED format is better for compressed waveform storage and metadata completeness. The data handling will initially be tested by creating continuous waveform databases for the units and separating the components appropriately. The original response files are saved locally into the working WOR directory of the Seisan file structure, and then entered through the Seisan software to create a duplicate response file with the proper file naming scheme, and saved to the appropriate database. 18 databases will be created: 3 for the Nanometrics X/Y/Z components, and 15 for the Ref Tek X/Y/Z. Due to the theoretically higher sensitivity of the Nanometrics Trillium seismometer, we will initially look for first arrivals on the X/Y/Z component of the three Nanometrics units. This should be faster than loading and manipulating 54 sets of 60 minute long data from a remote server, which previous tests have suggested causes significant lag in simple picking of phases. After initial conformation and registration of events into .S files, selected smaller time windows of the Ref Tek waveforms can be evaluated for events and phase arrivals. After registration of the events into .S files, the .S files can be appended to create a single .S file and windowed output of all of the collected waveform files into a single waveform file. This will allow for: archival of the raw data, archival of the formatted continuous data, and duplicate formatted event data with phase picks and processing on a smaller waveform time window for efficient data handling.

After initial testing of the Nanometrics data from several days in May, many events have been observed on several scales including regional large scale (Magnitude 2-3) events recorded by the KGS network outside of Wellington. Local events interpreted as microseismic events have had a range of qualitative magnitudes and frequency ranges recorded as high as 70 Hz. Various filter configurations have been tested to observe events recorded by all three of the seismometers. Many of these events are close to the noise levels of the filtered frequency ranges. Once properly formatted Ref-Tek data is available, we will be able to compare the differences in detection level and frequency noise level for the stations.

*The use of high frequency range band pass filtering has exhibited an increased visualization of micro events (**Figure 4**). A frequency range of 40-70 Hz for high frequency events was determined based upon the frequency spectra of the ambient noise level. The frequency range of 5-30 Hz has been saturated by ambient noise i.e.*

unable to distinguish known micro events from noise. Narrow (5-10 Hz band pass widths) have been useful for pulling events from the noise, particularly in the range of 60-70 Hz. Due to the enclosed metal vault construction, there has not been a problem with the 60 Hz AC commercial power line noise.

A preliminary concern with picking the high frequency events (40-70 Hz) in narrow band-pass windows (5-10 Hz band-pass widths) is the picking of surface noise from construction level activity. An example would be the movement of heavy machinery such as a back hoe driving around, and then unloading a bucket of rocks. This scenario would create long time duration noise with impulse events that could be picked in a narrow frequency range. Also, the percentage of the bandwidth of these filters is relatively small, and caution is being taking in the interpretation of this data in the narrow frequency range. Further review of this method will be compared to the other stations once data is properly formatted."

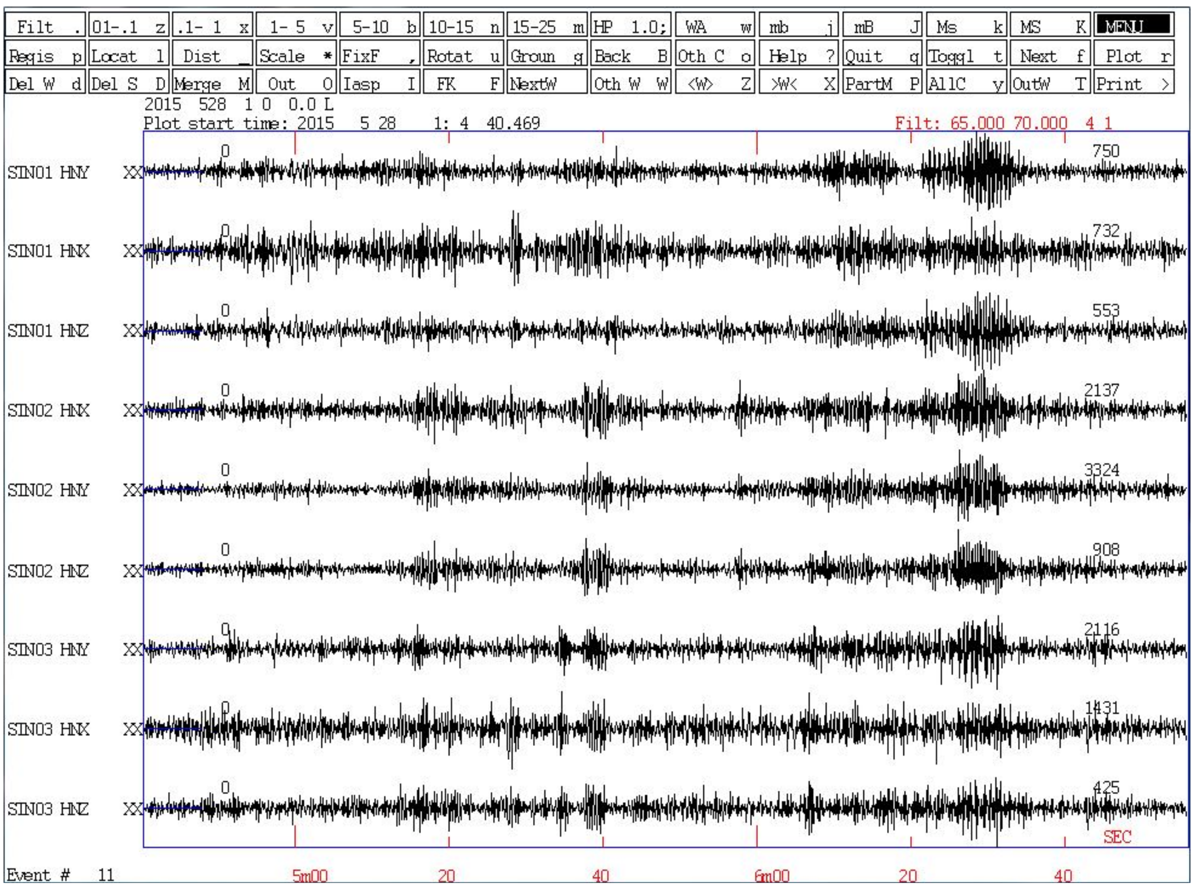


Figure 4. "The high frequency events observed are close to the noise floor, and the envelope of the events varies from station to station. The collective comparison of multiple stations will be important in the determination of the high frequency events and their robustness for picking micro events."

July 6th –

Discussion of a mass spectrometer and the requirements of the instrument to perform sampling of Mississippian waters. A summary from L. Watney's email describing the specifications and requirements is below:

- "The quad mass spec will be used to measure gases at the wellsite. It is portable, but large enough for the need to carry to the well location via pickup or van.
- The gas samples to be analyzed will be at low temperature and low pressure suited for sampling of vapor from the Mississippian monitoring wells or vapor from depressurized samples from the U-Tube.
- The mass spec. will require tuning in a lab environment and once at Wellington for a round of well sampling, should be temporarily stored when not in use in the field in a clean, air conditioned location. I will need to discuss with Dana.
- We are unsure about the detection limit of Xe, but our preference is to use Kr for the Mississippian injection and SF6 for the Arbuckle. SF6 is reserved for the Arbuckle due to the possibility of masking by a heavier HC gases that could affect detection of the SF6.
- Ar has mass that is very similar to CO2 so use of Ar with the Mississippian CO2 injection is questionable.
- We agree that a mass spec with a range of 100-200 amu is preferred, higher so we can also record the range of HC gases that could precede an oil bank when CO2 releases lighter HC from oil that it contacts.
- In terms of dosage and cost, I'll work with Eugene once he is able to break away from the EPA permit questions that continue to this day.
- Use of the mass spec by the KGS after these CO2 injections -- similar applications would be envisioned with this unique instrument for the region, perhaps with new funding for next gen CO2-EOR with tracers as we have previously proposed, testing new technologies for monitoring such as the use of EM which is currently being discussed."

After careful consideration, it was decided that laboratory analysis would be sufficient to fulfill the needs of a mass spectrometer until a perfluorocarbon tracer is introduced with the CO_2 for the Arbuckle injection.

July 7th

A conference call was held with a company interested in exploring the feasibility of using electromagneitic (EM) technology in the Arbuckle CO_2 injection. Although exhibiting potential, discussion was deferred.

July 7th –

Conference call with EPA to address the remaining questions that have been based on 1) EPA/Cadmus difficulty in rebuilding our simulation, and 2) added questions about the simulation to make it conservative including elements such as relative permeability.

The KGS received an Excel table with the Berexco/KGS testing and monitoring strategy tables for the above-confining-zone/plume/pressure-front monitoring. The file provides a summary of important information exchanges and highlights details where more information has been requested by the EPA.

Comments on the two shallow water monitoring well completion reports were also received, along with request for more details for EPA.

<u>July 8th</u>

John Victorine updated the online data analysis tools to incorporate the gridding and mapping with ColorLith to display spatial changes for up to three brine components from the database. This is intended to use the mapper to show changes in brine composition when CO_2 is injected. Future additions will hopefully include concentrations of CO_2, HC gases, and tracers.

Plot control was used to select the brine curves and allow the user to change the minimum and maximum values that are used to compute the ColorLith (**Figure 5**).

<u>Red-Green-Blue</u>
PH-TDS-Borate
PH-TDS-Strontium
Sodium-Chloride-TDS

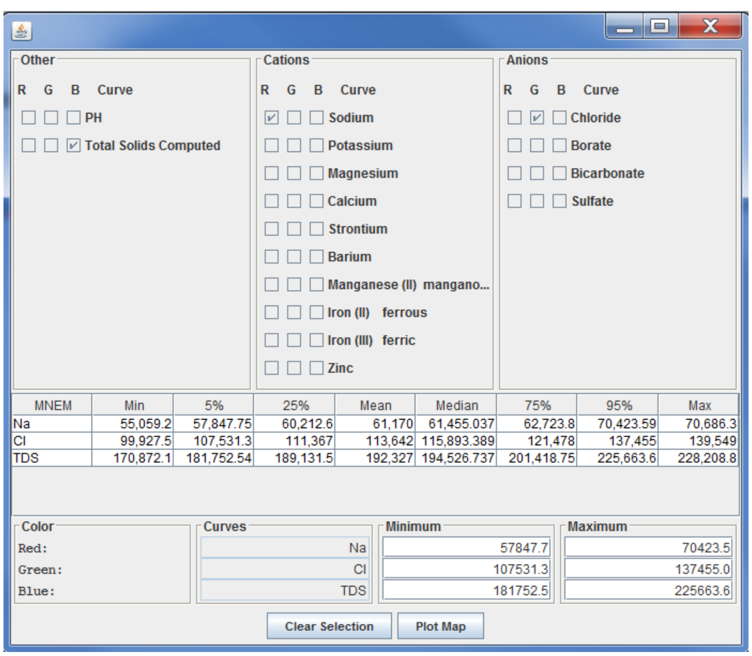


Figure 5. Plot control for gridding variables obtained from brine analyses.

July 9th - A bar and whisker plot was also added to the gridding and mapping plots (**Figure 6**). The function of these plots will be improved over time, including options for the user to control the cell size, generating "report" outputs, and enhancing the flow and interface of the mapping dialogs.

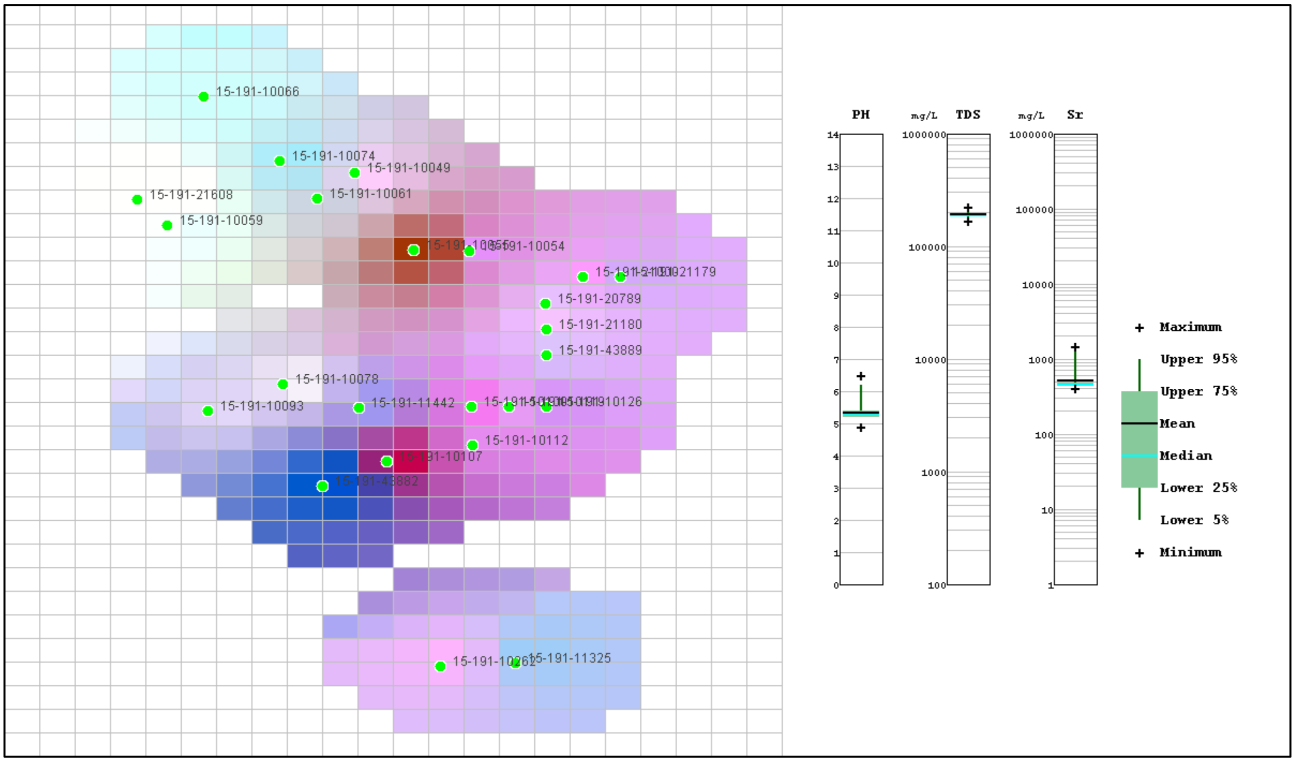


Figure 6. Whisker plots alongside gridding map.

<u>July 9th</u>

An error during the retrieval of the GPS data resulted in a loss of recorded information from April 15th to early July. Discussions are taking place to transmit the GPS data via telemetry in order to mitigate the risk of future data losses and expedite processing.

Email from Mike Taylor regarding InSAR:

> "InSAR status-
> So far, we have acquired six images each over two SAR track footprints, viewing from two different directions. The imagery was acquired between the end of March, 2015, through to the present, and the next two images have been requested as well. Data quality is very good over the major roads and other manmade infrastructure. Over agricultural fields, some decorrelate entirely, others are very coherent but with a phase signature that varies from field to field

```
and is likely related to soil moisture.  Still, we will be able to
place upper limits on the deformation and subsurface pressure changes,
particularly at shallow depth, because the field-specific signals are
uniform across each field, without the curvature that would be
observed if the deformation was associated with a subsurface  source."
```

We are considering the addition of portable radar reflectors for the Arbuckle injection, but this is pending us moving forward with the Class VI permit.

July 9th

From weekly update in reference to "Berexco Testing and Monitoring Tables 6-24-15" and "General Instructions New AoR Delineation 7-7-15")

1. On July 2, discussed use of an Ascii grid export for a simplified, conservative CMG model incorporating an orthogonal grid and input parameters for achieving a conservative model.

2. July 7th. It was determined that Ascii grid file could not be successfully imported without resolving irregularities in the grid. A scaling error was also discovered after running the new version of CMG software requiring re-submission of a new model domain.

3. Following discussions talked to STOMP developers at PNNL and including expression of concerns about warning noted in use of STOMP on use of grids such as our build in Petrel. We also discussed how a model boundary should be handled to match that used by CMG. We also learned of an alternative means to import Petrel grids from PNNL and are currently creating our own version of STOMP that we intend to share with EPA to facilitate decision-making on the AoR as well facilitate updates to the model with the injection begins. EPA positively acknowledged our effort to work with them to ensure the successful use of STOMP. EPA confirmed that they were working successfully with a coarser grid version of the CMG model shared earlier and had been using this to evaluate our responses toward completing a conservative model toward finalizing an AoR. This also requires updating since the scale change.

4. Received RAI table on Testing and Monitoring and importantly, remaining questions pertaining to the USDW determination.

5. Obtained positive response documents we previously provided to EPA regarding safe injection and addressing seismicity with the operational plan.

July 10th

Response to DOE Peer Review recommendations from the IEAGHG submitted (see NETL Carbon Storage Peer Review form for additional details) (**Figure 7**).

U. S. Department of Energy
National Energy Technology Laboratory

RESPONSE TO PEER REVIEW RECOMMENDATIONS FORM

FY15 Carbon Storage Peer Review
March 2 – 6, 2015

Award Number	FE0006821
Principal Investigator	Lynn Watney
Performing Organization	University of Kansas Center for Research
NETL Federal Project Manager	Brian Dressel

SECTION I: RECOMMENDATIONS

This section is to be completed by the Principal Investigator (PI) and NETL Federal Project Manager (FPM).

Provided in the individual boxes below are the Review Panel's Recommendations, for the above referenced project, based on the presentation during the FY15 Carbon Storage Peer Review. The Strategic Center for Coal (SCC) Management has reviewed the Recommendations for each project and has determined that a response by the PI is not required for some Recommendations. The boxes for these Recommendations have been pre-filled and no further action is required by the PI. The PI and NETL FPM are required to develop a consensus response for all other Recommendations. The response has four parts which must be addressed:

1. Develop a consensus narrative response.
2. Identify if there is a scope, cost or schedule impact.
3. Indicate whether the Recommendation will or will not be incorporated into the project's Statement of Project Objectives or Statement of Work by placing an "X" on the appropriate line.
4. If incorporated, designate a planned completion date for the Recommendation by marking a three-month range and calendar year.

Once consensus is reached between the PI and the NETL FPM, these responses will be provided to the respective NETL Technology Manager and Division Director for review and approval. Please see accompanying email for more detailed instructions.

Review Panel Recommendation 1 (R1)

The contingency plan where Class VI approval is delayed beyond the expected approval date for completing the project by the due date (September 2016) needs to be articulated.

(1) The application for a Class VI geosequestration well permit remains under review by U.S. EPA and the mutually agreed upon schedule calls for a draft version of Class VI permit to be issued by August 31st. Following a public comment period in the fall, the approved permit to allow CO2 to be injected would be received by December 29, 2015. The remaining time on the DOE contract would allow for the CO2 injection to be finished by September 30, 2016. A no-cost time extension will be requested of DOE/NETL to permit post-injection monitoring for one year, until September 30, 2017, the duration requested of EPA. The project intends to generate sufficient cost savings in BP3 to carry over into the post-project period and perform all necessary monitoring without requiring additional funds.

(2) Cost, Schedule or Scope Impact: (check the appropriate box)		**Outside project scope**
	x	**Cost/Schedule impact**

NATIONAL ENERGY TECHNOLOGY LABORATORY

Figure 7. Page 1 response to the DOE Peer Review recommendations from the IEAGHG

July 16th

The Gridding and Mapping Module for the CO2 project was released by John Victorine.

Brine Data Gridding & Mapping Module has been completed for the CO2 Project. Help document remains. A download function allows 1) the user to download the Web App to run PC without the internet and 2) unzip the file, the program files are located under a directory called 'GRID' so it is safe to unzip where ever you like. The Help Document will be added to the Zip file. As usual, the web site will also have an Applet version so the software can run as a Web APP. Google Chrome is NOT recognizing the Java JRE so IE and Firefox browsers are needed.

The web site address is at: http://www.kgs.ku.edu/PRS/Ozark/Software/GRID/index.html.

The user can select any of the "Search By" buttons on the main Gridding and Mapping Module Panel resulting in a list. The Total column is the number of individual wells that have brine data, the higher the number the better. Eventually, the "Search By" Formations button will be removed since all of the brine data will be coming from the Mississippian as the CO2 injection proceeds. The "Map" Button will become enabled when one highlight a brine data item in the list and click on the "Select" Button.

The map dialog allows the user to select up to 3 brine data chemical species and simultaneously display their concentrations a map. Each chemical constituent is a single color (Red, Green and Blue). The program will automatically display brine data that is available in the download the he user selects. The user needs to select the check boxes from left to right otherwise the color mix will not come out right. Eventually, this problem will be fixed.

The Table below the check boxes contains statistics of the chemical data that is displayed (see **Figure 2**). The minimum and maximum are initially selected from the 5% and 95% columns, but you can change the min and max with the text fields at the bottom of the dialog. You can also change the well labels on the map in the "Add Well Labels By" radio buttons. The default is the API-Number. When you create a report the program automatically uses the "Well Order" radio button and then re-displays the selected radio button. An example report created is at http://www.kgs.ku.edu/PRS/Ozark/Software/GRID/Example/Output.html. A composite view of the base map, data table, and mapping is also included below in **Figure 8**.

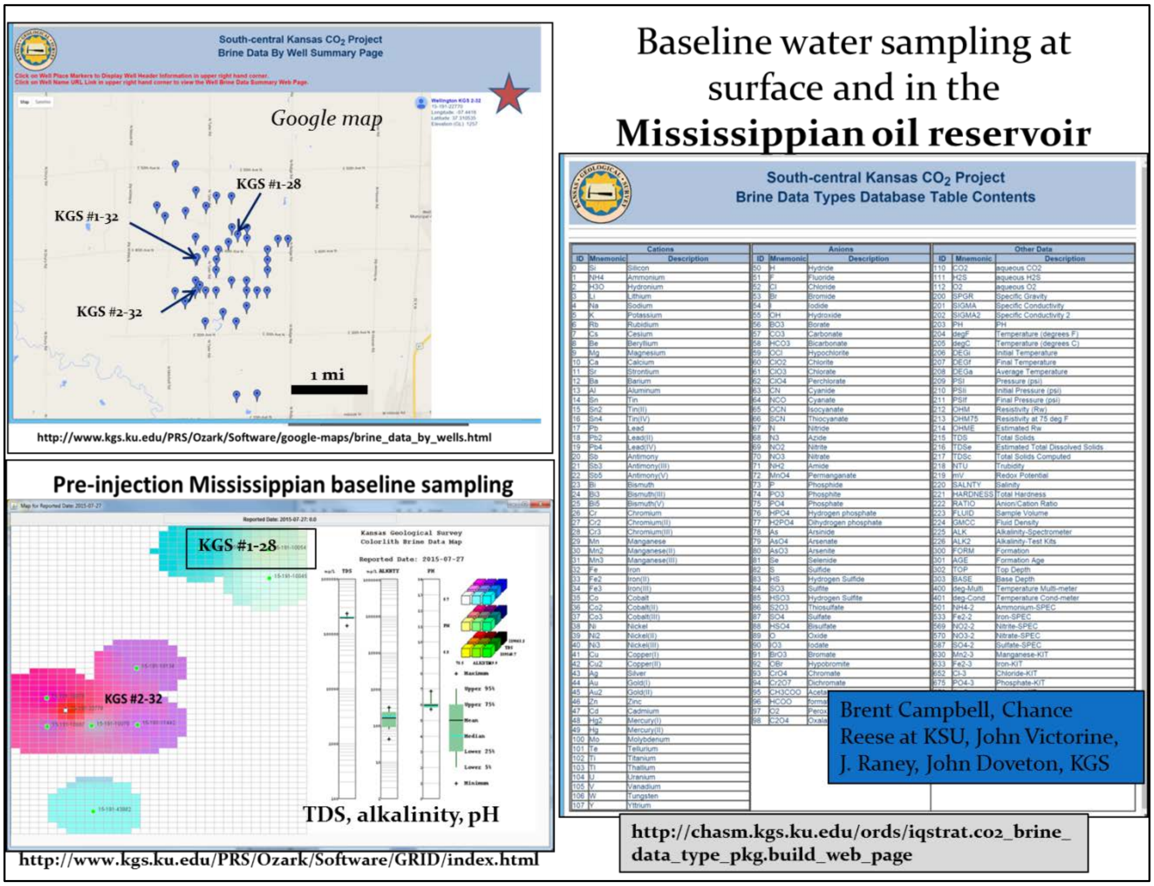


Figure 8. Composite view of maps and tables of brine chemistry provided by the new Java applications.

July 16th

Relative permeability curves were calculated for both drainage and imbibition for 9 rock types (RQI) for CO2-brine systems in the Arbuckle. Both drainage and imbibition curves were used because drainage occurs during the first part of injection, but after injection ceases, imbibition then occurs, so using imbibition curves in estimates is appropriate. The relative permeability calculations are based on a water wet system. These results are believed to be reasonable, and should improve the model in terms of estimated residual trapping of CO2.

July 17th

Weekly update on Class VI application to Brian Dressel:

> *1. EPA has requested that the QASP be finalized and approved prior to any further sampling events. EPA provided the document describing the protocol of the private well sampling on Tuesday. This document was incorporated into the QASP as an addendum and is included in Appendix C. EPA will witness the next sampling event.*

2. The KGS and Tbirdie developed a schedule to sample two domestic water requested by EPA. The KGS has been in verbal contact with both of the landowners and received permission to sample the wells.

3. A nearby certified lab has confirmed that they could process the water samples within several day turnaround times. Isotopes will also be used to help differentiate the sampled waters. Water will also be collected from Spring Creek near the domestic wells will be used to evaluate local conditions where modern drainage is interacting with well water. This is what has been inferred from the hydrogeologic mapping, where a shallow paleo valley cuts an older terrace as well as the Wellington Shale. The valley also lies below and adjacent to Spring Creek. Tiraz and I thought that use of isotopes could help to verify hydraulic connectivity between the creek alluvium, paleovalley alluvium, and the higher, yet older terrace that is present at Wellington Field.

4. A hydrogeological report is being prepared that will include the geochemical results of water wells and placed in the context of maps and cross sections conveying the stratigraphic and lithologic distribution of the shallow unconfined aquifer now significantly refined by the KGS. The hydrogeologic-database consists of 144 wells with a range of parameters including sediment profiles, elevations, and static water levels. This report will be immediately submitted to EPA soon after surface and shallow water analyzes are received.

3. New relative permeability curves have been developed for the Arbuckle modeling per EPA's request. This data will be incorporated into the CMG model as one of the final components to prepare a conservative simulation as requested by EPA. The grid and files of variables will be exported from CMG for use in the STOMP simulation software.

4. TBirdie has acquired the pre-processing (conversion) software and STOMP from Pacific NW National Lab to build and will complete a simulation that will parallel the CMG-based model. The intent is to expedite the validation of the AoR by actively participating in the modeling. This process and workflow being addressed will provide a means to rapidly update EPA during CO2 injection as model gets revised so that focus of efforts can be to address the DOE-sponsored research.

<u>July 21st</u>

Re-purging of the shallow monitoring wells at Wellington was accomplished;

The 200’well had a fluid water level of 39’6” from the surface.
The 100’ well had a fluid water level of 19’1” from the surface.

July 23rd

Difficulties were encountered when purging the 200’ well. An air bailer was employed as an alternative and successful method. Ten gallons of water were recovered from the 200’ well in the first 20 minutes. Initial fluid level was at 63’ (**Figure 9**).

Figure 9. Photo taken while purging the last 3’ of fluid from SW-2.

Final report from J. Bruns below:

“Report from today.
9:00-11:30 Went after parts and built bailer in shop.
12:00 Check fluid level and found it at 63 feet from the surface. Ran in air bailer.
1:00 Began bailing on the 200' monitoring well.

Time	Total accumulated gallons
1:30 -	15 murky water
1400-	22 murky
230.	26 murky
3:00	32 murky
330-	40 murky slight gray
4:00	48 gray tint
4:30.	53 total gallons recovered

* the last 3 gallons were very dirty (grey)

There was a cup full of sand in the bottom of the sample bucket on the last couple of gallons, this shows we were right on bottom.

We bailed the well down to only 4" to 6" left in the bottom of the hole.
Picture of the actual bailer and the sand from the bottom two gallons recovered is provided in **Figure 10**.

Figure 10. Sand from the bottom 2 gallons recovered in SW-2.

9:05 PM: It is 104' 4" down to water in the 200' well at 8:30 pm on 7/23/15. That is 95'-6" of recovery in 4 hours.

The 100' well measured 19'-6" from the surface, which is a 5" lower measurement than two days ago, but could be an instrument variable.

7/24/15. 8:00 am. 102' down to fluid on the 200' well.

(per J. Bruns email)

<u>July 27th</u>

Updated drilling report for KGS 2-32 shows that well is in the process of being equipped for CO2 injection (**Figure 11**).

LEASE NAME Wellington KGS #2-32 (1330081)	COUNTY Sumner STATE KS
WELL LOCATION NE NW NE SE (2680' FSL, 709' FEL)	SEC 32-31S-1W
OPERATOR Berexco LLC	API# 15-191-22770
CONTRACTOR: Fossil Drilling, Inc.	ELEVATION 1257' - GR 1269' - KB
RIG: Fossil #3 Toolpusher: Kerry Clark 620-388-2676	GEOLOGIST: Tyler Sanders 316-807-0197
Cc: Evan, Richard Email daily: Dana FINAL: AEB, well file	SPUD DATE: 3/20/2015, 7:00 am

4/27/15	Ran 5-1/2" X 2-7/8" Arrowset PKR. Set @ 3638' KB. Ran swab- fluid level 1800' from surface, 100' free oil on top. Recovered 10.8 BW on swab down. Had 700' fill up after 1 hour. Acidized Mississippi perfs with 2500 gallons 10% NEFE-HCl and 250 ball sealers. Treated 3 BPM @ 1300# initially, increased to 5.7 BPM @ 700# towards end. ISIP 50#, 30 seconds to vacuum. TLTR 90 BTF. Ran swab- fluid level 1100' from surface. Recovered 44.7 BW on swab down. Next hour recovered 20.8 BTF with trace oil. Shut down.
4/28/15	Ran swab- fluid level 2000' from surface, 50' oil on top. Swabbed 26.7 BTF. Release PKR and run across perfs to remove any remaining ball sealers. Reset PKR @ 3638' KB. Ran swab. Recovered 16.8 BTF on swab down. 1st Hour 19.1 BTF, fluid level 2800' from surface 2nd Hour 23.4 BTF 3rd Hour 16.7 BTF 4th Hour 13.4 BTF 5th Hour 13.4 BTF 6th Hour 20 BTF. Fluid level stayed 2800' from surface. Caught fluid samples. Shut down.
4/29/15	Ran swab- fluid level 2000' from surface, 75' free oil on top. Injected 2 BPM for 10 minutes- took fluid on vacuum. Injected 4 BPM for 10 minutes- stabilized pressure 150#. TOH w/ tubing and PKR. RDMO BX Rig #13.
4/30/15	Waiting for pulse test scheduled for the week of May 10.
5/12/15	Ran pulse test in well.
5/27/15	Too muddy to move in rig/injection tubing.
6/8/15	MIRU Contract WS Rig. TIH w/ nickel coated Arrowset-1X PKR with Viton rubber and 1.875" stainless steel profile nipple for X-style blanking plugs, nickel coated on-off tool and 110 jts TK-70XT coated tubing. Pump packer fluid and set PKR @ 3636' KB. Annulus held 150#. RDMO Contract WS Rig. Will MIT well 6/10/15.
6/10/15	MIT well to 350#- held. Witnessed by Jonathan Hill of KCC District #2 office.
6/23/15	Permit for carbon dioxide injection approved by KCC.
7/7/15	Installed 2" 2250# fiberglass water injection line from Wellington Unit #52I injection well to Wellington KGS #2-32 well.
7/27/15	Waiting on high pressure stainless steel fittings to finish hooking up wellhead.

Figure 11. Well completion status Berexco Wellington KGS #2-32.

July 27th

Seismometer array continues to be analyzed to build the catalog and provide a solid methodology to resolve depth and magnitude. This update provided by B. Graham on a 3.0 magnitude event near Conway Springs, located west of Wellington is located in **Figure 12**.

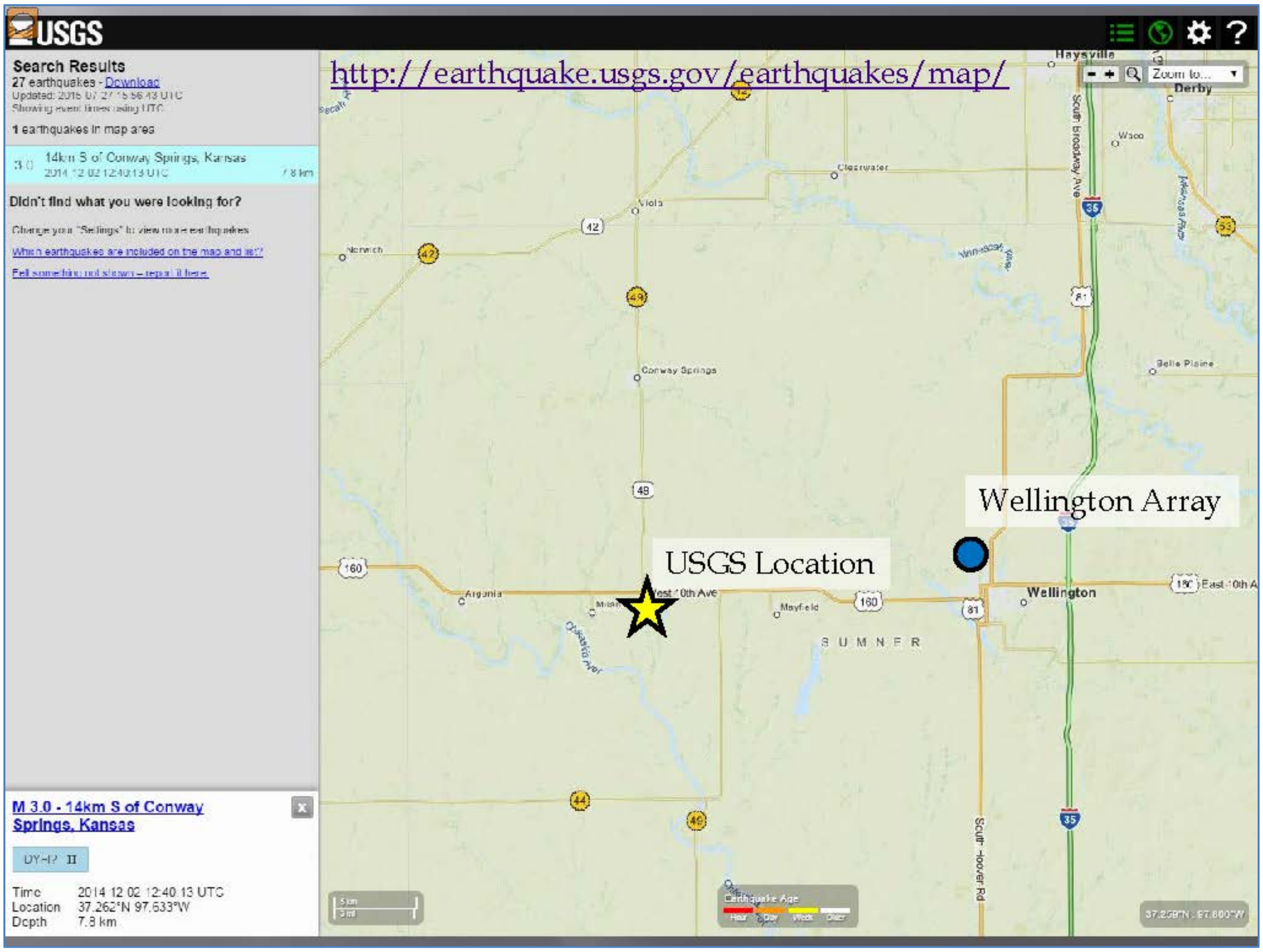


Figure 12. Location of a prior earthquake examined for testing purposes.

On December 2nd 2014, an earthquake south of Conway Springs, KS was recorded by USGS network with a calculated magnitude 3.0 at 7.8 km depth was detected and archived in the USGS database. Event is approximately 18 km West-South-West of the Wellington Array.

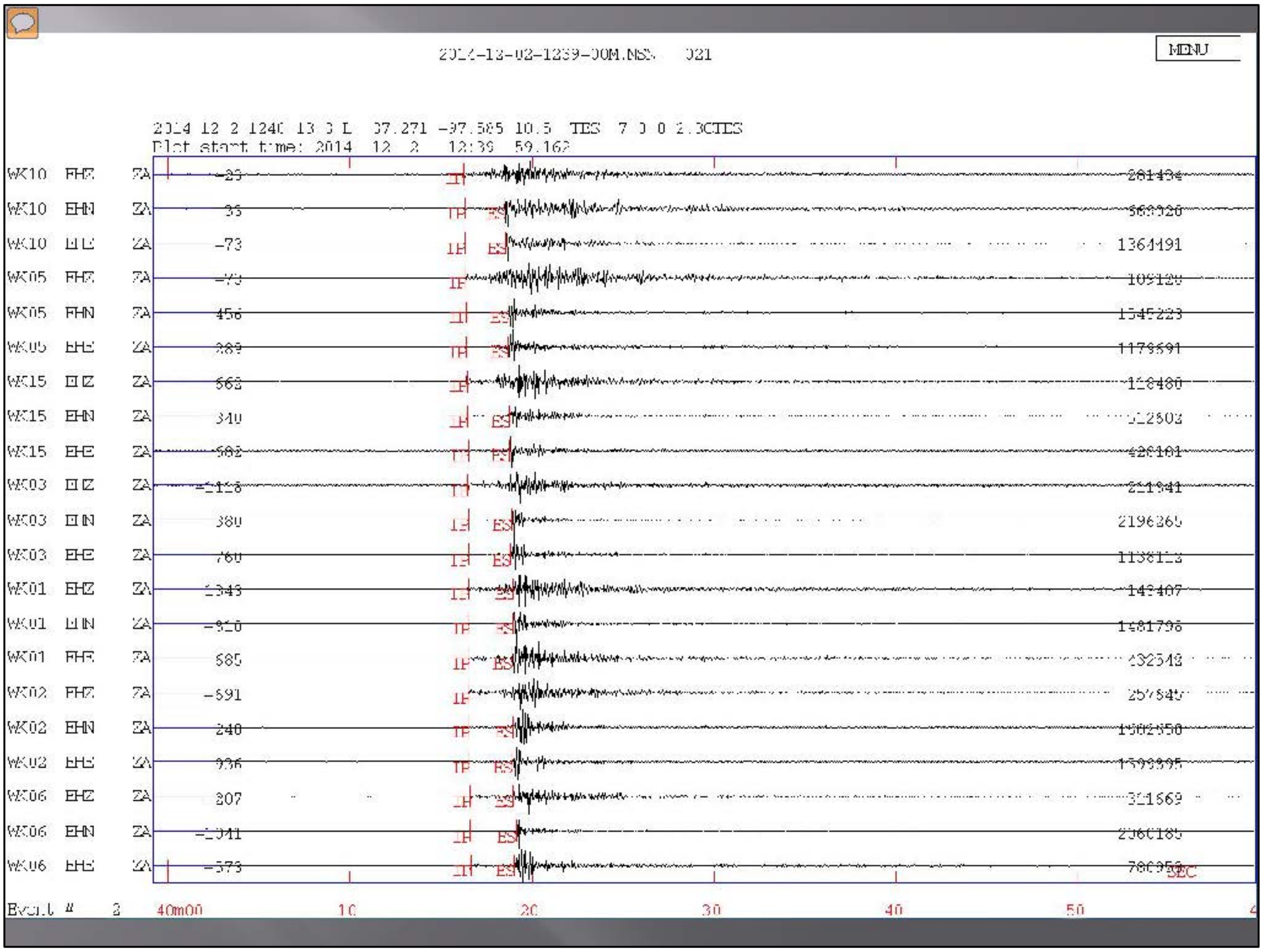


Figure 13. The Conway Springs event as detected by the Wellington seismometer array.

The Wellington Array detected the event clearly and was able to create a preliminary location and Coda Magnitude of 2.4 (**Figure 13**).

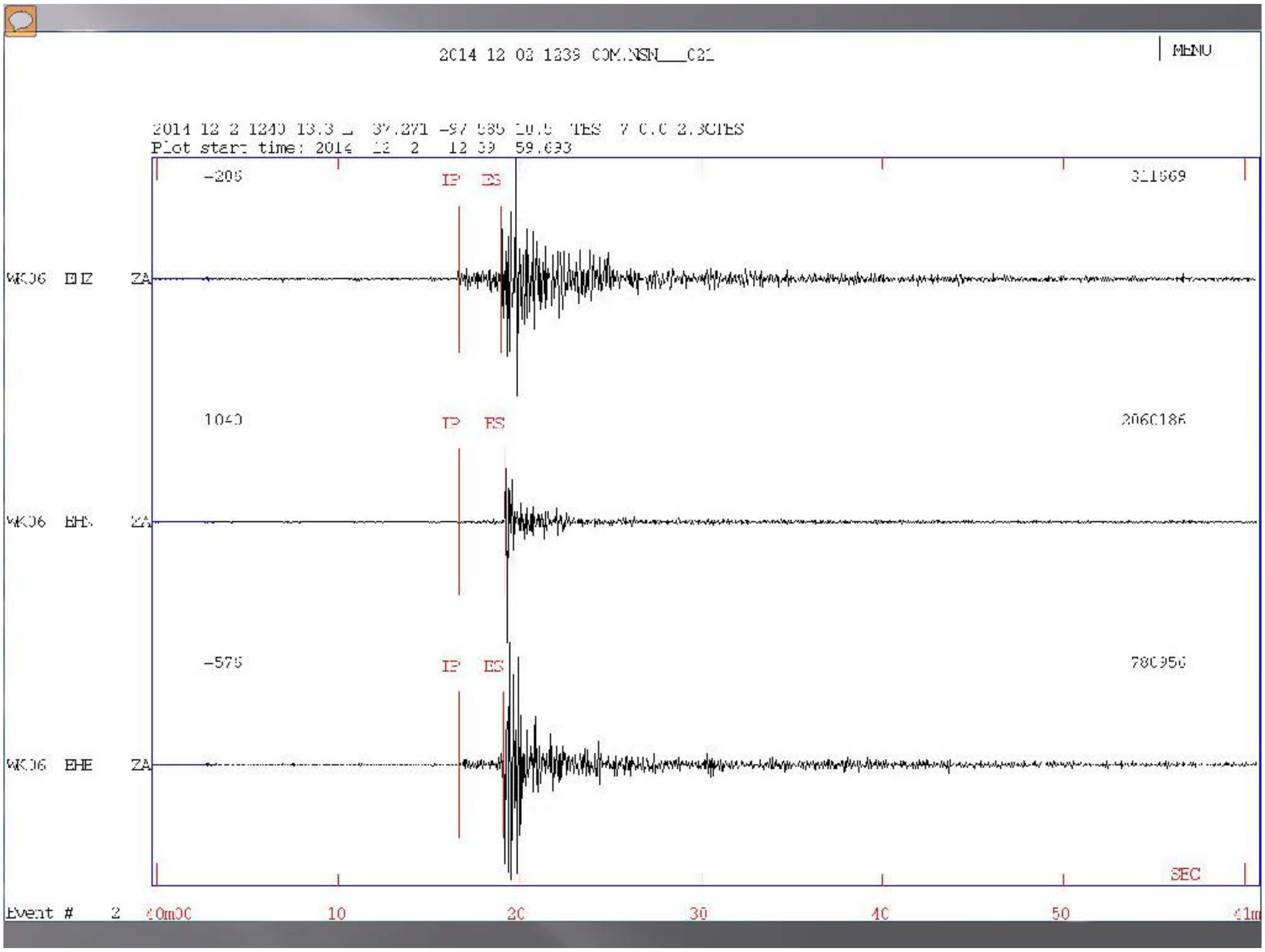


Figure 14. Conway Springs event from a single Wellington seismometer.

This is a close up of single station (station WK06), three channel (Z, North and East) pick of the registered event. Note the P and S wave arrival (**Figure 14**). Further analysis addressed in **Figures 15-18**.

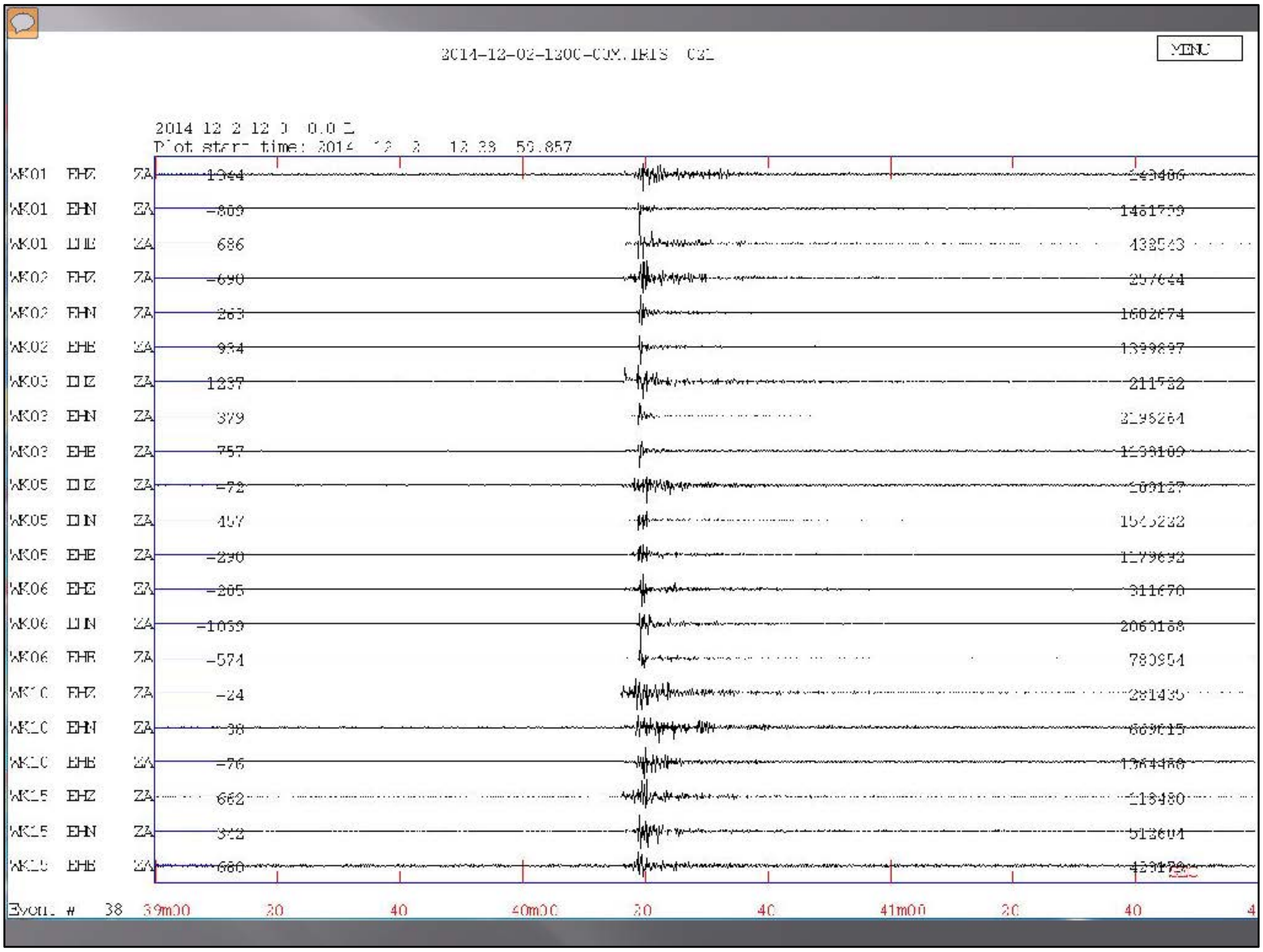


Figure 15. The event is registered and picked for P and S wave arrivals. The program then uses the velocity model and arrival times to determine a location and error ellipse.

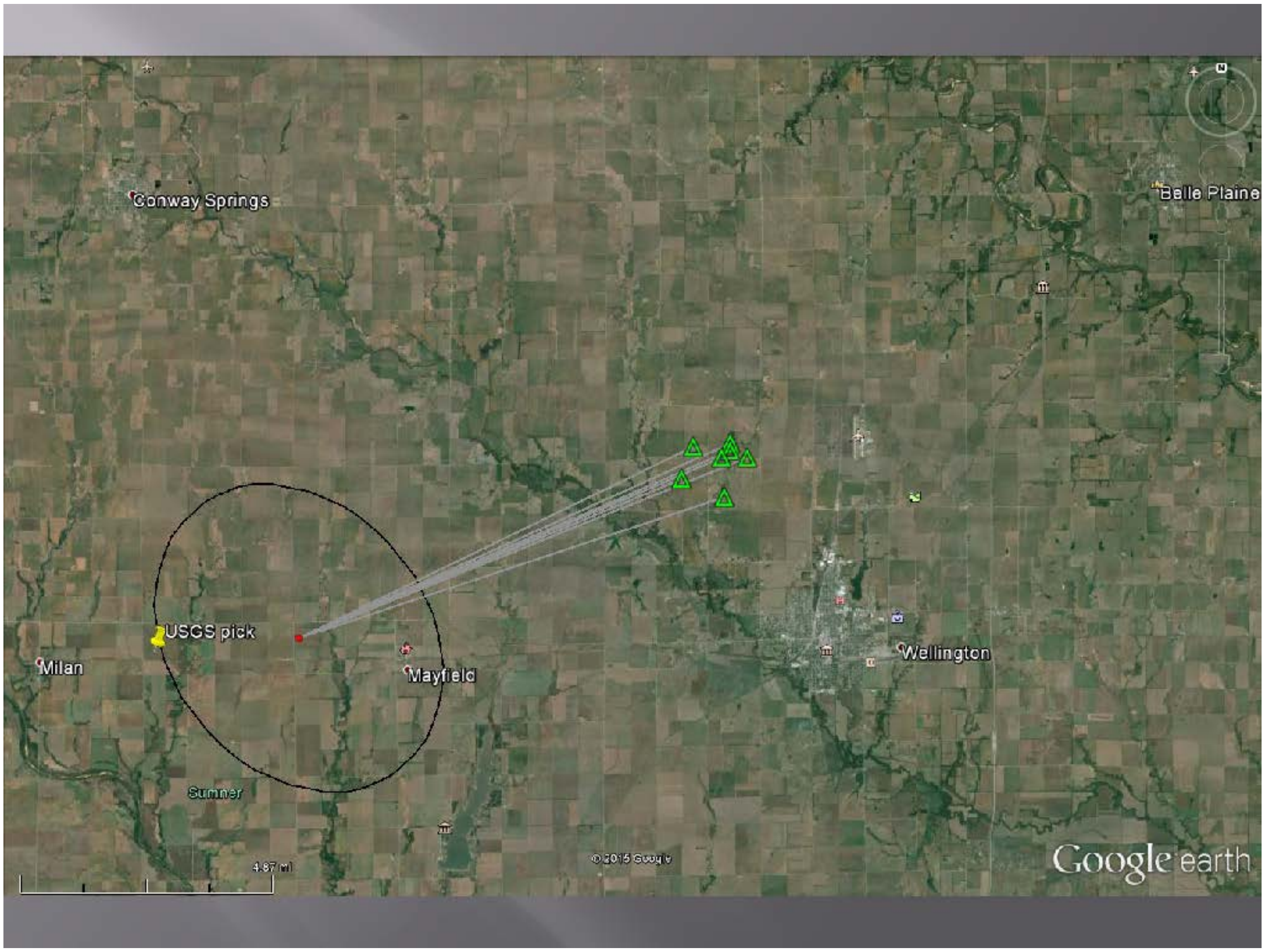


Figure 16. This is a Google Earth map generated by the Seisan program of the location of the picked event, the error ellipse, and its location relative to the USGS estimated location.

The estimated event locations differ by 2.8 miles (4.3 km) and the depth estimated by the USGS is 7.8 km compared to 10.5 km calculated with the array. The differences are due to the velocity model accuracy and proximity of the sensors. The velocity model used by the Wellington Array is derived from well logs from 1-32 inside the perimeter of the array. The array however is less sensitive to the azimuthal directivity due to its location in the East North East direction. Utilizing another sensor outside the array would further enhance the accuracy of events outside the array.

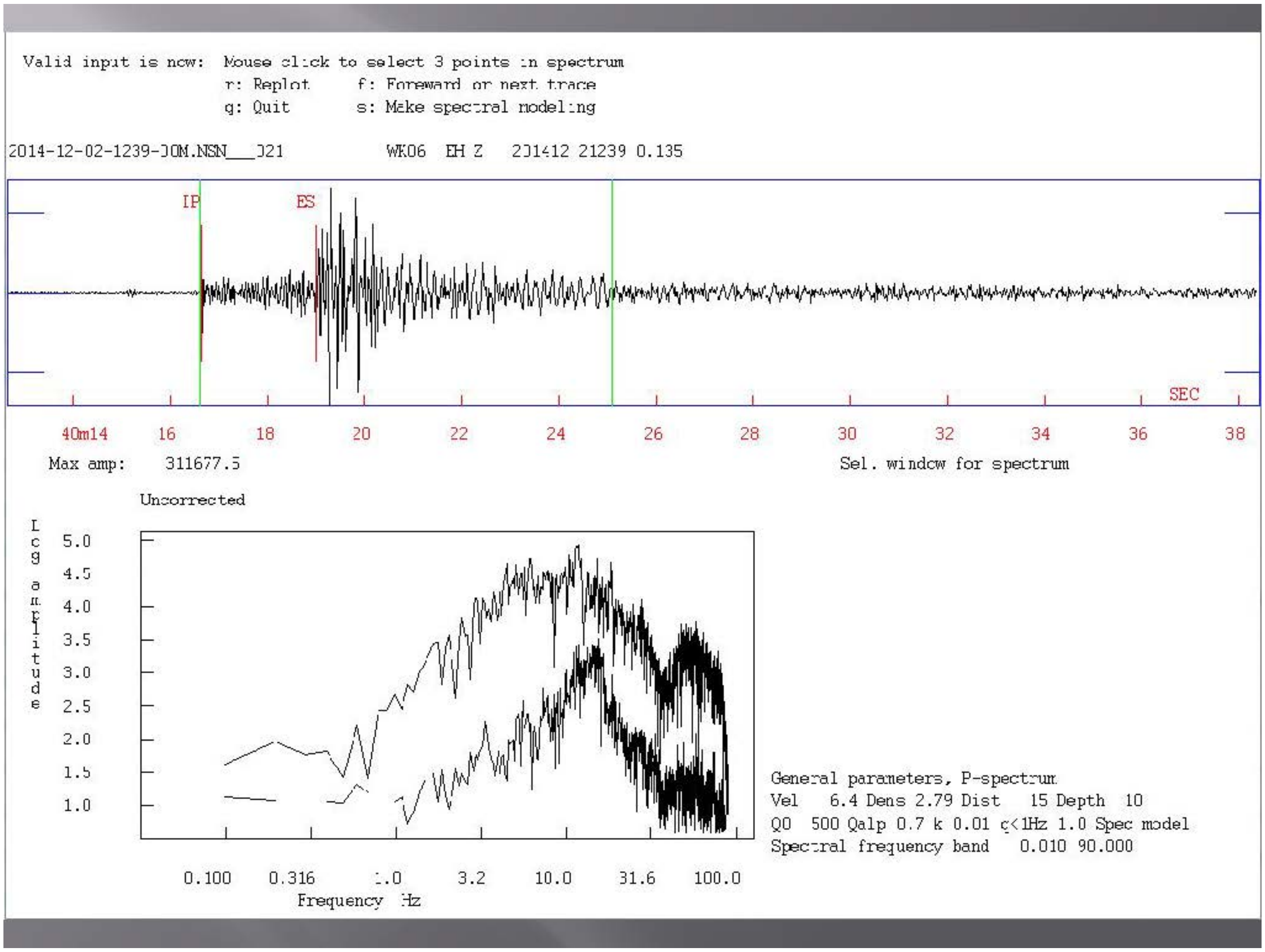


Figure 17. EXTRA: An example of the frequency spectra of the event. Note the comparison of the signal over the noise as well as the preservation of the high frequency range (>10 Hz) which is usually attenuated significantly or absent in most earthquakes, therefore not recorded.

July 27th

Draft of field and laboratory analysis of the Mississippian wells received from K-State **(example Figure 18**). The commercial lab being used held the test results due to a confirmed, high barium concentration on Well 24.

Pre-CO2 Injection Averages		Nelson	South Erker	Well #24	Well #25	Well #32	Well #41	Well #45	Well #47	Well #53	Well #61	Well #62	Well #63	Well #82
Sample Date:		6/16/2015	6/25/2015	6/24/2015	6/24/2015	6/24/2015	6/25/2015	6/17/2015	6/23/2015	6/17/2015	6/18/2015	6/18/2015	6/19/2015	6/25/2015
Depth:														
Cordinates:														
Meters														
		Average	Average	Average	Average	Average	Average	Average	Average	Average	Average	Average	Average	Average
Notes		10 µm Filtered	Unfiltered	10 µm Filtered	10 µm Filtered	10 µm Filtered	10 µm Filtered	10 µm Filtered	10 µm Filtered	10 µm Filtered	10 µm Filtered	10 µm Filtered	10 µm Filtered	10 µm Filtered
ORP (mV)		-102.90	-31.30	-47.43	-102.80	-70.30	-44.40	-90.37	-83.27	-30.67	-14.70	7.83	-81.47	-87.37
pH		5.67	5.99	5.83	5.94	5.74	5.80	6.13	5.81	5.98	5.87	5.83	5.73	5.75
Temperature Multi Meter (°C)		33.90	32.93	33.03	28.27	35.87	37.20	28.67	34.67	34.67	31.63	33.80	37.33	42.60
Conductivity (mS/cm)		178.30	166.10	192.73	161.73	173.23	174.50	150.67	163.63	169.70	165.47	171.00	164.03	127.33
Calculated TDS (mg/L)		119461.00	111287.00	129131.33	108361.33	116066.33	116915.00	100946.67	109634.33	113699.00	110862.67	114570.00	109902.33	85313.33
Salinity (ppt)		89.20	81.10	96.53	81.93	88.53	88.43	73.33	82.57	85.97	83.87	84.57	82.07	61.43
Temperature Conductivity Meter (°C)		-	36.07	32.60	27.73	35.63	37.20	28.43	-	-	-	-	37.13	42.63
Turbidity (NTU)		22.12	10.96	1.95	2.35	2.68	0.19	7.61	2.62	2.68	11.25	4.65	5.16	2.57
Spectrophotometers														
Test	Test Range	Average	Average	Average	Average	Average	Average	Average	Average	Average	Average	Average	Average	Average
Notes		10 µm Filtered	Unfiltered	10 µm Filtered	10 µm Filtered	10 µm Filtered	10 µm Filtered	10 µm Filtered	10 µm Filtered	10 µm Filtered	10 µm Filtered	10 µm Filtered	10 µm Filtered	10 µm Filtered
Alkalinity	25 - 400 mg/L	52.950	97.150	116.950	95.050	75.550	81.000	43.100	207.450	320.600	217.700	150.000	213.600	83.400
Ammonia	1 - 12 mg/L	6.890	2.505	1.185	1.790	1.390	1.260	Over Range	4.615	6.145	5.820	6.900	5.975	1.610
Iron	0.2 - 6 mg/L	Over Range	Over Range	Over Range	Over Range	Over Range	Over Range	Over Range	Over Range	Over Range	Over Range	Over Range	Over Range	Over Range
Nitrate	0.23 - 60 mg/L	Over Range	Over Range	Over Range	Over Range	Over Range	Over Range	Over Range	Over Range	Over Range	Over Range	Over Range	Over Range	Over Range
Nitrite	0.015 - 2 mg/L	4.655	0.046	Under Range	0.021	Under Range	0.052	Under Range	Under Range	Under Range	2.636	Under Range	Under Range	0.053
Sulfate	150 - 900 mg/L	730.750	Over Range	553.950	Over Range	Over Range	Over Range	764.600	Over Range	Over Range	879.500	Over Range	Over Range	Over Range
Test Kits														
Test	Test Range	Test Result	Test Result	Test Result	Test Result	Test Result	Test Result	Test Result	Test Result	Test Result	Test Result	Test Result	Test Result	Test Result
Notes		10 µm Filtered	Unfiltered	10 µm Filtered	10 µm Filtered	10 µm Filtered	10 µm Filtered	10 µm Filtered	10 µm Filtered	10 µm Filtered	10 µm Filtered	10 µm Filtered	10 µm Filtered	10 µm Filtered
Alkalinity	20 - 400 mg/L	45.00	65.00	55.00	45.00	50.00	70.00	45.00	40.00	10.00	35.00	50.00	50.00	60.00
Arsenic	0 - 500 ppb	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Chloride	500 - 100,000 mg/L	100000.00	130000.00	155000.00	145000.00	135000.00	130000.00	140000.00	140000.00	100000.00	145000.00	135000.00	150000.00	140000.00
Dissolved Oxygen (DO)	1 - 12 mg/L	-	-	-	-	-	-	-	-	-	-	-	-	-
Ferrous Iron		Over Range	Over Range	Over Range	Over Range	Over Range	Over Range	Over Range	Over Range	Over Range	Over Range	Over Range	Over Range	Over Range
Manganse	0 - 3 mg/L	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Phosphate		-	-	-	-	-	-	-	-	-	-	-	-	-
Sulfate		Over Range	Over Range	Over Range	Over Range	Over Range	Over Range	Over Range	Over Range	Over Range	Over Range	Over Range	Over Range	Over Range

Figure 18. Analysis sheet submitted by KSU

August 2nd

KIOGA short course given in Wichita, KS - "**Carbon Dioxide EOR Applications for Kansas Operators.**" Ninety-eight feet of core from the Mississippian oil reservoir in KGS 2-32 were displayed at the event. The presentations continued through the course of the day.

The final agenda is below:

Carbon Dioxide EOR Applications for Kansas Operators

- **1. Highlight the work being conducted related to CO2-EOR in the state (Lynn 10:00-10:20am)**
  - Regional and statewide CO2-EOR and storage assessments
  - Southwest Kansas CO2-EOR Initiative
  - Summary of Hall-Gurney CO2, pilot and commercial scale CO2-EOR
  - A new Kansas CO2-EOR Initiative
    - Proof of concept needed with a successful CO2-EOR injection at Wellington
    - Prospectus for Governor's Conference
- **2. Introduction to Wellington CO2-EOR small-scale test (Lynn 10:20-10:45)**
    - Support of DOE-NETL, Contract DE-FE0006821
    - Participation in Wellington CO2-EOR Project by *Kansas Independent Oil and Gas Industry and those serving the industry*
      - *Berexco, LLC – operator of the field and field-based activities, Linde, Praxair – CO2 supply, Fossil Drilling, MudCo, Devilbiss Coring Services, Halliburton, Core Lab, Trilobite Testing, Schlumberger, CMG, Continental Analytical Services, Inc.*

- *Other collaborators – LLNL, LBNL, IRIS-PASSCAL, Tbirdie Consulting, Inc., KGS, KU Geology, KSU Geology*

- **3. Characterization of carbonate reservoirs by "exotic" logs (NMR, microresistivity imaging, geochemical log, etc.) --John Doveton (10:45-11:30)**
- ***11:30 – 12:00 -- Examine 98 feet of Mississippian core from the KGS #2-32 (http://chasm.kgs.ku.edu/ords/qualified.well_page.DisplayWell?f_kid=1044998939)***
- ***LUNCH 12:00-12:30 p.m. -- Continue examination Mississippian core from the KGS #2-32***
- **4. Site characterization – Lynn , Mina Fazelalavi and John Victorine (12:30-1:00**)
    - Summary of stratigraphy, sedimentology, and diagenesis of the Mississippian reservoir – Drilling, coring, logging, and testing the Mississippian at Berexco Wellington KGS #1-32, KGS #1-28, #2-32
        - Core analysis and well testing - routine and special; ties to well logs and use in the geocellular model (*FZI* indices, flow units)
        - Well completion – acidizing
- **5. Petrel geocellular model and seismic inversion – Jason Rush (1:00-1:20)**
- **6. Reservoir characterization and well testing (1:20-1:40)**
    - Capillary pressure and relative permeability
    - Pulse/interference test in KGS #2-32
- **7. Compositional simulation of CO2-EOR pilot -- Eugene Holubnyak (1:40-2:00)**
- **8. Monitoring performance of CO2 injection – 2:00-2:20**
    - **Fluid monitoring – baseline and during CO2 injection – Lynn, Saugata Datta & Brent Campbell (KSU), John Victorine, Jenn Raney, Tiraz Birdie (Tbirdie) and Lynn**
    - **Microseismic monitoring – Lynn, George Tsoflias (KU), Alex Nolte (KU, KGS), Brandon Graham (KU, KGS), John Victorine and Jenn Raney (KGS), Lynn**
    - **InSAR-cGPS – Lynn, Mike Taylor (KU), Drew Schwab (KU, KGS), Tandis Bidgoli (KGS)**
- **9. Open discussion of the Wellington CO2-EOR project and implementing CO2-EOR in Kansas – Lynn moderating (2:20-3:00)**

Posters shown during the core workshop included in **Figures 19 and 20.**

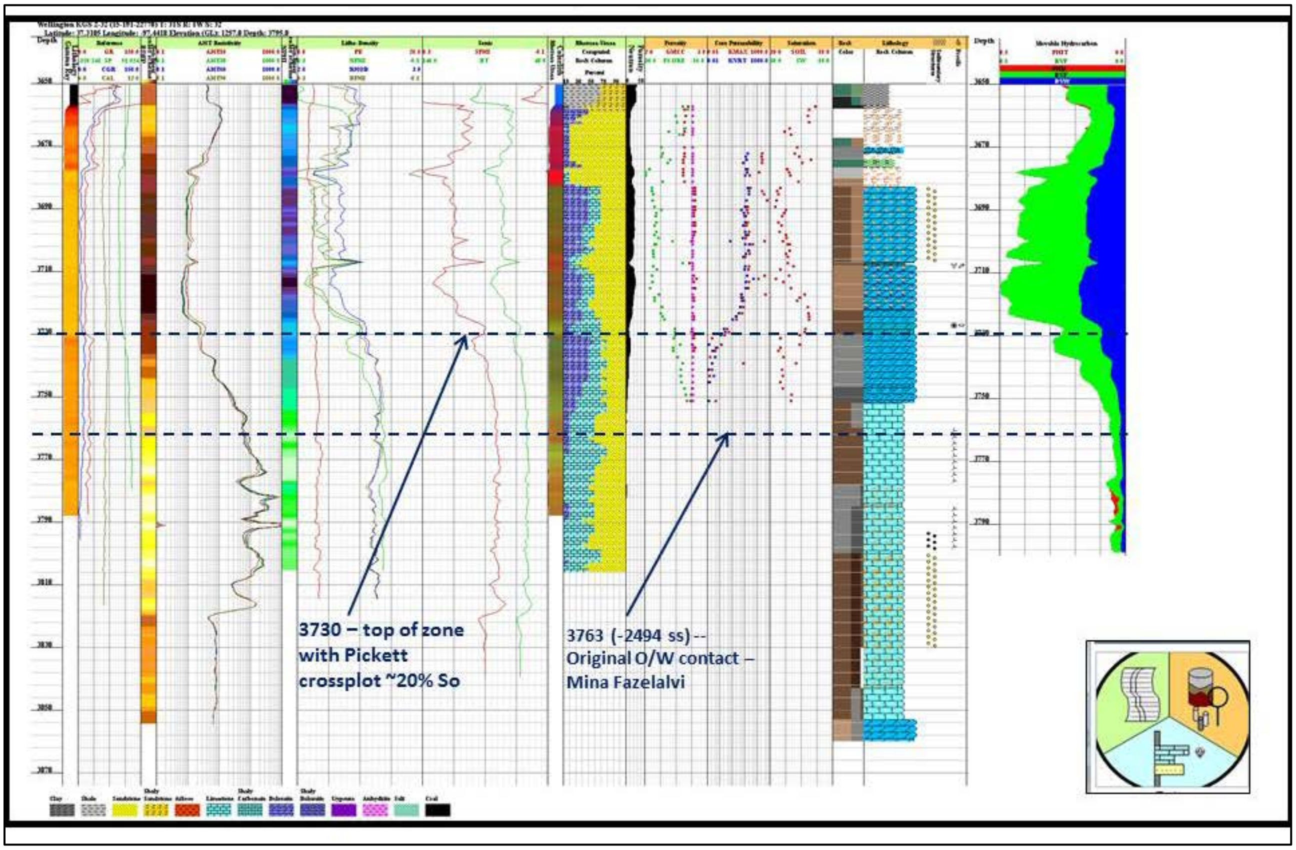


Figure 19. Berexco Wellington KGS #2-32 showing well logs, lithologic interpretation from logs, core analysis, lithology from core description, and moveable oil (green, residual oil saturation [not how uniform it is at about 23-25% of the pore space] and water saturation in blue).

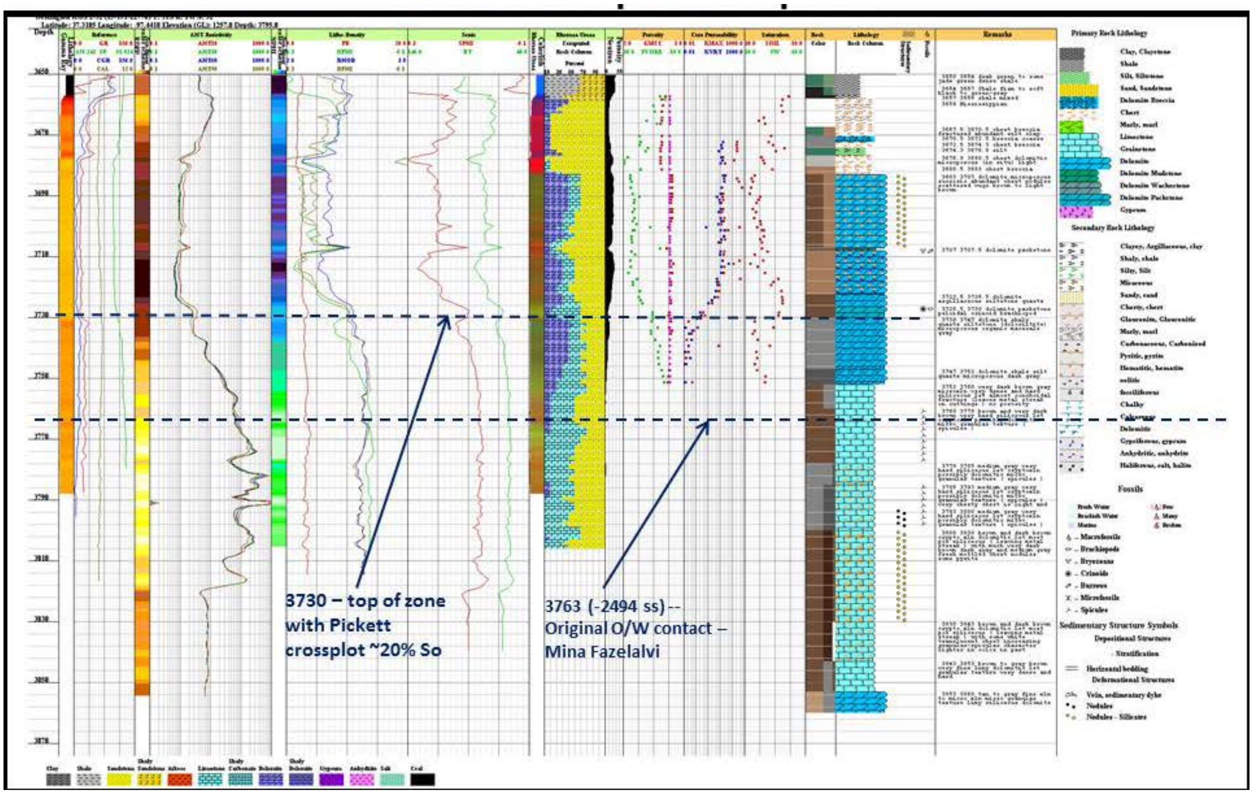


Figure 19. Berexco Wellington KGS #2-32 as before less the moveable oil. The core description here includes both a graphic and written description. The graphic is constructed automatically by parsing the description and relaying components in graphical form.

<u>August 3rd</u>

The drilling report for KGS 2-32 was updated (**Figure 20**) to reflect the installation of a stainless steel wellhead. Water injection also started as part of the process to re-pressure the Mississippian reservoir to the original reservoir pressure.

LEASE NAME Wellington KGS #2-32 (1330081)	COUNTY Sumner STATE KS
WELL LOCATION NE NW NE SE (2680' FSL, 709' FEL)	SEC 32-31S-1W
OPERATOR Berexco LLC	API# 15-191-22770
CONTRACTOR: Fossil Drilling, Inc.	ELEVATION 1257' - GR 1269' - KB
RIG: Fossil #3 Toolpusher: Kerry Clark 620-388-2676	GEOLOGIST: Tyler Sanders 316-807-0197
Cc: Evan, Richard Email daily: Dana FINAL: AEB, well file	SPUD DATE: 3/20/2015, 7:00 am

4/25-26/15	Shut down.
4/27/15	Ran 5-1/2" X 2-7/8" Arrowset PKR. Set @ 3638' KB. Ran swab- fluid level 1800' from surface, 100' free oil on top. Recovered 10.8 BW on swab down. Had 700' fill up after 1 hour. Acidized Mississippi perfs with 2500 gallons 10% NEFE-HCl and 250 ball sealers. Treated 3 BPM @ 1300# initially, increased to 5.7 BPM @ 700# towards end. ISIP 50#, 30 seconds to vacuum. TLTR 90 BTF. Ran swab- fluid level 1100' from surface. Recovered 44.7 BW on swab down. Next hour recovered 20.8 BTF with trace oil. Shut down.
4/28/15	Ran swab- fluid level 2000' from surface, 50' oil on top. Swabbed 26.7 BTF. Release PKR and run across perfs to remove any remaining ball sealers. Reset PKR @ 3638' KB. Ran swab. Recovered 16.8 BTF on swab down. 1st Hour 19.1 BTF, fluid level 2800' from surface 2nd Hour 23.4 BTF 3rd Hour 16.7 BTF 4th Hour 13.4 BTF 5th Hour 13.4 BTF 6th Hour 20 BTF. Fluid level stayed 2800' from surface. Caught fluid samples. Shut down.
4/29/15	Ran swab- fluid level 2000' from surface, 75' free oil on top. Injected 2 BPM for 10 minutes- took fluid on vacuum. Injected 4 BPM for 10 minutes- stabilized pressure 150#. TOH w/ tubing and PKR. RDMO BX Rig #13.
4/30/15	Waiting for pulse test scheduled for the week of May 10.
5/12/15	Ran pulse test in well.
5/27/15	Too muddy to move in rig/injection tubing.
6/8/15	MIRU Contract WS Rig. TIH w/ nickel coated Arrowset-1X PKR with Viton rubber and 1.875" stainless steel profile nipple for X-style blanking plugs, nickel coated on-off tool and 110 jts TK-70XT coated tubing. Pump packer fluid and set PKR @ 3636' KB. Annulus held 150#. RDMO Contract WS Rig. Will MIT well 6/10/15.
6/10/15	MIT well to 350#- held. Witnessed by Jonathan Hill of KCC District #2 office.
6/23/15	Permit for carbon dioxide injection approved by KCC.
7/7/15	Installed 2" 2250# fiberglass water injection line from Wellington Unit #52I injection well to Wellington KGS #2-32 well.
7/27/15	Waiting on high pressure stainless steel fittings to finish hooking up wellhead.
8/3/15	Finished hooking up wellhead and began injecting water. Instantaneous rate 300 BWIPD @ 0# tubing pressure. Backed rate off to 150 BWIPD.

Figure 20. Status of the CO2-EOR injection well, #2-32 as conveyed by the "drilling" report.

August 7th

Halliburton will analyze the microresistivity imaging log (XRMI) that was run in Berexco KGS #2-32 in order to translate their interpretations to a XRMI composite log with stratigraphic interpretations to augment the existing structural interpretation. The stratigraphic information was summarized in a written report (**Figure 21**), but the specific interest is to use the "tadpole" vectors to determine subtle depth patterns of dip related to deposition of the high-frequency cycles present in the Mississippian. Halliburton is also reinterpreting the spectral/diopole sonic log for geomechanical information using our assigned pore pressure for estimates of bulk moduli and stress magnitudes.

XRMI STATISTICAL ANALYSIS

BEREXCO LLC

WELLINGTON KGS #2 – 32

2680' FSL & 709' FEL

NE NW NE SE

Section 32 – 31S – 1W

Sumner County, Kansas

3819 to 3856 – Laminated calcareous silty clay and cherty limestone – Strike N40W – Structure down to the S35W at 5 degrees. Possibly some gas breakout.

3798 to 3819 – Laminated calcareous chert and silty limy sandy clay – Strike N40W – Structure down to the S35W at 1.9 degrees. Fractures observed – 3 high angle induced, 3814 to 3818, strike ENE by WSW – High angle fractures – 1 partial, 1 closed and 2 microfaults – E – W strike.

3755 to 3798 – Cherty clay and calcareous sandy silt with limestone layers – Strike N55W – Structure down to the SSW at 4.4 degrees – Fractures observed – 3780 to 3795 – 6 high angle induced – strike E12N by W12S – 1 partial at 3768 and 1 partial at 3797 – high angle with strike E10N by W10S – 1 high angle partial at 3757 with strike NE – SW – 8 high angle closed with strike E – W and 3 microfaults, 3759 to 3763, 2 with strike N – S at 45 degrees and 1 with strike N72E at 33 degrees.

3725 to 3755 – Shaly limy dolometic chert – Strike N55W – Structure down to the S30W at 3.5 degrees – Fractures observed, 3737 to 3751, 7 high angle – strike ENE by WSW, 1 high angle closed, 3725, strike W12N by E12S, 3730, 1 partial – strike N52W – 1 microfault, 3753, strike N58E at 28 degrees.

3698 to 3725 – Calcareous sandy shaly porous chert – Strike WNW by ESE – Structure down to the SSW at 2.8 degrees – Fractures observed – 9 randomly oriented fractures and microfaults were observed, 3704 to 3712.

3657 to 3698 – Porous chert and calcareous clay – Strike WNW by ESE – Structure down to the S20W at 5.1 degrees. Fractures observed – 14 randomly oriented fractures and microfaults – 3658 to 3664 and 3680 to 3697. Shale deformation observed – Strike N40W – Structure down to the S35W at 9.6 degrees.

3627 to 3657 – Carbonaceous shale and calcareous silt and clay – Strike N40W – Structure down to the S5W at 1.5 degrees. Fractures observed – 4 closed and 3 microfaults randomly oriented – Soft sediment deformation clay and silt – Strike E – W – Structure down to the S at 5.1 degrees.

3577 to 3627 – Carbonaceous clay and sandy calcareous silt – Strike NW – SE – Structure down to the S35W at 3.5 degrees. Fractures observed – 17 closed fractures and microfaults are randomly oriented. Compaction deformed shale and silty limy clay – Strike NW – SE – Structure down to the S40W at 7.9 degrees.

3534 to 3577 – Carbonaceous clay and silty shaly limestone – Strike NW – SE – Structure down to the SW at 1.1 degree. 6 randomly oriented closed fractures and microfaults were observed.

3498 to 3534 – Silty limestone, carbonaceous shale and calcareous clay – Bimodal current along strike – NE – SW – Structure down to the SSE at 1.5 degrees. Fractures observed, 3509 to 3527, – 7 microfaults and fractures. The compacted shale appears to have bimodal current aligned NE – SW with structure down to the S at 3.1 degrees.

3455 to 3498 – Carbonaceous clay, silty shale and limestone – Strike S25E – Structure down to the S35W at 3.8 degrees. Fractures observed, 3459 to 3480, 5 high angle fractures and 1 microfault with predominant E – W strike.

3426 to 3455 – Laminated carbonaceous shale and shaly lime – Strike N35W – Structure flat.

3366 to 3426 – Carbonaceous clay, silty limestone and sandy clay – Strike N35W – Structure down to the S35W at 2.5 degrees. Observed fractures – 32 closed fractures and microfaults are randomly oriented. Deformation laminations have structure down to the S35W at 5.3 degrees.

3326 to 3366 – Limy silt and clay – Strike S55E – Structure down to the S12W at 2.6 degrees.

3280 to 3326 – Carbonaceous shale and limestone – Strike W15N by E15S – Structure down to the S15W at 5.1 degrees. Fractures observed – 3 closed and 3 microfaults with primary strike NNW by SSE with angles from 20 to 55 degrees.

3242 to 3280 – Laminated fossiliferous limestone with cherty clay layers and inclusions – Strike WNW by ESE – Structure down to the SSW at 3.2 degrees. 7 closed fractures and 7 microfaults randomly oriented were observed varying from 11 to 52 degrees.

3212 to 3242 – Carbonaceous shale and silty limestone – Strike NE – SW – Structure down to the SE at 2.5 degrees. Fractures observed, 3240 to 3242, 2 closed striking N50E at 50 degrees – 12 microfaults and 1 closed, 3213 to 3228, randomly oriented varying from 15 to 60 degrees.

3184 to 3212 – Fossiliferous vugular limestone – slightly shaly and cherty – Strike N40W – Some bimodal NE – SW current with structure down to the S30W at 2.1 degrees. Fractures observed – 10 randomly oriented closed varying from 21 to 88 degrees – 5 microfaults with variations of E – W strike and aligned 38 to 88 degrees,

3140 to 3184 – Carbonaceous shale and fossiliferous limestone – some layers of silt and sandy clay – Strike N55W – Structure down to the S5W at 4 degrees. Fracture analysis – 3173 to 3184, 3 microfaults and 1 closed – E – W strike – 3 at 85 degrees and 1 at 22 degrees – 3157 to 3170, 4 closed fractures and 4 microfaults variations of E – W strike varying from 18 to 88 degrees – 3143 to 3149, 3 closed and 2 microfaults – ENE by WSW strike varying from 52 to 88 degrees.

3091 to 3140 – Fossiliferous limestone with silty clay layers and inclusions – Strike NW – SE – with bimodal current NE – SW – Structure down to the S40W at 1 degree. Fractures observed, 3118 to 3139, 1 closed and 5 microfaults – primary strike WNW by ESE – 39 to 89 degrees. 3091 to 3103 – 4 closed and 4 microfaults – variations of E – W strike 29 to 82 degrees. Compaction deformation beds – Strike N35W – Structure down to the S70W at 3 degrees.

3059 to 3091 – Limestone – fossiliferous and cherty with carbonaceous clay and silty shale – Strike WNW by ESE – Bimodal NE – SW current – Structure down to the S at 2.4 degrees. Fractures observed – 8 closed and 9 microfaults – randomly oriented from 16 to 80 degrees, Compaction deformed beds – Structure down to the SSW at 6.9 degrees.

3037 to 3059 – Slightly cherty shaly limestone fan deposit – Strike NE – SW – Structure down to the NW at 0.5 degrees. Fractures observed – 1 closed at 3039 – strike ENE by WSW at 86 degrees – 1 at 3056 – strike NNW by SSE at 82 degrees – 3042 to 3045 – 3 microfaults – strike N30W at 70 to 82 degrees. Compacted zones – 3040 to 3047 and 3052 to 3057 – structure down to the W13N at 6 degrees.

3023 to 3037 – Fossiliferous clay and calcareous silt – Strike N30W – Bimodal current NE – SW – Structure down to the S80W at 1.1 degree. Fractures observed, 3024 to 3028, 3 closed and 2 microfaults – variations of N – S strike at 33 to 83 degrees.

2980 to 3023 – Silty clay and fossiliferous shale – Strike N60W – Structure down to the SSW at 1.1 degree. 2940 to 2980 – Calcareous clay and silt – Strike E – W – Structure down to the N at 0.7 degree. 2 closed fractures observed, 2957 to 2961 – strike W10N by E10S at 88 degrees.

2910 to 2940 – Slightly coarsening upward calcareous clay and silt – Bimodal current along NE – SW strike – Structure down to the S30 E at 1.4 degree. Fractures observed, 2011, 2 closed fractures strike WNW by ESE at 17 and 37 degrees. Compaction deformation zone 2914 to 2930 – structure down to the S70W at 1.9 degree.

2840 to 2910 – Calcareous clay and silt – Strike N30W – Bimodal current N30E by S30W – Structure down to the S50W at 0.8 degree.

2811 to 2840 – Fine grained laminated silt and clay fan deposit – Strike NE – SW – Structure down to the N55W at 1.6 degree. Fractures observed, 2813, 2835, 2836, closed – strike ENE by WSW at 88 degrees.

2797 to 2811 – Clay and sand – Strike N30W – Structure down to the S60W at 6.8 degrees – fracture at 2809 – strike W12N by E12S at 88 degrees.

2771 to 2797 – Sand and silty clay – Strike N35E with bimodal current – Structure down to the S35E at 1.5 degree. Fractures observed – 2 high angle induced 2773 to 2774, strike W15n by E15S – 2 high angle microfaults 2781 to 2782, strike N35E and 1 closed at 2796 strike N – S at 52 degrees. Fining upward sedimentary deposition with structure down to the SSW at 9 degrees.

2735 to 2771 – Sand and calcareous silt – Strike N35W – Structure down to the NE at 2.2 degrees. Fractures observed – 3 high angle induced fractures 2747, 2763 and 2768 – strike W15N by E15S – 1 high angle closed fracture 2736, strike E – W – 1 microfault 2739, strike NNW by SSE at 43 degrees.

2698 to 2735 – Low energy sand, silt and clay – Strike NNE by SSW with bimodal current – Structure down to the W at 0.6 degrees – fractures observed – 1 high angle closed at 2733 – strike N10W – 3 microfaults at 2706 and 2715 – high angle strike E – W at 2713 strike N60W at 51 degrees. Compacted shale deformation zones have structure down to the W at 12 degrees.

2660 to 2698 – Calcareous clay and dolometic silt – Strike W15N by E15S – Structure down to the S10W at 1.3 degree. Fractures observed – 2 high angle induced at 2663 – strike W10N by E10S – 3 high angle closed, 2681 to 2687, strike E10N by W10S and W10N by E10S – 2 high angle microfaults, 2676 and 2678, strike E12N by W12S. Compaction deformation zones – structure down to the S5W at 7.8 degrees.

This represents our best analysis of the computed data. Since the conversion of electrical measurements to geologic events is not an exact science, neither Halliburton nor this analyst will be liable for these results.

We thank you for selecting Halliburton as your evaluation company. We sincerely appreciate it! OKC Evaluation Team – Charlie Redmond – Manager – James Willingham – Team Leader – Erik Hutto – Lead Analyst – Layne Hamilton – Analyst – Vukenkeng Che-Alota – Analyst – Aleno Bashkirtseva – Analyst – Phong Tong – Data Technician – Leah Kelley – Data Technician – Scott Carr – Sales – Paul McRill – Analyst – August 7, 2015

4

Figure 21. Sedimentary and structural featured observed by Halliburton in the XRMI microresistivity imaging log ran in the Mississippian section of well #2-32.

August 17th

T Birdie addressed land surface deformation for CO_2 injection via geomechanical modeling. A contour map shows the expected land surface deformation (rise) due to CO_2 injection in the Arbuckle (**Figure 22**). The deformation occurs in a fairly wide uplift of approximately 3 mm as predicted by the model. These are preliminary results that will be refined by conducting sensitivity simulations with alternate geomechanical properties in some of the formations above the Arbuckle. However, for InSAR planning purposes it would be safe to assume that we can expect land surface deformation in excess of 1 mm and therefore we should earnestly keep our data acquisition systems active to capture this rise. Anticipated surface deformation also applies to the Mississippian.

The effectiveness of the InSAR could be a very important, cost-effective means to indirectly monitor pressure in the CO_2 injection zone vitally important to help in verifying the area affected by the CO_2 plume. High quality satellite data coupled with the calibration provided by our continuous GPS system in place provides a means to test this technology.

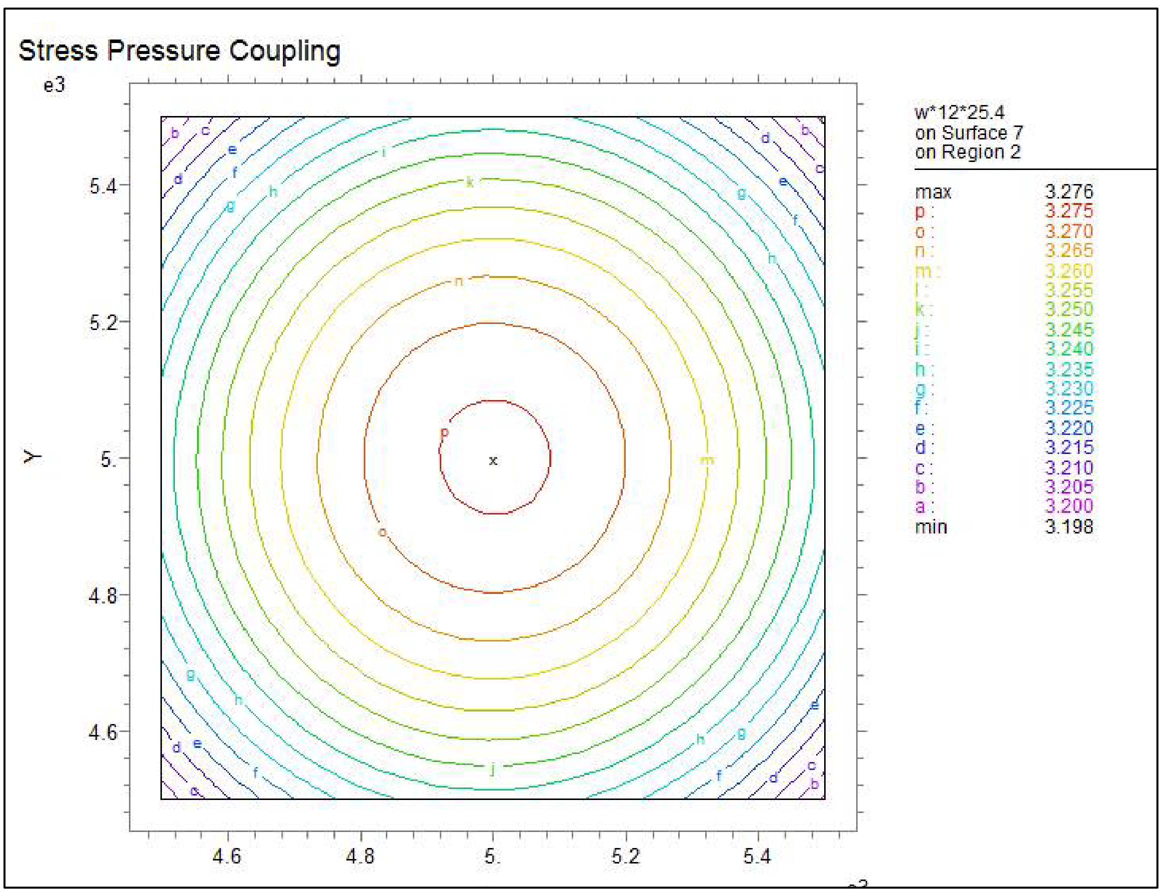


Figure 22. Contour map shows the expected land surface deformation (rise) due to CO_2 injection in the Arbuckle. The areal extent of map is 1,000 feet by 1,000 feet. The legend on the right represents land surface deformation in mm.

<u>August 17-20th</u> – DOE Carbon Storage R&D Meeting

We conveyed our readiness of monitoring technologies to begin CO2 injection:

1) Shallow water well monitoring
2) 18- seismometer array for passive seismic monitoring
3) cGPS and InSAR surface deformation to monitor pressure changes in reservoir during CO2 injection
4) Monitoring wells in underpressured Mississippian reservoir overlying the caprock
5) High resolution 2D seismic survey to verify any leakage through the caprock (baseline acquired in late August 2015)
6) Engineering analysis in place for optimizing CO2 injection performance (**Figure 23**)
7) Use Mississippian CO2-EOR as dress rehearsal for the Class VI injection

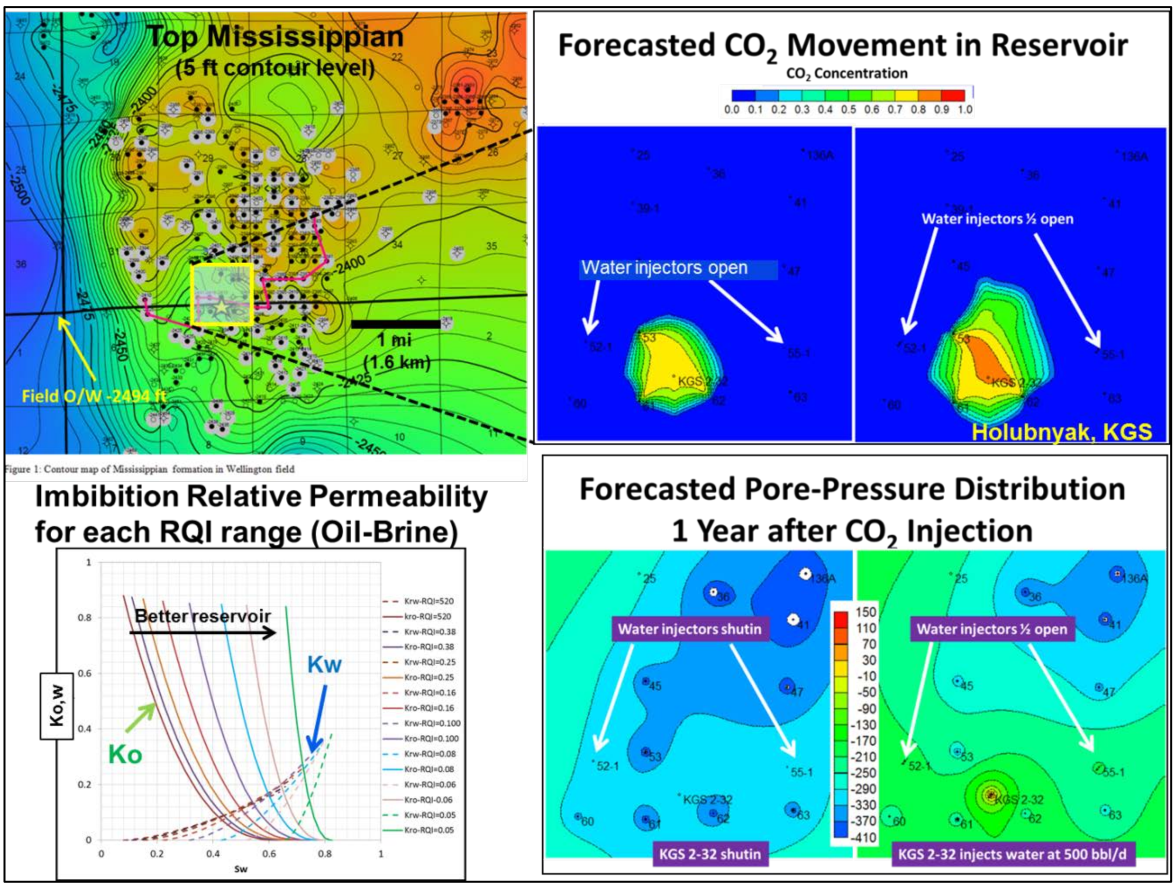


Figure 23. (upper right) Top Mississippian structural elevation (25 ft contour interval), (upper right) forecasted CO2 movement from the injection well, #2-32, (lower right) pore pressure distribution used to control the sweep of the CO2, and (lower left) relative permeability curves that are being calibrated with two analyses of core.

The work of the hydrogeology of the area around Wellington was conveyed in terms of addressing the variable nature of the salinity and yield of the shallow aquifer system (**Figure 24**).

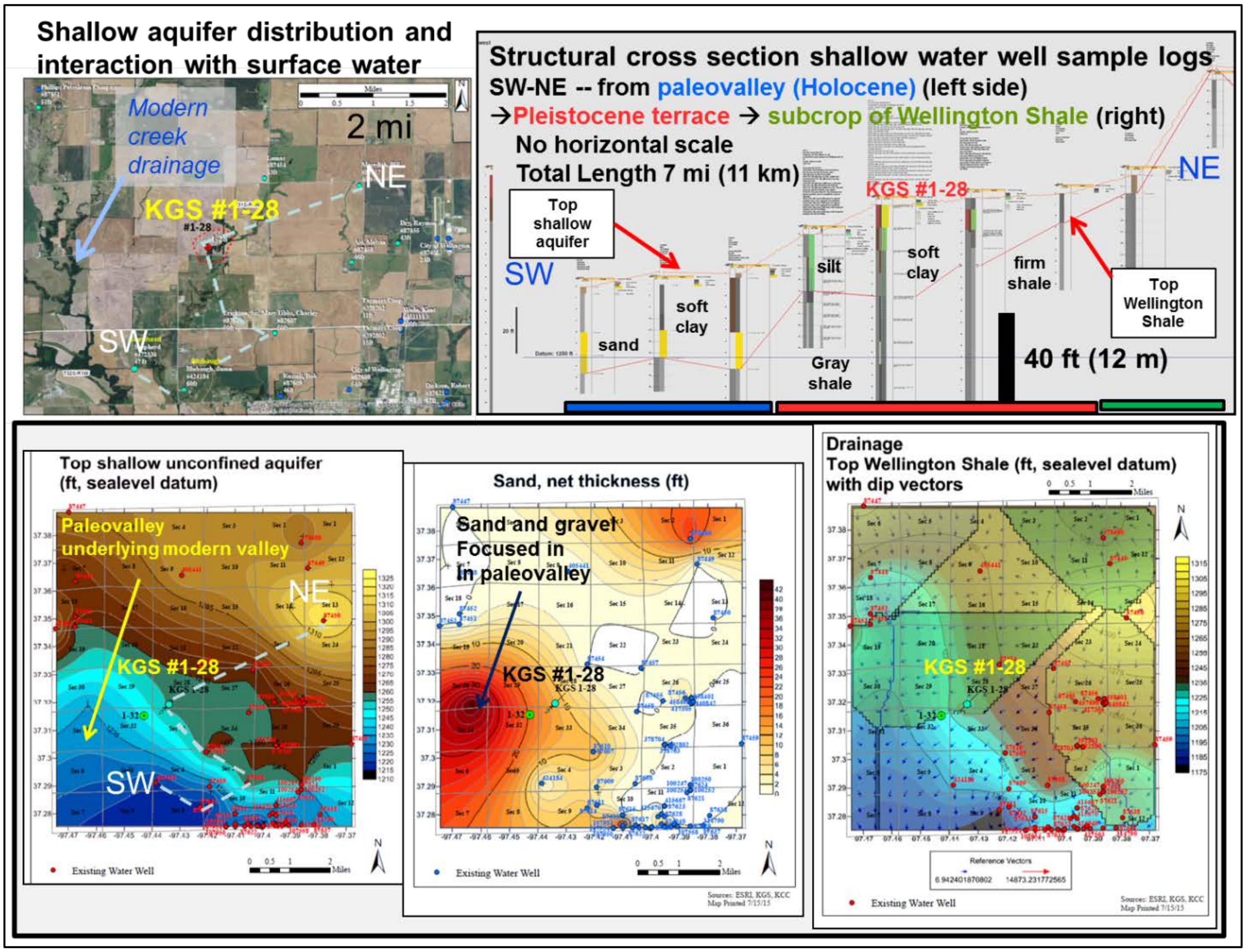


Figure 24. Selected maps and cross section from the hydrogeology report to be shared with EPA regarding the distribution of the shallow aquifer system in the Wellington Field area. A shallow incised paleovalley lies beneath the Modern valley on the west side of the map. The paleovalley also cross cuts an older terrace deposit that is present at Wellington.

Induced seismicity in the Wellington Field area was addressed on both an oral presentation and in a poster at the August review meeting. The emphasis was in the precautions and monitoring in place so as to provide rapid response to ensure safe injection. The induced seismicity in the area is summarized on what occurred in 2014, with nearby brine disposal totaling 128 million barrels, well above the past that is equivalent to 23 million metric tons of CO2 injected, again eclipsing any intent to disposal of that amount of CO2 locally in a commercial scale project **Figure 25**. The illustration goes on to compare this with our test injection, under 1000 bbls per day of CO2 and a total of 142,000 bbls over ~7 months.

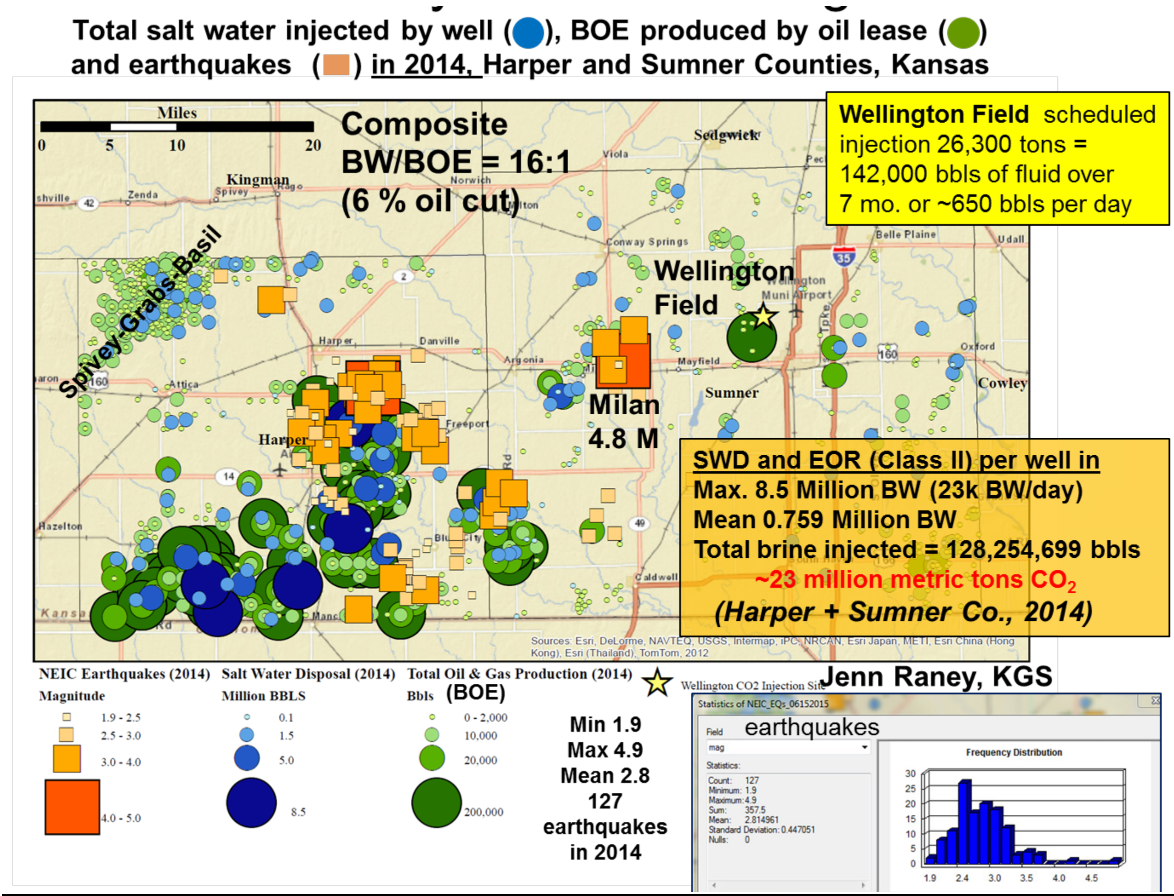


Figure 25. Comparison of cumulative oil produced, brine disposed of in the Arbuckle, and earthquake location and magnitude in Harper (west) and Sumner (east) counties in south-central Kansas. This is compared with the projected CO2 rate and total barrel equivalent to be injected at Wellington Field.

The seismicity that is being reported by USGS and soon our Wellington seismometer array will be conveyed to the team using a pseudo 3D display of the earthquakes with a new Java application (**Figure 26**). The events are color coded by depth, magnitude, or time.

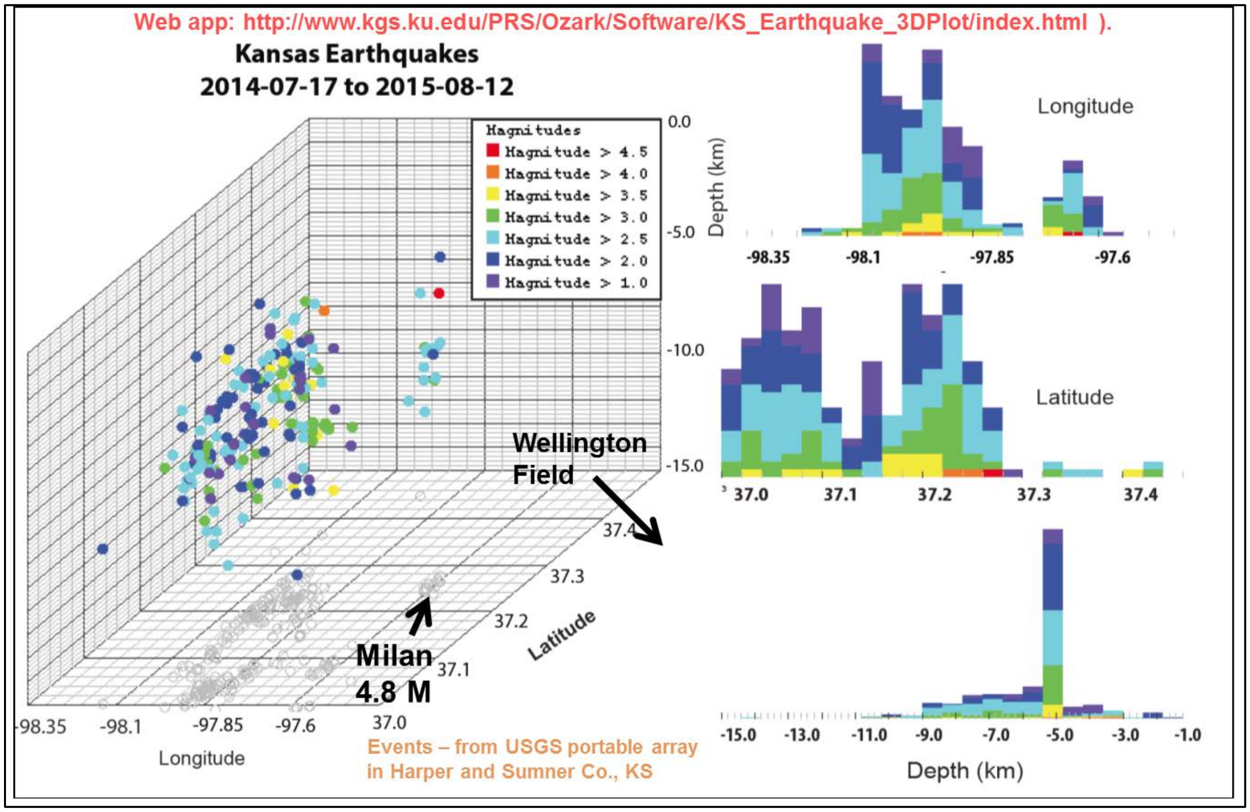


Figure 26. Pseudo 3D display of earthquakes using a new Java application. Display shows hypocenters.

August 25th

New rock mechanics solutions received from Halliburton for KGS 2-32, 1-32, and 1-28 using the processing of wireline logs, the spectral sonic and XRMI.

September 2nd

The final QASP was approved by EPA. An additional memorandum was sent from a Quality Assurance group at EPA along with the approved QASP on September 11th. This memorandum is related to interpretation of the field blank results.

September 3rd

Watney presented at the KDHE Geology & Well Technology Section Fall Seminar in Wichita, Kansas. The talk was titled, "*An Operational Plan for Safe and Effective CO2 Injection at Wellington Field, Kansas in Perspective of Recent, Nearby Seismic Activity*." Much of the material presented was delivered at the DOE-NETL annual review meeting held in Pittsburgh in August.

September 23rd

Final QASP uploaded to the EPA GS Data Tool. (Version 7).

ONGOING ACTIVITIES

TASK 1. PROJECT MANAGEMENT AND REPORTING

Key Findings

1. Progress on the Class VI saline aquifer CO2 test injection and preparations for the upcoming Class II CO2-EOR injection at Wellington Field are on track. The site continues on track to become a viable calibration site and field demonstration of a suite of monitoring technologies.
2. The monitoring methods employed in the CO2-EOR may be help to steer the CO2 so that the sweep efficiency might be improved.
3. Refined model predictions are being made for both the Arbuckle and the Mississippian as new information is acquired and processed.
4. The optimization of CO2 utilization and storage in the Mississippian oil reservoir shows promise based on the newest findings that are being incorporated into the Mississippian geomodel.
5. Induced seismicity is definitely if interest to the Wellington project and the seismometer array will pay considerable dividends in distinguishing between more far field induced events and that which could be generated with the CO2 injection, albeit smaller for the Wellington tests in the framework of microseismicity to allow us to distinguish matrix versus fracture flow.

Plans for Fourth Quarter 2015 (anticipated start of BP3, December 1, 2015)

1. Complete installation of on-site CO2 storage equipment and injection skid.
2. Begin CO_2 injection into the Mississippian.
3. Finalize EPA's determination of the presence of a USDW for the Class VI permit application as an important step to allow EPA to make decisions about the Class VI application.

PRODUCTS

Publications, conference papers, and presentations

Watney, L., et al., August 2015, Workshop – Annual meeting of the Kansas Independent Oil and Gas Association, Wichita, Kansas.

Watney, et al., 2015, present at KDHE Geology & Well Technology Section Fall Seminar on Thursday, September 3, 2015, Wichita Kansas.

Watney et al., 2015, DOE site visit September 29 and 30, Wichita, Kansas.

PARTICIPANTS & OTHER COLLABORATING ORGANIZATIONS

A project organization chart follows (**Figure 27**). The work authorized in this budget period includes office tasks related to preparation of reports and application for a Class VI permit to inject CO_2 into the Arbuckle saline aquifer. Tasks associated with reservoir characterization and modeling are funded in contract DE-FE0002056.

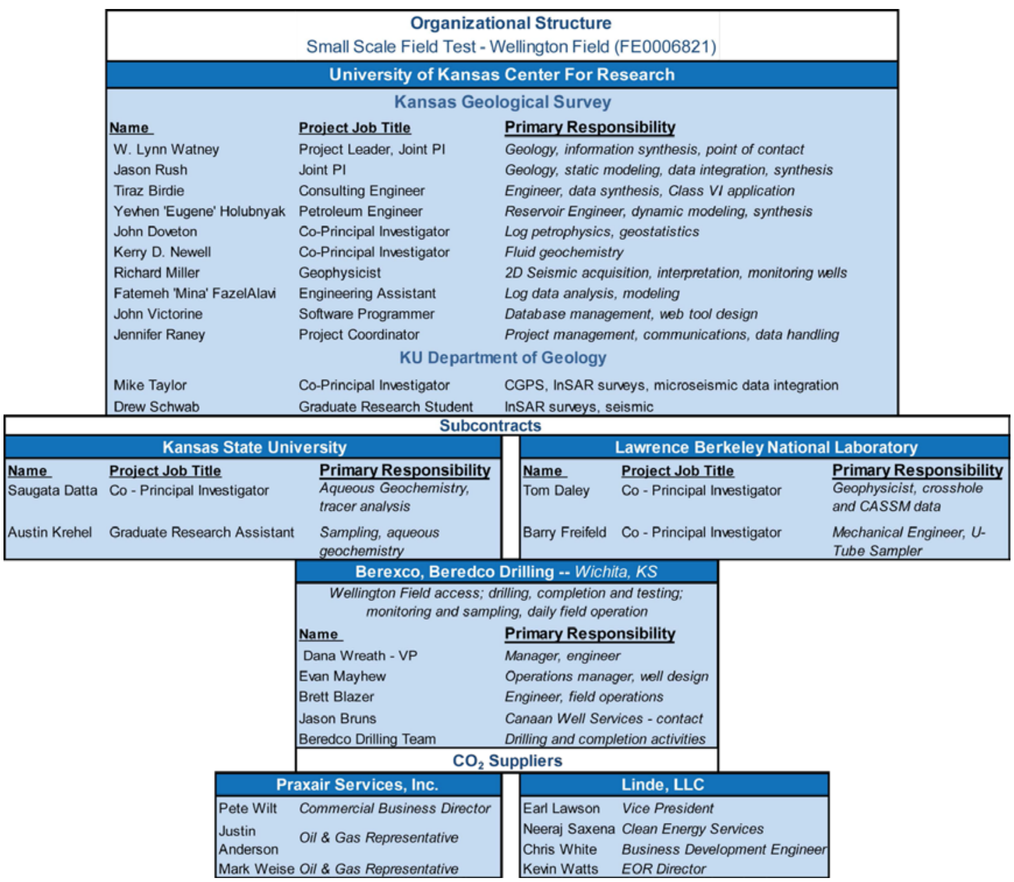


Figure 27. Organizational Chart.

IMPACT

See earlier discussion.

CHANGES/PROBLEMS

Please refer to earlier discussion.

BUDGETARY INFORMATION

Cost Status Report

Please refer to the next page.

	BP2 Starts 9/1/14	Ends 8/31/15			BP3 Starts 9/1/15	Ends 9/30/16			
Baseline Reporting Quarter	7/1/14 - 9/30/14 Q12	10/1/14 - 12/31/14 Q13	1/1/15 - 3/31/15 Q14	4/1/15 - 6/30/15 Q15	7/1/15 - 9/30/15 Q16	10/1/15 - 12/31/15 Q17	1/1/16 - 3/31/16 Q18	4/1/16 - 6/30/16 Q19	7/1/16 - 9/30/16 Q20
Baseline Cost Plan (from SF-424A)									
Federal Share	$1,997,070.75	$325,087.75	$325,087.75	$325,087.75	$325,087.75	$325,087.75	$325,087.75	$325,087.75	$325,087.75
Non-Federal Share	$258,982.75	$184,656.00	$184,656.00	$184,656.00	$184,656.00	$0.00	$0.00	$0.00	$0.00
Total Planned (Federal and Non-Federal)	$2,256,053.50	$509,743.75	$509,743.75	$509,743.75	$509,743.75	$325,087.75	$325,087.75	$325,087.75	$325,087.75
Cumulative Baseline Cost	$10,644,409.78	$11,154,153.53	$11,663,897.28	$12,173,641.03	$12,683,384.78	$13,008,472.53	$13,333,560.28	$13,658,648.03	$13,983,735.78
Actual Incurred Costs									
Federal Share	$0.00	$50,936.04	$74,137.93	$435,392.38	$409,244.41	$0.00	$0.00	$0.00	$0.00
Non-Federal Share	$0.00	$33,953.80	$1,409,519.41	$0.00	$119,600.00	$0.00	$0.00	$0.00	$0.00
Total Incurred Costs-Quarterly (Federal and Non-Federal)	$0.00	$84,889.84	$1,483,657.34	$435,392.38	$528,844.41	$0.00	$0.00	$0.00	$0.00
Cumulative Incurred Costs	$392,195.05	$477,084.89	$1,960,742.23	$2,396,134.61	$2,924,979.02	$2,924,979.02	$2,924,979.02	$2,924,979.02	$2,924,979.02
Variance									
Federal Share	$1,997,070.75	$274,151.71	$250,949.82	-$110,304.63	-$84,156.66				
Non-Federal Share	$258,982.75	$150,702.20	-$1,224,863.41	$184,656.00	$65,056.00				
Total Variance-Quarterly Federal and Non-Federal)	$2,256,053.50	$424,853.91	-$973,913.59	$74,351.37	-$19,100.66				
Cumulative Variance	**$10,245,738.88**	**$10,670,592.79**	**$9,696,679.20**	**$9,771,030.57**	**$9,751,929.91**				

THIS NUMBER WAS REDUCED BY $594.94 FROM PREVIOUS SUBMISSION - NOT CLEAR WHY

KUCR PROCESSED KSU COST SHARE FEB 2015 BUT BACKDATED IT TO 11/30/2014,THUS THE CHANGE

Appendix A. Operating Plan for Safe and Efficient Injection (OPSEI)

Wellington OPSEI is designed to ensure that the CO_2 injection operations are conducted in a safe manner that does not endanger life or property and is no more risky or intrusive than normal oilfield operations in Kansas. The plan integrates activities outlined in the permit document (Section 8 – System Operation, Section 10- Testing and Monitoring Plan, and Section 13- Emergency Remedial Response Plan). It consists of the following 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
- Monitoring-based Rapid Response Plan
- Wellington Seismic Action Plan
- Emergency Remedial Response Plan

The **Injection Control Plan** is designed to limit injection to safe levels that will maintain the hydraulic seal above the injection zone, thereby ensuring that the CO2 remains confined within the injection zone at depths of greater than 4,000 feet below land surface. It is also developed to ensure that injection occurs at a rate that will not harm the integrity of the injection well, which can cause leakage.

The **Monitoring and Rapid Response Plan** is designed to provide early warning of CO2 plume and pressure front deviations, which will trigger an analysis of the causes of the deviation, a potential revision of the expected plume movement, and place in action a set of enhanced monitoring activities to ensure safe injection. The plan places more emphasis on analysis of wellhead and downhole pressure and temperature data in the injection and monitoring wells, geochemical monitoring of groundwater in the injection zone and the overlying Mississippian and shallow reservoirs, and (integral and derivative) Hall plot analysis as recommended in the EPA Underground Injection Control National Technical Workgroup report "*Minimizing and managing potential impacts of injection-induced seismicity from Class II disposal wells: Practical Approaches*" -- http://www.epa.gov/r5water/uic/ntwg/pdfs/induced-seismicity-201502.pdf.

The success of the Monitoring and Rapid Response Plan to provide early warning is based on prioritizing the monitoring technologies by establishing: 1) reliability of the data that is recorded and approaches used to analyze the data, 2) frequency that the data is acquired during injection and therefore speed of a possible response or corrective action; 3) sensitivity and precision of the monitoring method and its ability to detect small changes in CO2 plume behavior; 4) location and therefore resolution from which the data is collected, e.g., at the injection and monitoring well detecting changes within and in proximity to the injection zone itself; 5) spatial resolution and coverage of the CO2 plume; and 6) ability to detect movement out of the injection zone both above and below the injection zone. Significant changes detected in the behavior of CO2 plume will require an update of the dynamic model.

The top tier methodologies are primarily engineering analytical methods that utilize data required in the Class VI permit and are both commonplace and best practices for managing fluid injection. These measurements include injection pressure, temperature, injection profile monitoring, interference tests, chemical composition, and passive seismic monitoring. The methods relying on fluids and pressure based data provide the primary means to prevent leakage of CO2, with the ability to recognize behavior that falls outside of predictions made from the composition simulations.

The **Wellington Seismic Response Plan** is designed to limit injection should certain seismic event thresholds be reached, and if the seismicity is attributable to injection. It is an amalgamation of the Kansas Seismic Response Plan which relies on a seismic event score, and EPA preferred seismic magnitude based thresholds to limit injection rates.

The **Wellington Emergency Remedial Response Plan** is designed to implement an set of remedial measures to protect Underground Sources of Drinking Water (USDW) should an unforeseen natural disaster, well failure, or CO2 escape from the injection zone occur.

Injection Control Plan

Table 1 Operating Limits for Safe Injection

Parameter[1]	Upper Limit	Note
Downhole Injection Pressure @5,050 ft	2,600[2] psi	~70% of the fracture gradient based pressure of 3,788 psi (assuming a
Surface Pressure	1,200 psi	
Annulus Pressure	100 psi	Annulus to be filled with corrosion resistant fluid and remain unpressurized. Some pressure increase/decrease could
Injection Rate	Average of 300 tons/day over a 7 day period	

1 All gauge pressures, temperatures, and injection rate will be transmitted to a SCADA system, which will be programmed to initiate shutdown and inform Berexco over cellular network should the safe operating limits be exceeded.

2 A stringent pressure threshold of 2,600 psi (0.7 x Fracture Gradient) is a voluntarily limitation of the KGS, and is subject to the results of the Pressure Fall-Off Test (FOT) verifying that the formation conditions are as presently assumed. In the event that the formation is determined to be "tighter" than assumed on completion of the FOT, then a request will be made to the EPA to allow injection up till the EPA allowable limit of 90% of the fracture pressure.

Monitoring based Rapid Response Plan (table)

Monitoring Activity	Frequency of Evaluation	Monitoring Objective	Expected Range	Deviation Triggering Reevaluation	Potential Causes of Deviation	Level 1 Response Action(s)	Level 2 Response (Actions)	Notes
CASSM - Early detection of plume at KGS2-28	weekly	Determine plume front/validate CO2-brine model	Plume expected to arrive at KGS 2-28 within 45-60 days of commencement of injection	Plume arrival at KGS 2-28 within 15 days of commencement of injection	Presence of preferential flow pathway(s)/	• Validate plume detection with U-Tube sampling • Conduct Hall Plot analysis • Conduct Pressure Fall-Off Test (FOT) • If necessary, recalibrate model • Revise projections of plume and pressure front • Recalculate AoR • Determine if any Corrective Action (CA) required • Report finding to EPA Director.		
CASSM – Non-detection of plume at KGS2-28	weekly	Determine plume front/validate CO2-brine model	Plume expected to arrive at KGS 2-28 within 45-60 days of commencement of injection	Plume not detected within 120 days of commencement of injection	Non-radial migration of CO_2 through preferential pathway(s), escape of CO_2into basement, breach of caprock, well integrity failure	• Conduct Hall Plot analysis • Conduct Pressure Fall-Off Test (FOT • Review annulus pressure data • Sample Mississippian and shallow well • Conduct MIT • If necessary, recalibrate model • Revise projections of plume and pressure front • Recalculate AoR • Determine if any Corrective Action (CA) required • Report finding to EPA Director.		Procedure to be repeated every 30 days if breakthrough at KGS 2-28 not achieved within 120 days of commencement of injection.
Sudden loss of downhole and/or wellhead pressure at injection well	Continuous	Monitor for leakage from well or caprock	Near steady pressures, increasing mildly with injection (except during start and stoppage of injection)	> 25% drop in pressure (over average of past 5 minutes)	Potential leakage from well, breach of caprock, or formation of new fracture(s)	• Pause injection • Review downhole, wellhead, and annulus pressure data. • Determine if loss of pressure due to CO_2 supply. If positive, rectify problem, report findings to EPA Director and resume injection. • Conduct Hall Plot analysis. • Sample and test water quality in the Mississippian and shallow monitoring wells • Conduct MIT • Utilize all available monitoring data to calibrate model and predict plume extent • If necessary, implement Level 2 response • Report finding to EPA Director.	• Conduct Pressure Fall-Off Test (to determine if loss of pressure due to formation enhancement • Obtain InSAR scene and analyze for caprock breach (if deemed feasible)	

Unexpected increase of downhole or wellhead pressure gradients at injection well	Continuous	Monitor for interception of barrier boundary, well plugging, reduced formation permeability	Near steady pressures, increasing slightly with time (except during start and stoppage of injection)	Unexpected increase in pressure gradient over time	Interception of barrier boundary, well plugging, reduced formation permeability due to chemical reactions, reduction of permeability due to lower downhole temperature	• Review downhole and wellhead temperature and pressure data. • Conduct Hall Plot analysis. • Determine if increase in pressure due to cooling effect of CO_2, formation plugging, or geochemical reactions. If positive, continue pumping but closely monitor pressures so as to not exceed operational limits. • If pressure buildup due to interception of barrier boundary, then if necessary, revise conceptual model. • Recalibrate model and make fresh projections of plume and pressure front • Recalculate AoR • Determine if any Corrective Action (CA) required • Report finding to EPA Director.		
Felt Earthquake of magnitude 3.0 or greater with hypocenter within 1 mile of injection well	Continuous	Provide early warning of major earthquake	Earthquake magnitude < 2.0	Felt magnitude > 3.0	Presence of unknown fault(s)	Implement Wellington Seismic Action Plan		
InSAR – surface deformation not detectable	monthly	Estimate subsurface pressure distribution in the injection zone based on land surface uplift estimated by InSAR interferograms	Detectable surface deformation (> 1 mm) in the close proximity to injection well	Unable to quantify any surface deformation within 120 days of commencement of pumpage	Experimental nature of InSAR technology	Make estimate of land surface deformation based on pressures measured at KGS 1-28 and KGS 2-28. If sub-mm deformation projected, then continue monitoring since deformation less than 1 mm are not easily identifiable. If > 1 mm deformation estimated, then rely on downhole pressure controls for safe injection.		Due to limited historical InSAR data which would account for seasonal influences/vegetation growth, and due to the experimental nature of the InSAR technology, the level of accuracy will be established during the course of the project.
2D Seismic – Detection of plume above injection zone	One approximately midway during injection, and one post-injection	Confirm plume location	Plume confined in (Arbuckle) injection zone	CO_2 suspected above injection zone	Potential breach of confining zone	Pause injection Execute Emergency Remedial Response Plan		
3D seismic - Detection of plume above	One post-injection survey	Confirm plume location	Plume confined in (Arbuckle)	CO_2 suspected above injection zone	Potential breach of confining zone	Pause injection Execute Emergency Remedial Response Plan		

injection zone			injection zone					
2D Seismic – <u>non-detection</u> of plume	One approximately midway during injection, and one post-injection	Confirm plume location	Plume to remain confined in (Arbuckle) injection zone	Non-detect of CO2 along seismic line	Plume escape along preferential pathway(s) in plane(s) out of the seismic line	If plume detected by other monitoring technologies, then: • Pause injection • Conduct Hall Plot analysis. • Utilize all available monitoring data to calibrate model and predict plume extent • Recalibrate model and make fresh projections of plume and pressure front • Recalculate AoR • Determine if any Corrective Action (CA) required • Report finding to EPA Director. If non-detect of plume by other monitoring technologies also, then: • Pause injection • Conduct water quality testing of Mississippian and shallow wells • Conduct MIT • Discuss path forward with EPA Director	Budget allowing, conduct additional seismic survey(s) if CO_2 plume cannot be detected by other monitoring technologies.	Absence of CO_2 could be due to (highly unlikely) escape of CO_2 in the basement

Wellington Seismic Action Plan

Background

The Wellington Seismic Action Plan (WSAP) is designed to ensure that CO_2 injection does not result in any harmful seismic activity. The plan is built upon the Kansas Seismic Action Plan (KSAP, http://kcc.ks.gov/induced_seismicity/draft_state_action_plan.pdf), which was developed in September 2014 on the direction of Kansas governor Sam Brownback following a series of relatively large earthquakes in south-central Kansas. The goal of the KSAP is to ensure that fluids injected into the subsurface in Kansas are managed so as to not cause any detrimental tremors. To realize the safe injection goals of the WSAP, a local array of seismometers has been installed at the Wellington site (Figure 1) to monitor seismicity, and to ensure that the CO_2 injection activity does not produce undesirable earthquakes.

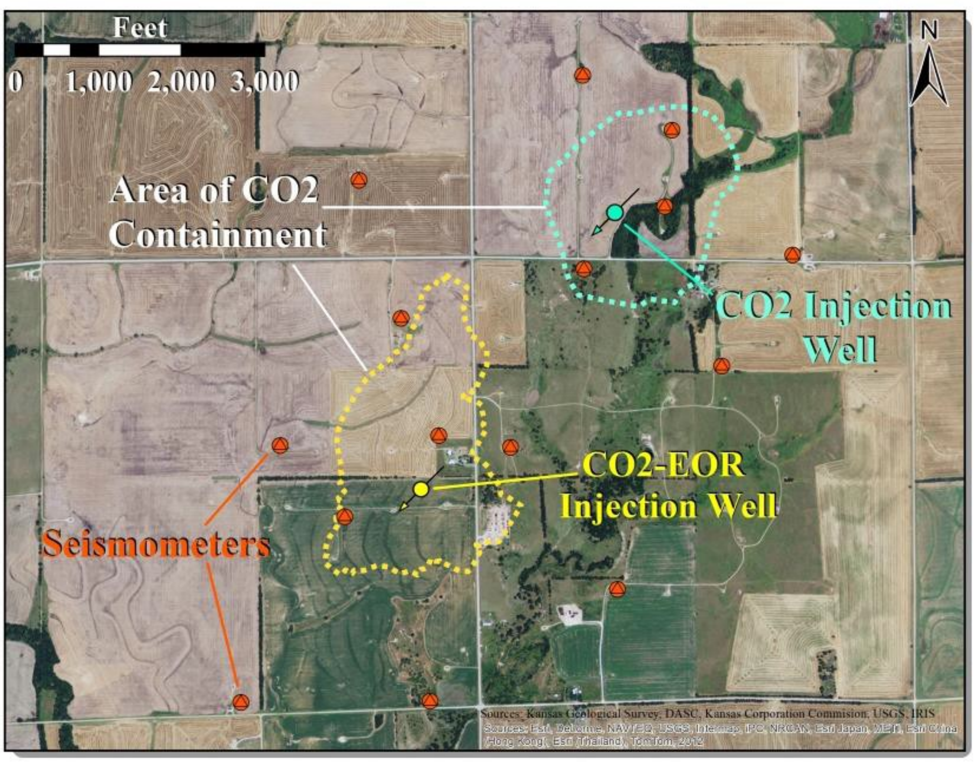


Figure 1 Seismometer network at the Wellington sequestration site.

The KSAP consists of a response action plan which is triggered if a *particular* seismic event results in exceedance of a threshold seismic action score (SAS). The SAS for an event is determined by adding the numeric value of the square of the magnitude of an earthquake to the sum of the individual weighted scores for each of the variables listed in Table 1.

$$\textbf{SAS} = \textbf{Magnitude}^2 + \textbf{Score}_{\textbf{felt}} + \textbf{Score}_{\textbf{structure}} + (2 \times \textbf{Score}_{\textbf{number}}{}^3) + \textbf{Score}_{\textbf{local recursion}}{}^3 + \textbf{Score}_{\textbf{recursion regional}} + \textbf{Score}_{\textbf{recursion time}}$$

The formula attempts to weigh two significant discriminators of seismic events:

Risk – The risk component is captured by the “felt” and “structure” variables. If an event is felt or if a usable structure is within 6 miles of the event, there is some risk of property damage which heightens the importance of the event. Conversely, if the event is not felt or there are no usable structures near, risk to property is minimal and lessens the immediate need for response

Clustering and timing – If seismic events are clustered over a short period in a fashion inconsistent with historical activity, it may be indicative of induced seismicity as opposed to a natural occurrence. While natural seismic events are always of interest, the focus of the plan is on induced seismicity, which is less understood. Thus, the formula places more emphasis on possible induced events. The formula variables for “number”, “local recursion”, “regional recursion”, and “recursion time” are used to address clustering and timing. The score for the number of earthquakes within a six-mile radius of a current earthquake event over the previous 30-day period is given twice the weight of the other factors. The rationale for the added weight is that the number of earthquakes gives an indication as to the degree of “clustering”.

Additionally, the recursion variables also attempt to discriminate between natural and induced seismic events. Recursion refers to the empirical observation that naturally occurring seismicity occurs in an exponential manner– for instance, every seismic event of magnitude 3 would be preceded by 10 magnitude 2 events and 100 magnitude 1 events. Recursion observations require the acquisition of a statistically significant number of earthquake events acquired over a relatively long term. A large number of events of similar size in a relatively short time period may be an indicator of induced (as opposed to natural) seismicity. Thus, natural recursion rates get a lower score than rates that are apparently not natural.

The local recursion (within 6 miles of an event) gives some idea as to activity within the location accuracy of most current regional networks, while the regional recursion looks at all data for Kansas recorded over the last 35 plus years on the KGS database from the USGS, the Oklahoma Geological Survey, and KGS. Both variables are important in ascertaining if activity is part of an overall regional, natural pattern of activity which would be of interest, and the more important localized activity which is the focus of this plan.

Lastly the "recursion time" variable places additional importance on multiple seismic events of similar size in a 24-hour period. Similar sized events are defined as those within magnitude 0.5 of each event (e.g. 2.0-2.5, 1.75-2.25, etc.). Again, multiple, similar magnitude events in a short time period may be an indicator of induced (as opposed to natural) seismicity.

Table 1 – Seismic Scores

	Risk Variables		Clustering Variables			
Score	**Felt[1]**	**Usable Structure[2,3]**	**Additional Number in Past 30 days[3]**	**Localized Natural[4] Recursion[3]**	**Regional Natural[4] Recursion (Kansas Database[5])**	**Additional # of Events[3] +/- 0.5 Magnitude Over +/- 24 hrs**
0	No	No	0	yes	yes	0
1	Yes	Yes	1	no	no	1
2			2			2
3			3			3
4			≥ 4			4

1 *Based on USGS "Did You Feel It" web site or credible reports*
2 *Based on aerial mapping or field observation*
3 *Within a 6 mile radius*
4 *Natural from the axiom, for every 100 magnitude 1 seismic event there will be 10 magnitude 2s and 1 magnitude 3 seismic event*
5 *Kansas database includes all earthquakes recorded in Kansas since the 1970s by KGS, USGS, or OGS*
http://www.kgs.ku.edu/Geophysics/Earthquakes/historic.html

Wellington Seismic Action Plan (WSAP)

The WSAP consist of a series of monitoring and analytical activities, along with remedial actions, that are to be implemented if certain seismic threshold levels are exceeded. These thresholds are based on a) the KSAP SAS score adopted by the KCC and KDHE, and b) the conventional seismic intensity magnitude (Richter Scale) utilized by the EPA for managing CO_2 injections at the ADM facility in Decatur, IL. The relationship between the Richter magnitude of an event and the accompanying damage to infrastructure is presented in Table 2. As can be noted from Table 2, seismic events of magnitude less than 4, rare not expected to cause any significant damage. The sensitivity of the Wellington seismometer network is presented in Figure 2. Seismic events above -0.5 can be detected at the site.

The response action to be implemented for various SAS and seismic intensity levels are presented in Table 3. The response will only be initiated if the epicenter of the seismic events is within a mile of the injection well, because the model results indicates an induced pressure of less than 15 psi beyond this distance. If either the SAS (column 1) or the Richter (column 2) threshold is exceeded, the corresponding response action specified in column 3 will be executed. For example, if the SAS score is less than 17 and the seismic event is of magnitude less than 3.0, then operations are to continue with proper documentation of the event for semi-annual reporting to EPA. On the other end, if the SAS score is greater than 17 or if the seismic magnitude exceeds 3.0 and is felt, then operations will pause and a series of investigation and/or remedial measures implemented before commencing operations on approval of the EPA Director. The Wellington project has voluntarily adopted these stringent measures to ensure safe operations at the CO_2 injection site.

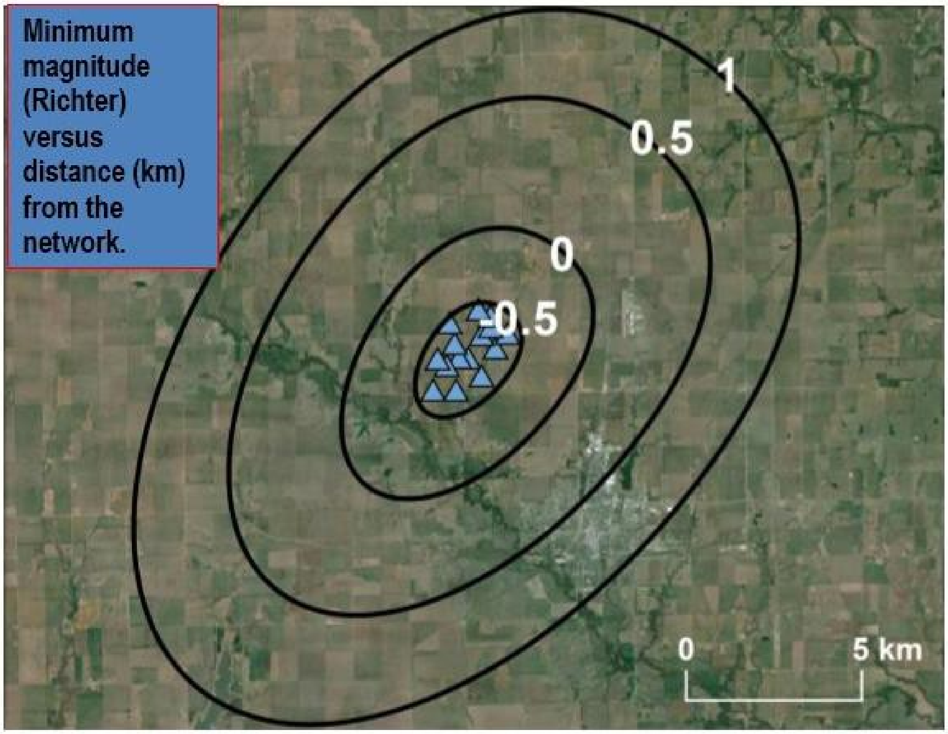


Figure 2 Coverage and sensitivity of the Wellington seismometer network. Explanation: Each isoline bounds the area within which the network can detect events for the magnitude specified by the isoline. Source: Geophysics Division, Kansas Geological Survey.

Table 2 Seismic Event and associated earthquake effect and global frequency of occurrence.

Richter Magnitudes	Description	Earthquake Effects	Frequency of Occurrence
Less than 2.0	Micro	Micro-earthquakes, not felt.	About 8,000 per day
2.0-2.9	Minor	Generally not felt, but recorded.	About 1,000 per day
3.0-3.9	Minor	Often felt, but rarely causes damage.	49,000 per year (est.)
4.0-4.9	Light	Noticeable shaking of indoor items, rattling noises. Significant damage unlikely.	6,200 per year (est.)
5.0-5.9	Moderate	Can cause major damage to poorly constructed buildings over small regions. At most slight damage to well-designed buildings.	800 per year
6.0-6.9	Strong	Can be destructive in areas up to about 160 kilometres (100 mi) across in populated areas.	120 per year
7.0-7.9	Major	Can cause serious damage over larger areas.	18 per year
8.0-8.9	Great	Can cause serious damage in areas several hundred miles across.	1 per year
9.0-9.9	Great	Devastating in areas several thousand miles across.	1 per 20 years
10.0+	Epic	Never recorded; see below for equivalent seismic energy yield.	Extremely rare (Unknown)

Table 3 WSAP threshold limits and corresponding response action plan. The response action specified in column 3 will be executed if either the KSAP Threshold Condition (column 1) <u>or</u> the Seismic Event Magnitude Threshold Condition (column 2) is exceeded.

KSAP Threshold Condition	Seismic Event Magnitude Threshold Condition[1]	Response Action Plan
<17	Seismic event > M2.0 and less than M3.0[2] and no felt report[3]	1. Continue site activities per permit conditions. 2. Document event for reporting to EPA in semi-annual reports.

< 17	Seismic event greater than M3.0[2] and no felt report[3]	3. Continue site activities per permit conditions. 4. Within 24 hours of the incident, notify EPA Director of the operating status of the facility. 5. Review seismic and operational data. 6. Report findings to the EPA Director and issue corrective action, if necessary.
Greater than or equal to 17	Seismic event greater than M3.0[2] and local observation or felt report [3]	1. Pause injection. 2. Within 24 hours of the incident, notify EPA Director of the operating status of the facility. 3. Monitor well pressure, temperature, and annulus pressure to verify well status and determine the cause and extent of any failure; identify and implement appropriate remedial actions (in consultation with the EPA Director) 4. Determine if leaks to ground water or surface water occurred. 5. If leak detected, a. Notify the EPA Director within 24 hours of the determination. b. Identify and implement appropriate remedial actions (in consultation with the EPA Director). 6. Review seismic and operational data.

1 Seismic event within a mile of the injection well.
2 Determined by local Wellington or USGS seismic monitoring stations or reported by the USGS National Earthquake Information Center using the national seismic network.
3 Confirmed by local reports of felt ground motion or reported on the USGS “Did You Feel It?” reporting system.
4 Within 30 days of change in operating status.

Emergency Remedial Response Plan

A summary of the response activities to be implemented if emergency events occur is documented in Table 4 below. These response actions are to be conducted as required by the Class VI rule to protect a USDW at an injection site. Explanation of each remedial response in the table is presented in Section 13 of the Class VI injection permit. All emergency events will result in the following actions:

1. Immediate shut down of the injection well,
2. Identification and characterization of the release,
3. Notification to the EPA UIC program director of the event within 24 hours,

4. Implementation of the appropriate Emergency Response Remedial Plan presented in the table below.

Table 4 Emergency Remedial Response Plan

Event	Response
Annulus Pressure Failure	Determine if failure is in tubing or borehole. Conduct necessary repairs and an annulus pressure test. Submit results to EPA Region VII Director and request permission to resume injection.
Mechanical Integrity Test Failure	If the annular pressure test fails (internal MIT) or an analysis of the temperature log indicates external MIT failure, appropriate steps will be taken to address the loss of mechanical or wellbore integrity and determine if the loss is due to the packer system or the tubing. RST logs may be run to determine well bore integrity. An annulus pressure test will be conducted along with a temperature log following remediation to confirm integrity.
Damage to Wellhead	In the event of damage to wellhead, the nearby area will be isolated. Safe distance and perimeter will be established using a hand-held air quality monitor. Steps may be taken to log well in order to detect CO_2 movement outside of casing. Appropriate steps will be implemented to repair the damage and conduct survey conducted to ensure wellhead leakage has ceased.
Well Blowout due to Equipment Failure	In the event of a well blow out, the well will be "killed" by pumping fluid with a heavy fluid such that the downhole pressure is greater than the formation pressure in order to stop the well from flowing.

Seismic Detection of CO_2 Escape	If any seismic monitoring technique detects escape of CO_2 into formations above the primary confining zone, then appropriate investigative and remedial will be immediately deployed. If the release is along the well bore and above the above the primary confining zone, then a suite of wireline logs will be used to identify the location of failure in the well, and repairs conducted. If the leakage is farther away, or through the primary confining zone, then a plan will be developed in consultation with the EPA to identify the extent of the problem and to develop remedial measures.

Appendix B. KGS's Opinion Regarding Likelihood of Inducing Earthquakes Due to CO_2 Injection in the Wellington Oilfield

This report was prepared to address concern expressed by the EPA about the potential for inducing earthquakes due to injection at the Wellington CO_2 sequestration site. There is heightened awareness and concern about induced seismicity following the observed cluster of (relatively large magnitude) earthquakes in southern Kansas commencing in summer of 2014 and continuing through early 2015. The location of the (greater than magnitude 2) earthquakes recorded between January 2014 and June 2015 is shown in Figure 1. Most of the earthquakes occurred in Harper and western Sumner counties west of Wellington, where there is a large number of new active Class II injection wells that are disposing large amounts of salt water produced from horizontal wells completed in the Mississippian Lime (Figure 1). As shown in Figure 2, there has been a sharp increase in the number of Class II wells in Harper and Sumner counties in the past three years, along with an exponential increase in the amount of brine volume disposed in the Arbuckle Group. In 2014 alone, the amount of brine disposed in Harper County increased to 104 million barrels (MMBL) from 39 MMBL in 2013. As can be inferred from Figure 3, prior to the recent increase in disposed volume, there were less than a handful of quakes (of magnitude greater than 2.0) occurring annually in Harper and Sumner counties. In 2014, as the disposed volume increased to 128 MMBL (primarily in Harper County), the number of earthquakes jumped to 108.

Due to the increase in earthquake activity, the Kansas Corporation Commission (KCC) has identified five areas of seismic concern in Harper and Sumner counties (Figure 4), and restricted the amount of brine that can be injected in these critical areas to 8,000 barrels of saltwater per day. Additionally, the KCC order limits the daily injected volume in all wells in Harper and Sumner County outside these five areas to 25,000 barrels per day. Each injection well in all of Harper and Sumner counties is also restricted to a maximum well head pressure of 250 psi. Since imposing these restrictions, the frequency and number of earthquakes have been observed to decrease (Figure 5). While not conclusive, the data compilation and analyses suggests a possible association between injecting high rates/volumes in Class II wells and seismic activity in Harper and western Sumner counties.

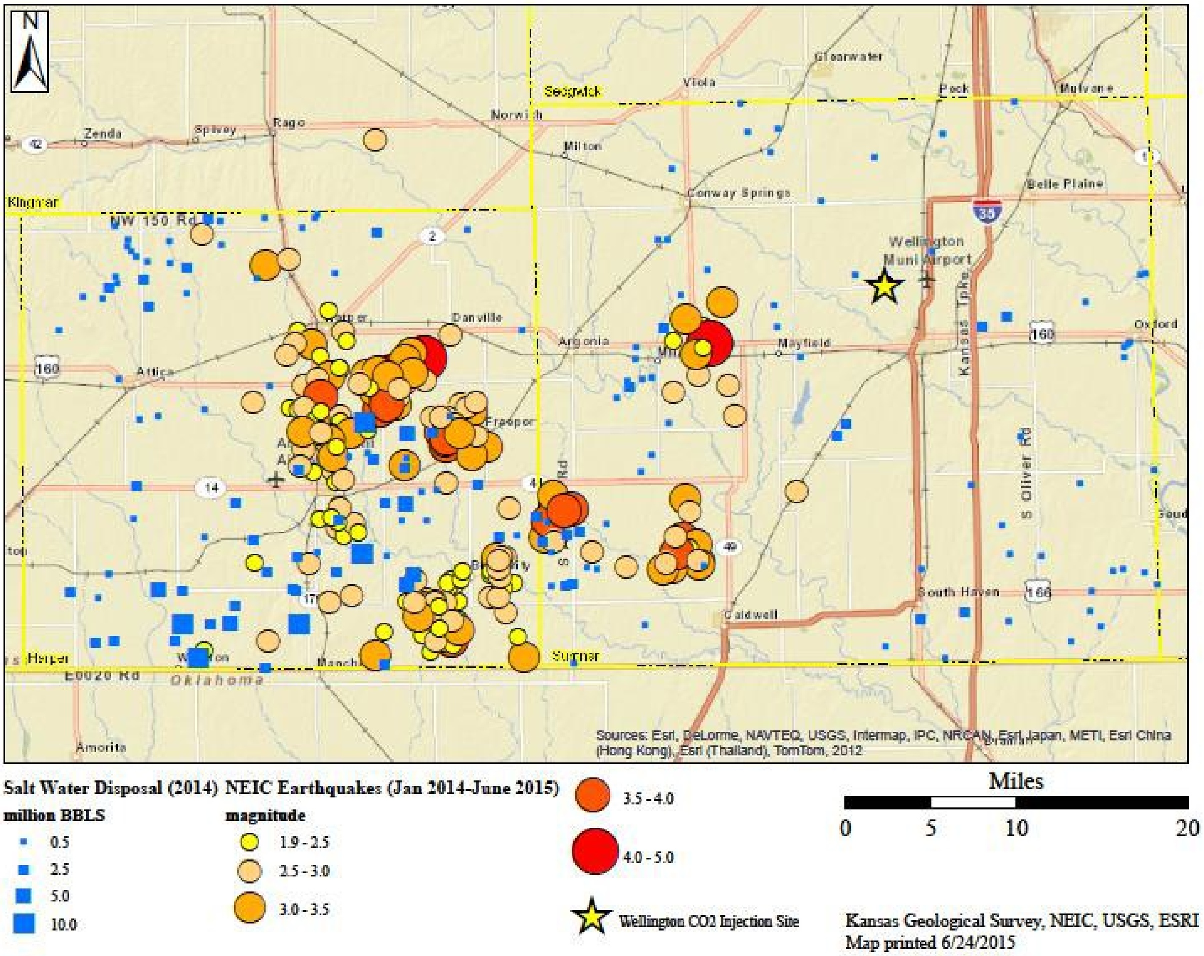


Figure 1 Location of earthquakes with magnitude 1.9 or higher in south-central Kansas from January 2014 to June 2015. Source: National Earthquake Information Center (earthquakes) and Kansas Corporation Commission (saltwater disposal well data).

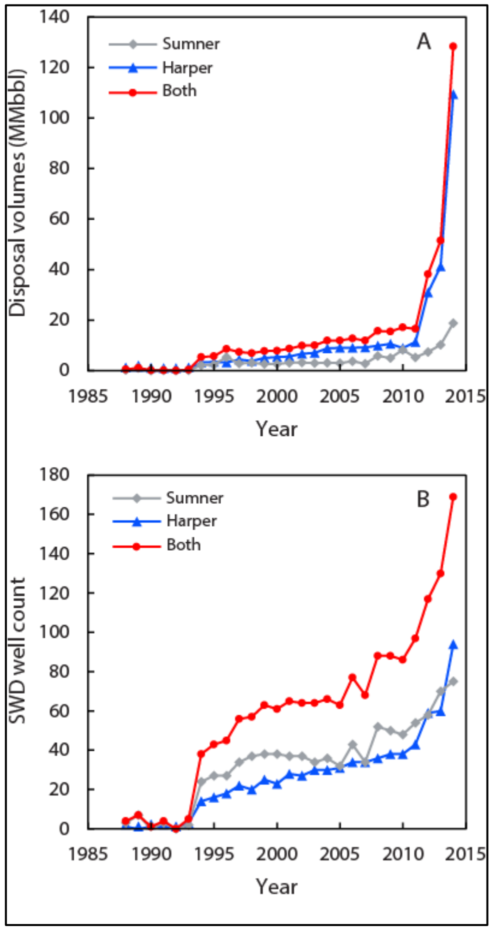


Figure 2 Location and amount of annual injection in Class II wells in Harper and Sumner counties. Figure from Tandis Bidgoli, Kansas Geological Survey. Data source: Kansas Corporation Commission.

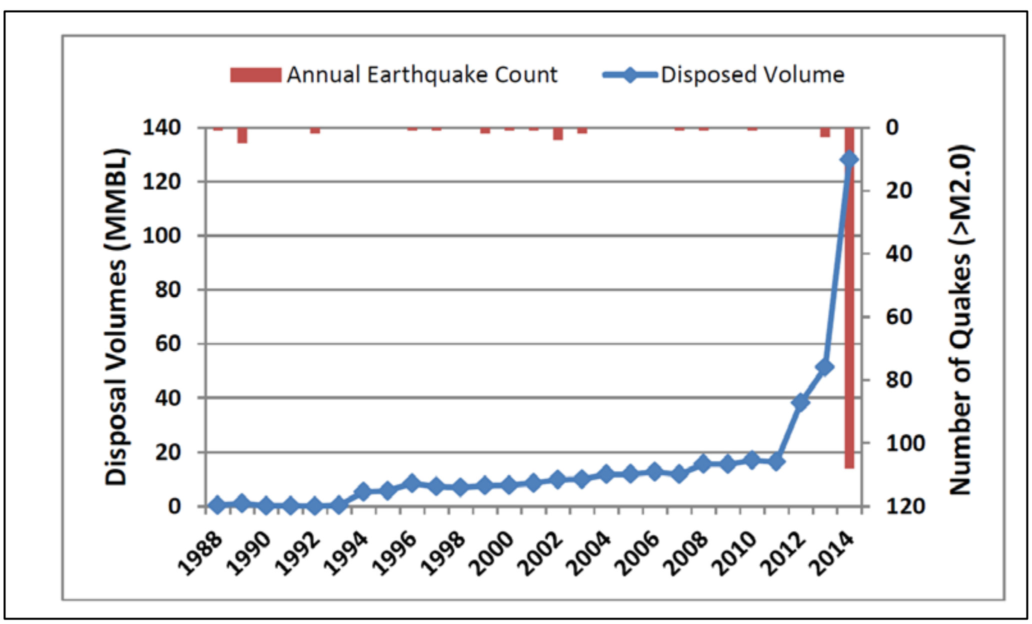


Figure 3 Relationship between disposal volume and seismicity in Harper and Sumner counties. Figure by Tiraz Birdie, Source: Kansas Corporation Commission and IRIS Earthquake Browser.

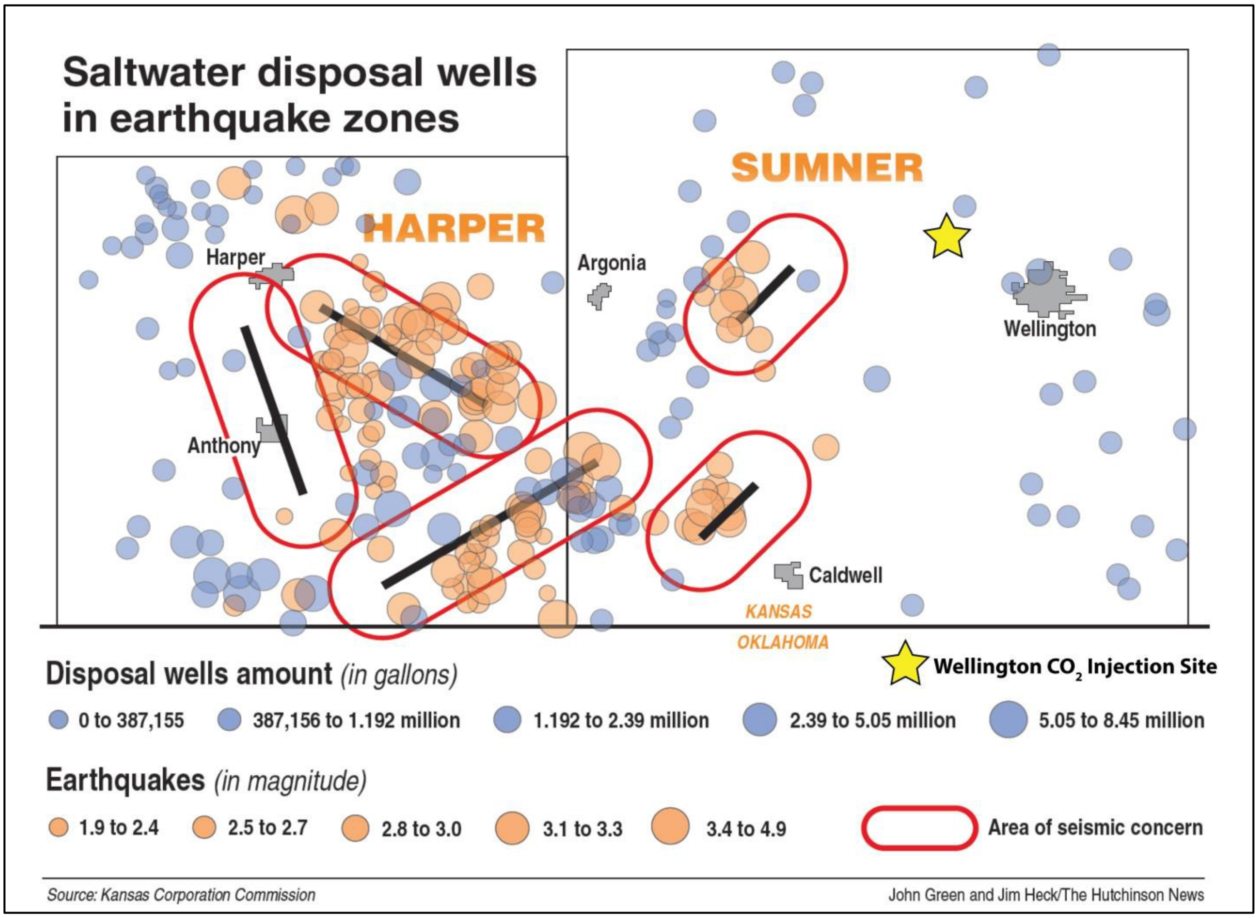


Figure 4 Areas of seismic concern in which the Kansas Corporate Commission has restricted disposal volumes in Class II wells.

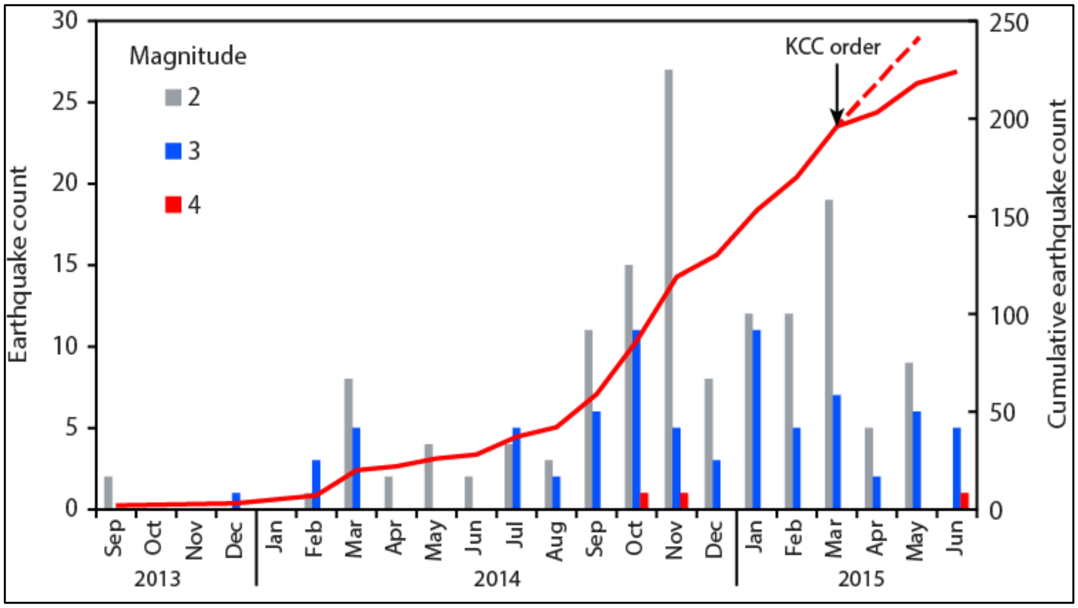


Figure 5 Earthquake count prior to and following Kansas Corporate Commission's order restricting disposal volumes in Class II wells. Figure from Tandis Bidgoli, Kansas Geological Survey. Data source: National Earthquake Information Center.

In contrast to the Class II wells active in proximity to the Mississippian Lime horizontal wells, liquid waste injection at industrial facilities occurs through Class I wells, which are regulated by the KDHE with a more stringent set of operating conditions. Specifically, the injection is to occur only under gravity (i.e., the surface pressure at the wellhead is less than zero). The locations of the Class I wells are shown in Figure 6, and these wells have been used to dispose fairly large quantities of waste for decades in the Arbuckle aquifer without inducing any earthquakes. For example, at the Occidental Chemicals site north of Wellington, between 50-200 million gallons (MG) of brine, which equates to approximately 1.6-6.4 million barrels (MMBL), has been injected annually in wells at the facility. Cumulatively, approximately 700 MG (22.2 MMBL) is injected at the plant annually through five active wells. This is substantially higher than the 0.42 MMBL of CO_2[1] that is to be injected at the Wellington site over a period of nine months. Additionally, the injection rate at the Occidental site is as high as 175 MG/yr (15,000 barrels per day) at wells no. 8, 9, and 10, which is significantly higher than the approximately 1,550 barrels per day that is to be injected at the Wellington sequestration site. The injection data at the Occidental site suggests that the Arbuckle aquifer is capable of absorbing large amount of fluids injected under gravity conditions without any detrimental seismic repercussions.

It is worth noting that the groundwater level in the Arbuckle at the proposed Wellington injection well (KGS 1-28) is about 593 ft below ground surface (Section 4.6.8.3 of permit application). Under this condition, an induced bottom hole pressure of approximately 290 psi could be accommodated (assuming a brine chloride concentration of approximately 100,000 mg/l) and still maintain gravity-fed conditions. Based on the model projections discussed in Section 5 of the Class VI injection well permit, injection of 150 tons/day of CO_2 at the Wellington site is projected to induce a bottom hole pore pressure increase of between 317 and 442 psi. This is not too much greater than the gravity-fed allowable Class I pressure of 290 psi derived above, and the maximum pressure difference of 152 psi (442 psi-290 psi) is less than KCC mandated limit of 250 psi surface pressure for brine disposal wells in areas of seismic concern in Harper and Sumner counties[2]. If the injection of CO_2 however is found to induce unacceptably high magnitude pre-shocks, then the injection rate can be restricted to a maximum induced pressure of 290 psi in order to operate under Class I conditions.

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[1] Assuming a maximum injection volume of 40,000 tons and a specific gravity of 0.8.

[2] Neglecting frictional forces.

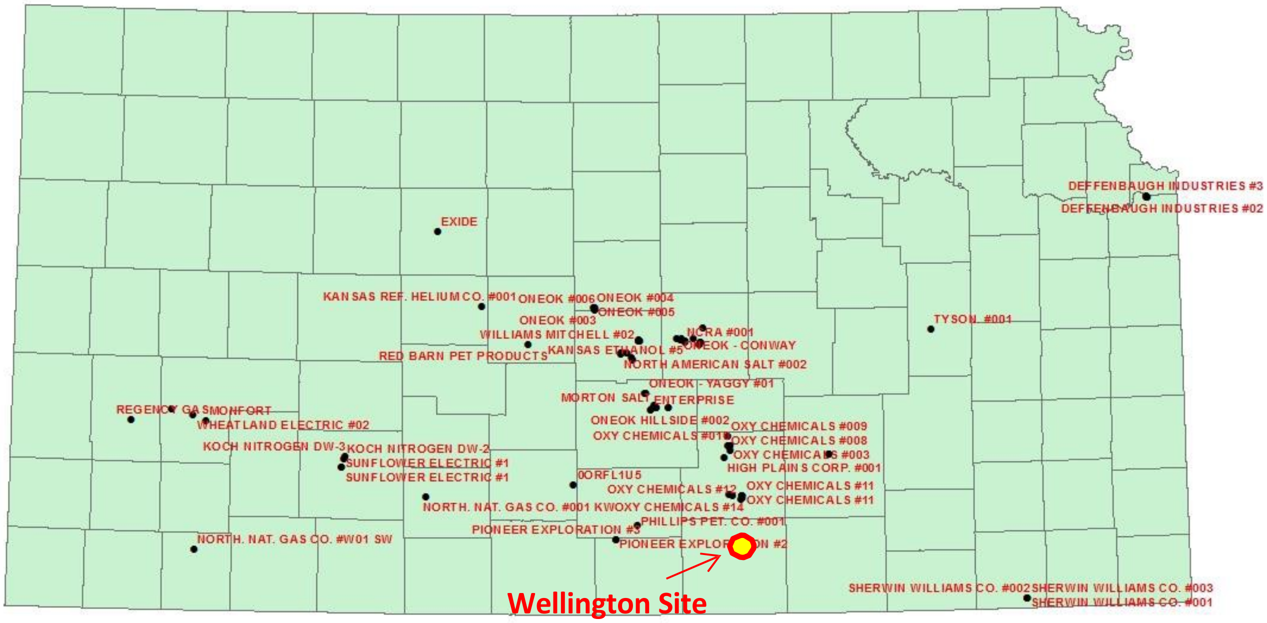

Figure 6 Location of Class I injection wells in Kansas with facility/owner names
Wellington site which can potentially detect pre-shocks.

If the magnitudes of the pre-shocks reach a critical threshold as defined in the Wellington Seismic Action Plan, it will trigger measures to conduct enhanced monitoring and potentially limit injection to safe levels. Additionally, as recommended by the EPA induced-seismicity committee (http://www.epa.gov/r5water/uic/ntwg/pdfs/induced-seismicity- 201502.pdf), the Wellington Testing and Monitoring Plan has been updated to include conducting periodic Hall Plot analysis, which can potentially identify faults intercepted by the (induced) pressure front. This will also trigger focused monitoring and additional risk analysis as documented in the Wellington Rapid Response Plan.

To summarize, it is KGS's opinion that the recent spate of seismic activity west of the Wellington CO_2 injection site is likely linked to high volumes of injection into the Arbuckle Group in recent years at Class II wells in Harper and western Sumner counties. The total volume to be injected at the pilot-scale CO_2 Wellington sequestration site is too low in comparison to induce damaging earthquakes in the area.

Wellington Oil Field Small Scale Carbon Capture and Storage Project Wellington, KS

Class VI Injection Well: Quality Assurance and Surveillance Plan

Prepared by: Kansas Geological Survey

Copy available for review from KGS.

Lawrence, KS

August 2015

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Appendix D. Brief review of the hydrogeology of the shallow unconfined aquifer in north-central Sumner County, Kansas

W. Lynn Watney, Jennifer Raney, Tiraz Birdie, John Victorine

Summary

The shallow geology at the Wellington CO_2 injection site is reflective of general conditions in Sumner County, KS, with alternating thin loess/clay deposits in the uplands and relatively thick sand/gravel deposits in the lowlands formed by modern drainage. The alluvial deposits in the lowlands favor local infiltration from precipitation and are likely to be hydraulically connected with perennial creeks in the area. On the other hand, the terrace deposits in the uplands are composed of the clayey/loess Bethany Series, which, with the underlying Wellington Shale provides impedance to infiltration, and due to the thick underlying salt (halite) beds, results in brackish water in shallow wells lying between the incised valleys in the area.

It is demonstrated through geologic cross sections and maps that the three shallow highly brackish monitoring wells at the Wellington site (SW-1, SW-2, and SW-3) are located in the uplands and that the two (relatively fresh) domestic wells (Shepherd and Blubaugh), that are to be sampled for water quality, are located in the incised valley along the perennial Slate Creek. This explains the cause for the sharply varying water quality at the Wellington site and the two domestic wells southwest of the site.

Background

The objective of this brief study conducted in July 2015 is to provide addition detail of the geohydrology in a small area (approximately 24 mi^2) surrounding the small -scale CO_2 injection site at Wellington Field, Sumner County, Kansas, referred to here as the Wellington Project. The motivation for the study is to understand and explain why groundwater at the Wellington site is highly saline (TDS > 10,000 ppm) in comparison to two domestic wells approximately 2 miles southwest of the Wellington site which have relatively better quality water. The goal is to compare water quality in context of the lithology and stratigraphy derived from a set of shallow domestic water wells examined in the study area. The information is presented as a series of maps and cross sections that are compared with information published on the geohydrology and Neogene and Quaternary stratigraphy. Conclusions are drawn from lithologic and stratigraphic synthesis and compared with findings in the literature and personal communications from experts in geohydrology and Neogene and Quaternary stratigraphy.

Study Area

Sumner County and the Wellington Project are located in the Wellington-McPherson Lowlands that is part of the Central Plains physiographic subprovince (Figure 1, Mandel, 2008). The region is often mantled by up to 3-5 m of loess deposits, which overlie thick deposits of Pleistocene or Pliocene alluvium preserved as upland terrace deposits. In Sumner County these terrace deposits can be up upwards of 40 ft (12 m) thick as exposed along the Chikaskia River located approximately 12 mi (20 km) southwest of the Wellington project site (Figure 2, locality #12 in Fig. 2, Mandel, 2008). A cross section through the Chikaskia River of Mandel (2008) is presented in Figure 3 which shows the floodplain of the modern river labeled T-0 and two older terraces, T-1 and T-2, containing successions of alluvial deposits and paleosols identified by their A horizons. Terrace T-2 dominates the valley floor (Mandel, 2008) and appears to be juxtaposed with the modern river deposits. A 8 ft (2.5 m) thick coarse-grained deposit lies adjacent to the river alluvium. Terrace T-1 also cross cuts the older, higher T-2 terrace that are noted stacked paleosols and alluvial strata dominantly by fine-grained sediment. A mid-level T-2 paleosol is dated at 3100 yrs. BP and T2 ranges from 1760 to 10,800 yrs. BP (Mandel, 2008).

The Sumner County General Soil Map (Figure 4, USDA, 1978) illustrates the distribution of the soil associations that are closely related to the terrace deposits on which the soils are formed (Mandell, 2015, personal communication). The Chikaskia River site of Mandell (2008) located southwest of the Wellington Project, is highlighted on the soil map which shows a low terrace (Pleistocene age as identified by Mandell) lying juxtaposed to the flood plain association of silt loam and silty clay loam along the river. These deposits are adjacent to a higher sandy loam (older Pleistocene) that is deposited on the upland.

At the Wellington project mapped area, Slate Creek located in the southwestern portion of the map has the same lower flood plain and lower terrace association bordered by a silty loam to silty clay loam on the upland (Figure 4). The latter deposit mantles the remaining mapped area according to USDA and is named the Bethany-Kirkland-Tabler association (USDA, 1978). This association is now referred to as the Bethany series, described as:

The Bethany series consists of deep soils that formed in loess or alluvium of Pleistocene age over shale of Permian age. These soils are on summits and backslopes of paleoterraces in the Central Rolling Red Prairies (MLRA-80A). Slopes are 0 to 5 percent. Mean annual air temperature is about 15 degrees C (59 degrees F), and mean annual precipitation is about 865 mm (34 in) (https://soilseries.sc.egov.usda.gov/OSD_Docs/B/BETHANY.html)

GEOGRAPHIC SETTING:

Parent material: loess or alluvium of Pleistocene age over shale of Permian age
Landscape: alluvial plain

Landform: summits and backslopes of paleoterraces
Slopes: 0 to 5 percent

Soil moisture regime: Udic-Ustic.

Mean Annual Precipitation: 787 to 940 mm (31 to 37 in)

Mean Annual Air Temperature: 13.9 to 16.1 degrees C (57 to 61 degrees F)
Elevation ranges from 290 to 420 meters (950 to 1380 feet)

Frost free days range from 181 to 240
Thornthwaite Annual P-E indices: 44 to 64

The Bethany series is a silt loam, to silt clay loam that varies from reddish brown to dark brown to dark grayish brown. It is generally clay-rich and plastic/sticky when wet. This matches with the “gumbo” clay encountered at the Wellington shallow well SW-1 (KGS, 2015) which prevented the standard rotary bit from penetrating the clay rich layer at the bottom of this series.

The geologic map of Walters (1961) (Figure 5) identifies the same Pleistocene lower terrace deposits along the Chikaskia River and Slate Creek as shown in the soil map of USDA. The Wisconsin-age terrace deposit, (Qw, in close-up geologic map, Figure 6) present along Slate Creek is described as chiefly arkosic sand and gravel with lenses of silt and clay. As noted by Walters (1961) "*yield large quantities of water to wells*". Note that Qw is mapped to extend northward on the N-S oriented tributary to Slate Creek, called Spring Creek, located near the western side of the newly mapped area above the label Qw. Northward, Spring Creek is mapped as residing on Wellington Shale bedrock (Pw). Downstream from Qw along Slate Creek is another terrace, Qckl. It is noted by Walters (1961) as "*yielding moderate water supplies to wells locally*". This terrace continues southeastward following Slate Creek.

A major portion of the newly mapped area including the Wellington Project site is mapped by Walters (1961) as Qc, Illinoisan to Recent silt and clay contains minor amounts of sand and gravel described as "*not yield appreciable quantities of water to wells"*. This is identified in USDA soil map as Bethany-Kirkland-Tabler association (USDA, 1978).

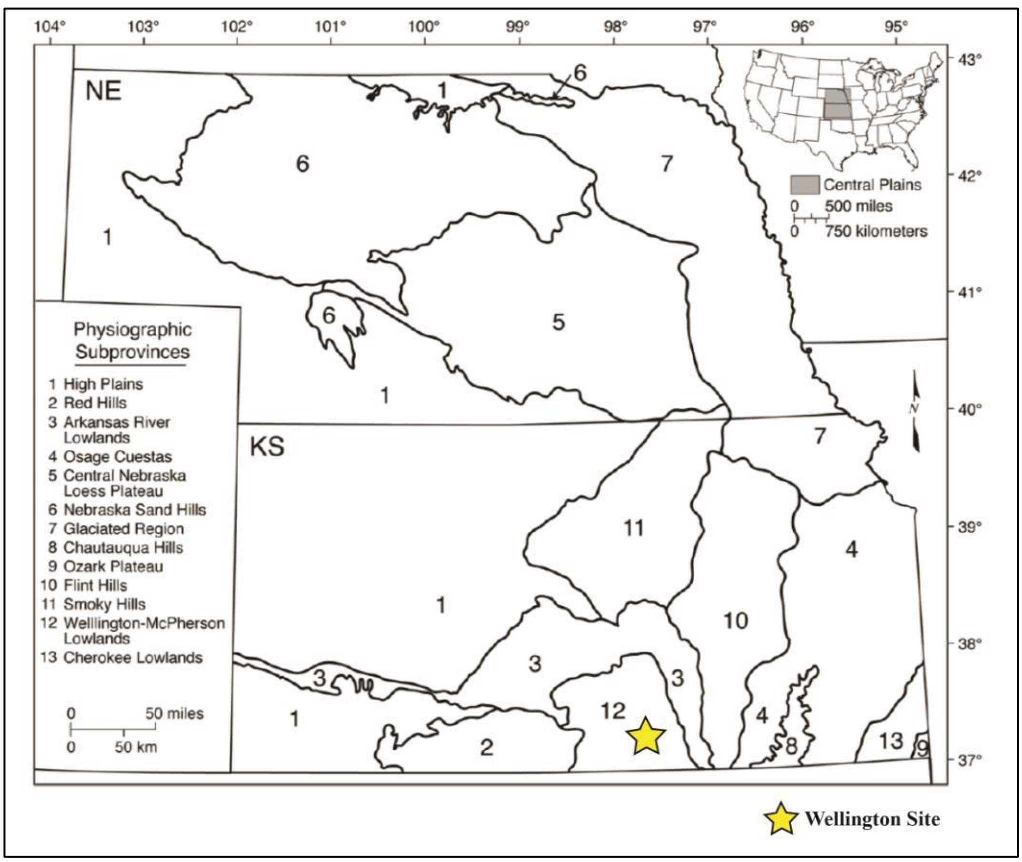


Figure 1 Map of physiographic sub provinces of the Central Plains of Kansas and Nebraska (from Mandel, 2008, after Wilson, 1978). Sumner County, Kansas is located in subprovince 12 – the Wellington-McPherson Lowlands.

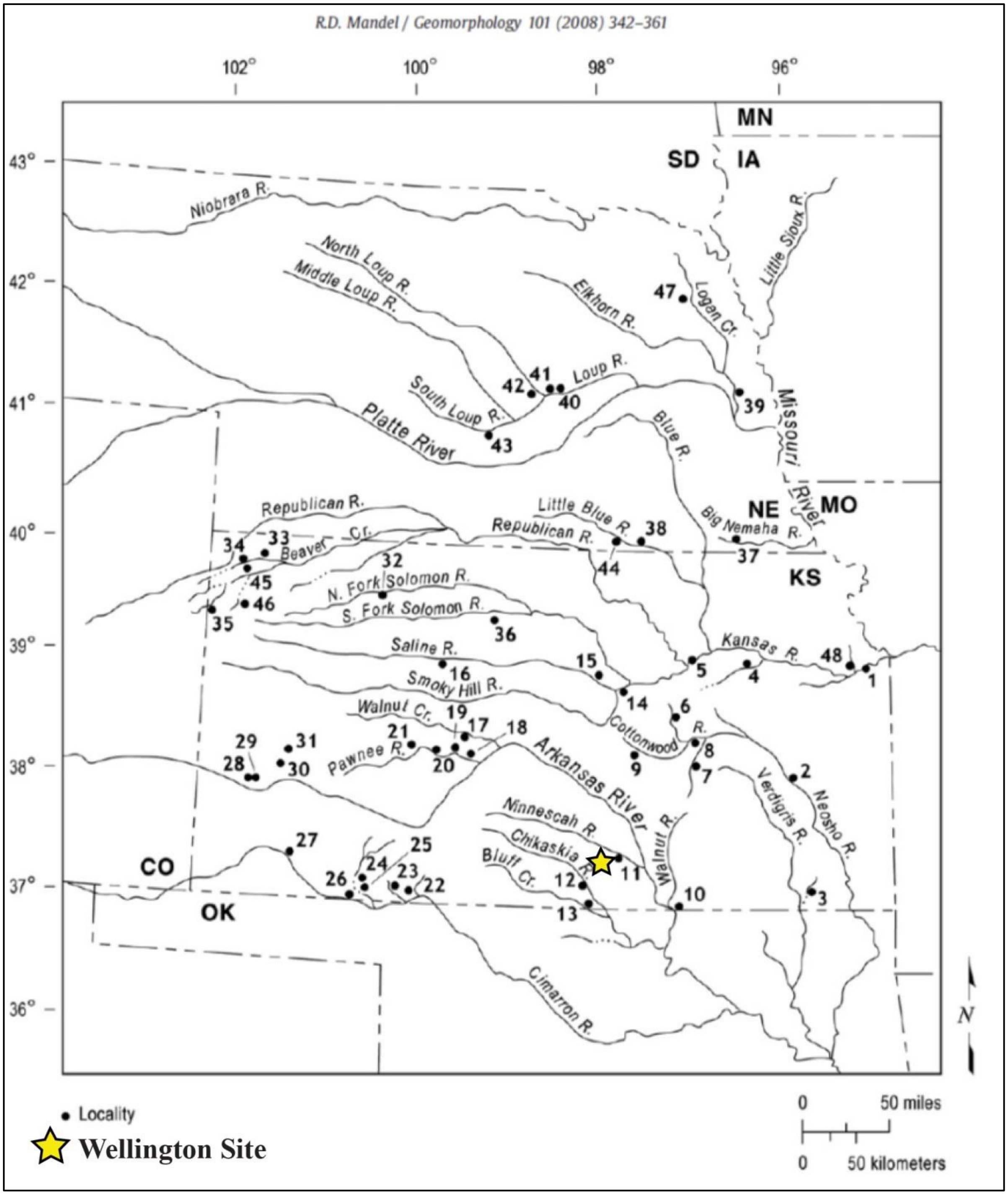


Figure 2 Map of Central Plains with locality #12 that is focused on in this report located on the Chikaskia River in Sumner County, Kansas south of the Wellington Project Site (Mandel, 2008).

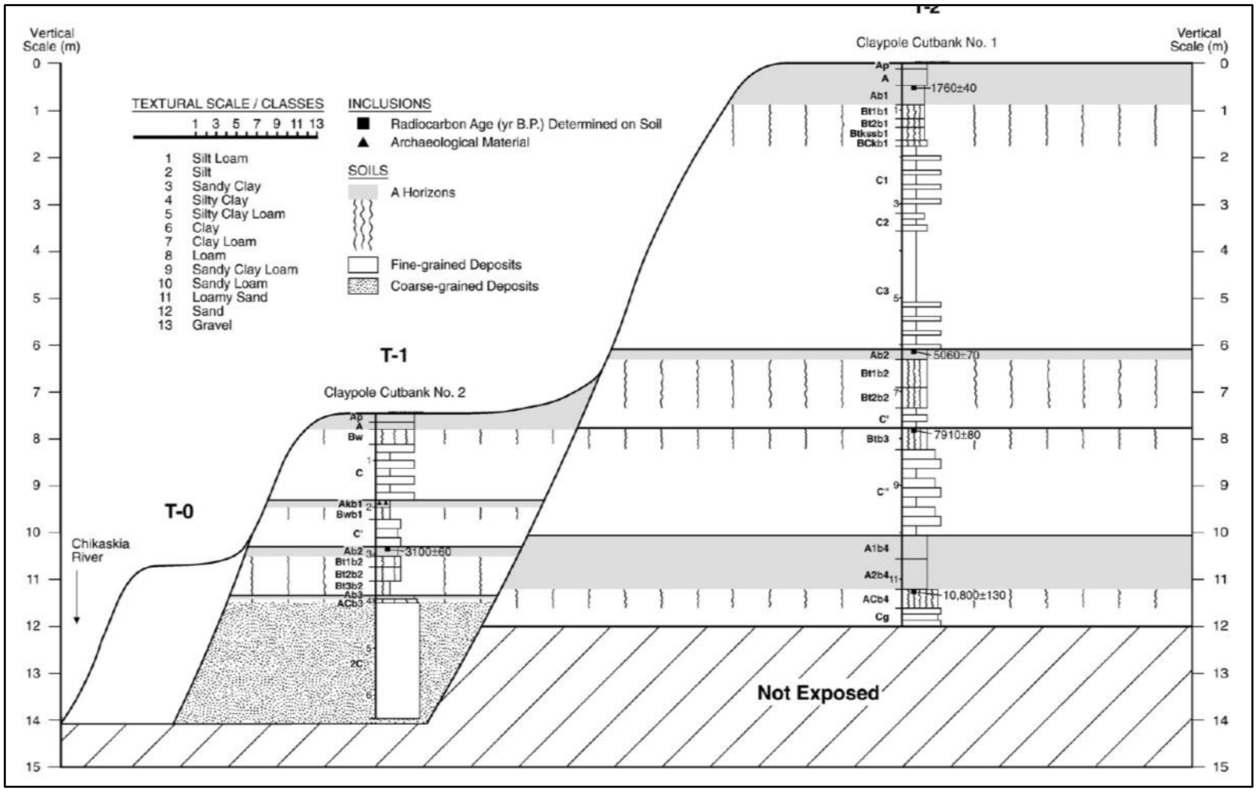


Figure 3 Cross section of valley floor of the Chikaskia River at locality #12 (from Mandell, 2008) located ~12 mi southwest of the Wellington Project site located in the map in Figures 2 and 4.

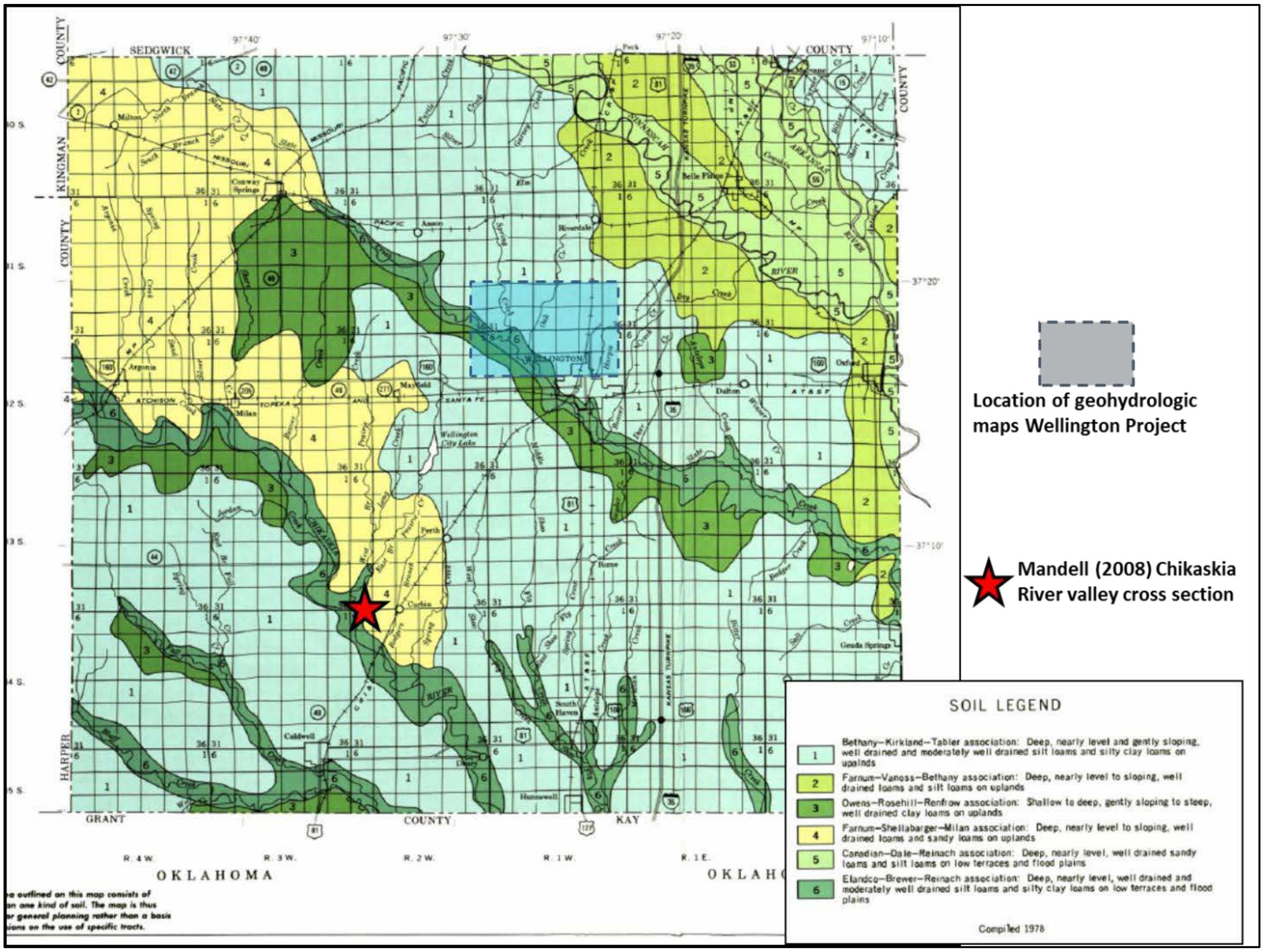


Figure 4 General soil map of Sumner County, Kansas (USDA, 1978). Star symbol locates site #12 along the Chikaskia River of Mandell (2008).

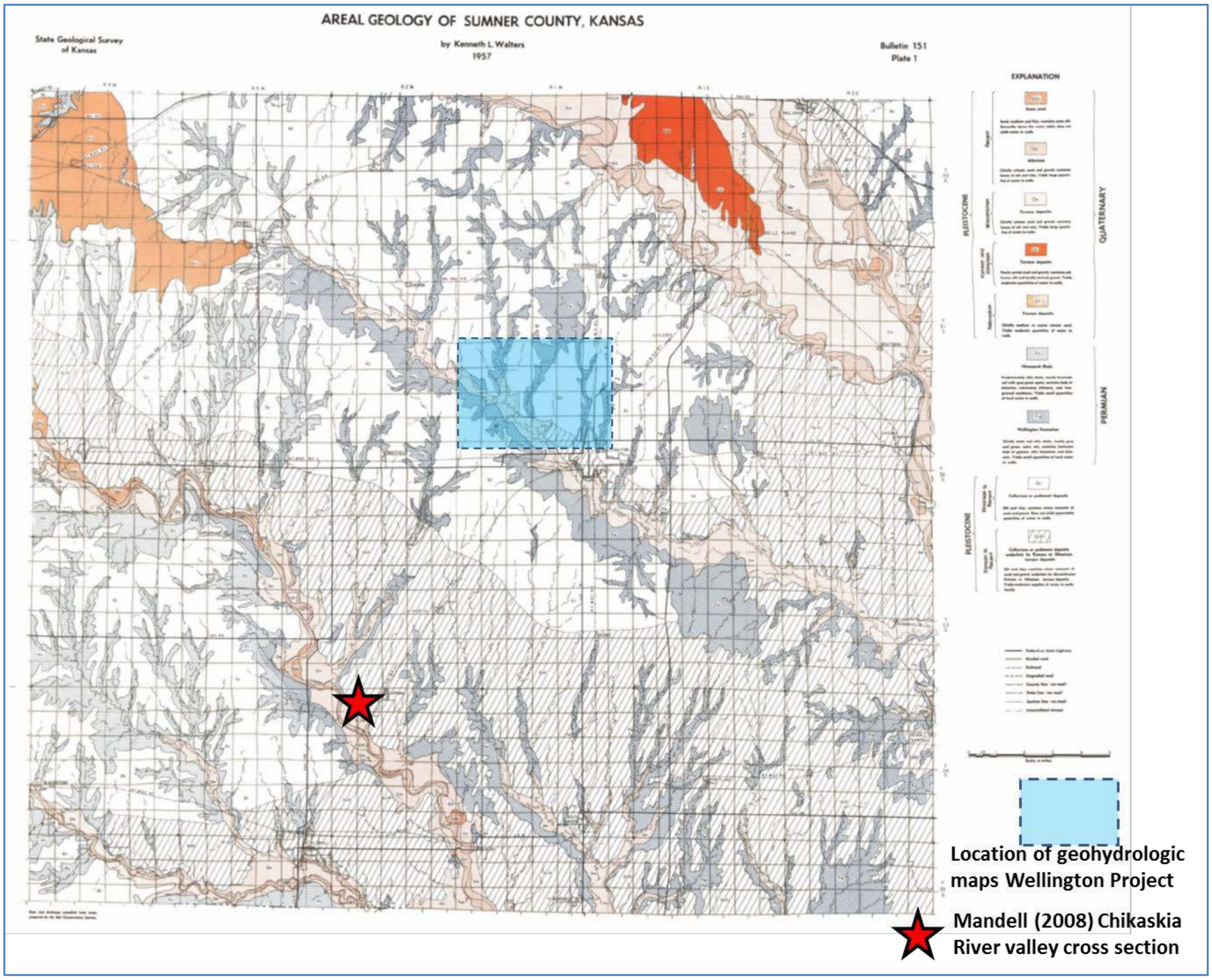
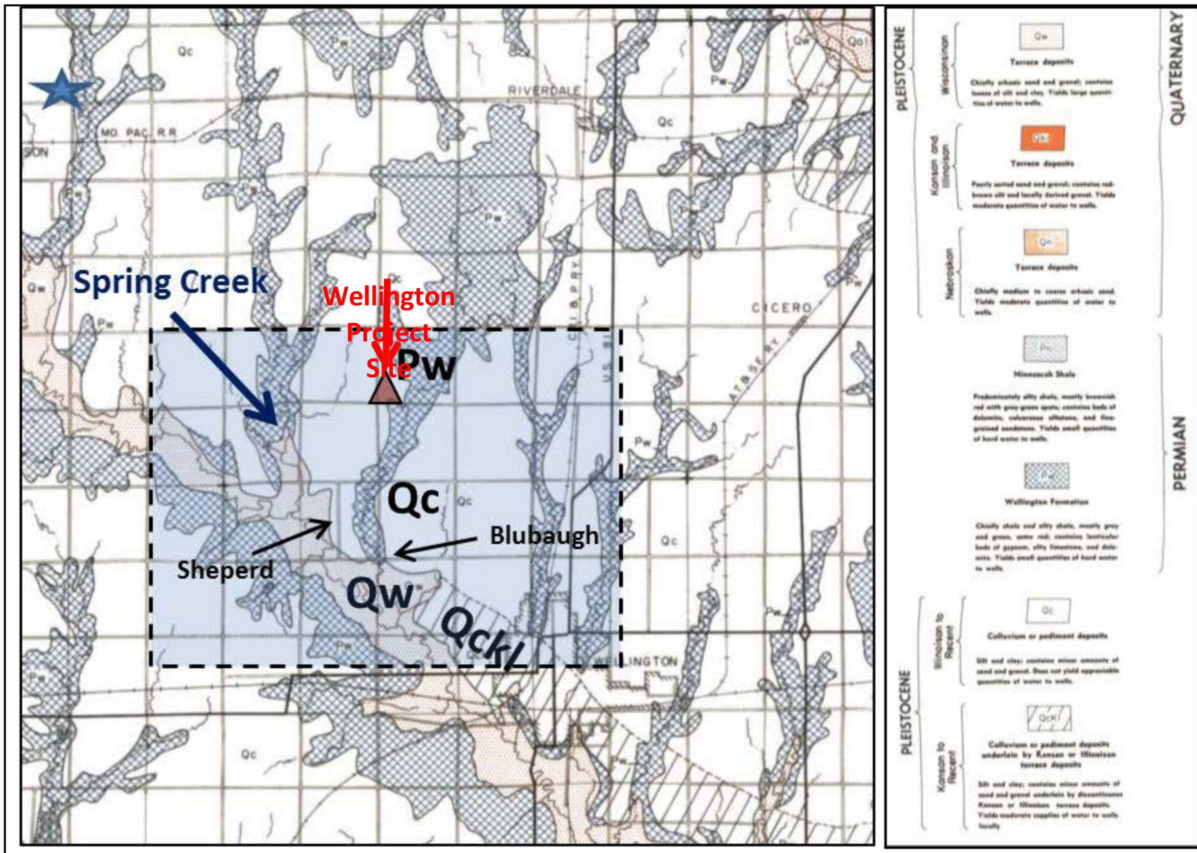


Figure 5 Areal geology of Sumner County, Kansas (Walters, 1961). Locality #12 of Mandell (2008) located by a red star in reference to the new mapped area (light blue highlighted) surrounding the Wellington Project to the northwest.



Qw → Wisconsin age terrace, chiefly arkosic sand and gravel, contains lenses of silt and clay. Yields large quantities of water to wells.
Qckl → Kansan or Illionoisan terrace deposit yields moderate supplies of water to wells locally
Qc → Illinoisan to Recent silt and clay contains minor amounts of sand and gravel. Does not yield appreciable quantities of water to wells. Identified in USDA soil map as Bethany-Kirkland-Tabler association (USDA, 1978).
Pw → Wellington Shale

Figure 6 Excerpt of map from areal geology of Sumner County, Kansas (created by Walters in 1957 and published in report of Walters, 1961). Area mapped for geohydrology surrounding the Wellington site outlines with dashed black line. Red triangle denotes the location of the Wellington site. Domestic wells to be sampled are labeled with arrow pointing to the map location. Symbols identify key surficial deposits pertinent to the discussion of the geohydrology.

The mapped area for the geohydrologic study around Wellington Project is shown in the areal photograph in Figure 7. Spring and Slate creeks and the Wellington Project site are identified for reference in this figure. In addition, the two domestic wells to be sampled, Shepherd and Blubaugh, are labeled on the map, located about 2 miles south of the Wellington Project site. The Shepherd well is located in the Qw terrace that lies alongside the modern alluvium of Slate Creek (Walters, 1961). The Blubaugh well is at the juncture of Qw and Qc terraces as mapped by Walters (Figure 6).

The yields at the time of completion of the two operating domestic wells to be sampled, Shepherd and Blubaugh, were 10 and 15 gpm, respectively (Figures 8 and 9). Both wells are still being used today for domestic purposes using local chemical treatment. The Shepherd well contains 10 ft of sand overlying another 8 ft of sand and shale that extends to the base of the soft sediment. Hard shale was encountered at 38 ft, believed to be the top of the Lower Permian Wellington Shale. The WWC-5 report on the Blubaugh shows only two feet of sand that was encountered at the base of a 17 ft thick bed of top soil and clay (**Figure 9**). The underlying blue shale, extending to a depth of 60 ft, is identified as the Wellington Shale in the present investigation. The lithologic column at the two domestic well sites is shown in figures 10 and 11.

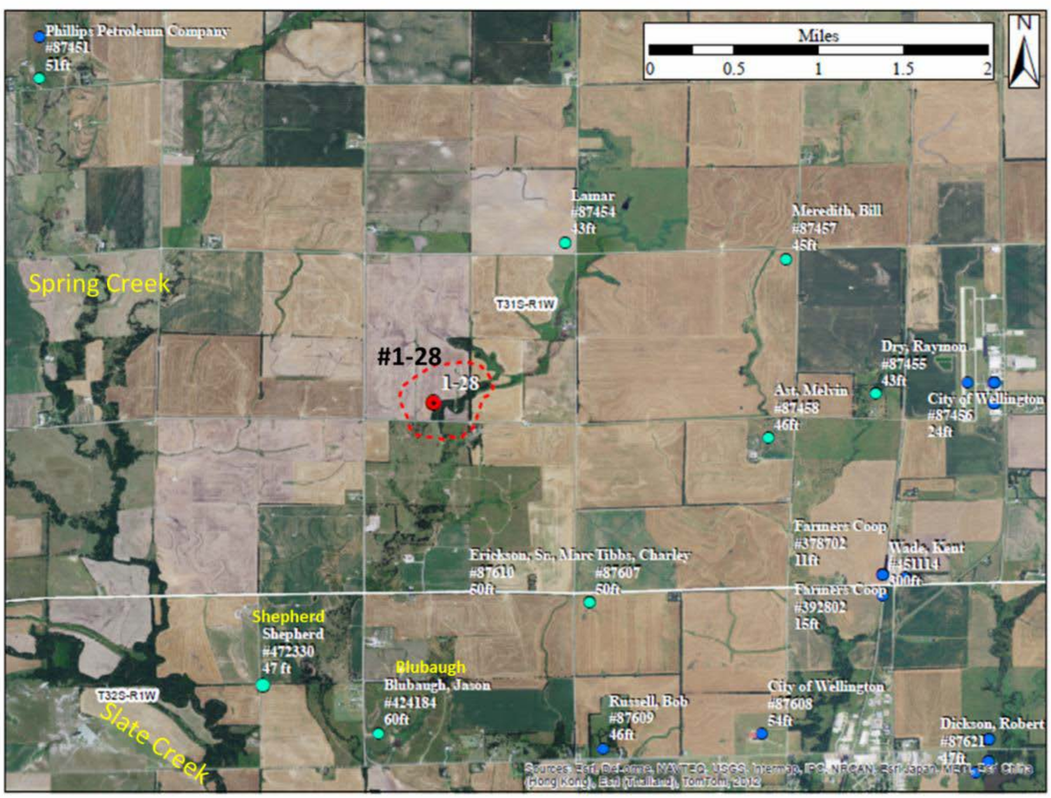
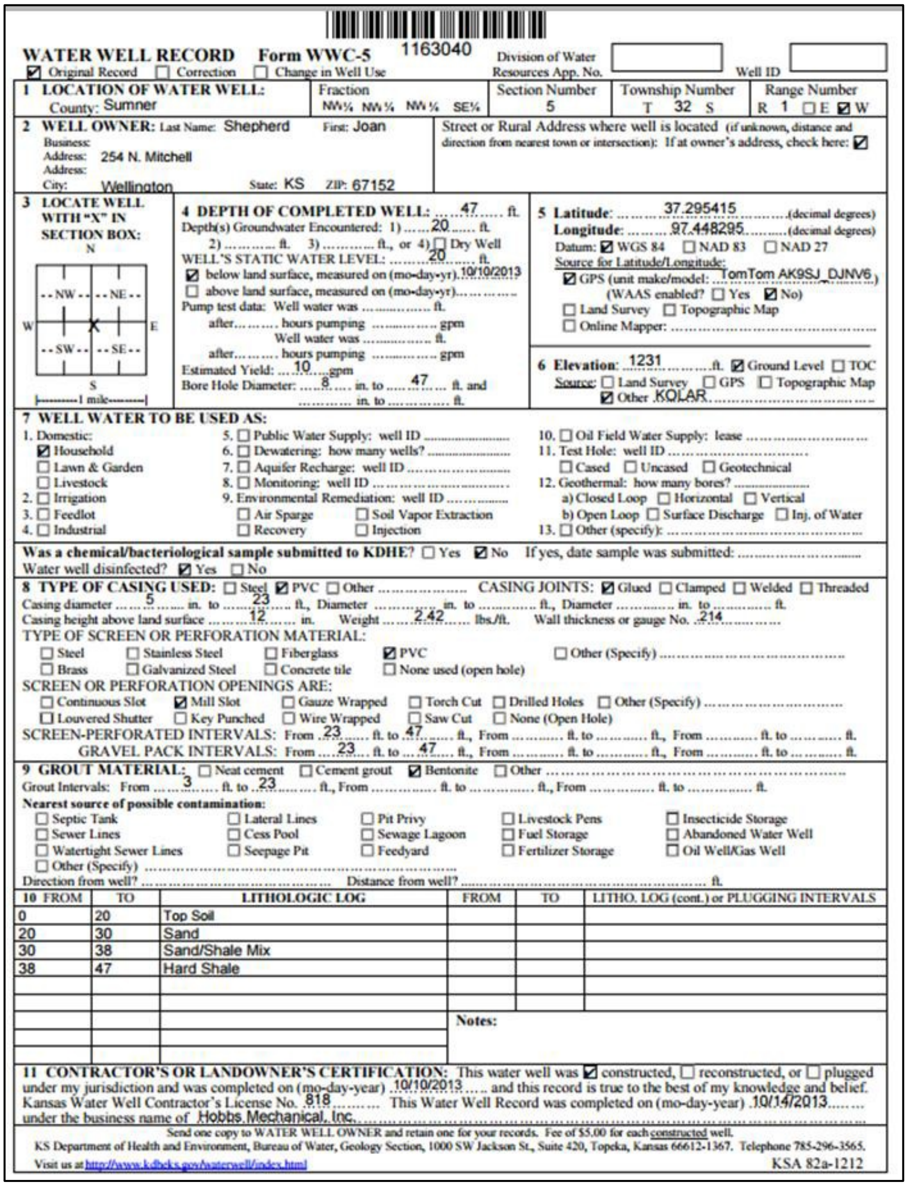


Figure 7 Area of investigation for the geohydrologic study in the vicinity of the Wellington Project. The Area of Review (AoR) for the Arbuckle CO_2 small scale injection is outlined in the dashed red line. Several shallow water wells are included in this map for reference including the Shepherd and Blubaugh domestic wells highlighted with yellow text located approximately 2 miles south of the Wellington project. These two wells will be sampled for water quality.



WATER WELL RECORD Form WWC-5 1163040

Division of Water Resources App. No. ______ Well ID ______

☑ Original Record ☐ Correction ☐ Change in Well Use

1 LOCATION OF WATER WELL: County: Sumner | Fraction: NW¼ NW¼ NW¼ SE¼ | Section Number: 5 | Township Number: T 32 S | Range Number: R 1 ☐ E ☑ W

2 WELL OWNER: Last Name: Shepherd First: Joan
Business:
Address: 254 N. Mitchell
Address:
City: Wellington State: KS ZIP: 67152

Street or Rural Address where well is located (if unknown, distance and direction from nearest town or intersection): If at owner's address, check here: ☑

3 LOCATE WELL WITH "X" IN SECTION BOX:
N
NW NE
W X E
SW SE
S
1 mile

4 DEPTH OF COMPLETED WELL: 47 ft.
Depth(s) Groundwater Encountered: 1) 20 ft. 2) ...... ft. 3) ...... ft., or 4) ☐ Dry Well
WELL'S STATIC WATER LEVEL: 20 ft.
☑ below land surface, measured on (mo-day-yr) 10/10/2013
☐ above land surface, measured on (mo-day-yr) ......
Pump test data: Well water was ...... ft. after ...... hours pumping ...... gpm
Well water was ...... ft. after ...... hours pumping ...... gpm
Estimated Yield: 10 gpm
Bore Hole Diameter: 8 in. to 47 ft. and ...... in. to ...... ft.

5 Latitude: 37.295415 (decimal degrees)
Longitude: 97.448295 (decimal degrees)
Datum: ☑ WGS 84 ☐ NAD 83 ☐ NAD 27
Source for Latitude/Longitude:
☑ GPS (unit make/model: TomTom AK9SJ_DJNV6) (WAAS enabled? ☐ Yes ☑ No)
☐ Land Survey ☐ Topographic Map
☐ Online Mapper: ......

6 Elevation: 1231 ft. ☑ Ground Level ☐ TOC
Source: ☐ Land Survey ☐ GPS ☐ Topographic Map ☑ Other KOLAR

7 WELL WATER TO BE USED AS:
1. Domestic: ☑ Household ☐ Lawn & Garden ☐ Livestock
2. ☐ Irrigation
3. ☐ Feedlot
4. ☐ Industrial
5. ☐ Public Water Supply: well ID ......
6. ☐ Dewatering: how many wells? ......
7. ☐ Aquifer Recharge: well ID ......
8. ☐ Monitoring: well ID ......
9. Environmental Remediation: well ID ...... ☐ Air Sparge ☐ Soil Vapor Extraction ☐ Recovery ☐ Injection
10. ☐ Oil Field Water Supply: lease ......
11. Test Hole: well ID ...... ☐ Cased ☐ Uncased ☐ Geotechnical
12. Geothermal: how many bores? ...... a) Closed Loop ☐ Horizontal ☐ Vertical b) Open Loop ☐ Surface Discharge ☐ Inj. of Water
13. ☐ Other (specify): ......

Was a chemical/bacteriological sample submitted to KDHE? ☐ Yes ☑ No If yes, date sample was submitted: ......
Water well disinfected? ☑ Yes ☐ No

8 TYPE OF CASING USED: ☐ Steel ☑ PVC ☐ Other ...... CASING JOINTS: ☑ Glued ☐ Clamped ☐ Welded ☐ Threaded
Casing diameter 5 in. to 23 ft., Diameter ...... in. to ...... ft., Diameter ...... in. to ...... ft.
Casing height above land surface 12 in. Weight 2.42 lbs./ft. Wall thickness or gauge No. .214
TYPE OF SCREEN OR PERFORATION MATERIAL:
☐ Steel ☐ Stainless Steel ☐ Fiberglass ☑ PVC ☐ Other (Specify) ......
☐ Brass ☐ Galvanized Steel ☐ Concrete tile ☐ None used (open hole)
SCREEN OR PERFORATION OPENINGS ARE:
☐ Continuous Slot ☑ Mill Slot ☐ Gauze Wrapped ☐ Torch Cut ☐ Drilled Holes ☐ Other (Specify) ......
☐ Louvered Shutter ☐ Key Punched ☐ Wire Wrapped ☐ Saw Cut ☐ None (Open Hole)
SCREEN-PERFORATED INTERVALS: From 23 ft. to 47 ft., From ...... ft. to ...... ft., From ...... ft. to ...... ft.
GRAVEL PACK INTERVALS: From 23 ft. to 47 ft., From ...... ft. to ...... ft., From ...... ft. to ...... ft.

9 GROUT MATERIAL: ☐ Neat cement ☐ Cement grout ☑ Bentonite ☐ Other ......
Grout Intervals: From 3 ft. to 23 ft., From ...... ft. to ...... ft., From ...... ft. to ...... ft.
Nearest source of possible contamination:
☐ Septic Tank ☐ Lateral Lines ☐ Pit Privy ☐ Livestock Pens ☐ Insecticide Storage
☐ Sewer Lines ☐ Cess Pool ☐ Sewage Lagoon ☐ Fuel Storage ☐ Abandoned Water Well
☐ Watertight Sewer Lines ☐ Seepage Pit ☐ Feedyard ☐ Fertilizer Storage ☐ Oil Well/Gas Well
☐ Other (Specify) ......
Direction from well? ...... Distance from well? ...... ft.

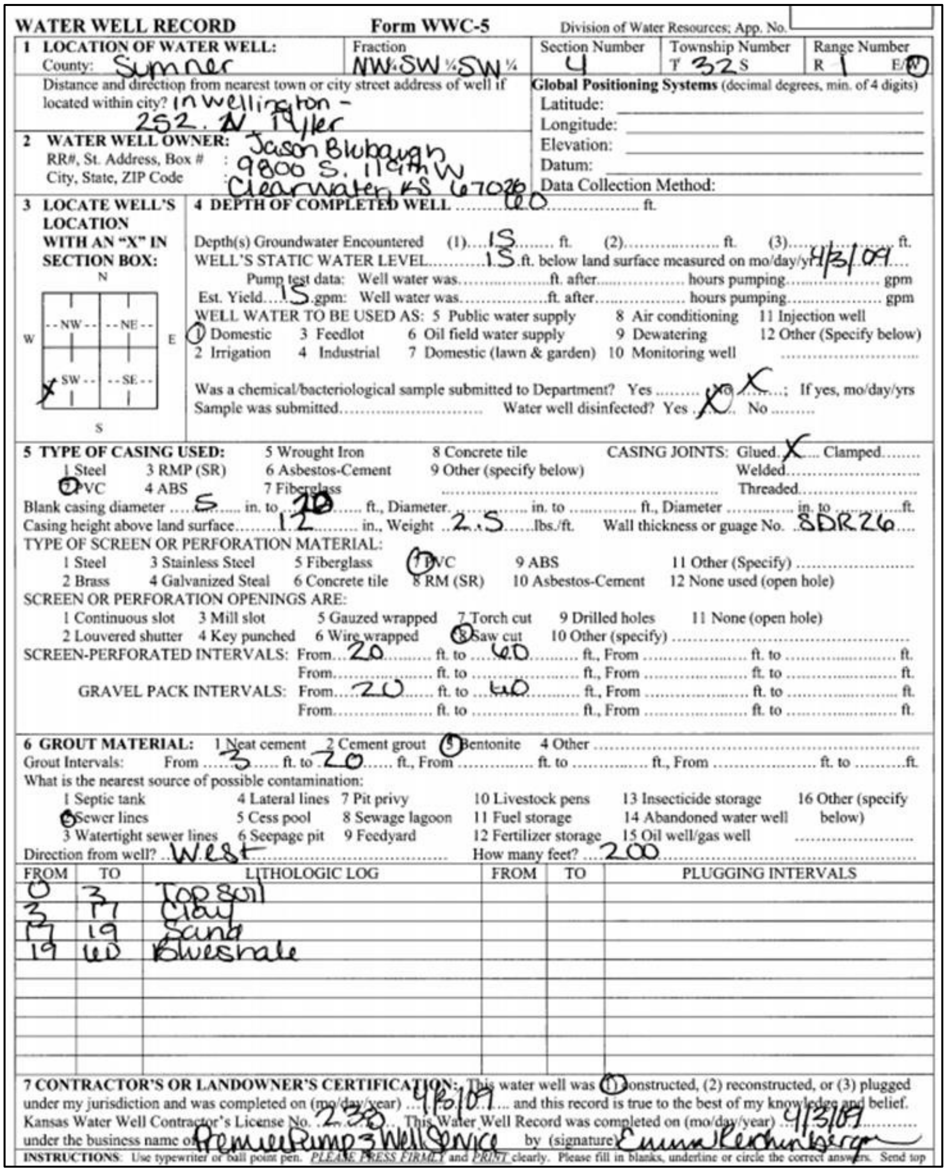
10 FROM	TO	LITHOLOGIC LOG	FROM	TO	LITHO. LOG (cont.) or PLUGGING INTERVALS
0	20	Top Soil			
20	30	Sand			
30	38	Sand/Shale Mix			
38	47	Hard Shale			

Notes:

11 CONTRACTOR'S OR LANDOWNER'S CERTIFICATION: This water well was ☑ constructed, ☐ reconstructed, or ☐ plugged under my jurisdiction and was completed on (mo-day-year) 10/10/2013 and this record is true to the best of my knowledge and belief. Kansas Water Well Contractor's License No. 818 This Water Well Record was completed on (mo-day-year) 10/14/2013 under the business name of Hobbs Mechanical, Inc.

Send one copy to WATER WELL OWNER and retain one for your records. Fee of $5.00 for each constructed well.
KS Department of Health and Environment, Bureau of Water, Geology Section, 1000 SW Jackson St., Suite 420, Topeka, Kansas 66612-1367. Telephone 785-296-3565.
Visit us at http://www.kdheks.gov/waterwell/index.html KSA 82a-1212

Figure 8 WWC-5 record for the Shepherd domestic well (Source: Kansas Geological Survey).



WATER WELL RECORD Form WWC-5 Division of Water Resources; App. No.

1 LOCATION OF WATER WELL: County: Sumner | Fraction NW¼ SW¼ SW¼ | Section Number 4 | Township Number T 32 S | Range Number R 1 E/W

Distance and direction from nearest town or city street address of well if located within city? In Wellington - 252 N. Tyler

Global Positioning Systems (decimal degrees, min. of 4 digits) Latitude: Longitude: Elevation: Datum: Data Collection Method:

2 WATER WELL OWNER: Jason Blubaugh
RR#, St. Address, Box #: 9800 S. 119th W
City, State, ZIP Code: Clearwater KS 67026

3 LOCATE WELL'S LOCATION WITH AN "X" IN SECTION BOX: N, NW, NE, W, E, SW, SE, S

4 DEPTH OF COMPLETED WELL 40 ft.

Depth(s) Groundwater Encountered (1) 15 ft. (2) ft. (3) ft.
WELL'S STATIC WATER LEVEL 15 ft. below land surface measured on mo/day/yr 4/3/09
Pump test data: Well water was ft. after hours pumping gpm
Est. Yield 15 gpm: Well water was ft. after hours pumping gpm
WELL WATER TO BE USED AS: 5 Public water supply 8 Air conditioning 11 Injection well 1 Domestic 3 Feedlot 6 Oil field water supply 9 Dewatering 12 Other (Specify below) 2 Irrigation 4 Industrial 7 Domestic (lawn & garden) 10 Monitoring well
Was a chemical/bacteriological sample submitted to Department? Yes No X; If yes, mo/day/yrs Sample was submitted Water well disinfected? Yes X No

5 TYPE OF CASING USED: 1 Steel 2 PVC 3 RMP (SR) 4 ABS 5 Wrought Iron 6 Asbestos-Cement 7 Fiberglass 8 Concrete tile 9 Other (specify below) CASING JOINTS: Glued X Clamped Welded Threaded
Blank casing diameter 5 in. to 20 ft., Diameter in. to ft., Diameter in. to ft.
Casing height above land surface 12 in., Weight 2.5 lbs./ft. Wall thickness or guage No. SDR26
TYPE OF SCREEN OR PERFORATION MATERIAL: 1 Steel 2 Brass 3 Stainless Steel 4 Galvanized Steal 5 Fiberglass 6 Concrete tile 7 PVC 8 RM (SR) 9 ABS 10 Asbestos-Cement 11 Other (Specify) 12 None used (open hole)
SCREEN OR PERFORATION OPENINGS ARE: 1 Continuous slot 2 Louvered shutter 3 Mill slot 4 Key punched 5 Gauzed wrapped 6 Wire wrapped 7 Torch cut 8 Saw cut 9 Drilled holes 10 Other (specify) 11 None (open hole)
SCREEN-PERFORATED INTERVALS: From 20 ft. to 40 ft., From ft. to ft. From ft. to ft., From ft. to ft.
GRAVEL PACK INTERVALS: From 20 ft. to 40 ft., From ft. to ft. From ft. to ft., From ft. to ft.

6 GROUT MATERIAL: 1 Neat cement 2 Cement grout 3 Bentonite 4 Other
Grout Intervals: From 3 ft. to 20 ft., From ft. to ft., From ft. to ft.
What is the nearest source of possible contamination: 1 Septic tank 2 Sewer lines 3 Watertight sewer lines 4 Lateral lines 5 Cess pool 6 Seepage pit 7 Pit privy 8 Sewage lagoon 9 Feedyard 10 Livestock pens 11 Fuel storage 12 Fertilizer storage 13 Insecticide storage 14 Abandoned water well 15 Oil well/gas well 16 Other (specify below)
Direction from well? West How many feet? 200

FROM	TO	LITHOLOGIC LOG	FROM	TO	PLUGGING INTERVALS
0	3	Top Soil			
3	17	Clay			
17	19	Sand			
19	40	Blueshale			

7 CONTRACTOR'S OR LANDOWNER'S CERTIFICATION: This water well was (1) constructed, (2) reconstructed, or (3) plugged under my jurisdiction and was completed on (mo/day/year) 4/2/09 and this record is true to the best of my knowledge and belief. Kansas Water Well Contractor's License No. 238. This Water Well Record was completed on (mo/day/year) 4/3/09 under the business name of Premier Pump & Well Service by (signature)
INSTRUCTIONS: Use typewriter or ball point pen. PLEASE PRESS FIRMLY and PRINT clearly. Please fill in blanks, underline or circle the correct answers. Send top

Figure 9 WWC-5 record for the Blubaugh domestic well, (Source: Kansas Geological Survey).

The stratigraphic and basic lithologic information from the WWC-5 was used to create a series of lithologic columns for key wells used to create cross sections including the Shepard and Blubaugh wells (Figures 10 and 11).

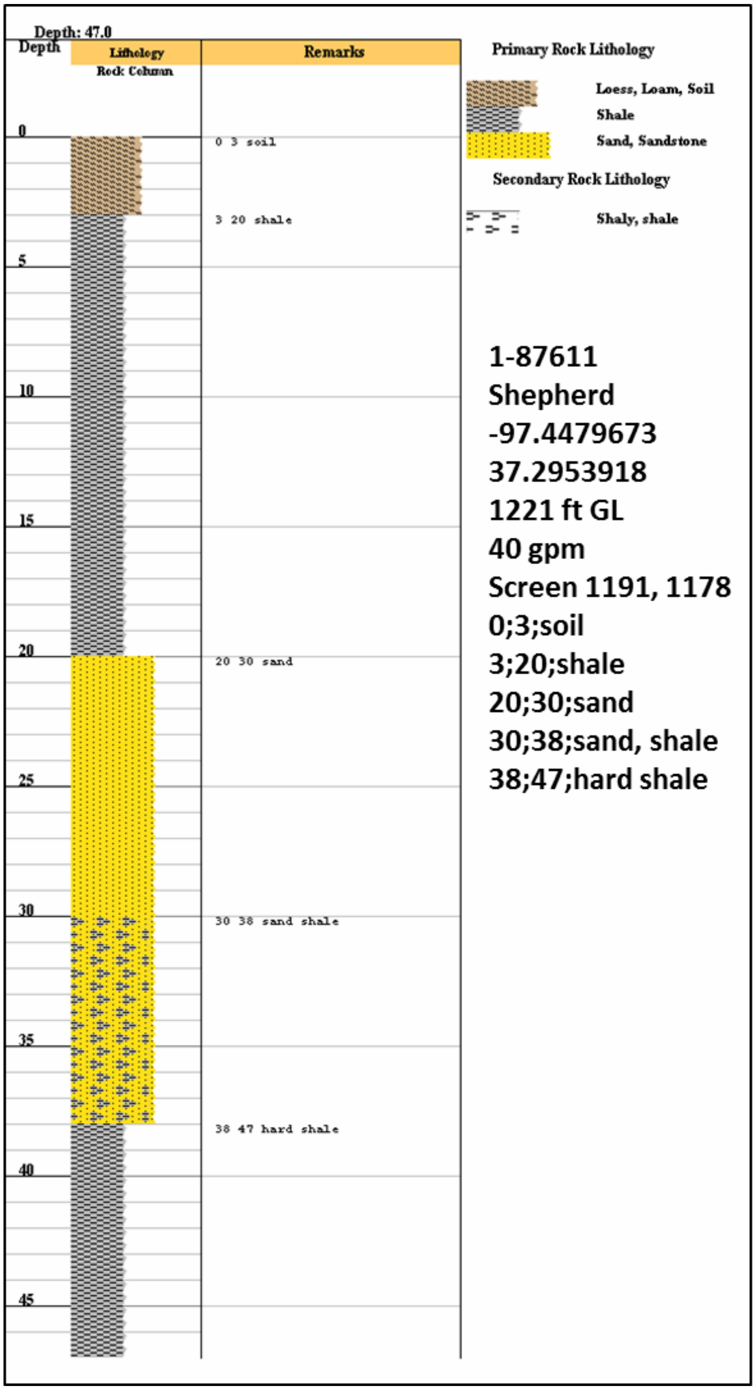


Figure 10 Graphic lithologic column of the Shepherd well. Hard shale is encountered at 38 feet inferred to be the top of the Wellington Shale.

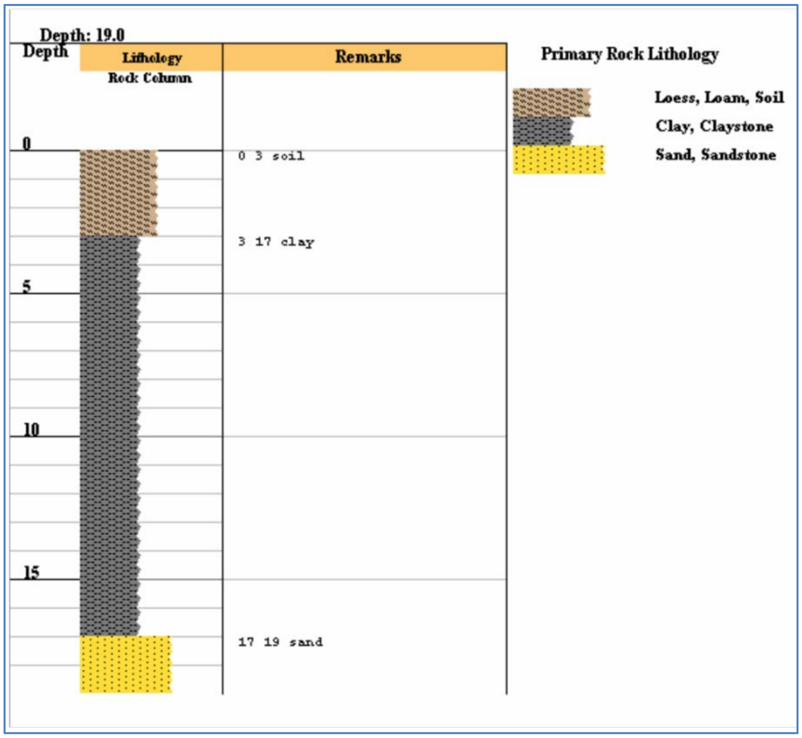


Figure 11 Blubaugh domestic well. Blue shale lies beneath the sand at 19 ft (below the depth shown in the figure) is inferred to be the top of the Wellington Shale. The softer clay and the sand are part of the unconsolidated interval yielding the water used for domestic purposed**.**

Methodology

The mapped region selected for this study around the Wellington Project includes the Shepherd and Blubaugh wells to be sampled. Information on existing shallow water wells was compiled into an Excel database. The resulting maps, well profiles, and cross sections were used to provide a geohydrological context for the mapped area. This new information is then compared to previous work on the surface geology and geohydrology as previously discussed above.

A total of 141 wells were extracted from the WWC-5 database http://www.kgs.ku.edu/Magellan/WaterWell/index.html. Eighty seven wells were selected. Wells not selected have 1) limited or no information to record and map or 2) wells in dense clusters used for environmental monitoring were not all used, but a representative well was used to convey information about those locations. The resulting Excel database is submitted with the report so that wells not mapped will be available for inspection. Each well in the database also contains a URL hyperlink to the actual well record in the WWC-5 online database.

In addition, three shallow water monitoring wells (SW-1. SW-2, SW-3) at the Wellington Project were added to the Excel database illustrated in the following three profiles (Figures 12, 13, and 14). Monitoring well, KGS SW-1, a 100 ft deep well, has 9 ft of friable silty sand overlying a minimum of 8 ft of very soft clay (gumbo). Cuttings were not collected from this well below 22 ft after drilling recommenced due to late conveyance of notice to the driller.

Well SW-2, was drilled immediately after SW-1 at a location ~200 feet to the south. This well was drilled without any interruption to a depth of 200 ft, estimated to be ~35 ft above the halite beds in the Lower Permian Hutchinson Salt. Ten feet of ochre colored sand, 10 ft of brown unconsolidated silt and sand was encountered above 40 ft of brown to gray soft shale, inferred to be same gumbo soft clay in SW-1 (Figure 13).

SW-3 was the third monitoring well to be drilled to a depth of 50 ft. The upper 25 ft contains loose silt with moderate argillaceous content (Figure 14). The top of the Wellington firm shale was set at 30 ft.

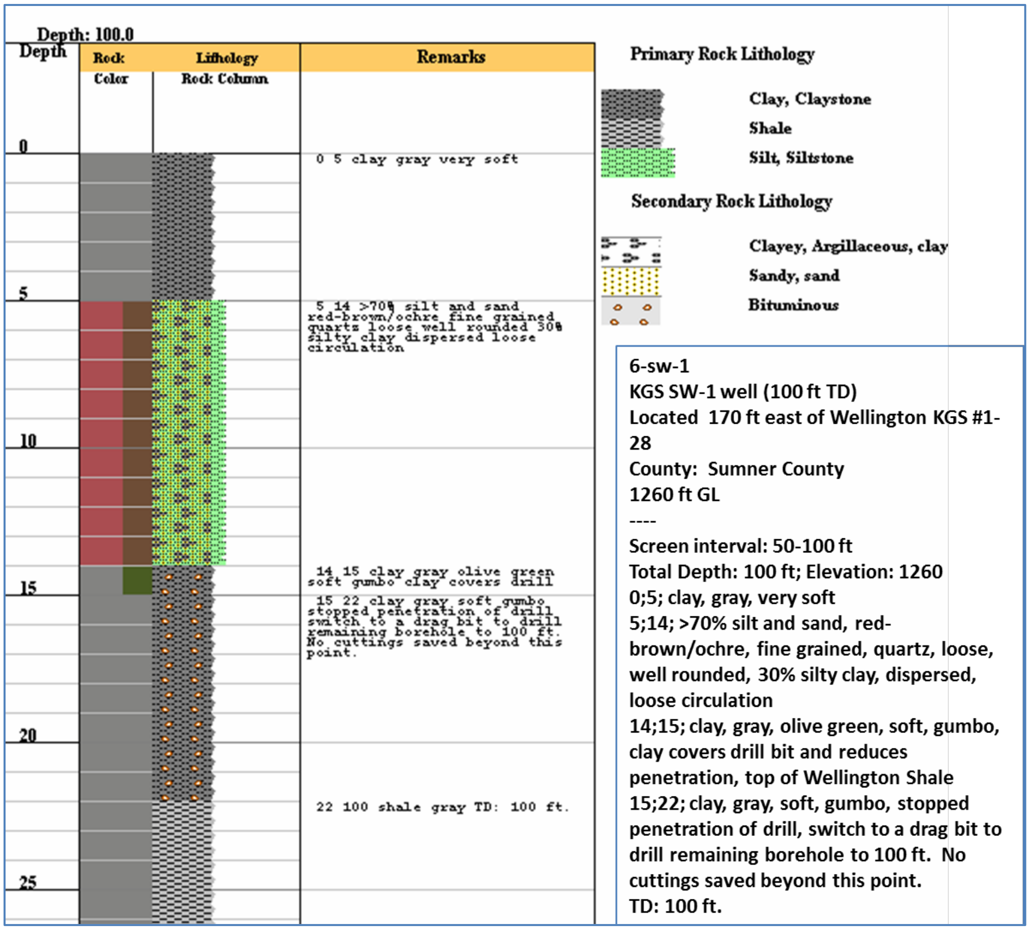
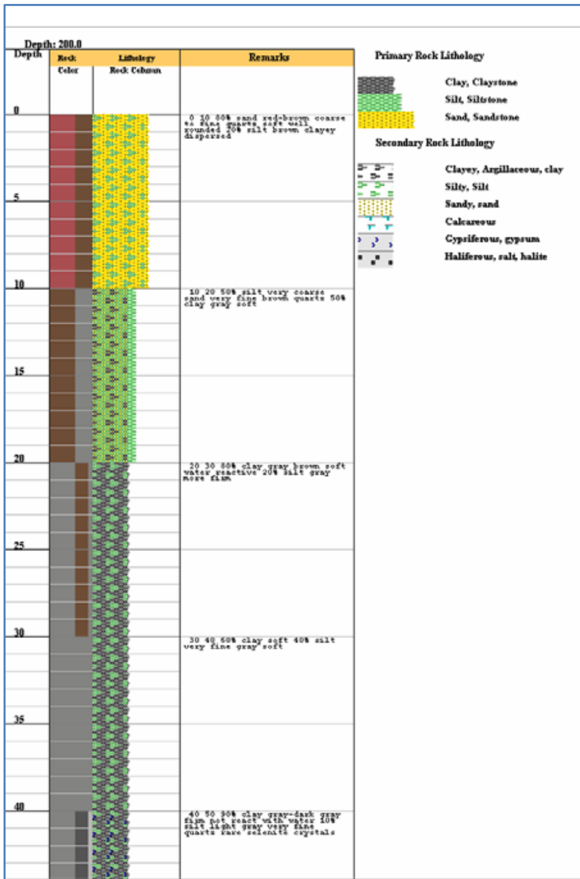


Figure 12 SW-1 lithologic column. Well was drilled to 100 ft. Samples were collected to the 22 ft depth when the drill bit became clogged by the gumbo shale. Drilling commenced with a different bit to drill to total depth. Reddish brown silt and sand is found at 5-14 ft with soft green and gray (gumbo) clay to 22 ft when cuttings were no longer collected.



SW-2
KGS SW #2 well (200 ft TD)
Located 190 ft southeast of Wellington KGS #1-28
County: Sumner County
1257 ft G
Screen interval: 100-200 ft
Total Depth: 200 ft; Elevation: 1257
0;10; 80% sand, red-brown, coarse to fine; quartz, soft, well rounded; 20% silt, brown, clayey, dispersed
10;20; 50% silt, very coarse, sand, very fine, brown, quartz, 50% clay, gray, soft
20;30; 80% clay, gray brown, soft, water reactive, 20% silt, gray, more firm
30;40; 60% clay, soft, 40% silt, very fine, gray, soft
40;50; 90% clay, gray-dark gray; firm, not react with water, 10% silt, light gray, very fine, quartz, rare selenite crystals
50;60; 90% clay, gray to dark gray, 10% silt, gray, very fine, firm, rate selenite crystals
60;70; 95% clay, gray to light gray, brown, 5% silt, gray, very fine, firm, frequent selenite
70;80; clay, gray to dark gray; common satin spar (fibrous gypsum)
80;90; clay, gray to dark gray; common satin spar
90;100; clay, gray to dark gray; common satin spar
100;110; clay, gray to dark gray; common satin spar
110;120; clay, gray to dark gray, firm, abundant satin spar and alabaster (finely crystalline gypsum)
120;130; clay, gray, very soft, mush
130;140; clay, gray, very soft, water reactive, common satin spar, rare limestone, brown, micrite
140;150; clay, gray to dark gray, very soft, water reactive, common limestone, brown, micritic
150;160; 50% silt, light gray and ochre brown (dispersed), very fine, 50% clay, light gray, possible water source
160;170; 50% silt, light gray to dark gray, soft, 50% clay, light gray to dark gray, very soft, common limestone, gray, micritic, common satin spar
170;180; 50% silt, light gray to dark gray, soft, 50% clay, light gray to dark gray, very soft, common limestone, gray, micritic, common satin spar
180;190; clay, gray to dark gray, very soft, common limestone, gray, micritic, common satin spar
190;200; clay, gray, very soft, common limestone, gray, micritic, common satin spar (Total depth)
235; halite, projected depth

Figure 13 Lithologic column for SW-2, a monitoring well at Wellington. Well was drilled to 200 ft, approximately 35 ft above the Hutchinson Salt Member. The top of the Wellington Shale is at 40 ft (the firm gray to dark gray shale). Sand is present from 0-10 ft, sandy silt 10 to 20 ft, and silty soft clay down to the Wellington Shale at 40 ft.

Presence and implications of gypsum in shallow unconsolidated zone -- The intervals between depths of 40 and 70 ft in SW-2 and 25 ft and 40 ft in SW-3 contain clear euhedral selenite gypsum crystals.

Below these depths the gypsum becomes satin spar fibrous gypsum in the firm unweathered shale near to slightly below the top of the Wellington Shale. The satin spar is believed to have developed early when the Wellington Shale was deposited filling shrinkage cracks in the evaporite beds or filled fractures formed during the transformation from anhydrite to gypsum noted to occur as burial temperatures decrease to under ~50° C and the Permian strata are eroded (Liu and Zheng, 2013). Thus, the satin spar gypsum was probably precipitated at shallowing depths when anhydrite became unstable.

In contrast, the formation of clear lipid selenite crystals is closely associated with the depth of permeable silt and sand deposits in the shallow unconfined aquifer present at the Wellington Project site. The selenite and its presence in the lower portion of the shallow aquifer above the Wellington Shale containing the in situ burial satin spar suggests that the latter has dissolved and again precipitated as selenite as undersaturated meteoric water encountered the gypsiferous Wellington Shale. Seasonal changes in wet and dry conditions could lead to intermittent supersaturation in the pore fluids leading to the precipitation of gypsum. Samples from SW-2 and SW-3 contain aggregates of silt and sand grains included in crystals of clear selenite suggesting that this process is common at this location.

Concomitant with the selenite is the elevated salinity of the water in the shallow aquifer at the Wellington Project site.

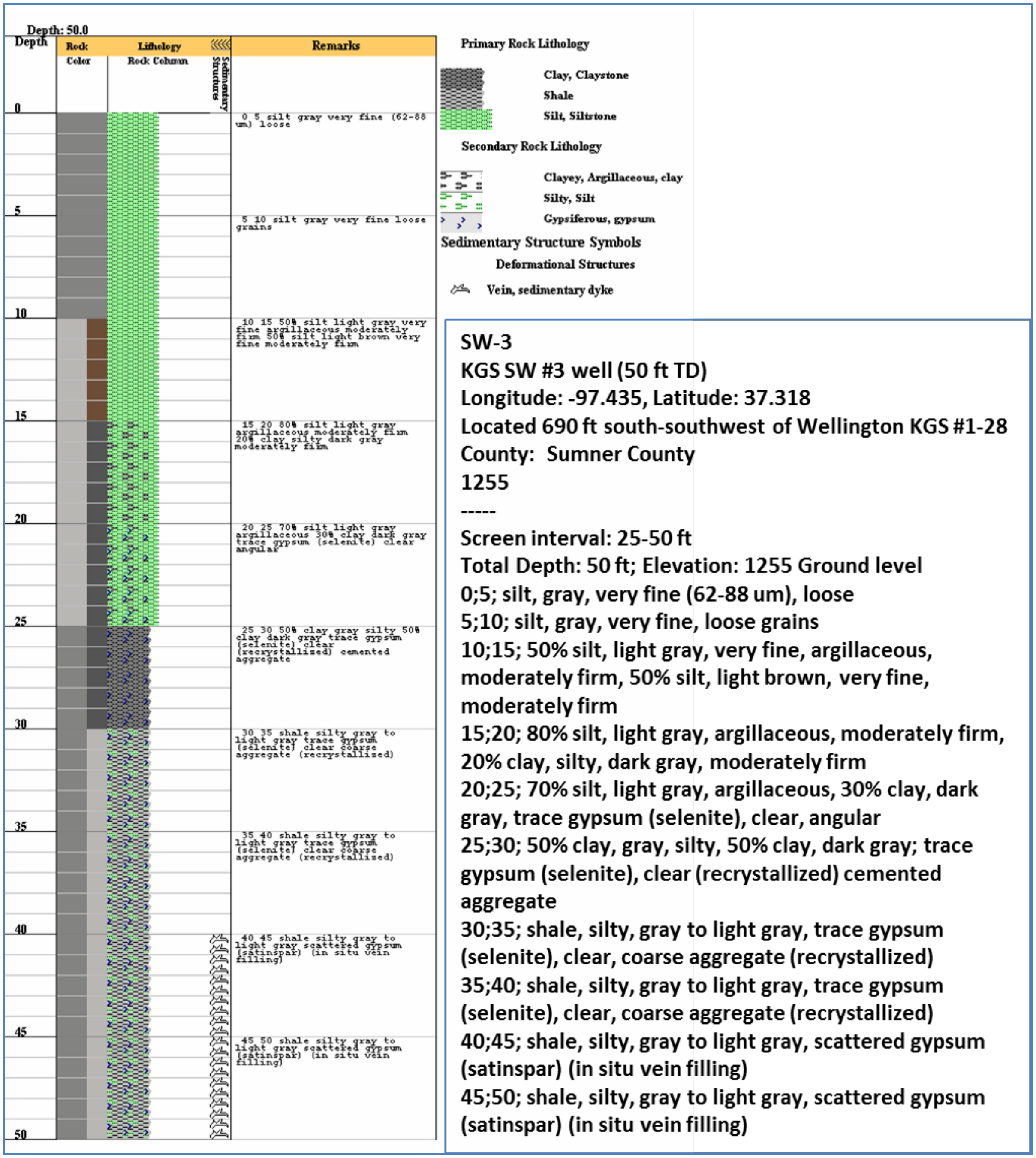
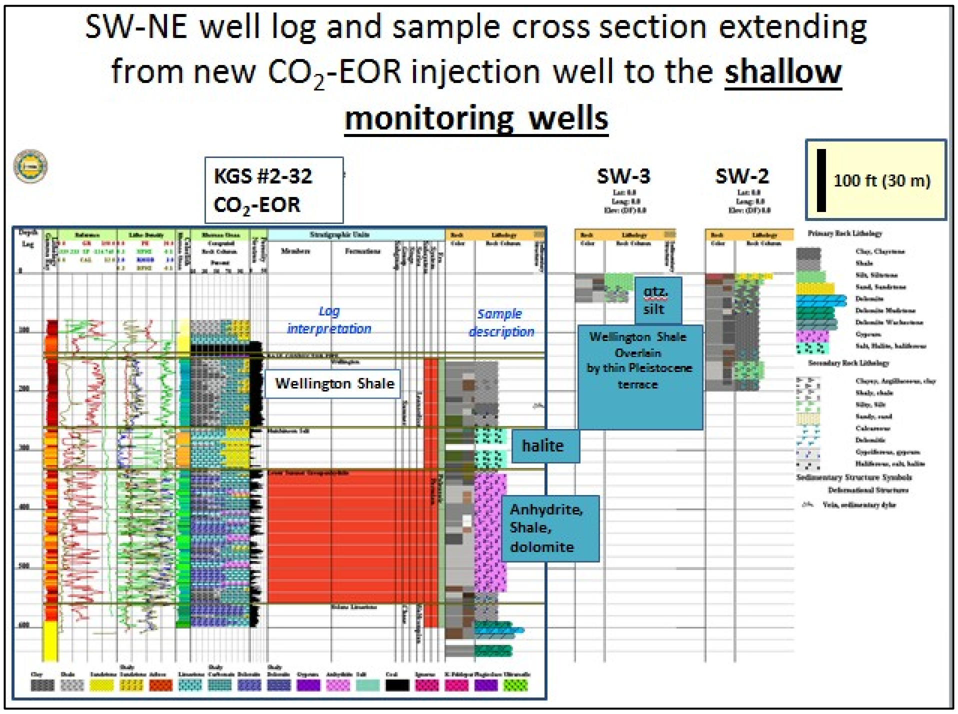


Figure 14 Lithologic column of SW-3 monitoring well at Wellington. Silt occurs to a depth of 25 ft. The silt is increasingly mixed with clay. The argillaceous to silty clay from 20 to 25 ft contains gypsum and from 25 to 30 ft the clay turns to firm shale, thus the top of the Wellington Shale is chosen at 30 ft.

The three monitoring wells and the new deep Mississippian injection well, KGS #2-32, illustrate the continuity of the Wellington Shale beneath the shallow aquifer at the Wellington Injection Site. A new set of well cuttings from #2-32 combined with wireline logs starting at 142 ft below the surface show that the Wellington Shale is continuous below that depth to the top of the Hutchinson Salt, a 200 ft thick bed of halite. A cross section connecting wells #2-32, SW-3, and SW-2 illustrated the thin nature of the shallow aquifer located on a shale aquiclude (seal) of the Wellington Shale that isolates the perched thin shallow aquifer resting on the shale (Figure 15). The Wellington Shale is isolating the meteroric water from the contact with the halite.



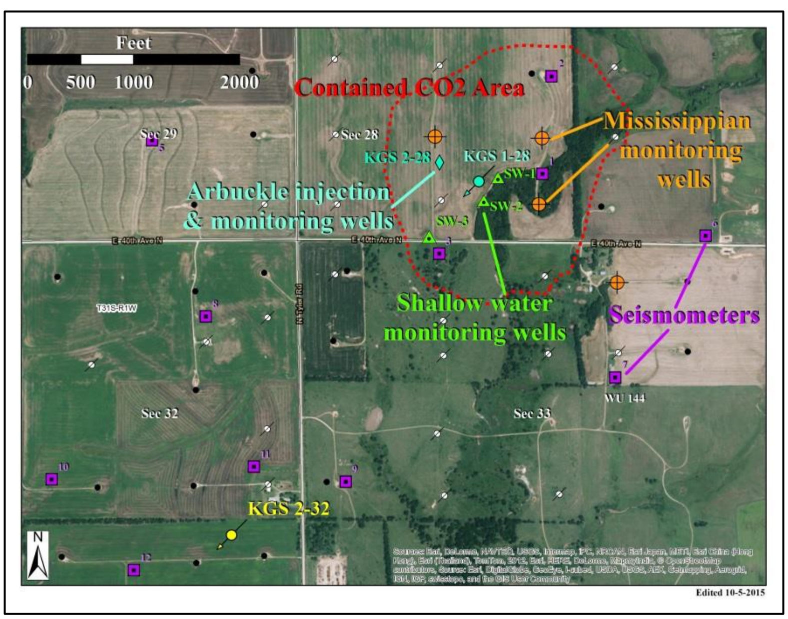


Figure 15 Wireline logs and sample description of the deep Mississippian well, KGS #2-32 located ~ 1 mi southwest of the SW monitoring wells. Halite lies immediately beneath the Wellington Shale (purple color along the sample description noted by corroded crystals of halite in the fresh cuttings described at the wellsite). KGS #2-32 is compared to the SW-3 and SW-2 as a cross section datumed at the land surface. The inset map shows the AoR and the location of the monitoring wells.

The cuttings description for the deep test penetrated through the entire Permian is presented in Figure 16. The halite as it is preserved in the undersaturated drilling mud consists of scattered halite chips of clear cubic crystals. Below the halite is bedded gypsum.

Cuttings description, Shallow interval
Berexco Wellington KGS #2-32
15-191-22770-00-00
1W-31S-Sec32
Longitude: ___, Latitude: ___
County: Sumner County
KB:1266
GL: 1257
Depth interval: 150-650 ft
CL: 42,000
RM: 0.527
150;160; Shale, gray, moderately firm **(Wellington Shale)**
160;170; Shale, gray, moderately firm, scattered satin spar (vein fill, not recrystallized)
170;180; Shale, gray to light gray, moderately firm, scattered satin spar
180;190; 70% shale, gray, 30% claystone, brown, common satin spar
190;200; 60% shale, gray, 40% claystone, brown
200;210; 90% shale, gray, 10% satin spar
210;220; 60% shale, dark gray, 20% gray shale, 10% brown shale, 10% satin spar
220;230; 90% claystone, gray, 5% alabaster (depositional type vs. vein fill), 5% satin spar
230;240; 90% claystone, gray-light gray, olive green, trace red claystone, scattered gypsum, trace halite (dissolved smoothed edges of clear crystals)
240;250; 80% shale, olive green, 10% shale, gray, scattered alabaster, trace halite
250;260; 80% shale, olive green, 10% shale, gray, scattered alabaster, trace halite
260;270; halite, 90% shale, gray-green, 10% shale, brown, scattered alabaster and satin spar **(Hutchinson Salt)**
270;280; halite, 70% shale, olive green, 20% shale, dark gray, 10% shale, brown, trace gypsum
280;290; halite, 70% shale, olive green, 20% shale, dark gray, 10% shale, brown, trace gypsum
290:300; halite, 70% shale, olive green, 20% shale, dark gray, 10% shale, brown, scattered halite, clear, smooth, trace gypsum
300;310; halite, 70% shale, olive green, 20% shale, dark gray, 10% shale, brown, scattered halite, clear, smooth, trace gypsum
310;320; halite, 70% shale, olive green, 20% shale, dark gray, 10% shale, brown, scattered halite, clear, smooth, trace gypsum
320;330; halite, 60% shale, dark gray; 30% shale, olive gay, 10% gypsum
330;340; 60% shale, dark gray; 30% shale, olive gay, 10% gypsum **(Lower Sumner Group anhydrite)**
340;350; gypsum, 60% shale, dark gray; 30% shale, olive gray, 10% gypsum, trace halite
350;360; gypsum, 70% shale, gray, 30% shale, dark gray, 10% alabaster
360;370; gypsum, 70% shale, light gray, 20% gypsum, alabaster
370;380; 70% gypsum, alabaster, light gray, light brown, dense, 30% claystone, light gray
380;390; 70% gypsum, alabaster, light gray, light brown, dense, 30% claystone, light gray
390;400; 80% gypsum, alabaster, 20% claystone, gray
400;410; 80% gypsum, alabaster, 20% claystone, gray, scattered claystone, gray
410;420; 80% gypsum, alabaster, gray, white, scattered dolomite, microcrystalline, dense, gray
420;430; 80% gypsum, alabaster, gray, white, scattered dolomite, gray, light brown, microcrystalline, dense
430;440; 90% gypsum, alabaster, light gray, light brown, 10% shale, light gray
440;450; 70% gypsum, alabaster, 10% shale, dark gray, 10% shale, light gray
450;460; 70% gypsum, alabaster, 10% shale, dark gray, 10% shale, light gray, scattered alabaster, translucent
460;470; 95% gypsum, alabaster, 5% shale, light gray
470;480; 95% gypsum, alabaster, 5% shale, light gray
480;490; 95% gypsum, alabaster, 5% shale, light gray
490;500; 95% gypsum, alabaster, 5% shale, light gray
500;510; 95% gypsum, alabaster, 5% shale, light gray
510;520; 90% gypsum, alabaster, 10% shale, light gray
520;530; 80% gypsum, alabaster, 20% shale, light gray
530;540; 80% gypsum, alabaster, 10% dolomite, brown, microcrystalline, 10% shale, gray
540;550; shale, 70% gypsum, alabaster, 25% shale, light to dark gray, 5% dolomite, brown, dark brown, peloid packstone
550;560; 70% shale, gray to dark gray, olive green, 30% gypsum, alabaster, trace dolomite, brown, mottled, microcystaline
560;570; 50% shale, gray to dark gray, 45% gypsum, alabaster, 5% dolomite, micrite
570;580; 75% shale, gray, 15% dolomite, brown, micrite, 10% gypsum, alabaster
580;590; 70% shale, gray, 25% gypsum, alabaster, 5% dolomite, brown, micrite
590;600; 60% dolomite, gray, brown, micrite and microcrystalline, 35% shale, gray, 5% gypsum, alabaster **(top Chase Group)**
600;610; 50% dolomite, brown, 50% shale, gray
610;620; 60% dolomite, brown, gray, wackestone-grainstone, peloid, bioclastic, porosity
620-630; 50% dolomite, micrite, 50% shale, gray
630;640; 50% dolomite, micrite, 50% shale, gray
640;650; 50% dolomite, micrite, 50% shale, gray

Berexco Wellington KGS #2-32 completed logged and cased (3/30/15)

- Sample logging commenced below surface conductor pipe at 150 ft.
- Samples caught every 10 ft
- 150 ft -- **Wellington Shale** *(dark gray shale with scattered satin spar gypsum)*
- 260 ft – **top Hutchinson Salt** -- sparse halite noted corresponding with same wireline log depth (*rounded clear crystals affected by dissolution in freshwater drilling mud*)
- 340 ft – **base of Hutchinson Salt** (*halite gone, lt gray and olive-gray shale and alabaster gypsum begin*)
- 540 ft – **top of Chase Group** (*first dolomite samples, brown dense distinctive from above appear*)

30

Figure 16 Cutttings description of the uppermost portion of the deep Mississippian injection well, KGS #2-32.

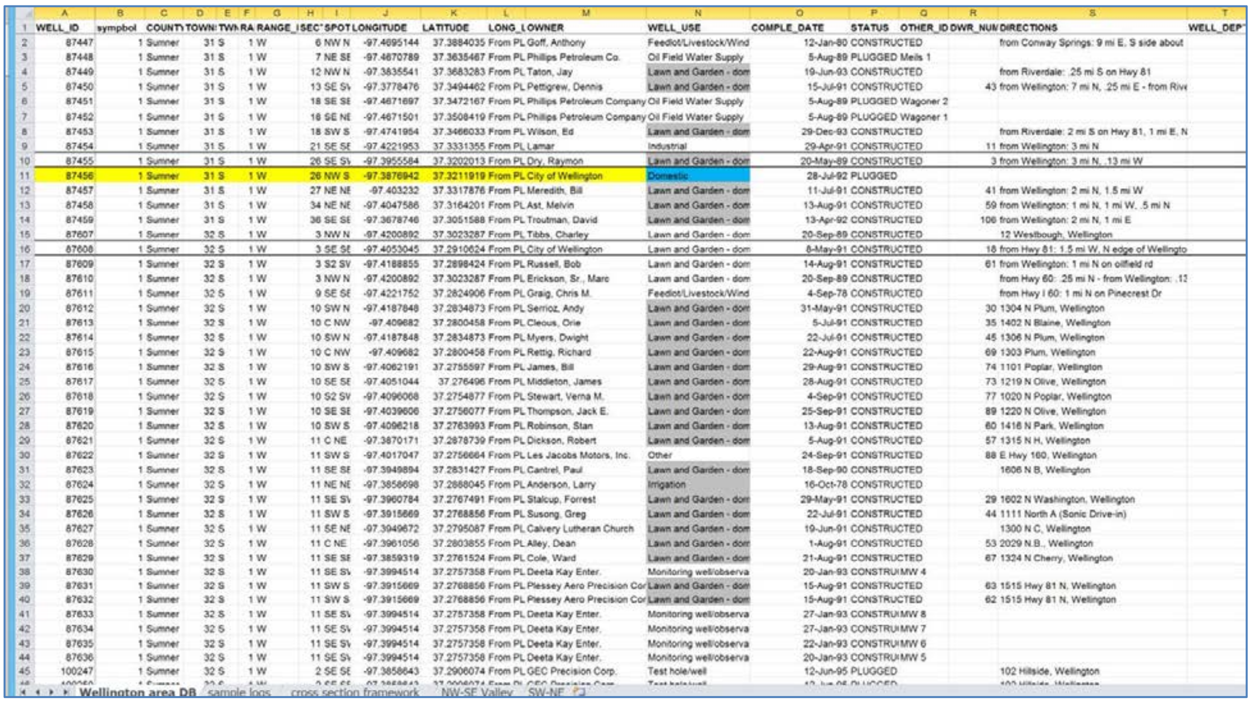
The shallow aquifer identified at the Wellington Project Site was extended to the mapped area for the study shown in figures 6 and 7. It is evident that previous work has established a systematic framework for the shallow aquifer based on a distinction of Modern and Holocene sediments differentiated by lithologies, elevation and location with respect to modern surface drainage. What is particularly evident is that the antecedent landscape is dominated by a series of terraces that in this region are associated with paleo drainage in association with the Wellington-McPherson Lowlands. According to Mandell (personal communication, 2015) the terraces are associated with the paleo Arkansas River drainage. As noted in Figures 3-6, the older terraces are located at higher elevations. Younger terraces succeed and cross cut the older terraces in close proximity to the current creek and river drainages. The shallow sediments residing at the Wellington site are classified by Walters (1961) as Qc, Pleistocene to recent silt and clay containing minor amounts of sand and gravel and are concluded to not yield appreciable quantities of water. The mapping in the area is an attempt to place the Wellington Project site in the context of (active or plugged) water wells in the area to understand the stratigraphy and to use this information to understand what might control the observed variations in the yields and water quality in the shallow aquifer.

An Excel workbook was developed based on information found in shallow wells in the WWC-5 database. Wells used in the mapping contain all or most of the following parameters:

- brief sample descriptions
- static water elevation
- reported estimated yield
- surface elevation
- top of shallow aquifer below the Modern surficial soil layer
- top of the Lower Permian Wellington Shale Member of the Sumner Group
- elevation of total depth of well penetration
- net thickness gravel and sand
- net sand
- net silt
- net thickness clay
- total gravel, sand, silt
- top and base of screened interval
- computed thicknesses of lithology and stratraphic units

Excerpts from the Excel database are shown in Figure 17a and 17b.

The lithologic, stratigraphic, and elevation data were used to build several maps and two cross sections. The graphics are used to illustrate spatial attributes of the shallow aquifer system. The mapped area covering ~ 24mi^2 is located north and west of the city of Wellington.



	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T
1	WELL_ID	sympbol	COUNTY	TOWN	TWN	RA	RANGE_	SEC	SPOT	LONGITUDE	LATITUDE	LONG_	OWNER	WELL_USE	COMPLE_DATE	STATUS	OTHER_ID	DWR_NUM	DIRECTIONS	WELL_DEP
2	87447	1	Sumner	31	S	1	W	6	NW N	-97.4695144	37.3884035	From PL	Goff, Anthony	Feedlot/Livestock/Wind	12-Jan-80	CONSTRUCTED			from Conway Springs: 9 mi E, S side about	
3	87448	1	Sumner	31	S	1	W	7	NE SE	-97.4670789	37.3635467	From PL	Phillips Petroleum Co.	Oil Field Water Supply	5-Aug-89	PLUGGED	Meils 1			
4	87449	1	Sumner	31	S	1	W	12	NW N	-97.3835541	37.3683283	From PL	Taton, Jay	Lawn and Garden - dom	19-Jun-93	CONSTRUCTED			from Riverdale: .25 mi S on Hwy 81	
5	87450	1	Sumner	31	S	1	W	13	SE SW	-97.3778476	37.3494462	From PL	Pettigrew, Dennis	Lawn and Garden - dom	15-Jul-91	CONSTRUCTED		43	from Wellington: 7 mi N, .25 mi E - from Rive	
6	87451	1	Sumner	31	S	1	W	18	SE SE	-97.4671697	37.3472167	From PL	Phillips Petroleum Company	Oil Field Water Supply	5-Aug-89	PLUGGED	Wagoner 2			
7	87452	1	Sumner	31	S	1	W	18	SE NE	-97.4671501	37.3508419	From PL	Phillips Petroleum Company	Oil Field Water Supply	5-Aug-89	PLUGGED	Wagoner 1			
8	87453	1	Sumner	31	S	1	W	18	SW S	-97.4741954	37.3466033	From PL	Wilson, Ed	Lawn and Garden - dom	29-Dec-93	CONSTRUCTED			from Riverdale: 2 mi S on Hwy 81, 1 mi E, N	
9	87454	1	Sumner	31	S	1	W	21	SE SE	-97.4221953	37.3331355	From PL	Lamar	Industrial	29-Apr-91	CONSTRUCTED		11	from Wellington: 3 mi N	
10	87455	1	Sumner	31	S	1	W	26	SE SW	-97.3955584	37.3202013	From PL	Dry, Raymon	Lawn and Garden - dom	20-May-89	CONSTRUCTED		3	from Wellington: 3 mi N, .13 mi W	
11	87456	1	Sumner	31	S	1	W	26	NW S	-97.3876942	37.3211919	From PL	City of Wellington	Domestic	28-Jul-92	PLUGGED				
12	87457	1	Sumner	31	S	1	W	27	NE NE	-97.403232	37.3317876	From PL	Meredith, Bill	Lawn and Garden - dom	11-Jul-91	CONSTRUCTED		41	from Wellington: 2 mi N, 1.5 mi W	
13	87458	1	Sumner	31	S	1	W	34	NE NE	-97.4047586	37.3164201	From PL	Ast, Melvin	Lawn and Garden - dom	13-Aug-91	CONSTRUCTED		59	from Wellington: 1 mi N, 1 mi W, .5 mi N	
14	87459	1	Sumner	31	S	1	W	36	SE SE	-97.3678746	37.3051588	From PL	Troutman, David	Lawn and Garden - dom	13-Apr-92	CONSTRUCTED		106	from Wellington: 2 mi N, 1 mi E	
15	87607	1	Sumner	32	S	1	W	3	NW N	-97.4200892	37.3023287	From PL	Tibbs, Charley	Lawn and Garden - dom	20-Sep-89	CONSTRUCTED			12 Westbough, Wellington	
16	87608	1	Sumner	32	S	1	W	3	SE SE	-97.4053045	37.2910624	From PL	City of Wellington	Lawn and Garden - dom	8-May-91	CONSTRUCTED		18	from Hwy 81: 1.5 mi W, N edge of Wellingto	
17	87609	1	Sumner	32	S	1	W	3	S2 SV	-97.4188855	37.2898424	From PL	Russell, Bob	Lawn and Garden - dom	14-Aug-91	CONSTRUCTED		61	from Wellington: 1 mi N on oilfield rd	
18	87610	1	Sumner	32	S	1	W	3	NW N	-97.4200892	37.3023287	From PL	Erickson, Sr., Marc	Lawn and Garden - dom	20-Sep-89	CONSTRUCTED			from Hwy 60: .25 mi N - from Wellington: .12	
19	87611	1	Sumner	32	S	1	W	9	SE SE	-97.4221752	37.2824906	From PL	Graig, Chris M.	Feedlot/Livestock/Wind	4-Sep-78	CONSTRUCTED			from Hwy I 60: 1 mi N on Pinecrest Dr	
20	87612	1	Sumner	32	S	1	W	10	SW N	-97.4187848	37.2834873	From PL	Serrioz, Andy	Lawn and Garden - dom	31-May-91	CONSTRUCTED		30	1304 N Plum, Wellington	
21	87613	1	Sumner	32	S	1	W	10	C NW	-97.409682	37.2800458	From PL	Cleous, Orie	Lawn and Garden - dom	5-Jul-91	CONSTRUCTED		35	1402 N Blaine, Wellington	
22	87614	1	Sumner	32	S	1	W	10	SW N	-97.4187848	37.2834873	From PL	Myers, Dwight	Lawn and Garden - dom	22-Jul-91	CONSTRUCTED		45	1306 N Plum, Wellington	
23	87615	1	Sumner	32	S	1	W	10	C NW	-97.409682	37.2800458	From PL	Rettig, Richard	Lawn and Garden - dom	22-Aug-91	CONSTRUCTED		69	1303 Plum, Wellington	
24	87616	1	Sumner	32	S	1	W	10	SW S	-97.4062191	37.2755597	From PL	James, Bill	Lawn and Garden - dom	29-Aug-91	CONSTRUCTED		74	1101 Poplar, Wellington	
25	87617	1	Sumner	32	S	1	W	10	SE SE	-97.4051044	37.276496	From PL	Middleton, James	Lawn and Garden - dom	28-Aug-91	CONSTRUCTED		73	1219 N Olive, Wellington	
26	87618	1	Sumner	32	S	1	W	10	S2 SV	-97.4096068	37.2754877	From PL	Stewart, Verna M.	Lawn and Garden - dom	4-Sep-91	CONSTRUCTED		77	1020 N Poplar, Wellington	
27	87619	1	Sumner	32	S	1	W	10	SE SE	-97.4039606	37.2756077	From PL	Thompson, Jack E.	Lawn and Garden - dom	25-Sep-91	CONSTRUCTED		89	1220 N Olive, Wellington	
28	87620	1	Sumner	32	S	1	W	10	SW S	-97.4096218	37.2763993	From PL	Robinson, Stan	Lawn and Garden - dom	13-Aug-91	CONSTRUCTED		60	1416 N Park, Wellington	
29	87621	1	Sumner	32	S	1	W	11	C NE	-97.3870171	37.2878739	From PL	Dickson, Robert	Lawn and Garden - dom	5-Aug-91	CONSTRUCTED		57	1315 N H, Wellington	
30	87622	1	Sumner	32	S	1	W	11	SW S	-97.4017047	37.2756664	From PL	Les Jacobs Motors, Inc.	Other	24-Sep-91	CONSTRUCTED		88	E Hwy 160, Wellington	
31	87623	1	Sumner	32	S	1	W	11	SE SE	-97.3949894	37.2831427	From PL	Cantrel, Paul	Lawn and Garden - dom	18-Sep-90	CONSTRUCTED			1606 N B, Wellington	
32	87624	1	Sumner	32	S	1	W	11	NE NE	-97.3858698	37.2888045	From PL	Anderson, Larry	Irrigation	16-Oct-78	CONSTRUCTED				
33	87625	1	Sumner	32	S	1	W	11	SE SW	-97.3960784	37.2767491	From PL	Stalcup, Forrest	Lawn and Garden - dom	29-May-91	CONSTRUCTED		29	1602 N Washington, Wellington	
34	87626	1	Sumner	32	S	1	W	11	SW S	-97.3915669	37.2768856	From PL	Susong, Greg	Lawn and Garden - dom	22-Jul-91	CONSTRUCTED		44	1111 North A (Sonic Drive-in)	
35	87627	1	Sumner	32	S	1	W	11	SE NE	-97.3949672	37.2795087	From PL	Calvery Lutheran Church	Lawn and Garden - dom	19-Jun-91	CONSTRUCTED			1300 N C, Wellington	
36	87628	1	Sumner	32	S	1	W	11	C NE	-97.3961056	37.2803855	From PL	Alley, Dean	Lawn and Garden - dom	1-Aug-91	CONSTRUCTED		53	2029 N.B., Wellington	
37	87629	1	Sumner	32	S	1	W	11	SE SE	-97.3859319	37.2761524	From PL	Cole, Ward	Lawn and Garden - dom	21-Aug-91	CONSTRUCTED		67	1324 N Cherry, Wellington	
38	87630	1	Sumner	32	S	1	W	11	SE SW	-97.3994514	37.2757358	From PL	Deeta Kay Enter.	Monitoring well/observa	20-Jan-93	CONSTRU	MW 4			
39	87631	1	Sumner	32	S	1	W	11	SW S	-97.3915669	37.2768856	From PL	Plessey Aero Precision Cor	Lawn and Garden - dom	15-Aug-91	CONSTRUCTED		63	1515 Hwy 81 N, Wellington	
40	87632	1	Sumner	32	S	1	W	11	SW S	-97.3915669	37.2768856	From PL	Plessey Aero Precision Cor	Lawn and Garden - dom	15-Aug-91	CONSTRUCTED		62	1515 Hwy 81 N, Wellington	
41	87633	1	Sumner	32	S	1	W	11	SE SW	-97.3994514	37.2757358	From PL	Deeta Kay Enter.	Monitoring well/observa	27-Jan-93	CONSTRU	MW 8			
42	87634	1	Sumner	32	S	1	W	11	SE SW	-97.3994514	37.2757358	From PL	Deeta Kay Enter.	Monitoring well/observa	27-Jan-93	CONSTRU	MW 7			
43	87635	1	Sumner	32	S	1	W	11	SE SW	-97.3994514	37.2757358	From PL	Deeta Kay Enter.	Monitoring well/observa	22-Jan-93	CONSTRU	MW 6			
44	87636	1	Sumner	32	S	1	W	11	SE SW	-97.3994514	37.2757358	From PL	Deeta Kay Enter.	Monitoring well/observa	20-Jan-93	CONSTRU	MW 5			
45	100247	1	Sumner	32	S	1	W	2	SE SE	-97.3858643	37.2906074	From PL	GEC Precision Corp.	Test hole/well	12-Jun-95	PLUGGED			102 Hillside, Wellington	

Wellington area DB | sample logs | cross section framework | NW-SE Valley | SW-NE

Figure 17a Left side of a portion of the Excel database.

	A	T	U	V	W	X	Y	Z	AA	AB	AC	AD	AE	AF	AG	AH	AI	AJ	AK	A
1	WELL_ID	WELL_DEPTH	ELEV	STATIC_I	Static sea	EST_YIELD	topsoil	top aquifer	gravel&sd	net sand	net silt	net clay	top screen	base screen	top Wellington	Top top base aquife	grav+sand+silt	TD	comment	topo lo
2	87447	97	1290	26	1264		1290	1288	0	0	0	2	1260	1193	1281	7	0	1193	7 ft red Wellin	5 ft abc
3	87448	53	1270	8	1262		1270	1267	50	0	0	0	1237	1217	1217	50	50	1217		10 ft ab
4	87449	44	1301	24	1277		1301	1298	0	0	0	23	1277	1257	1275	23	0	1257	brown clay	5 ft abc
5	87450	44	1324				1324	1321	0	0	0	10	1300	1280	1311	10	0	1280	soft green cla	30 ft ab
6	87451	51	1260	10	1250		1260	1257	48	0	0	0	1237	1209	1209	48	48	1209	gravel at base	on cree
7	87452	74	1271	10	1261		1271	1268	68	0	0	0	1240	1200	1200	68	68	1200	base in grave	20 ft ab
8	87453	97	1285	21	1264		1285	1282	0	0	0	38	1258	1188	1244	38	0	1188	red to gray cl	upland
9	87454	43	1262	13	1249		1262	1262	0	0	0	13	1230	1219	1249	13	0	1219	clay to shale	10 ft ab
10	87455	43	1262	18	1244		1262	1262	0	0	0	20	1229	1219	1242	20	0	1219	clay shale	5 ft abc
11	87456	24	1277	18	1259		1277	1271	0	6	0	12			1253	18	6	1253	put well at bas	upland
12	87457	45	1270	25	1245		1266	1262	0	0	0	4	1245	1225	1262		0	1225	clay then shal	5 ft abc
13	87458	46	1263	26	1237		1263	1257	0	0	0	6	1237	1217	1250	7	0	1217	3 ft above intermittent	
14	87459	60	1263	40	1223		1263	1260	0	0	0	16	1223	1203	1244	16	0	1203	clay shale	15 ft ab
15	87607	50	1263	27	1251		1263	1260	0	12	0	20	1236	1213	1228	32	12	1213	fine sand	upland
16	87608	54	1262	34	1228		1262	1259			19		1228	1208	1240	19	19	1208	sandy clay	crest n
17	87609	46	1232	26	1206		1232	1229				12	1206	1186	1220	9	0	1186	clay	5 ft abc
18	87610	50	1263	25	1238		1263	1260	0	14	0	19	1238	1213	1228	32	14	1213	fine sand	interfluv
19	87611	45	1221	20	1201	40	1221	1219	3	10	0	18	1191	1178	1178	41	13	1176	sandy clay	edge of
20	87612	38	1220	18	1202		1220	1218	0	4	0	20	1202	1186	1196	22	4	1182	thin sand	north sl
21	87613	62	1234	42	1192		1234	1231	0	0	0	24	1192	1172	1207	24	0	1172	clay	interfluv
22	87614	46	1219				1219	1215	0	13	0	0	1193	1173	1202	13	13	1173		9 ft abc
23	87615	46	1235	26	1209		1235	1230	0	15	0	0	1209	1189	1215	15	15	1189		interflue
24	87616	44	1227	22	1205		1221	1221	0	0	0	19	1205	1183	1202	19	0	1183	clay	interfluv
25	87617	46	1227	26	1201		1227	1224	0	0	0	10	1201	1181	1214	10	0	1181	clay	interflue
26	87618	45	1229				1229	1226	0	8	0	5	1204	1184	1213	13	8	1184	sand	interfluv
27	87619	56	1223				1223	1220	0	0	0	20	1187	1167	1200	20	0	1167	brown shal	interfluv
28	87620	46	1228	26	1202		1228	1225	0	36	0	7	1202	1182			36	1182	all sand	interfluv
29	87621	47	1240				1240	1240	0	0	0	17	1213	1193	1223	17	0	1193	clay	daainag
30	87622	57	1220				1220	1220	0	0	0	20	1183	1163	1200	20	0	1163	clay	drainag
31	87623	50	1240	23			1240	1239	2	0	0	22	1220	1190	1215	24	2	1190	2 ft coarse gr	interfluv
32	87624	66	1225	22	1203	3	1225	1225	2	0	0	20	1170	1160	1185	40	2	1159		drainag
33	87625	60	1235	40	1195		1235	1235	0	9	0	20	1195	1185	1203	32	9	1185	sandy clay	interfluv
34	87626	41	1232				1232	1224	0	0	0	26	1211	1191	1198	26	0	1191	lt grn shale	below v
35	87627	50	1235	17	1218	17.5	1235	1233	0	0	0	6	1218	1185	1227	6	0	1185	thin shale	interfluv
36	87628	46	1233				1233	1233	0	0	0	15	1207	1187	1218	15	0	1187	clay	interfluv
37	87629	44	1232	24	1208		1232	1232	0	0	0	24	1208	1188	1212	20	0	1188	clay	interfluv
38	87630	25	1222.24	17.95	1204.29		1222.2	1221.24	5	1	0	17	1207.24	1198.24			6	1197.2	mixed ss	interfluv
39	87631	46	1232	26	1206		1232	1232	0	8	0	7	1207	1186	0		8	1186	sand	below v
40	87632	46	1232	26	1206		1232	1232	0	0	0	39	1206	1186	1193	39	0	1186	clay	below v
41	87633	18	1211.35	8.53	1202.82		1211.4	1210.95	5	4	0	8	1203.85	1193.85			9	1193.4	sd gravel	near dr
42	87634	18	1220.7	12.72	1207.98		1220.7	1218.7	2	4	0	8	1213.2	1203.2			6	1202.7	sand	north c
43	87635	25	1222.4	17.47	1204.93		1222.4	1221.4	5	2	0	1	1207.4	1198.4			7	1197.4	sd gravel	north c
44	87636	20	1218.35	14.57	1203.78		1218.4	1217.85	4	4	2	1	1208.35	1199.35			10	1198.4	sd gravel	north c
45	100247	32	1263	10	1253		1263	1260	0	0	0	3					0	1260		10 ft ab

Figure 17b. Right slide of the Excel database (continuation of Figure 17a).

A series of maps and a cross section are shown in in Figures 18-22. Figure 18 shows the location of KGS #1-28 (the Arbuckle CO_2 injection well). To the west of this well is the location of a modern drainage called Spring Creek. This is also noted on the map shown in Figure 6. As noted in Figure 6, Spring Creek overlies either Permian bedrock or the Qw terrace described as a lower Holocene terrace consisting chiefly of sand and gravel which are noted to yield large quantities of water.

Figure 19 is an elevation map of the top of the shallow unconfined aquifer constructed from information in the WWC-5 database. Lower elevations (highlighted in blue) occupies the southwest and southern reaches of the mapped area immediately below KGS #1-28. Figure 20 shows the net thickness of sand in the shallow aquifer concentrated in the area immediately west of the KGS #1-28 and in the northeast along a e topographic low.

Figure 21 shows the elevation of top of the Wellington Shale or base of the shallow aquifer. The southwestern area is again at a lower elevation and suggests that the Wellington Shale was eroded by the paleo valley or that this is due to a structural relief. A paleo valley is the likely cause, leading to the removal of Wellington Shale.

The sample log cross section shown in Figure 22 extends from what is inferred to be a paleo valley on the left (identified with an orange horizontal bar). The cross section index is shown in Figure 19. The cross section extends through the area of the Shepherd and Blubaugh domestic wells to be sampled in the southwest and extends through the Wellington Site up to the northeastern portion of the mapped area.

The lithology of the western edge of the cross section, located in the inferred paleo valley, contains a thick sand at the bottom of the section adjacent to the top of the Wellington Shale. In contrast, the lithology at the Wellington site is silty with more clay and interpreted as the higher older terrace that was apparently cut by the younger terrace in the adjoining paleo valley to the west. Significantly, this cross section is believed be analogous and likely equivalent to the profile of the modern river deposits and older terraces illustrated by Mandell (2008) in the drainage basin immediately south of Spring and Slate Creek, along the Chikaskia River (Figure 3). It is argued here that the lateral connectivity of these temporally and spatially distinct terraces demonstrated by Mandell (2008) likely apply to the Wellington site. Permeable hydrostragraphic units comprising the lower terrace along the creek may not be laterally connected to the (older) higher terrace at the Wellington site.

The full SW to NW cross section discussed above is shown in Figure 23. Note the paleo valley northeast of the higher elevation which coincides with the large sand thickness in Figure 20. The basal contact of the surface aquifer and the contact with the Permian Wellington Shale is identified by the red line. The wavy orange line is the land surface. Note the basic conformance of the two surfaces. A Pleistocene alluvial terrace exist in the vicinity of the three shallow water wells at Wellington (SW-1,SW -2, and SW - 3), and east of these wells. as described further below. The terrace continues eastward in the cross section until reaching the fourth well from the east side where the terrace laps onto the Wellington Shale. At this well location, only a thin mantle of soil/loess overlies the Wellington Shale. The Pleistocene terrace is again present in the next two wells as the elevation falls and is then replaced by sand-rich paleo valley deposits in the northeastern-most well.

The northeastern-most well is topographically higher than the paleo valley deposits on the west side of the cross section where gravel-rich sediment occurs. The lack of gravel in the northeastern paleo valley suggests that the two valleys are distinct units, i.e., the gravel-rich sediment is inferred to be along the headland of the paleo valley and does not extend and connect to the northeastern valley where sand is present. Mapping of the paleo valley and sediments, an isopach of the shallow aquifer and the elevation of the Wellington Shale suggest a continuous paleo valley system, but the liithofacies succession suggest otherwise. Also, the low in the Wellington Shale conforms to the thicker shallow aquifer supporting an incised valley interpretation.

Shallow water wells drilled at Wellington Field reside above the paleo valley to the west. The sand and gravel, abundant and thick in the paleo valley, are replaced by red-brown silty layer (with fine sand and sticky plastic clay) that is correlated to the Bethany series of soil and the underlying parent material of a Pleistocene terrace alluvial deposit. The terrace is interpreted by Mandel (personal communication, July, 2015) as an early deposit of the ancestral Arkansas River preserved as a high terrace in north-central Sumner County. The Bethany series is described and mapped in the Soil Survey of Sumner County (USDA Soil Conservation Service). This identification was made by Rolfe Mandel at the KGS (personal communication, July 23, 2015).

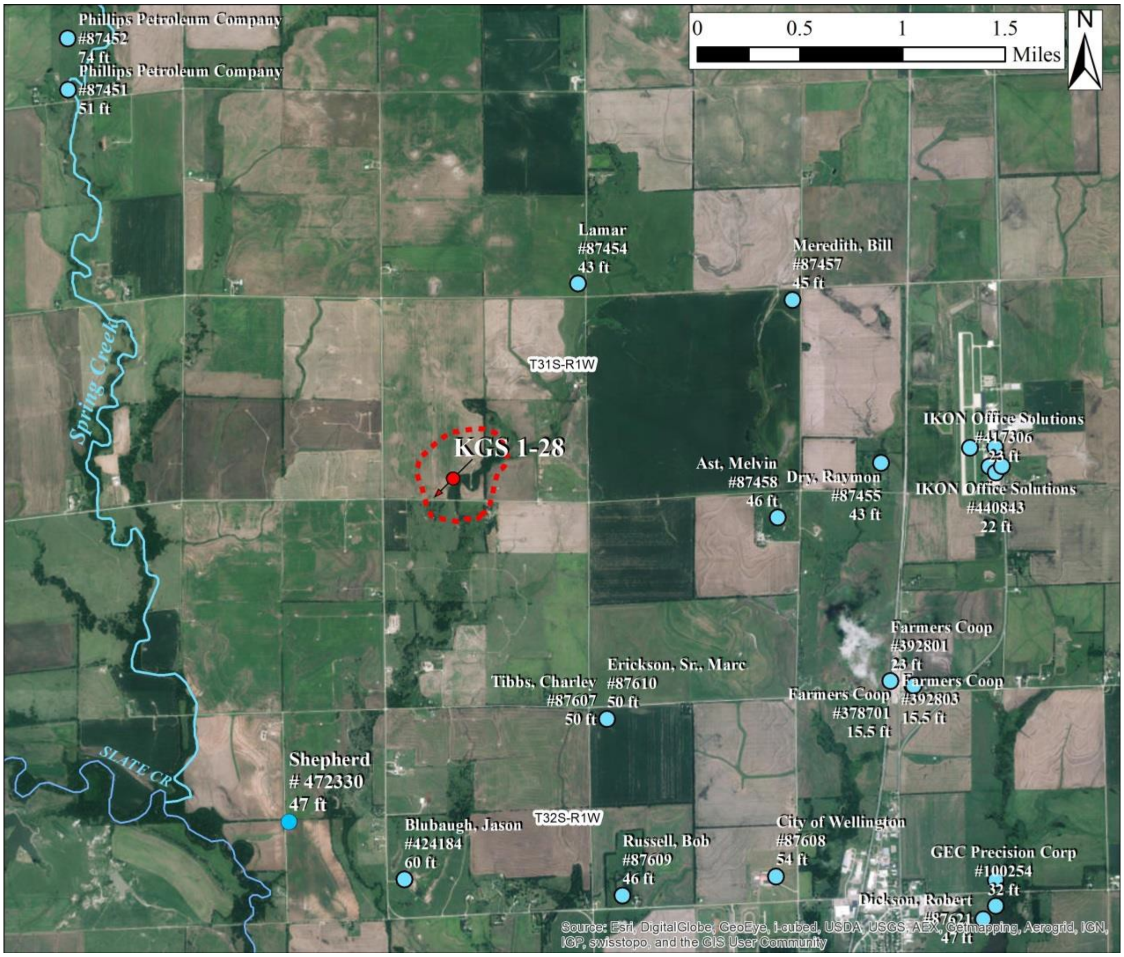


Figure 18 Extent of CO_2 plume surrounding Wellington injection well (KGS 1-28) and location of Shepard and Blubaugh water wells which have been selected for water quality sampling and comparison with shallow Wellington monitoring wells (SW-1, SW-2, and SW-3).

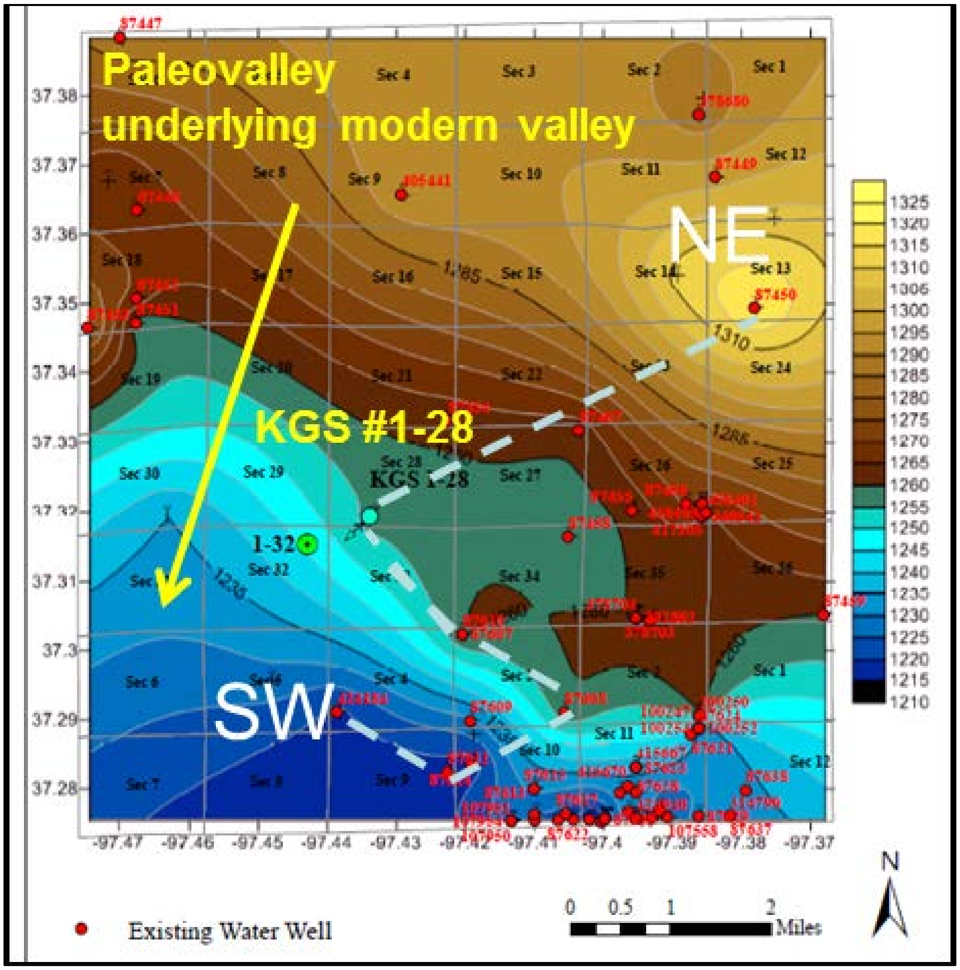


Figure 19 Elevation (ft, msl) of top of shallow unconfined aquifer in study area. Source: KGS WWC-5 water well database.

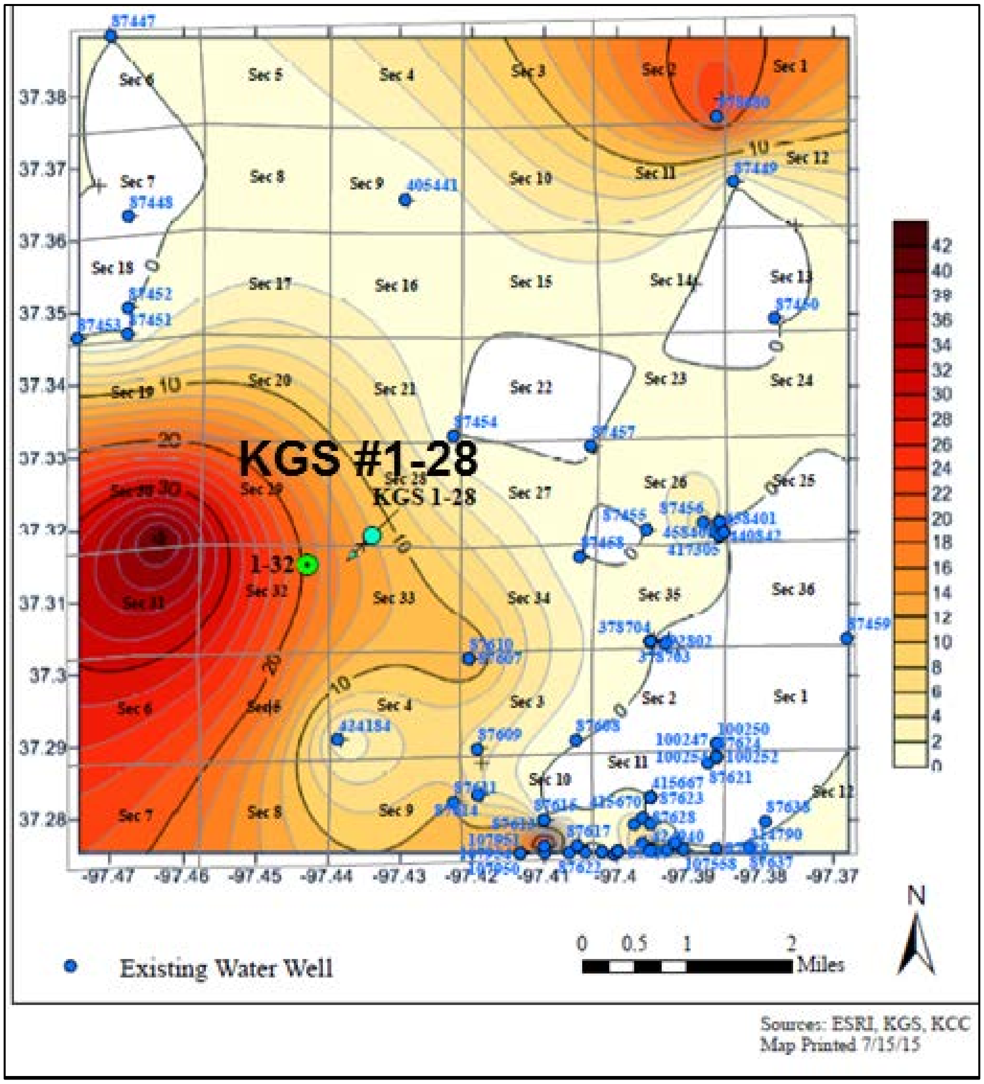


Figure 20 Net sand and gravel thickness in study area. Warmer colors indicate greater thickness. Thicknesses are in feet. Source: KGS WWC-5 water well database.

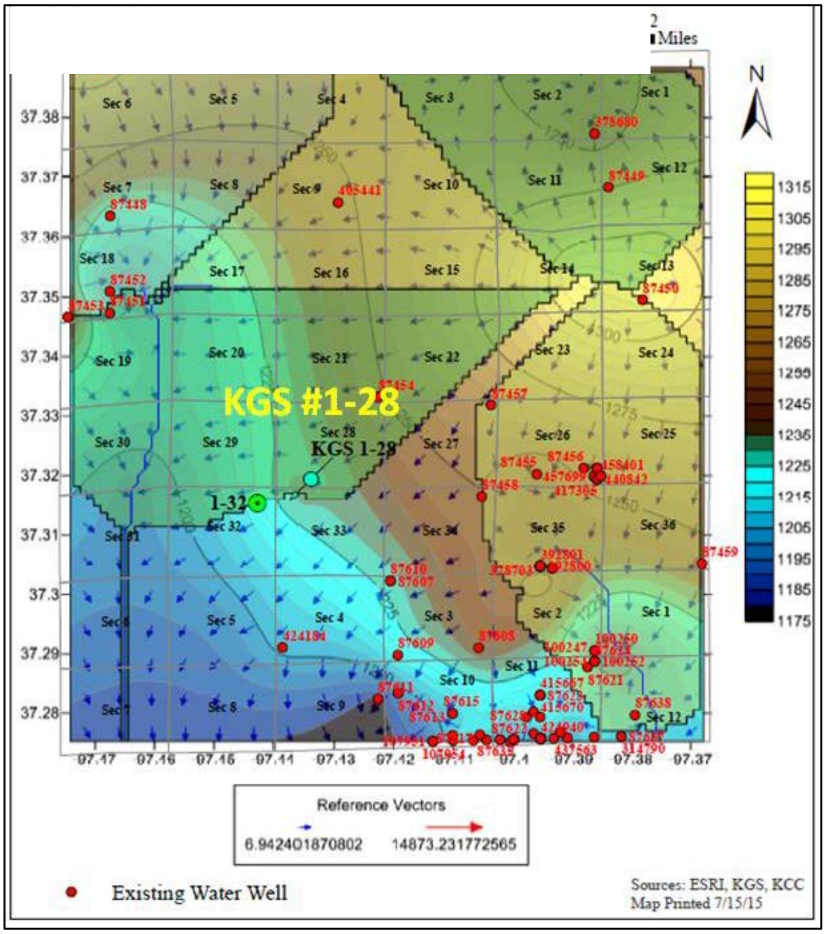


Figure 21 Elevation (ft, msl) to top of Wellington shale showing dip vectors of the surface. Source: KGS WWC-5 water well database.

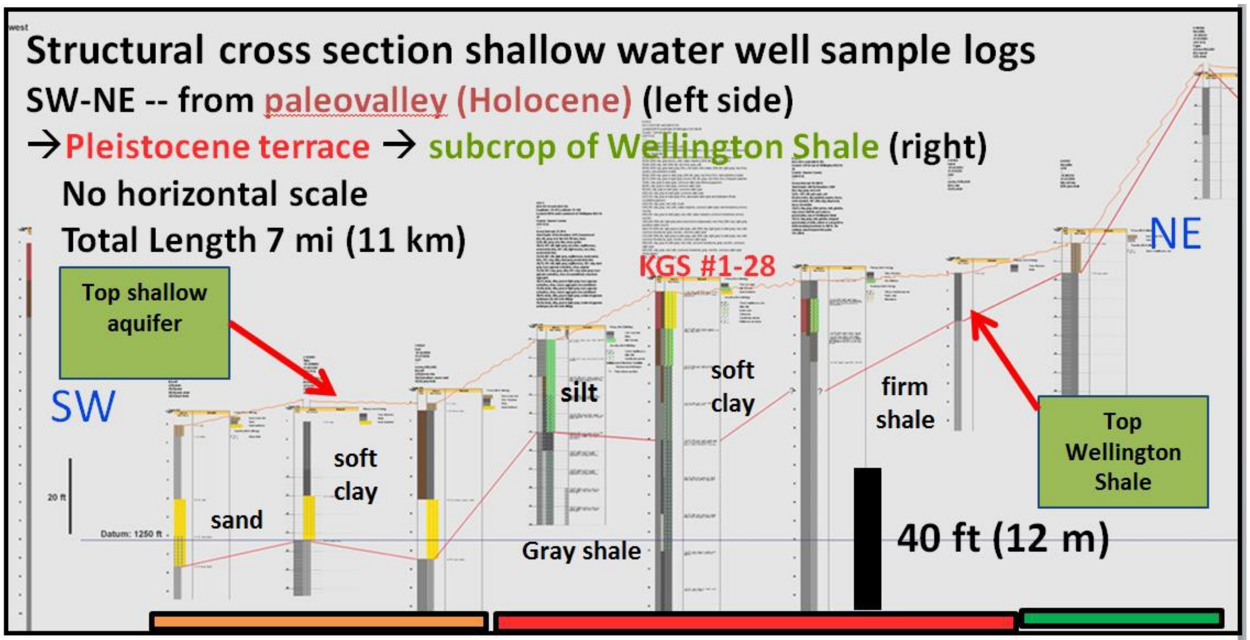


Figure 22 Structural cross-section through study area. (Source:Watney using data from Excel workbook, online Java Well Profile, and Coreldraw)

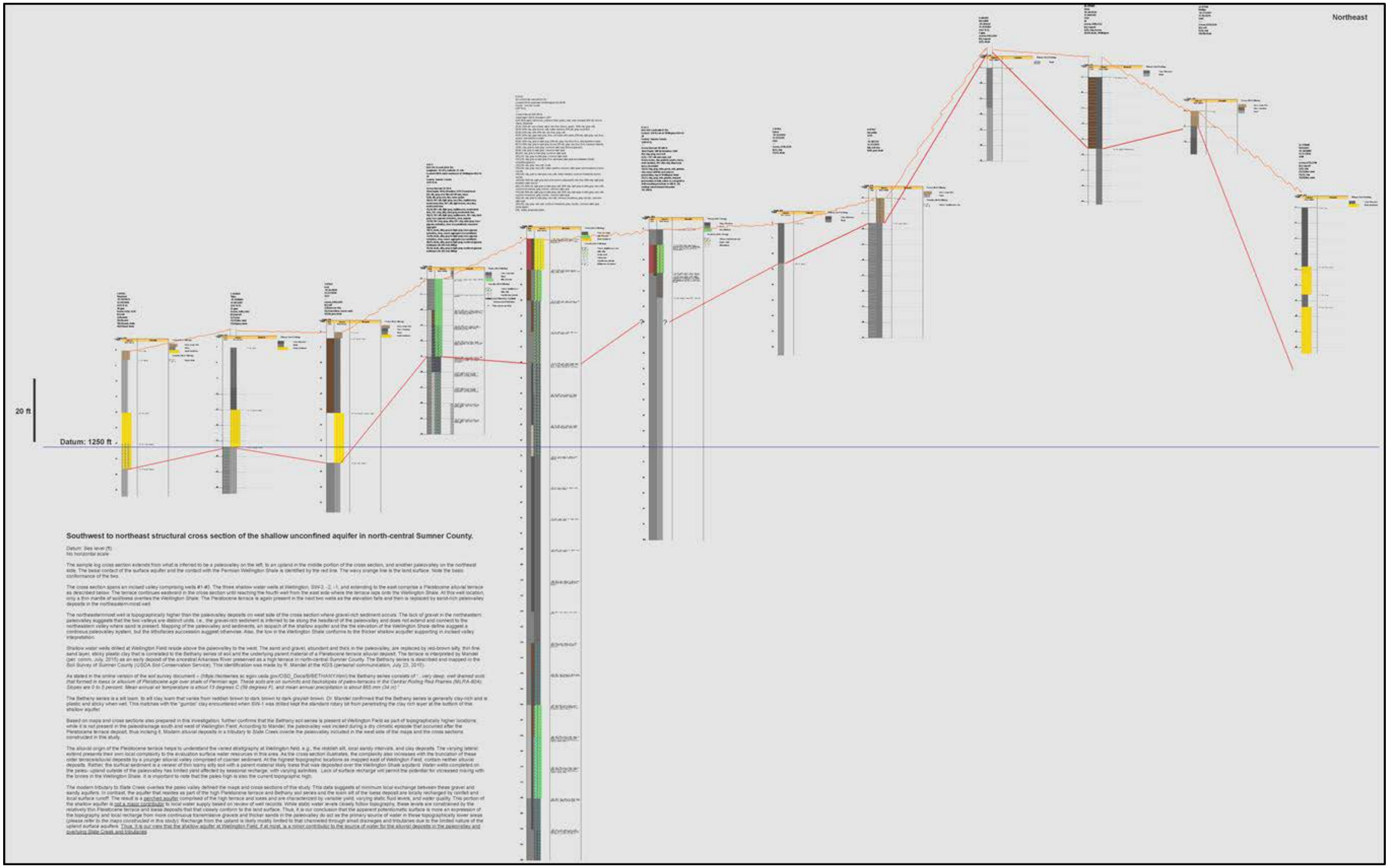

Northeast
20 ft
Datum: 1250 ft
Southwest to northeast structural cross section of the shallow unconfined aquifer in north-central Sumner County.
Datum: Sea level (ft)
No horizontal scale

Figure 23. Southwest to northeast structural cross section of the shallow unconfined aquifer in north-central Sumner County. (Source: Watney using data from Excel workbook, online Java Well Profile, and Coreldraw)

The location of the E cross section and the index is shown in Figure 19. Notice at the northeastern side of the cross section that the shallow aquifer/upper terrace consistently thins to the current topographic high to a point where the Wellington Shale directly underlies the modern soil, i.e., serving as the parent material (C horizon). Farther northeast, the elevation falls, the shallow terrace aquifer thickens and appears to be cross cut by a younger lower terrace deposit resembling the incised valley to the southwest which contains thick sand. Datum: Sea level (ft). No horizontal scale.

Conclusions

The two domestic wells, Shepherd and Bluebaugh, to be sampled for EPA are located in the sand-rich facies in both a paleo valley and the edge of a current valley of a tributary to Slate Creek. In contrast to other areas in the study area including the Wellington project site, this portion of the shallow aquifer shown in the maps and cross sections contains or lies in proximity to thick coarse clastics. The two operating domestic wells to be sampled have high yields and water which can be used with local chemical treatment. The paleo valley resides beneath and is likely hydraulically communicating with the alluvial deposits along Spring and Slate creeks. This potentially provides a source of water for the domestic wells in addition to local recharge in the area.

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