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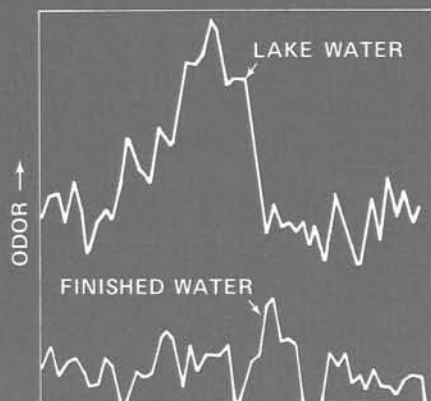
ILLINOIS DEPARTMENT OF ENERGY AND NATURAL RESOURCES

*Relationships between Odor and Commonly Measured
Water Quality Characteristics
in Surface Water Supplies*

by SHUNDAR LIN and RALPH L. EVANS

ILLINOIS STATE WATER SURVEY

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Abstract: Weekly threshold odor numbers (TONs) were determined for the waters of three impoundments and the finished water produced by treatment at each impoundment site during a 2-year period. The correlation between the TONs and each of 20 commonly measured biological, chemical, and physical parameters was examined. The correlation coefficients were generally low, except those for nitrate-nitrogen, sulfate, manganese, and chlorine demand. The magnitude of taste and odor in the three impoundments was found to be a seasonal function. High TONs generally occurred during the period from May through October, the period of anoxic conditions in bottom waters of impoundments. Regardless of the magnitude of TONs for the raw waters, the TONs for the three finished waters ranged from 3 to 10 about 95 percent of the time. The probable causes of the excessive TONs are discussed, and predictions of the occurrences and magnitude of odor are presented, based on stepwise multiple regression analyses.

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ABSTRACT

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INTRODUCTION

It is an accepted rule in the water industry that drinking water shall contain no impurity which can reasonably be expected to cause offense to the senses of sight, taste, or smell. As part of an effort to achieve this goal, the Illinois Pollution Control Board (IPCB) recommends a maximum threshold odor number (TON) of 3 in finished water. Despite the acceptance of the rule and the assignment of TON limitations, taste and odor problems continue to frustrate the skills of management and the patience of consumers.

Taste and odor problems are encountered in almost all water works which use surface water as a source. Tastes and odors in water can be derived from natural or man-made sources or a combination of both. The problems experienced are often associated with such factors as season, reservoir stratification and turnover, rainfall, stream flow, spring thaw, odor-producing organisms, decaying vegetation, and industrial spills. Some odor episodes are predictable; others are not.

Lin (1976a, 1976b, 1977a, 1977b) reviewed the literature on tastes and odors in water. He found that although there is a long history of taste and odor problems, there is very little information available on long-term studies of threshold odor in reservoirs. The purpose of this report is to provide information on such a study.

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Objectives and Report Plan

This study was performed on three central Illinois impoundments that serve as sources of public water supplies. The purposes of the study were:

1) To measure long-term TONs for raw and finished waters
2) To explore the relationships, if any, between TON and commonly measured water quality constituents
3) To identify the elements responsible for excessive TONS
4) To develop a procedure for predicting the occurrences of odor and its magnitude

This report describes the methods and procedures used in the study. It also presents the results and discussions related to the four objectives. The weekly TON values and odor types for the finished and raw lake waters are tabulated in appendices A, B, and C.

Acknowledgments

The writers extend their thanks to the following personnel who assisted in the study. The personnel of the water works at Canton, Decatur, and Eureka were most helpful in providing access to the lakes. Randy Rohman and Robert Grabel collected most of the samples and conducted the threshold odor number tests. Robert Sinclair assisted in the statistical analysis. Dave Hullinger, Gary Benker, Melbern E. Jannett, Wuncheng Wang, and Dana Shackleford performed chemical analyses. Dave B. Beuscher identified and enumerated algae samples. Tom Hill and Scott Bell examined benthic collections. The other personnel of the Water Quality Section also participated in the sample collections and odor tests. Linda Johnson typed the original manuscript, and Gail Taylor edited the manuscript. Illustrations were prepared by John Brother, Jr., and William Motherway. Marilyn J. Innes prepared the camera copy.

SAMPLES AND METHODS

Three man-made water supply impoundments were examined for a 2-year period extending from September 13, 1976, to October 16, 1978. They vary in size, water depth, drainage area, and water quality (table 1). Lake Decatur has a large surface area and a maximum depth of 5 m. Lake Eureka is a small body of water with a maximum depth of 6 m. Lake Canton has a mid-size surface area and a maximum depth of about 11 m.

The three impoundments were constructed principally as sources for public water supplies, and they also serve as recreation areas. Lake Canton started to fill in 1939, with the draining of Copperas Creek. Lake Decatur was formed by a dam on the Sangamon River, and storage began in April 1922. Lake Eureka was constructed in 1942 by the damming of a branch of Walnut Creek and was discontinued as a water supply source in October 1978. All three lakes have the typical serpentine shape of midwestern impoundments, as may be seen in figures 1, 2, and 3.

Table 1. Pertinent Physical Data for the Study Lakes

Lake	Surface area (ba)	Watershed area (ba)	Maximum depth (m)	Water volume $(10^6 \times m^3)$	Water withdraw (m^3/d)
Canton	88.2	3,845	11	3.73	7,600
Decatur	1166	23,470	5	26.50	60,600
Eureka	14.6	688	6	0.28	1,140

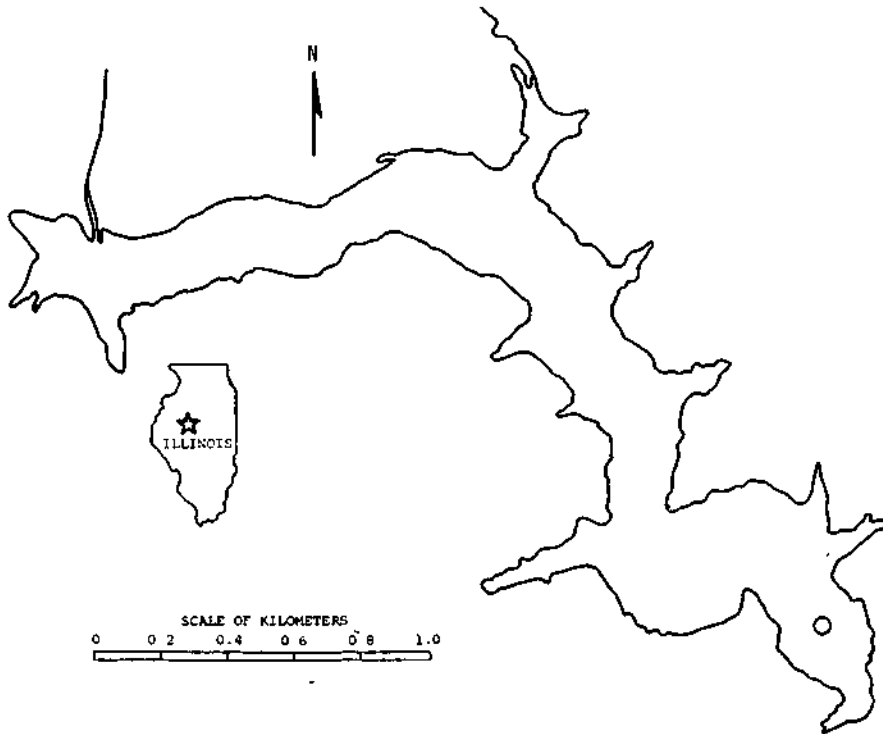Note: 1 ha = 2.471 acres; 1 m = 3.28 ft; 1 m^3 = 8.107X10^{-4} acre-ft; 1 m^3/d = 2.642X 10^{-4} mgd

Figure 1. Configuration of Lake Canton and location of sampling station
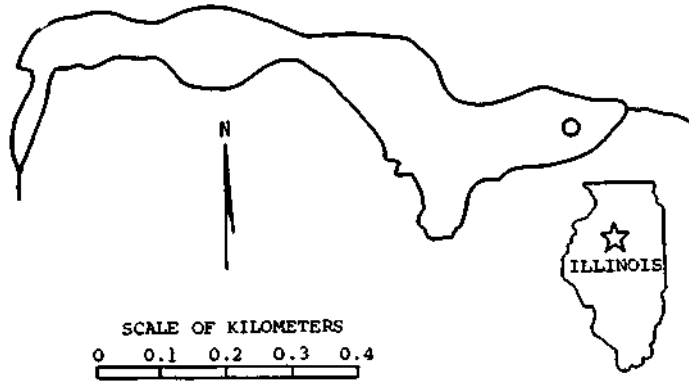
Figure 2. Configuration of Lake Eureka and location of sampling station
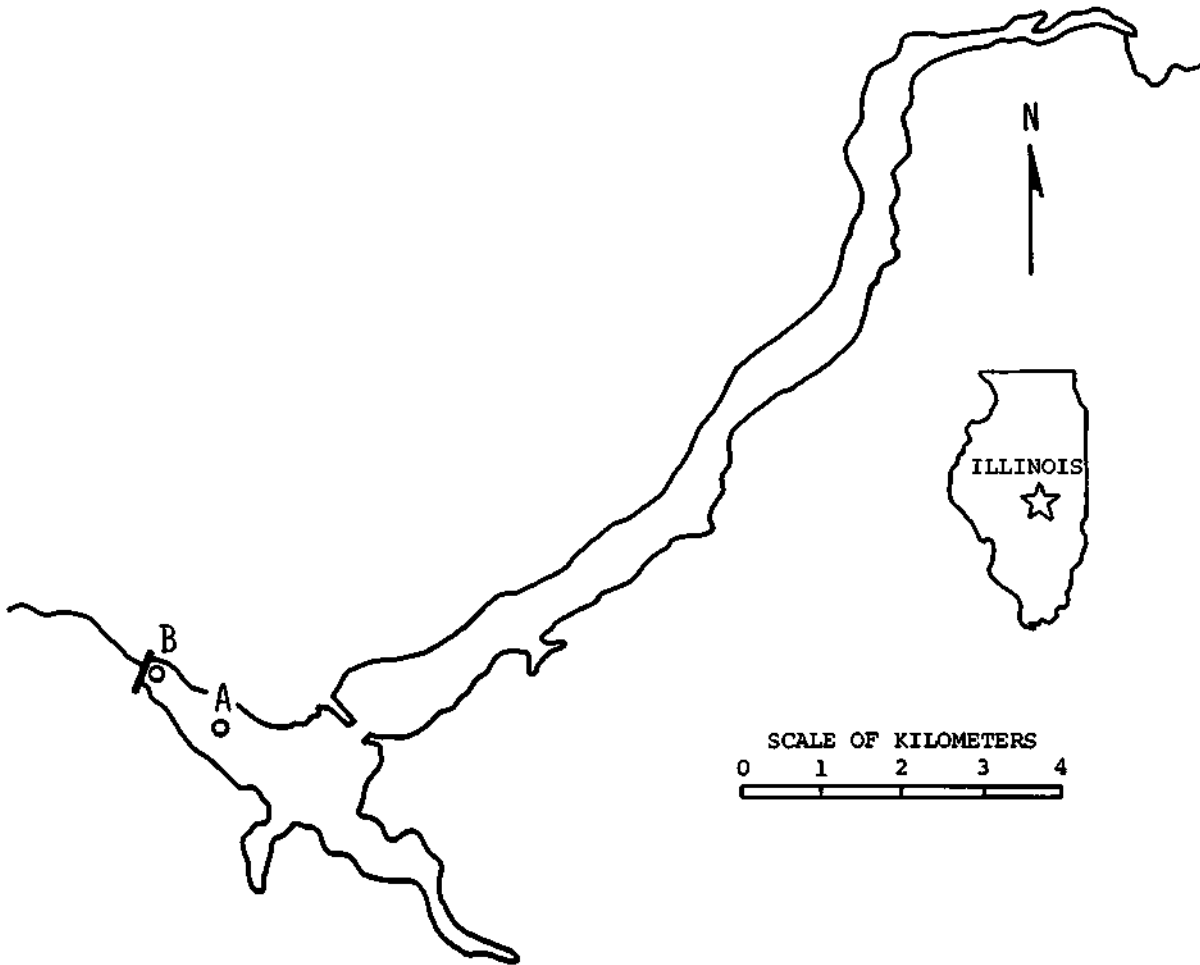
Figure 3. Configuration of Lake Decatur and locations of sampling stations

The sampling stations were located near the deepest parts of the three lakes. In Lake Canton (figure 1) the sampling point was about 70 m north of the intake tower. The sampling point at Lake Eureka (figure 2) was near the intake, about 40 m away from the dam. Three water samples were collected from each of these two lakes with a Kemmerer sampler at weekly intervals. Waters at the surface, mid-depth, and near the bottom were obtained at each sampling location. The samples were usually collected by boat, except during the ice-cover periods (December to March). During severe cold weather, ice at depths of 30 to 40 cm was broken through to collect samples. During periods of thin ice-cover, when it was impossible to reach the sampling locations, raw water samples were collected from the intakes of the Canton and Eureka Water Works. These samples represented the mid-depth waters of the lakes.

For Lake Decatur (figure 3), weekly samples were taken from either Station A or B. Samples at three depths were obtained from Station A by boat. During the thin ice-cover periods, three depth samples were taken from the sidewalk of the pumping house, at Station B near the intake. During the thick ice-cover periods, the ice was broken and water samples were taken about 20 m from the intake.

Water samples for chemical analyses were collected in 3.8-liter glass bottles. The finished waters were dechlorinated immediately after collection. Samples for total organic carbon were collected in 60-ml brown glass bottles and were preserved with HCl to a pH of 2 or less. Bacteria samples were collected in 200-ml sterile glass bottles and were placed on ice immediately upon collection. The algae samples were taken in small-necked 480-ml glass bottles preserved with a formaldehyde solution.

Sediment samples for benthic macroinvertebrate examination were collected by three grabs with an Ekman dredge (15×15 cm). The mud samples were then washed in a 30-mesh screen bucket, placed in quart jars, and preserved with 25 ml of formalin. In the laboratory, the samples were again washed in a 30-mesh sieve. The organisms were then picked from the bottom detritus, identified, counted, and preserved in 70 percent ethyl alcohol.

Field measurements were made for water and air temperatures, dissolved oxygen (DO), and water transparency. Water temperature and DO measurements were made at 30 cm intervals by a YSI model 51B DO meter. Table 2 lists the analytical methods used for physical, chemical, and biological determinations. Analyses as shown in table 2 were performed in accordance with *Standard Methods for the Examination of Water and Wastewater* (1975). The TONs were determined by the modified dilution method *{Standard Methods,* 1975; USEPA, 1976). A series of at least eight flasks was used. The first flask was always a blank, and from one to three additional blanks were inserted in the series. The series of flasks was kept at a room temperature of 60°C and was sniffed by a panel of four to eight persons. The water sample judged to be odor-bearing was diluted with odor-free water to a volume of 200 ml. The number of times this water had to be diluted until it reached an odor barely perceptible to the tester determined the TON. The type of odor for each sample was also recorded by the test panel.

Table 2. Analytical Procedures

Parameter	Unit	Analytical procedure
Threshold odor number		Dilution method (modified), 60 C
Turbidity	NTU	Nephelometric method
pH		pH meter
Alkalinity	mg/1 as CaCO$_3$	Titration with 0.02N H$_2$SO$_4$ to a pH of 4.5
Hardness	mg/1 as CaCO$_3$	EDTA titration
Ammonia-N	mg/1	Phenate method
Nitrate-N	mg/1	Chromotropic acid method
Silica (total)	mg/1 SiO$_2$	Heteropoly blue (colorimetric)
Iron (total)	mg/1	Phenanthroline (colorimetric)
Manganese (total)	mg/1	Periodate method (colorimetric)
Chemical oxygen demand	mg/1	Reflux with K$_2$Cr$_2$O$_7$ + H$_2$SO$_4$
Phosphorus (total)	mg/1	Ascorbic acid method, H$_2$SO$_4$ + NHO$_3$ digestion
Phosphorus (dissolved)	mg/1	Ascorbic acid method, H$_2$SO$_4$ + NHO$_3$ digestion
Sulfate (dissolved)	mg/1	Turbidimetric method
Chlorine demand	mg/1	Iodometric method, 30 min contact
Total organic carbon	mg/1	TOC analyzer
Standard plate count	counts/ml	Trypton glucose yeast agar, 35°C, 48 hrs
Actinomycetes	counts/ml	Actinomycetes isolation agar, 28°C, 7 days
Algae	counts/ml	Filtered (modified)
Water transparency	cm	Secchi disc, 24cm diameter

RESULTS AND ANALYSIS

Threshold Odor Number

The measurements of threshold odor numbers for the nine lake samples were made at weekly intervals throughout the study period. TON determinations for the three finished waters were performed weekly beginning January 3, 1977. The TON results are depicted in figures 4, 5, and 6. High TONs for the lake waters occurred at about the same time of year for each lake. The periods were October-November 1976; June through October 1977; and August-September 1978. The uncharacteristic odor episodes in Lake Eureka (figure 6) during the months of February and March 1977 will be discussed later.

Figures 4, 5, and 6 show that the TONs for the water near the bottom were generally greater than those for the other two depths. This is especially true for Lake Canton, the deepest of the lakes. Surface waters resulted in the lowest TONs. Similar conditions have been reported for reservoirs in Israel (Leventer and Eren, 1970).

A statistical summary of the observed TONs for each sampling location is given in table 3. Samples taken from deep stations gave greater TON ranges as well as higher geometric means and geometric standard deviations. A smaller TON gradient with depth occurred at Lake Decatur, presumably because of the high ratio of surface area to depth. The water column of Lake Decatur is not subject to the degree of thermal stratification experienced by the other lakes. The geometric means were 130 and 100 at Lakes Canton and Eureka, respectively, while at Lake Decatur the geometric mean was 67.
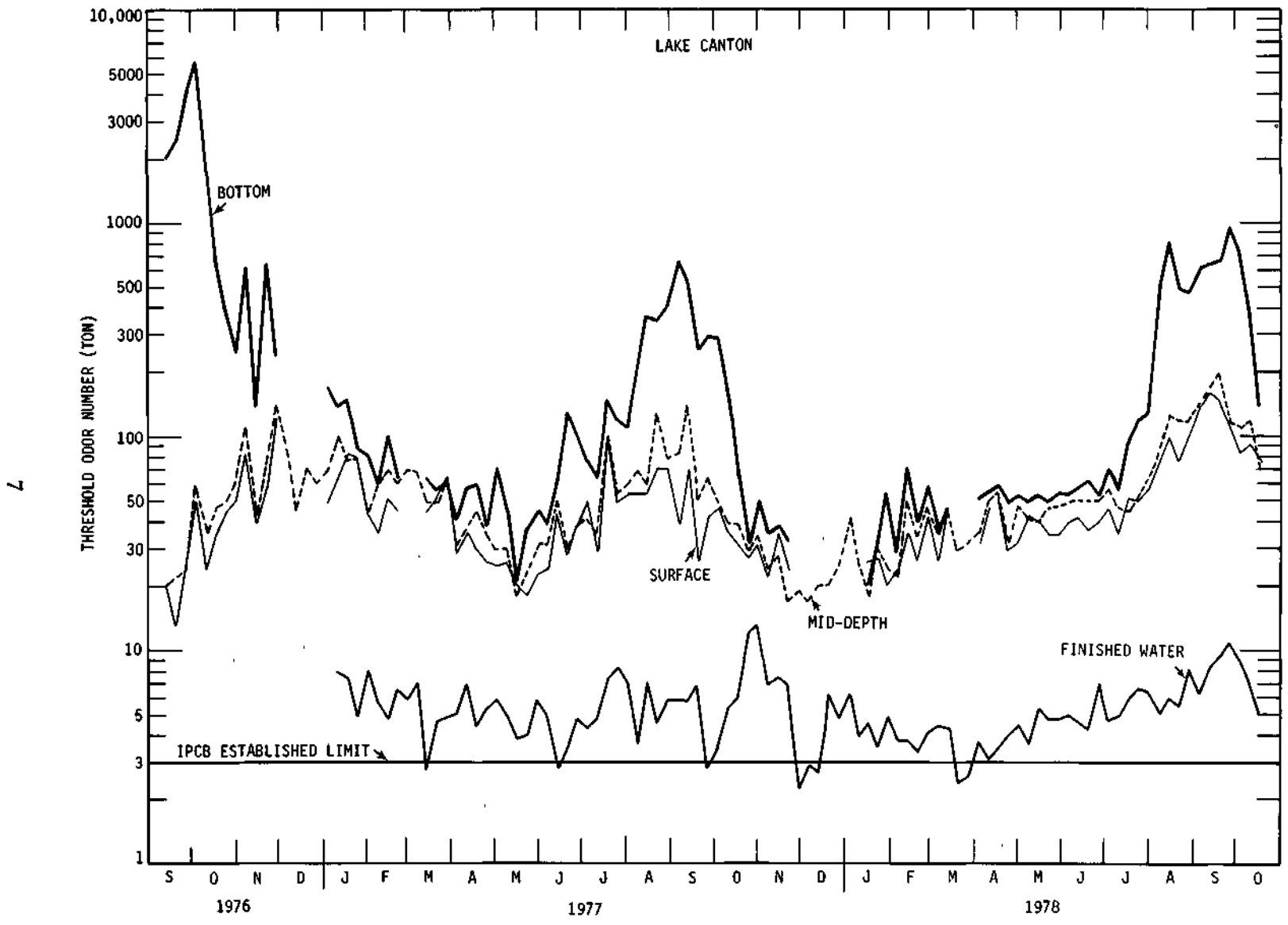
Figure 4. Temporal variations in threshold odor number (TON) in lake waters and finished water at Lake Canton
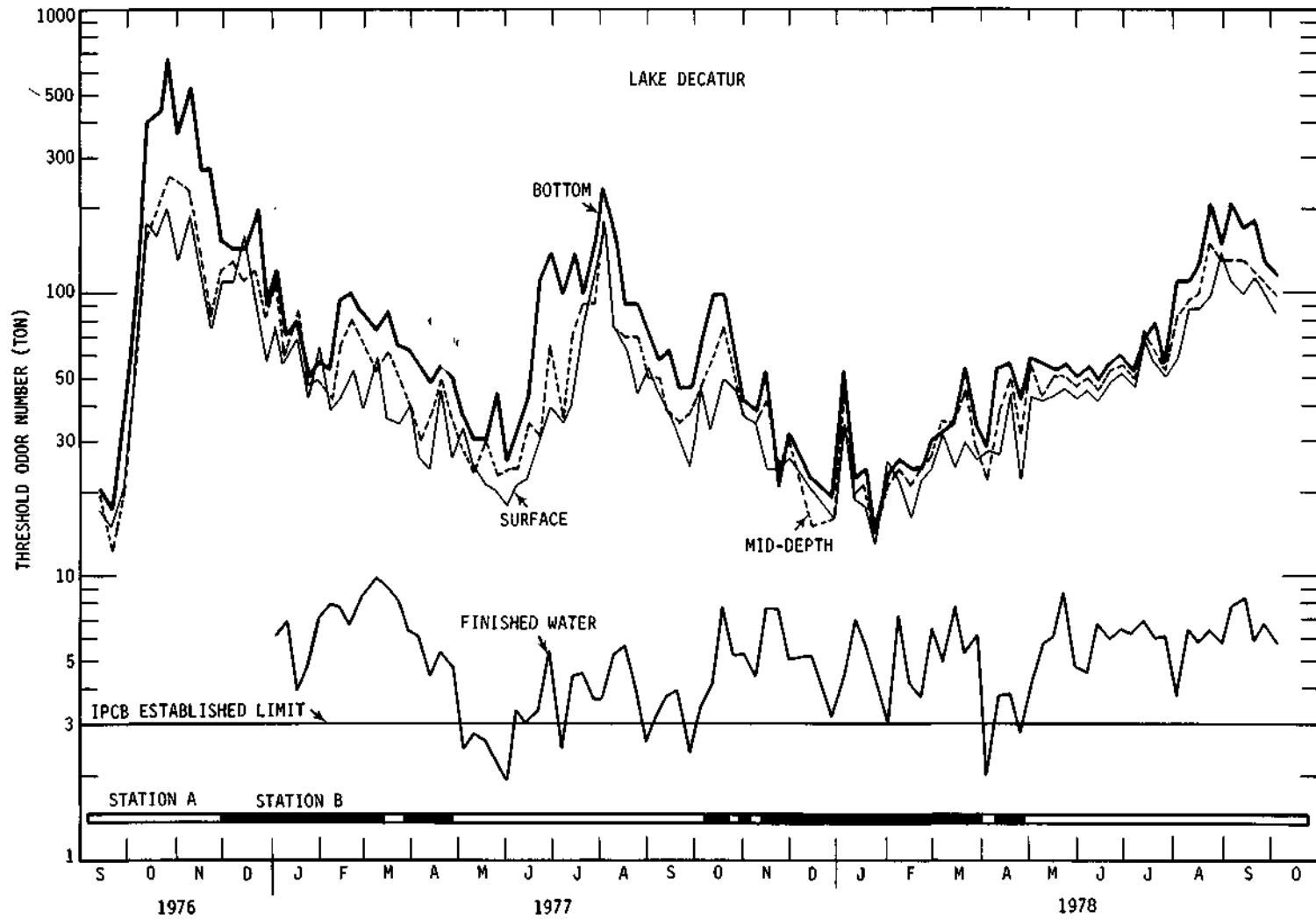
Figure 5. Temporal variations in threshold odor number (TON) in lake waters and finished water at Lake Decatur
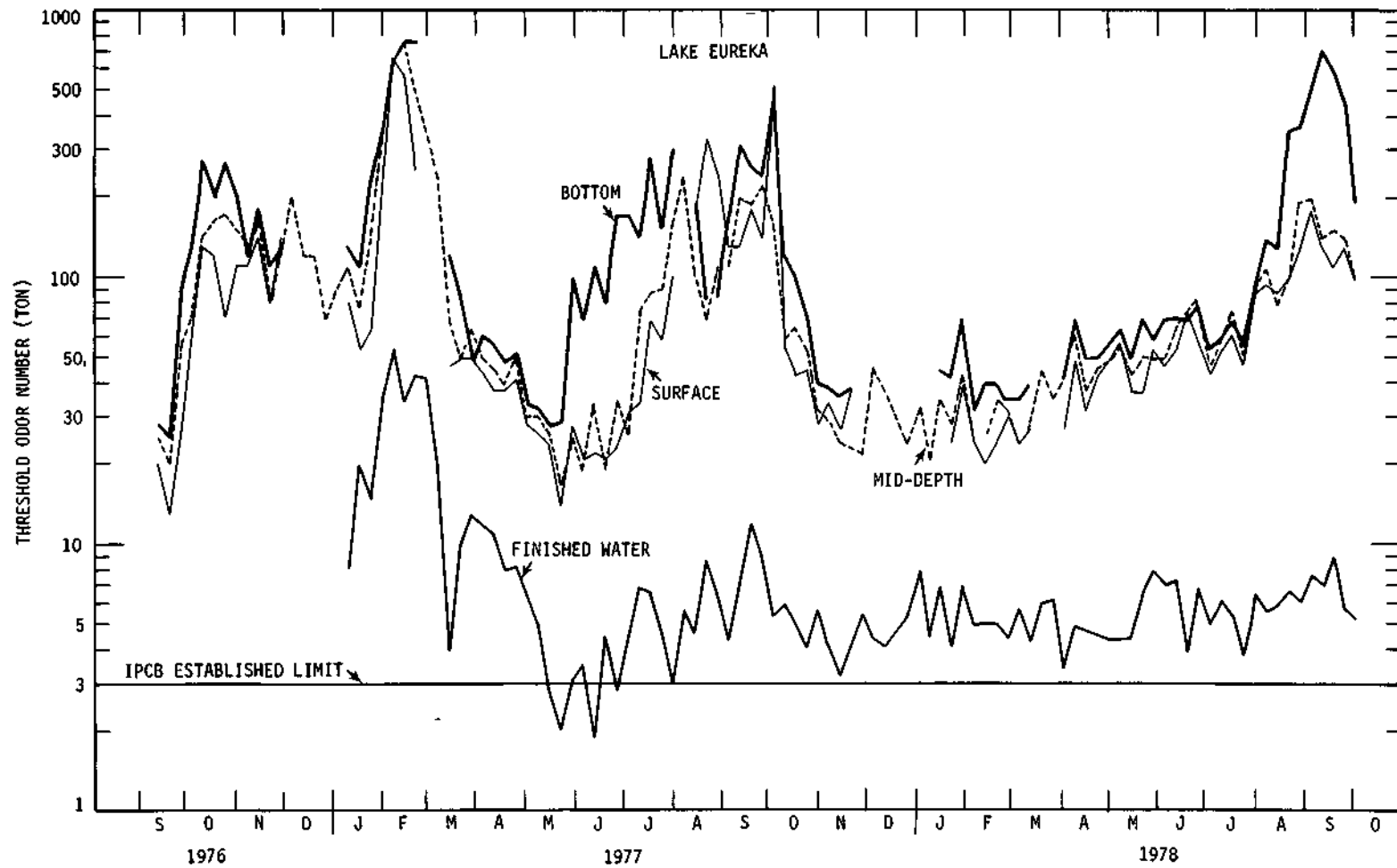
Figure 6. Temporal variations in threshold odor number (TON) in lake waters and finished water at Lake Eureka

Table 3. Statistical Summary of Threshold Odor Numbers

Water sample	Number of samples	Range	Geometric mean	Geometric standard deviation	95% confidence values
Lake Canton					
Surface	94	13-160	43	1.66	18-100
Mid-depth	110	13-200	49	1.75	19-130
Deep	94	13-5600	130	3.92	13-1200
Finished water	93	2.2-13	5.2	1.42	2.9-9.3
Lake Decatur					
Surface	106	13-200	45	1.91	15-130
Mid-depth	106	12-280	52	1.62	17-160
Deep	106	12-670	67	2.17	18-250
Finished water	90	1.9-10	5.0	1.47	2.6-9.4
Lake Eureka					
Surface	91	12-670	59	2.29	15-240
Mid-depth	107	12-740	68	2.27	17-270
Deep	91	12-780	100	2.45	23-390
Finished water	89	2.0-54	6.3	1.87	2.2-18
	80*	2.0-13	5.4	1.45	2.9-10

Excludes samples collected from January 3 through March 7, 1977 (dynamite used to break ice)

Figures 4, 5, and 6 show the TON limits stipulated by the IPCB (i.e., the threshold odor number should not exceed 3 in finished water) and the temporal variation in finished water at the three treatment plants. A TON of 3 or less is rarely achieved. Compliance with the IPCB TON standard was achieved in 8 of 93 samples at Canton, 12 of 90 samples at Decatur, and 5 of 89 samples at Eureka. With the exclusion of the 1977 winter samples for Eureka's finished water, the geometric means for the three finished waters were 5.0 (Decatur), 5.2 (Canton), and 5.4 (Eureka), as shown in table 3. This means that about 50 percent of finished water samples would be in compliance with the standard if the TON limit were 5 instead of 3. There is not a great deal of difference between TONs of 3 and 5.

The treatment processes at the three water plants are practically the same, i.e., the addition of lime, alum, powder-activated carbon, and chlorine prior to clarification, followed by rapid sand filtration and post-chlorination. Although (as can be seen in figures 4, 5, and 6) the processes substantially reduce the TON as introduced to the treatment system, nevertheless a finished water with a TON of 3 or less is not produced.

With the data assembled, the following equation (Steel and Torrie, 1960) was used to determine likely TON values at a 95 percent confidence level:

$$P[\ \bar{x} - t_{0.05}\ \{s^2\ [(n + 1)/n]\ \}^{1/2} \leqslant X \leqslant \bar{x} + t_{0.05}\ \{s^2\ [(n + 1)/n]\ \}^{1/2}\ ] = 0.95 \qquad (1)$$

where x represents the mean, s^2 is the variance, n is the number of observations, $t_{0.05}$ is a tabular value for Student's t distribution at the 5 percent probability level for n-1 observations, and X is the predicted TON.

The TON values recorded during the study were first transformed to logarithmic values. The TON values at a 95 percent confidence level were determined by applying the transformed values to equation 1 and taking the antilog. The results for each sampling

location are shown in column 6 of table 3. For example, 95 percent of the TONs for Lake Canton at the water surface will lie between 18 and 100. It is apparent that the 95 percent confidence values for the three finished waters are practically identical: 2.9-9.3 (Canton), 2.6-9.4 (Decatur), and 2.9-10 (Eureka, excluding January-March 1977 samples). It is also apparent that despite the wide range of TONs for the raw water the TONs for the finished water are quite consistent.

Correlations

It would be desirable if a simple chemical analysis could be used instead of the TON test. This would be possible if a strong correlation exists between TONs and some water quality characteristics.

The nature of the distribution of the data obtained for each parameter was determined by tests for skewness and kurtosis. If skewness values were equal to or less than 1.0, the data were considered normally distributed; for values greater than 1.0, the data were considered geometrically distributed. The range, mean or geometric mean, and standard deviation or geometric standard deviation for each parameter are listed in tables 4, 5, and 6.

As can be seen in these tables, the data for some parameters were normally distributed, the data for some parameters were geometrically distributed, and the data for some parameters were handled both ways. If the distribution was geometrical, the observed data were logarithmically transformed. A simple correlation was made between log-TON and each of the other 20 measured parameters. A tabulation of correlation coefficients (R) is shown in table 7. For most cases, the correlation coefficients were low. However, nitrate-N was reasonably correlated, though negatively, with TONs for Lakes Canton and Decatur. There was fair correlation between TON and Cl_2 demand, iron, manganese, total phosphorus, and organic carbon for some stations.

Other investigators (Hansen, 1976; Hendricks and Silvey, 1977; Roseboom et al., 1979; Weete et al., 1977) have reported on the lack of correlation between the number of actinomycetes and TONs and between algae and TONs. This was the case here, as shown in table 7. The metabolites produced by actinomycetes and some blue-green algae, not the densities of these microorganisms, are responsible for taste and odor. The metabolites exist even when the organisms do not. Unfortunately, the equipment required for detecting these metabolites (geosmin, mucidone, and 2-methyliso-borneol) are not available at most water works. Nevertheless, algal enumeration and species identification may provide some information regarding odor episodes.

Weete et al. (1977) reported that there was correlation between odor episodes in Lake Ogletree, Alabama, and temperature (> 15°C) and rainfall. For this study, however, water temperature, dissolved oxygen, and bacterial density (standard plate count) did not correlate with TONs (table 7). Nevertheless, they are important factors indirectly. During the periods of summer stagnation and increasing water temperatures, the bacterial decomposition of the bottom organic sediment exerts a high rate of oxygen demand on the overlying waters. When the oxygen up-take by bacteria and their by-products exceeds the oxygen replenishment by molecular diffusion or by algae, an anaerobic condition is created. Under these conditions, the bacteria use nitrate and then

Table 4. Summary of Observed Parameters for Lake Canton

(Concentrations in milligrams per liter unless otherwise indicated)

	Surface				Mid-depth				Deep			
Parameter	*Number of samples*	*Range*	*Mean**	*SD ***	*Number of samples*	*Range*	*Mean**	*SD ***	*Number of samples*	*Range*	*Mean**	*SD ***
Temperature (°C)	94	0-28.8	15.2	9.5	109	1.2-25.5	12.0	7.4	94	1.5-14.1	9.0	3.5
Dissolved oxygen	93	3.0-15.5	9.5	2.8	108	0-13.3	6.0	4.0	94	0-11.7	2.9	33
pH (units)	94	7.3-9.7			110	7.3-9.1			94	7.1-8.4		
Alkalinity, as CaCO$_3$	94	61-202	135	27	110	84-308	145	31	94	116-315	190	45
Hardness, as CaCO$_3$	93	99-380	220	51	109	113-400	232	55	93	107-407	250	59
Nitrate-N	93	0-2.25	0.79	0.72	109	0-224	0.83	0.74	93	0.01-2.28	0.61	0.66
Log silica	93	0.2-13.5	2.73	2.31	109	0.2-16.6	3.4	2.97	93	0-16.1	6.1	3.42
COD					108	0.1-31.0	12.0	5.20	92	0.06-40.0	13.5	6.1
Log COD	93	0.1-33.2	10.4	3.20								
Dissolved phosphorus					110	0-0.08	0.026	0.016				
Log dissolved phosphorus	94	0-0.33	0.018	2.44					94	0-0.82	0.06	3.62
Sulfate	83	38.6-75.4	52.0	8.3	99	14.5-76.0	51.0	9.6	83	6.9-114.4	44.6	22.0
Chlorine demand	93	0-12.4	5.2	2.8	108	0-13.9	6.0	2.7	92	0-17.0	9.6	3.5
Log turbidity (NTU)	94	0-19.0	2.8	4.04	110	0-38.0	2.6	6.72	94	0-50.0	7.3	3.34
Log ammonia-N	94	0-1.37	0.16	5.51	110	0-5.51	0.35	3.72	94	0-9.54	1.30	3.65
Log iron	94	0-1.46	0.17	2.99	110	0-6.36	0.23	2.87	94	0-6.40	0.72	2.55
Log manganese	94	0-1.00	0.08	5.59	110	0-3.60	0.16	4.48	94	0-12.54	0.85	5.88
Log total phosphorus	94	0-0.42	0.050	2.20	110	0-0.79	0.055	1.92	94	0-1.11	0.15	2.97
Log total organic carbon	94	2.5-35.5	7.96	1.78	108	1.5-50.0	7.4	1.70	94	1.5-35.0	8.2	1.68
Log standard plate count (c/ml)	92	14-7200	260	3.67	108	10-19,000	420	3.77	87	10-20,000	630	2.59
Log actinomycetes (c/ml)	87	1-1100	44	3.90	105	1-3600	81	3.56	92	1-1200	210	2.34
Log algae (c/ml)	93	15-4000	340	3.66	108	15-2300	200	3.42	93	4-800	97	2.86
Log TON (unitless)	94	13-160	43	1.66	110	13-200	49	1.75	94	13-5600	130	3.92

* *In the case of log parameters, the geometric means are given*

***In the case of log parameters, the geometric standard deviations are given*

Table 5. Summary of Observed Parameters for Lake Decatur

(Concentrations in milligrams per liter unless otherwise indicated)

Parameter	Surface				Mid-depth				Deep			
	Number of samples	*Range*	*Mean**	*SD ***	*Number of samples*	*Range*	*Mean**	*SD ***	*Number of samples*	*Range*	*Mean**	*SD ***
Temperature (C)	106	0.2-31.0	13.7	9.9	106	0.5-29.7	13.4	9.5	106	0.5-28.2	13.1	9.2
Dissolved oxygen	106	4.7-18.7	9.9	2.9	106	4.6-17.7	9.1	3.0	106	0.8-16.7	8.0	3.6
pH (units)	106	7.5-8.9			106	7.2-8.9			106	7.2-8.7		
Alkalinity, as $CaCO_3$	106	83-298	195	43	106	78-308	196	46	106	92-288	197	44
Hardness, as $CaCO_3$	106	146-481	298	75	106	133-505	301	79	106	133-501	300	76
Nitrate-N	106	0.2-12.3	3.58	3.09	106	0.22-12.93	3.58	3.08	106	0.01-12.66	3.58	3.06
Silica	102	0-37.0	5.7	4.7	103	0-16.3	5.0	3.5	103	0-17.6	5.4	3.6
COD					104	0-53.0	11.5	7.4	104	0-32.0	12.8	6.9
Log COD	105	0-72.4	6.8	7.93								
Dissolved phosphorus					106	0-0.16	0.055	0.032				
Log dissolved phosphorus	106	0-0.19	0.040	2.31					106	0-0.22	0.052	2.13
Log sulfate	96	6.9-183.6	48.5	1.34	96	6.9-109.6	48.0	1.32	95	6.9-114	47.0	1.31
Log Cl_2 demand	106	0-10.3	2.2	2.72	106	0-10.3	2.0	4.19	105	0-14.2	2.12	4.25
Log turbidity (NTU)	105	0-55.0	4.5	6.39	106	0.1-54.0	6.46	2.37	106	0-57.0	9.8	3.35
Log ammonia-N	104	0-0.65	0.50	5.81	105	0-0.63	0.46	5.37	105	0-0.60	0.06	4.21
Log iron	107	0-5.86	0.42	2.88	106	0-5.65	0.51	2.72	106	0-6.52	0.99	2.77
Log manganese	107	0-1.71	0.08	3.41	106	0-0.87	0.075	3.51	106	0-0.97	0.11	3.46
Log total phosphorus	106	0-0.54	0.109	1.92	106	0-1.28	0.11	2.06	106	0-0.50	0.13	1.97
Log total organic carbon	106	1.3-110.0	6.8	1.88	106	1.3-46.0	6.6	1.83	106	0.8-115	7.0	1.92
Log standard plate count (c/ml)	106	10-15,000	400	3.49	104	10-44,000	470	3.52	103	10-27,000	560	3.30
Log actinomycetes (c/ml)	104	1-2100	100	2.89	99	1-1300	150	2.66	100	1-2400	210	2.72
Log algae (c/ml)	105	4-3300	220	3.06	105	4-2000	140	2.75	102	0-580	62	6.00
Log TON (unitless)	106	13-200	45	1.91	106	12-280	52	1.62	106	12-670	67	2.17

* *In the case of log parameters, the geometric means are given*

***In the case of log parameters, the geometric standard deviations are given*

Table 6. Summary of Observed Parameters for Lake Eureka

(Concentrations in milligrams per liter unless otherwise indicated)

	Surface				Mid-depth				Deep			
Parameter	*Number of samples*	*Range*	*Mean**	*SD ****	*Number of samples*	*Range*	*Mean**	*SD ****	*Number of samples*	*Range*	*Mean**	*SD ****
Temperature (C)	90	0-30.2	16.1	10.0	107	1.1-26.8	13.3	8.5	90	1.1-20.0	11.7	5.8
Dissolved oxygen	91	0.2-22.1	9.6	3.9	107	0.3-13.8	6.4	4.0	91	0-13.6	4.1	4.4
pH (units)	91	7.4-9.2			108	7.1-9.0			91	7.3-8.6		
Alkalinity, as $CaCO_3$	91	110-419	233	73	107	127-444	243	73	91	124-470	263	67
Hardness, as $CaCO_3$	91	132-479	278	73	108	150-491	296	73	91	172-507	300	69
Nitrate-N	90	0.05-8.74	2.71	2.92	107	0.05-9.06	2.78	2.93	90	.04-8.33	2.34	2.83
Silica	90	0-16.3	5.3	3.6	106	0-16.6	6.3	3.8	90	0-18.5	7.8	3.4
COD					106	0-56.1	19.2	11.2	89	0-58.0	21.0	10.4
Log COD	90	0-95.0	16.1	3.45								
Log dissolved phosphorus	90	0-0.13	0.018	2.55	108	0-0.27	0.016	2.78	92	0-0.51	0.023	4.08
Sulfate	80	6.9-78.2	40.3	21.2	97	6.9-79.4	40.0	22.4	80	2.4-77.9	34.6	22.0
Chlorine demand									90	0-19.5	7.8	4.2
Log Cl_2 demand	90	0-18.6	3.6	5.07	106	0-18.2	4.26	3.77				
Log turbidity (NTU)	91	0-15.0	2.8	7.58	106	0-22.0	3.48	5.94	91	0-32.0	7.4	3.15
Log ammonia-N	91	0-1.28	0.108	4.20	108	0-2.10	0.154	4.13	91	0-7.96	0.523	4.35
Log iron	91	0-1.34	0.31	2.21	108	0-4.73	0.38	2.54	91	0-11.0	0.99	2.76
Log manganese	91	0-1.21	0.092	4.26	108	0-1.16	0.083	5.01	91	0-7.09	0.34	5.77
Log total phosphorus	91	0-0.35	0.080	2.14	106	0-0.46	0.088	1.95	91	0-1.84	0.141	2.64
Log total organic carbon	91	0.8-102.5	10.9	2.18	105	0.3-50.0	9.1	1.97	91	0.3-250	11.2	2.69
Log standard plate count (c/ml)	91	10-4300	310	3.47	107	10-30,000	410	3.89	91	10-23,000	510	3.51
Log actinomycetes (c/ml)	88	1-1300	59	3.52	105	1-1600	79	3.83	88	1-3700	140	3.43
Log algae (c/ml)	88	0-2700	230	2.92	105	0-1200	100	6.71	87	0-390	63	6.59
Log TON (unitless)	91	12-670	59	2.29	107	13-740	68	2.29	91	12-780	100	2.45

* *In the case of log parameters, the geometric means are given*
** *In the case of log parameters, the geometric standard deviations are given*

Table 7. Correlation Coefficients for Log TONs with other Measured Water Quality Parameters

(Concentrations in milligrams per liter unless otherwise indicated)

Parameter	Lake Canton			Lake Decatur			Lake Eureka		
	Surface	*Mid-depth*	*Deep*	*Surface*	*Mid-depth*	*Deep*	*Surface*	*Mid-depth*	*Deep*
Temperature (C)	.33	.27	.35	.11	.22	.45	-.08	.03	.15
Dissolved oxygen	.01	-.46	-.39	-.24	-.29	-.40	-.09	-.46	-.42
pH (units)	.35	.01	-.54	.05	-.02	-.06	-.02	-.19	-.49
Alkalinity	-.49	-.43	.44	-.40	-.42	-.46	-.13	.21	.38
Hardness	-.46	-.46	-.17	-.43	-.51	-.60	-.21	.33	-.22
Nitrate-N	-.58	-.66	-.56	-.78	-.75	-.71	-.33	-.47	-.53
Silica				-.53	-.24	-.28	.18	.06	.40
Log silica	-.09	-.12	-.04						
COD		.19	.45		.35	.35		.57	.26
Log COD	.19			.29			.41		
Dissolved phosphorus		-.07			.02				
Log dissolved phosphorus	-.09		.47	-.01		-.07	.28	.32	.19
Sulfate	-.13	-.38	-.70				-.29	-.49	-.49
Log sulfate				-.09	-.25	-.30			
Chlorine demand	.02	.30	.34						-.49
Log Cl$_2$ demand				.34	.32	.46	.56	.64	
Log turbidity	-.12	.07	.18	.28	.14	.20	.28	-.27	.36
Log ammonia-N	-.27	-.22	.33	-.09	.01	.07	.20	.33	.37
Log iron	-.03	-.01	.45	-.06	-.13	-.003	.49	.58	.54
Log manganese	.10	.23	.54	.31	.32	.31	.57	.58	.62
Log total phosphorus	.002	.03	.64	.12	-.02	-.19	.54	.55	.47
Log total orgainic carbon	.41	.33	.39	.45	.42	.35	.51	.44	.49
Log standard plate count (c/ml)	-.08	.07	-.20	-.42	-.18	.03	.15	.04	-.22
Log actinomycetes (c/ml)	.22	.003	.12	-.47	-.20	-.25	-.14	-.19	-.27
Log algae (c/ml)	.34	.38	.52	.35	.29	.28	.05	.08	.03

sulfate as oxygen sources. Iron, manganese, phosphorus, hydrogen sulfide, ammonia, and methane will be released from the muds. These are common occurrences for most Illinois impoundments.

Discussion

Finished Water

A comparison of the temporal variations in TONs for lake bottom water and finished water at Lake Canton (figure 4) shows that extremely high TONs developed for the bottom water during June through October 1977 and late July to October 1978, while taste and odor problems in the finished waters were observed from July through October 1977 and from August to October 1978. It appears that high TONs occur in the finished waters about 3 to 4 weeks after high TON pulses in the deep waters of Lake Canton. The odor types for the finished waters were generally characterized as chemical (chlorinous) and musty for the 1977 and 1978 episodes, respectively (appendix A).

The temporal variations of TONs in Lake Decatur's finished waters (figure 5) followed a similar pattern. The high TONs in the finished waters generally occurred about 1 to 2 weeks after high TONs occurred in the deep water of Lake Decatur. The odor types of the finished waters were usually described as musty and moldy during winter 1977-1978 and most of 1978 and as chlorinous during the summer and fall of 1977 (appendix B).

At Lake Eureka, unlike at the other two lakes, the odors of the finished waters were immediately responsive to odor episodes in the lake's waters. The TONs in the lake were about 100 from October 1976 to January 1977 (figure 6). The water level of the lake was low during this period. In an effort to improve the raw water quality that had been degraded because of low dissolved oxygen content, the covering ice was partially removed by two dynamite blasts — one on January 21 and the other on January 28, 1977. The inadvisability of such procedures is indicated by figure 6. On January 24, a strong hydrogen sulfide smell was detected immediately after 40 cm of ice was broken to enable the taking of water samples. The blasting had done a good job of mixing up the bottom muds in this shallow lake. High intensity taste and odor episodes continued through March 1977. As expected, it was very difficult for the water plant to produce acceptable finished waters using a septic water source. From late January to mid-March 1977, strong odors were emitted by the finished water. The odor types' were classified as fishy and septic. They were musty and grassy during the summer and fall of 1977 and were usually musty during August and September 1978 (appendix C).

The identification of the constituents contributing to high TONs in the finished waters at the three lakes is beyond the scope of the study. However, an effort is made here to relate high TONs for the lakes' waters with the data assembled.

Lake Canton

Very high TONs were observed for samples taken from the deep water at Lake Canton during September through November 1976 (figure 4). A maximum of 5600 occurred on October 4, 1976. Figure 7 shows that the lower water strata of Lake Canton
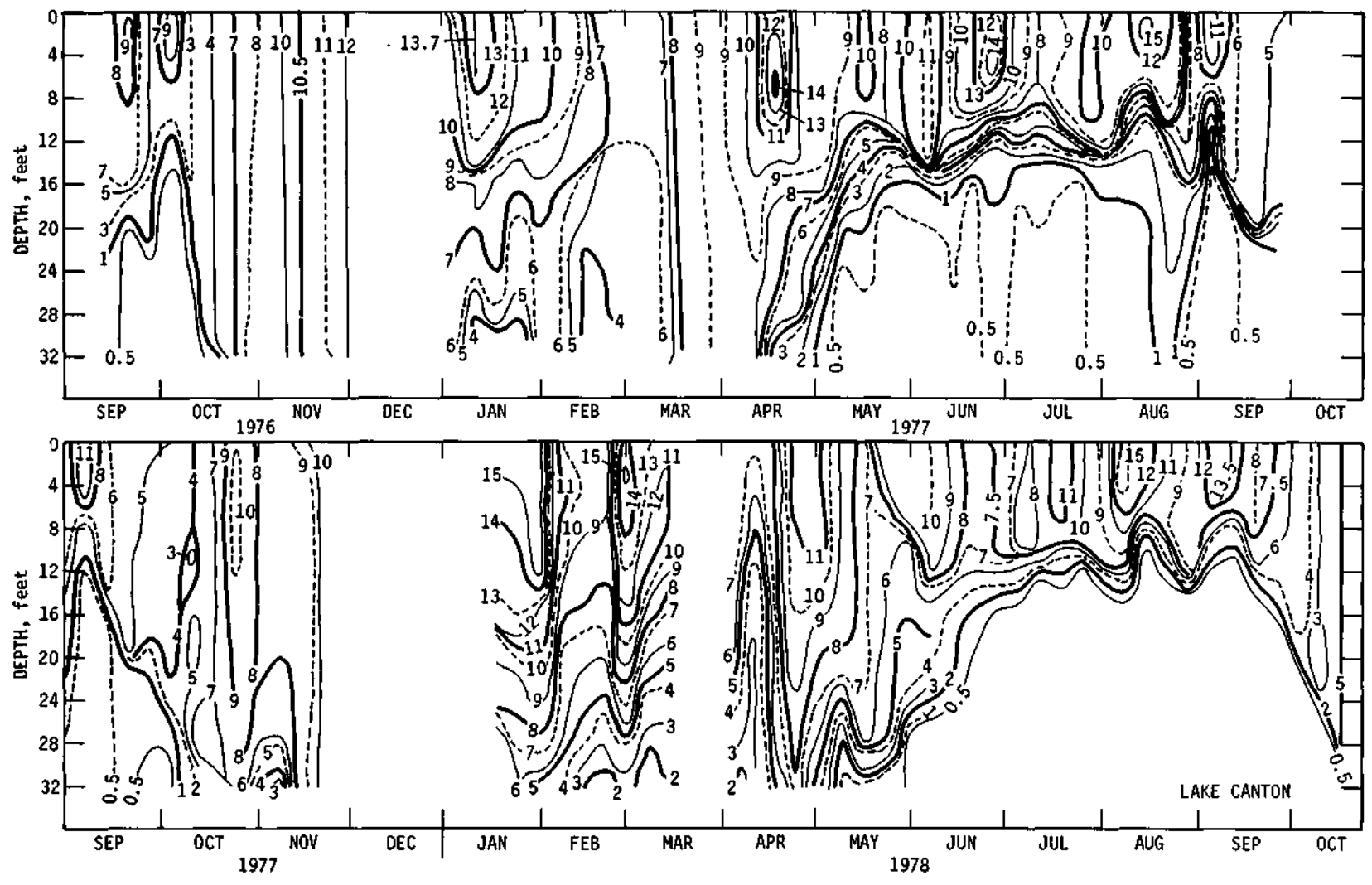
Figure 7. Isopleths of dissolved oxygen in Lake Canton

were void of dissolved oxygen during the summer and fall months, i.e., for a 5-month period extending from May through September 1977 and from mid-May to mid-October 1978. It is probable that oxygen depletion occurred during a similar 5-month period in 1976. The water temperatures of Lake Canton — surface, mid-depth, and deep — for the months from June through September were 20-28°C, 18-21°C, and 10-13°C, respectively. The anoxic zone in Lake Canton extended 4 to 6 m from the bottom. About 30 percent of the water volume of Lake Canton was void of oxygen during the 1978 stagnation period (Roseboom et al., 1979).

Table 4 shows that the concentrations of ammonia-N, iron, manganese, and phosphorus in the deep waters are significantly higher than those for the surface and mid-depth waters. These were more profound during the stagnation periods. Nitrate-N and sulfate contents in the deep waters decreased to very low levels under anoxic conditions. Sulfate, manganese, and alkalinity were found to be correlated to 1976 high TONs in the deep waters. The high TONs for the surface and mid-depth waters of Lake Canton during November 1976 (figure 4) were undoubtedly caused by the deep waters after the mid-October fall turnover (figure 7).

During the period of stagnation in 1977, nitrate-nitrogen decreased from 0.8 mg/1 in April to below 0.1 mg/1 in June through September. Sporadic high TONs in the summer were related to the increase of manganese and alkalinity. *Aphanizomenon flos-aquae,* an odor-producing blue-green alga, persisted in the surface water with densities of 1,700 to 4,000 counts/ml during late June to mid-September. This species of algae occurred in the mid-depth water at densities of 1,000 to 2,000 counts/ml in August and September. Usually the bottom samples contain low algae counts. Increases of *A. flos-aquae* (150-460) were observed from late August through September. The dying and sinking algae were correlated to the high TONs in the deep waters in August and September 1977. *Aphanizomenon flos-aquae* was also responsible for the taste and odor problems in the surface and mid-depth waters during 1977 episodes. As mentioned previously, the metabolic products, rather than algal densities, influence taste and odor conditions.

In 1978, the taste and odor problems in Lake Canton started late, beginning in mid-July (figure 4) six weeks after anoxic conditions developed in the lake bottom (figure 7). High TONs persisted for 2½ months. The causes of 1978 odor problems were the same as those for 1977.

Nineteen benthos samples were taken from the bottom muds of Lake Canton during April to mid-November in both 1977 and 1978. Only four taxa were recovered from the samples for benthic macroinvertebrates. The phantom midgefly larvae *(Chaoborus* spp.) frequently made up 100 percent of the total benthos population (table 8). This organism has the capability to survive in anaerobic conditions because of its ability to migrate to the upper aerobic layers for occasional replenishment of oxygen. This organism is the most common in Illinois lake bottoms.

The densities of *Chaoborus* spp. in the Lake Canton bottom increased in the spring, then decreased in the summer, and increased again in the fall (table 8). Comparison of the TONs plot in figure 4 showed no correlation between TONs and *Chaoborus.* Thus, *Chaoborus* is not a good indicator of taste and odor conditions.

Table 8. Benthic Macroinvertebrates in Muds of Lakes at Maximum Water Depths
(Number of individuals per square meter)

	Chao bonis	Chironomidae	*Tubificidae*	Oligochaeta	*Total*
Lake Canton					
6/27/77	**890**			**57**	**947**
8/1	**531**		**14**	**14**	**559**
8/22	**14**		**14**	**14**	**42**
9/19	**1,091**				**1,091**
10/10	**1,407**	**14**			**1,421**
11/14	**1,995**	**14**			**2,009**
4/14/78	**727**		**19**		**746**
4/17	**1,851**	**14**	**14**		**1,879**
5/12	**1,148**				**1,148**
5/26	**555**				**555**
5/29	**244**				**244**
6/19	**904**				**904**
6/29	**230**				**230**
7/25	**502**				**502**
8/30	**345**	**14**			**359**
9/1	**57**	**19**			**76**
9/20	**4,119**				**4,119**
10/14	**8,755**				**8,755**
10/24	**12,036**				**12,036**
Lake Decatur					
6/21/77	**158**	**72**		**158**	**388**
7/19	**2,067**	**187**	**14**		**2,268**
8/2	**1,851**	**29**		**57**	**1,937**
8/16	**761**	**57**	**86**		**904**
9/20	**72**	**230**	**57**		**359**
10/25	**43**	**158**			**201**
4/25/78		**215**	**57**		**272**
5/23		**144**	**72**		**216**
6/20	**72**	**172**	**29**		**273**
7/18	**603**	**43**		**72**	**718**
8/15	**129**		**29**		**158**
9/12	**158**		**43**		**201**
10/3	**301**	**29**		**115**	**545**
Lake Eureka					
6/27/77	**14**				**14**
8/1		**14**			**14**
9/13	**57**				**57**
10/10	**101**	**29**			**130**
11/14	**144**				**144**
4/14/78	**38**				**38**
4/17	**84**	**14**			**98**
6/1	**96**	**19**			**115**
6/19	**14**				**14**
6/23	**0**				**0**
7/24	**57**				**57**
7/29	**19**				**19**
8/30			**14**		**14**
9/22	**115**				**115**
10/2	**57**				**57**
10/24	**364**				**364**

Lake Decatur

High TONs persisted in the lake station of Lake Decatur during October and November 1976 (figure 5). The odor problems continued until late December 1976 at the intake station (B). The causes of these episodes are not clear-cut. The lake waters were never void of oxygen during that time (figure 8). The minimum DO concentration near the lake bottom was from 1 to 2 mg/1. As mentioned previously, Lake Decatur is shallow (maximum depth 5 m) with a large water surface. Because of the large expanse of water unsheltered to prevailing winds, thermal gradients are insignificant because of mixing.

There was no correlation between TONs and any measured parameter. The total organic carbon concentrations of the deep waters were high (32 to 38 mg/1) during the first half of October 1976. It is possible that residual metabolic products of algae and actinomycetes were responsible for 1976 episodes, but that is conjecture.

During the last half of February 1977, there was a short period of DO stratification (figure 8). After this, the rises of TONs for the deep waters near the intake occurred from mid-February to mid-March 1977 (figure 5). From early May to mid-August of 1977, with the exception of the first half of June 1977, the waters of Lake Decatur stratified in terms of DO (figure 8). During these periods, nitrate-N concentration in lake waters reduced from 13 to 0.84 mg/1. Algal densities in the lake waters increased, with *Aphanizomenon flos-aquae* the predominant species. Both *A. flos-aquae* and the enriched lake bottom created high TONs in the summer of 1977 (figure 5).

For a period from late May through September 1978, the waters of Lake Decatur stratified in terms of DO; nitrate-N concentrations decreased from 7 to 0.4 mg/1. Algal populations increased from about 400 counts/ml to a maximum of 3300 counts/ml on August 8 and then gradually decreased to 400 counts/ml at the end of September. *Aphanizomenon flos-aquae,* a taste and odor producer, also was the dominant species at all locations. Algal densities at each sampling location in 1978 were significantly higher than those in 1977. However, the odor problems in the lake water in 1978 occurred only in August and September (figure 5). The causes were the same as those in 1977: DO stratification, lower nitrate-N contents, algae, and organic sediments in the lake bottom. There were two taxa of benthos, *Chaoborus* spp. and Chironomidae spp., of importance in the lake bottom (table 8).

Lake Eureka

Abnormally high concentrations of total organic carbon, 60 and 250 mg/1, were present in the bottom of Lake Eureka on October 4 and 14, 1976, respectively. This could be the cause for high TONs during October and November 1976 (figure 6). The fall turnover occurred around mid-October (figure 9). This permitted the bottom waters to mix with the upper water strata, causing high TONs for the entire water column from mid-October through November 1976. The odor episodes in February 1976 have been discussed earlier.

In both 1977 and 1978, the waters of Lake Eureka thermally stratified for a 6-month period from mid-April to mid-September. During the period of thermal stratification, the bottom water temperature varied from 9 to 19°C. As shown in figure 9, the lower water stratum was void of DO during summer months (May through
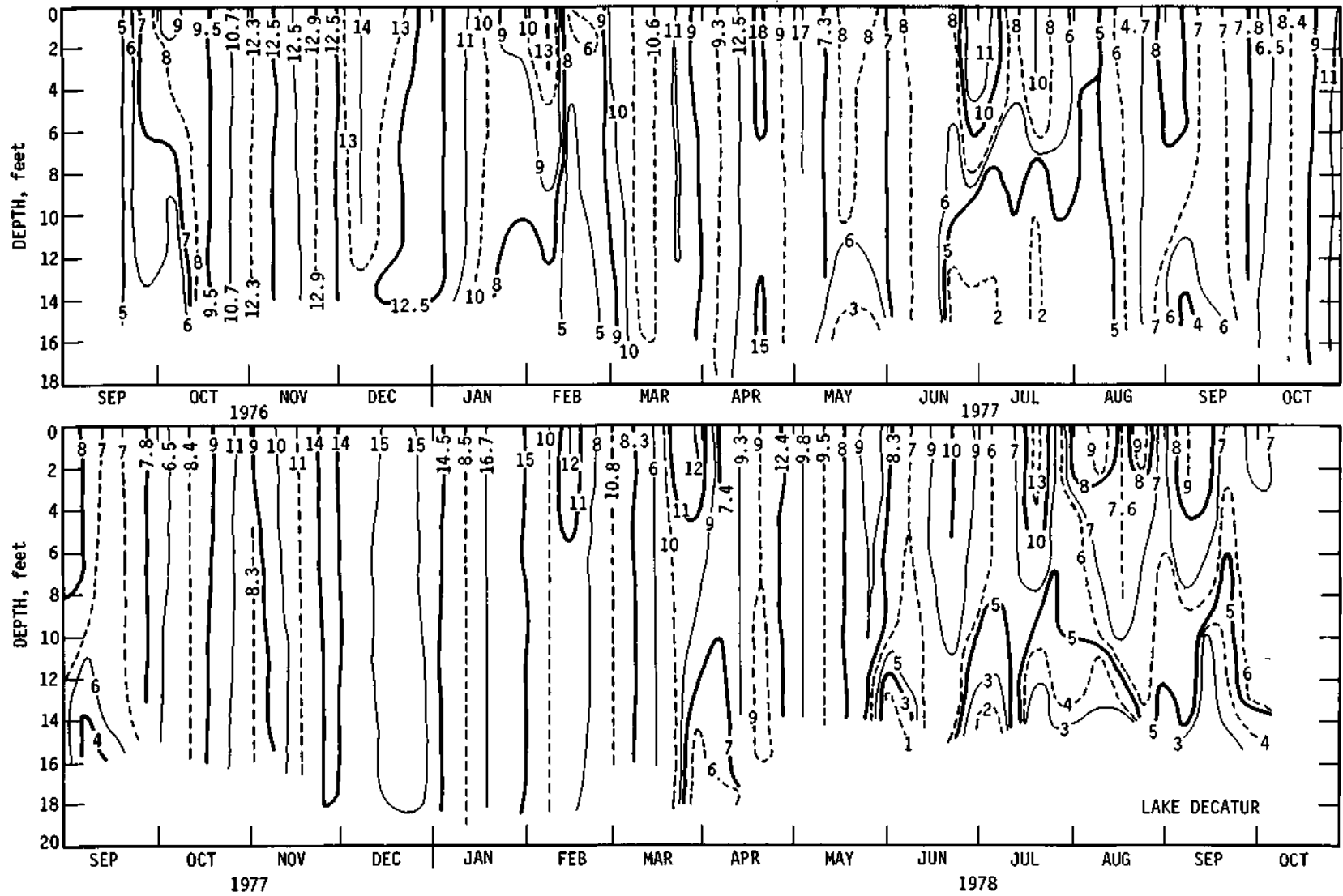
Figure 8. Isopleths of dissolved oxygen in Lake Decatur

21
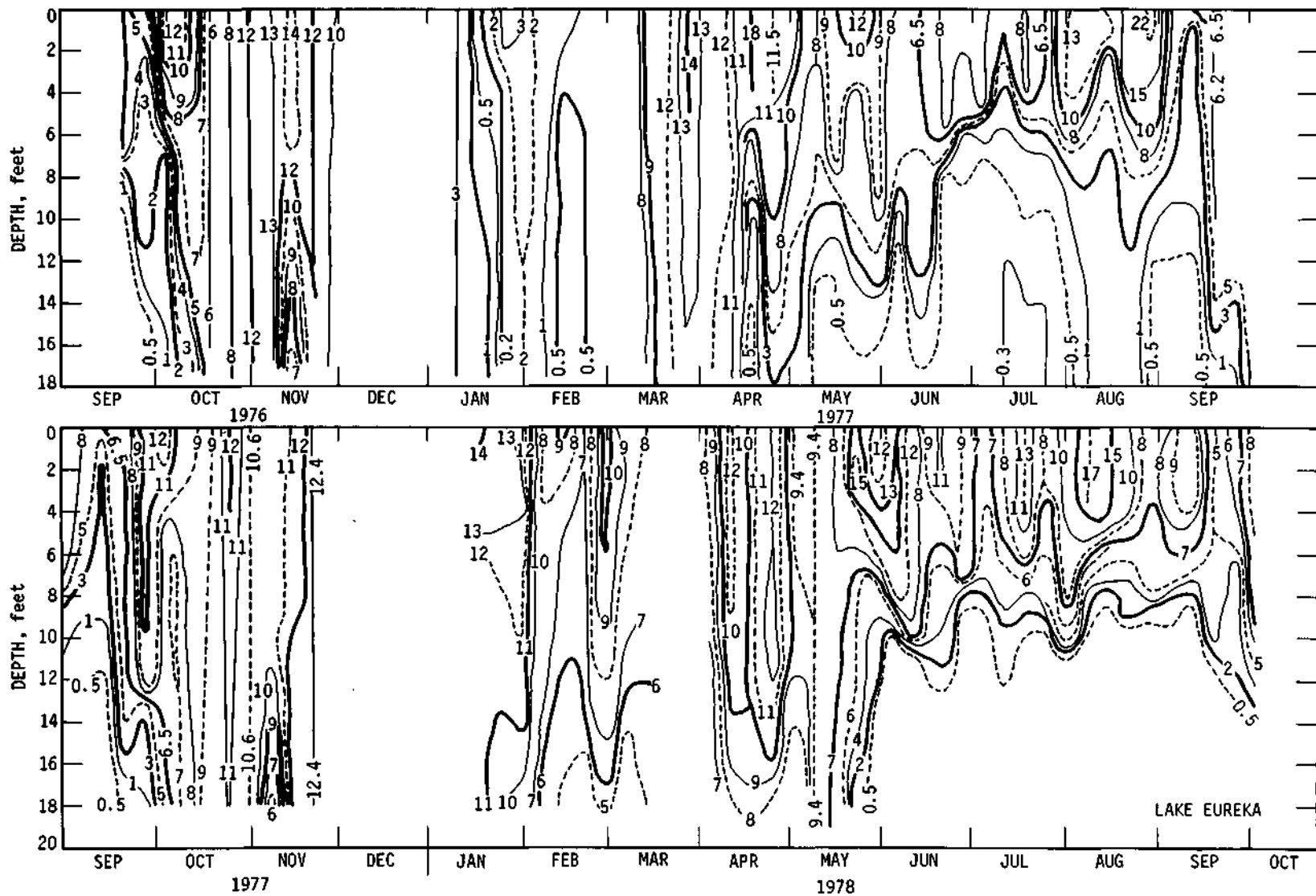
Figure 9. Isopleths of dissolved oxygen in Lake Eureka

September 1977 and June through September 1978). The volume of water completely void of DO in the summer of 1978 was 14 percent (Roseboom et al., 1979).

Unlike what was observed for Lakes Canton and Decatur, the water quality characteristics of Lake Eureka varied greatly from year to year. Nitrate-nitrogen contents for all three depth samples were very low (0.1 mg/1) during the first study year but were above 5 mg/1 for a period from October 1977 to September 1978. This was also the case for sulfate concentrations. In contrast, dissolved and total phosphates in the bottom waters increased ten-fold in the summer of 1977 but were constantly low in 1978.

Manganese and chlorine demand of the bottom waters showed good correlations with TONs. Sporadic increases of total organic carbon were also observed during 1977 and 1978 summer stagnation periods.

For the periods of June through October 1977 and late May to late July 1978, two algal species related to taste and odor, *Ceratium birundinella* (a flagellate) and *Stepbanodiscus niagarae* (a diatom), predominated and were present in almost all samples taken from the surface and at mid-depth. The TONs for the surface and mid-depth waters increased and persisted from late July to mid-October 1977. *Anacystis cyanea,* a blue-green alga, became dominant in the upper half of Lake Eureka for a period from August to mid-October 1978. During the period, *C. hirundinella* also prevailed and high TONs occurred for the lake waters. The odor types of the summer episodes in 1977 and 1978 were characterized as fishy and septic. The maximum density of *A. cyanea* was 2300/ml on August 7 and 11, 1978.

As shown in table 8, benthic macroinvertebrate populations at Lake Eureka were much less than those at Lakes Canton and Decatur. Again, the density of benthic organisms is not an indicator of taste and odor conditions.

Prediction of TONs

The data were subjected to stepwise multiple linear regression analyses to develop mathematical relationships that might be useful for predicting TONs. A pre-written SOUPAC program at the University of Illinois Computer Center was employed for analyses. Log values were used for any parameter which had a geometric population distribution. The standard multiple linear regression equation is in the form:

$$Y = a + a_1 X_1 + a_2 X_2 + \ldots + a_n X_n + e \tag{2}$$

where Y is the dependent variable, log TON; a is the intercept; a_1, a_2, etc. are constants; X's are independent variables, i.e., the 20 water quality constituents listed in table 7; and e is the probable error. Two separate analyses were performed. In one case all the data were used with corresponding TONs; in the other case only those data assembled during periods of high TONs were examined. The use of all data produced the better results.

The results of stepwise regression analyses with all data for each station are shown in table 9. All the equations show a fair degree of multiple correlation (R > 0.70). The R^2 values are also presented. The importance of any independent variable to the dependent variable is shown in the order of its appearance in the equation. For example,

Table 9. Regression Equations for Threshold Odor Number

Sample	*Regression equation*	R^2
Lake Canton		
Surface	$Y = -.081\ X_5 + .316\ X_2 + .089\ X_{11} + .284\ X_{13} - .0013\ X_4 - .717$	.60
Mid-depth	$Y = -.198\ X_5 + .11\ X_9 + .054\ X_{11} + 1.862$	.50
Deep	$Y = -.0097\ X_7 + .143\ X_{11} + .205\ X_{15} + .244\ X_3 + 1.537$	.70
Lake Decatur		
Surface	$Y = -.074\ X_5 + .152\ X_{15} - .10\ X_{11} + 1.438$	.71
Mid-depth	$Y = -.562\ X_5 - .0014\ X_3 + 2.199$	.63
Deep	$Y = -.053\ X_5 - 0.01\ X_4 - .016\ X_1 + 2.445$	*.66*
Lake Eureka		
Surface	$Y = .152\ X_{11} + .617\ X_{13} + .0022\ X_3 + .413\ X_{12} + 2.477$	.61
Mid-depth	$Y = .329\ X_{13} + .144\ X_{11} + .008\ X_6 - .017\ X_1 + 1.693$	.54
Deep	$Y = .154\ X_{11} + .0016\ X_3 - .24\ X_2 + .22\ X_{10} + .3971$	.57

Note; Y = log TON; X_1 = dissolved oxygen; X_2 = pH; X_3 = alkalinity; X_4 = hardness;
X_5 = nitrate-nitrogen; X_6 = COD; X_7 = sulfate; X_9 = log turbidity; ,
X_{10} = log ammonia nitrogen; X_{11} = log manganese; X_{12} = log total phosphorus;
X_{13} = log chlorine demand; X_{15} = log algae

nitrate-nitrogen concentrations in the waters of Lake Decatur have the best correlation (negatively) with log TONs. Log algae is the next important factor for the surface waters of Lake Decatur.

The equations in table 9 are not perfect. There is more scatter than desirable. Nevertheless, they may be useful in alerting the operators of the water treatment plants to those parameters important to taste and odor conditions in their impoundments.

CONCLUSIONS

The magnitude of taste and odor in the waters of the three impoundments is a seasonal function. High TONs generally occur during the period from May through October, the period of dissolved oxygen depletion in bottom waters. The time interval between high TONs in the bottom water and high TONs in the finished water varies from about 3 to 4 weeks to zero depending upon the relative size and depth of the impoundment. However, regardless of the magnitude of TONs in the raw water, the intensity of TONs in finished water ranges from 3 to 10 about 95 percent of the time. In this study the required TON of 3 in finished water was achieved only 6 to 13 percent of the time.

Most of the 20 measured biological, chemical, and physical characteristics of the lake water could not be significantly correlated with corresponding TONs. Those for which a reasonable correlation exists are as follows:

Lake	Positive	Negative
Canton		NO3-N
		SO4
Decatur		NO3-N
		Hardness
Eureka	Mn	
	Cl$_2$ demand	
	PO4-P	
	Fe	

All changes in the concentrations of these in-lake constituents are likely to occur because of bottom-mediated conditions and especially during periods of oxygen depletion.

There was no simple correlation between TONs and algal densities, actinomycetes, standard plate count, or benthos organisms. This does not mean that the by-products of these organisms do not contribute to TONs. The identification of these by-products was not within the scope of the study.

From the stepwise multiple regression analyses, nitrate and sulfate were determined to be the most important constituents affecting Lake Canton waters, and these are negatively correlated to TONs. At Lake Decatur, nitrate was a major governor of TON magnitude (negatively correlated). And at Eureka manganese and chlorine demand were the most important factors (positively correlated). This suggests that monitoring the depletion rate of sulfate and nitrate concentrations at Canton and Decatur would be a worthwhile endeavor to predict the likely occurrences of impending high TONs. Similarly, at Eureka tests for manganese and Cl$_2$ demand increases would be desirable.

For long-term control of TONs, the benefits to be derived from in-lake treatment designed to minimize the dissolved oxygen depletion of bottom waters should be a major consideration.

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Date	Surface	Threshold odor number Mid-depth	Deep	Finished	Surface	Odor type* Mid-depth	Deep	Finished
1976								
9/13	20	20	2,000		E			
9/20	13	22	2,400		Df	Df	Cs	
9/27	25	24	3,900		M	E	Cs	
10/4	50	59	5,600		G		Cs	
10/11	24	35	1,800		E	G	Cs	
10/18	35	46	650		E	E	Cs	
10/25	44	50	380		E	Mm	E	
11/1	50	56	250		M	E	E	
11/8	84	110	630		M	E	E	
11/15	39	42	140		E	E	E	
11/22	57	81	670		M	G	G	
11/29	120	140	240		G	M	E	
12/6		90				Ds		
12/13		45				M		
12/20		71				G		
12/27		61				Ep		
1977								
1/3	49	70	170		G	G	Cs	
1/10	63	99	140	8.0	M	Mm	E	M
1/17	83	77	150	7.4	G	E	E	Mm
1/24	79	79	86	4.9	E	E	E	E
1/31	43	43	81	8.0	M	G	Cs	E
2/7	35	59	59	5.7	E	E	E	G
2/14	52	69	100	4.8	Ch	G	G	E
2/21	39	60	64	6.6	Mm	G	M	G
2/28		70		5.9		E		V
3/7		69		7.1		E		Cc
3/14	45	49	64	2.8	G	G	Df	G
3/21	50	49	56	4.7	Mm	E	E	G
3/28	63	64	62	4.9	Mm	G	M	M
4/4	29	32	40	5.1	G	G	G	V
4/11	36	37	57	7.0	V	V	G	E
4/18	30	45	59	4.4	G	E	M	M
4/25	26	35	38	5.3	G	G	E	C
5/2	25	29	70	5.9	V	M	M	V
5/9	26	30	45	4.9	E	G	M	Ch
5/16	20	18	21	3.8	M	M	Ep	M
5/23	18	23	37	4.1	G	G	Ds	Cc
5/31	23	32	45	5.9	G	M	E	Cc
6/6	24	31	39	4.9	G	G	E	. Ep
6/13	44	50	61	2.8	G	G	Cs	Cc
6/20	28	29	130	3.5'	V	G	E	G
6/27	39	38	100	4.8	V	A	Ds	M
7/5	50	41	77	4.3	G	M	M	M
7/11	29	35	64	4.9	M	M	Ds	E
7/18	100	100	153	7.4	M	G	Ds	Cc
7/25	49	54	120	8.3	V	E	M	G

27

| Date | Surface | Threshold odor number | | | Surface | Odor type | | Finished |
		Mid-depth	Deep	Finished		Mid-depth	Deep	
1977								
8/1	54	59	110	7.1	G	G	G	M
8/8		70		3.7		M		Cc
8/15	54	60	370	7.1	Bs	G	Dp	Cc
8/22	70	130	350	4.6	V	M	Ds	M
8/29	70	79	410	5.9	E	M	Ds	Cc
9/6	39	83	670	5.8	G	E	E	Cc
9/12	70	140	540	5.8	G	E	Ds	Cc
9/19	25	51	250	6.9	G	M	Ds	Cc
9/26	42	63	290	2.8	G	M	DS	Cc
10/3	46	50	290	3.5	G	G	Df	Cc
10/10	35	39	150	5.3	G	G	Dp	Cc
10/17	30	39	63	6.0	G	G	G	Cc
10/24	27	29	32	12.0	G	G	G	Cc
10/31	31	34	50	13.0	G	G	Ds	Cc
11/7	22	24	35	6.9	G	G	E	Cc
11/14	35	38	38	7.4	G	G	G	Cc
11/21	24	17	32	6.9	A	A	A	Cc
11/28		19		2.2		G		Cc
12/5		17		2.9		G		M
12/12		20		2.7		E		M
12/19		20		6.3		M		M
12/27		25		4.8		E		M
1978								
1/3		41		6.3				M
1/9		24		3.9		M		M
1/16	26	18	20	4.6	Df	M	Mm	M
1/23	27	29	32	3.5	Df	M	Dp	M
1/30	20	24	53	4.9	G	Mm	Dp	Cm
2/6	24	22	29	3.8	M	G	Dp	G
2/14	35	49	70	3.8	G	G	Dp	Cm
2/20	27	34	40	3.4	V	G	M	M
2/27	42	46	59	4.1	G	G	Dp	M
3/6	26	35	37	4.4	G	G	E	M
3/13	47	46	46	4.3	Mm	M	M	M
3/20		29		2.4		M		M
3/27		31		2.6		Df		M
4/3	31	35	50	3.7	Mm	M	E	M
4/10	46	50	54	3.1	Df	Mm	Mm	Mm
4/17	53	54	59	3.5	Mm	M	Dp	Mm
4/24	29	32	49	4.0	Df	Df	Df	G
5/1	32	46	53	4.4	Df	Df	E	M
5/8	43	41	50	3.7	G	Df	E	Bs
5/15	39	41	53	5.4	M	E	Df	G
5/22	35	46	50	4.7	G	M	E	Cc
5/29	35	47	54	4.8	G	Df	E	Cc
6/5	39	49	53	5.0	G	Df	E	M
6/12	42	51	57	4.6	G	E	G	Cc

Appendix A,   Concluded

	Threshold	odor	number		Odor	type		
Date	Surface	Mid-depth	Deep	Finished	Surface	Mid-depth	Deep	Finished
1978								
6/19	37	50	62	4.3	V	M	Dp	Cc
6/26	40	50	53	7.0	M	M	Dp	M
7/3	46	57	70	4.7	G	G	Bs	M
7/10	35	46	56	5.0	V	G	Dp	M
7/17	51	44	93	5.9	M	M	E	M
7/24	50	53	120	6.7	G	Df	Ds	M
7/31	57	66	130	6.6	G	G	Ds	M
8/7	75	87	520	5.2	G	M	Ds	M
8/14	99	130	820	6.3	M	Mm	Cs	Bs
8/21	77	120	490	5.5	V	E	Cs	Mm
8/28	100	120	480	8.2	M	V	Cs	M
9/5	140	150	630	6.3	G	Mm	Ds	M
9/11	160	170	640	8.4	G	Ds	Ds	M
9/18	150	200	670	9.3	G	G	Ds	M
9/25	110	120	960	11.0	Mm	M	Ds	G
10/2	84	110	730	9.1	G	G	Ds	M
10/9	91	120	410	7.0	M	G	Ds	G
10/16	75	71	140	5.0	M	M	M	Cs

* A   – Aromatic
  B   – Balasamic (flowery)
  Bs – Sweetish
  C   – Chemical
  Cc – Chlorinous
  Ch – Hydrocarbon
  Cm – Medicinal
  Cs – Sulfuretted

  D   – Disagreeable
  Df – Fishy
  Dp – Pigpen
  Ds – Septic
  E   – Earthy
  Ep – Peaty
  G   – Grassy
  M   – Musty
  Mm – Moldy
  V   – Vegetable

Appendix B. Threshold Odor Number and Odor Type
of Lake Decatur and of Its Finished Water

Date	Surface	Threshold odor number Mid-depth	Deep	Finished	Surface	Odor type Mid-depth	Deep	Finished
1976								
9/14	17	20	20		G			
9/21	15	12	17		E	Df	Df	
9/28	20	20	33		Df	Df	Df	
10/5	50	50	70		E	E	G	
10/12	180	160	400		E	Df	Df	
10/19	160	200	430		G	G	E	
10/26	200	280	670		M	E	E	
11/2	130	250	360		E	Mm	G	
11/9	190	230	520		Ep	Df	G	
11/16	130	140	270					
11/23	73	81	270		Ep	Df	Ds	
11/30	110	120	150		Df	Df	G	
12/7	110	130	140		Df	Df	E	
12/14	160	110	140		Df	E	E	
12/21	99	120	200		Df	E	Ds	
12/28	57	82	93		Df	Df	Df	
1977								
1/4	77	110	120	6.0	Df	Df	E	Ep
1/11	57	61	70	7.0	E	M	Df	V
1/18	70	86	84	3.9	Df	Df	Df	E
1/25	42	46	50	4.7	M	G	Ds	Bs
2/1	65	49	53	7.1	Cc	E	Df	C
2/8	37	43	52	8.0	E	M	Ds	V
2/15	43	65	97	7.7	M	M	Ds	M
2/22	54	81	100	6.7	E	E	E	G
3/1	38	65	86	8.7	E	Df	Ds	V
3/8	59	53	75	10.0	E	Df	Df	Mm
3/15	36	62	87	9.1	Df	Df	G	Ch
3/22	35	51	66	8.2	Mm	E	G	Mm
,3/29	40	41	63	6.5	G	G	E	M
4/5	26	30	56	6.1	G	G	G	M
4/12	24	37	48	4.4	Df	Df	Df	M
4/19	45	49	53	5.4	V	E	E	Ep
4/26	26	36	49	4.7	G	G	G	G
5/3	34	28	37	2.5	Df	Df	Df	Cc
5/10	24	23	30	2.8	G	M	G	Ch
5/17	21	30	30	2.6	G	M	G	M
5/24	20	23	45	2.3	E	G	E	M
6/1	18	24	25	1.9	M	E	M	Cc
6/7	21	24	33	3.4	G	Df	G	Ch
6/14	22	35	43	3.0	G	G	G	G
6/21	31	31	110	3.4	Df	Df	E	Cc
6/28	40	64	140	5.5	Df	Df	V	Ch
7/6	35	35	99	2.5	Df	Df	M	Cc
7/12	40	70	140	4.5	Df	Df	Df	M
7/19	77	91	99	4.6	G	M	M	E
7/26	110	91	150	3.7	Df	Df	Df	M

Appendix B.   Continued

Date	Threshold odor number				Odor type			
	Surface	Mid-depth	Deep	Finished	Surface	Mid-depth	Deep	Finished
1977								
8/2	170	180	240	3.7	M	M	E	Cc
8/9	78	75	150	6.4	G	E	E	Cc
8/16	63	70	91	6.7	M	M	E	C
8/23	43	70	91	3.9	Mm	Mm	Mm	M
8/30	54	49	56	2.6	M	M	M	Cc
9/7	44	50	54	3.3	V	E	E	C
9/13	38	38	63	3.8	G	V	Df	Cc
9/20	29	35	46	4.0	Bs	Df	M	Cc
9/27	24	38	46	2.4	V	M	E	Cc
10/4	46	46	65	3.5	G	G	Mm	Cc
10/11	33	57	99	4.2	A	A	M	M
10/18	50	77	99	8.0	G	V	V	Cc
10/26	45	50	59	5.3	Df	Df	G	Cc
11/1	36	36	41	5.4	M	G	E	Cc
11/8	34	35	38	4.4	DF	G	M	Cc
11/15	24	42	53	7.7	Df	M	Ds	Cc
11/22	24	24	21	7.7	Df	Df	Df	C
11/29	26	30	32	5.1	Df	Df	Df	Cm
12/13	20	15	22	5.3	M	M	Dp	M
12/29	16	16	19	3.2	Df	Df	Df	M
1978								
1/4	35	49	52	4.6	M	M	M	M
1/10	19	20	22	7.1	M	M	M	M
1/17	18	21	24	5.7	G	E	E	V
1/24	13	14	13	4.0	Df	E	M	C
1/31	25	21	23	3.0	Df	Df	E	M
2/7	22	24	26	7.3	Df	M	M	Cc
2/15	16	21	25	4.1	Df	G	E	Cc
2/21	22	24	25	3.7	Df	M	M	M
2/28	24	27	30	6.6	M	E	M	M
3/7	32	35	32	5.0	E	Df	M	B
3/14	24	35	35	7.9	M	Df	G	M
3/21	30	46	54	5.4	M	M	M	M
3/28	26	29	34	6.2	M	M	M	Mm
4/4	28	22	29	2.0	M	Df	M	M
4/11	27	39	54	3.8	Dp	Dp	Dp	G
4/18	45	50	56	3.8	Df	Dp	Dp	Mm
4/25	22	31	42	2.8	Df	Df	Df	M
5/2	43	56	59	4.1	M	M	M	V
5/9	42	44	56	5.7	M	Df	Df	Bs
5/16	43	51	53	6.1	M	Mm	Mm	Mm
5/23	47	51	56	8.8	G	G	G	M
5/31	43	46	50	4.8	G	Df	M	M
6/6	46	50	56	4.6	G	G	G	M
6/13	42	45	49	6.8	Df	Df	G	M
6/20	49	53	57	6.0	G	V	G	M

Appendix B. Concluded

| Date | Threshold odor number | | | | Odor type | | | |
	Surface	Mid-depth	Deep	Finished	Surface	Mid-depth	Deep	Finished
1978								
6/27	52	55	61	6.5	G	Df	E	Cc
7/3	47	49	53	6.2	G	G	G	M
7/11	70	75	70	7.0	G	Df	E	M
7/18	57	63	79	6.0	Df	E	Dp	M
7/25	50	53	57	6.1	M	M	Mm	M
8/1	59	84	110	3.8	Df	Mm	E	Cc
8/8	88	94	110	6.5	Mm	Mm	E	Cc
8/15	88	99	130	5.8	Df	Df	Df	V
8/22	99	150	210	6.5	Df	Df	Df	M
8/29	140	130	150	5.8	Df	Df	Df	M
9/6	110	130	210	7.9	G	G	G	V
9/12	99	130	170	8.4	Mm	Mm	Df	Mm
9/19	120	120	180	5.9	G	E	E	M
9/26	100	110	130	6.8	Df	Df	Df	M
10/3	84	99	110	5.7	Df	M	G	M

Appendix C. Threshold Odor Number and Odor Type
of Lake Eureka and of Its Finished Water

	Threshold odor number				*Odor type*			
Date	*Surface*	*Mid-depth*	*Deep*	*Finished*	*Surface*	*Mid-depth*	*Deep*	*Finished*
1976								
9/13	20	25	28		Df			
9/20	13	20	25					
9/27	27	56	86		E	E	M	
10/4	64	70	130		G	E	Ep	
10/11	130	140	270		G	E	E	
10/18	120	150	200		Df	Df	Ep	
10/25	70	160	270		G	Df	E	
11/1	110	150	200		Df	G	Ep	
11/8	110	130	120		Df	Df	G	
11/15	140	160	180		Ds	Ds	G	
11/22	81	87	110		Ds	Ds	G	
11/29	140	130	130		Df	Df	M	
12/6		200						
12/13		120				Mm		
12/20		140				Dp		
12/27		93				Df		
1977								
1/3		91				Ds		
1/10	81	110	130	8.1	Mm	Ds	Ds	Df
1/17	54	77	110	20.0	Df	Df	Ds –	Df
1/24	65	140	230	15.0	Ds	Ds	Ds	Df
1/31	230	330	350	35.0	Ds	Ds	Ds	Df
2/7	670	670	650	54.0	Ds	Ds	Ds	Df
2/14	560	740	780	34.0	Ds	Ds	Ds	Df
2/21	250	480	760	43.0	Ds	Ds	Ds	Dp
2/28		340		42.0		Ds		Ds
3/7		230		20.0		Ds		Ds
3/14	46	70	120	4.0	V	V	V	Df
3/21	50	50	84	10.0	M	G	G	G
3/28	50	65	47	13.0	G	G	G	G
4/4	44	50	61	12.0	G	G	G	G
4/11	38	46	57	11.0	V	M	G	V
4/18	38	40	48	8.0	G	G	G	M
4/25	42	49	53	8.3	Df	G	Df	V
5/2	28	30	33		G	G	G	
5/9	26	30	32	4.9	G	E	Ds	G
5/16	24	26	28	2.8	Df	G	V	E
5/23	14	17	29	2.0	Mm	G	G	E
5/31	28	27	99	3.1	M	M	Cc	G
6/6	21	19	70	3.5	V	V	G	G
6/13	22	34	110	1.9	V	V	Ds	G
6/20	21	19	80	4„5	G	G	M	M
6/27	23	35	170	2.8	G	Mm	Cs	V
7/5	31	26	170	4.5	G	G	Dp	M
7/11	34	76	140	7.0	Ds	Ds	E	M
7/18	70	88	280	6.7	M	Df	Ds	V
7/25	59	91	150	4.7	Ch	M	Ds	E

| | Threshold odor number | | | | Odor type | | | |
Date	Surface	Mid-depth	Deep	Finished	Surface	Mid-depth	Deep	Finished
1977								
8/1	99	160	300	3.0	G	Dp	Ds	G
8/8		240		5.7		Ds		Cc
8/16	170	100	190	4.6	Df	Df	E	Cc
8/22	330	70	83	8.7	Df	Df	Ds	M
8/29	240	110	84	6.3	Df	Df	E	Df
9/6	130	110	170	4.4	Df	Df	Df	Ch
9/12	130	200	310	7.2	Df	Df	Df	
9/19	180	190	260	12.0	Df	Df	Df	Df
9/26	140	220	240	9.0	Df	Df	Df	G
10/3	520	160	430	5.4	Df	Df	Ds	G
10/10	54	59	120	5.9	Dp	Dp	Dp	Df
10/17	43	65	99	5.0	Df	Df	Df	Cc
10/24	45	54	70	4.1	Df	G	Ds	G
10/31	28	32	40	6.7	Df	Df	Df	M
11/7	34	29	38	4.1	Df	Df	M	G
11/14	27	24	32	3.2	Df	Df	Df	Cc
11/21	37	23	37	4.1	Df	Df	Df	Cc
11/28		22		5.5		Df		V
12/5		46		4.4		Df		G
12/12		35		4.1		G		M
12/27		24		5.3		Ds		G
1978								
1/3		33		8.0		Df		M
1/9		21		4.5		Df		M
1/16	24	35	40	7.0	Df	Df	Dp	G
1/23	24	28	35	4.1	Df	G	M	Mm
1/30	40	43	70	7.0	Mm	Mm	E	M
2/6	24	26	32	4.9	M	M	Dp	M
2/14	20	26	40	5.1	M	M	M	C
2/20	24	35	41	5.0	E	Ep	Dp	Bs
2/27	30	32	35	3.9	E	M	Dp	M
3/6	24	24	35	5.8	Mm	G	Ds	Cc
3/13	27	28	40	3.6	C	M	Df	C
3/20		45		6.0		M		C
3/27		35		6.2		M		M
4/3	27	41	41	3.4	Mm	Mm	Mm	Mm
4/10	49	56	70	4.9	Df	Mm	Mm	G
4/17	32	38	49	4.7	Df	Df	Df	G
4/24	42	45	50	4.5	Df	Df	Df	G
5/1	49	49	57	4.4	Df	Df	Df	G
5/8	57	54	64	4.4	Df	Df	Df	G
5/15	37	43	49	4.4	Df	G	G	Cc
5/22	37	50	70	6.6	M	M	M	M
5/29	54	49	59	8.0	Df	Df	M	Cc
6/5	47	50	70	7.0	Df	Df	G	M
6/12	53	66	71	7.3	Df	Df	Df	M
6/19	75	71	70	3.9	Df	M	Dp	C

Appendix C. Concluded

	Threshold odor number				Odor type			
Date	Surface	Mid-depth	Deep	Finished	Surface	Mid-depth	Deep	Finished
1978								
6/26	57	79	75	6.8	Df	Df	Dp	M
7/3	43	45	54	5.0	G	E	E	M
7/10	50	63	59	6.1	Df	Df	M	M
7/17	61	75	70	5.3	Df	Df	Dp	M
7/24	47	50	57	3.8	Df	Df	Ds	M
7/31	89	89	94	6.6	Df	Df	Cm	C
8/7	95	110	140	5.6	V	V	Ds	Cc
8/14	87	81	130	5.9	G	V	Cs	M
8/21	100	100	360	6.7	M	Df	Cs	M
8/28	130	190	370	6.1	Df	Df	Ds	M
9/5	180	200	520	7.6	G	E	Ds	M
9/11	130	140	710 '	7.1	Df	Df	Ds	G
9/18	110	150	590	8.9	Df	Df	Ds	Mm
9/25	130	140	450	5.7	Df	Df	Ds	V
10/2	99	99	190	5.2	Df	Df	Cs	M