Geologic Controls on Groundwater Recharge to the Central Oklahoma Aquifer

Kyle Murray, OGS Hydrogeologist

1. INTRODUCTION

During recent and historic droughts the sustainability of water resources in Oklahoma has come into question. Water resources can be sustainable when water resources planning integrates the best science available (Loucks 2000), while continuing research to improve understanding and adaptively managing the resource. The Oklahoma Water Resources Board (OWRB) recently published the **Oklahoma Comprehensive Water Plan** (OCWP) with the objective to *"ensure a dependable water supply for all Oklahomans through integrated and coordinated water resources planning by providing the information necessary for water providers, policy-makers, and end users to make informed decisions concerning the use and management of Oklahoma's water resources"* (OWRB 2012). The OCWP provides a reasonable framework for statewide planning and directives for the Regional Planning groups; however, prominent groundwater systems present unique challenges within this framework.

Groundwater was the source of approximately 36.6 percent of the 1,559 million gallons per day (MGD) of freshwater used in the state of Oklahoma in 2005 (Tortorelli 2009). One of the strategies for managing groundwater as a sustainable resource has been for OWRB to establish a maximum annual yield (MAY), which limits aquifer-wide annual groundwater consumption. The top 4 producers of groundwater in Oklahoma were the High Plains (252 MGD), Alluvial & Terrace (133 MGD), Rush Springs (51.6 MGD), and Central Oklahoma (40.3 MGD) aquifers. OWRB established MAYs for the High Plains in 2002 and for the Alluvial & Terrace aquifers (collection of approximately 15 aquifers) between 1978 and 2001. However, a MAY for the Rush Springs or Central Oklahoma has not yet been established. The Central Oklahoma aquifer may be the most pressing because it provides drinking water to ~26% of the state's groundwater sourced public supply. It is estimated that 26.7 MGD were used for public water supply from the Central Oklahoma aquifer, which is second only to public water supply from the Alluvial & Terrace aquifers (47.5 MGD) serving 35.6% of the state's groundwater sourced public supply.

2. GROUNDWATER RECHARGE

Groundwater resources are sustainable if the rate of recharge to the aquifer is equivalent to, or exceeds, the rate of withdrawal from the aquifer. So, it would be reasonable for the MAY to be less than or equal to the volume of water that annually recharges the aquifer. Unfortunately, recharge is one of the most difficult hydrologic parameters to measure or estimate (Cook and Kilty 1992). Common techniques used to estimate or measure recharge include: (1) streamflow hydrograph separation; (2) analysis of water-table fluctuations; (3) lysimeter measurements (4) tracer testing; (5) geophysical surveys; and (6) numerical modeling of a hydrologic system using a water-balance equation (Scanlon et al. 2002). Some of these techniques are limited to estimating recharge rates at specific locations; however, recharge rates have been shown to vary substantially across landscapes (Murray et al. 2003).

Estimates of groundwater recharge rates are essential for water-resources planning, such as when establishing a MAY. We could define groundwater recharge as the flux of water across the ground surface, using a simplified water-balance equation:

$$RECH_{GW} = P + Q_{in} - RO - ET - Q_{out} \pm Transfers \quad (1)$$

GEOLOGIC CONTROLS ON GROUNDWATER..., *continued*

where **RECHGW** is groundwater recharge; **P** is precipitation; Q_{in} is water injected into the aquifer, **RO** is runoff or net loss of surface water via streamflow; **ET** is evapotranspiration; Q_{out} is water pumped out of the aquifer; and **Transfers** represent inter-aquifer (i.e., inter-basin) transfers that add or remove water from the land overlying the aquifer. So, groundwater recharge (i.e., **RECHGW**) is a measure of change in water storage in the subsurface. Some variables such as Q_{in} or **Transfers** may be negligible, and therefore ignored, within some aquifers. Many of the variables in the water-balance equation can be measured directly (e.g., **P**, Q_{out}) at point locations or estimated using empirical or analytical models (e.g., **ET** or **RO**).

Groundwater recharge rates are dependent on many environmental factors including climatic conditions, vegetation, physiographic characteristics, soil type and geologic material through which water flows. Common techniques for estimating recharge require data that may be expensive and time consuming to collect; thus, new techniques must be developed to estimate spatially and temporally variable recharge rates (Cook and Kilty 1992). More recently, it was reported that accurate methods of estimating recharge are not available (Scanlon et al. 2002).

In this article, hydrogeologic conditions, land-use, groundwater use, precipitation, and groundwater recharge estimates are described for the Central Oklahoma aquifer. The objective is to highlight conditions that affect groundwater recharge rates to the Central Oklahoma aquifer. Future research and water resources planning could consider these data when estimating aquifer-wide recharge rates.

From the Director...

G. Randy Keller, Oklahoma State Geologist

By mid-May things are generally slowing down around OU, but not at the OGS. A new geologist, Brittany Pritchett, joined the OGS on July 1. She just finished her M. S. degree at the University of Oklahoma. The title was *"Effects of activity of water on the dissolution of Jarosite".* She will initially work with Rick Andrews on our ongoing data compilation efforts for petroleum, geothermal, and CO_2 sequestration studies. However, she will also be developing her own research program.

We continue to be excited by the improvements at the Oklahoma Petroleum Information Center (OPIC). The second phase of the re-roofing project and replacement of most of the air conditioners will begin soon, and two new lifts have arrived to make the retrieval of cores and cuttings more efficient and safer. The new core viewing room is air-conditioned and well-lighted and continues to be a big hit. We have been able to empty at lot of space that was filled with old furniture and other "treasures" by having surplus sales and now have a considerable amount of extra space available to store the cores and cuttings that keep arriving.

OGS seismologist Austin Holland and I were invited to serve as panelists at meeting focusing hydraulic fracturing and induced seismicity hosted by the University of Southern California. Mike Smith of the IOGCC, Lance Cole of the PTTC, and Dana Jurick from Devon also played major roles at this meeting so Oklahoma's perspective on this issue was well-represented.

3. CENTRAL OKLAHOMA AQUIFER

3.1 Geologic and Hydrogeologic Overview

The Central Oklahoma aquifer is comprised of Quaternary age alluvial and terrace deposits up to 100 feet thick (Christenson et al. 1992) and the Permian age sedimentary rocks of the Hennessey, Garber, and Wellington Formations, along with the Chase, Council-Grove and Admire (CCA) Groups. The geologic units comprising the Central Oklahoma aquifer extend from the northern to the southern border of the state of Oklahoma, but are only sufficiently permeable to serve as a water-bearing aquifer in central Oklahoma (**Figure 1**) between the Cimarron River on the north and the Canadian River on the south (Breit et al. 1990). Structural deformation results in layers that gently dip to the west at about 0.35 degrees. Depth to the base of the Central Oklahoma aquifer, ranging from 100 to 1000 feet below the land surface, is defined by the depth at which total dissolved solids (TDS) concentration reaches 5000 mg/L (Breit et al. 1990).
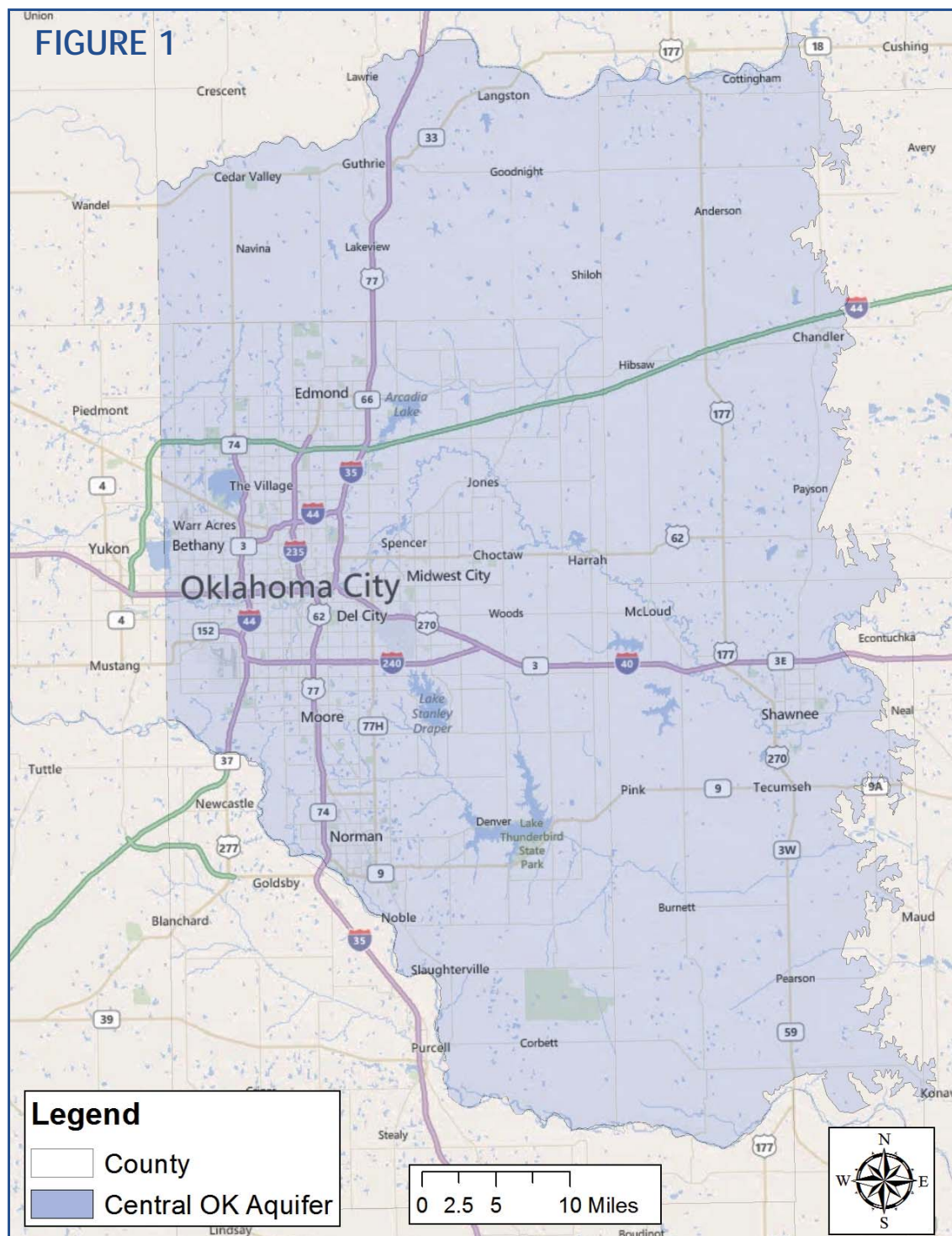
The Hennessey Group is up to 700 feet thick (Wood and Burton 1968) and composed predominantly of reddish-brown, low permeability mudstone and lesser amounts of siltstone and fine-grained sandstone. Western portions of the Garber Sandstone are confined by the Hennessey Group, which is present over approximately 17% of the Central Oklahoma aquifer extent (**Figure 2**). Because the Garber and Wellington were formed as part of a deltaic system they are lithologically similar and contain a complex of interfingering beds of sandstone, siltstone, and shale. Sandstone beds are commonly 5 to 10 feet thick, but may be as much as 40 feet thick. Cumulative thickness of the undifferentiated Garber-Wellington may be up to 1600 feet (Christenson et al. 1992). Geophysical logs show that sandstone comprises 35 to 75 percent of the Garber and Wellington in Oklahoma and Logan Counties (Carr and Marcher 1977). Because the source material was near present day

FIGURE 1

Legend
County
Central OK Aquifer

0 2.5 5   10 Miles

Figure 1. Extent of Central Oklahoma aquifer.

Oklahoma City, the percentage of sand and permeability decrease with distance from Oklahoma City. The CCA Groups underlie the Wellington Formation and consist of fine-grained sandstone, shale, and limestone up to 940 feet cumulative thickness (Bingham and Moore 1975).

Groundwater well records show that approximately 27, 436, 139, and 161 wells are completed in the Hennessey, Garber, Wellington, and CCA units, respectively (USGS-NWIS 2012) within the extent of the Central Oklahoma aquifer. Because of lithologic similarities between the formations and difficulty in distinguishing them (see examples in **Figures 3A, 3B, and 3C**), there are approximately 283 wells that are completed in the undifferentiated Garber-Wellington. The few wells that are completed in the Hennessey yield negligible amounts of water. Yields for wells completed in the Garber and Wellington range from 50 to 634 gallons per minute (gpm), and CCA ranges from 10 to 120 gpm (Christenson 1998). Well yields are related to the grain-size/grain-size distribu-

Figure 2. Extent of geologic units comprising the Central Oklahoma aquifer.
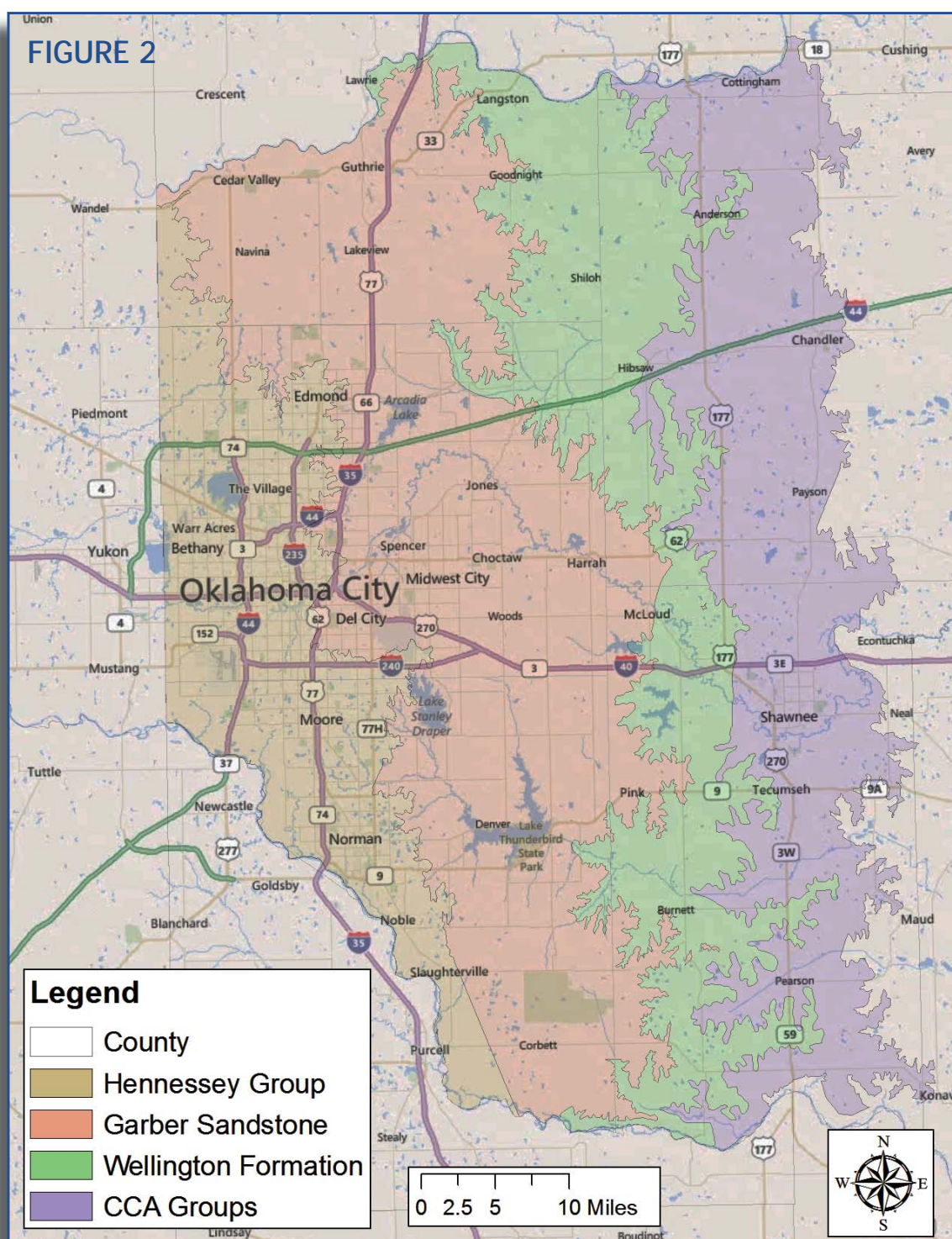
Figure 3. Representative outcrop and hand samples of the A) Garber Sandstone, B) Wellington Formation, and C) CCA Groups. (Photos courtesy of Kyle Murray, OGS Staff.)

Figure 3A. Representative outcrop and hand sample of the Garber Sandstone.

Figure 3B. Representative outcrop and hand sample of the Wellington Formation.

Figure 3C. Representative outcrop and hand samples of the CCA Groups.

tion of the clastic sediments comprising each unit as shown in **Figures 3A, 3B, and 3C**. When the completed interval of a well draws water from a portion of the aquifer with larger, well-sorted grains (such as in the Garber sample — **Figure 3A**) this translates to larger pore spaces, higher permeability and higher well yield.

3.2 Land Use and Groundwater Use

The Central Oklahoma aquifer has an extent of approximately 1.85 million acres (~2890 square miles) underlying all of Cleveland and Oklahoma Counties and parts of Canadian, Kingfisher, Lincoln, Logan, Payne, Pottawatomie, and Seminole Counties. Herbaceous natural/semi-natural grassland vegetation covers 39.1% of the aquifer extent, followed by forest at 29.2%, developed land at 16.8%, agricultural land at 13.1%, and open water, barren land, shrub or emergent wetlands comprising the remaining 1.8% of the landscape (USGS-NLCD 2012). Total groundwater use from the Central Oklahoma aquifer was estimated to be 40.3 MGD or ~45,175 acre-feet in 2005 (Tortorelli 2009). Use was comprised of public

water supply (66.1%), domestic/commercial (18.6%), industrial/mining (7.3%), irrigation (4.4%), livestock & aquaculture (3.2%), and thermoelectric power generation (0.3%). Municipalities such as Chandler, Del City, Edmond, Guthrie, Midwest City, Norman, Oklahoma City, and Shawnee draw some portion of their water from the Central Oklahoma aquifer. Groundwater use for public supply was estimated to be 26.7 MGD (29,852 acre-feet) in 2005.

Because the objective of this article is to highlight conditions that affect groundwater recharge rates to the Central Oklahoma aquifer, it is important to compare historic groundwater use estimates to changes in groundwater storage. Total groundwater use has changed substantially over time, with an early estimate being ~10,000 acre-feet in 1970 (Pettyjohn and Miller 1982). Total groundwater use and groundwater use for public supply from 1990 to 2005 are illustrated in **Figure 4**.
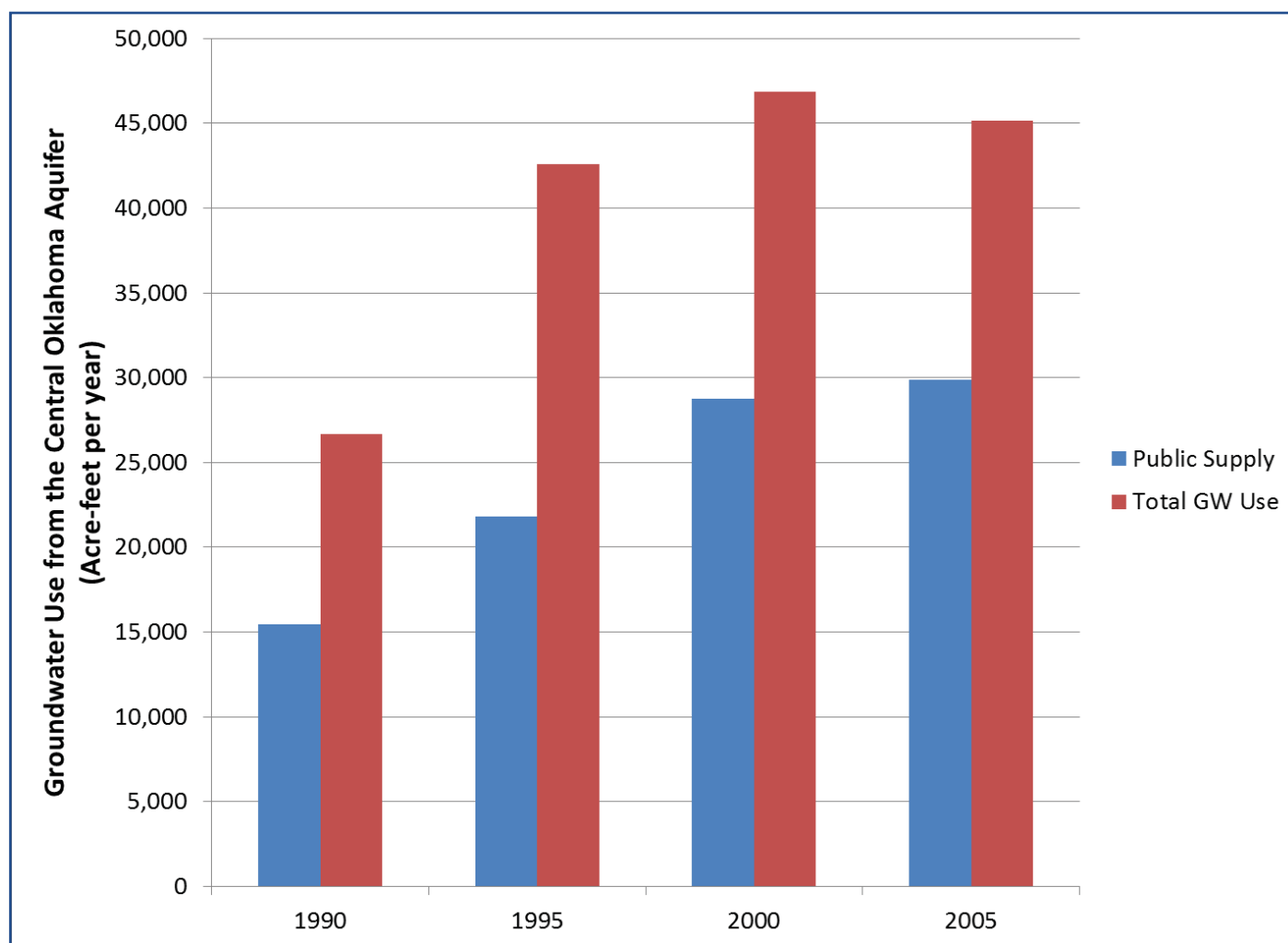

Figure 4. Groundwater use from the Central Oklahoma Aquifer, 1990 (Lurry and Tortorelli 1996), 1995 & 2000 (Tortorelli 2012), 2005 (Tortorelli 2009).

3.3 Precipitation Patterns

Estimates of annual precipitation at 17 Mesonet station locations were used to interpolate precipitation over the extent of the Central Oklahoma aquifer. Annual 30-yr normalized precipitation at Mesonet stations ranged from 32.48 in/yr (Marshall in Logan County) to 40.91 in/yr (Bowlegs in Seminole County) (OCS-Mesonet 2012). Annual precipitation increases from west to east, with lowest precipitation amounts in the Guthrie area of Logan County and highest precipitation in the Shawnee area of Pottawatomie County. Interpolating Mesonet station estimates results in 33.0 to 40.3 in/yr with a mean precipitation of 37.1 in/yr over the extent of the Central Oklahoma aquifer.

3.4 Historic Groundwater Recharge Estimates

Wood and Burton (1968) estimated recharge to be 5% of the average annual precipitation, but using groundwater production and water-level data they estimated recharge in the North Canadian River area to be greater than 5%. Carr and Marcher (1977) reported that the rate of recharge was nearly equivalent to baseflow (i.e., discharge of groundwater to streams). Therefore, baseflow measurements made on Wildhorse Creek were used to estimate recharge to the Central Oklahoma aquifer to be 10% of annual precipitation. This recharge rate is likely to vary seasonally with highest recharge rates occurring when vegetation is dormant so that water will infiltrate rather than evapotranspire (Carr and Marcher 1977).

Another study of groundwater recharge in central Oklahoma was completed by the Department of Geology at Oklahoma State University. Average annual runoff and precipitation data (1931 – 1960) were combined with precipitation gage data from Enid, Okena, and Pauls Valley (1970 – 1980) and generalized soils maps to estimate ground-water recharge rates for the unconfined part of the Garber-Wellington aquifer. A computerized stream hydrograph separation technique resulted in an estimated recharge rate of 2.11 inches per year for water years 1973, 1976, 1978, and 1979 (Pettyjohn and Miller 1982), which is approximately 5.7% of the 30-year normalized annual precipitation in the Central Oklahoma aquifer.

4. DISCUSSION

If 5 to 10% of the average annual precipitation (37.1 in/yr) were to recharge the Central Oklahoma aquifer then recharge would range from 1.86 in/yr to 3.71 in/yr. These rates of recharge over the entire aquifer extent (~1.85 million acres) would result in 286,718 to 571,895 acre-feet of recharge per year. Because recharge to the Central Oklahoma aquifer is not likely to occur where the Hennessey (0.31 million acres) or Alluvial & Terrace deposits (0.26 million acres) are present at the

surface, the effective recharge area may be reduced to 1.28 million acres and 5% to 10% of annual precipitation would result in 198,807 to 396,544 acre-feet of recharge per year. Under any of these scenarios, groundwater recharge to the Central Oklahoma aquifer would far exceed the range of estimated groundwater use (26,682 acre-feet to 46,844 acre-feet) from 1990 to 2005. Because estimated recharge far exceeds estimated groundwater use, the potentiometric surface would be expected to increase over the course of time. A groundwater recharge estimation method referred to earlier (e.g., analysis of water-table fluctuations) could be used to validate this conceptual trend. When comparing the potentiometric surface from 1986/1987 (Christenson et al. 1992) to the potentiometric surface from 2009 (Mashburn and Magers 2011), there is an effective decrease in potentiometric levels. These conflicting results (i.e., greater recharge than groundwater use versus decreasing potentiometric levels) suggest that additional studies to "measure" or model spatially and temporally variable recharge rates and improved methods for estimating groundwater use are warranted. Future studies of recharge or groundwater use should include ranges of uncertainty that can be accounted for during water planning.

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Oklahoma Research: 2011

The following list of 2011 Master's Theses and PhD Dissertations is a compilation of research completed by students at *The University of Oklahoma ConocoPhillips School of Geology & Geophysics*. We will be providing similar lists from Oklahoma State University and Tulsa University in future issues.

PhD Dissertations:

Depositional history and reservoir characteristics of structurally confined foredeep turbidites, northern Chicontepec Basin, Mexico
—Supratik Sarkar

Master's Theses:

Sequence stratigraphic framework of the Caney Shale, Arkoma Basin southeastern Oklahoma
—Andrea Marie Magoon

Mineralogy, internal zonation, and thermal history of the Little Three Pegmatite, Ramona, California
—Kerry Anne Paul

Sedimentologic, geochemical, and detrital zircon data from the Middle Permian El Reno Group of northwest Oklahoma: implications for paleogeography and wind patterns of western Pangaea
—Alisan Colleen Templet

Chemical weathering in glacial meltwater stream, Wright and Taylor Valley, Antarctica
—Allison Renee Stumpf

Geochemical characterization and comparison of condensates from the Barnett Shale, Fort Worth Basin, Texas and the Woodford Shale, Arkoma Basin, Oklahoma
—Shanshan Liu

Facies control on production in the Jackfork Group, Latimer and Pushmataha counties, Oklahoma
—Levi Barrett Melton Pack

Production-induced changes in reservoir geomechanics
—Sunday O. Amoyedo

Field characterization and analog modeling of natural fractures in the Woodford Shale, southeast Oklahoma
—Henry Badra

An integrated paleomagnetic, geochemical, and diagenetic study of the Mississippian Barnett Shale, Fort Worth Basin, Texas
—John Christopher Deng

Electron probe micro-analysis of the Woodford Shale, south central Oklahoma
—Matthew Wayne Totten

A controlled-source seismic and gravity study of the High Lava Plains (HLP)
—Catherine Michelle Cox

Paleomagnetic and petrological investigation of Long Mountain Granite, Wichita Mountains, Oklahoma
—Matthew Evan Hamilton

Earthquake Report 1ˢᵗ Quarter 2012

Austin Holland, OGS Research Seismologist; Amie Gibson, OGS Research Scientist II

The Oklahoma Geological Survey (OGS) recorded **259 earthquakes within Oklahoma from January 1 to March 31, 2012**. There were 18 felt earthquakes in the first quarter of 2012 shown in **Table 1**. 110 earthquakes occurred in Lincoln County with the majority of those associated with aftershocks of the Nov. 2011 M5.6 Prague Earthquake sequence. **107** earthquakes were located in **Oklahoma County** with **most of those consistent with the ongoing Jones earthquake swarm**. There were **17** earthquakes located in **Seminole County** and **16** earthquakes located in **Okfuskee County**. All

earthquakes located in Oklahoma for the first quarter of 2012 can be seen in **Figure 1**. Current seismic activity continues to be concentrated within central Oklahoma.
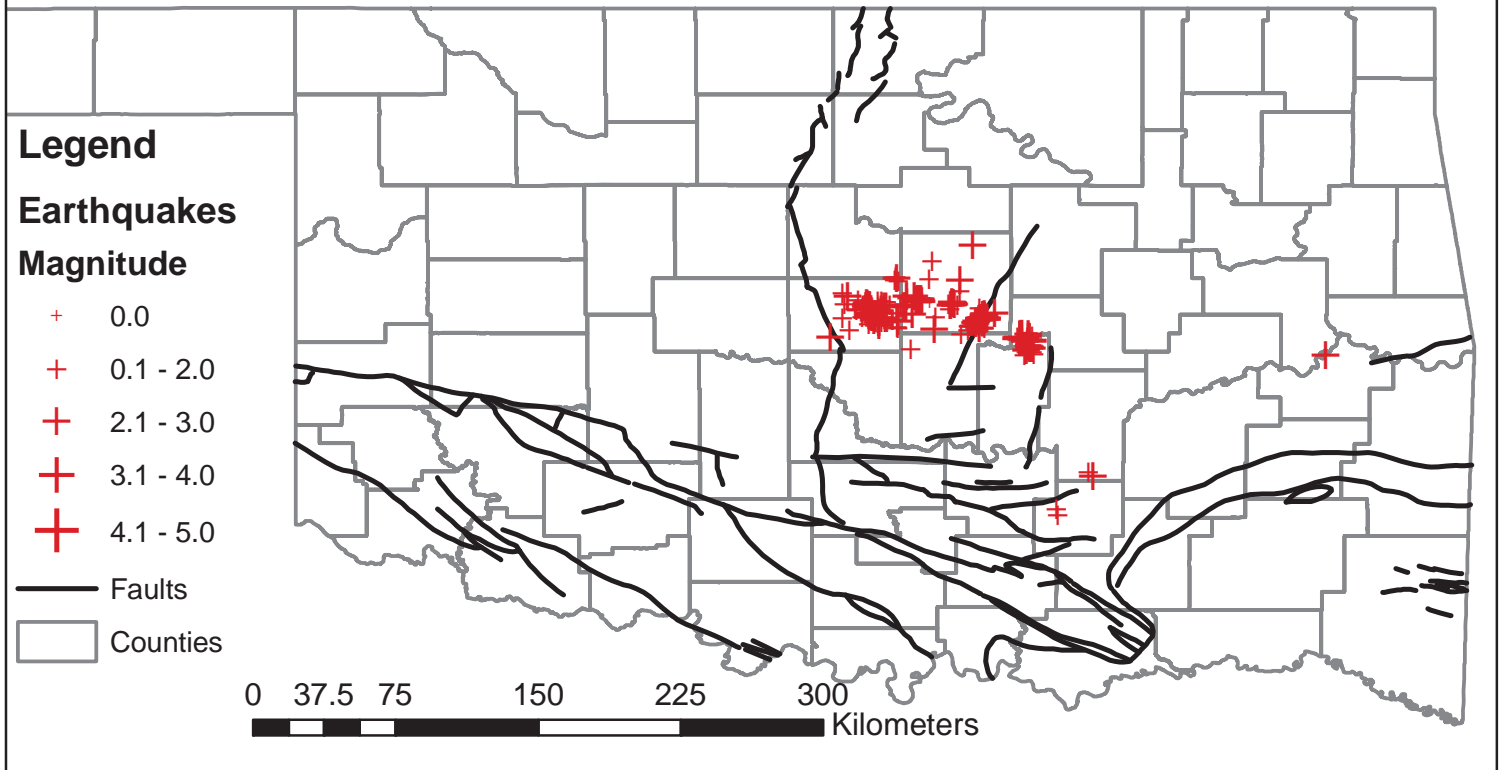
The OGS adopted 2 complete NSF Earthscope Transportable Array (TA) seismic stations. These stations are U32A in Woodward County and X37A in Pittsburg County. These are very high quality broadband stations and add coverage where the existing OGS network did not have stations. In addition the TA vault at station W35A was adopted by the OGS. We installed a 3-com-

Table 1. Felt Earthquakes for January 1 through March 31, 2012
(MMI is the maximum reported Modified Mercalli Intensity)

Origin Time (UTC)	Longitude	Latitude	Depth km	Magnitude	Type	MMI	County
1/1/12 13:23	-96.7629	35.5296	1.5	2.8	ML	II	Lincoln
1/1/12 14:15	-96.7672	35.5266	1.2	2.8	ML	III	Lincoln
1/3/12 10:56	-96.7522	35.5363	2.3	3.4	ML	II	Lincoln
1/6/12 4:02	-96.7685	35.5387	1.0	2.9	ML	II	Lincoln
1/9/12 2:50	-97.2785	35.5443	6.7	2.8	ML	III	Oklahoma
1/17/12 13:26	-96.5472	35.386	1.8	3.0	ML	II	Seminole
1/26/12 19:04	-96.9001	35.6098	0.1	2.9	ML	II	Lincoln
2/7/12 16:29	-96.5377	35.4301	0.0	3.3	ML	IV	Seminole
2/8/12 19:04	-97.283	35.5762	2.7	2.8	ML	IV	Oklahoma
2/18/12 6:24	-97.2688	35.5422	4.5	2.6	ML	II	Oklahoma
2/18/12 20:28	-96.8623	35.7171	2.9	2.8	ML	II	Lincoln
2/22/12 0:30	-97.2795	35.5421	5.0	2.9	ML	III	Oklahoma
2/26/12 9:15	-97.0648	35.6228	0.4	2.9	ML	II	Lincoln
2/29/12 22:20	-97.1622	35.7235	0.9	3.0	mbLg	III	Logan
3/8/12 5:17	-97.0688	35.6213	0.3	2.9	ML	III	Lincoln
3/10/12 10:11	-96.5719	35.4462	0.9	3.1	ML	III	Okfuskee
3/25/12 14:09	-97.245	35.5013	1.6	2.5	ML	II	Oklahoma
3/31/12 11:54	-96.5787	35.4419	5.0	3.3	ML	IV	Okfuskee

Figure 1

2012 1st Quarter Earthquakes

Legend

Earthquakes

Magnitude

+   0.0

+   0.1 - 2.0

+   2.1 - 3.0

+   3.1 - 4.0

+   4.1 - 5.0

——   Faults

☐   Counties

0   37.5   75   150   225   300

Kilometers

ponent high gain short period seismic system at station W35A. The remaining TA stations have all moved out of Oklahoma with the exception of the backbone station added to the OGS Leonard Observatory. The permanent stations installed and operating in Oklahoma can be seen in **Figure 2**.

Download 2012 1ˢᵗ quarter earthquake file and complete list of felt earthquakes (CSV):

http://www.okgeosurvey1.gov/media/quarterlies/2012_qt1.csv

http://www.okgeosurvey1.gov/media/quarterlies/2012_qt1felt.csv

Oklahoma Research: 2011, *continued...*

Seismic sequence stratigraphy of More Basin, Norwegian sector of the North Sea
          —Aslihan Deliktas

Suppression of aliasing artifacts on 3D land data via constrained least-squares migration
          —Alejandro Cabrales-Vargas

Two phase regional deformation within the Puget Lowland
          —Christopher Glenn Mace

An integrated paleomagnetic, rock magnetic, and diagenetic study of the Marcellus Shale within the Valley and Ridge province of Pennsylvania and West Virginia
          —Earl Berry Manning

Fluctuating dust in the late Paleozoic ice house: records from an oceanic atoll, Akiyoshi, Japan
          —Elisheva M. Patterson

Kinetics of methane hydrate formation & dissociation under Mars relevant conditions
          —Seth Reilly Gainey

Remagnetization of the Alamo Breccia, Nevada
          —Stacey Coleen Evans

Rock strength determination in shale caprock through inversion of 3D seismic in the Forties field, UK
          —Aliya M. Urazimanova

Subsurface and experimental analyses of fractures and curvature
          —Evan Richard Staples

LIDAR characterization and reservoir modeling of an Upper Jackfork Group basin floor fan deposit at Degray Spillway, Caddo Valley, Arkansas
          —Brett David Schlichtemeier

Oklahoma Seismic Stations

Network
- ▲ (yellow) Leonard Observatory
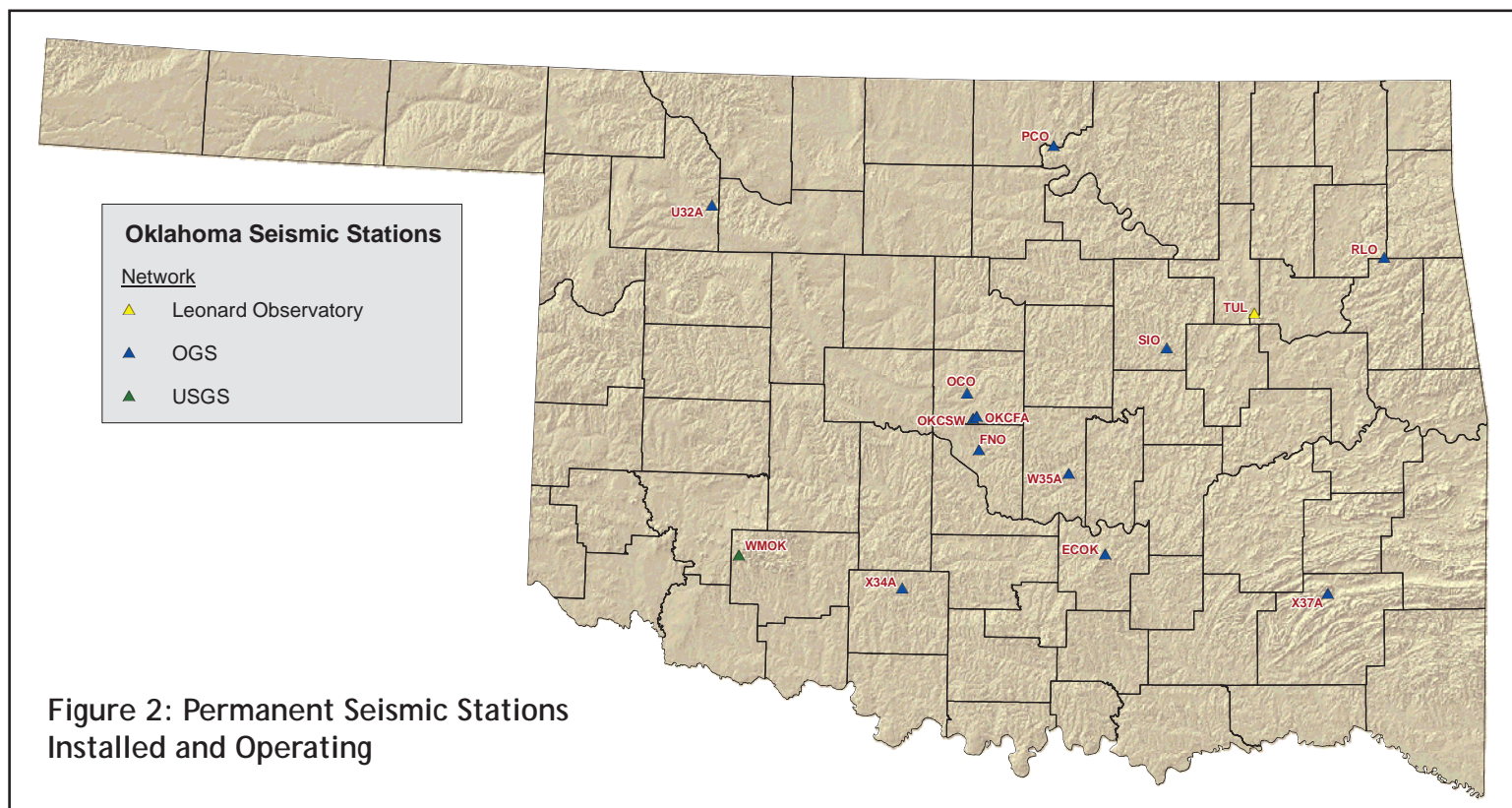- ▲ (blue) OGS
- ▲ (green) USGS

Figure 2: Permanent Seismic Stations Installed and Operating

Rock-based characterization of the Lower Silurian Longmaxi Gas-Shale in southwest Sichuan Basin, China

—*Majia Zheng*

Lithofacies characterization and sequence stratigraphic framework for some gas-bearing shales within the Horn River Basin, northeastern British Columbia

—*Katie Melissa Hulsey*

Integrated geomechanics and geological characterization of the Devonian-Mississippian Woodford Shale

—*Rafael Sierra Perez*

The effect of obliquity change on gas hydrate stability zones on Mars

—*Margaret Jean Root*

Removing footprint from legacy seismic data volumes

—*Oswaldo Davogustto Cataldo*

An integrated geophysical analysis of the External Pre-Rif domain, Morocco

—*Christine Marie Worthington*

Synthesis and geochemistry of tourmaline crystals with high concentrations of Ti, V, Cr, Mn, Cu, and Zn

—*Matthew Vanburen Cleveland*

3D basin model of the Serbian Banat region of the Pannonian Basin, Serbia

—*Hulya Yilmaz*

The origin and significance of sandstone injectites within the Pennsylvanian Jackfork Group deepwater depositional system

—*Ryan Christopher Davison*

Tectono-stratigraphic analysis of the Oil Creek and Davis sandstones in Sherman-Marietta basin, Grayson County, Texas

—*Austin Scott Heape*

Effect of prestack processing flows on acquisition footprint as seen on geometric attributes: the Red Fork Formation case study

—*Yavuz Ozan Elis*

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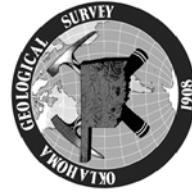
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LISTEN TO TECHNICAL PRESENTATIONS:

Independent consultant Kurt Rottmann, who led two sold-out workshops on the Mississippian Play for the OGS in 2011, *"Mississippian Arbuckle Disposal Wells -- Are They a Missed Opportunity?"*

Cody Knepper, NuTech Energy Alliance, *"Current Reservoir Evaluation Techniques in MidCon Plays"*

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