Modeling groundwater vulnerability to contamination from produced water storage in Lea County, New Mexico

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Acknowledgements

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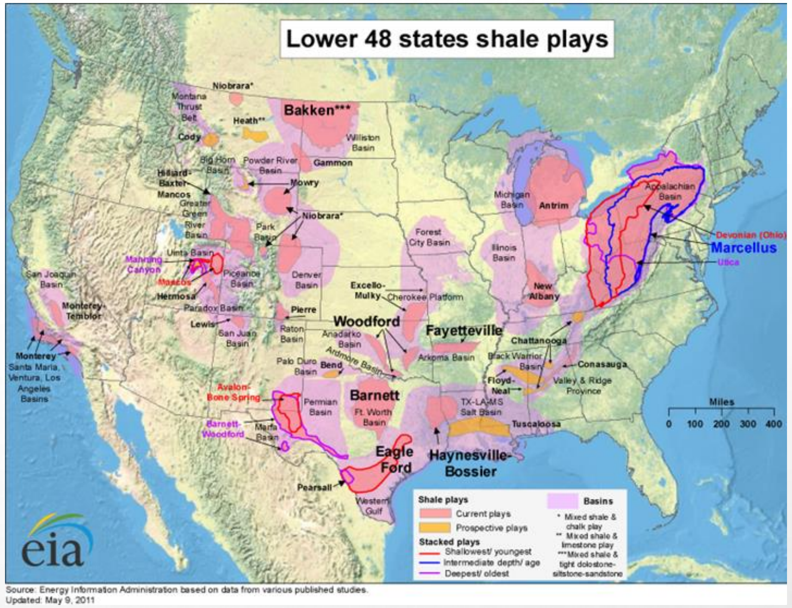
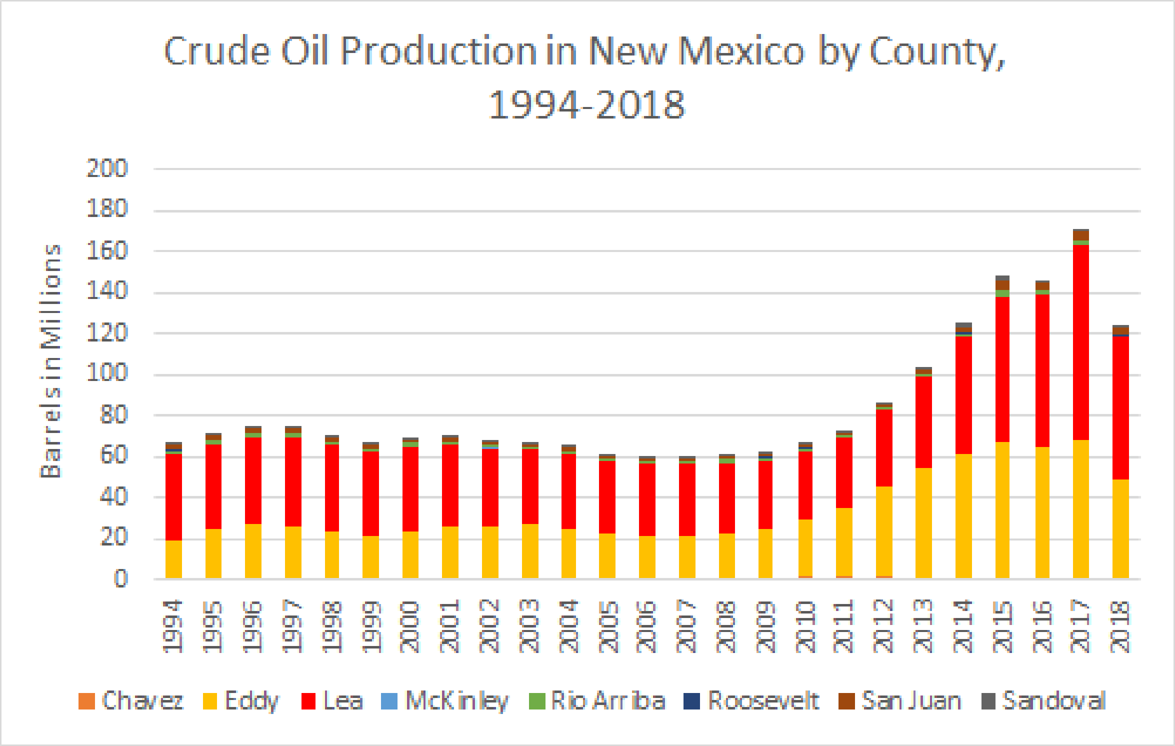
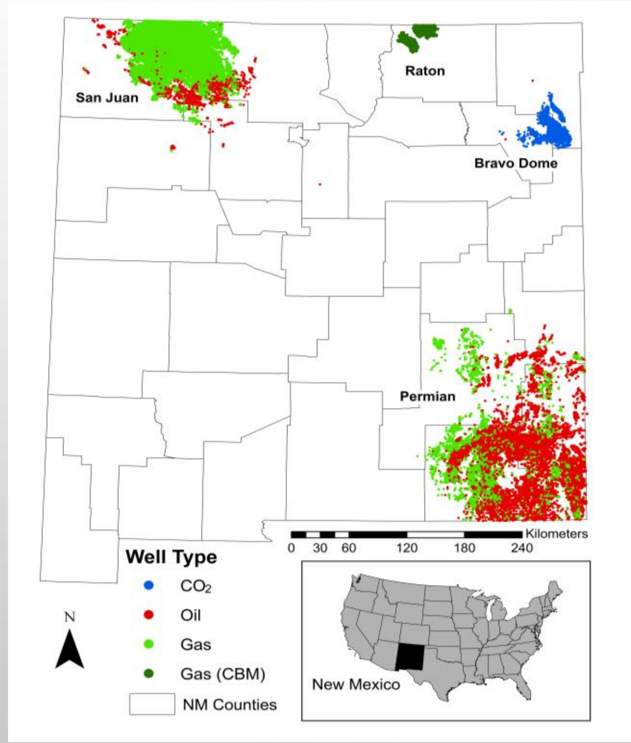
OIL PRODUCTION IN NEW MEXICO



- Long production history
- Production has doubled in the last five years
- >40k Wells in the Permian Basin, NM produce 95% of state’s oil. Includes Lea, Eddy, and Chaves counties

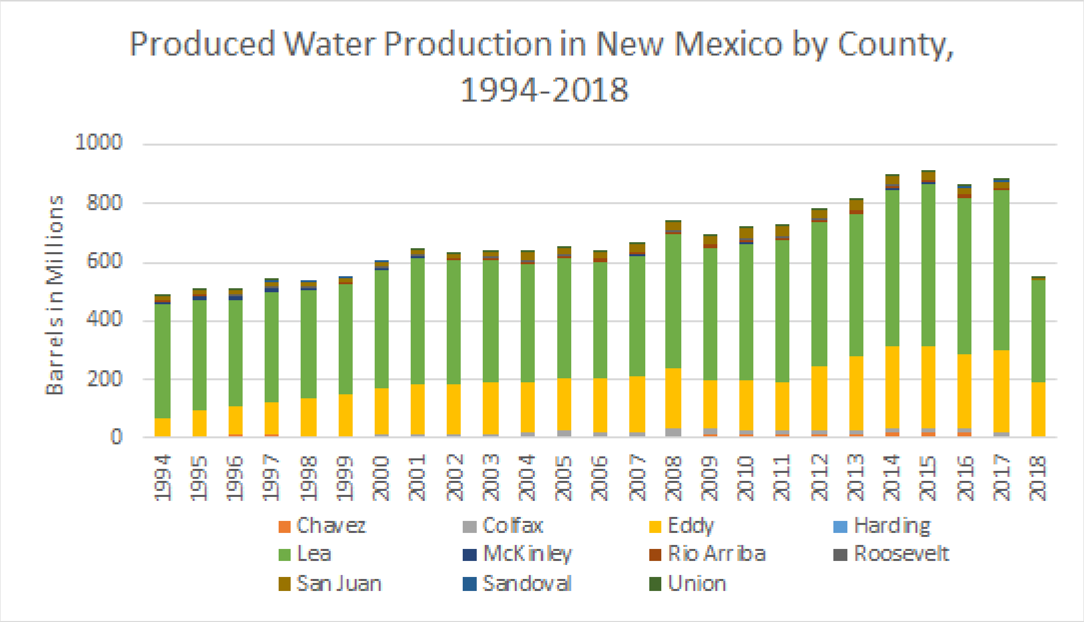


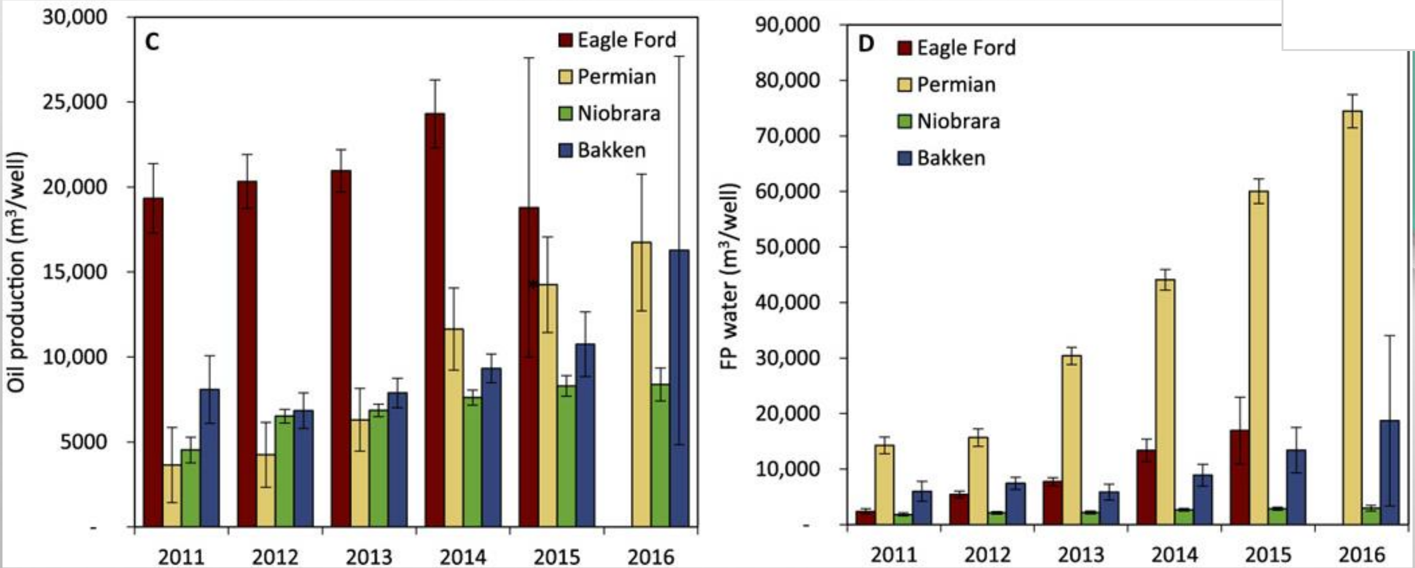


>500k bbl oil/day

PRODUCED WATER

- Wells in the Permian Basin, NM produce 94% of state's produced water
- Water-to-oil ratio (WOR) is largest in the country ~ 5:1





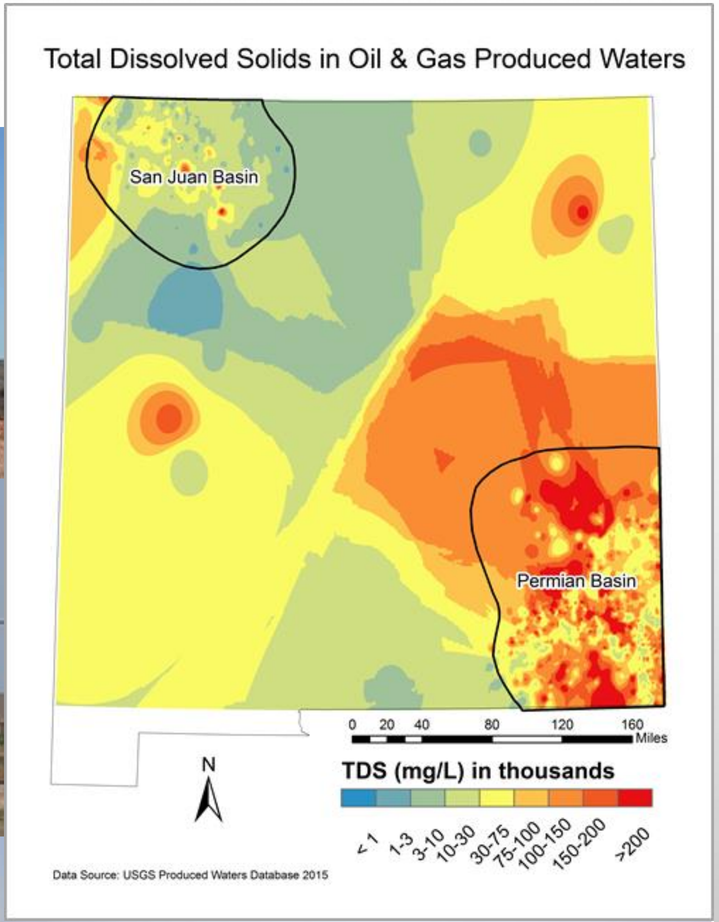
Kondash, A. J., Lauer, N. E., & Vengosh, A. (2018). The intensification of the water footprint of hydraulic fracturing. *Science advances*, *4*(8), eaar5982.

> 2 million barrels produced water/day

GROUNDWATER VULNERABILITY

Why?

- Produced chemistry
  - Total dissolved solids (TDS)
    - ~100k ppm
- Storage Requirements
  - Separation process
  - Prior to disposal
  - Recycling, treatment and reuse
- Storage Types
  - Tanks and pits
    - Head vs. volume
    - Siting and design regulations



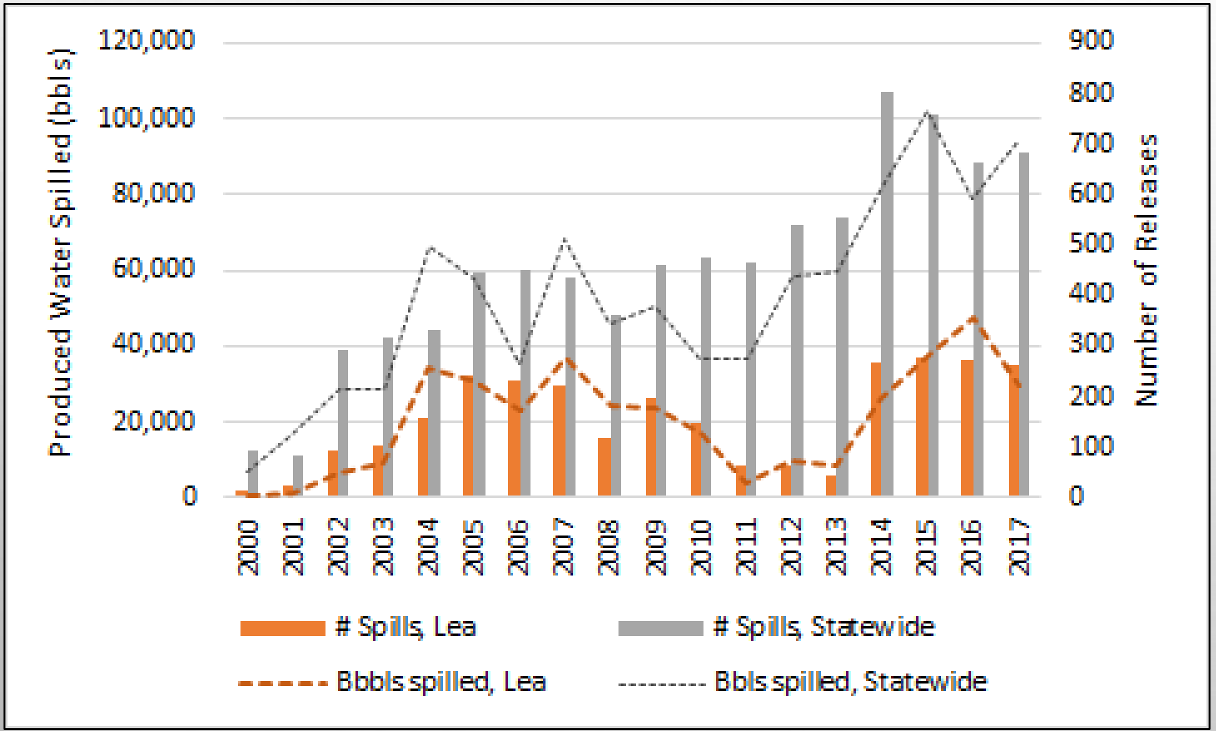
Lea County is dependent upon groundwater (99.96%) for all uses

Image source (clockwise from top): TDS Map, derived from Cather et. al, 2016; Produced water pit: https://www.flickr.com/photos/katsrcool/6969282139/; tank battery: https://www.videoblocks.com/video/oil-well-large-storage-tank-battery-engkcx9; tank battery: http://www.castagra.com/wp-content/uploads/2013/11/fracking-2.jpg

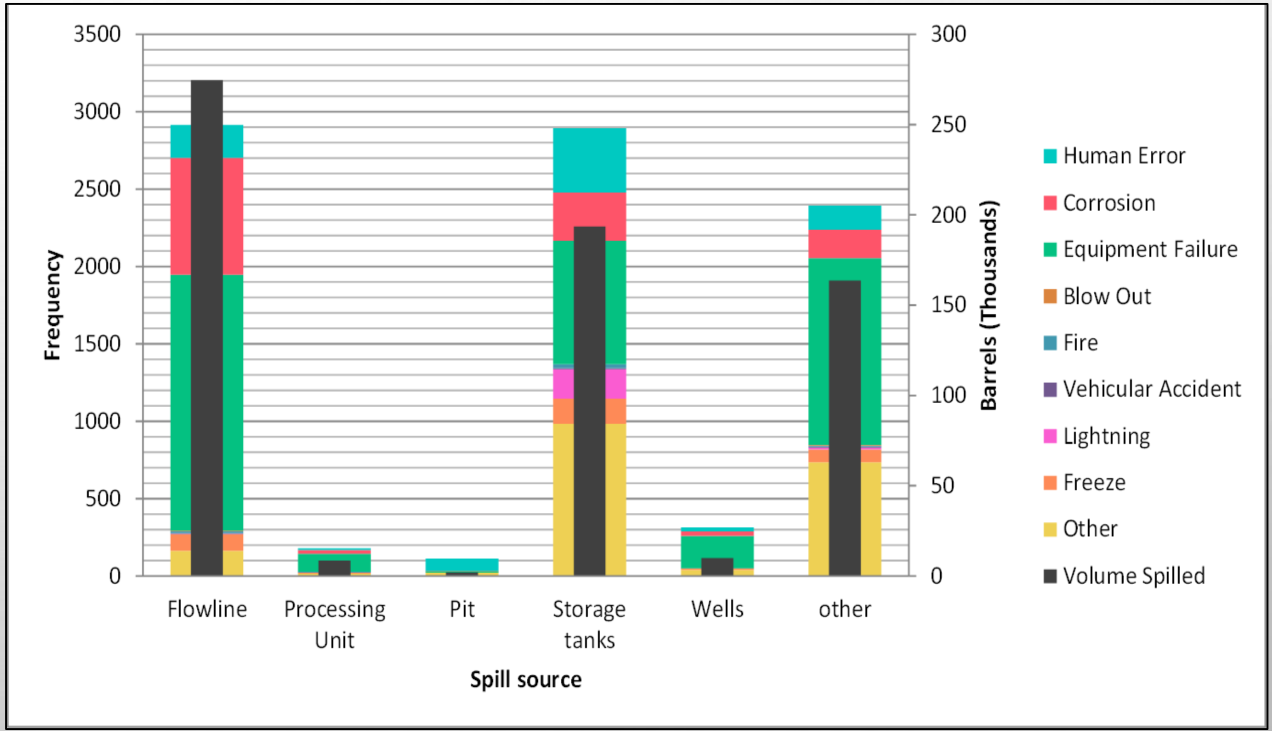
SPILLS

Occurrence & Volume → Source → Cause

Occurrence and Volume of Spills



Spill Sources and Causes



Data Sources: NM OCD Spills Database, 2018

RESEARCH QUESTION

What factors influence the likelihood of spill occurrence? In which locations is groundwater most vulnerable to contamination as a result of long-term releases from storage?

Why?

- Future production trends
- Existing storage locations, design, age, etc.
- Regulatory response
- Prioritization of on-site assessments of releases

Proof-of-Concept and Preliminary Analysis

METHODS

Consequences (Vulnerability)

Likelihood (Probability)

	Negligible	Minor	Moderate	Significant	Severe
Very Likely	Low Med	Medium	Med Hi	High	High
Likely	Low	Low Med	Medium	Med Hi	High
Possible	Low	Low Med	Medium	Med Hi	Med Hi
Unlikely	Low	Low Med	Low Med	Medium	Med Hi
Very Unlikely	Low	Low	Low Med	Medium	Medium

Risk = probability * vulnerability

Probability ~ Count Model Regression

Vulnerability ~ GIS-based DRASTIC methodology (Aller, 1985)

COUNT MODEL DATA SOURCES

- Monthly data 2006-2018 (NM OCD, 2018)
- Number and volume of releases
- Active Production Wells
  - Produced Oil (bbl), Gas (MCF), Produced Water (bbl)
- Active SWDs Volume Injected (bbl)
- Retail Gasoline Price (USD) (EIA, 2018)
  - U.S. All Grades All Formulations

Image Credits (clockwise from top): Leaking tank: http://www.globalpropertysystems.com/wp-content/uploads/2016/01/leakingTank.gif; Disposal well: EJ Sullivan Graham, 2016; Trucks: http://eaglefordtexas.com/wp-content/uploads/sites/9/2016/04/oil-and-gas-trucks-in-Montney-Canada.jpg

COUNT MODEL FORMULATION

$$y_i: count\ variable$$
$$y_i \in \{0,1,2,\ldots\}$$

We want to model y_i using X_i

We start with a Poisson distribution:

$$P(y_i = y|\lambda_i) = \frac{e^{-\lambda_i}.\lambda_i}{y!} \qquad for\ y \in \{0,1,2,\ldots\}$$
$$\lambda_i = E(y_i|X_i) \geq 0$$

λ_i is a function of X_i.

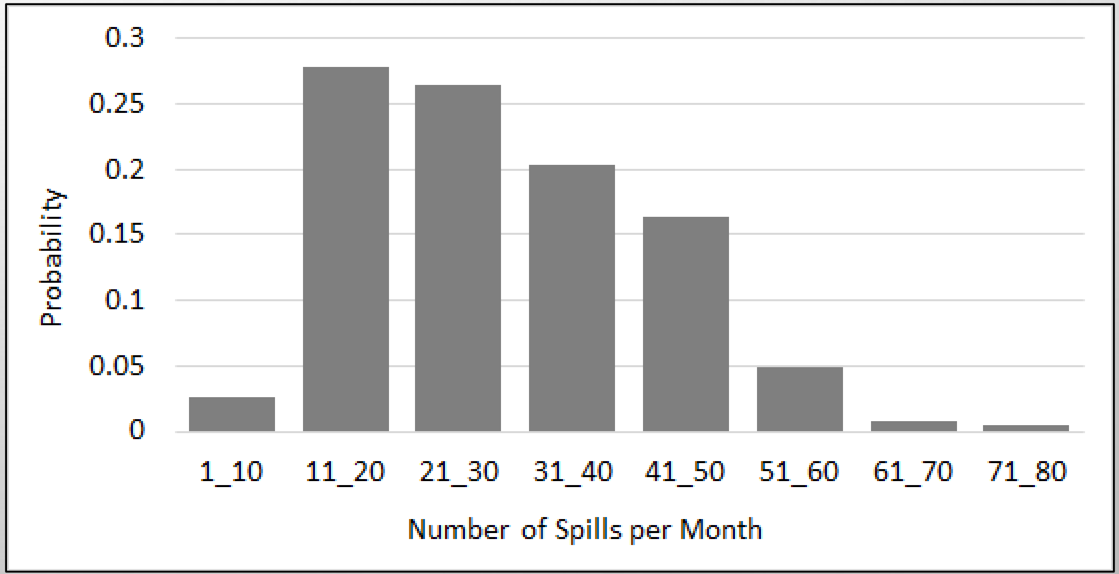
$$\lambda_i = P(y_i = y|X_i) = h(X_i) = H(X_i'\beta) \geq 0$$

Usually,

$$\lambda_i = P(y_i = y|X_i) = e^{X_i'\beta} \geq 0$$
$$\begin{cases} P(y_i = y|X_i) = \dfrac{e^{-\lambda_i}.\lambda_i}{y!} \\ \lambda_i = e^{X_i'\beta} \end{cases}$$

COUNT MODEL - RESULTS

```
Poisson regression                              Number of obs     =        153
                                                LR chi2(3)        =     764.36
                                                Prob > chi2       =     0.0000
Log likelihood = -864.77018                     Pseudo R2         =     0.3065

------------------------------------------------------------------------------
  spillcount |      Coef.   Std. Err.      z    P>|z|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
     oilmbbl |   .0830875   .0058457    14.21   0.000     .0716302    .0945448
    injwells |  -.0016325   .0002252    -7.25   0.000    -.0020739   -.0011911
    gasoline |   -.574426   .0293592   -19.57   0.000     -.631969   -.5168831
       _cons |   5.157747    .120775    42.71   0.000     4.921033    5.394462
------------------------------------------------------------------------------

. margins, dydx(_all)

Average marginal effects                        Number of obs     =        153
Model VCE    : OIM

Expression   : Predicted number of events, predict()
dy/dx w.r.t. : oilmbbl injwells gasoline

------------------------------------------------------------------------------
             |            Delta-method
             |      dy/dx   Std. Err.      z    P>|z|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
     oilmbbl |   2.474704   .1779268    13.91   0.000     2.125974    2.823434
    injwells |  -.0486232   .0067457    -7.21   0.000    -.0618446   -.0354018
    gasoline |  -17.10889   .9104313   -18.79   0.000     -18.8933   -15.32447
------------------------------------------------------------------------------

. predict pr30, pr(30)
(14 missing values generated)
```



DRASTIC INDEX

Depth to Groundwater

Recharge

Aquifer media

Soil media

Topography

Impact of vadose Zone

Hydraulic **C**onductivity

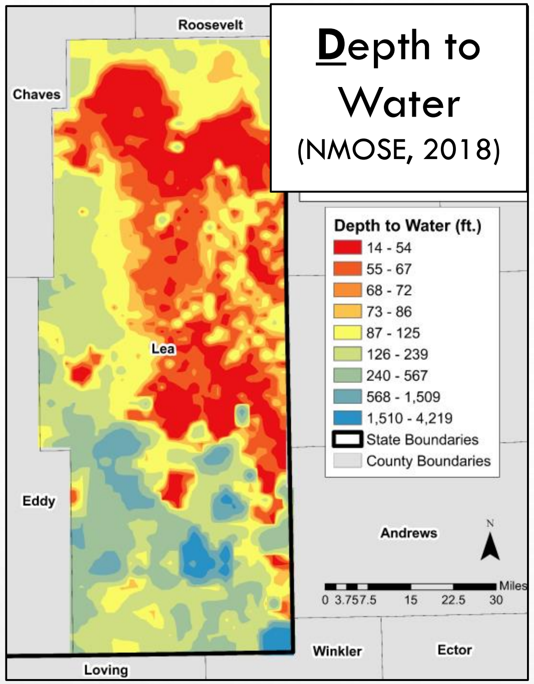
Rating (r): 1-10 where increasing values represent vulnerability
Weight (w): 1-5 where increasing values represent importance

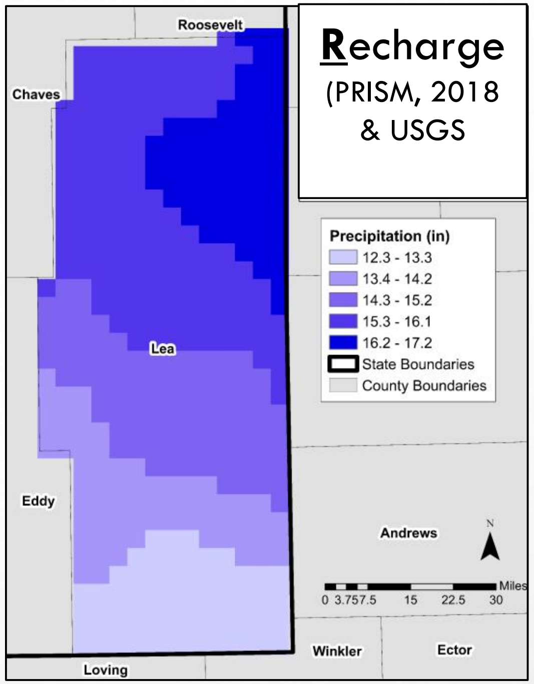
Feature	Rating	Rating (σ)	Weight
D	1-10	3.5	5
R		3.4	4
A		2.6	3
S		3.2	2
T		3.8	1
I		2.7	5
C		3.5	3

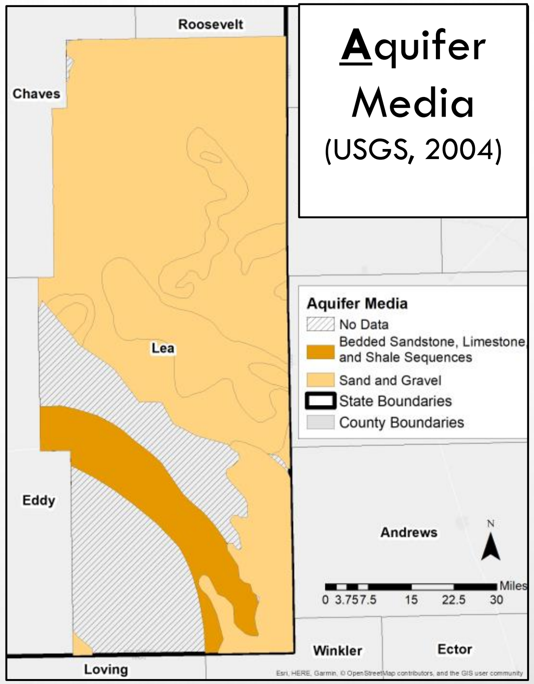
$$\text{DRASTIC Index} = D_rD_w + R_rR_w + A_rA_w + S_rS_w + T_rT_w + I_rI_w + C_rC_w$$

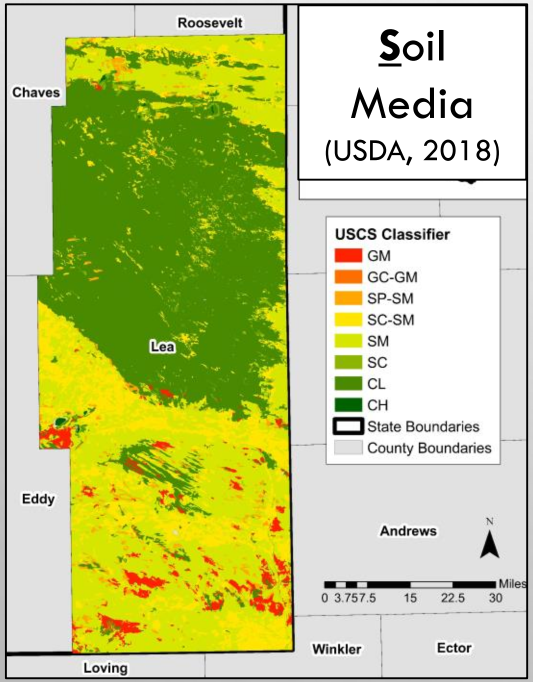
DRASTIC DATA SOURCES

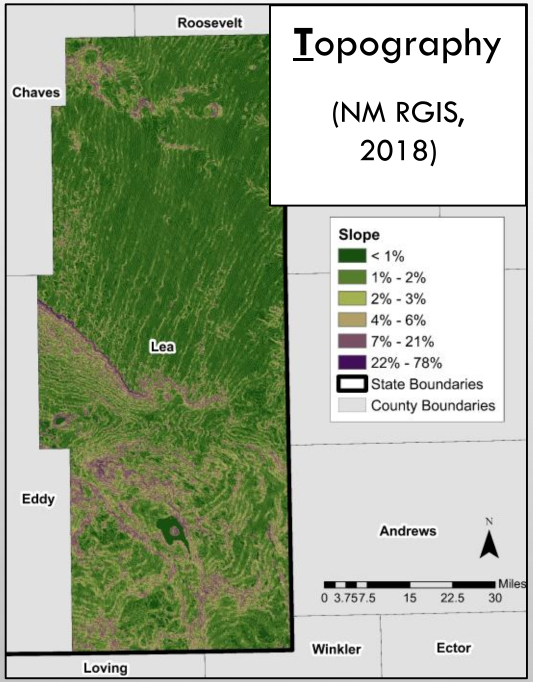
- Multiple scales
- Various formats (rasters, points, shapefiles)
- Aggregated to TR (36 mi^2)

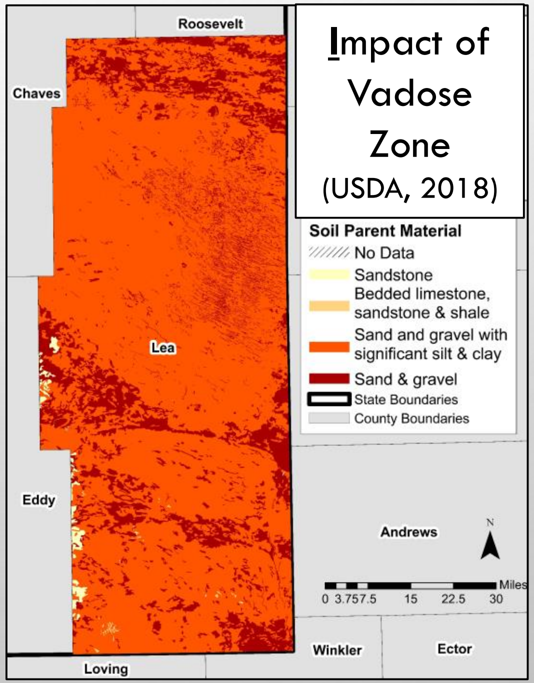


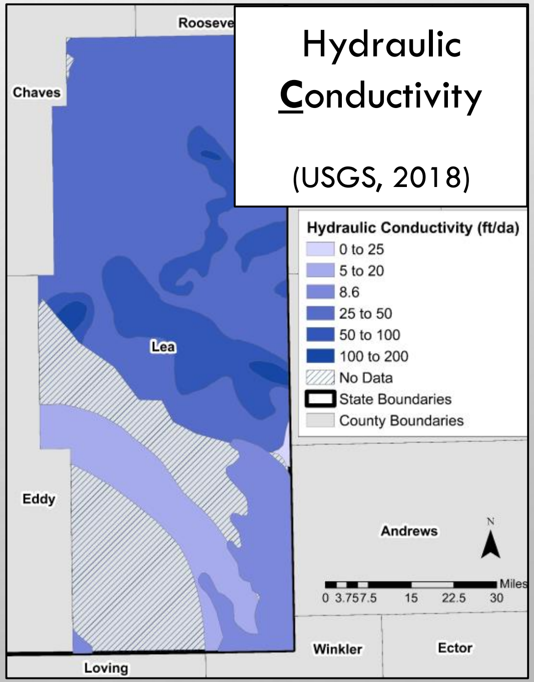






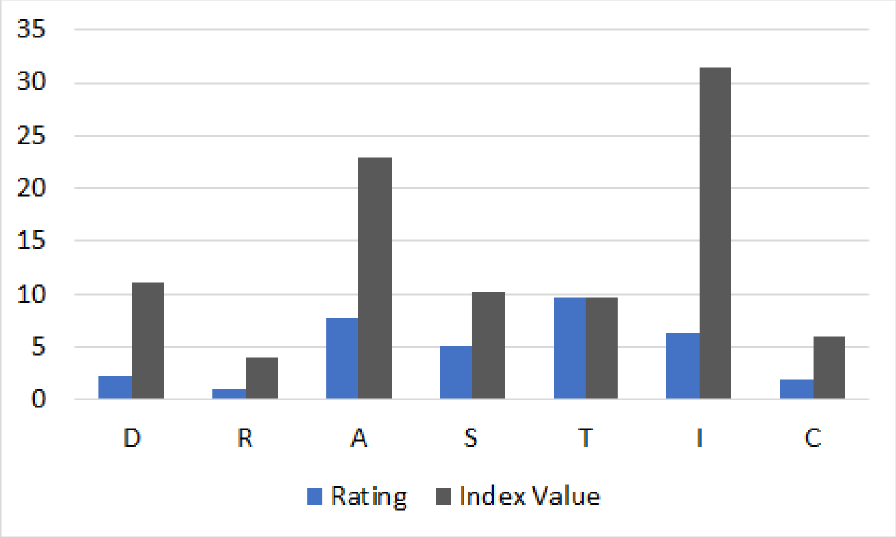




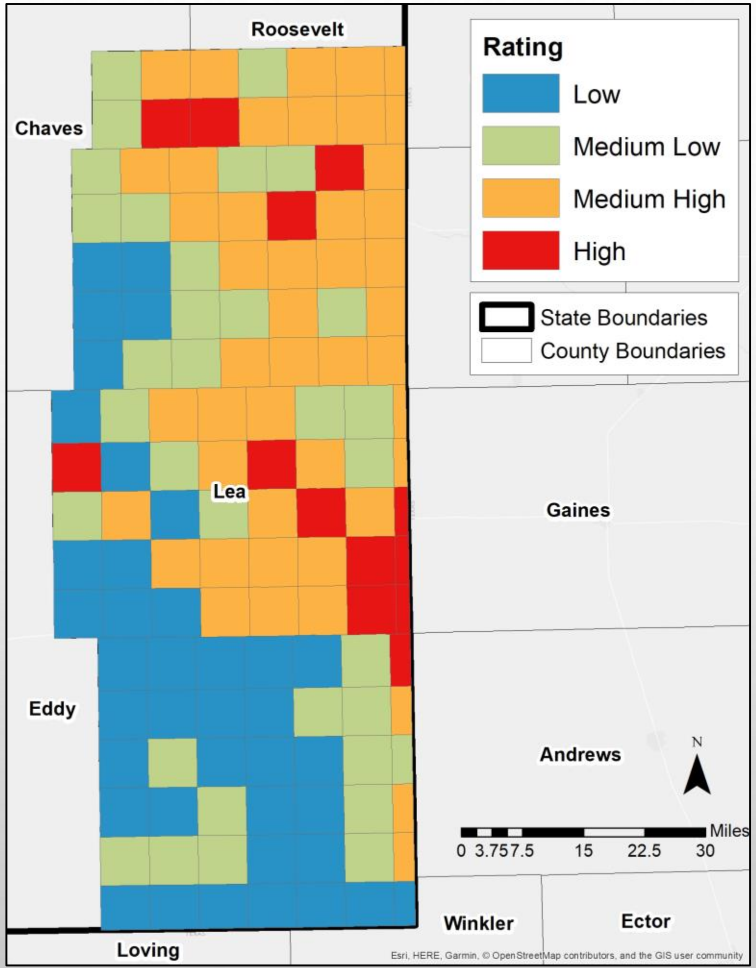


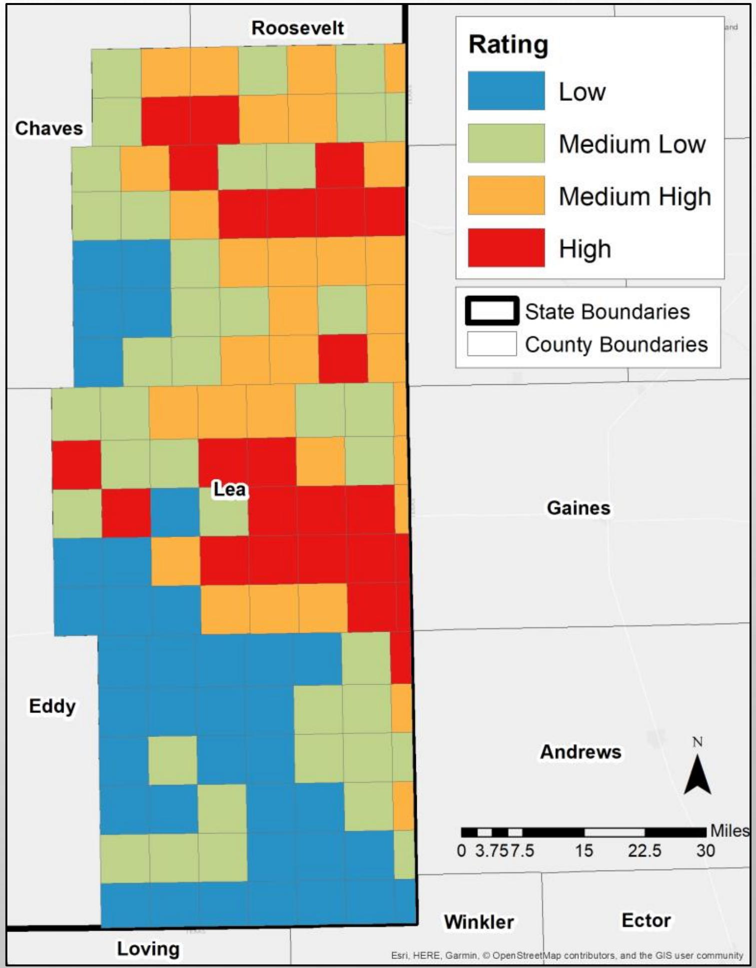
DRASTIC - RESULTS

- Parametric Sensitivity
- Spatial trends
- Data availability
- Uncertainty

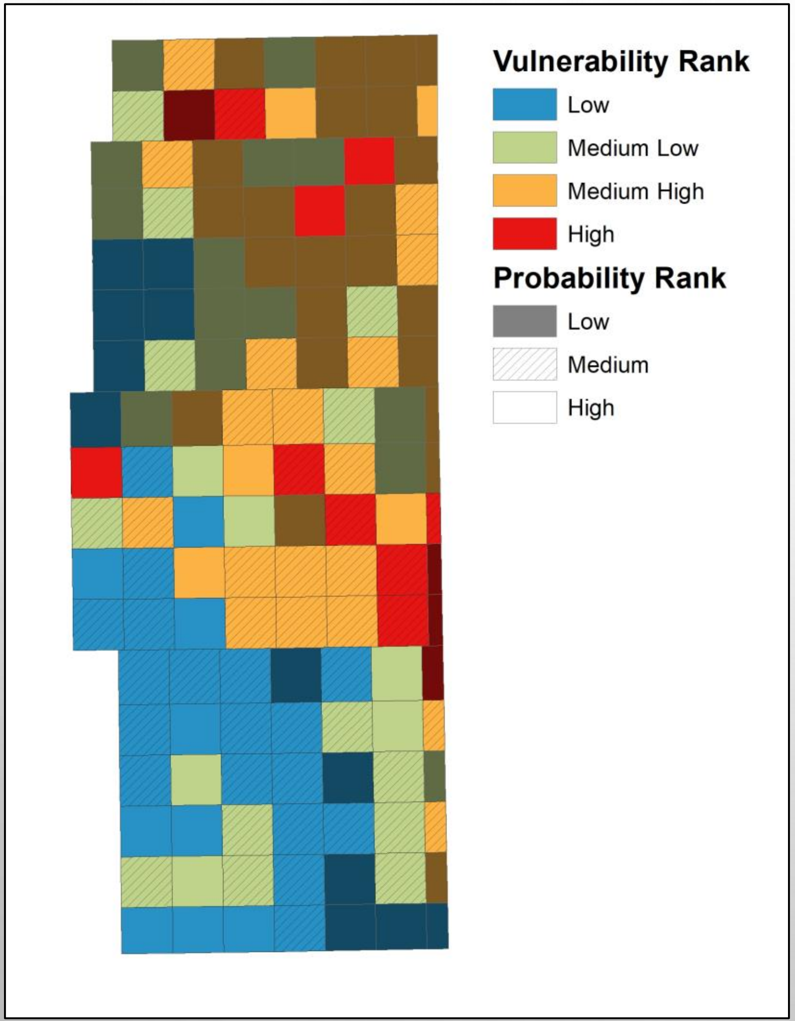


Parameter ratings (raw) vs. weighted index values





RISK ESTIMATION



Vulnerability and DRASTIC parameters

Probability

- Oil production 2006-2017
- Relational
- Relative to average value

Additional Parameters

- Disposal wells
- Well age
- Temporal trends

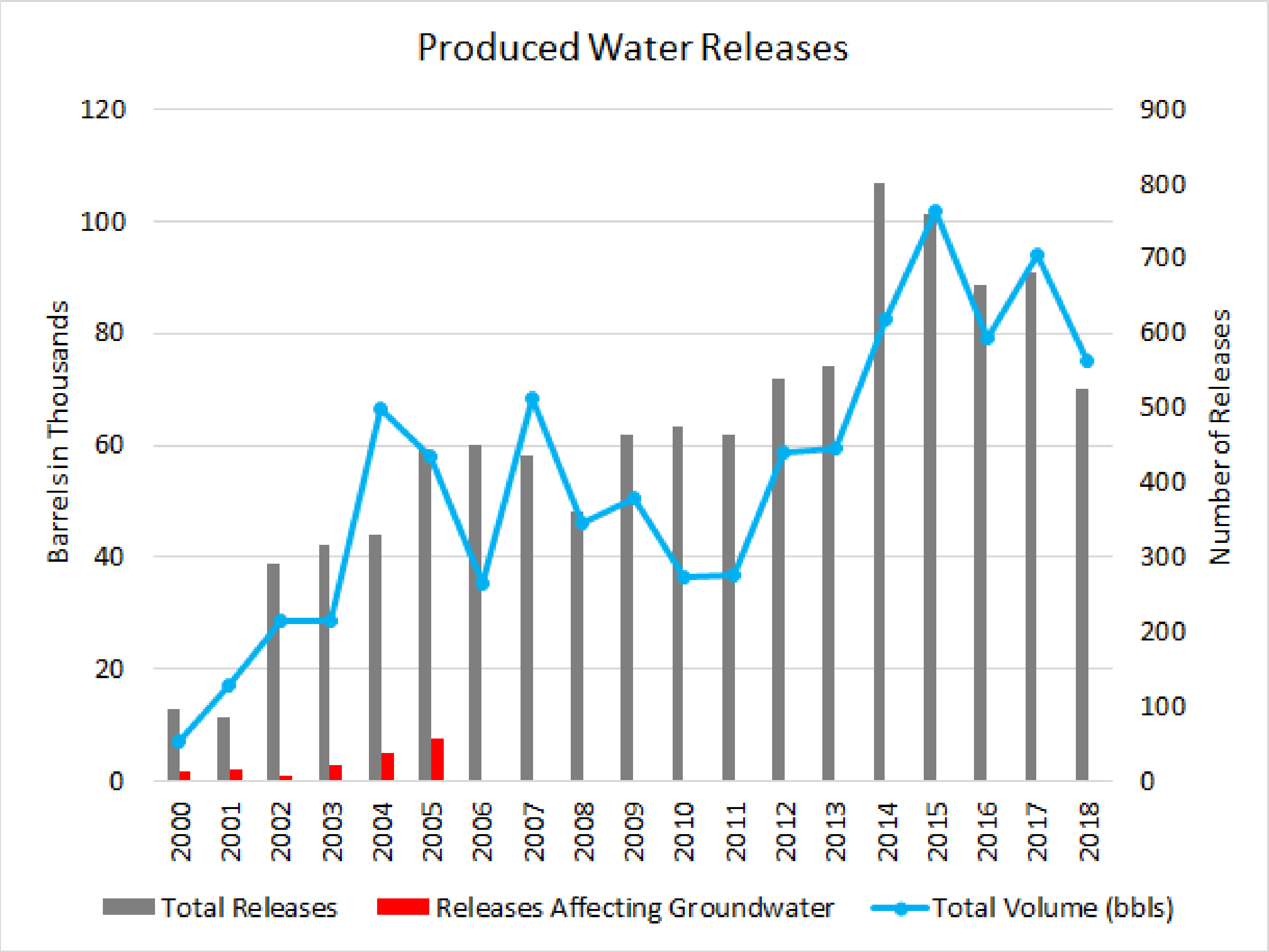
SPILL DATA AVAILABILITY AND TRENDS

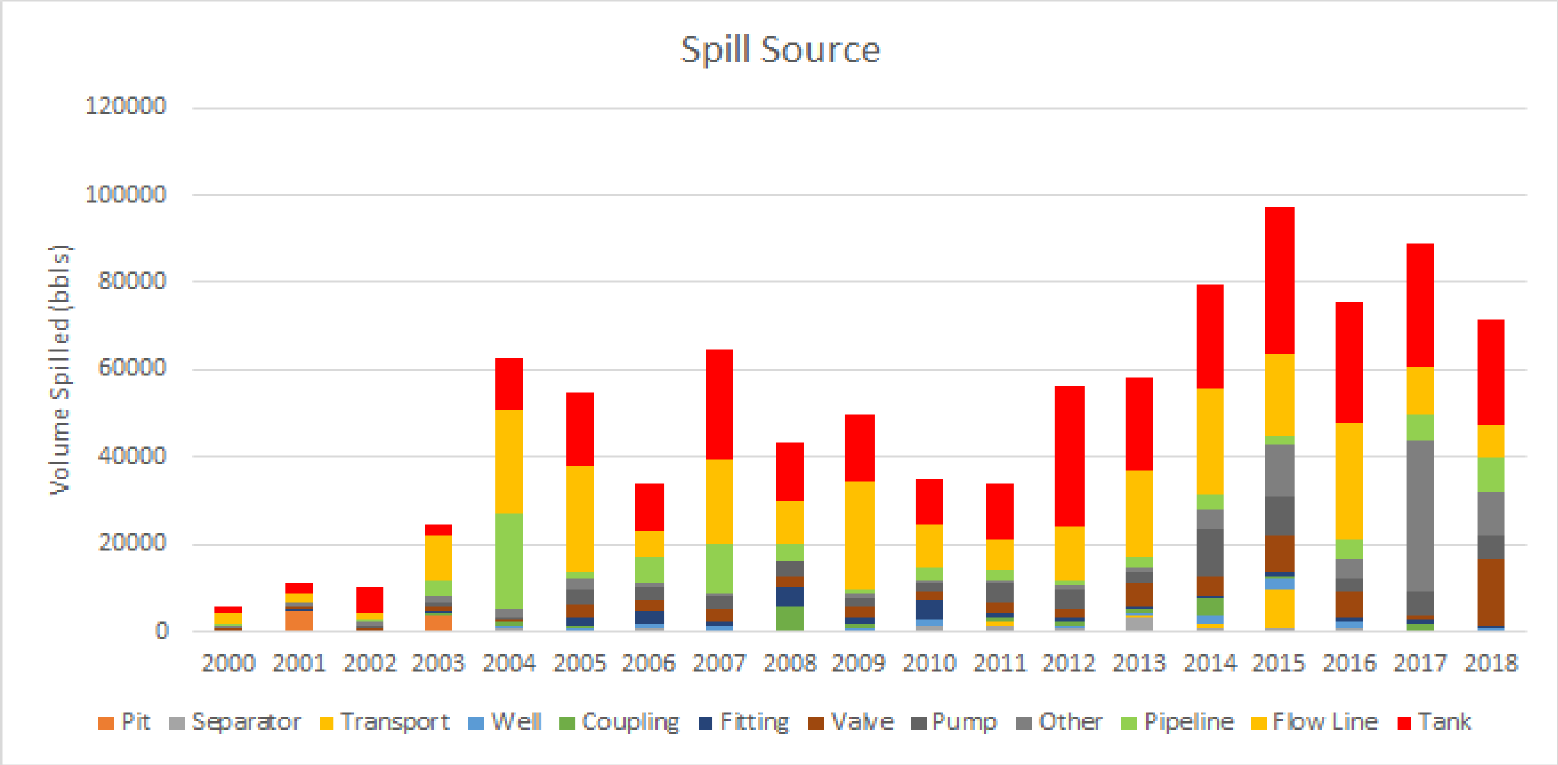
Reporting Requirements

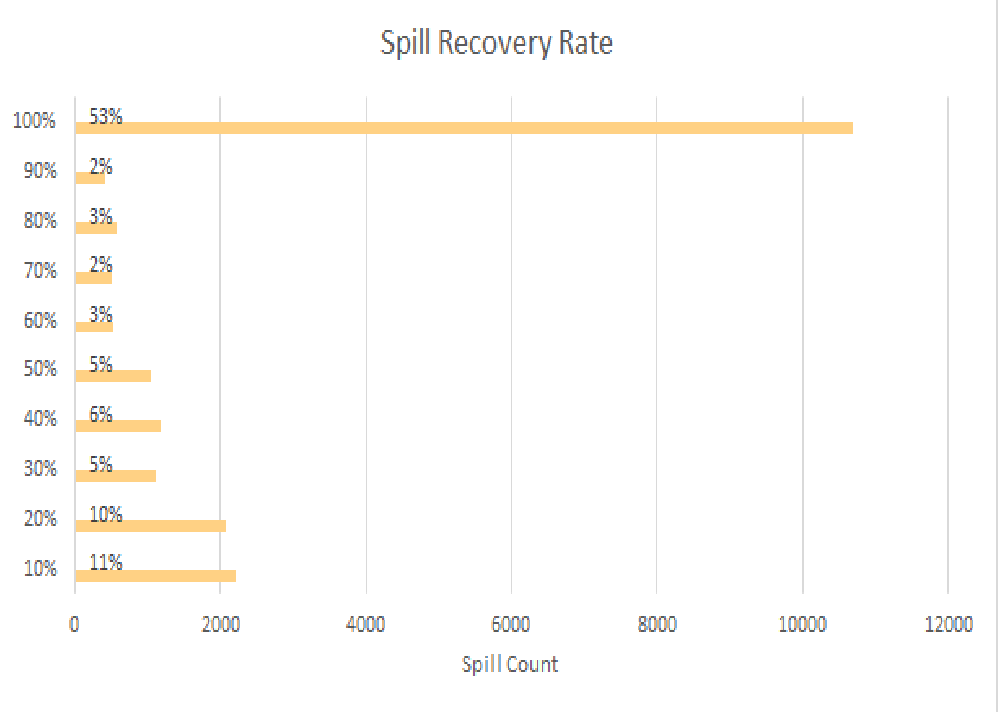
What has been reported?

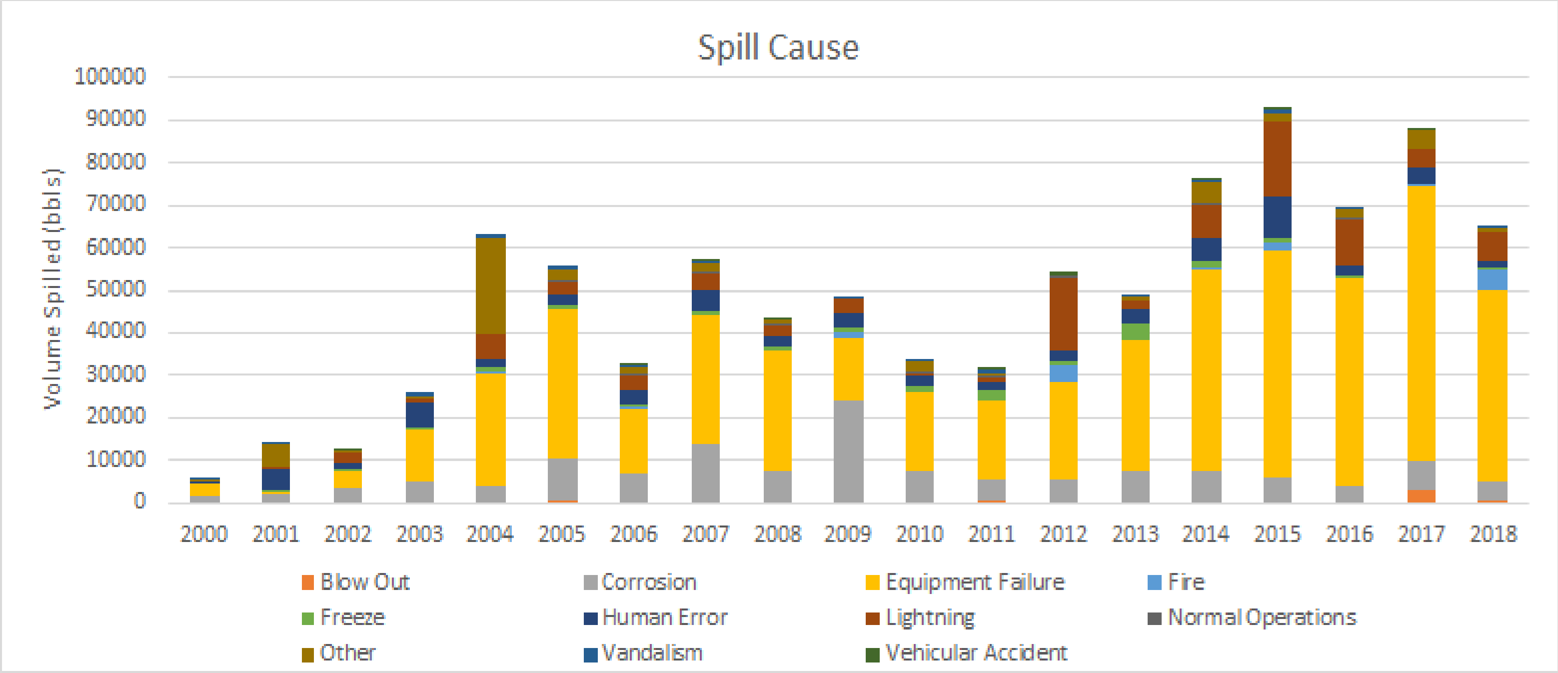
Description	Reported Values
Coordinates	62%
County	69%
Incident Type	76%
Spill Cause	81%
Volume Spilled	86%
Spill Source	87%
Material Spilled	97%
Spill Date	99%

GROUNDWATER IMPACTS




Spill Source
Volume Spilled (bbls)
120000
100000
80000
60000
40000
20000
0
2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017 2018
Pit Separator Transport Well Coupling Fitting Valve Pump Other Pipeline Flow Line Tank


Spill Recovery Rate
100% 53%
90% 2%
80% 3%
70% 2%
60% 3%
50% 5%
40% 6%
30% 5%
20% 10%
10% 11%
0 2000 4000 6000 8000 10000 12000
Spill Count


Spill Cause
Volume Spilled (bbls)
100000
90000
80000
70000
60000
50000
40000
30000
20000
10000
0
2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017 2018
Blow Out Corrosion Equipment Failure Fire
Freeze Human Error Lightning Normal Operations
Other Vandalism Vehicular Accident

EMERGING TRENDS IN WATER MANAGEMENT

- Conventional Methods:
  - Trucking
  - SWD disposal
  - Secondary recovery
- Conveyance
- Treatment and reuse
  - NMAC 19.15.34 “Part 34”
  - Siting and design requirements
  - 28 facilities state wide (14 in DI&II)
  - >10Mbbls recycled

Press

Arthur D. Little Analysis Finds Collaboration is Central to Unlocking Enormous Oil and Gas Potential of US Permian Basin

Posted by OilVoice Press - OilVoice

Oil and gas adapts to drought as extraction grows in the Permian

Adrian C Hedden, Carlsbad Current-Argus Published 7:58 a.m. MT Oct. 28, 2018

Industry officials say they could lead the way on water sustainability

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Permian Water Disposal A Thorn In Our Side, Oil Execs Say

By Michelle Casady

Law360 (October 11, 2018, 10:28 PM EDT) -- Disposing of water used in oil and gas operations in the relatively rural stretches of the Permian Basin is one of the biggest challenges facing energy companies, executives from Shell and Callon Petroleum Co. said at a Houston energy panel on Thursday.

Callon Petroleum's biggest water worry for its Permian operations used to be sourcing enough water to frack its wells, but that has "quickly morphed to disposal," Joseph C. Gatto, president, CEO and director of Callon said. And because so much wastewater is trucked out of the Permian, energy companies have to contend with high volume trucking activity that makes the roads in the region dangerous, Amir Gerges, general manager for Permian Shell, said.

"If anything could constrain our growth, it could be water," Gerges said. "I think we're going to find a solution, because once one company cracks that nut, others will follow suit."

The remarks came as part of an energy summit at Rice University's Baker Institute Center for Energy Studies in Houston.

Credits: https://oilvoice.com/Press/23941/Arthur-D-Little-Analysis-Finds-Collaboration-is-Central-to-Unlocking-Enormous-Oil-and-Gas-Potential-of-US-Permian-Basin; https://www.daily-times.com/story/money/industries/oil-gas/2018/10/28/oil-and-gas-adapts-drought-extraction-grows-permian/1606290002/; https://www.law360.com

FUTURE WORK

- Model validation
- Data challenges
- Additional and confounding factors
- Water storage locations and temporal trends
- Expanded research area

THANK YOU!

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Image credit:
EJ Sullivan Graham

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