ROCK PROPERTIES DERIVED FROM CONTINUOUS PRESSURE MONITORING IN THE ARBUCKLE GROUP OF OKLAHOMA

Perilla-Castillo, Paula J. Geology and Geophysics, University of Oklahoma

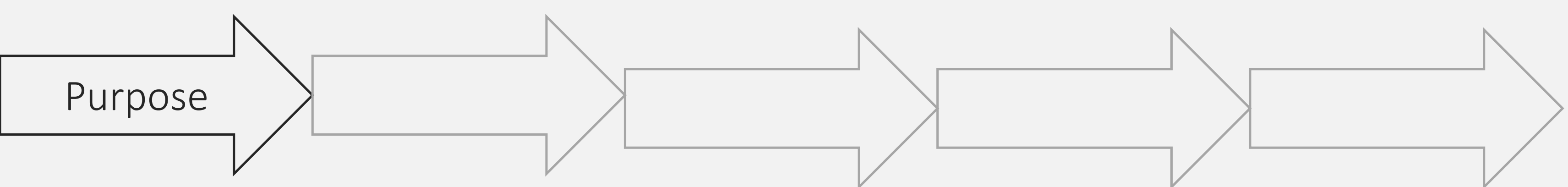
MURRAY, Kyle E., Oklahoma Geological Survey, University of Oklahoma

KROLL, Kayla A., Lawrence Livermore National Laboratory

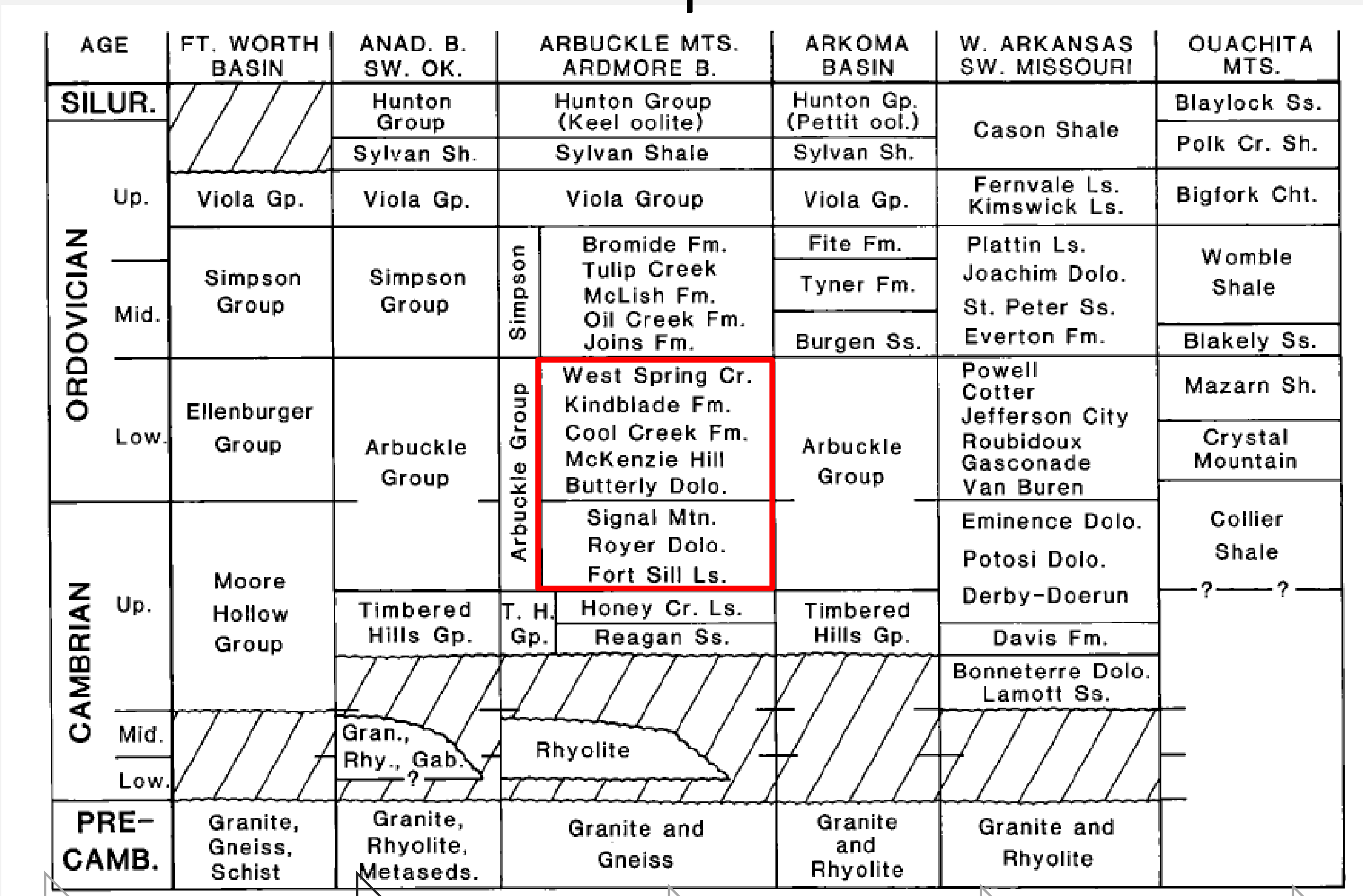
WALKER, Ella L., Oklahoma Geological Survey, University of Oklahoma

Objectives

- Analyze effects of solid earth tides and atmospheric pressure on water level fluctuations observed in inactive SWD wells.
- Compute reservoir parameters and elastic properties of rocks from tidal strain and tidal gravitational potential.



The Arbuckle Group in Oklahoma



Introduction

The Arbuckle Group in Oklahoma

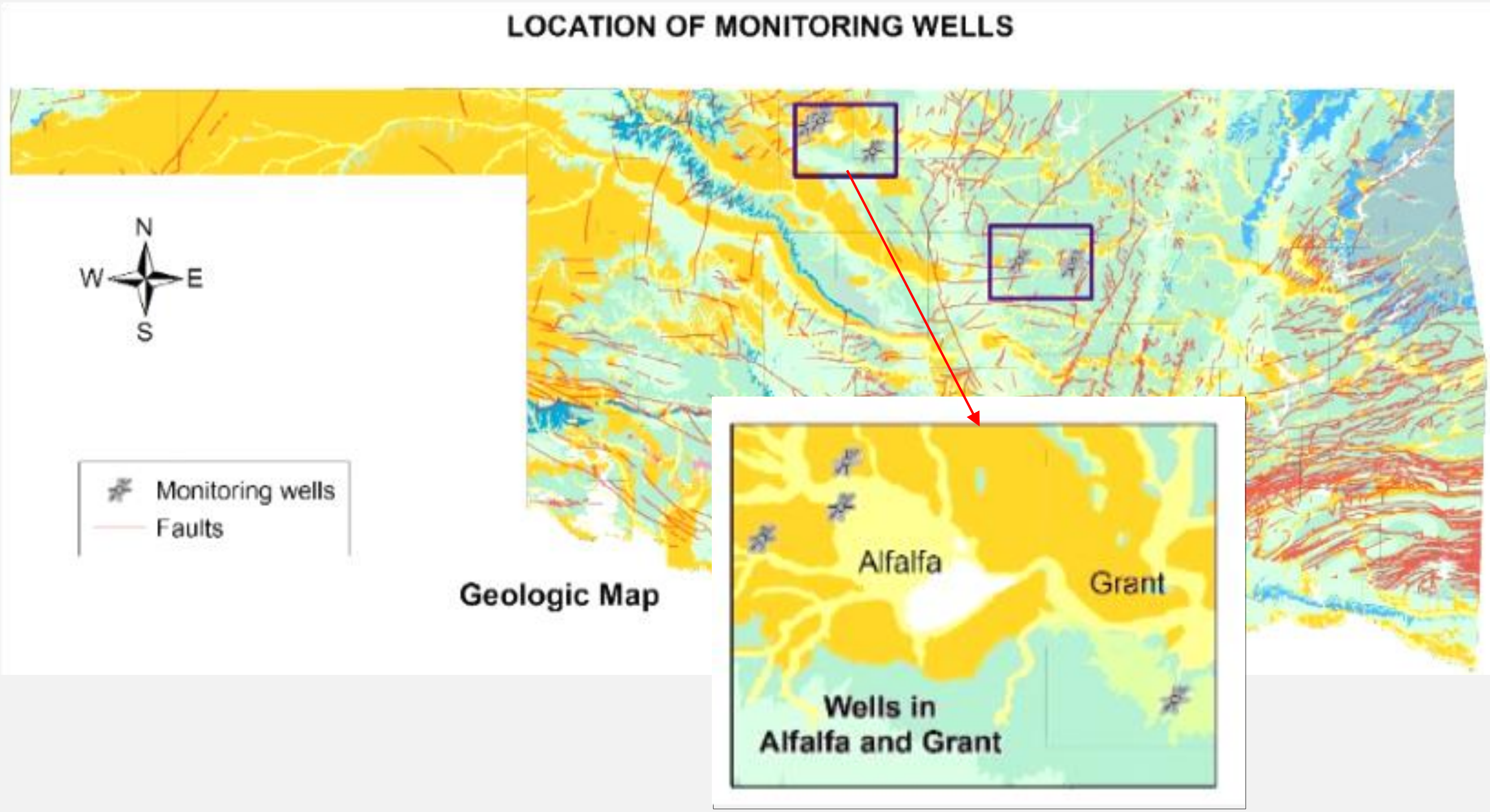
Commonly used as a saltwater disposal (SWD) zone

Zone	Mbbl of SWD in 2009	Mbbl of SWD in 2010	Mbbl of SWD in 2011	Mbbl of SWD in 2012	Mbbl of SWD in 2013	Mbbl of SWD in 2014
Multiple-Undiff	114837	119355	141226	135938	131955	131646
Other or Unspec.	13921	11213	12270	11752	11713	10745
Permian	48996	51156	69411	82715	87947	89770
Virgilian	27261	27360	29359	38863	38687	42222
Missourian	21706	25912	24601	29348	31656	34438
Desmoinesian	32894	33267	33504	34825	33565	32450
Atokan-Morrowan	40812	33886	34963	40140	35831	33581
Mississippian	9102	9354	9259	9140	8531	8315
Woodford	838	415	434	244	265	258
Dev to Mid Ord	102868	98721	94838	100482	102070	105858
Arbuckle	434230	449406	525027	566047	842631	1046913
Basement	1368	771	621	1379	820	2162
Statewide Total	848832	860817	975513	1050873	1325670	1538358

Saltwater disposal volumes for 2009-2014 in Mbbl
Murray, 2015

Introduction

Study Area

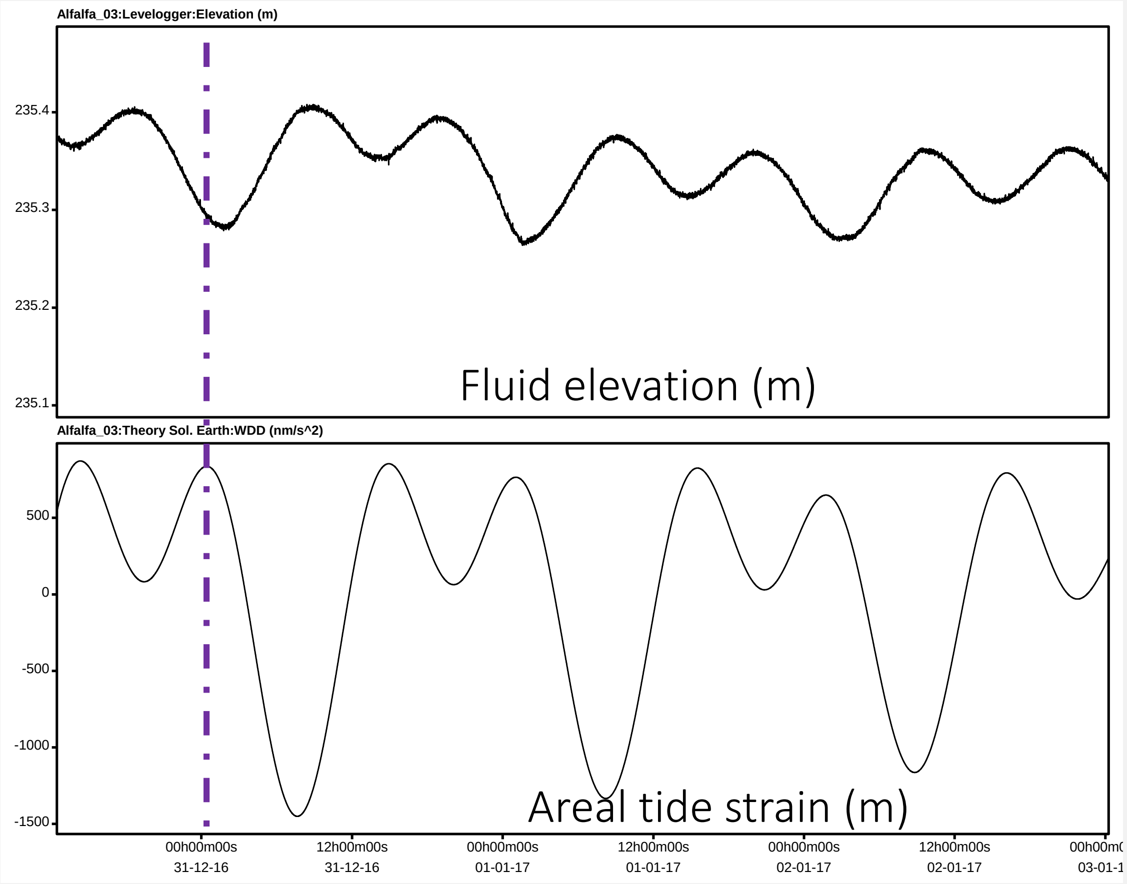


Introduction

Solid Earth Tide Stress

Motions of the moon and the sun create stresses that result in strains in the crust of the Earth.

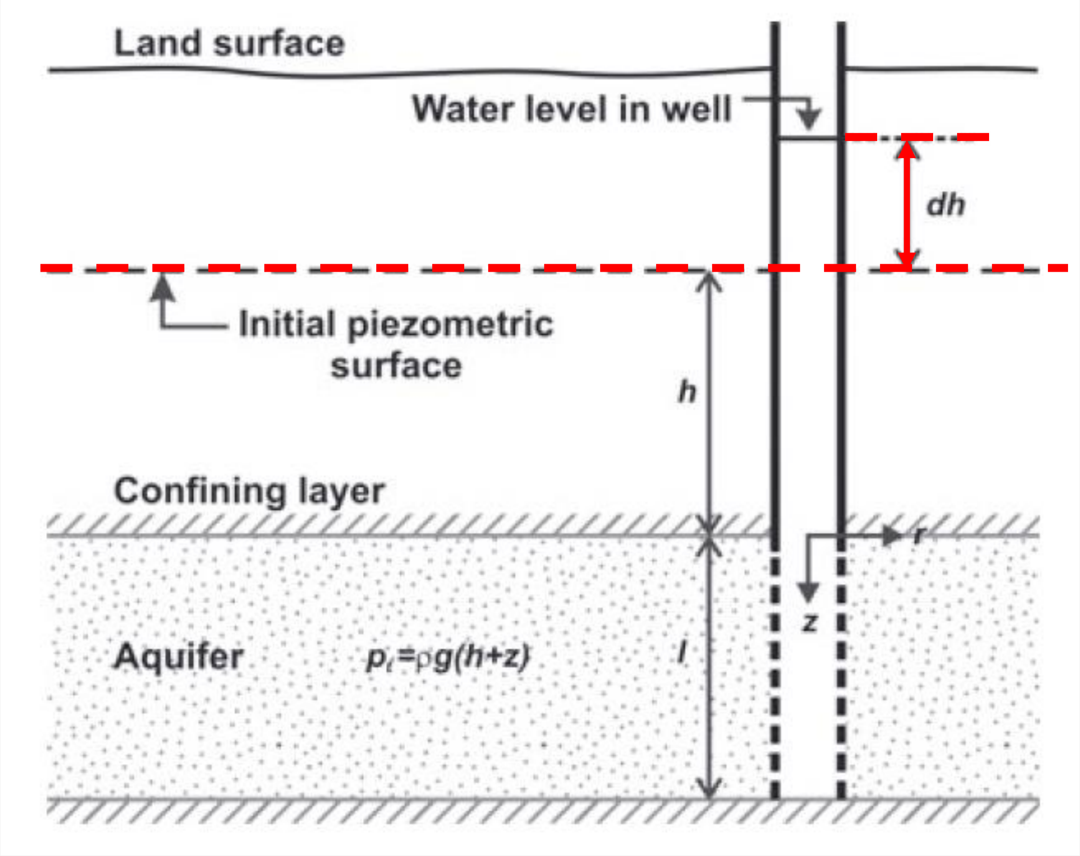
Strains result in fluctuations in water levels of confined aquifers/reservoirs.



Introduction

Earth Tide Stress

Time-series analysis of the fluctuations can be used for estimating properties of the reservoir such as **specific storage**, **porosity**, **matrix compressibility**, **storage coefficient**, and **transmissivity**



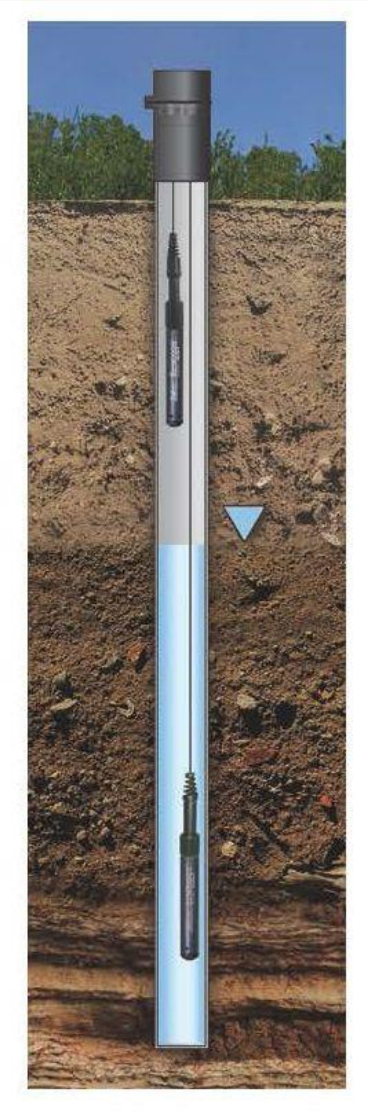
Graphic representation of a well drilling a confined aquifer
From Cutillo and Bredehoeft (2011)

Methodology

1. Instrumentation of wells

Baseline measurements of fluid levels and downhole pressure/temperature prior to deployment of pressure transducers.

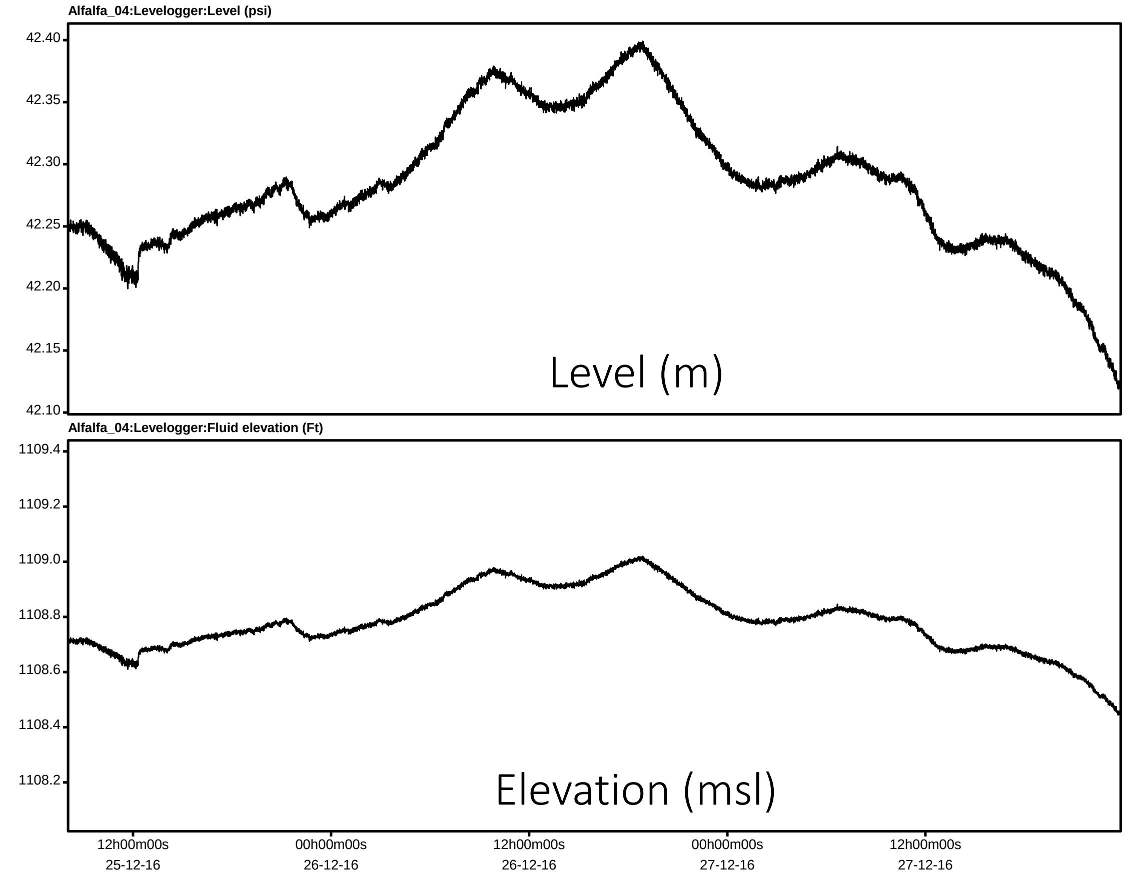
Pressure and temperature are measured every 30 seconds



Methodology

2. Normalization of data

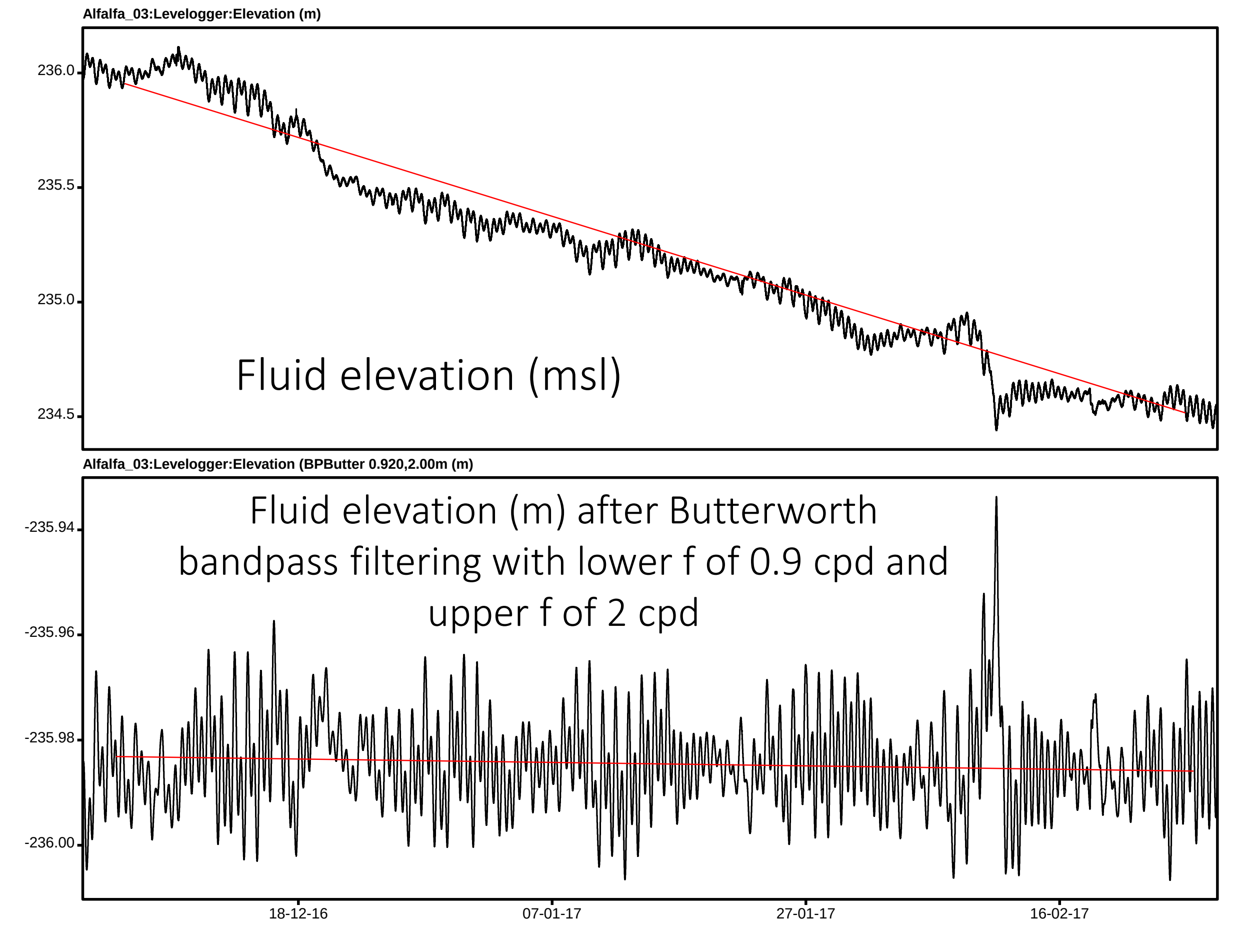
Pressure data is normalized to a datum (elevation above sea level).



Methodology

3. Baseline trends

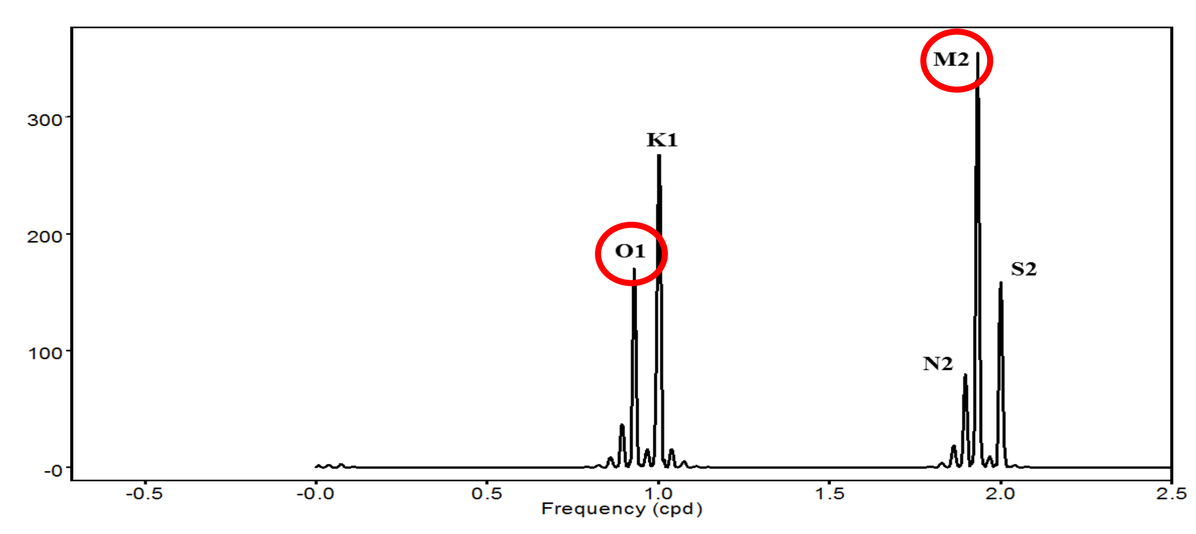
Analysis of the uncompensated data to identify possible long-term trends that result from regional flow, evapotranspiration, injection, and seasonal changes.



Methodology

4. Tidal Signal Identification

Using FFT, Tsoft identifies each component, which has distinct amplitude (A), frequency (*f*), and phase relation (Φ).



Spectrum of the tidal components in a theoretical tide

Symbol	Frequency (cycles per day)	Explanation
O_1	0.93	Main lunar diurnal
K_1	1.00	Lunar-solar diurnal
M_2	1.93	Main lunar semidiurnal
S_2	2.00	Main solar semidiurnal
N_2	1.90	Lunar elliptic

Methodology

Methodology

5. Computation of properties

Specific Storage: Volume of water released from storage from a unit volume of aquifer per unit decline in hydraulic head

Specific storage can be computed if the changes in head can be measured and the Poisson's ratio (v) for the reservoir is known.

$$(1)\ S_S = -\left[\left(\frac{1-2v}{1-v}\right)\left(\frac{2\bar{h}-6\bar{l}}{ag}\right)\right]\boxed{\frac{dW_2}{dh}}$$

v is the Poisson's ratio (dimensionless),
$\bar{h}$ and $\bar{l}$ are Love's numbers (constants) used in tidal analysis (dimensionless),
a is the radius of the Earth (L); and
g is acceleration due to gravity (L/T^2).

Methodology

5. Computation of properties

Specific Storage

$$(2)\ W_2(\theta, \varphi, t) = gK_m bf(\theta) cos[\beta(\varphi, t)]$$

K_m is the general lunar coefficient (L) (53,7 cm),
b is the amplitude factor that has a distinct value for each tidal component with period Ƭ (dimensionless),
f(θ) is the latitude function (dimensionless); and
β(ϕ, *t*) is a phase term that depends on the longitude ϕ and the Greenwich Mean Time (GMT) t.

Methodology

Methodology

5. Computation of properties

Specific Storage

dW2/dh can be replaced by ratio between component amplitude (theorical) and component amplitude in the head measurements

$$(3)\ S_S = -\left[\left(\frac{1-2v}{1-v}\right)\left(\frac{2\bar{h}-6\bar{l}}{ag}\right)\right]\frac{A_2(T,\theta)}{A_h(T)}$$

$$(4)\ A_2(T,\theta) = gK_m bf(\theta)$$

Tidal component	b	f(θ)
O_1	0.377	sinθcosθ
K_1	0.531	sinθcosθ
M_2	0.174	$0.5\cos^2\theta$
N_2	0.908	$0.5\cos^2\theta$
S_2	0.423	$0.5\cos^2\theta$

Methodology

Methodology

5. Computation of properties

Storativity: Volume of water released from storage by a confined aquifer per unit surface area of aquifer per unit decline in hydraulic head normal to surface equal to product of specific storage and saturated thickness

$$(5)\ S = Ss * b$$

Results

Summary of results					
Well	Latitude (θ) (Degrees)	Tidal componen t	Ss (cm-1)	Ss (ft-1)	S (unitless)
Alfalfa 03	36.812	O1	1.60E-04	4.87E-05	0.07
		M2	3.76E-05	1.15E-05	0.02
Alfalfa 04	36.783	O1	3.99E-04	1.22E-04	0.17
		M2	2.47E-04	7.51E-05	0.11
Grant 06	36.637	O1	2.34E-04	7.15E-05	0.10
		M2	2.37E-04	7.21E-05	0.10

Specific storage range 1.15E-05 to 1.22E-4 (1/ft)
Storavity range 0.02 to 0.17 (dimensionless)

Preliminary conclusions

- Values of Ss are in accordance with the values for a confined aquifer.
- For the Arbuckle Group, reported values of Ss are one order of magnitude less than the results obtained from this research.
- Values of S are one to two order of magnitude higher than reported values.
- However, values for Ss and S reported include the Simpson Group, in what is known as the Arbuckle-Simpson Aquifer. The Arbuckle-Simpson Aquifer is more shallow and it mixes two different units.

Future Work

Computation of:

- reservoir porosity from barometric efficiency
- transmissivity
- permeability
- matrix compressibility

From time-series analysis of water-level fluctuation

Identification of specific formations within the Arbuckle Group to characterize each formation

Acknowledgments

This work was supported by the Oklahoma Independent Petroleum Association (OIPA) and the Oklahoma Geological Survey (OGS).

To

- Dr. Kyle E. Murray, Ph.D.
- Ella Walker, M.Sc.
- Jordan Williams, Water Resources Geologist.

References

- Bredehoeft, J. D., 1967, Response of Well-Aquifer Systems to Earth Tides: Journal of Geophysical Research: Solid Earth, v. 72, no. 12, p. 13.
- Cutillo, P. A., and Bredehoeft, J. D., 2011, Estimating Aquifer Properties from the Water Level Response to Earth Tides: Groundwater, v. 49, no. 4, p. 11.
- Doodson, A. T., and Warburg, H. D., 1941, Admiralty manual of tides: Her Majesty's Stationary Office.
- Hsieh, P. A., Bredehoeft, J. D., and Farr, J. M., 1987, Determination of aquifer transmissivity from earth tide analysis: Water Resources Research, v. 23, no. 10, p. 8.
- Kroll, K. A., Cochran, E. S., and Murray, K. E., 2017, Poroelastic properties of the Arbuckle Group in Oklahoma derived from well fluid level response to the 3 September 2016 Mw5.8 Pawnee and 7 November 2016 Mw5.0 Cushing Earthquakes: Seismological Research Letters, v. In press, p. 22.
- Mehnert, E., Valocchi, A. J., Heidari, M., Kapoor, S. G., and Kumar, P., 1999, Estimating Transmissivity from the Water Level Fluctuations of a Sinusoidal Forced Well: Groundwater, v. 37, no. 6, p. 6.
- Merritt, M. L., 2004, Estimating Hydraulic Properties of the Floridian Aquifer System by Analysis of Earth-tide, Ocean-Tide, and Barometric Effects, Collier and Hendry Counties, Florida: US Geological Survey Water-Resources Investigations Report, v. 03-4267, p. 76.
- Rahi, K. A., 2010, Estimating the hydraulic parameters of the Arbuckle-Simpson Aquifer by analysis of naturally-induced stresses: Doctoral Dissertation Oklahoma State University, p. 168.
- Rojstaczer, S., and Agnew, D. C., 1989, The influence of formation material properties on the response of water levels in wells to earth tides and atmospheric loading: Journal of Geophysical Research, v. 94, no. B9, p. 8.
- Van-Camp, M., and Vauterin, P., 2005, Tsoft: graphical and interactive software for thre analysis of time series and Earth tides: Computers & Geosciences, v. 31, p. 10.

THANK YOU

QUESTIONS?