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THE JOURNAL OF THE OKLAHOMA CITY GEOLOGICAL SOCIETY

VOLUME 65

~ MARCH | APRIL 2014 ~

NUMBER 2

Structural Analysis of the Boktukola Syncline,
Central Ouachita Mountains, Oklahoma;

Inventory of Class II Underground Injection Control
Volumes in the Mid-Continent;

And Much More.

Inventory of Class II Underground Injection Control Volumes in the Midcontinent



ABSTRACT

Water and other fluids have been injected into the subsurface for decades in enhanced oil recovery (EOR) operations and for saltwater disposal (SWD). In recent years, hydraulic fracturing and horizontal wells have allowed development of unconventional oil and gas reservoirs or to redevelop conventional resources. Intense leasing, drilling, and production from the Mississippian zone of southern Kansas and northern Oklahoma are prime examples of this. Because it is economic to produce at low oil-cuts such as in the Mississippian, there is a disproportionate increase in the co-production of water. After separating water from oil and gas at the wellhead, producers are left with co-produced water having ~150,000 ppm median concentrations of total dissolved solids which is typically disposed of in SWD wells.

Research has cited an increasing number of seismic events in the midcontinent, some of which are potentially induced by fluid injection. Unfortunately, limited data are published for volumes and pressures of fluids injected or distribution of those fluids into subsurface zones. The objectives of this research were to compile Class II underground injection control (UIC) data for the year 2011 and inventory injection data by geologic zone in Kansas and Oklahoma. EOR injected (EORI) fluid volumes totaled 265.5 million barrels (MMbbl) in Kansas and 1093 MMbbl in Oklahoma with the Desmoinesian and Atokan-Morrowan zones receiving the highest EORI fluid volumes. SWD volumes totaled 754.0 MMbbl in Kansas and 891.9 MMbbl in Oklahoma with the Arbuckle and Devonian to Middle Ordovician zones receiving the highest SWD volumes. The Arbuckle Group is underpressured throughout most of the midcontinent and has an unwavering capacity to accept fluids without any observed increases in pressure. Future studies of relationships between fluid injection and seismicity must carefully compare extraction/injection histories, characterize hydrogeologic parameters, identify critically stressed faults, and explain mechanisms by which pore pressure diffuses or increases stress along a fault plane.

INTRODUCTION

Fluid Production in the U.S. Midcontinent (Kansas and Oklahoma)

Petroleum production began in the U.S. midcontinent before 1900. Oil and gas have both been continuously produced in Kansas and Oklahoma since 1906. Oil production in Kansas during 1906 was approximately 3.63 million barrels of oil (MMBO) and peaked at ~124 MMBO in 1956 (Adkins-Heljeson, 2013) as shown in Figure 1. Oil production in Oklahoma during 1906 was approximately 18.1 MMBO and peaked at ~278 MMBO in 1927 (OCC, 2012) as shown in Figure 2. Gas production in Kansas during 1906 was approximately 12.2 million barrels of oil equivalent (MMBOE) and peaked at ~160 MMBOE in 1970 (Adkins-Heljeson, 2013; EIA, 2013b). Gas production in Oklahoma during 1906 was approximately 0.62 MMBOE and peaked at ~399 MMBOE in 1990 (EIA, 2013b; OCC, 2012).

Since the year 2000 there has been an increase in the proportion of horizontal wells and hydraulic fracturing to stimulate producing formations in Oklahoma (Murray, 2013). Horizontal wells and hy-

draulic fracturing have increased production from unconventional shale plays and contributed to a resurgence of production from conventional sandstone and carbonate reservoirs in the midcontinent. Crude-oil production was approximately 41.5 MMBO in Kansas and ~76.7 MMBO in Oklahoma during 2011, ranking as the 9th and 5th highest producing U.S. states, respectively (EIA, 2013a). Gross natural-gas production was approximately 43.7 MMBOE in Kansas and ~89.3 MMBOE in Oklahoma during 2011, ranking as the 13th and 5th highest producing U.S. states, respectively (EIA, 2013b).

Dewatering projects, such as in the Hunton Lime, are prevalent throughout the midcontinent. Other plays, such as the Mississippian of southern Kansas and northern Oklahoma, also produce large volumes of water per unit of oil or gas. By multiplying water:oil ratio (3.7) by oil production and water:gas ratio (2.1) by oil-equivalent gas production, Murray (2013) estimated Oklahoma's statewide produced-water volumes to range from 811 to 925 MMbbl between 2000 and 2011. Historic (i.e., prior to 2000) produced-water volumes are difficult to estimate, but may have been similar to present-day volumes assuming that lower water:oil and water:gas ratios

from conventional production were offset by higher petroleum-production rates that peaked between ~1960 and ~1980 (Figure 1) and between ~1965 and ~1995 (Figure 2) in Kansas and Oklahoma, respectively.

Underground Injection Control (UIC) Well Designations

The underground injection control (UIC) program was implemented by the U.S. Environmental Protection Agency (EPA) in the 1980s to manage and regulate fluid injections into the subsurface. Six UIC well designations (Class I, II, III, IV, V, and VI) are used to manage injections from various industries. The EPA maintains regulatory authority over subsurface fluid injection but may delegate authority of Class II wells to state agencies. The Kansas Corporation Commission and Oklahoma Corporation Commission are delegated authority over Class II UIC wells, except in Osage County, Oklahoma where EPA maintains authority. Current regulatory controls over Class II UIC wells were designed to protect potable-water sources from contamination. Class II UIC wells fulfill two basic purposes in the oil and gas sector, enhanced oil-recovery injection (EORI) and salt-water disposal (SWD). EORI wells are designed

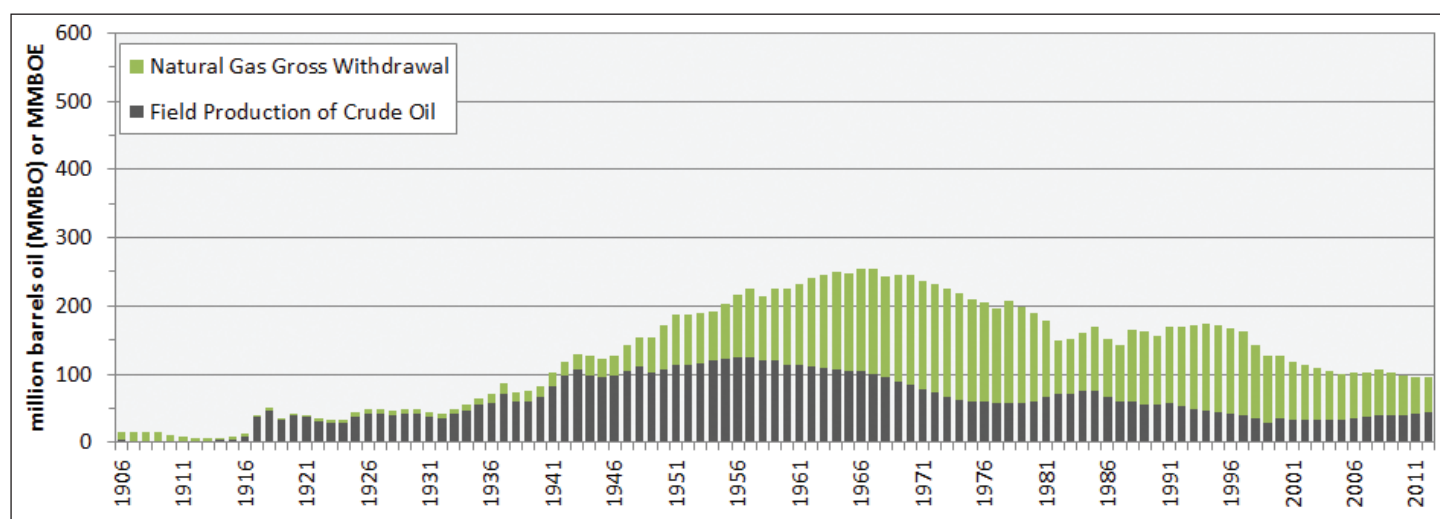


Figure 1. Annual field production of crude oil and annual natural gas gross withdrawal in Kansas from 1906 to 2012. Sources: Adkins-Heljeson (2013) and EIA (2013b)

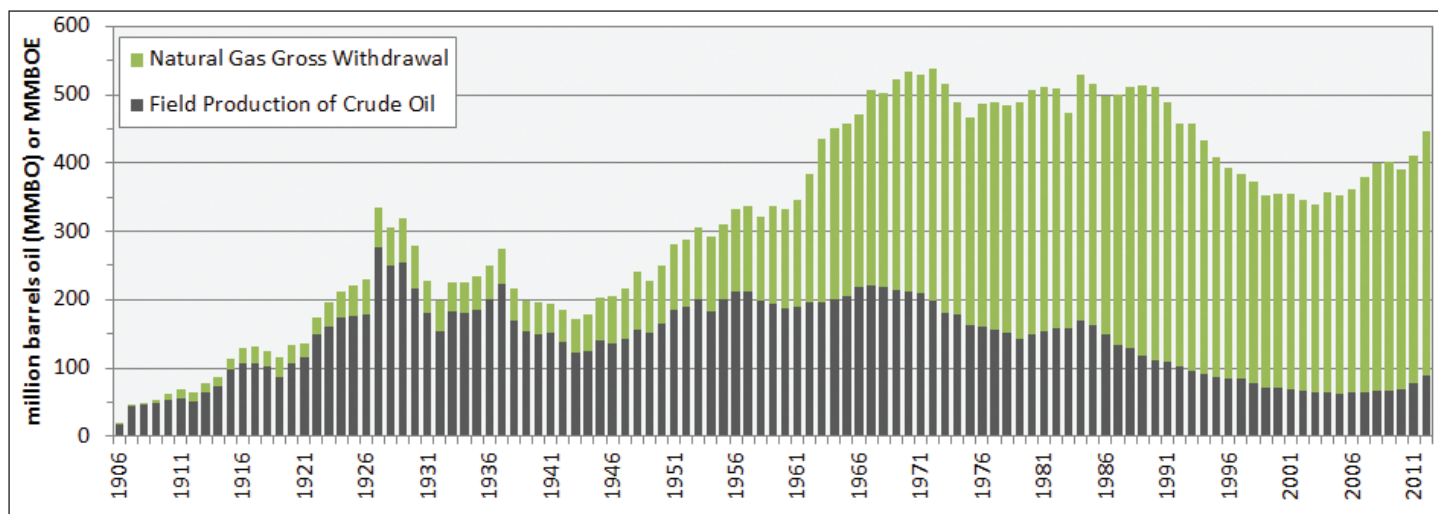


Figure 2. Annual field production of crude oil and annual natural gas gross withdrawal in Oklahoma from 1906 to 2012. Sources: EIA (2013b) and OCC (2012)

to inject fluids (water and/or CO₂) into the subsurface to mobilize oil and/or gas into production wells. During EORI, pressure across the field is monitored so as not to exceed virgin pressure conditions. SWD wells are designed to dispose of brine water that was co-produced with oil and gas. SWD wells ideally function on a vacuum or require low wellhead-injection pressures.

Potential for Induced Seismicity from Fluid Injection

Fluid injection, including EORI (Davis and Pennington, 1989) and SWD (Horton, 2012; Keranen et al., 2013; Nicholson and Wesson, 1990), have been shown to contribute to seismicity mainly by reducing normal stress so that movement occurs along a pre-existing fault (Healy et al., 1968; NRC, 2012; Raleigh et al., 1976). Some of the largest magnitude earthquakes associated with SWD injections were centered in the midcontinent states of Arkansas, Oklahoma, and Texas (Frohlich, 2012; Horton, 2012; Keranen et al., 2013). Regardless of potential connections, research on the topic of induced seismicity recognizes the uncertainty and the difficulty in distinguishing between natural or induced seismic events. One

major limitation of this line of research relates to the unknown quality of UIC data including x-y location, z elevation, zone of completion, volume and pressure. Integrated hydrogeologic, structural geologic, and seismologic studies are required because mechanisms for fluid-injection induced seismicity are related to stresses and strength of faults, hydraulic properties of injection zones, and pressure diffusion (Ellsworth, 2013; Holland, 2013).

Objectives

Absent from the fluid-injection induced seismicity literature are broad-scale perspectives on fluid-injection volumes and pressures and accurate reporting of geologic intervals that receive those fluids. The objectives of this research were to compile and summarize volumes of water used for EORI and SWD in the midcontinent and summarize volumes by geologic injection zone.

METHODOLOGY

Because data related to UIC programs in Kansas and Oklahoma were reported to multiple organizations and uniquely formatted, multiple databases were designed and maintained during the course of this

research. API numbers were used to manage data associated with unique well locations.

Compile UIC Well Locations and Injection Volumes

Fluid-injection volumes into Class II UIC wells in 2011 were obtained from the Kansas Corporation Commission and the Oklahoma Corporation Commission (Lord, 2012; Snider, 2013) and used to create a relational database for each state (i.e., Kansas UIC and Oklahoma UIC). Records were managed using API number when appending data to the respective Kansas UIC or Oklahoma UIC database. Well-completion data were obtained from the Kansas Geological Survey or Oklahoma Corporation Commission well databases and interactive web-sites (KGS, 2013; OCC, 2013). Fluid injections in Osage County, Oklahoma Class II UIC wells, regulated by EPA, have different reporting procedures, therefore, were not included in this study.

Attribute Injection Zones for Wells

Injection zones were represented using twelve categories: Permian, Virgilian, Missourian, Desmoinesian, Atokan-Mor-

rowan, Mississippian, Woodford, Devonian to Middle Ordovician (Dev to Mid Ord), Arbuckle, Basement, Multiple-Undifferentiated, and Other or Unspecified. 'Producing' or 'injection' formation(s) were correlated to the appropriate zone (Figure 3) based on the Stratigraphic Guide to Oklahoma Oil and Gas Reservoirs (Boyd, 2008). When producing or injection formation was not specified in the Kansas UIC or Oklahoma UIC databases, the completion reports (e.g., Oklahoma Corporation Commission's Form 1002A) or other digitally accessible records were examined for each API number in Kansas (<http://www.kgs.ku.edu/Magellan/Qualified/index.html>) or Oklahoma (<http://www.occpermit.com/WellBrowse/Home.aspx>). The injection formation(s) for the most recent completion of each API number was determined, when possible, and added as an attribute. When records indicated that the injection interval consisted of multiple groups or formations (e.g., Bartlesville and Dutcher) from more than one zone, then the well was attributed as 'Multiple-Undifferentiated.' When records indicated that a formation (e.g., Cretaceous Niobrara) other than the ten designated zones (Figure 3) was used for injection or the target formation was not discernible, the well was attributed as 'Other or Unspecified.'

Summarize Volumes by Injection Zones

Class II underground injection control wells were selected (i.e., queried) within the Kansas UIC and Oklahoma UIC databases, grouped by injection zone and injection type (e.g., EORI or SWD), and injection volumes were summed. From these queries, total water-injection volumes were estimated for each zone in Kansas and Oklahoma during 2011.

RESULTS AND DISCUSSION

The Kansas UIC database contained 9559 UIC wells of which 6118 wells had reported EORI water volumes and 3441 wells had SWD volumes in 2011. The Okla-

Zone	Group	Formation	
Permian		Garber	
	Chase	Brown Dolomite	
	Council Grove	Pontotoc	
	Admire	Belveal	
Virgilian	Wabaunsee	Cisco Lime	
	Shawnee	Pawhuska	
	Douglas	Endicott	
Missourian	Hoxbar	Tonkawa	
		Lansing	
		Cottage Grove	
		Kansas City	
		Hogshooter	
		Layton	
		Cleveland	
Desmoinesian	Marmaton	Oswego	
	Cabaniss	Skinner	
	Krebs	Red Fork	
		Burbank	
		Bartlesville	
		Hartshorne	
Atokan-Morrowan	Atoka	Gilcrease	
	Morrow	Dutcher	
	Springer	Cromwell	
Mississippian	Chester	Wamsley	
		Manning	
	Meramec	Caney	
		Miss Lime	
		Miss Chat	
		St. Louis	
		Mayes	
Osage	Sycamore		
Kinderhook	Kinderhook		
Woodford	Upper Devonian	Woodford	
Dev to Mid Ord	Middle Devonian	Misener	Key to Symbols
	Lower Dev - Silurian	Hunton	Sandstone
	Cincinnatian	Sylvan	
		Viola	Carbonate
	Simpson	Bromide	
		Wilcox	
McLish		Shale	
Oil Creek			
Arbuckle	Arbuckle Group	West Spring Creek	Coal
		Kindblade	
		Butterly Dolomite	Granite
Basement & Crystalline Rock	Cambrian	Reagan	
	Pre-Cambrian	Granite	

Figure 3. Correlation chart of groups, sub-groups or formations comprising injection zones. Modified from Stratigraphic Guide to Oklahoma Oil and Gas Reservoirs (Boyd, 2008).

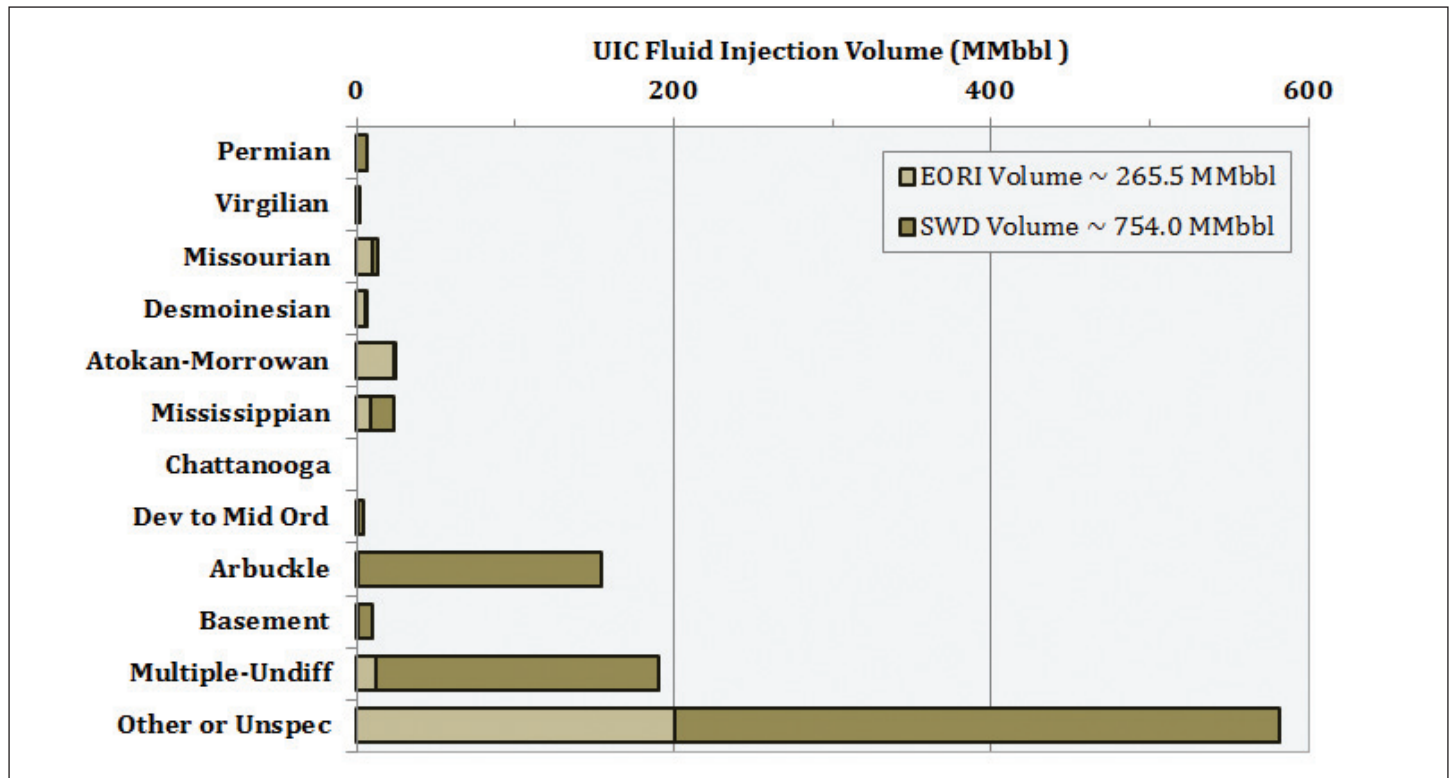


Figure 4. Fluid volumes injected, by zone, into UIC wells in Kansas during 2011.

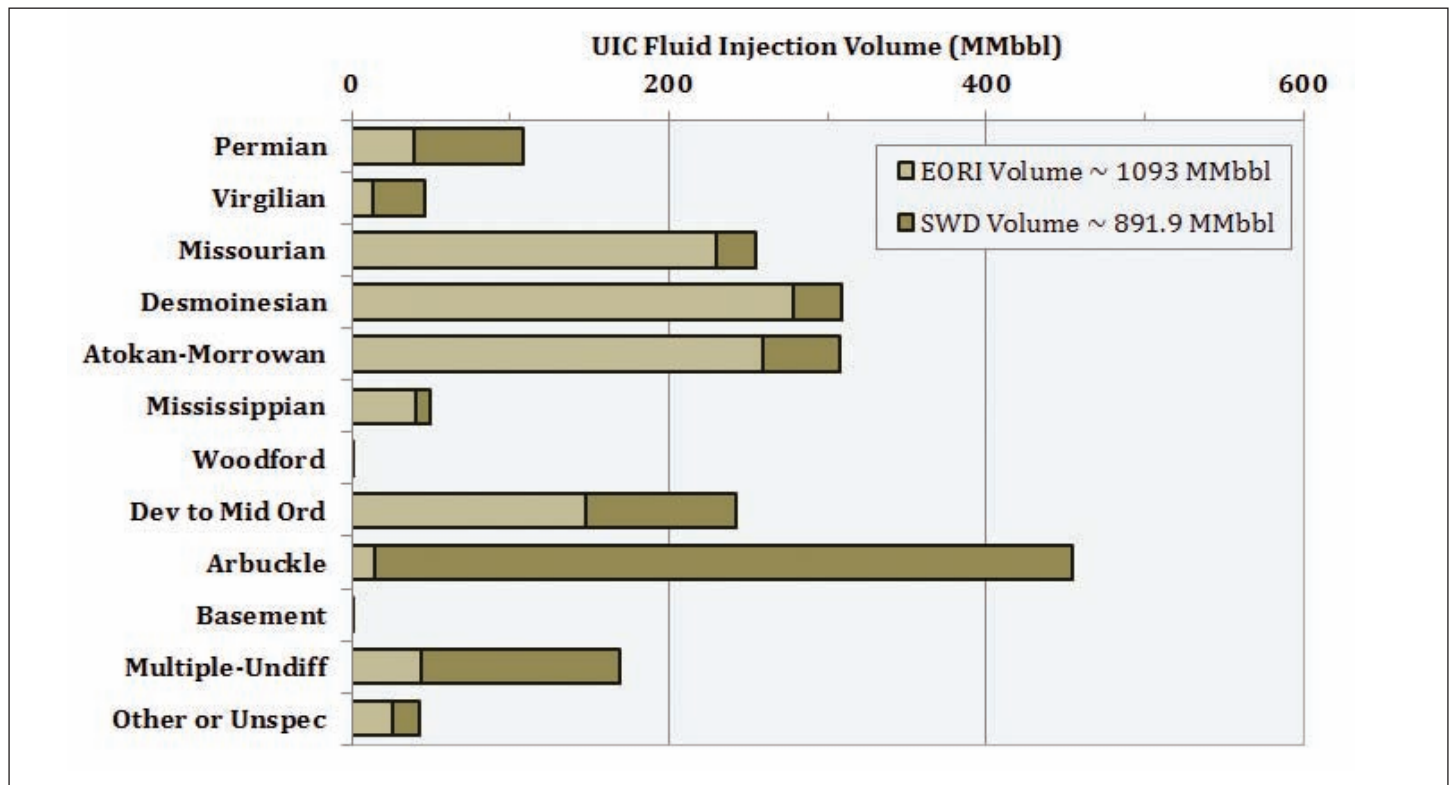


Figure 5. Fluid volumes injected, by zone, into UIC wells in Oklahoma during 2011.

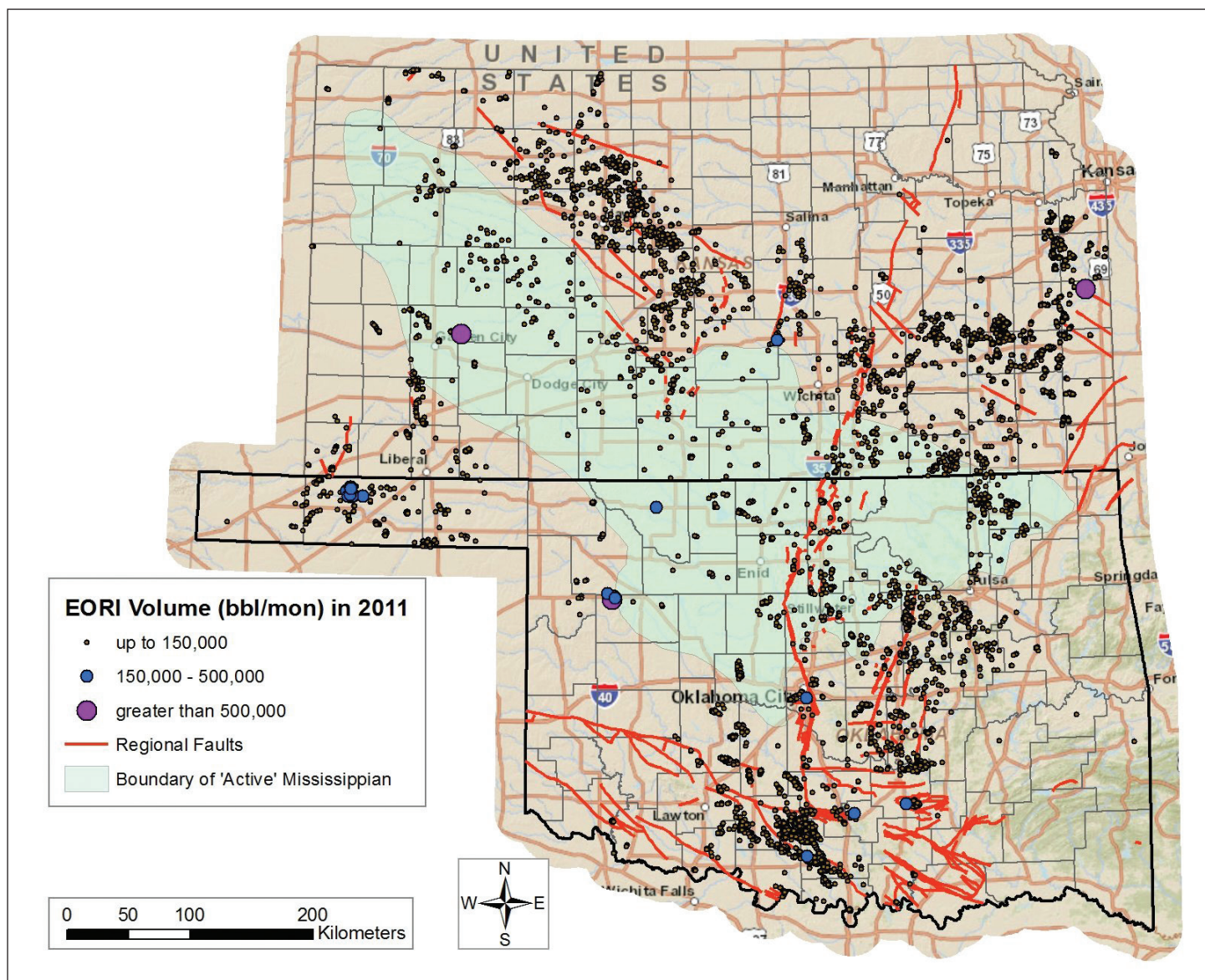


Figure 6. Locations of EORI wells in the midcontinent. Faults from Cole (1976), Nodine-Zeller and Thompson (1977), and Northcutt and Campbell (1995).

homa UIC database contained 9630 UIC wells of which 5506 had reported EORI water volumes and 4124 wells has SWD volumes in 2011.

Class II UIC Statewide Volumes by Geologic Injection Zone

Total volume of EORI fluid in Kansas was ~265.5 MMbbl in 2011. A substantial number of Kansas UIC wells were not attributed with a known injection zone, so

the largest EORI volumes are illustrated in Figure 4 as going to ‘Other or Unspecified’ zones. Injection zones in Kansas receiving the largest volumes of EORI fluid were the Atokan-Morrowan and Missourian. Total volume of EORI fluid injection in Oklahoma was 1093 MMbbl in 2011. The Desmoinesian (278.3 MMbbl) and Atokan-Morrowan (259.2 MMbbl) zones received the largest volumes of EORI fluid in Oklahoma (Figure 5). EORI volumes into the Arbuckle and underlying

PreCambrian Basement zones were minimal, which suggests that EORI has a low probability of inducing seismic activity.

Total volume of SWD in Kansas was ~754.0 MMbbl in 2011. Because the completion zones were unknown for a high percentage of Kansas UIC wells, the largest SWD volumes are illustrated in Figure 4 as going to ‘Multiple-Undifferentiated’ and ‘Other or Unspecified’ zones. The Arbuckle and Mississippian zones received

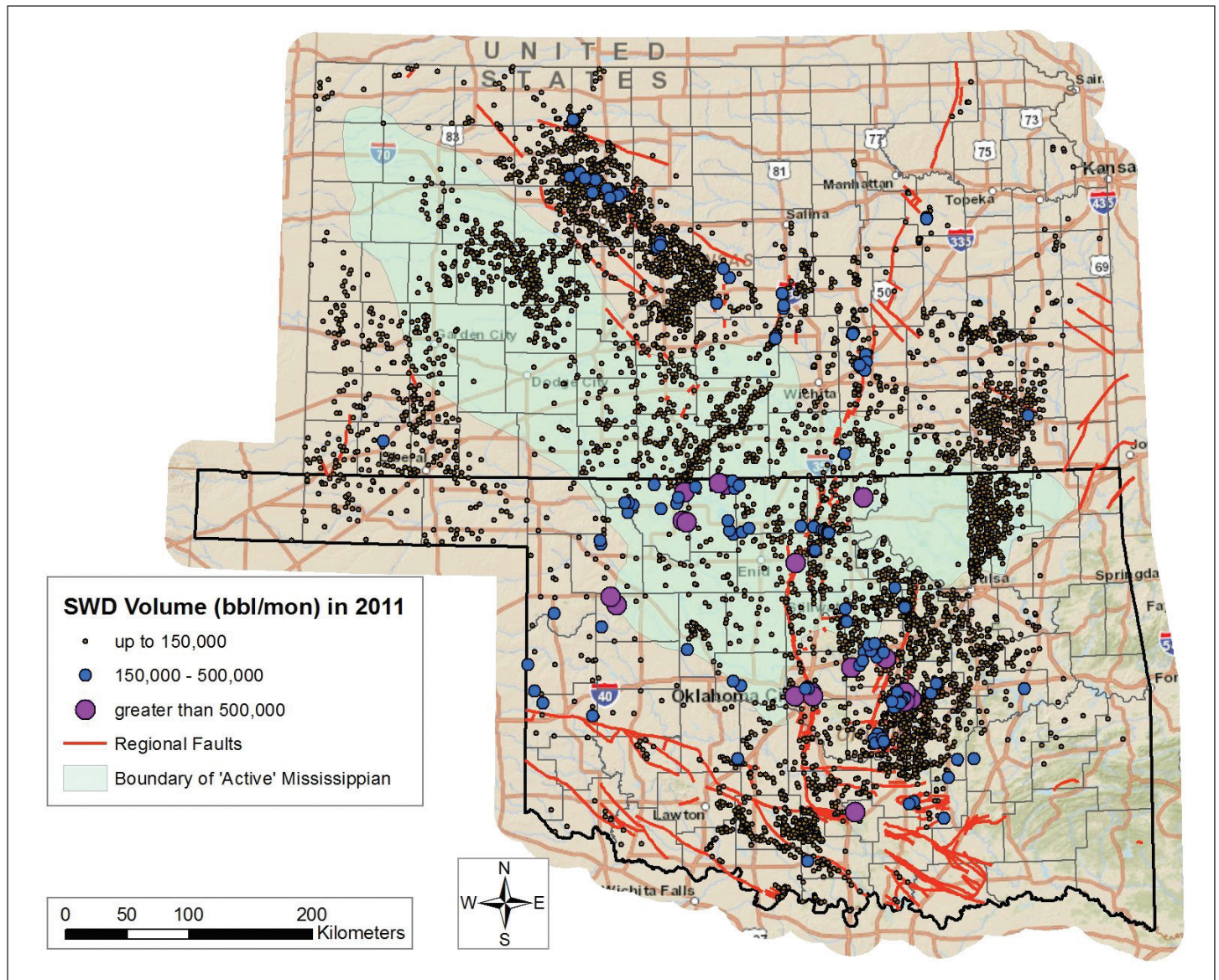


Figure 7. Locations of SWD wells in the midcontinent. Faults from Cole (1976), Nodine-Zeller and Thompson (1977), and Northcutt and Campbell (1995).

the largest amounts of SWD in Kansas. Total volume of SWD in Oklahoma was ~891.9 MMbbl in 2011 as illustrated in Figure 5. The Arbuckle (440.1 MMbbl) and Permian (68.5 MMbbl) zones received the largest amounts of SWD fluid in Oklahoma, with substantial amounts also being injected into Multiple-Undifferentiated (125.5 MMbbl) zones. Because the Arbuckle directly overlies the Precambrian basement, SWD wells have higher probability (than EORI wells) for

inducing seismicity. Those wells that are completed in the Basement or attributed as 'Multiple-Undifferentiated' with completion intervals in the Basement should be further examined (e.g., proximity to faults) to reduce risk of induced seismicity.

Highest Volume Class II UIC Wells

There were many active EORI wells in Kansas (6118) and Oklahoma (5506)

during 2011; however, only a small fraction (0.27%) of the EORI wells, shown in Figure 6, injected substantial volumes (>150,000 bbl/month). This injection rate was notable in the Barnett Shale region of Johnson County, Texas where 33.3% of the UIC wells exceeded 150,000 bbl/month and seismicity was potentially induced (Frohlich, 2012).

There were also many active SWD wells in Kansas (3441) and Oklahoma (4124)

during 2011. A small fraction (2.64%) of the SWD wells in Kansas and Oklahoma exceeded 150,000 bbl/mon (Figure 7).

Research Priorities for Understanding Fluid-Injection-Induced Seismicity

Measurement of pre-injection hydrologic conditions and formation pressure, along with increased temporal resolution of injection rates and pressures are critical for understanding the dynamic relationships between fluid injection and seismicity (Ellsworth, 2013). Thorough evaluation of the presence or absence of faulting near fluid-injection wells (Frohlich, 2012) is also a priority for understanding potential for induced seismicity. Reasonable esti-

mates of field-scale historic and future fluid-injection and withdrawal volumes must be made for all production or injection zones so that critical pore pressures can be understood. Integrated hydrogeologic, structural geologic, and seismologic datasets may then be evaluated to establish mechanisms by which fluid injection increases pore pressure along a fault plane. These integrated scientific studies would be useful for the development of adaptable regulatory requirements and best-management practices for fluid injection.

ACKNOWLEDGEMENTS

The authors acknowledge colleagues at the Oklahoma Geological Survey for re-

viewing preliminary versions of this article. Charles Lord of the Oklahoma Corporation Commission and Alan Snider of the Kansas Corporation Commission are acknowledged for providing UIC volumes data in the midcontinent. Analyses presented in this article are based on information available to the authors, and do not necessarily represent the views of the Oklahoma Geological Survey, University of Oklahoma, their employees, or the State of Oklahoma. The accuracy of the information contained herein is not guaranteed by the authors, Oklahoma Geological Survey, or the University of Oklahoma.

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Biographical Sketch

Kyle E. Murray has worked as a Hydrogeologist for the Oklahoma Geological Survey (OGS) since 2011. He earned a B.A. in Geography/Environmental Studies from Shippensburg University-Pennsylvania in 1995, an M.S. in Hydrogeology from Wright State University-Ohio in 1997, and a Ph.D. in Geological Engineering from Colorado School of Mines-Colorado in 2003. Kyle lived in Colorado from 1997 to 2004, during which he worked as an environmental consultant and a GIS Specialist for the USGS. From 2004 to 2011, he was a faculty member in the Departments of Geology and Environmental Science and Engineering at the University of Texas at San Antonio.

Kyle E. Murray

After joining the OGS, Kyle was appointed as an adjunct faculty member in the ConocoPhillips School of Geology and Geophysics at the University of Oklahoma (OU). Dr. Murray supervises undergraduate and graduate research projects involving geology, hydrogeology, and petroleum geology of Oklahoma. Kyle's research emphasis at OGS and OU is on the interplay between water and energy resources. He has presented this line of research in public venues and conferences held by GWPC, GSA, AAPG, and NGWA. In 2014, he is partnering with OERB's committee for Sustaining Oklahoma's Energy Resources to present Produced Water workshops in Ardmore, Woodward, Tulsa, and Oklahoma City.



Biographical Sketch

Austin Holland is a research seismologist with the Oklahoma Geological Survey (OGS). He has been with the OGS since January of 2010. Since arriving at the OGS Austin has worked on issues of triggered seismicity. He is currently finishing his Ph.D. at the University of Arizona where his focus was primarily on measuring deformation of the Earth using high precision GPS and earthquake seismology. He received his Masters of Science in Geophysics from the University of Texas at El Paso, and his Bachelors of Science in Geology from the University of Idaho. He worked at the Department of Energy's Idaho National Laboratory for 12 years in the seismic monitoring program.

Austin Holland