Produced Water Volumes and Management Practices

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Key Produced Water Points

- There are nearly 1 million oil and gas wells in the U.S. that generate a very large volume of produced water
- Different types of oil and gas production have different water needs and generate different amounts and types of wastewater
- Oil and gas companies must manage the water in a way that meets regulations and has an affordable cost
- There are different water management options that are chosen in different locations. The oil and gas companies may choose different options and strategies over time as the factors affecting their decisions change.

Produced Water Inventory for the U.S. in 2007

- Clark, C.E., and J.A. Veil, 2009, *Produced Water Volumes and Management Practices in the United States*.
- The report contains detailed produced water volume data for 2007
  - ~21 billion bbl/year or 58 million bbl/day
  - 882 billion gallons/year or 2.4 billion gallons/day

http://www.veilenvironmental.com/publications/pw/ANL_EVS__R09_produced_water_volume_report_2437.pdf

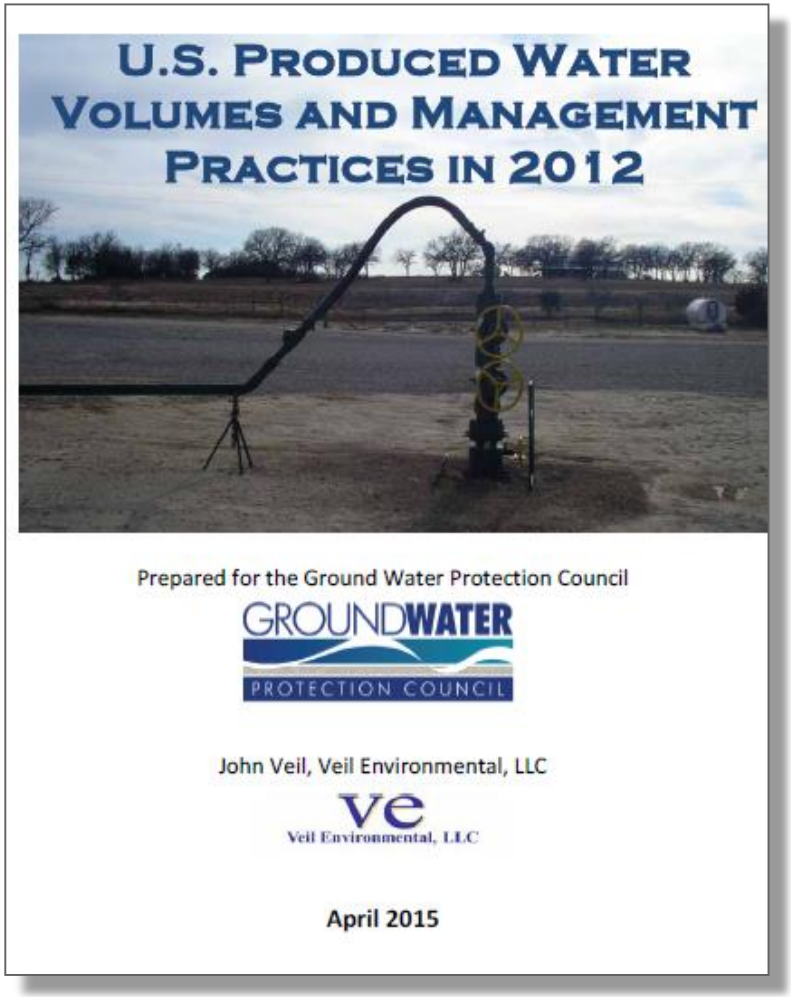
U.S. Produced Water Volume by Management Practice for 2007 (1,000 bbl/year)

	Injection for Enhanced Recovery	Injection for Disposal	Surface Discharge	Total Managed	Total Generated
Onshore Total	10,676,530	7,144,071	139,002	18,057,527	20,258,560
Offshore Total	48,673	1,298	537,381	587,353	587,353
Total	10,725,203	7,145,369	676,383	18,644,880	20,995,174

- Onshore – 98% goes to injection wells
  - 60% to enhanced recovery
  - 40% to disposal
- Offshore – 91% goes to discharge

Update to Detailed Produced Water Inventory for the U.S.

- GWPC contracted with Veil Environmental to update the earlier report using 2012 as the baseline year.
- Data were collected during the second half of 2014
- Report was published in April 2015



http://www.veilenvironmental.com/publications/pw/prod_water_volume_2012.pdf

Approach

- Data were collected from state oil and gas agencies
  - Agencies were asked to complete two tables showing oil, gas, and water production volumes and water management practices
- Additional data were collected from some state environmental protection agencies and from several federal agencies (EPA, BLM, BOEM/BSSE
- All water coming to the surface from an oil or gas well, regardless of its origin, was counted as produced water
  - Produced (formation) water
  - Frac flowback water
  - Water resulting from enhanced recovery operation
- Data and details were summarized for each state separately

Example of a State Summary - Oklahoma

The Oklahoma Corporation Commission (OCC) was unable to provide produced water volume data for this study because they do not receive produced water volume data from the oil and gas operators.[38] Although the OCC did not submit a completed questionnaire, they do have detailed data on the volume of fluids injected into Class II wells – that database is available on the OCC website. A spreadsheet titled "UIC Injection Volumes 2012" was downloaded from http://www.occeweb.com/og/ogdatafiles2.htm. It shows the monthly injected volume from each Class II well. By sorting and summing the different Class II well types, data were compiled into Table 5-47.

Table 5-47 — 2012 Injection Volumes and Well Count

Well Class	2012 Total Volume Injected (bbl)	# Wells
2D	663,588,934	2,743
2DCm	139,760,197	271
2DNC	336,233,517	1,041
2R	772,523,366	4,492
2RIn	324,725,454	1,614
2RSI	1,063,102	11
SWD	87,257,515	237
Total	**2,325,152,584**	**10,409**

Oklahoma Summary (2)

The Well Class abbreviations were clarified by the OCC.[22] 2D, 2DCm, 2DNC, and SWD wells were all used for disposal. 2DCm wells were designated as commercial disposal wells, whereas 2DNC wells were non-commercial disposal wells. The wells classified as 2D and SWD have not been designated as commercial or non-commercial. Wells classified as 2R, 2RIn, and 2RSI were all used for enhanced recovery. The 2RSI wells were used for simultaneous injection operations (water generated from an oil and gas producing zone was injected into a lower injection zone in the same well without bringing the water to the surface).

The number of injection wells in each well class changed throughout the year as new wells were approved and older wells were closed. The numbers shown in Table 5-47 were considered to be an approximation. A presentation by the OCC (Griffith 2013) noted that Oklahoma had 10,800 active injection or disposal wells in 2012. The well count from that presentation was close to the well count from the OCC spreadsheet.

Table 5-48 shows the information from Table 5-47 converted to the format used for the other states. Although not an exact match, the volume of water injected for disposal and for enhanced recovery was assumed to be equal to the volume of produced water generated for the sake of this report.

Table 5-49 was prepared by the author to be comparable with the results shown for each other state. It uses a water volume equal to the injection volume, oil and gas production volumes from EIA, and well counts from Griffith (2013).

Table 5-48 — 2012 Produced Water Management Practices for Oklahoma

Management Practice	# Wells Using That Practice	Total Volume of Produced Water Managed by That Practice (bbl/year)	Percentage of Produced Water Managed by That Practice
Injection for enhanced recovery	6,117	1,098,311,922	47%
Injection for disposal	4,021	1,087,079,966	47%
Surface discharge	0	0	0
Evaporation	0	00	
Offsite commercial disposal (injection)	271	139,760,197	6%
Beneficial reuse	0	0	0
Total Volume Managed		2,325,152,584	

Oklahoma Summary (3)

Produced water volume was not subdivided into water from oil wells and water from gas wells. Therefore, it was not possible to determine WORs or WGRs. However, many of the oil wells were older wells that have high water production. Presumably the overall WOR for Oklahoma wells would be equal to or higher than the values from most other states.

Table 5-49 — 2012 Production for Oklahoma

Type of Hydrocarbon	# Wells Producing Primarily That Type of Hydrocarbon	Total Volume of Produced Water Brought to Surface (bbl/year)	Volume of Hydrocarbon Produced (bbl/year or Mmcf/year)
Crude oil from conventional	117,000	2,325,152,584	92,988,000 bbl/yr
Natural gas from conventional formations	65,500		1,448,579 Mmcf/yr
Natural gas from unconventional formations	No data		574,882 Mmcf/yr
Total	182,500	2,325,152,584	92,988,000 bbl/yr 2,023,461 Mmcf/yr

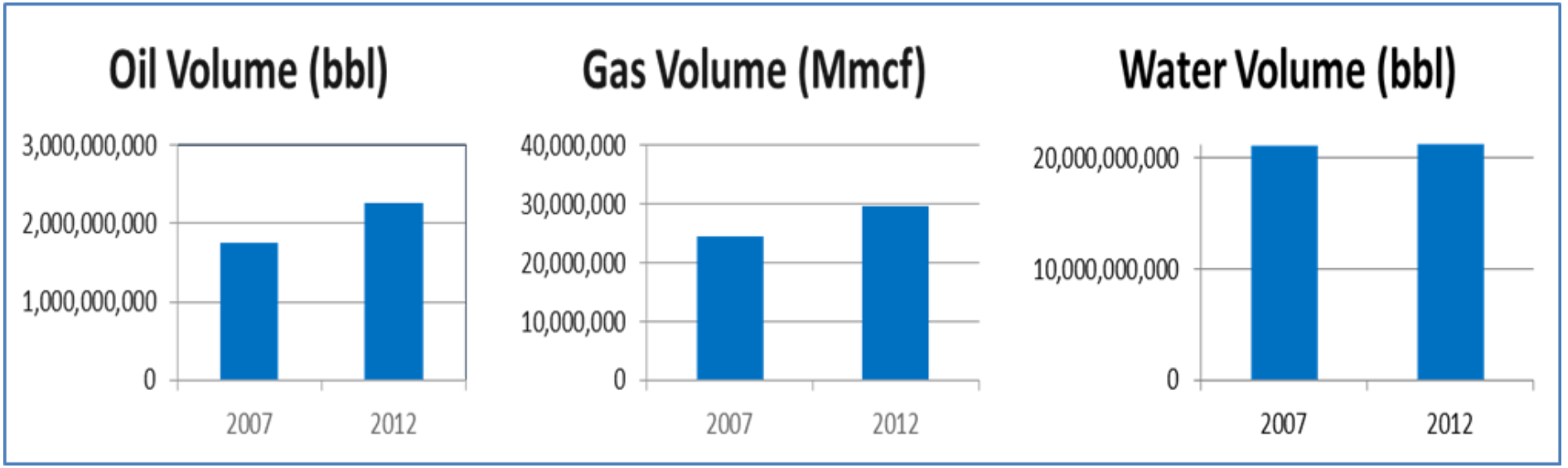
Observations from the 2015 Study

- Produced water volume
- Produced water management practices
- Data availability
- Data quality

Produced Water Volumes

Five Year Changes in Fluid Production

- Between 2007 and 2012
  - U.S. oil production increased by 29%
  - U.S. gas production increased by 22%
  - U.S. water production increased by <1%
    - 21.2 billion bbl vs. 21 billion bbl



Top Ten States in 2012 Water Production

Ranking	State	2012 Water (bbl/yr)	% of Total Water
1	Texas	7,435,659,000	35
2	California	3,074,585,000	15
3	Oklahoma	2,325,153,000	11
4	Wyoming	2,178,065,000	10
5	Kansas	1,061,019,000	5
6	Louisiana	927,635,000	4
7	New Mexico	769,153,000	4
8	Alaska	624,762,000	3
9	Federal Offshore	358,389,000	2
10	Colorado	320,191,000	2

Ratio of Water to Oil Production

- Not all states provided separate water from oil production and water from gas production
- The weighted average water-to-oil (WOR) for 21 states is 9.2 bbl water/bbl oil.
  - Two of the key water producing states (Texas and Oklahoma) were unable to distinguish the water generated from oil wells vs. water coming from gas wells. Both of those states have large numbers of older wells from mature fields that typically have very high WORs (much higher than the weighted average). It is very likely that if the wells from those states were averaged in, the national weighted average WOR would be higher than 10 bbl/bbl.

State	Crude Oil (bbl/year)	Water from Oil (bbl/year)	WOR
Alabama	11,310,000	37,858,000	3.3
Alaska	192,368,000	768,133,000	4.0
Arizona	51,900	66,700	1.3
Arkansas	6,567,600	174,614,000	26.6
California	197,749,000	3,071,362,000	15.5
Illinois	8,908,000	105,268,000	11.8
Indiana	2,350,000	48,931,000	20.8
Kansas	43,743,000	971,009,000	22.2
Michigan	7,400,000	25,000,000	3.4
Mississippi	24,146,000	228,069,000	9.4
Missouri	175,000	2,103,000	12.0
Montana	26,495,000	179,085,000	6.8
Nebraska	2,514,000	57,873,000	23.0
Nevada	368,000	5,865,000	15.9
New Mexico	85,341,000	674,902,000	7.9
New York	360,000	208,000	0.6
North Dakota	243,272,000	284,426,000	1.2
Ohio	5,063,000	4,860,000	1.0
South Dakota	1,754,000	5,296,000	3.0
Virginia	9,700	54,400	5.6
Wyoming	45,382,000	1,646,601,000	36.3
Total Volume	905,327,200	8,291,584,100	
Weighted Average WOR			9.2

Ratio of Water to Gas Production

- The weighted average water-to-gas ratio (WGR) for 17 states is 97 bbl water/Mmcf gas.
  - The range of values from the different states was so large that using a WGR is not meaningful.

State	Total Gas (Mmcf)	Water from Gas (bbl/year)	WGR
Alabama	216,000	68,761,000	318
Alaska	3,182,000	1,019,000	0.3
Arizona	116	14,200	122.4
Arkansas	1,137,000	10,253,000	9.0
California	174,000	3,222,000	18.5
Indiana	8,800	8,635,000	981.3
Kansas	299,000	90,010,000	301.0
Michigan	130,000	92,000,000	707.7
Mississippi	437,000	3,167,000	7.2
Montana	67,000	3,748,000	55.9
Nebraska	1,200	769,000	640.8
New Mexico	1,252,000	101,028,000	80.7
New York	27,000	301,000	11.1
North Dakota	259,000	6,721,000	25.9
Ohio	86,000	682,000	7.9
Virginia	146,000	3,177,000	21.8
Wyoming	2,079,000	531,464,372	255.6
Total Volume	9,501,116	924,971,572	
Weighted Average WGR			97

Why Did Oil and Gas Increase While Water Remained the Same?

Here is my hypothesis:

- Conventional production generates a small initial volume of water that gradually increases over time. The total lifetime water production from each well can be high
- Unconventional production from shales and coal seams generates a large amount of flowback and produced water initially but the volume drops off, leading to a low lifetime water production from each well
- Between 2007 and 2012, many new unconventional wells were placed into service and many old conventional wells (with high water cuts) were taken out of service
- The new wells generated more hydrocarbon for each unit of water than the older wells they replaced

Three Example States Showing Changes from 2007 to 2012 That Support the Hypothesis

- Arkansas:
  - Oil production increased nearly 8%
  - Gas production (mostly from the unconventional Fayetteville Shale) increased by over 400%
  - Water production increased by 11%

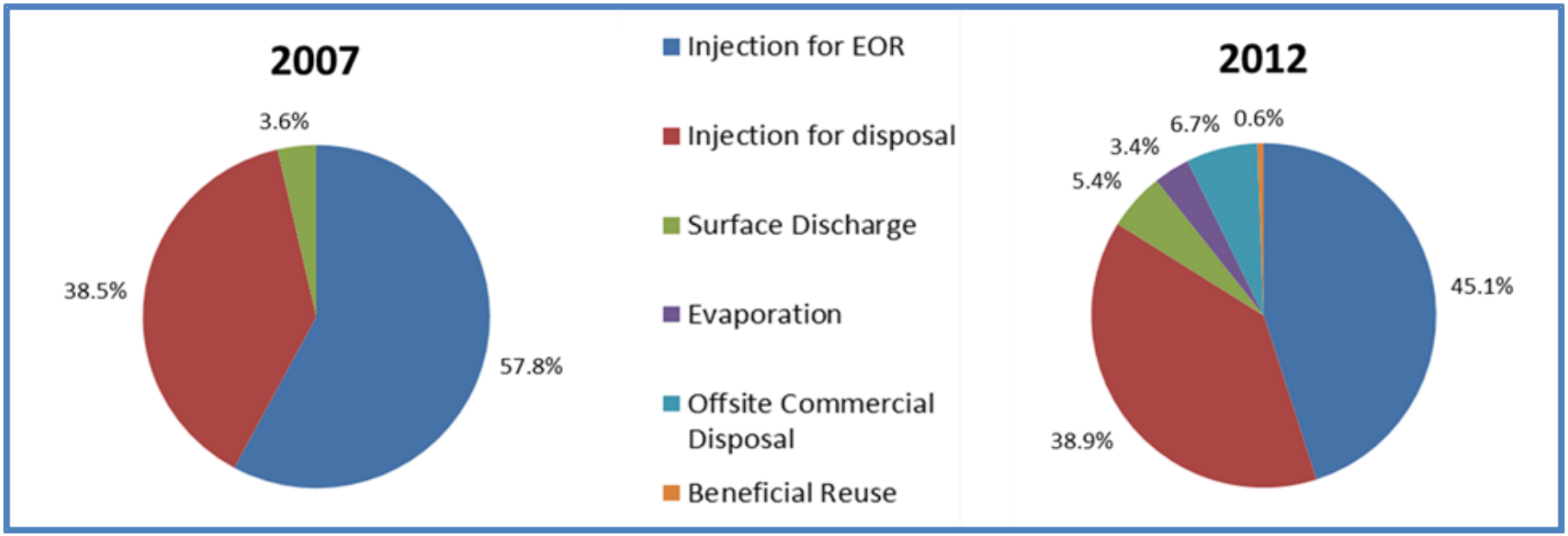
- North Dakota:
  - Oil production (mostly from the unconventional Bakken Shale) increased by over 500%
  - Gas production increased by over 300%
  - Water production increased by just 216%

- Pennsylvania:
  - Oil production increased by 280%
  - Gas production (mainly from the unconventional Marcellus Shale) increased by more than 1,300%
  - Water production increased by 870%.

Produced Water Management Practices

2012 Produced Water Management Practices

- Water management follows similar trends to the 2007 data
  - Nearly all water from onshore wells is injected
  - Nearly all water from offshore wells is treated and discharged



2012 Produced Water Management Practices

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	Injection for Enhanced Recovery (bbl/yr)	Injection for disposal (bbl/yr)	Surface discharge (bbl/yr)	Evaporation (bbl/yr)	Offsite Commercial Disposal (bbl/yr)	Beneficial Reuse (bbl/yr)	Total Prod Water Managed (bbl/yr)
2012							
Onshore Total	9,225,152,000	7,947,716,000	605,129,000	691,142,000	1,373,131,000	125,737,000	19,968,007,000
%	46.2	39.8	3.0	3.5	6.9	0.6	100.0
Offshore Total	62,703,000	62,703,000	515,916,000	0	0	0	641,322,000
%	9.8	9.8	80.4	0.0	0.0	0.0	100.0
U.S. Total	9,287,855,000	8,010,364,000	1,121,045,000	691,142,000	1,373,131,000	125,737,000	20,609,274,000
%	45.1	38.9	5.4	3.4	6.7	0.6	100.0
2007							
Onshore Total	10,676,530,000	7,144,071,000	139,002,000	No data	No data	No data	17,959,603,000
%	59.4	39.8	0.8	No data	No data	No data	100.0
Offshore Total	48,673,000	1,298,000	537,381,000	No data	No data	No data	587,353,000
%	8.3	0.2	91.5	No data	No data	No data	100.0
U.S. Total	10,725,203,000	7,145,369,000	676,383,000	No data	No data	No data	18,546,955,000
%	57.8	38.5	3.6	No data	No data	No data	100.0

Water Management other than Injection and Discharge

- The 2012 data provide more information on other practices
- Evaporation is used in several western states
- Where offsite commercial disposal facilities are available, some of the water is sent there.
  - Most commercial facilities use disposal wells
  - Some use evaporation ponds
- Beneficial reuse (other than reinjection for enhanced recovery operations) is difficult to quantify
  - Some states recycle their flowback water to make new drilling and frac fluids
  - Some states allow spreading of produced water on unpaved roads for dust control and on other roads for deicing during winter weather
  - There is limited reuse for irrigation in a few states where the water already has low salinity or has been treated to low salinity

Data Availability

2012 Data Availability

- Some states collect produced water volume data – many do not
  - Some times more than one agency has responsibility for relevant data – often they don't know what data the other agency has
- Unless state law or regulation requires produced water data submittal, the companies will not do it
  - Companies only provide the data elements that are required
- Other than injection volumes, most states do not keep track of how produced water is managed
  - Particularly true for beneficial reuse
- Data can be stored in huge databases that require IT expertise for making queries
  - Regulatory staff may not know how to do queries
- State agencies are often overworked and understaffed
  - They have little time to compile data for external requests

2012 Data Availability (2)

- Where data were not available through the state agencies, additional efforts were made to estimate water volumes and management practices.
  - Online databases
  - Other reports
  - Extrapolations from nearby states
- Many assumptions were necessary. The report tries to state the assumptions clearly.
  - Other readers may disagree with those assumptions, which could lead to other findings or conclusions
- Some federal agencies were able to provide requested data directly, while other insisted on a cumbersome FOIA process that often took more than a month.
  - The FOIA requirement was applied inconsistently, even within the same agency.
- One agency charged for its services.

Data Quality

2012 Data Quality

- The raw data are not precise. Water volumes are measured by comparing relative heights in a tank, by pump capacity and running time, or by bucket and stopwatch, among other methods. These methods give results that have some relevance to true volume, but are not precise.
- The process of getting data from the field to the agencies has potential for additional errors.
  - Transcription of field notes to paper forms or electronic forms
  - Transcription into agency databases
  - Inconsistent interpretation of what and how to report by companies
  - Rounding errors (i.e., significant figures)

Final Thoughts

- The 2012 data are imprecise but represent the most complete and current estimates available
- This type of national data collection effort is very difficult and time-consuming
  - There is no easy way to obtain national estimates of produced water volume
- In the absence of a consistent methodology to collect produced water volumes and management information, it is unlikely that the challenges of estimating produced water volumes and management practices will decrease in the future