

# ENVIRONMENTAL FLUCTUATIONS IN CENTRAL OKLAHOMA TEMPORARY PONDS

Jeffrey Howard Black

Department of Biology, Oklahoma Baptist University, Shawnee, Oklahoma and J. Willis Stovall Museum of Science and History, University of Oklahoma, Norman, Oklahoma.

Temporary ponds in central Oklahoma present an extremely variable physicochemical environment. A number of properties show extensive circumdiel variations and some even showed large differences among locations within a pond at one time.

The magnitude of the spatial and short-term variations in the environment of these small ponds is an important consideration in taking measurements.

## INTRODUCTION

It is well established that organisms inhabiting small bodies of water face an extremely changeable environment (1, 2). The change may be spatial as the organisms move or are carried from one part of the pond to another, or temporal as the environment changes rapidly over relatively short periods of time. Because temporary ponds have not been well studied from a limnological standpoint, we still know relatively little concerning the environmental conditions their inhabitants must face.

As part of a general study of the ecology of small ponds in Oklahoma, I have examined certain aspects of these environmental changes. This paper attempts to illustrate the spatial and short-term temporal variations and to describe the processes that give rise to them in three small ponds from 17 January 1969 to 5 January 1971.

Ponds included in this study are located in the oak-hickory savannah of central Oklahoma between 9.6 and 35.4 km east of Norman. Locations and morphometric descriptions of these ponds are given in Table 1.

## MATERIALS AND METHODS

Temperature was measured with a Whitney Underwater Thermometer (Model TC-5). Total dissolved solids were measured using a Myron L DS Meter (Model 532T 1). This meter measures electrical conductivity but reads directly in ppm total dissolved solids. All other measurements were made using reagents and procedures furnished by the Hach Chemical Company in their Model DR-EL test kit, which has been developed and proven to be a convenient and accurate means of testing water in the field.

Sampling was carried out by reaching out from shore or by wading into the pond and then reaching ahead to the desired sampling position. Care was exercised to obtain samples from an area where water had not been disturbed by the observer.

A water sample was obtained by lowering an inverted sampling bottle to the desired depth and then righting the bottle and letting it fill. This procedure, although rather crude, is considered satisfactory. However, its use for sampling oxygen might be questioned. Eriksen (1) used a

TABLE 1. Geographic location and morphometric data for the basins of Pond 1 and Pond 2, Cleveland County, and Pond 3, Pottawatomie County.

	Pool 1	Pool 2	Pool 3
Location	SW $\frac{1}{4}$ , SE $\frac{1}{4}$ , Sec. 29, T.9N., R.1W., Cleveland Co.	SE $\frac{1}{4}$ , SE $\frac{1}{4}$ , Sec. 22, T.9N., R.1E., Cleveland Co.	SE $\frac{1}{4}$ , SE $\frac{1}{4}$ , Sec. 9, T.9N., R.2E., Pottawatomie Co.
Maximum length (m)	32.1	31.8	10.8
Maximum effective length (m)	29.7	31.8	10.8
Maximum width (m)	5.4	9.3	8.9
Maximum effective width (m)	5.4	9.3	8.9
Maximum depth (cm)	27.0	30.0	23.0
Mean depth (cm)	13.1	14.9	5.9
Surface area (m <sup>2</sup> )	126.0	189.0	139.0
Volume (m <sup>3</sup> )	1645.0	2813.0	811.0
Length of shoreline (m)	69.3	71.0	30.3

method similar to mine and believed it introduced little error. I found oxygen values so low that, within the precision of my method, they were recorded as zero. I feel, as did Eriksen, that sampling small ponds in this way is satisfactory for obtaining general estimates of oxygen.

Unless otherwise indicated, samples for determining all properties except oxygen content were taken from within a few centimeters of the surface over the deepest part of the pond during the day. Samples used for determining oxygen were usually obtained at the same location but at mid-depth in the water column.

## RESULTS AND DISCUSSION

Variations in a number of limnological properties were related to certain climatic fluctuations. Below I group the climatic fluctuations, somewhat arbitrarily, under a series of causative processes.

### Vertically localized heating and cooling and related processes

It has long been known that lakes often have pronounced vertical thermal gradients. Although it has been suggested that thermal stratification is usually absent or unimportant in small ponds (3, 4), the occurrence of sharp gradients in ponds less than ½ m deep is now well established (1, 5).

These ponds showed vertical thermal gradients. The largest difference observed was 10.3 C from top to bottom (approximately 18 cm) in Pond 2 on 15 June 1970 at 1215 hr. Smaller differences but still of two degrees or more were commonly noted.

Top and bottom temperatures were measured, usually within a few hours of noon. Measurements showed thermal gradients of more than one degree 38% of the time in Pond 1, 81% of the time in Pond 2, and 76% of the time in Pond 3.

Whether a pronounced thermal gradient was present or not seemed to depend on time of day and force of wind. Pond 1 is thought to have shown a distinct thermal gradient least often because it was the most exposed of the ponds and frequently disturbed by cattle.

The effect of time of day on the thermal gradient is illustrated in Table 2. During the daylight hours surface waters were warmed both by transfer of heat from the atmosphere and by direct absorption of solar energy. Thus, thermal gradients directly related to depth were often observed when wind mixing was not great. During

TABLE 2. *Circumdiel cycle of limnological conditions in Pond 3 on 9 to 10 April 1970.*

	9/IV/70	10/IV/70		
	1745 hr	0030 hr	0645 hr	1215 hr
Temperature (C)				
Air	23.0	16.1	8.5	24.5
Mid-pool, 10 cm deep				
Surface	19.7	14.3	10.1	27.0
Bottom	19.5	14.7	10.2	21.7
Mid-pool, 20 cm deep				
Surface	19.7	14.3	10.1	27.0
Bottom	18.0	15.2	10.3	18.2
Total dissolved solids (ppm)				
Mid-pool, 10 cm deep				
Surface	65	65	65	65
Bottom	—	70	70	70
Mid-pool, 20 cm deep				
Surface	65	65	65	65
Bottom	80	110	70	70
Chemical features (ppm except pH)				
Total alkalinity	40	45	43	45
Phenolphthalein alkalinity	0	0	0	0
Calcium hardness	20	22	25	20
pH	6.79	6.53	6.49	6.93
Oxygen (mid-depth)	6.0	1.0	1.5	6.5
Light penetration				
Transmittance (%)	46.1	48.5	50.0	48.0
Turbidity (JTU)	252	235	225	240

the sampling reported in Table 2, such gradients were found at 1745 hr on 9 April and 1215 hr on 10 April.

At night heat was lost from the top layers and they cooled. This cooler water tended to sink, giving rise to convection currents which prevented the formation of thermal gradients.

Weak inverse thermal gradients were noted at night, as on 10 April at 0030 hr (Table 2). Eriksen (1) noted a similar phenomenon and suggested it was due to the upper layers cooling more rapidly than they could sink to their density layer. Values for total dissolved solids in Table 2 suggest that vertical chemical stratification may also have been important. At 1745 hr on 9 April, bottom waters had a higher dissolved solid content than surface waters. These ions were probably released by decomposition and trapped in the lower layers during the day because of thermal stratification and thus gave rise to chemical stratification. Oxygen was low at mid-depth during the evening, and it seems assured that it was low in the bottom waters for part of the day. These deoxygenated waters would have had a low redox potential favoring the release of certain ions from bottom muds (6). Whatever the cause, the total dissolved solids built up in the bottom water during the day and early evening so that there was pronounced chemical stratification at 0030 hr on 10 April. This means that the upper layers would have had to cool below the bottom water temperature before an inverse density gradient was established and convective mixing initiated.

Chemical stratification was not always limited to the evening hours as was the case presented in Table 2. An example of daytime stratification is provided in Figure 1, where the value for total dissolved solids at 1515 hr is more than twice as high at the bottom (160 ppm) as at the surface (70 ppm) in a total depth of 15 cm. It seems surprising that such a pronounced gradient, perhaps arising as a result of thermal stratification, was observed so early in the afternoon. If these ponds had mixed the previous night and stratified that morning, then the gradient must have formed in a short time.

Since thermal stratification was commonly observed, determinations of oxygen at the top and bottom of the ponds often showed large differences. Pond 1 was too shallow to permit separate oxygen determinations, but they were made 9 times in Pond 2 and 8 times in Pond 3. Oxygen in surface waters was always higher than in bottom waters with the exception that, on 1 March 1969, in Pond 2, the values for the two levels were the same.

Bottom oxygen was usually below 5 ppm and in several cases close to 0 ppm. As measurements were taken within a few hours of noon and towards the beginning of the daily period of stratification, it is considered likely that vertical gradients in oxygen were present much of the time thermal stratification was present. Results in Table 3 support this idea and show gradients in oxygen at 1215 hr and 1815 hr during thermal stratification, but not at 0015 hr when temperature profiles indicate mixing was occurring.

During periods of thermal stratification, it could be assumed that other substances were disturbed along vertical gradients in the pond similar to those observed for total dissolved solids and oxygen.

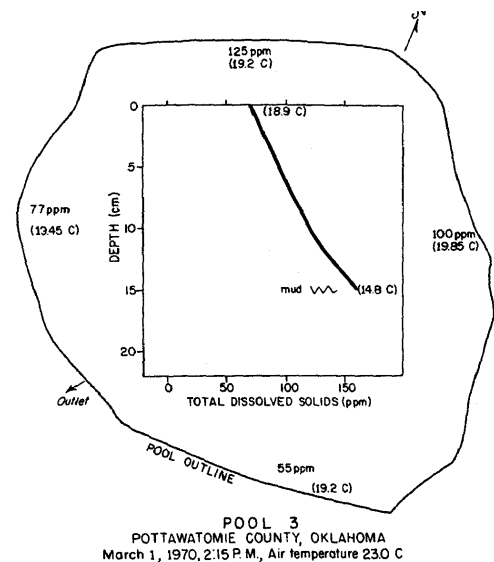


FIGURE 1. A summary of the limnological conditions in Pool 3 at 14:15 hr on 1 March 1970. The values for temperature and total dissolved solids at four locations around the edge of the pool as well as the vertical profile of total dissolved solids and the top and bottom temperatures in the middle of the pool are presented.

TABLE 3. *Circumdiel cycle of limnological conditions in Pond 3 on 5 to 6 March 1970.*

	5/III/70			6/III/70
	0615 hr	1215 hr	1815 hr	0015 hr
Temperature (C)				
Air	12.2	28.4	30.9	17.1
Near edge, 2 cm deep				
North edge	13.8	25.0	22.8	17.9
South edge	12.8	29.0	24.3	17.8
East edge	12.9	32.9	24.9	16.8
West edge	13.2	30.0	21.8	17.0
Mid-pool, 15 cm deep				
Surface	14.6	30.5	25.0	19.5
7 cm	14.8	25.8	25.0	19.7
Bottom	14.9	24.1	25.0	19.7
Mid-pool, 20 cm deep				
Surface	14.6	30.5	25.0	19.1
7 cm	14.8	27.1	25.0	19.4
14 cm	14.9	23.4	24.9	19.7
Bottom	15.3	21.2	24.7	20.1
Total dissolved solids (ppm)				
Near edge, 2 cm deep				
North edge	61	55	57	62
South edge	70	63	57	73
East edge	62	63	60	85
West edge	69	58	61	70
Mid-pool, 15 cm deep				
Surface	54	52	55	60
Bottom	54	52	60	60
Mid-pool, 20 cm deep				
Surface	54	52	60	60
Bottom	54	52	65	60
Chemical features (ppm except pH)				
Total alkalinity	52	52	50	45
Phenolphthalein alkalinity	0	0	0	0
Calcium hardness	20	20	15	22
pH	6.94	6.95	6.70	6.60
Oxygen				
Surface	0.6	4.5	4.0	1.0
Bottom	0.6	3.0	2.5	0.8
Light penetration				
Transmittance (%)	49.5	59.0	40.0	61.0
Turbidity (JTU)	225.0	178.0	290.0	162.0

TABLE 4. *Circumdiel cycle of temperature changes in Pond 1 on 19 to 20 September 1969.*

	19/IX/69		20/IX/69			
	1630 hr	2215 hr	0215 hr	1715 hr	1115 hr	1500 hr
Temperature (C)						
Air	30.0	17.0	14.0	13.5	26.0	29.0
Near edge, 2 cm deep						
Northwest edge	32.8	22.7	19.9	18.0	28.7	32.7
North edge	32.2	23.0	20.7	18.3	28.0	32.5
Northeast edge	32.6	22.8	20.8	18.2	27.7	32.0
East edge	32.7	21.6	19.7	17.7	22.7	32.0
Southeast edge	32.2	22.8	19.4	18.1	26.9	32.7
South edge	31.1	23.8	21.3	18.5	27.4	32.1
Southwest edge	30.7	23.1	21.4	18.6	27.5	31.4
West edge	32.4	21.6	19.7	17.8	29.1	32.6
Mid-pool, 20 cm deep						
Surface	31.9	23.9	21.9	19.2	27.0	31.7
10 cm	29.4	23.9	21.9	19.2	25.6	30.2
Bottom	26.6	24.0	21.9	19.2	24.0	28.7

## Horizontally localized processes

Examples of horizontal variations in temperature at 2 cm depth at eight locations in Pond 1 are provided in Table 4. The maximum difference was 6.4 C at 1115 hr between the east and west sides. This occurred because the east edge of the pond was shaded by trees when the sun was in the east and did not warm up as quickly in the morning as other areas of the pond. Excluding this case, differences of more than one degree were noted every time measurements were made during this sampling period.

Except for the difference due to shading, it is not possible to provide a definitive explanation for these temperature differences, even though they are probably related to differences in bottom topography and average depth at different locations in the pond.

Large horizontal differences in chemistry were noted in all ponds. An example is provided for total dissolved solids for Pond 3 on 1 March 1970 (Figure 1). The reading for the south edge of the pond was 55 ppm, while that for the north edge was 125 ppm.

To obtain a clearer understanding of these horizontal differences, measurements of total dissolved solids at the surface were made approximately every ½ m on a transect across Pond 3 (Table 5). A twofold increase was noted from one side of the pond to the other and perhaps related to uptake and release of nutrients and other materials by higher plants and their remains, which varied in both quantity and kind horizontally.

As indirect evidence for this hypothesis, it was noted that these gradients were more commonly observed and more intense in Pond 3, which possessed more higher aquatic plants than either of the other ponds.

## Circumdiel climatic changes

Table 3 provides an example from Pond 3 of circumdiel variations. Surface temperature varied extensively, and seemed to follow changes in air temperature quite closely. The minimal circumdiel range noted in surface temperature was approximately 16 C at mid-pond with a maximum of 20 C on the east side. Circumdiel variations deeper in the pond were less but still large. A temperature difference of over 9 C was noted in the bottom waters of the deepest part of the pond (20 cm depth).

Fluctuations of this magnitude (Table 3) were the rule with a circumdiel range in surface temperature of more than 10 C every time appropriate measurements were made.

There is an unexplained aspect to the circumdiel temperature changes in Table 4. Even though Pond 1 was thermally stratified by 1115 hr on 20 September 1969, the bottom temperature did not stay constant during the afternoon; at 1500 hr it had increased by over 4 C. It may be that the pond cooled, mixed, warmed, and restratified with a higher bottom temperature all between the two times or that a sizeable fraction of incoming solar energy penetrated to the bottom of this shallow pond and was absorbed there as heat by the sediments leading to increased bottom water temperatures.

Chemical conditions also showed circumdiel fluctuations (Table 3). The highest oxygen concentrations at the surface and bottom were recorded about noon and the lowest values near midnight or a few hours after. Low oxygen in the early morning was probably related to the slowness at which gas diffuses across a relatively undisturbed air-water interface (6), as well as to lack of production of oxygen at night by plants.

Total dissolved solids also showed circumdiel changes. A change from 70 to 110 ppm was noted in Pond 3 (Table 2). Circumdiel changes in total dissolved solids was usually not of this magnitude, with the

TABLE 5. Variations in concentration of total dissolved solids at the surface on a transect across Pond 2 at 1400 hr on 15 May 1970.

Approximate distance from west shore (cm)	Depth (cm)	Total dissolved solids (ppm)
0.5	2.5	95
1.0	4.0	88
1.5	5.0	80
2.0	5.5	75
2.5	6.5	67
3.0	8.0	65
3.5	8.0	60
4.0	9.0	62
4.5	9.0	67
5.0	6.0	65
5.5	5.0	60
6.0	5.0	50
6.5	3.0	52
7.0	2.0	45

results in Table 3 giving a more typical picture. Total dissolved solids varied by no more than 15 ppm at a location with slightly higher values in the midnight samples, perhaps related to predominance of anabolic processes.

Total alkalinity and pH showed minor circumdiel changes (Table 2 and 3). More basic conditions prevailed during the day when plants were taking up carbon dioxide and more acidic conditions occurred at night when plants and decomposers were adding carbon dioxide to the water.

Turbidity showed, at times, extensive circumdiel variations (Table 3). As the degree of turbidity influences other conditions, especially light penetration, fluctuations in this factor may profoundly affect general conditions in the ponds.

### Freezing and melting

Winter air temperatures of central Oklahoma fluctuate widely and fall below 0 C quite often. These small ponds were partially frozen, periodically, throughout the winter. Ice cover did not usually extend completely to the bottom, although this was noted once for Pond 1. Frozen periods were usually of short duration but could last one or two weeks.

Table 6 illustrates chemical conditions in Pond 3 while it was frozen. This table compares the chemistry of water under the ice with that of water obtained by melting some of the ice in the laboratory and the chemical conditions the next day when the ice had melted naturally.

Water under the ice contained much higher concentrations of total dissolved

TABLE 6. *A comparison of limnological conditions in Pond 3 with and without ice cover and also of water obtained by melting some of the ice.*

	10/1/70		11/1/70
	Under ice	Melted ice	Without ice
Total dissolved solids (ppm)	132	38	75
Total alkalinity (ppm CaCO <sub>3</sub> )	80	20	45
Phenolphthalein alkalinity (ppm CaCO <sub>3</sub> )	0	0	0
Calcium hardness (ppm CaCO <sub>3</sub> )	40	10	20
pH	7.05	6.67	5.88-6.10
Oxygen (ppm)	0.0	0.0	0.0
Iron (ppm)	3.20	0.15	3.25
Light penetration			
Transmittance (%)	52.2	87.2	65.8
Turbidity (JTU)	210	50	140

TABLE 7. *Limnological conditions in Pond 1 near noon on a series of days from 28 March to 24 April 1969.*

Date	28/III	1/IV	4/IV	8/IV	10/IV	12/IV	15/IV	17/IV	24/IV
Maximum depth (cm)	25	21	18	14	10	8	4	22	17
Temperature (C)									
Surface	—	22.5	—	20.2	—	—	29.9	—	16.1
Bottom	—	22.3	—	19.9	—	—	29.6	—	14.1
Chemical features (ppm except pH)									
Total alkalinity (as CaCO <sub>3</sub> )	—	42	90	124	132	170	200	30	100
Phenolphthalein alkalinity (as CaCO <sub>3</sub> )	—	0	0	0	0	0	0	0	0
Calcium hardness (as CaCO <sub>3</sub> )	—	40	—	—	90	110	120	—	57
pH	7.29	7.75	8.10	7.80	—	8.50	—	—	7.33
Oxygen	—	9.0	—	8.0	—	6.0	—	—	7.0
Iron	0.62	0.78	0.60	0.55	0.40	0.32	—	—	0.55
Light penetration									
Transmittance (%)	42.0	55.5	38.0	33.5	64.0	44.0	23.0	0.5	13.5
Turbidity (JTU)	280	195	320	360	150	275	500+	500+	500+

solids, total alkalinity, iron, and calcium hardness than either melted ice or mixed water from the next day. As expected, melt water had very low concentrations of these materials.

### Drying and filling

Although these ponds usually contained water, each was completely dry several times. Pond 1 was dry four times from February 1969 to April 1970, but never for more than two or three weeks at a time. Pond 2 was the most likely to be dry and refilled with water six times during the observation period. It was dry for over three months during the summer of 1969. Pond 3 dried out three times during the summer, but filled again within two or three weeks.

These ponds went through alternating periods of water level rise and fall and these were associated with limnological changes. Table 7 presents a representative series of observations on limnological conditions over a period of about one month in Pond 1.

Total alkalinity and calcium hardness changed extensively and this change was inversely related to depth of water. When the weather was dry, evaporation and seepage caused loss of water with lowering of the pond level causing increased concentrations of dissolved substances. When rain fell, the water level would quickly rise from precipitation and runoff from surrounding areas. This added water contained lower quantities of materials than the pond water in which materials had been concentrated by evaporation. Thus, the chemical conditions of the ponds would be expected to change rapidly during and just after a rainfall of any appreciable amount.

The extent of changes that can occur after a rain are illustrated by results for total alkalinity in Pond 1 on 15 and 17 April, just before and after a rain (Table 7). Total alkalinity changed from 200 to 30 ppm.

Limnologically significant properties such as pH, iron, and light penetration did not show any obvious correlations with water level (Table 7).

### SUMMARY

This study has revealed that temporary ponds in central Oklahoma constitute an extremely variable physico-chemical environment. Properties were found to show extensive circumdiel variations and some showed large differences among locations within a pond at one time.

To illustrate the variability further, the lowest and highest values found during the entire study at all stations for each of a number of limnological properties are presented in Table 8. For comparison, the table also presents the extremes measured within a pond at one time and those measured within a pond during any one 24-hour period. It will be noted that the range for a property at one time or within a 24-hour period is often an appreciable fraction of the range for that property during the en-

TABLE 8. *Variations in physico-chemical data within the pond at one time, during a 24-hour study, and during the entire study for all ponds.*

Property	Time		
	Within the pond at one time	During 24 hours at one station	During the entire study at all stations
Temperature (C)	18.25—30.10	10.1—30.1	—0.5—39.4
Total dissolved solids (ppm)	70—160	75—132	15—425
Total alkalinity (ppm CaCO <sub>3</sub> )	14—30	45—80	10—330
Ca hardness (ppm CaCO <sub>3</sub> )	15—22	20—40	15—120
pH	5.1—6.3	5.88—7.05	4.95—9.25
Oxygen (ppm)	2.0—7.5	1.0—10.0	0.0—15.0
Turbidity (JTU)	170—500+	162—290	2—500+
Light transmittance (%)	00.0—65.5	40.05—61.0	0.0—99.8
Iron (ppm)	0.18—2.0	0.30—3.5	0.0—3.5
Chloride (ppm)	4.0—6.5	5.0—20.0	4.0—50.0
Nitrate nitrogen (ppm)	3.7—5.0	1.0—5.0	0.0—9.5

tire study. This means that organisms must not only possess mechanisms by which they can cope with or avoid large gradual changes of the environment over relatively long periods of time but that they must also have means with which to deal with rather sudden temporal and spatial changes.

The magnitude of the spatial and short-term temporal variations in these small ponds should sound a note of warning. The common procedure of measuring limnological properties occasionally at one position, often the middle, of such ponds is not satisfactory for gaining a knowledge of the conditions within the pond. The present study has clearly shown that only detailed studies and extensive sampling will allow us to gain a workable understanding of the environment of temporary ponds in central Oklahoma.

### ACKNOWLEDGMENTS

I am very grateful to Drs. Andrew Robertson, Charles C. Carpenter, and Howard P. Clemens for helping bring this paper to a climax. A special thanks goes also to Catherine Walsh for her help in typing the manuscript. The Oklahoma Biological Survey provided financial support for this study.

### REFERENCES

1. C. H. ERIKSEN, *Int. Verein. Theor. Angew. Limnol. Verh.* 16: 506-14 (1966).
2. R. HARTLAND-ROWE, *Int. Verein. Theor. Angew. Verh.* 16: 577-84 (1966).
3. M. G. GEORGE, *Hydrobiologia* 18: 265-73 (1961).
4. E. P. ODUM, *Fundamentals of Ecology*, 3rd ed., W. B. Saunders, Philadelphia, 1974.
5. W. G. MOORE, *Southwest. Nat.* 15: 83-110 (1970).
6. G. E. HUTCHINSON, *A Treatise on Limnology, Vol. I, Geography, Physics, and Chemistry*, J. Wiley, New York, 1957.