# Spatial and Seasonal Variability in the Water Quality Characteristics of an Ephemeral Wetland

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**Ephemeral wetlands are shallow bodies of water that may exhibit fluctuations in physicochemical parameters on a spatial, daily, or seasonal scale. The objective of this research is to characterize the natural environmental variability in limnological parameters within an ephemeral wetland in central Oklahoma. Sampling of the system occurred on a monthly basis between June 2002 and October 2004. Seasonal variation was apparent in all of the parameters measured, with water temperature (5 - 38°C, dissolved oxygen (3-14 mg/l), pH (4.5-9.5), suspended solids (175-2800 mg/l), and total organic carbon (5-130 mg/l) exhibiting the greatest variability. Thermal stratification across a maximum depth of 30 cm was recorded on several occasions during the summer of 2002, which resulted in vertical profiles of dissolved oxygen, pH, and suspended solids. The stability of this stratification was extremely low and light to moderate winds provided enough turbulence to cause mixing of the system.** *© 2007 Oklahoma Academy of Science*

## INTRODUCTION

Ephemeral wetlands are typically small, shallow, fishless habitats containing water for some part of the year. They are isolated in that there is no direct inlet or outlet and they usually depend on groundwater or surface runoff to initiate the hydroperiod, which may last for weeks or months. Eventually percolation of water through the soil or evaporation leave the wetlands dry once again (Brooks 2004). These systems are distributed globally (Keeley and Zedler 1998), and historically they may have been among the most abundant and diverse habitats known. In southwestern North America, ephemeral waters range from small water-filled depressions of less than a square meter in total area to much larger playa lakes.

The ecological significance of ephemeral wetlands is only starting to be appreciated. Rather than being lifeless puddles, these systems often contain a variety of invertebrate organisms and can also provide habitat to vertebrate species such as amphibians and waterfowl (Babbitt and Tanner 2000; Naugle et al. 2001; Gibbons 2003; Sharitz 2003; Taft and Haig 2003). The physical/chemical variables that structure the community composition in these wetlands are the same as those in other water bodies including temperature, dissolved oxygen, pH, conductivity, total suspended solids, and light penetration. However, compared with permanent aquatic systems, ephemeral wetlands often exhibit significant temporal variation in water chemistry due to their generally shallow nature and changing water level. For example, Black (1976) reported that water temperatures in an ephemeral wetland ranged between 0.5°C and 39.4°C over the course of two years and Serrano and Toja (1995) reported pH values between 4.0 and 10.6 seasonally. Scholnick (1994) found total alkalinity in desert ephemeral pools to significantly increase as the hydroperiod progressed.

While spatial variation in the form of thermal stratification is best documented for larger, permanent water bodies, there is also some evidence that shallow ephemeral systems thermally stratify. Eriksen (1966) discovered temperatures in "two highly turbid puddles" located in California and

Montana could vary by as much as 16°C over a depth of 30 cm, and Black (1976) reported daily thermal stratifications in three ephemeral wetlands in central Oklahoma, with temperature varying as much as 10.3°C in as little as 18 cm of water. Serrano (1994) reported a 15°C change in temperature in 40 cm of water in ephemeral wetlands in Spain.

Variation in water temperature can also result in stratification of other variables such as dissolved oxygen, pH, and conductivity. Serrano (1994) found a positive correlation between temperature, conductivity, pH, and dissolved oxygen. These associations were most evident during the late afternoon, and generally disappeared overnight.

The number of studies that have examined the spatial and temporal patterns in water chemistry and physical characteristics of ephemeral wetlands is still rather limited (Eriksen 1966; Black 1976; Serrano 1994; Serrano and Toja 1995). Characterizing this variability can aid in understanding how the resident invertebrate community is structured, and can also assist in predicting how risks to these wetlands, such as the input of chemical contaminants, could influence resident species. Considering factors such as water temperature, dissolved oxygen levels, and pH can influence the response of aquatic organisms to anthropogenic inputs such as chemical contaminants, an understanding of the natural abiotic changes in ephemeral systems is important when attempting to predict the effects that pollutants may have on wetland communities. The cumulative effect of multiple stressors, both natural and anthropogenic, on resident invertebrate species is an area of particular concern and might provide insight regarding the interaction between an organism and its environment.

The present work represents part of a larger study investigating the interaction between environmental variables and contaminant effects in ephemeral wetlands. Variables such as temperature, suspended solids, and organic carbon can significantly modify the biological response to a contaminant (Persoone et al. 1989; Larrain et al. 1998; Van Veen et al. 2002; Herbrandson et al. 2003), and given these interactions, it is important to characterize the limnological variability within a wetland to better understand how contaminants might behave in it. Our objectives are to characterize the spatial and temporal fluctuations in select physical and chemical parameters within an ephemeral wetland in central Oklahoma. We sought to describe the prevalence of summertime thermal and chemical stratification, as well as capture the annual variability that may occur in the parameters that were measured.

## METHODS

### Study Site

The ephemeral wetland that was the focus of this study is located in a rural area approximately 15 km southwest of the city of Stillwater in Payne County, Oklahoma. The upland area is dominated by a mix of grasses including old world bluestem (*Bothriochloa ischaemum*) and Bermuda grass (*Cynodon dactylon*) (Amy Ganguli, Oklahoma State University, personal communication), and cattle occasionally graze the field surrounding the site in late spring and early summer and use the wetland for drinking water. The system typically fills after a 7-10 cm rain, and water will persist for several months depending on soil saturation, air temperatures, and relative humidity. When full, the dimensions of the wetland approach 0.16 ha with a maximum depth of 60-80 cm and an average depth of 30 cm.

### Limnological Characteristics

To evaluate summertime stratification in the water column, water samples were collected at 5-cm depth increments from one location near the middle of the wetland twice a month between June and September 2002. Sampling was accomplished by attaching a 15-m length of Tygon® tubing (Fisher Scientific, Pittsburg, PA) to a meter stick that was held underwater by a ring stand placed at the sampling point. The tubing extended to the shoreline where it was attached to a Nalgene® hand pump (Fisher Scientific, Pittsburg, PA) that was used to pull water into a 500 mL polyethylene flow cell. The cell contained a YSI Model 600XL probe attached to a 650 MDS meter (YSI inc., Yellow Springs, OH) for determination of temperature, dissolved oxygen, conductivity, and pH. Once water chemistry was determined, the flow cell and tubing was emptied, and the meter stick was slowly lowered 5 cm where the process was repeated. Water from each 5-cm depth was also collected in acid washed polyethylene bottles and transported back to the laboratory on ice for determination of alkalinity, hardness and total suspended solids (TSS) following standard methods (APHA 1998). Stability and Birgean work values were determined for the wetland following methods developed and revised by Birge (1915, 1916) and Wetzel and Likens (1991). Light attenuation was measured with a LI-COR model LI-193SA spherical photometer attached to a LI-1000 data logger (LI-COR Inc. Lincoln, Nebraska, USA).

Twice a month, during spring, fall, and winter, a Hydrolab Quanta probe (Hydrolab Corporation, Austin, TX.) was used to determine water temperature, dissolved oxygen, conductivity, and pH. These parameters were measured at the surface (within 5 cm of the air-water interface), middle, and bottom (within 5 cm of the sediment-water interface) of the water column near the center of the wetland. In addition, water was collected in an acid (10% $HNO_3$) washed polyethylene bottle from approximately 5 cm below the surface for determination of alkalinity, hardness, and TSS. Approximately 100 ml of collected water was acidified with phosphoric acid and refrigerated at 4°C (APHA 1998) for total organic carbon (TOC) analyses by the Chemical Analysis Laboratory at the University of Georgia (Athens, GA). Once water chemistry had been determined, the data were graphed to show effects of depth or season.

## RESULTS

### Stratification

While not apparent on every sampling event, stratification of several limnological parameters was recorded on four occasions during the summer months. For example, at 1400 hr on 14 July 2002, the vertical temperature profile in the deepest part of the wetland ranged from 34°C at the surface to 26°C near the bottom (Figure 1a). This 8°C change occurred in less than 30 cm of water. Dissolved oxygen ranged from 11.2 mg/L near the surface to 2.6 mg/L near the bottom of the wetland and pH varied from 9 standard units at the surface to 7 standard units at 30 cm in depth (Figures 1b and 1c). This stratification occurred on a mostly sunny day with temperatures above 32ºC and with light winds averaging below 15 km/h. During days when sustained winds or frequent wind gusts were greater than 15 km/h, small wave action was noticed and stratification was not apparent.

High turbidities are common in ephemeral wetlands in central Oklahoma as indicated in Figure 1d. Total suspended solids (TSS) ranged from 200 mg/L at the surface to 1300 mg/L near the bottom at 30 cm. Given these high levels of TSS, light penetration was reduced by 76 % within the first 10 cm of water and 97 % at 25 cm (Figure 1e).

### Seasonal Variation

The wetland dried in August 2002, and remained dry until late September 2002 when fall rains filled it overnight, to a depth near 40 cm at its maximum. Rain events in May and June 2003 filled the wetland to a depth near 50 cm once again (Figure 2a). In July 2003, water depth in the system dropped to 10 cm until fall rains in October and November refilled it. In 2004, the wetland remained inundated due to unusually consistent rain from January through October, with maximum water depths ranging between 20 and 50 cm throughout the sampling period. The summer of 2004 was characterized as having both lower tempera-

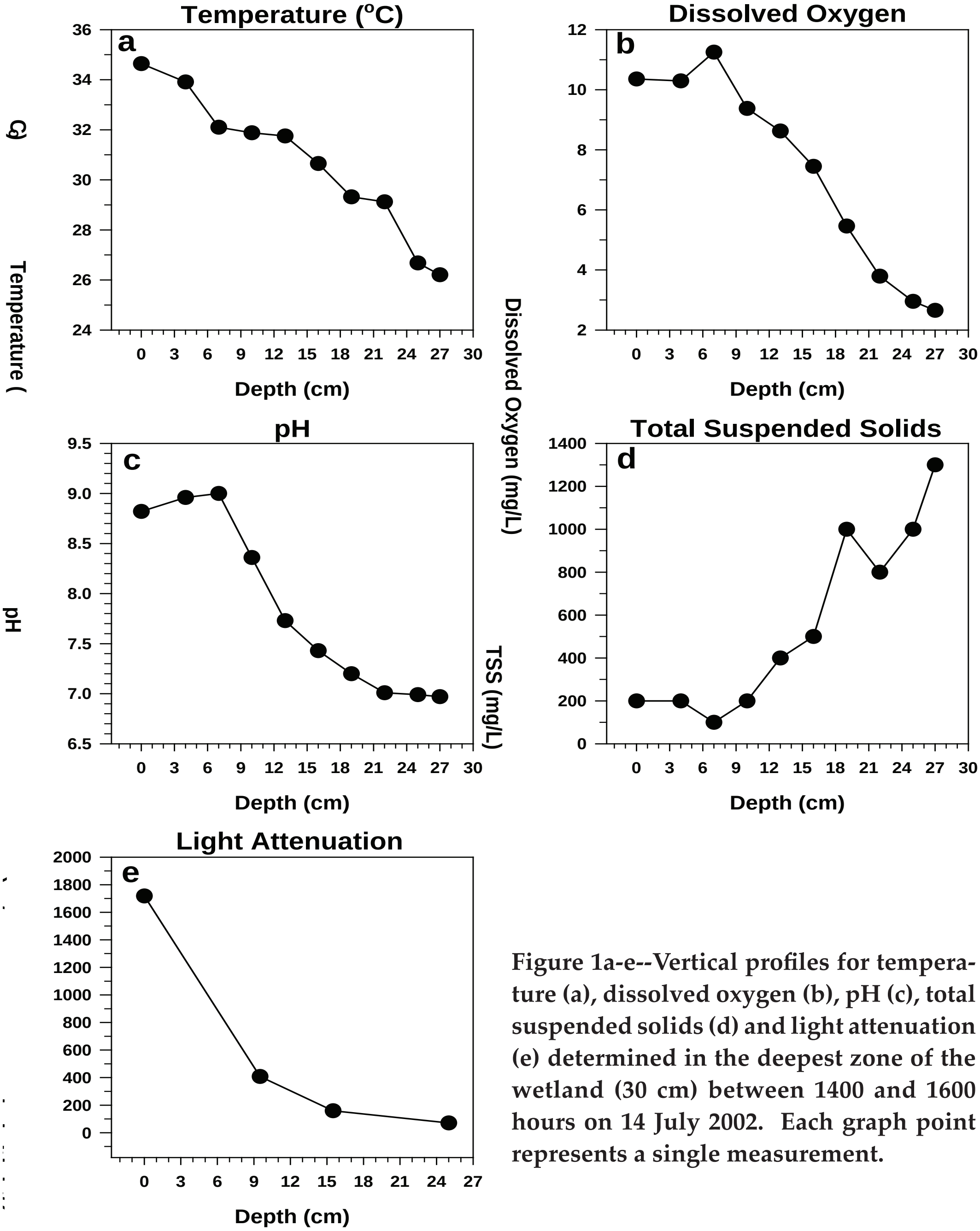

**Figure 1a-e--Vertical profiles for temperature (a), dissolved oxygen (b), pH (c), total suspended solids (d) and light attenuation (e) determined in the deepest zone of the wetland (30 cm) between 1400 and 1600 hours on 14 July 2002. Each graph point represents a single measurement.**

tures and greater rainfall than the previous 2 years (Oklahoma Mesonet). Water depth throughout the study was greatest during spring or just after heavy rains.

## Physical-chemical parameters

Water temperature at mid-column (depth range = 5 to 25 cm) between May 2003 and October 2004 ranged from a low of 4.8°C in December 2003 to 37.9°C in late August of both years (Figure 2b). Dissolved oxygen at mid-column fluctuated depending on time of year and recent rainfall events. Generally, lower DO levels occurred during the warmer months with values increasing as water temperatures fell. Maximum DO values of 14 mg/L occurred in January of 2004, with a minimum value of 3.41 mg/L recorded in late September 2004 (Figure 2b).

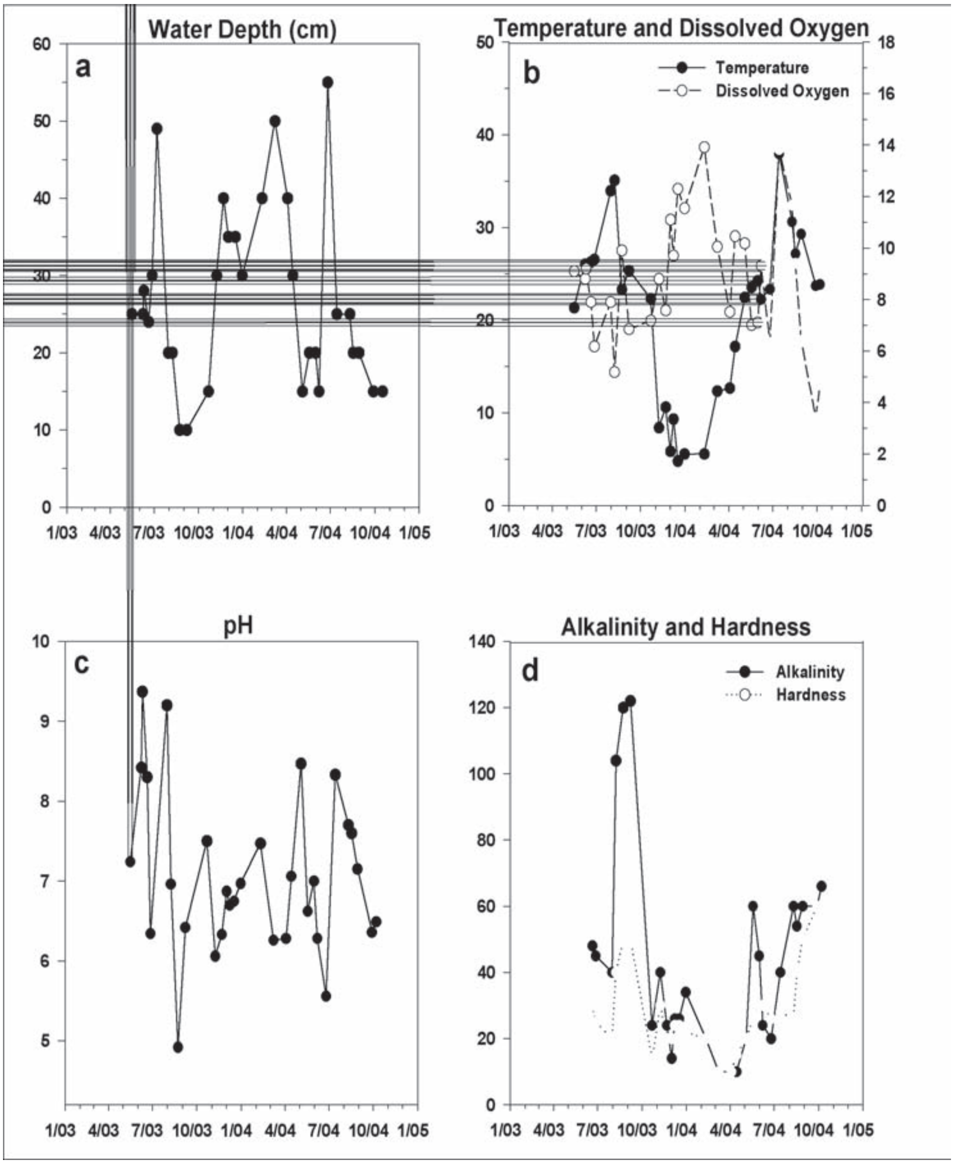

**Figure 2a-d--Seasonal variation in limnological parameters: wetland water depth (a), temperature and dissolved oxygen (b), pH (c), alkalinity and hardness (d), taken from the middle of the water column in the deepest zone of the wetland from April 2003 to October 2004. X-axis indicates the sampling date.**

The pH values ranged from just below 5 standard units in August 2003 to above 9 standard units in July 2003 (Figure 2c). Average pH over the sampling period was just under 7. Increases in pH were observed for several days following rainfall events such as September 2003 where pH increased from below 5 to 7.5 standard units, and in May 2004 when pH increased from near 6 to just above 8 standard units. These increases were then followed by a slow decline in values during periods of little precipitation.

Alkalinity and hardness were highest during summer months of 2003 and 2004, with alkalinity reaching 122 mg/L $CaCO_3$ and hardness reaching 60 mg/L $CaCO_3$ (Figure 2d). Alkalinity and hardness values as low as 10 mg/L $CaCO_3$ occurred during winter and spring of both years. Rainfall lowered both alkalinity and hardness for several weeks, as indicated by the sudden drop in both values in September 2003 when alkalinity declined from 122 to 25 mg/L $CaCO_3$ and hardness declined from 50 to just below 20 mg/L $CaCO_3$. Average hardness during the sampling period was near 30 mg/L $CaCO_3$, which is classified by the USEPA (2002) as soft water. Similarly, conductivity (Figure 3a) generally held between 0.1 and 0.2 mS/cm with a peak reaching 0.45 mS/cm in late summer months of 2003 as the wetland began to dry out. The lowest conductivity values of 0.05 mS/cm occurred during the spring of 2004, just after the wetland had filled completely.

Wetland depth and total suspended solids exhibited an inverse relationship, where high TSS values occurred when the wetland was most shallow. Conversely, increasing water depth appears to decrease both suspended solids and conductivity. The maximum TSS of 2859 mg/L occurred during late August 2003, when depth was less than 10 cm (Figure 3b). In late June 2004, a maximum wetland depth of 55 cm was associated with the lowest TSS value of 146.9 mg/L. TOC ranged from 4.66 mg/L in December 2003 to 132.0 mg/L in October 2004 (Figure 3c). Cattle were observed grazing on the upland habitat and using the wetland for drinking water from March to September 2004.

## DISCUSSION

### Stratification

Thermal stratification in large bodies of water and the factors that lead to its development and loss have been well documented with reviews in most basic limnology textbooks (e.g. Cole 1983; Wetzel 2001). During spring and summer, incident radiation results in a temperature differential between successively deeper layers of water, while heat loss in autumn and/or winter lead to uniform temperatures and mixing. Temperature-induced density differences between water layers can stabilize stratified systems, a phenomenon that can be expressed as the relative thermal resistance to mixing (RTR, Wetzel 2001). RTR is the amount of energy, provided by wind or convection currents, that is required to mix water layers of differing densities (Birge 1910; 1916). As the temperature difference between layers increases, more energy is required to mix the two layers. While heat loss during cooler seasons can lead to vertical density currents that mix water, in most cases wind provides the major driving force to break stratification. The potential for a system to remain stratified or mix is therefore largely the result of the opposing forces of water density differences and the wind.

Factors promoting and breaking stratification in large lakes are the same as those influencing stratification of ephemeral wetlands. With the often high levels of turbidity in ephemeral systems (Cooper 1988; Hartland-Rowe 1966), much of the light entering the surface is converted to heat (Schreiner 1984), which can facilitate stratification. However, effects of wind and vertical density currents are much more influential in these systems due to their small size and shallow water-depths. While local geology may influence the production of a thermocline (for depressional wetlands the effect of wind may be negated if it is shielded by the surrounding landscape), the wetland examined in this study is largely open on the southern end which is the direction from which the predominant winds blow during the summer.

Stability (S) estimates were calculated for the wetland during stratification employing methods of Birge (1915) and Idso (1973). Stability is a measure of the amount of energy required to mix a thermally stratified lake to an isothermal state, without the addition or subtraction of heat (Ambrosetti and Barbanti 2000). Stability is a function of lake size and morphometry, with smaller, shallower lakes having less stability (Wetzel 2001). Wind affects lake stability by distributing heat throughout the lake and breaking stratification (Birge 1916). The amount of

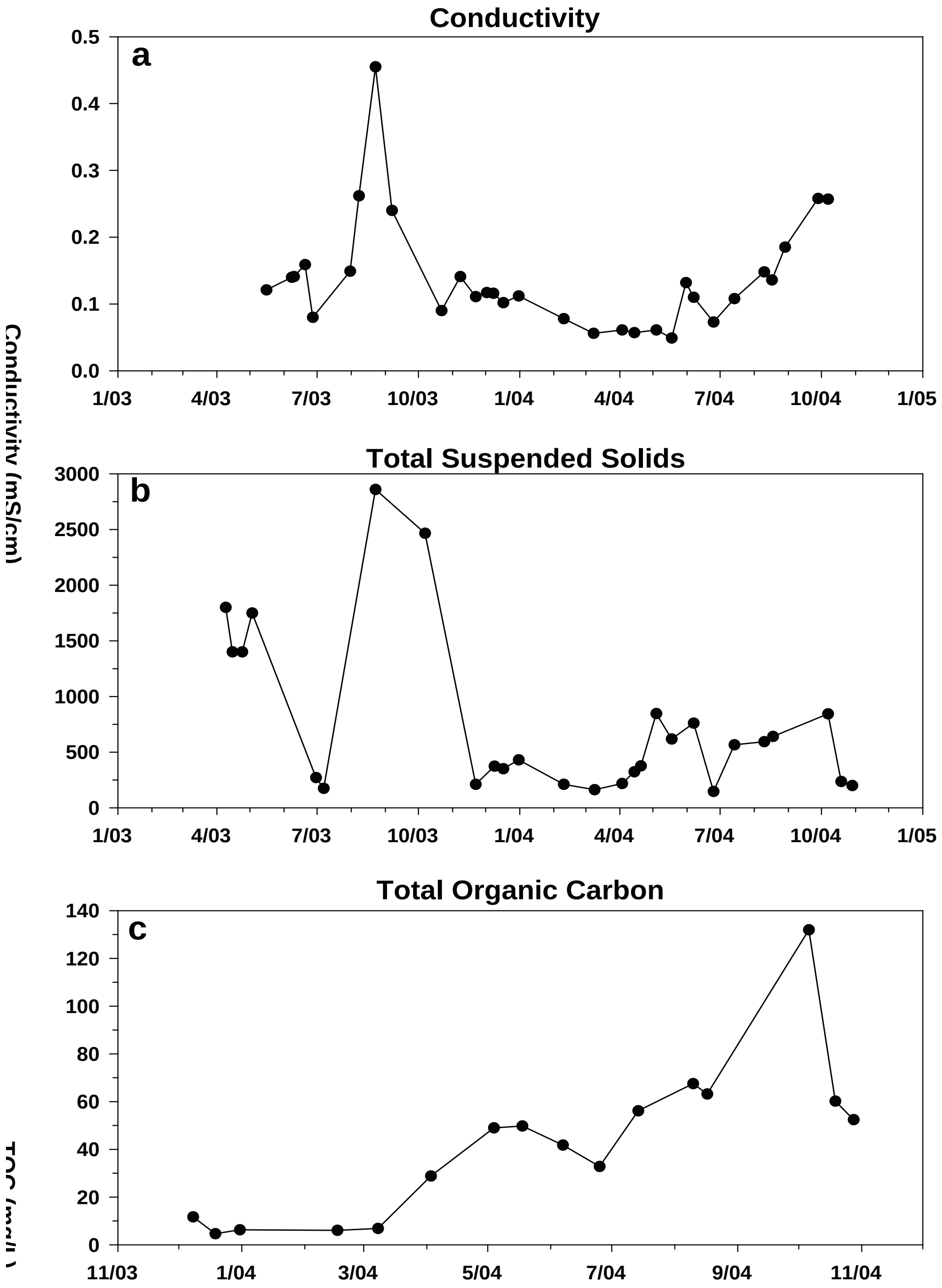

**Figure 3a-c--Seasonal variation in limnological parameters: conductivity (a), total suspended solids (b), and total organic carbon (c) taken from the middle of the water column in the deepest zone of the wetland from April 2003 to October 2004. X-axis indicates the sampling date.**

energy needed from the wind to break stratification, or Birgean work (B), was calculated at 1.06 and added to the stability calculation (S= 0.10) to arrive at (G), or the amount of work per unit area needed by the wind to evenly distribute heat throughout the lake. While large deep lakes commonly have G values in the thousands or tens of thousands (Ambrosetti and Barbanti 2000; Wetzel 2001; Allot 1986), the wetland in this study had a value of 1.16, meaning the system is relatively unstable and the wind need not provide much energy before stratification is broken. Typically in large, deep lakes, stability (S) estimates will exceed Birgean work (B) values. However, in smaller more shallow lakes, as is the case here, B will exceed S (Ambrosetti and Barbanti 2000). This is a result of the difference in total lake volume and morphometric differences between large and small lakes.

While it was not directly tested in this study, Angelibert et al. (2004) and Serrano (1994), suggest stratification in ephemeral wetlands is broken by cooler temperatures overnight, leading to high fluctuations in diurnal water chemistry and a polymictic system. In fact, Black (1976) found that temperatures could change by 20°C in one 24 h period in his studies on wetlands in central Oklahoma.

In this study, primary producers may be responsible for the dissolved oxygen and pH results which indicate super-saturated oxygen concentrations near the surface and decline with depth. With respiration occurring near the bottom, $CO_2$ concentrations increase, potentially causing the observed decline in pH with depth (Wetzel 2001). Serrano (1994), Black (1976), and Eriksen (1966) have all recorded similar thermal and chemical stratification results in their studies of shallow wetlands. In addition to influencing lake heating and stratification, suspended solids can potentially limit phytoplankton due to light attenuation (Lind et al. 1992; Carignan and Planas 1994). On the other hand, while studies investigating chlorophyll concentration in highly turbid ephemeral wetlands are limited, phytoplankton levels may be sufficient to provide food for the often-high densities of filter-feeding zooplankton. In the present study, despite the stratified distribution of suspended solids, 76% of the light entering the surface was attenuated in the top 10 cm which may indicate insufficient light was available for primary producers. However, Lind et al. (1992) also reported, in studies of Lake Chapala in Mexico, that chlorophyll $\alpha$ concentrations were consistently highest at the most turbid site within the lake and it is commonly held that only 1% transmission of surface light is needed for photosynthesis (Ryther 1956). Furthermore, Sand-Jensen (1989) states that aquatic plant communities can acclimate to photosynthesize under significant shading regimes with far less than 1% light transmission, provided enough time and a relatively stable amount of light is available during acclimation.

### Seasonal water chemistry

DO and temperature varied widely throughout the study period with maximum DO values being recorded when water temperature was lowest. Heavy rainfall also increased DO as illustrated in August 2004 (Figure 2b). Other than exhibiting high variability, pH exhibited no seasonal trend. Pickens and Jagoe (1996), Scholnick (1994), Black (1976), and Daborn and Clifford (1974) also found no seasonal trend with regard to pH, however, Serrano and Toja (1995) reported pH to increase gradually toward the end of the hydroperiod due to high primary productivity in studies of wetlands in Spain. Primary producers can reduce carbon dioxide concentrations through photosynthetic activity, which reduces carbonic acid levels and eventually increases pH.

Alkalinity and hardness increased during the summer which may be the result of evaporation. Scholnick (1994) also observed increases in alkalinity within desert ephemeral pools. He speculates the increase in total alkalinity occurred due to reduction of iron, sulfate, manganese, and calcium from the sediments, which might allow carbon dioxide to accumulate over time in the form of bicarbonate.

TOC increased from March through October 2004 (Figure 3c). This marked increase may have partially resulted from cattle grazing the upland habitat from March to September of the same year, which may add a significant source of nutrients and lead to wetland eutrophication, or excess nutrients (primarily nitrogen and phosphorus). Waiser and Robarts (2004) and Olivie-Laquet et al. (2001) also reported organic carbon in wetlands to increase from spring to fall. The sources of organic carbon are likely to vary depending on surrounding land use. Wide variations in stored carbon levels of depressional wetlands in Georgia, USA, were attributed to historical agricultural land uses (Craft and Casey 2000). In contrast, wetlands in forested areas may receive most of their organic carbon inputs from leaf litter (Colburn 2004).

## SUMMARY

Ephemeral wetlands are characterized by temporal changes in abiotic characteristics that occur on both daily and seasonal scales. Thermal stratification in these shallow habitats was observed on several occasions; however, stability of the stratification was very low. Seasonal changes in parameters such as pH, conductivity, hardness, and total organic carbon, among others, were also observed indicating short-term and long-term fluctuations in water chemistry occur in ephemeral wetlands. The potential biotic effects resulting from the dynamic nature of these systems remains largely unexplored.

We would like to thank N. Cooper (Stillwater, OK. USA) for her assistance in the field. C. Davis and A. Echelle (Stillwater, OK. USA) reviewed previous drafts of this manuscript and the Ecotoxicology and Water Quality Research Laboratory at Oklahoma State University funded part of this research.

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Received: March 9, 2007; Accepted May 4, 2007