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Groundwater quality surrounding Lake Texoma during short-term drought conditions

Donald H. Kampbell[a,*], Youn-Joo An[b], Ken P. Jewell[a], Jason R. Masoner[c]

[a]US Environmental Protection Agency, Office of Research and Development, National Risk Management Research Laboratory, PO Box 1198, Ada, OK 74820, USA
[b]School of Earth and Environmental Sciences (BK21), Seoul National University, Seoul, South Korea
[c]US Geological Survey, Oklahoma City, OK 73116, USA

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"Capsule": *Stressors such as nitrates and total salts in ground water could potentially become a health or environmental problem during drought conditions.*

Abstract

Water quality data from 55 monitoring wells during drought conditions surrounding Lake Texoma, located on the border of Oklahoma and Texas, was compared to assess the influence of drought on groundwater quality. During the drought month of October, water table levels were three feet (0.9 m) lower compared with several months earlier under predrought climate conditions. Detection frequencies of nitrate ($>$ 0.1 mg/l), orthophosphates ($>$ 0.1 mg/l), chlorides ($>$ MCL), and sulfates ($>$ MCL) all increased during drought. Orthophosphate level was higher during drought. Largest increases in concentration were nitrate under both agriculture lands and in septic tank areas. An increase in ammonium–nitrogen was only detected in the septic tank area. The study showed that stressors such as nitrate and total salts could potentially become a health or environmental problem during drought.
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Keywords: Groundwater; Well; Water quality; Drought; Stressor; Nitrate

1. Introduction

Since 1999, Subsurface Protection and Remediation Division (SPRD) of National Risk Management Research Laboratory (NRMRL) in US Environmental Protection Agency has initiated the installation of ground water monitoring wells surrounding a watershed lake to monitor and evaluate the ground water quality seeping into the lake. Export of pollutants by subsurface flow from areas surrounding lakes and streams can lead to adverse effects on human health and aquatic life. Mitigating the effects of pollution requires determining the delivery path such as base flow discharge and loading rates from subsurface sources. The information can be used to assess the ecosystem assimilative capacity of stressors to be integrated into a model useful for watershed management.

Although this was a multi-year study, the first year experienced climatic conditions similar to a severe drought. The well water parameter measurements were used to show the influence of drought conditions on subsurface water quality. This paper is limited to the analysis of monitoring results between August and mid-October 2000, focusing on the evaluation of groundwater quality at 55 producing wells. Water quality parameters measured were inorganics (nitrate, nitrite, ammonia, orthophosphate, sulfate, chloride), dissolved methane, dissolved organic carbon (DOC), methyl *tert*-butyl ether (MTBE), BTEX compounds (benzene, toluene, ethylbenzene and xylenes), and a suite of metals. Among these, the main parameter of the study is nitrate, which is the most common nutrient in groundwater (Nolan and Stoner, 2000). The objective of this study was to investigate the vulnerability of groundwater quality to drought. In addition, common factors that influence the groundwater quality including land use and soil type are discussed.

* Corresponding author. Tel.: +1-580-436-8564; fax: +1-580-436-8703.
E-mail address: kampbell.donald@epa.gov (D.H. Kampbell).

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2. Materials and methods

2.1. Study area

This lake is located on the border of Oklahoma and Texas. Lake Texoma (93,000 surface acres) is an important man-made impoundment of Red and Washita rivers in southern Oklahoma and northern Texas. Following its completion in 1947 by The US Army Corps of Engineers, it rapidly became a focus of the recreation, real estate, and farming industries in the region. The possibility for groundwater contamination in the areas surrounding Lake Texoma exists due a potential generation of stressors to lower groundwater quality. After a number of representative chemical release sites and stressor sources in the surrounding watershed were characterized in detail, several impact sites having potential stressors sources, such as being near agriculture, landfills, housing areas, oil production fields and heavy use recreational activity, were selected for well installation. A paired reference site, having similar physical characteristics as its impact site, was also chosen based on its proximity to the impact site. Over 70 wells were installed in selected study sites and sampling of groundwater has been done on a quarterly basis.

During the monitoring period, Oklahoma has experienced a very dry season during the summer 2000. Between August and mid-October 2000, total rainfall over the region was about 4% of annual rainfall in 2000 (US Corps of Engineers, 2001). The average rainfall during this period is about 0.42 inches (0.01 m) per month in Lake Texoma basin, while the average rainfall is 2.25 inches (0.06 m) per month in 2000. Groundwater levels were affected substantially in most study areas. Water levels decreased during this period. Since drought conditions may increase the risk of groundwater contamination, we examined the sensitivity and vulnerability of groundwater quality to drought.

2.2. Field sampling

Groundwater samples were collected at 55 producing monitoring wells around the Lake between August and mid-October 2000. Locations of monitoring wells are shown in Fig. 1. Study sites and their dominant land use classification are listed in Table 1. This period was a very dry season, as shown in Fig. 2. The numbers of water producing wells in impact and reference sites are 46 and 9, respectively. Seven pairs of impact and reference sites were used in this study. Fourteen wells of 55 wells were also sampled in June and July 2000, which are predrought months for comparison. Hereafter, predrought and drought indicate June–July and August-mid October, respectively. Ten percent or more of the samples were duplicated as a quality assurance requirement.

Monitoring well sampling was done using a peristaltic pump and 0.25 inch diameter polyethylene low-density tubing. The depth to water table was measured from top of well casing (TOC) using a depth meter (Solist). Two well volumes were purged from the well at a 500–600 ml/min pump rate before collection of samples. The first well volume was pumped from the bottom of the well to remove sediments. Then the pump intake tubing was raised to near mid-screen for remaining water removal. After one well volume was removed at the mid-screen depth, flow was directed into a 500-ml suction flask used as a flow-through cell and the pump flow was reduced to near 200 ml/min. During active pumping meter probes for temperature, pH, conductivity, dissolved oxygen (DO), and redox potential were submerged into the flow-through cell flask. Meter readings were recorded every 5 min until equilibration occurred. Turbidity was measured and if greater than 5 NTU the water sample for metals was filtered. Ferrous iron, total alkalinity, hydrogen sulfide, and free carbon dioxide were also measured at the field site.

Suitable containers and preservatives were used when collecting samples for later laboratory analyses. Protocol guidelines are listed in EPA/600/R-98/128 (USEPA, 1988). Water quality parameters measured in the laboratory were inorganics (nitrate, nitrite, orthophosphate, ammonia, sulfate, and chloride), dissolved methane, total organic carbon (TOC) (or DOC), volatile organic compounds (VOCs) and a suite of metals. All samples collected were stored in a cooler with blue ice and delivered the same day to the analytical laboratory. Polyethylene bottles were rinsed with the well water and then filled with samples for inorganics analysis. Samples for dissolved methane analysis were collected in a 60-ml glass serum bottle, were preserved with diluted sulfuric acid to pH <2, and capped with aluminum seals and Teflon-faced septa. Samples for dissolved organic carbon analysis were collected in a 60-ml glass bottle and acidified to pH <2 with 1:1 water: sulfuric acid. Sample for DOC was passed through a 0.10-μm filter to remove particulate organic carbon. Samples for the analysis of volatile organic compounds were collected in 40-ml glass VOA vials with lead-lined septa. Trisodium phosphate was used as preservative (Kovacs and Kampbell, 1999). A VOA field blank was also included. Samples for metal analysis were filtered and collected in a polyethylene acid-washed bottle and preserved with nitric acid to pH <2.

2.3. Laboratory analysis

Table 2 listed the water quality parameters measured, methods used and the limits of detection (LOD). Nitrate, nitrite, ammonia and orthophosphate were determined colorimetrically by Lachat FIA methods (Lachat Instruments Milwaukee, WI) with the LODs of

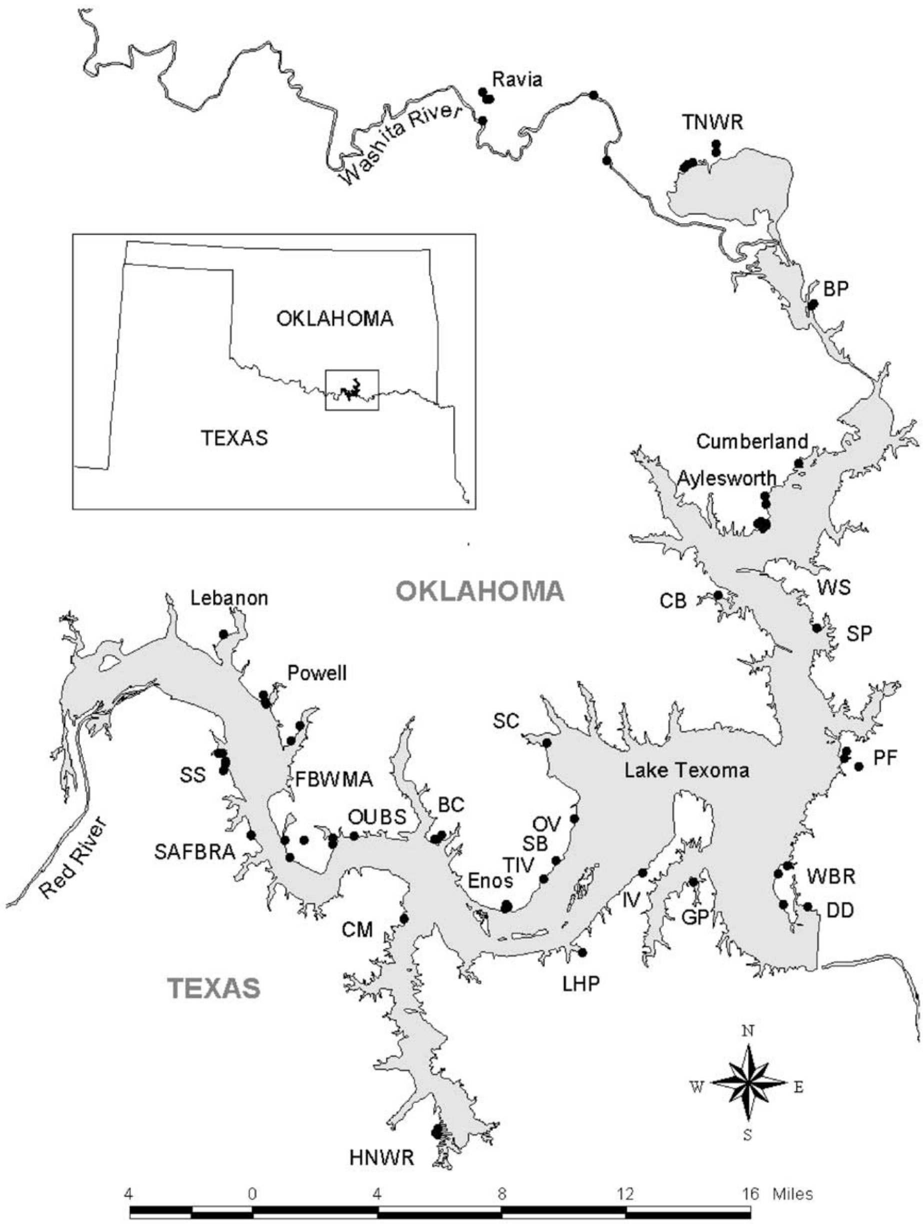

Fig. 1. Locations of monitoring wells surrounding Lake Texoma.

0.02–0.10 mg/l. Nitrate and nitrite were reported as total nitrogen. Waters capillary electrophoresis method was used to measure chloride and sulfate concentrations. Total dissolved solids and hardness were measured by Standard Methods 2540C and 2340C, respectively (Eaton et al., 1995). Dissolved methane (CH_4) in water samples was measured by a GC headspace equilibration technique (Kampbell and Vandegrift, 1998; Perry et al., 1988). This method is applicable to the analysis for gases in the headspace of water containers to determine the concentration of gases dissolved in the water based on Henry's Law. A headspace of 10% was prepared by adding high purity helium that forces water through a needle piercing the septa out of the bottles. The bottle was shaken for 5 min and a headspace sample was injected into a Hewlett Packard P 200 series gas chromatograph (GC) equipped with thermal conductivity detector. The concentration of dissolved gas in the original water samples were determined from the concentration of the gas in the headspace, the bottle volume, and the temperature of the sample. Samples for DOC analysis were purged with nitrogen gas to remove inorganic carbon, followed by the EPA Method 415.1. The concentrations of DOC were determined by using TOC analyzer (Dohrmann DC-80).

MTBE and BTEX were analyzed by a purge and trap gas chromatography procedure (EPA Method 502.2 and 503.1). Autosampling was performed using a Dynatech Precision autosampler system in line with a

Table 1
Study sites surrounding Lake Texoma

Study site abbrev	Study site name	Dominant land use classification	Well no.
TNWR	Tishomingo National Wildlife Refuge	Agriculture, migratory fowl	(5)[a], 6, 7
Ravia	Ravia	Agriculture, cattle and poultry operation	9, *10* [b], 13, (15)
FBWMA	Fobb Bottoms Wildlife Management Area	Agriculture	27, 28, 29, 30, 31
OUBS	OU Biological Station	–	*41*
Powell	Powell A&G Lease No. 238	Agriculture, migratory fowl	32, 33, (34), *42, 43A*
SB	Sandy Beach	Agriculture	SB
SC	Sandy Creek	–	*45*
AF	Aylesworth Flats	Petroleum production	16, 17, 18, 19, 20, 53
Cumberland	Cumberland	–	*52*
SS	Slickum Slough	Petroleum production	T1[c], T2, T3, T4, T5
SAFBARA	Shepard Air Force Base Recreational Area	–	T6
HMWR	Hagerman National Wild Refuge	Petroleum production	T8, T9, T10
DD	Dennison Dam	Recreation—beach	21
WBR	West Burns Run	Recreation—boating, camping	47, 48, 57
CM	Cedar Mills	Recreation—boating	T7
IV	Island View	Recreation—beach	T12
LH	Loes Highport Marina	Recreation—boating	T11
GP	Grandpappy Point Marina	Recreation—boating	T13
CB	Catfish Bay Marina	Boat repair activities (copper paint)	49, 50
BP	Butcher Pen	Septic tank, automobile repair	11, 12
Enos	Enos	Septic tank	24, 25, 26
TIV	Tayor Island View	Septic tank	TIV
OV	Oak View	–	*46*
SP	Sand Point	Septic tank, Recreation—boating	43B
WS	Willow Springs	–	*(44), 54*
BC	Buncomb Creek	Septic tank	36
	Lebanon	Deactivated dump site	(35)
PF	Platter Flats	Decommissioned landfill	54A, 55

[a] Non-producing or abandoned wells are in parentheses. Total numbers of study site and producing wells are 27 and 55, respectively in this study.
[b] Reference wells in italic.
[c] Wells in Texas.

Tekmar LSC 2000 sample concentrator. MTBE and BTEX concentrations were measured using a Hewlett Packard 5890 GC equipped with a photoionization detector. A fused silica DB-WAX column (J&W Scientific, 30 m length × 0.254 mm i.d. × 0.5-μm film thickness) was used with the following temperature program: 40 °C for 5 min, 50 °C/min to 54 °C, 54 °C for 5 min, 50 °C/min to 88 °C, 88 °C for 6 min, 20 °C/min to 225 °C, and 225 °C for 0.5 min. Injection port and detector temperatures were 150 and 250 °C, respectively. Helium carrier gas at 1.2 ml/min and nitrogen make-up gas at 30 ml/min were used. Fluorobenzene was used as a reference peak to monitor any retention time shift during analysis. Metal scans were performed using a inductively coupled plasma atomic emission spectroscopy (EPA Method 6010A, Perkin-Elmer Optima 3300 DV ICP). The metals scan analyzed 26 elements including sodium (Na), calcium (Ca), magnesium (Mg), cadmium (Cd), chromium (Cr), lead (Pb), zinc (Zn), and etc. LODs ranged from 0.001 mg/l for Mg, beryllium (Be) and strontium (Sr) to 0.479 mg/l for Na. Quality assurance measures performed on the set of samples included analytical duplicates, known analytical quality controls (AQCs) and blanks.

2.4. Data analysis

Adjusted detection frequency was calculated based on the same threshold for the compounds that will be compared together. Although lower report limit was available for orthophosphate as shown in Table 1, orthophosphate concentration equal or greater than 0.10 mg/l was used as detectable concentration because the LOD of other nutrients (nitrite, nitrate and ammonia) was 0.10 mg/l. Unadjusted detection frequencies based on all detections regardless of concentration showed no loss of information, however, the unadjusted method was inappropriate for comparing occurrence data among compounds with different LODs because detection frequencies have negative relationship with

Table 2
Water quality parameters measured, method used and their limit of detection (LOD)

Parameter[a]	Method	LOD
Field analysis		
Turbidity (NTU)	Hach Kit model 2100 P	0.5
Temperature (°C)	Portable meter and probe	NA[b]
pH	Portable meter and probe	NA
Conductivity (μs/cm)	Portable meter and probe	1
Dissolved oxygen (DO)	Portable meter and probe	0.1
Redox potential (mV)	Portable meter and probe	NA
Ferrous iron, Fe^{2+}	Standard Method 3500-FED, 1,10-pheanathroline colorimetric method	0.1
Alkalinity	Hach Kit AL-DT, Bromcresol green titration method	20
Hydrogen sulfide, H_2S	Hach Kit-HS-C, Effervescence method	0.1
Laboratory analysis		
Nitrite, NO_2^-	Lachat FIA method 10-107-05-1-A	0.10
Nitrate, NO_3^-	Lachat FIA method 10-107-04-2-A for nitrite and nitrate	0.10
Ammonia, NH_3	Lachat FIA method 10-107-06-1-A	0.10
Orthophosphate, PO_4^{3-}	Lachat FIA method 10-115-01-1-A	0.02
Sulfate, SO_4^{2-}	Waters capillary electophoresis N-601	1.00
Chloride, Cl^-	Waters capillary electophoresis N-601	1.00
Dissolved methane, CH_4	GC headspace equilibration technique	0.001
DOC	EPA Method 415.1	0.40
Hardness (mg/l $CaCO_3$)	Standard Method 2340C	0.50
Salinity (units)	Conductivity/salinity meter (Orion model 160)	0.1
Total dissolved solid (TDS)	Standard Method 2540C	1
MTBE and BTEX (μg/l)	Purge and trap gas chromatography	1
A suite of metals	ICP atomic emission spectroscopy	0.001 – 0.479

[a] Units of mg/l otherwise noted.
[b] NA: not applicable.

LOD (Kolpin et al., 1998; Kolpin et al., 1995). To identify the contamination level of each parameter, median concentration, the 50th percentile of a sample, was calculated. Median was used because the skewing data in outliers has little effect on it.

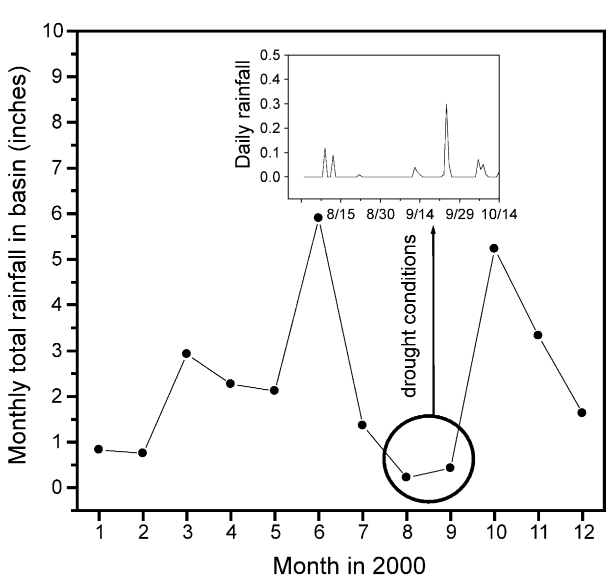

Fig. 2. Monthly total rainfall during 2000 in Lake Texoma basin.

3. Results and discussion

3.1. Nutrients level in impact and reference wells

Table 3 shows the nitrate level in impact wells and reference wells in agriculture, oil production, and septic tank area. Seven combinations of impact and reference sites were compared for concentration of nitrate. Nitrate was found in 80% of impact wells. In agriculture and septic tank areas, nitrate concentrations were generally higher in impact wells compared to

Table 3
Nitrate level in impact and reference wells

Land use	Impact: Reference[a]	Level (mg/l)
Agriculture	Ravia(2): Ravia(1)	11.65: 0.10
	FBWMA(5): OUBS(1)	1.81±1.64 [b]: 0.35
	Powell(2): Powell (2)	6.82, 5.28: 0.47, 0.34
	SB(1): SC(1)	9.82: 0.47
Oil production	AF(6): Cumberland(1)	0.11, 0.12: 0.85
	SS(5): SAFBARA(1)	–
Septic tank	TIV(1): OV(1)	6.48: 0.38

[a] Number of wells is in parentheses.
[b] Mean±S.D.

reference wells. This indicated that the potential stressors in their locations could have actual influence on the water quality of wells.

3.2. Occurrence of nutrients during predrought and drought conditions

Water quality from 14 monitoring wells located at nine study sites during predrought and drought was compared to assay the effects of drought on groundwater quality. Water table data were also compared. The water table dropped during drought season. Lower groundwater levels were observed at 12 of the 14 monitoring wells (Fig. 3) and median value of TOC was increased from 9.67 to 12.7 ft in drought condition, which was a three-foot or 31% drop.

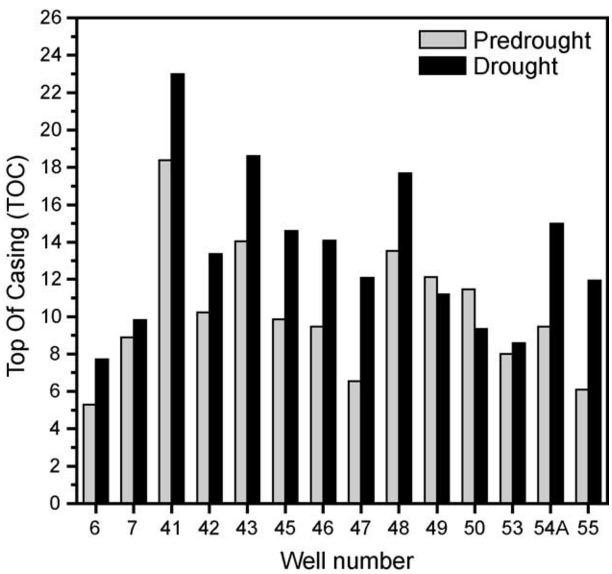

Fig. 3. Top of Casing (TOC) of monitoring wells surrounding Lake Texoma during predrought (June–July) and drought (August–mid October) conditions in 2000.

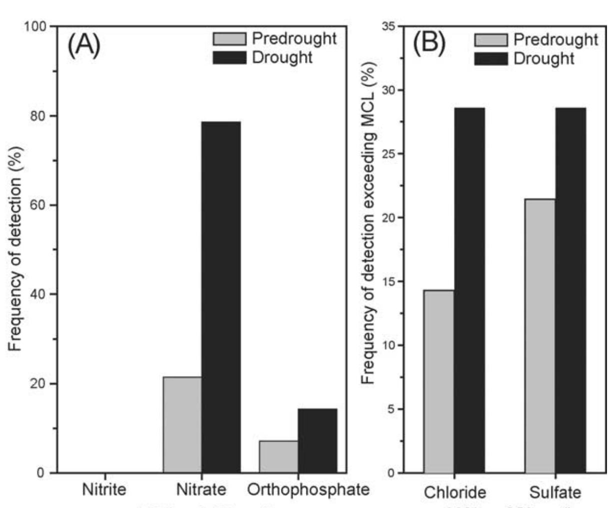

Fig. 4. Detection frequency of (A) nitrite, nitrate, and orthophosphate and (B) chloride and sulfate exceeding MCL during predrought and drought conditions.

Fig. 4A shows that the detection frequencies for nitrate and orthophosphate based on the same LOD of 0.1 mg/l. Nitrates were found as 21.4% (3 of 14 wells) and 78.6% (11 of 14 wells) for predrought and drought conditions, respectively. Orthophosphate concentration equal or greater than 0.10 mg/l was detected in 1 of 14 wells (7.1%) and 2 of 14 wells (14.3%) for predrought and drought conditions, respectively. This indicated that nitrates and phosphate occurred more frequently during drought season, so was more widespread and consequently the gross concentration would be greater. No detectable nitrite was found in this sampling event because the groundwater was aerobic and nitrite is not stable with oxygen.

Since the detection frequency does not show the contamination level, it was plotted against the concentration as shown in Fig. 5 A and B. Nitrate detections ranged from <0.10 to 0.48 mg/l (median of 0.33) for predrought and to 0.59 mg/l (median of 0.34) for drought (Fig. 5A). Individual t-test showed the nitrate levels of predrought and drought were not significantly different ($P=0.66$, $\alpha=0.05$). Since there are only three data points for orthophosphate > 0.10 mg/l, all detectable orthophosphate concentrations (> 0.02 mg/l) were

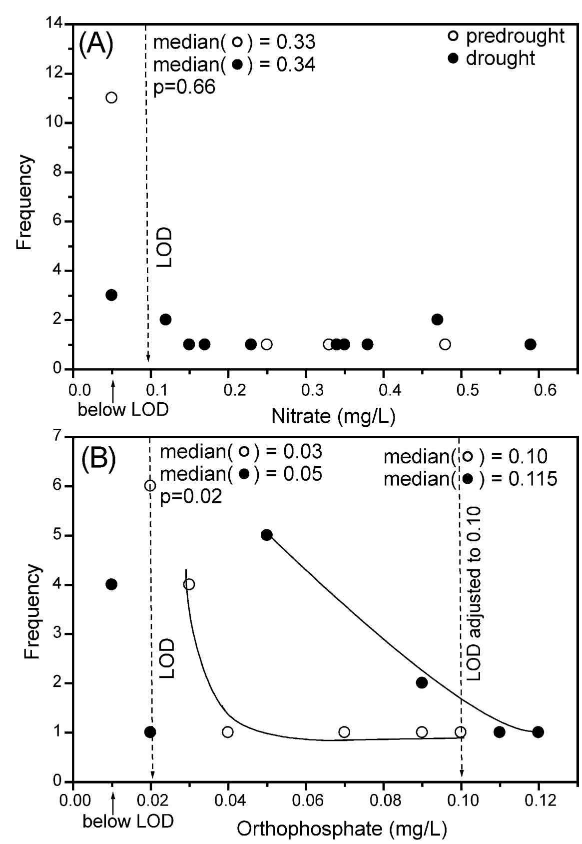

Fig. 5. Relationship between detection frequency and concentration of (A) nitrate and (B) orthophosphate during predrought and drought conditions.

also plotted with detection frequencies to show the contamination level of orthophosphate during predrought and drought periods as shown in Fig. 5B. Phosphate detections ranged from 0.02 to 0.09 mg/l (median of 0.03) for predrought and to 0.12 mg/l (median of 0.05) for drought. Individual t-test showed that the significant difference occurred during drought ($P=0.02$, $\alpha=0.05$) and orthophosphate contamination level was higher during drought season than predrought condition.

Chloride and sulfate were present in all wells sampled. Fig. 4B shows that the detection frequency of chloride and sulfate exceeding US EPA's Maximum Contaminant level (MCL), which is 250 mg/l, was 14.3% (2 of 14) and 21.4% (3 of 14), respectively before drought. It increased to 28.7% (4 of 14) for both during drought conditions. The detection of chloride and sulfate exceeding MCL was also more frequent during drought. This was consistent with the tendency of nutrients during drought compared to predrought conditions. Comparisons of the nutrients and other inorganics data before and during the dry season showed that drought conditions could increase the risk of groundwater contamination.

3.3. Water quality (nutrients) and land-use during drought conditions

Water quality from 42 monitoring wells located within impact areas under 19 areas of four different land uses was compared to the effects of land use on groundwater quality during drought. The comparison was conducted to determine any potential effect on the relation between water quality and land use. (Wells in landfill and copper discharge areas were excluded due to low well numbers). Fig. 6 shows the detection frequencies of three nutrients of the wells under agriculture, oil production, recreation and septic tank areas based on the common threshold of 0.10 mg/l. The most frequent detectable nutrient was nitrate with detection frequency of 54.8% (23 of 42 wells), followed by orthophosphate with 14.3% detection (6 of 42 wells), and ammonia with 7.1% detection (3 of 42 wells). Nitrate was previously reported to be the most common nutrient in groundwater (Mueller et al., 1995; Nolan and Stoner, 2000). Occurrence of nitrate was most frequent in areas under agricultural land, due to the land application of pesticides and fertilizer including nitrogen and phosphorus in these areas. Nitrate is also frequent in septic tank area (87.5%, 7 of 8 wells), followed by recreation areas (37.6%, 3 of 8 wells) and lowest in oil production land (14.3%, 2 of 14 wells). The sources of nitrate include fertilizers, N_2 fixed by leguminous plants, livestock manure, and septic tanks (Richards et al., 1996). The frequent occurrence of nitrate in agriculture and septic tanks areas had a more direct relationship with the existence of the possible stressors in each area. Among three nutrients studied, nitrate had the highest concentration in well water (Fig. 7A). Median concentration of nitrate was higher in agricultural land (1.98

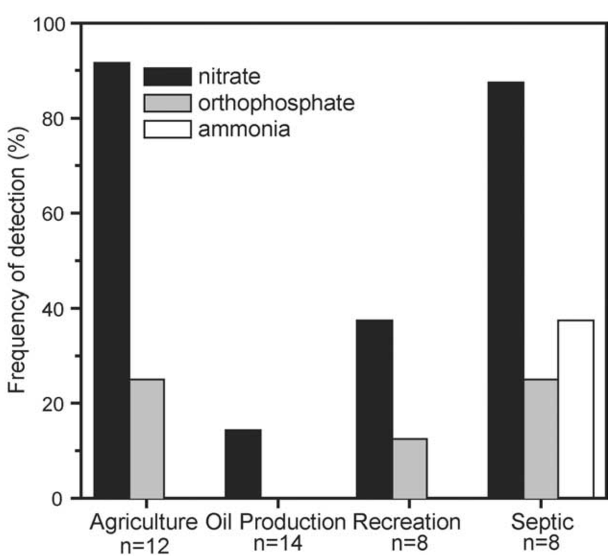

Fig. 6. Detection frequency of nutrients in monitoring wells surrounding Lake Texoma, according to land use during drought conditions in 2000.

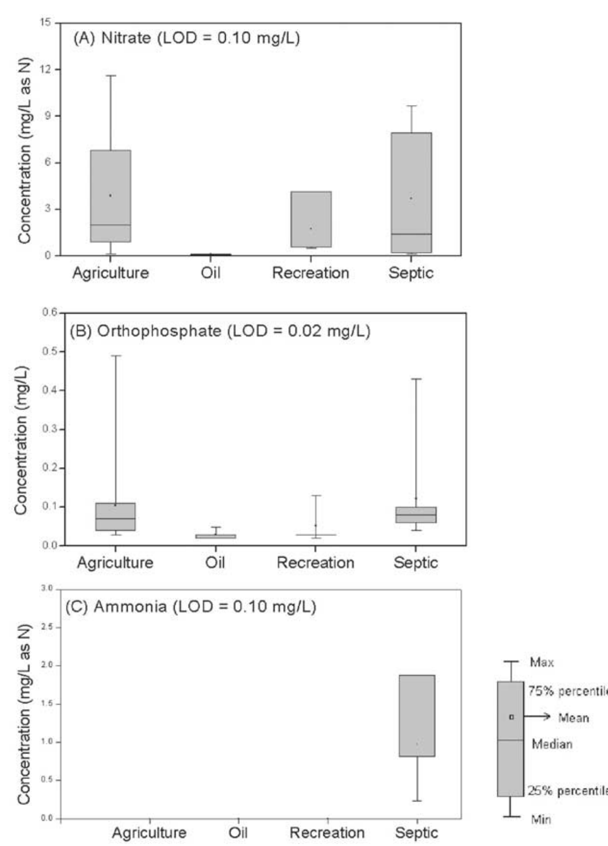

Fig. 7. Concentration of detectable nutrients in monitoring wells surrounding Lake Texoma, according to land use during drought conditions in 2000.

mg/l) and septic tank area (1.41 mg/l), followed by recreational land use (0.59 mg/l), and lowest in oil production land (0.12 mg/l). The result was a consistent trend with the detection frequencies of nitrate in each land use.

Phosphorus should always be present in sewage and animal metabolic waste and orthophosphate is the most thermodynamically stable form (Hem, 1989). Detection frequencies of orthophosphate were highest in agricultural and septic tank area (25%), followed by recreational use (12.5%). No orthophosphate > 0.10 mg/l was found in oil production area. When all detectable orthophosphate concentrations (> 0.02 mg/l) were as shown in Fig. 7B, median concentration of orthophosphate was nearly the same in septic tank (0.08 mg/l) and agriculture areas (0.07 mg/l) and lower in oil production and recreational land (0.03 mg/l). Ammonia was present in wells nearby septic tanks with a median concentration of 0.82 mg/l (Fig. 7C). Occurrence of ammonia may indicate the contamination of groundwater by animal material recently decomposed. Under aerobic condition, ammonia is converted to ammonium hydroxide. Most of ammonium hydroxide can be converted to nitrite and nitrate by nitrification (Nolan and Stoner, 2000).

The results obtained show that the groundwater quality has been affected by the land use of the area, as previously reported elsewhere (Eckhardt and Stackelberg, 1995). Frequent detection of nutrients in the wells nearby agriculture and septic tank area showed that these wells were vulnerable to the contamination by the potential stressors. The data indicated that drought conditions have little effect on the relationship between water quality and land-use.

3.4. Water quality (nutrients) and soil type during drought conditions

Soil type is reported to be one of the parameters that may influence nitrate concentration in shallow groundwater (Nolan and Stoner, 2000). Water quality data from 15 monitoring wells located within agriculture and septic tank land uses was compared with assessing the effects of soil type on groundwater quality during drought conditions. The comparison was conducted to see any potential effect on the relationship between water quality and soil type by drought conditions. Nitrate concentrations were compared in sandy and clayey soils under the same land use. There was not enough soil texture data for all land use; nitrate concentrations in agricultural lands and septic tank areas were compared between sandy and clayey soils. Both concentration and detection frequency of nitrate are higher in sandy soils than clayey soils as shown in Fig. 8. Sandy soils with a higher porosity can transmit water and nitrate at a greater rate than clayey soils, also denitrification can occur in poorly drained soils that are usually anaerobic (Nolan and Stoner, 2000).

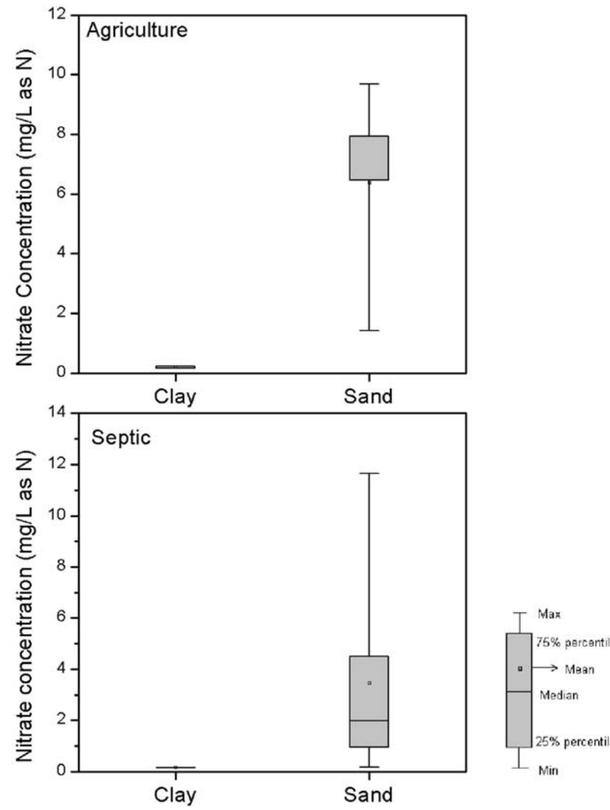

Fig. 8. Nitrate concentration of monitoring wells surrounding Lake Texoma in sandy and clayey soils during drought conditions in 2000.

3.5. Other water quality investigated

No H_2S was detected. Dissolved methane in most of samples was below detection limit and detectable concentrations of dissolved methane were very low. Ferrous iron found was also at low concentrations. Detectable MTBE was found once in an oil production area (Slickum Slough) with concentration of 1.35 µg/l. Toluene was detected at an oil production area (Aylesworth plots) and a recreational area (Dennison dam) and the concentrations found were low. No detectable benzene, ethylbenzene and xylenes were found in any wells. Although detectable MTBE was found in lake water during summer 2000 (An et al., 2000, 2001, 2002), it does not appear to transport from lake water to groundwater. Detectable copper was found in one sample of well water nearby the boating repair area where copper is used as a paint ingredient.

4. Conclusions

Groundwater was collected at 55 producing monitoring wells surrounding Lake Texoma between August and mid-October 2000 (drought) to assess the influence of drought on groundwater quality. Fourteen wells of 55 wells were also sampled in June and July 2000 (predrought) for comparison. The main water quality parameter was nitrate, and others measured were nitrite, ammonia, orthophosphate, sulfate, chloride, dissolved methane, DOC, VOC, and a suite of metals. During drought season, the water table levels were three feet (0.9 m) lower compared to those under predrought conditions. Detection frequencies of nitrate ($>$ 0.1 mg/l), orthophosphates ($>$ 0.1 mg/l), chlorides ($>$ MCL), and sulfates ($>$ MCL) all increased during drought. Occurrence of nitrate was most frequent and level was higher in areas under both agricultural lands and in septic tank areas, followed by recreation areas, and lowest in oil production land. Orthophosphate level was also higher during drought. Both concentration and detection frequency of nitrate were higher in sandy soils than clayey soils. Overall, this study demonstrated that stressors such as nitrates that were more widespread and total salts could potentially become a health or environmental problem during drought conditions.

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