



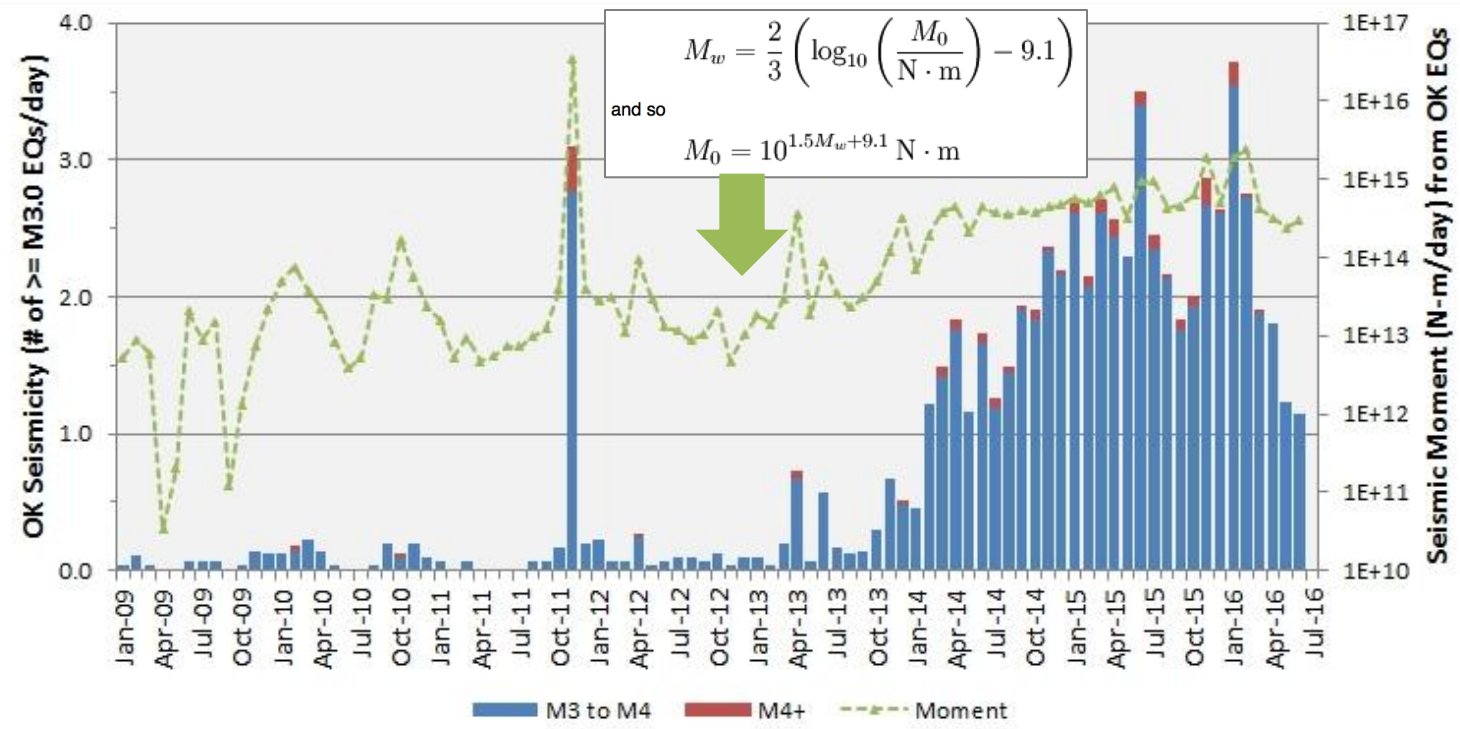
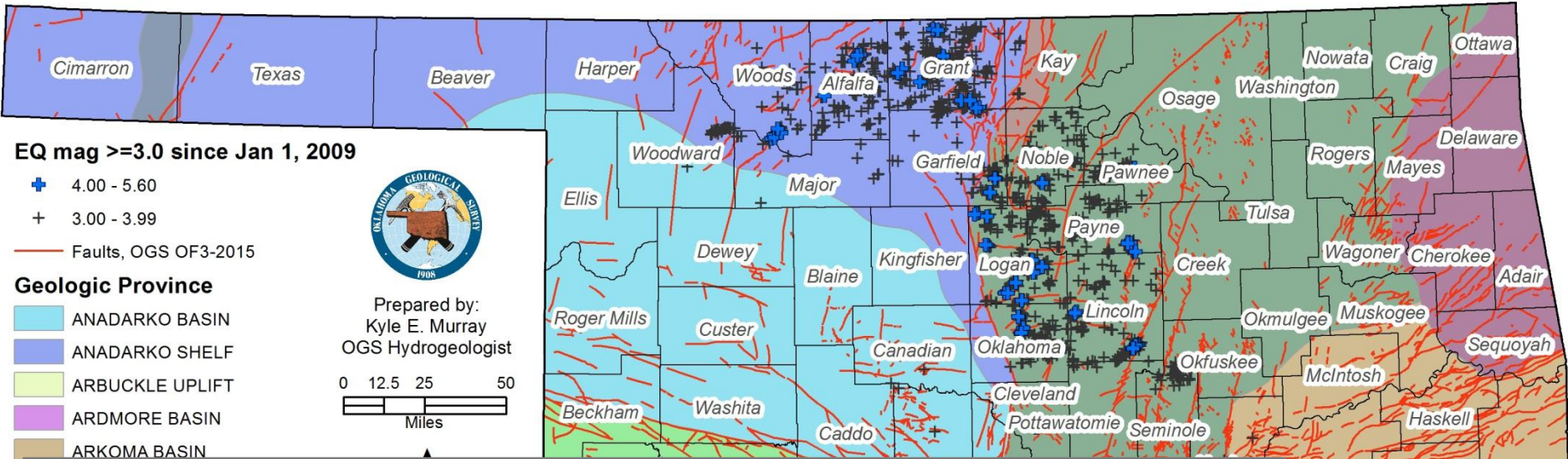
The UNIVERSITY of OKLAHOMA
Mewbourne College of Earth and Energy
ConocoPhillips School of Geology and Geophysics
ConocoPhillips

Kyle E. Murray, PhD, Hydrogeologist

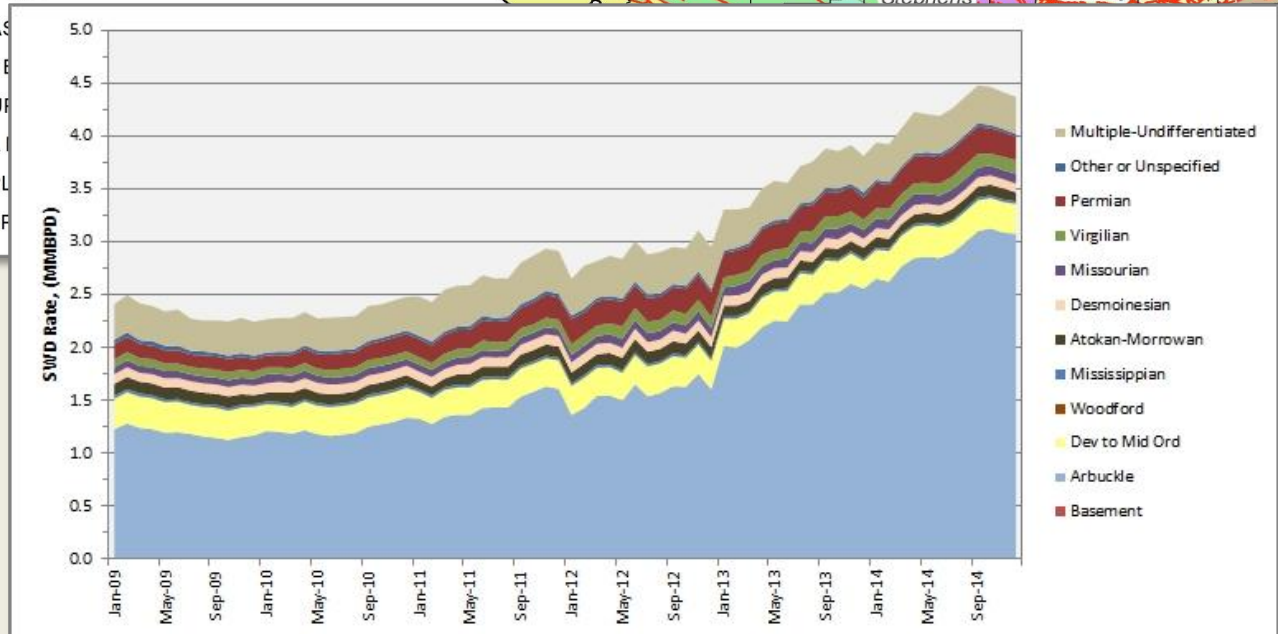
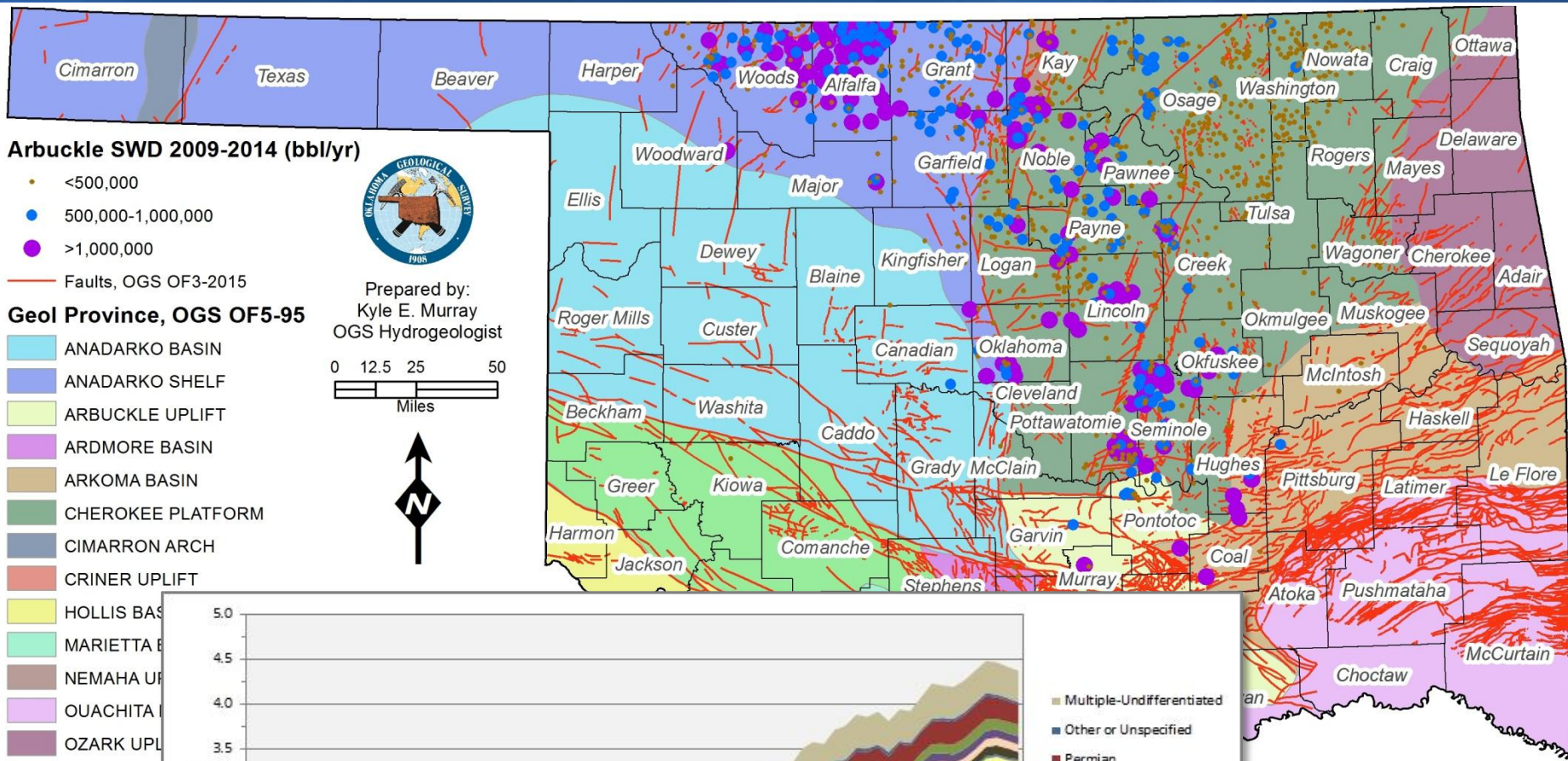
Presents:

Quantity and Quality of Produced Water in Oklahoma

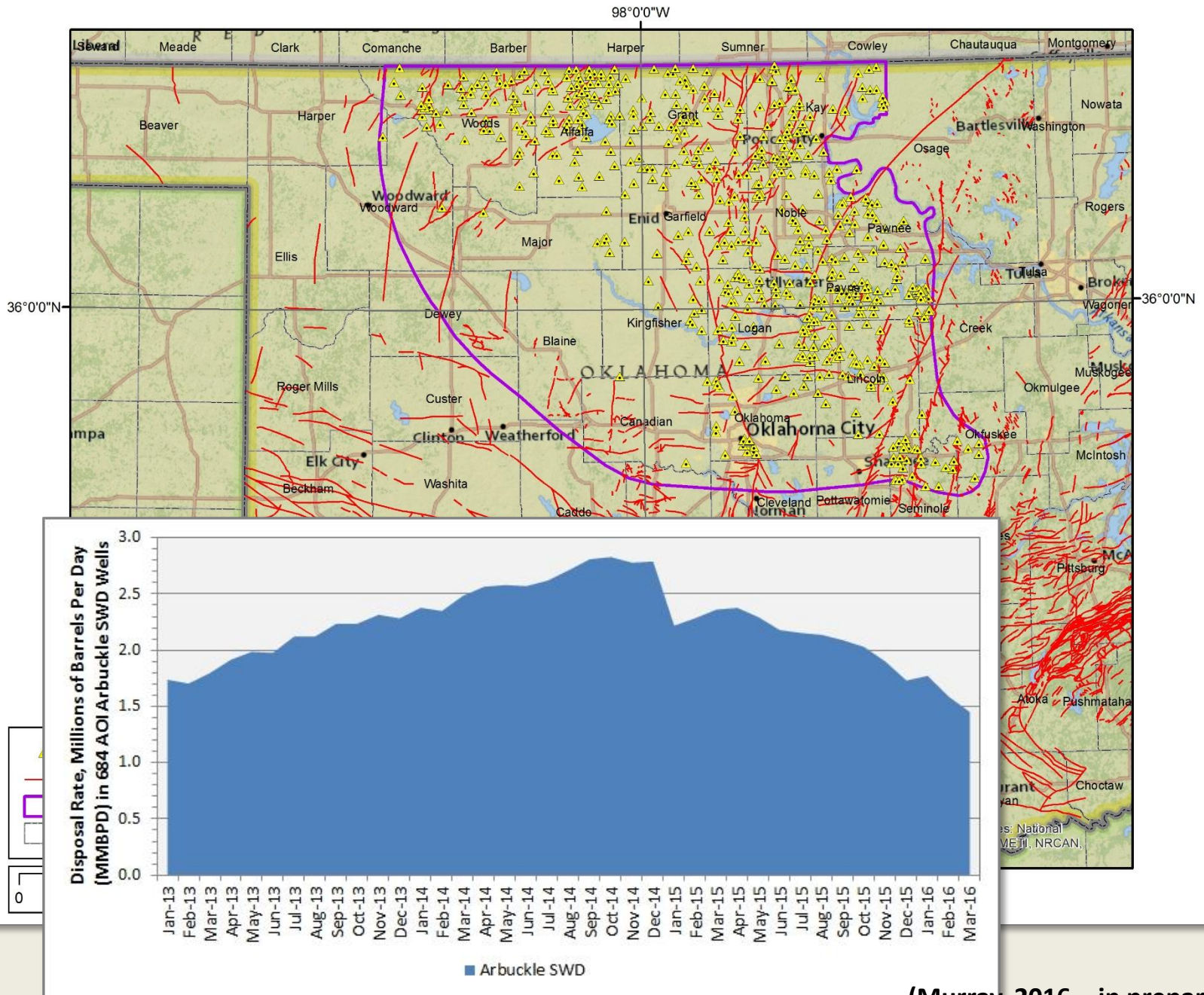
Earthquakes Mag ≥ 3.0 , Jan 1, 2009–Jun 7, 2016



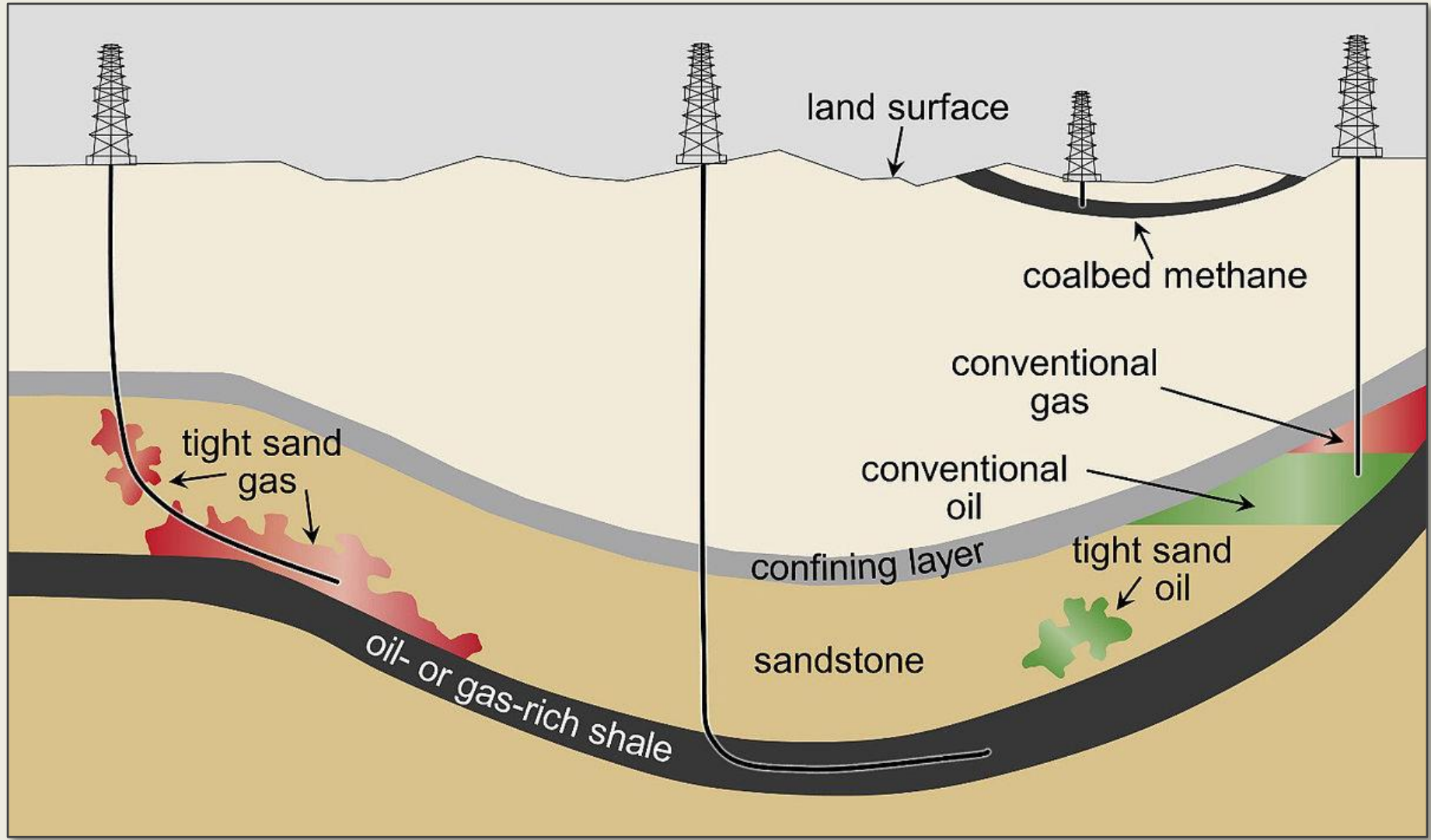
Arbuckle SWD in Oklahoma, 2009–2014



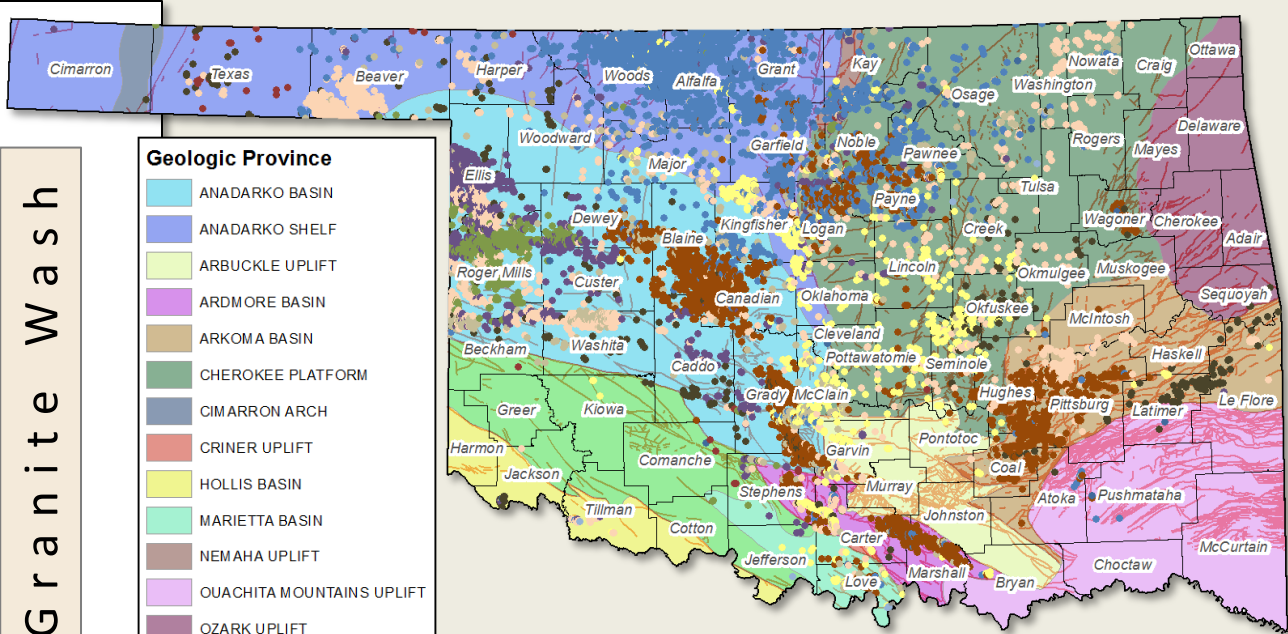
Arbuckle SWD in Area of Interest (AOI) Jan 2013–Mar 2016



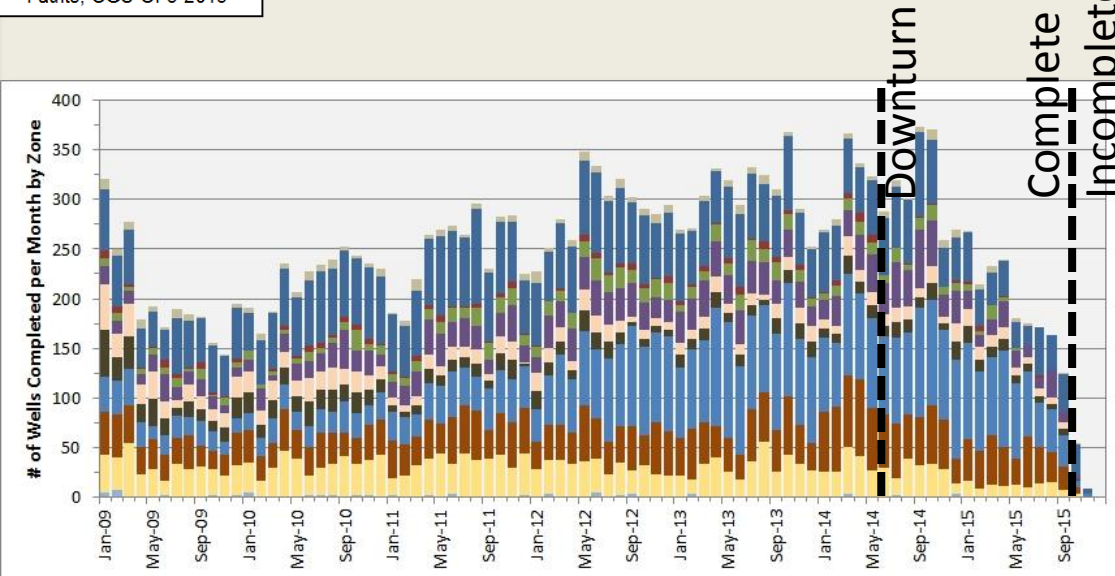
Conventional vs. Unconventional Production



Zone	Group	Formation
Multiple-Undiff		
Other or Unspec.		
Permian		Garber
	Chase	Brown Dolomite
	Council Grove	Pontotoc
Virgilian	Admire	Belveal
	Wabaunsee	Cisco Lime
	Shawnee	Pawhuska
	Douglas	Endicott
Missourian	Hoxbar	Tonkawa
		Lansing
		Cottage Grove
		Kansas City
		Hogshooter
Desmoinesian	Marmaton - Deese	Layton
		Cleveland
	Cabaniss - Deese	Oswego
		Skinner
	Krebs - Deese	Red Fork
		Burbank
Bartlesville		
Atokan-Morrowan	Atoka	Hartshorne
		Gilcrease
		Dutcher
		Cromwell
Mississippian	Springer	Wamsley
		Manning
		Caney
	Meramec	Miss Lime
		Miss Chat
		St. Louis
		Mayes
Osage	Sycamore	
	Kinderhook	
Woodford	Upper Devonian	Woodford
Dev to Mid Ord	Middle Devonian	Misener
		Frisco
	Hunton	Bois d'Arc
		Henryhouse
		Chimneyhill
	Cincinnatian	Sylvan
		Viola
	Simpson	Bromide
Wilcox		
McLish		
Arbuckle	Arbuckle Group	Oil Creek
		West Spring Creek
		Kindblade
		Cool Creek
		McKenzie Hill
		Butterly dolomite
		Signal mountain
Royer dolomite		
Basement & Crystalline Rock	Cambrian	Reagan
	Pre-Cambrian	Granite



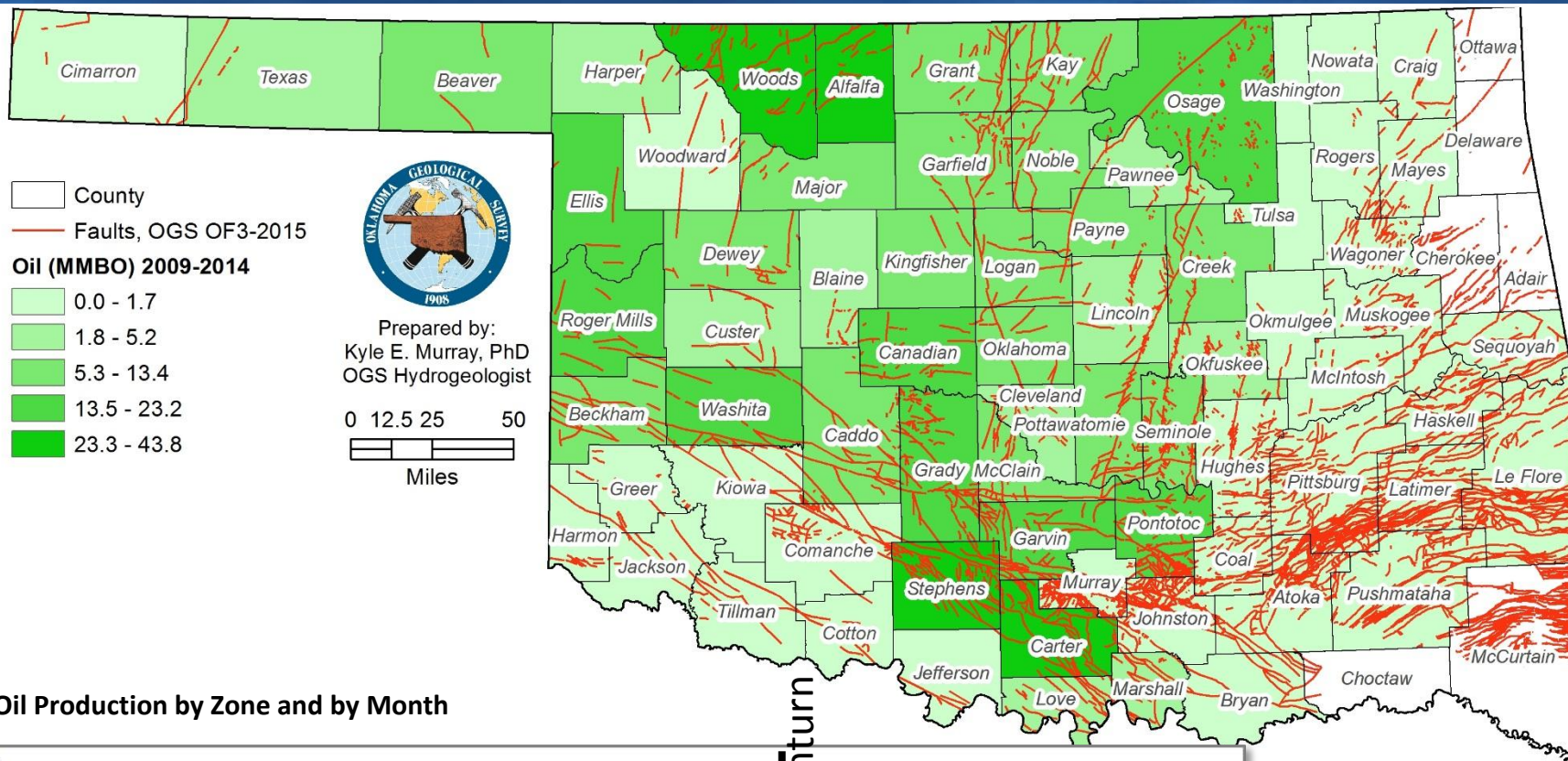
Wells that Started Producing from 2009–2015



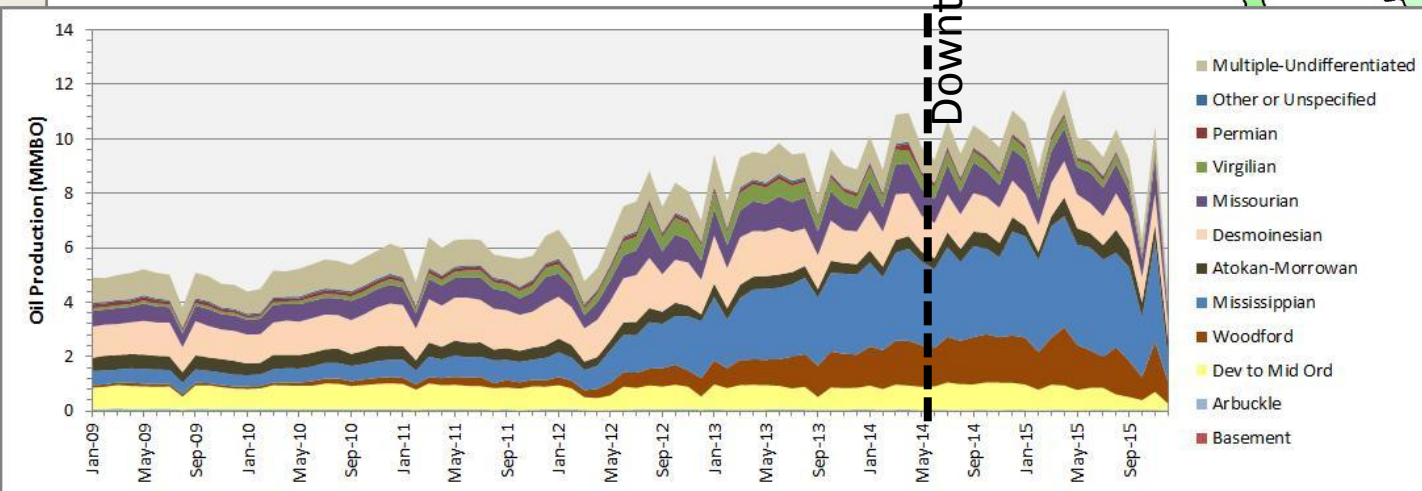
Completions by Zone and by Month, 2009–2015

(Murray, 2016 – in preparation)

Oil Production by County 2009–2014 and by Zone 2009–2015

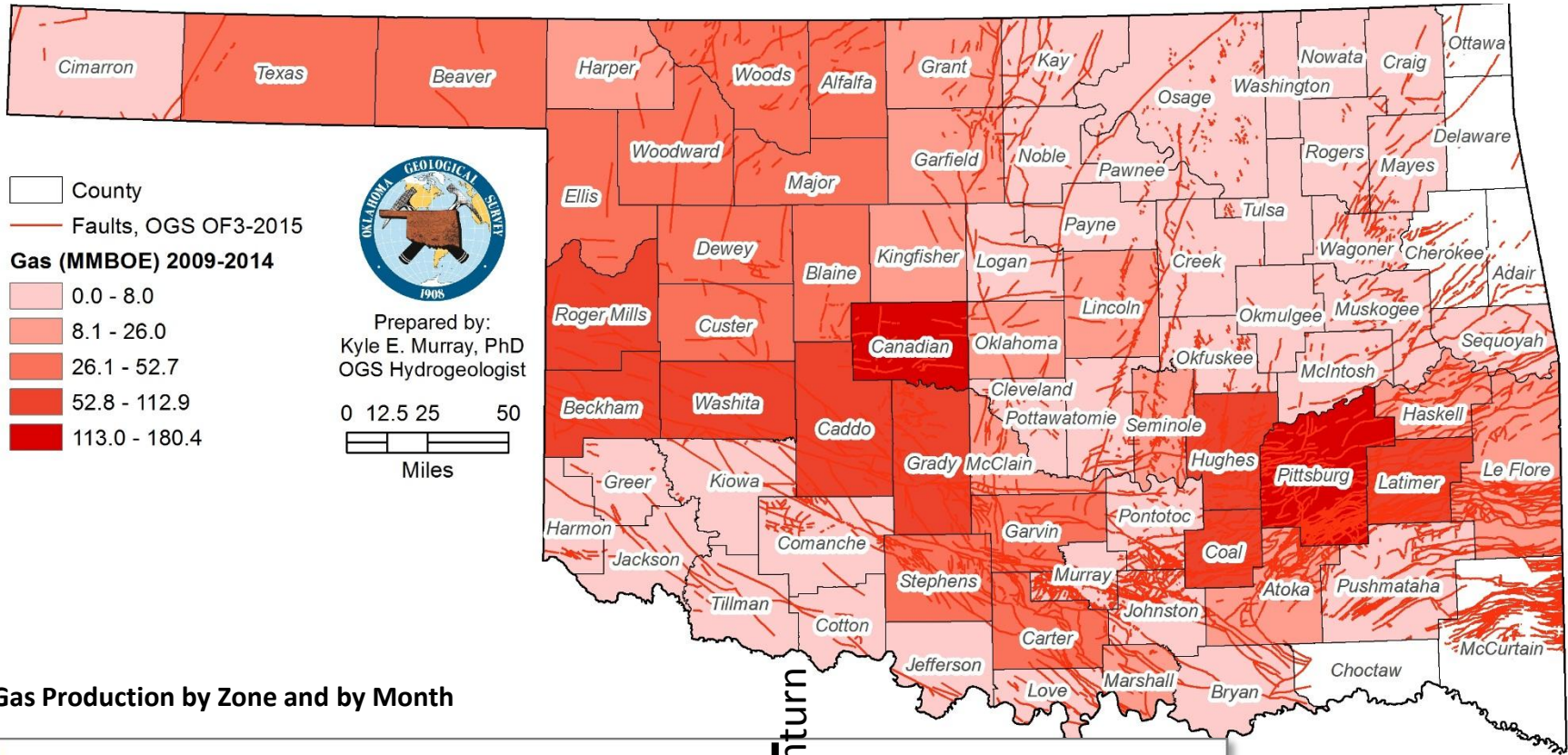


Oil Production by Zone and by Month

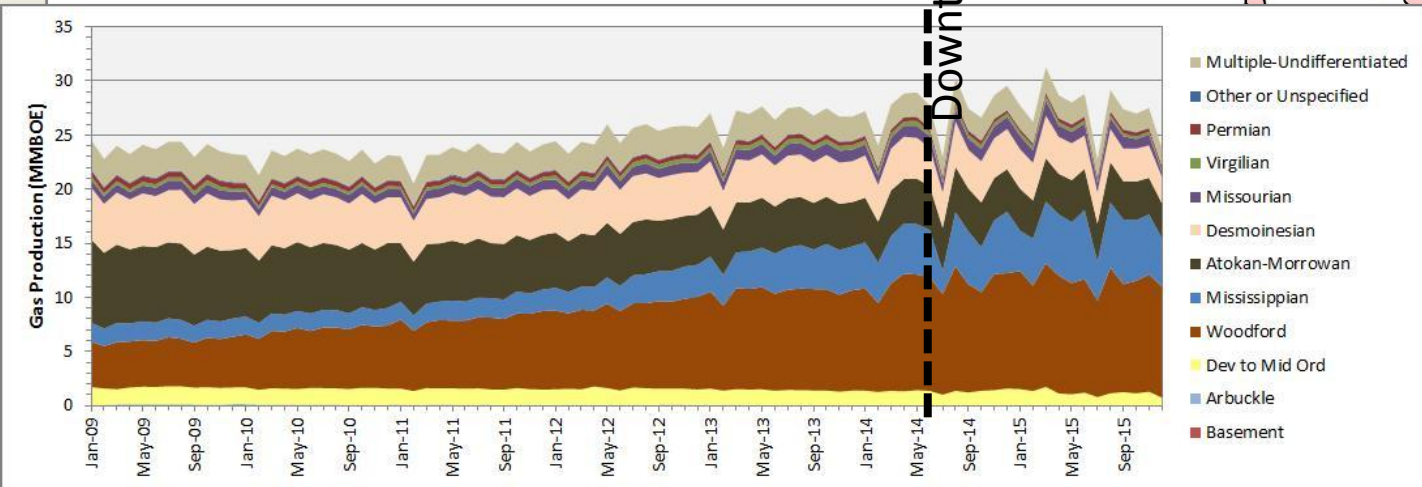


(Murray, 2016 – in preparation)

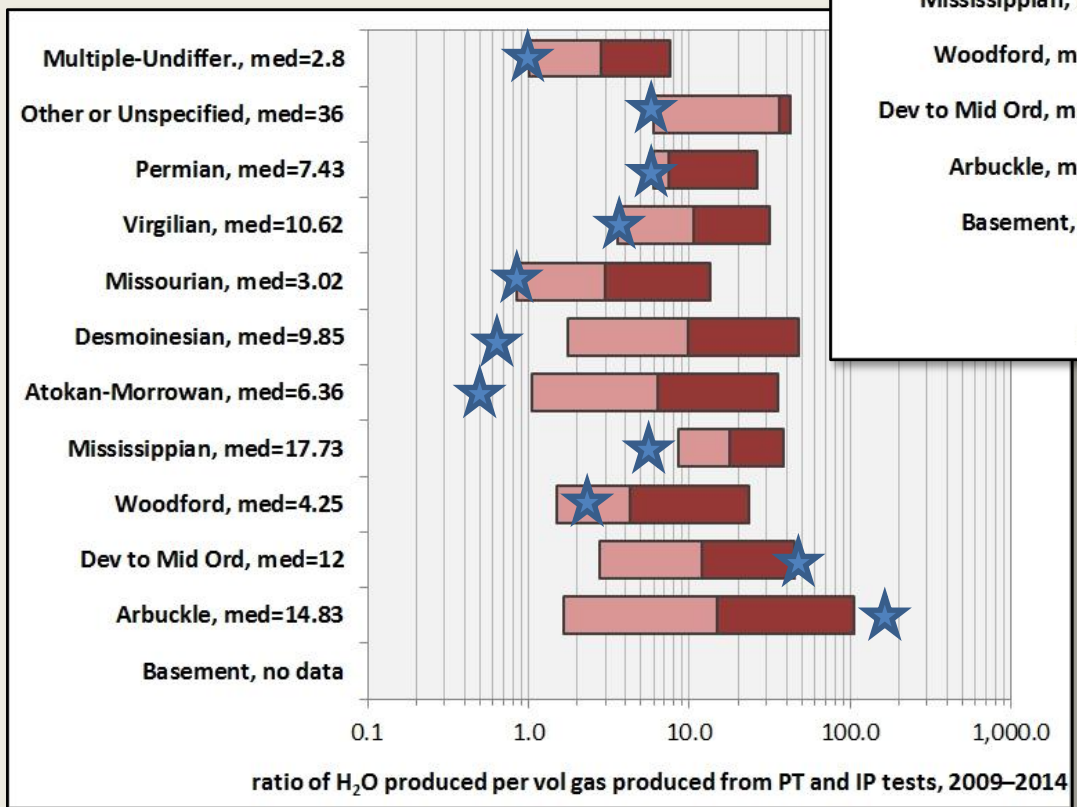
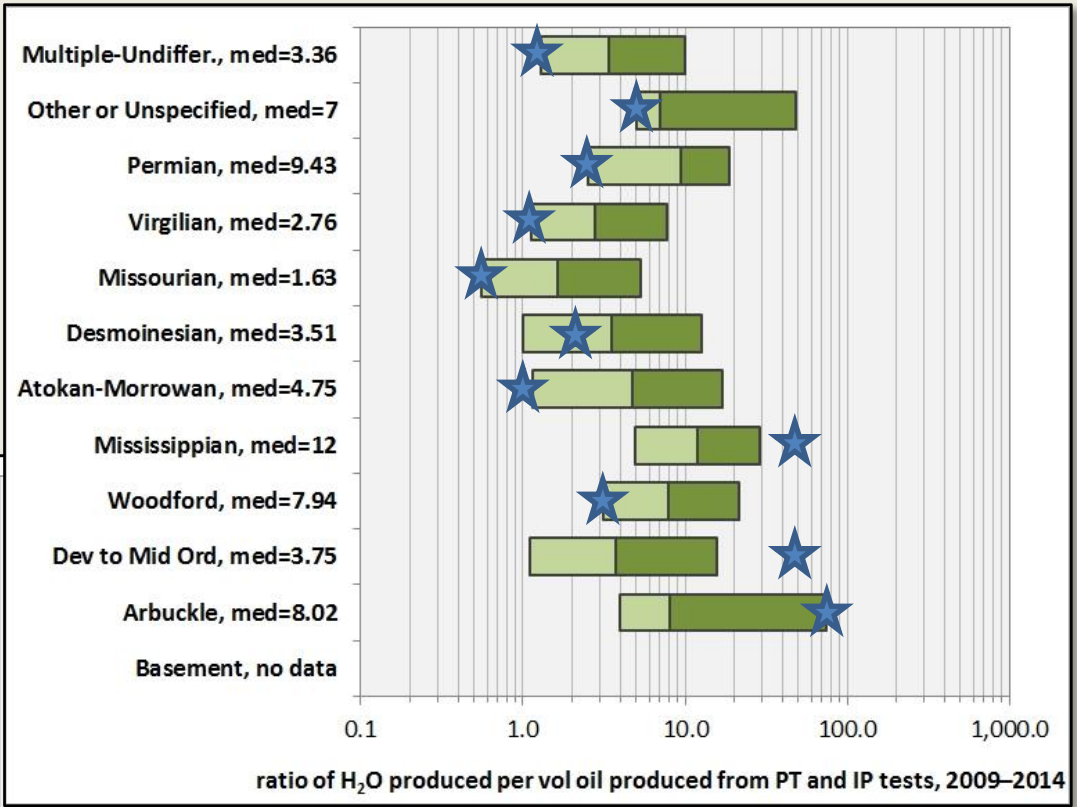
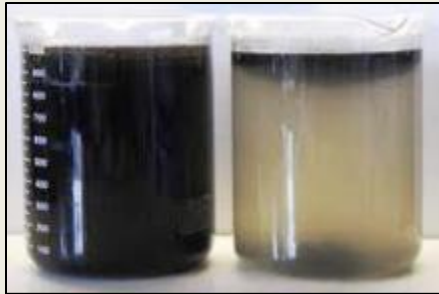
Gas Production by County 2009–2014 and by Zone 2009–2015



Gas Production by Zone and by Month

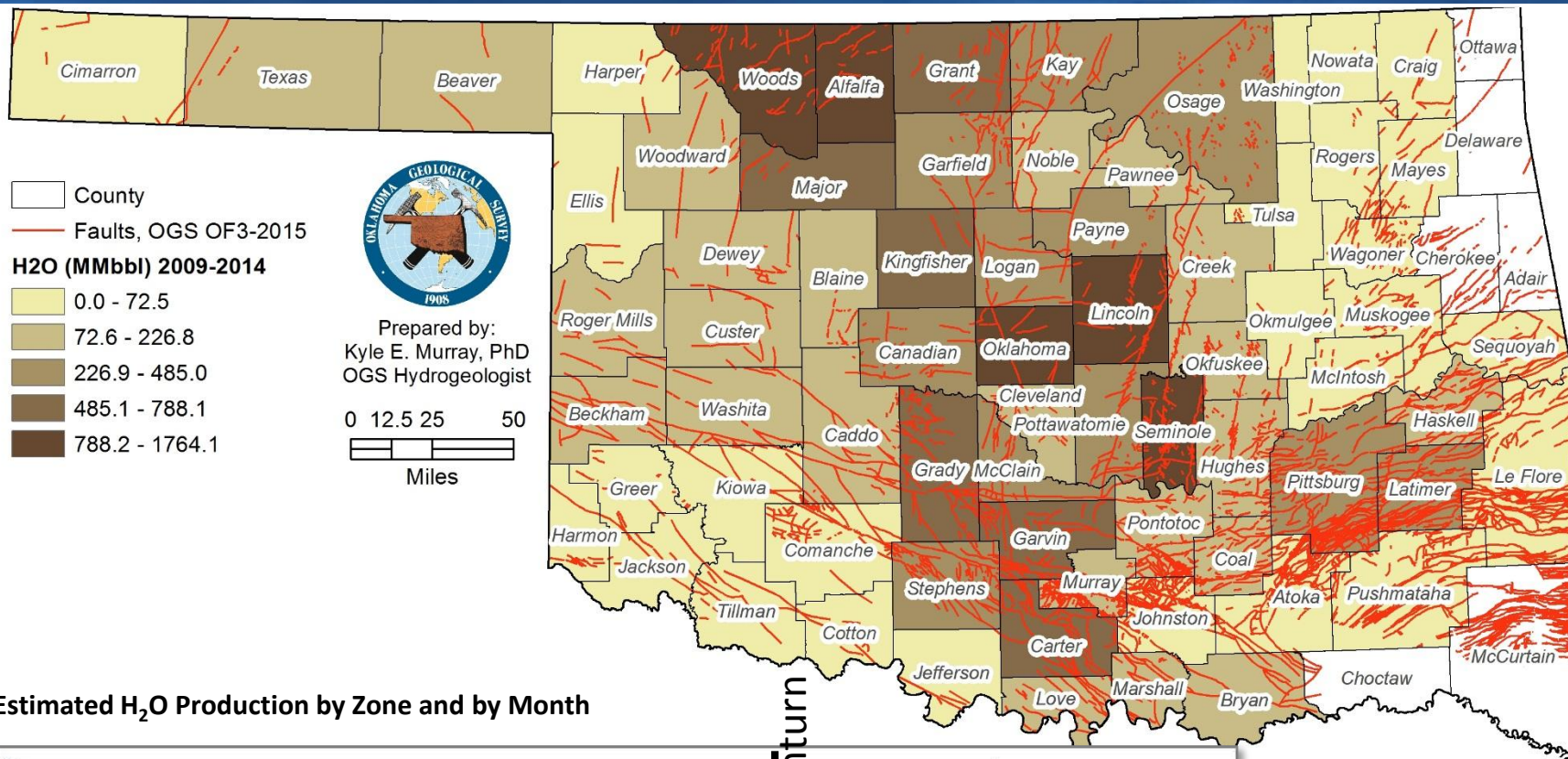


“Calibrated” ratios used to calculate produced H₂O from 2009–2015

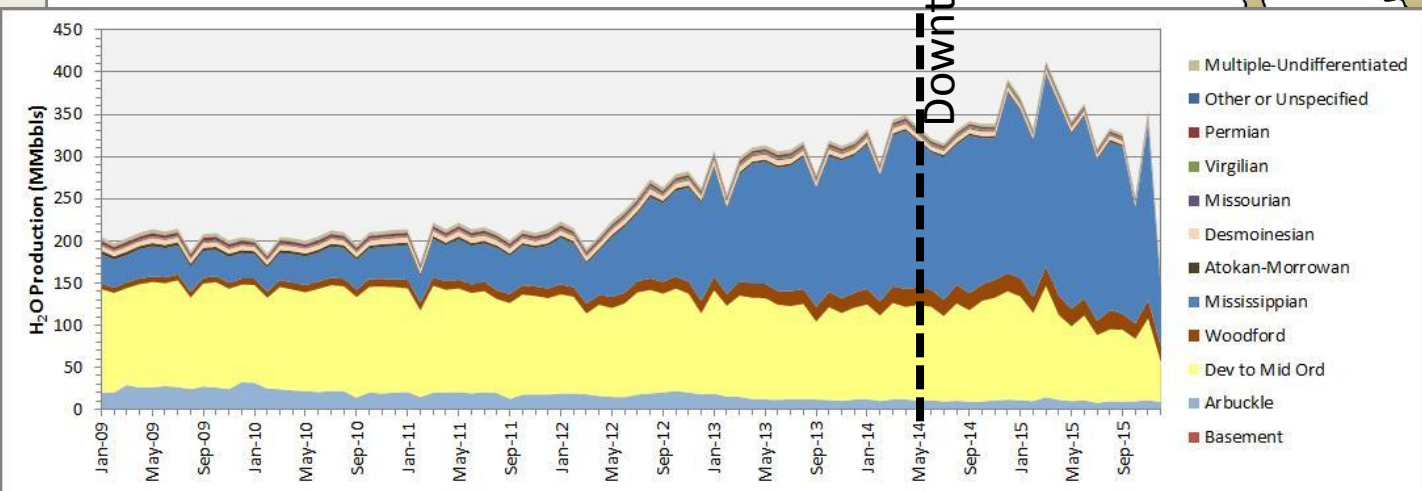


- Assume produced H₂O from County X is disposed into County X
- Compare produced H₂O vs. SWD
- Adjust H₂O:oil and H₂O:gas by zone to maximize r² value of produced H₂O vs SWD volume

Produced H₂O by County 2009–2014, and by Zone 2009–2015



Estimated H₂O Production by Zone and by Month



<http://eerscmap.usgs.gov/pwapp/>

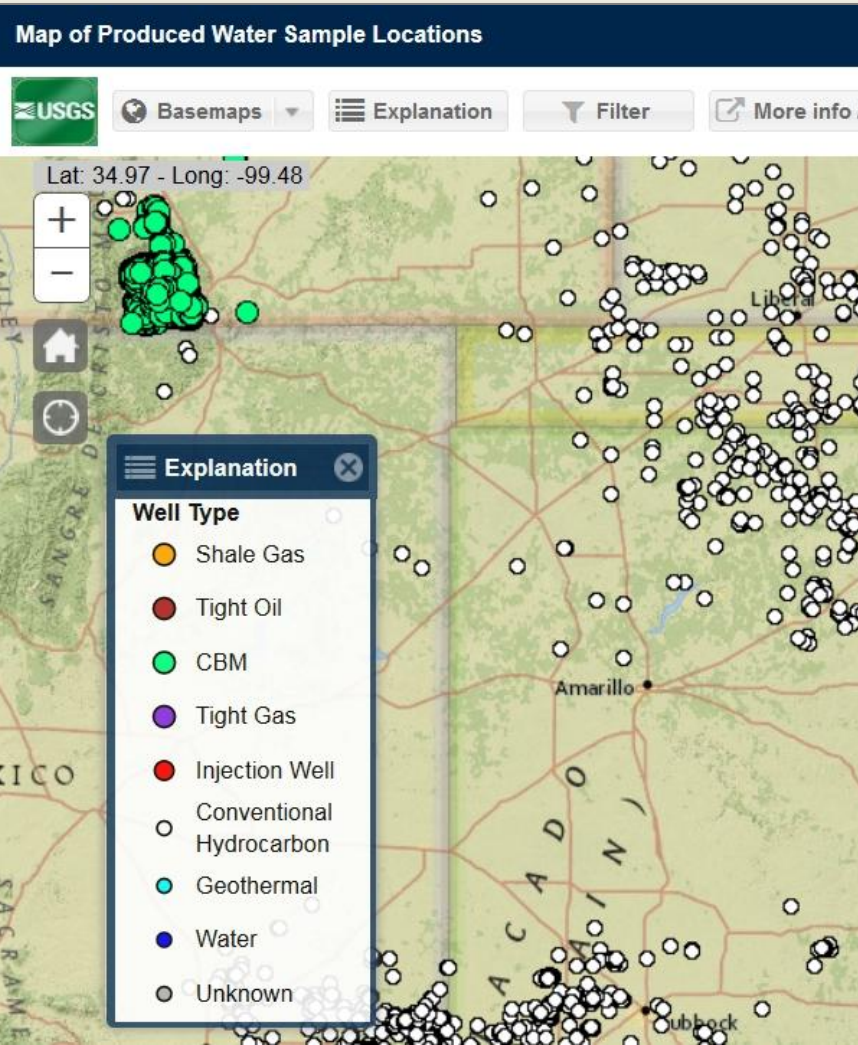
U.S. Geological Survey National Produced Waters

Geochemical Database v2.2 (PROVISIONAL)

Documentation

02/16/2016

By Madalyn S. Blondes¹, Kathleen D. Gans², Elisabeth L. Rowan¹, James J. Thordsen², Mark E. Reidy¹, Mark A. Engle^{1,3}, Yousif K. Kharaka², Burt Thomas^{2,4}

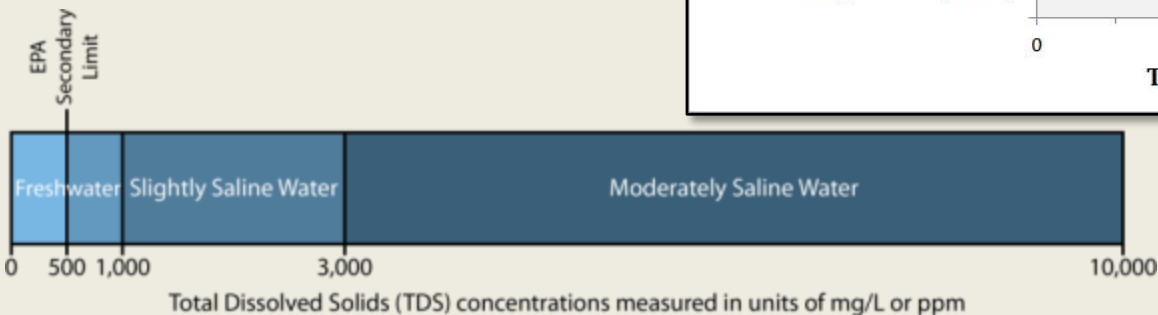
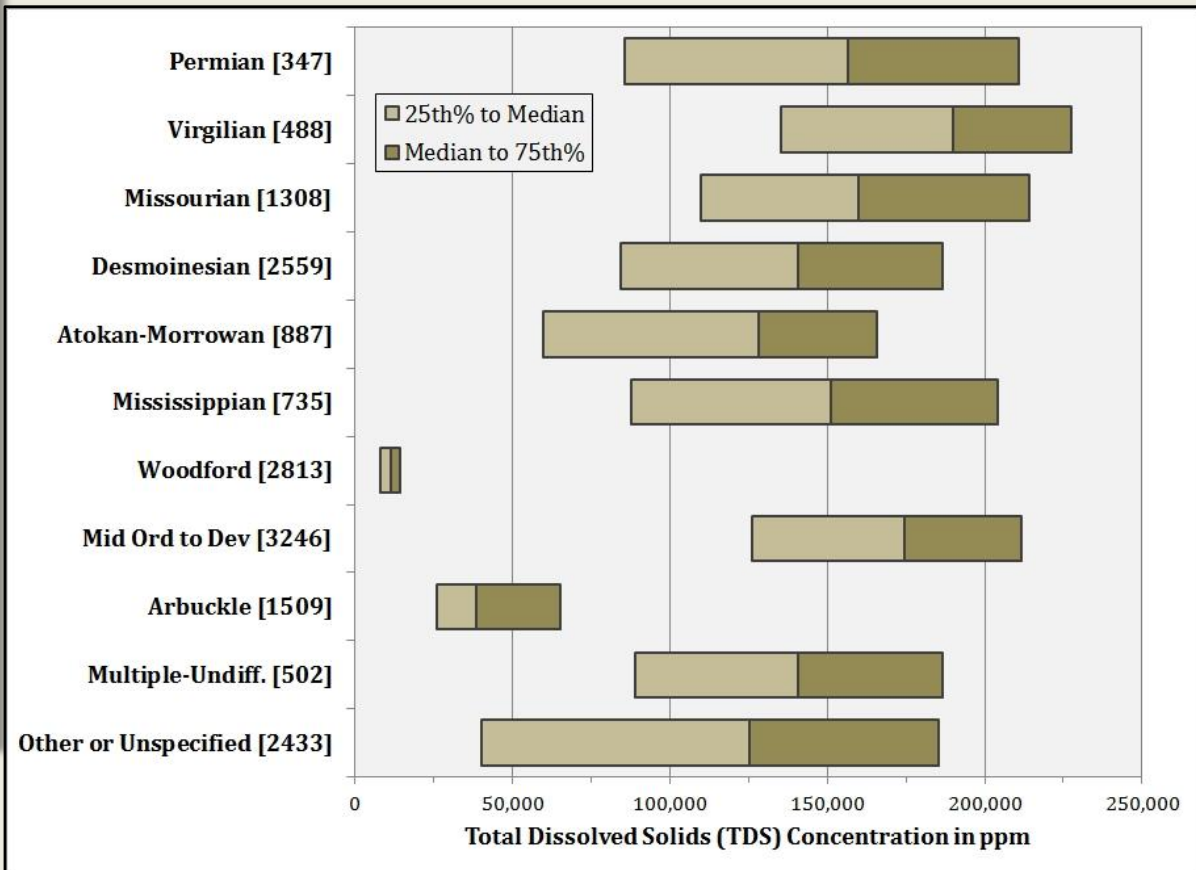


TDS Concentrations in H₂O Produced from Oil & Gas Wells

numWells	COUNTY	meanTDS	meanFe	meanCl
985	OSAGE	131478	59	80772
822	SEMINOLE	147630	34	90864
538	CREEK	139251	76	85743
507	OKLAHOMA	211358	161	129614
461	KAY	217863	145	134411
377	POTTAWATOMIE	154386	47	94441
319	STEPHENS	121926	57	74978
300	LINCOLN	181306	36	111673
297	BEAVER	95535	43	58522
265	GARVIN	164799	145	101382
255	NOBLE	229277	82	141757
251	LOGAN	213835	129	131787
232	CARTER	119608	24	73887
212	PONTOTOC	77727	37	47273
205	GARFIELD	228332	79	141576
200	OKFUSKEE	147245	107	90742
189	HARPER	193125	19	118811
171	BECKHAM	35597	110	20908
169	CADDO	128381	32	78786
155	HUGHES	142650	15	87675
152	MCCLAIN	220134	76	134795
150	KINGFISHER	143350	149	88221
148	PAWNEE	160483	38	98337
136	GRANT	231095	130	142478
133	PAYNE	190767	81	118758
131	CLEVELAND	198612	79	121555
111	GRADY	151809	119	93382

Data for:

pH, TDS, TSS, Ag, Al, As, Au, B, BO₃, Ba, Be, Bi, Br
 BrO₃, CO₂, CO₃, HCO₃, Ca, Cd, Ce, ClO₃, ClO₄, Cl, ClO₂, ClO
 Co, Cr, Cs, Cu, F, FeTot, FeIII, FeII, FeS, FeAl, FeAl₂O₃, Ga...



(Murray, 2016 – in preparation)

Comparison of Desalination Technologies

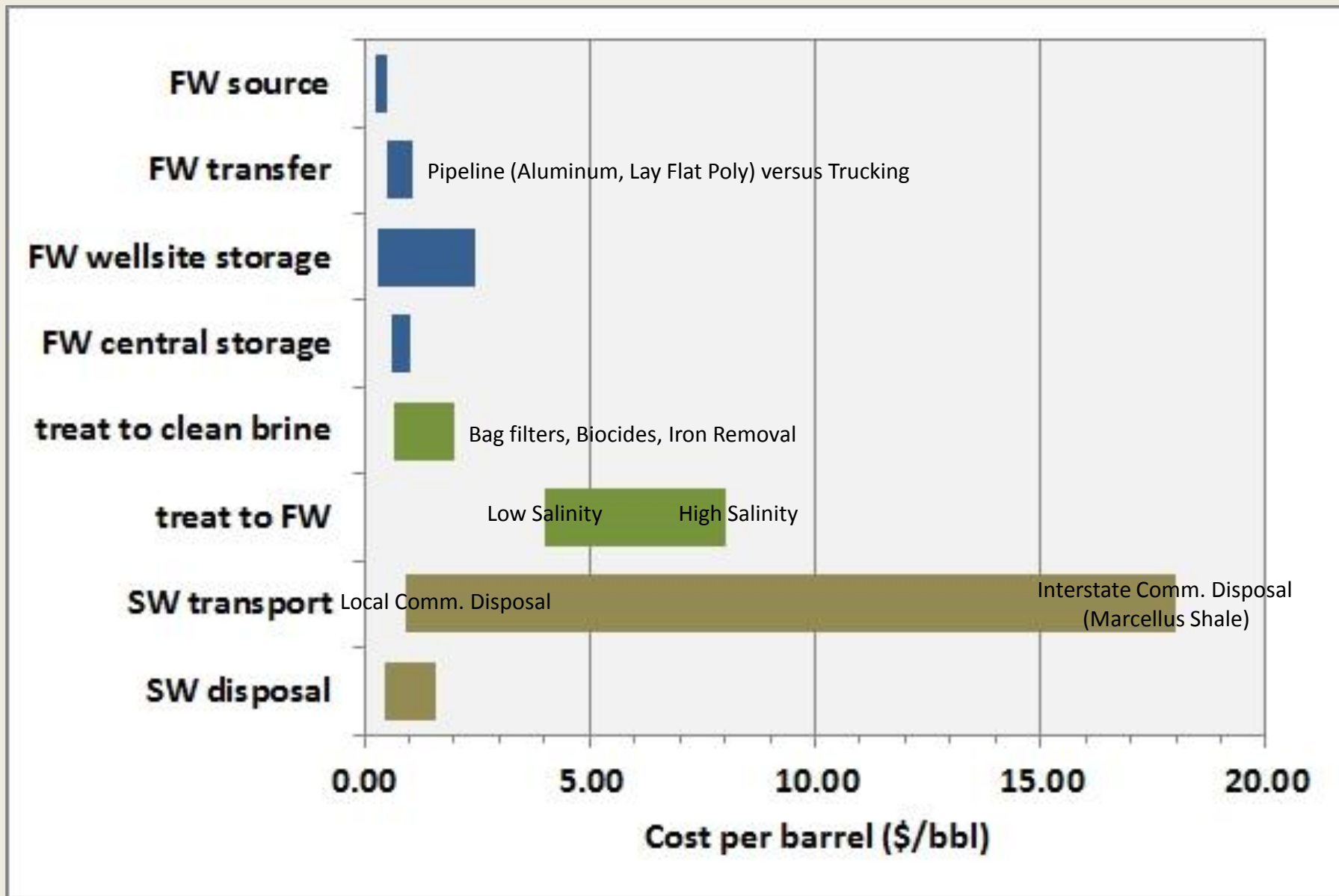
Technology	Feed Quality TDS (mg/L)	Process Recovery (%)	Energy Consumption (kWh/m ³)	Energy Cost (\$/bbl)*	Product Quality TDS (mg/L)
Reverse Osmosis (RO)	< 45,000 ^{b,e}	40–65 ^b	4–6 ^d	0.04–0.06	< 250 ^f
Membrane Distillation (MD)	> 50,000 ⁱ	65–95 ^g	20.5–66.7 ^j	0.19–0.63	< 50 ⁱ
Multi-Effect Distillation (MED)	< 100,000 ^e	20–35 ^b	14–21 ^d	0.13–0.20	< 10 ^d
Multi-Stage Flash (MSF)	< 100,000 ^b	10–20 ^b	19–27 ^d	0.18–0.25	< 10 ^d
Mechanical Vapor Compression (MVC)	< 200,000 ^c	40 ^{a,b}	10.4–13.6 ^a	0.10–0.13	< 10 ^b

*Estimate based on industrial electricity cost: 5.92 cents/kWh¹⁰

References

- a. Koren 1994
- b. Watson et al. 2003
- c. Shaffer et al. 2013
- d. Al-Karaghoul et al. 2012
- e. Fritzmann et al. 2007
- f. Tonner 2008
- g. Camacho et al. 2013
- h. Colorado School of Mines 2009
- i. U.S. Energy Information Administration 2014
- j. Tarnacki et al. 2012

Water Sourcing, Transfer, Treatment, and Disposal Costs in O&G



(from Kyle Murray presented on Sep 28, 2015 at Ground Water Protection Council meeting, Oklahoma City, OK)

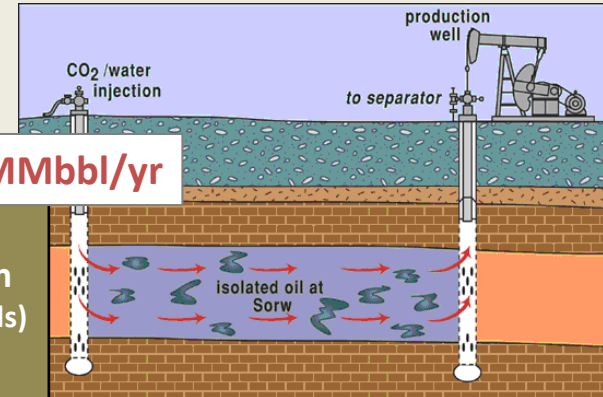
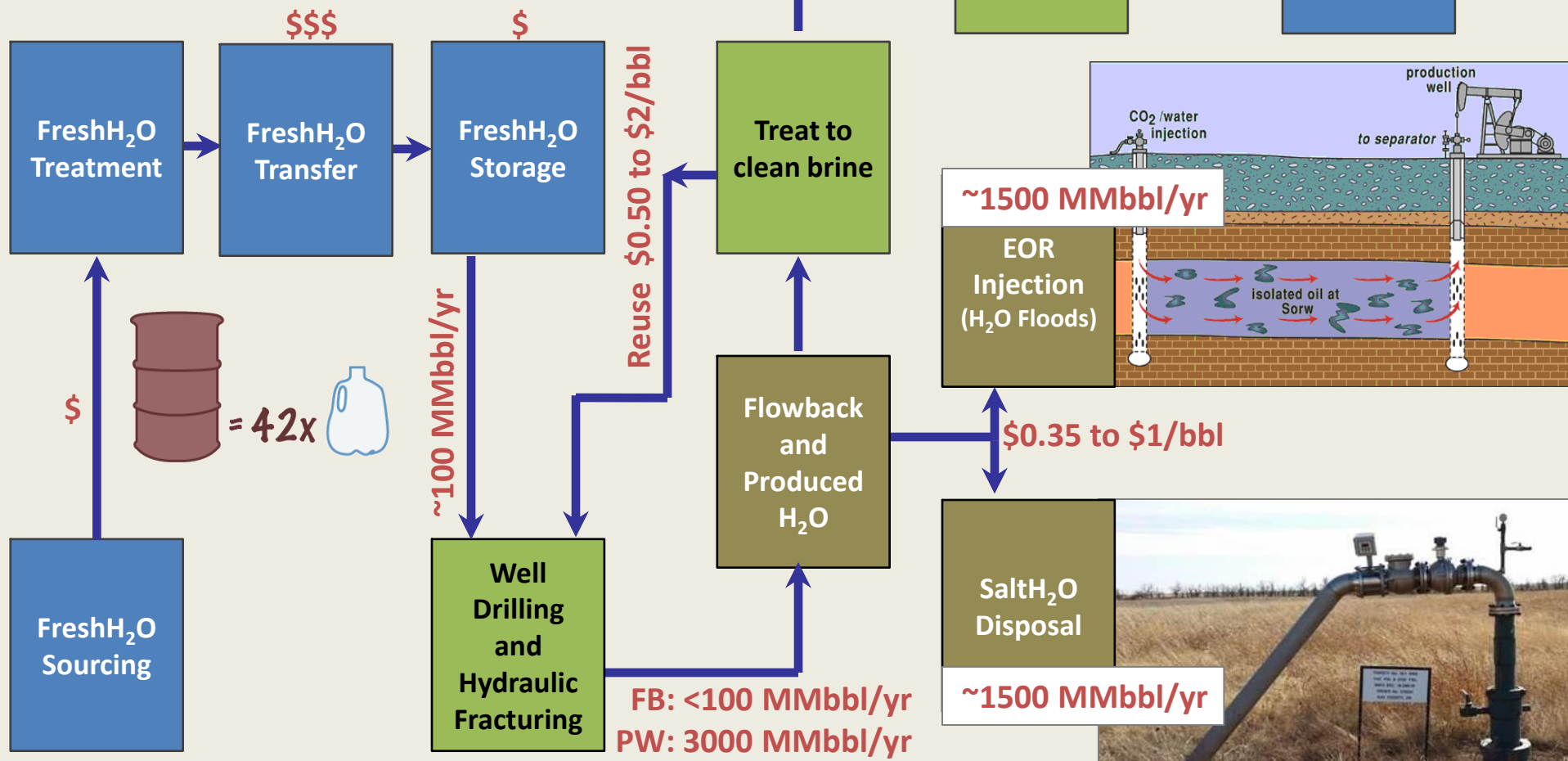
Water Sourcing, Transfer, Treatment, Reuse, & Disposal Flowchart



Produced Water Technologies, LLC

Key

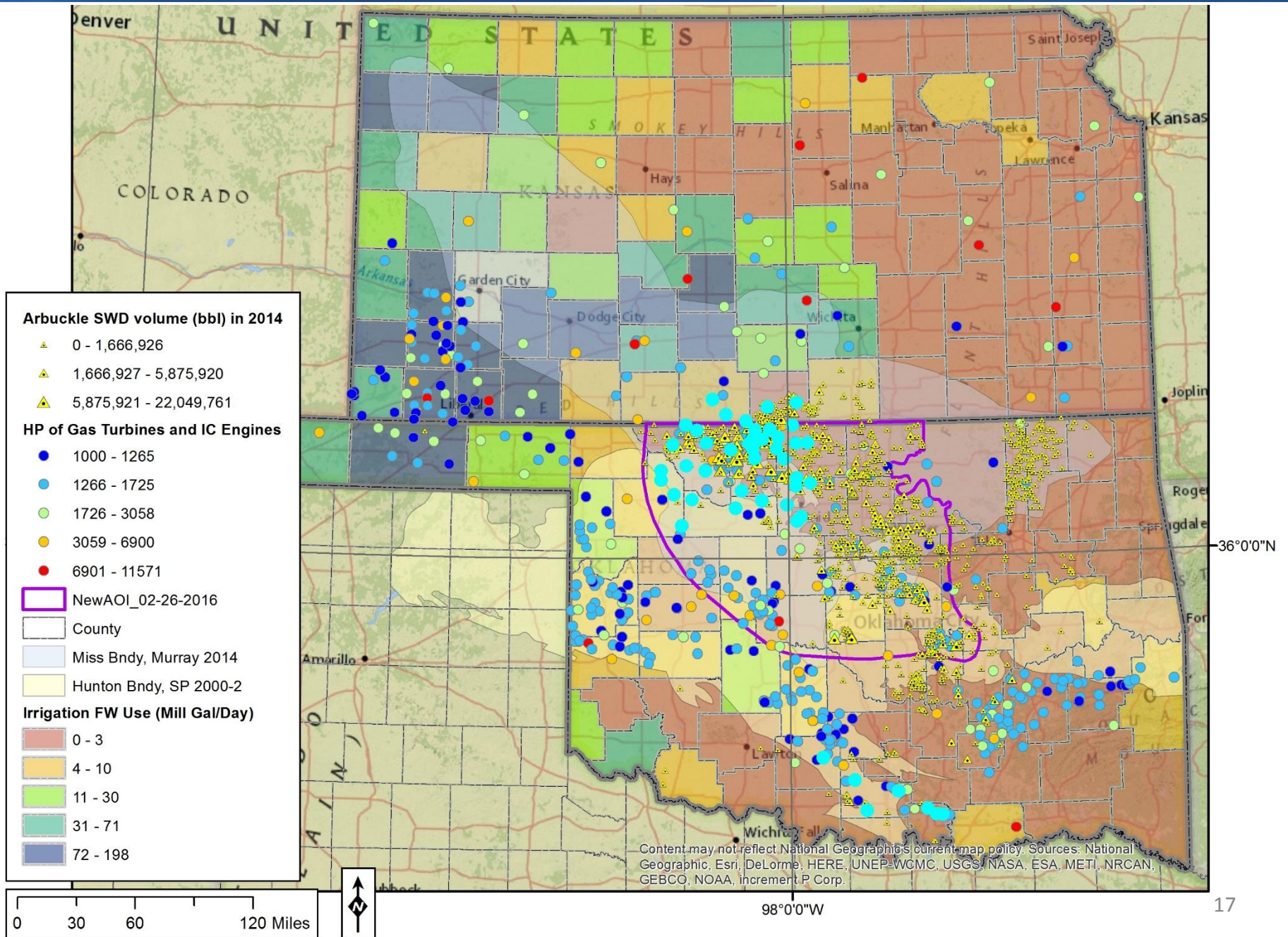
- FreshH₂O
- SaltH₂O
- Treated H₂O



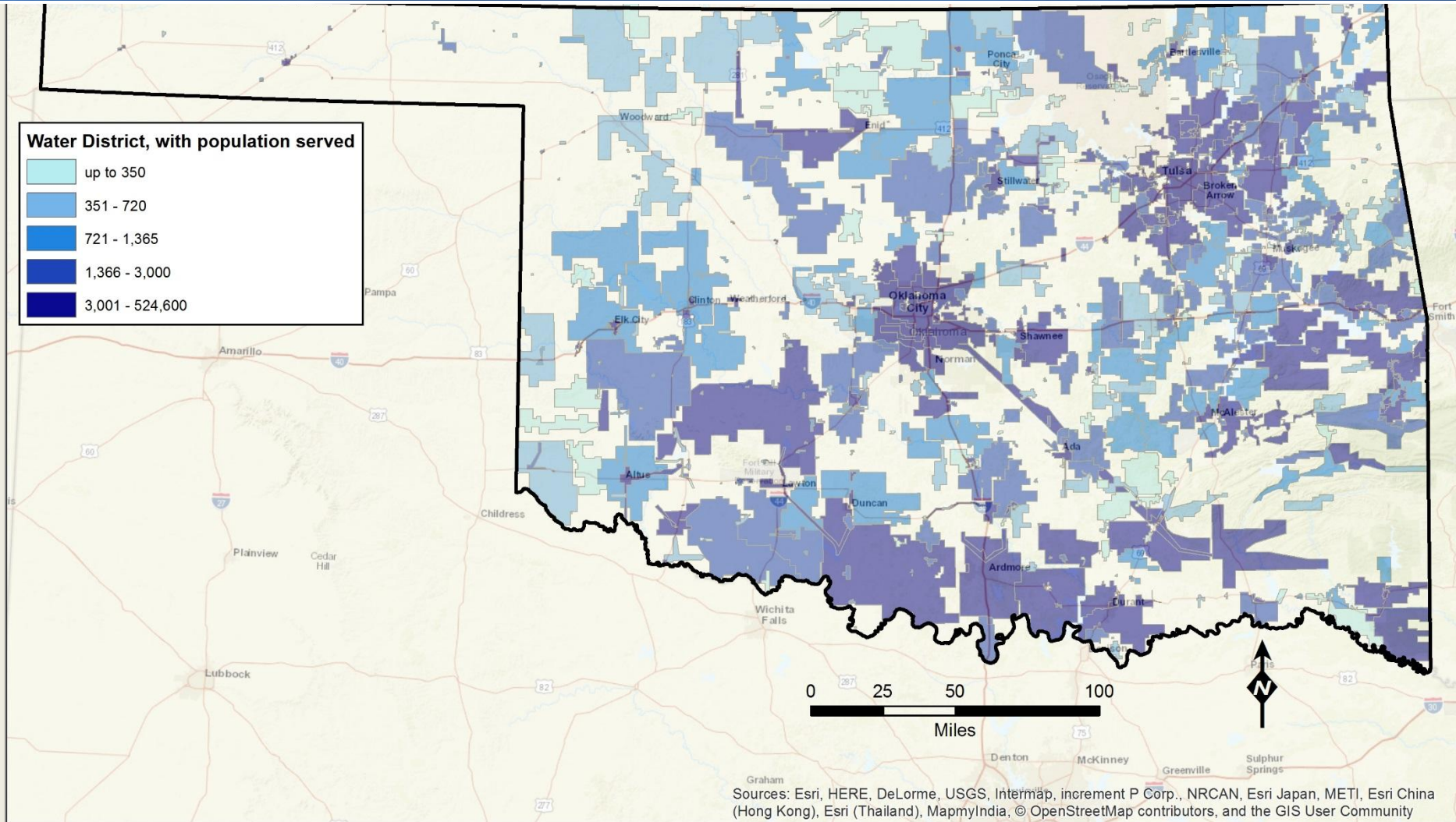
Multiple Stakeholders Must Cooperate/Collaborate

- **SWD Operators (aka Oil, Gas, H₂O Producers)**
- **Mid-Stream Companies**
- **End Users of Treated/Distilled H₂O (aka Irrigated Agric., Water Districts, or Water Flood Operators)**
- **Produced H₂O Transfer Company (aka Service Companies)**

Targa Compressors and Engines, freshwater Irrigation by County



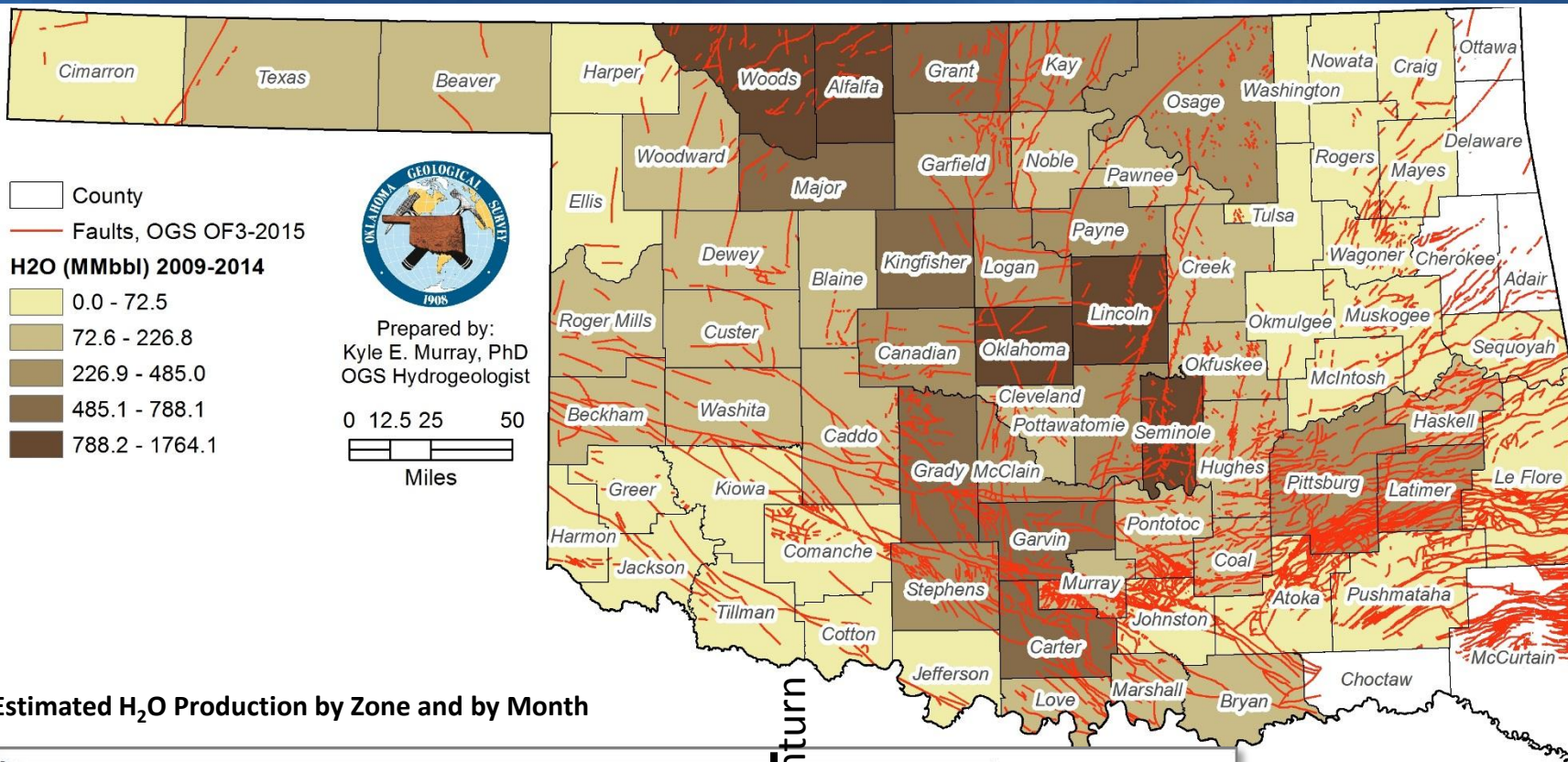
Oklahoma Water Districts



Countless Stakeholders Will Benefit

- **SWD Operators (aka Oil, Gas, H₂O Producers)**
- **Mid-Stream Companies**
- **End Users of Treated/Distilled H₂O**
- **Produced H₂O Transfer Company (aka Service Companies)**
- **Drought-Prone Regions of Oklahoma**
- **Private Citizens & Public Health**
- **Oklahoma Economy**

Produced H₂O by County 2009–2014, and by Zone 2009–2015



Estimated H₂O Production by Zone and by Month

