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WATER QUALITY CHANGES IN AN IMPOUNDMENT AS A CONSEQUENCE OF ARTIFICIAL DESTRATIFICATION

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WATER QUALITY CHANGES IN AN IMPOUNDMENT

AS A CONSEQUENCE OF ARTIFICIAL DESTRATIFICATION

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CHAPTER I

INTRODUCTION

Impoundments are built to store water which can be used for a variety of purposes. Impoundment waters are an important source of water supply for many municipalities in the United States. Impoundments are also built to develop water for irrigation and provide flood control, hydroelectric power, recreation (boating, swimming, fishing, and water skiing), and regulation of downstream water qualities and quantities. The effects of impoundment on water quality have been under investigation for many years dating back to 1890. An extensive quantity of literature is available from water quality studies conducted in special impoundments. In addition to the numerous reports on the measurement of water quality in lakes and impoundments, several studies discuss in qualitative terms the actual and anticipated effects of impoundments on water quality. Churchill (1957), Ingels (1959), Love (1961), Kittrell (1959), Symons (1969) and many others have reported on the water quality effects of impounding free flowing streams.

Several beneficial and detrimental effects of an impoundment are summarized in Table 1 (Symons, 1969). According to Symons (1969),

TABLE 1

IMPOUNDMENT INFLUENCES OF WATER QUALITY

POSSIBLE BENEFITS	POSSIBLE DETRIMENTS
Turbidity Reduction	Less Mixing
Hardness Reduction	Lower Reaeration
Organic Reduction	Build-up of Pollutants
BOD reduction	Algal Blooms
Color reduction	Aesthetics
Coliform Reduction	Tastes and odors
Smoothing Action	No Bottom Scour
	Thermal Stratification
	Low dissolved oxygen
	Iron and manganese dissolution
	Hydrogen sulfide production
	Carbon dioxide increase
	pH reduction
	Organic Persistance

reduced turbidity is due to low horizontal velocities and long detention times. Reduced hardness can occur due to algal assimilation of carbon dioxide and subsequent precipitation of calcium carbonate. Impoundment usually causes a reduction in BOD and color due to long detention times which permit biodegradation. Coliform reduction can be attributed to long detention times which allow natural die-off. Due to impoundment water volumes there tends to be a smoothing action of peak concentration of incoming pollutants. However, on the detrimental side less overall mixing may occur because reduced horizontal velocities can cause undesirable wastes to accumulate in localized areas. There is usually less surface reaeration because of lower surface renewal rates and increased water depths. Due to nutrient inputs there may be increased algal problems in shallow littoral zones, appearing as aesthetically-displeasing scums, or causing tastes and odors. Because of decreased horizontal velocities there is usually no bottom scour, thus allowing organic sediment accumulation. Also, with increased depth thermal stratification may develop.

Thermal stratification is the term applied to the segregation of the waters of a natural lake or man-made impoundment into horizontal layers exhibiting differences in temperature, density and viscosity. The primary causes of thermal stratification are the peculiar temperature--density relationship of water, low thermal conductivity of water, and stream inflows in late spring and early summer that tend to be warmer than impounded surface waters.

When thermal stratification occurs in summer months the warm, light water lying over the cold water of the hypolimnion acts as a lid on the system. This lid prevents the bottom, dense water from circulating to the surface where it would be reaerated. Because the cold layers are usually below the photosynthetic zone, algal reaeration also does not occur. The oxygen removed from the water by the decomposition of organic matter is not replaced. The organic materials in the water when it entered the reservoir, in the bottom deposits, and in the bodies of dead plankton settling from the overlying strata, combine to deplete the dissolved oxygen of the hypolimnion. The detention of water for several months in the hypolimnion may permit total oxygen depletion even in reservoirs with inflows of water of good quality. The anaerobic condition created permits several undesirable reactions to occur which tend to lower the water quality. Sulfates are reduced and odorous hydrogen sulfide is formed. Hydrogen sulfide as well as the sulfides of iron and manganese create a negative oxidation--reduction potential. Iron and manganese are reduced and go into solution and the concentrations of soluble iron and soluble manganese may increase in the bottom water. Excess carbon dioxide is created and the pH of the water is lowered. Anaerobic decomposition can also produce some undesirable organics. . . undesirable because of tastes and odors, and, occasionally, because of toxicity. Even the cold temperatures of these bottom waters might be considered pollutants because this characteristic might adversely affect downstream uses. All of these reactions are potentially detrimental to water quality; thus, when the bottom water of a stratified impoundment is released through power turbines, poor quality water might be discharged downstream and this could cause deterioration of downstream water quality. Also, during overturns these bottom waters become mixed with the rest of the reservoir waters and may pollute the entirety for a short period of time.

Impounded waters are an important source of water supply for many municipalities in the United States. When reservoir water quality deteriorates it puts an additional burden on the water treatment plant. If this deterioration could be avoided by some method of in-reservoir treatment this additional burden could be eliminated and better quality water could be produced more cheaply and easily. Examples of in-reservoir treatment techniques for water quality control are:

1. application of copper sulfate for algal control,
2. cutting of weeds along shorelines,
3. adjustment of lake levels for mosquito control,
4. evaporation suppression with mononuclear films, and
5. chlorination.

In addition to the above, several methods for correcting the reduction in dissolved oxygen resources have received consideration. Several methods which have been evaluated for small lakes or reservoirs include:

1. Multilevel Penstock Intakes: This would permit withdrawal of water from the surface stratum, with its high oxygen content, regardless of the water surface level.

2. High-level Penstock Weir: A weir with its top about 25 feet below the water surface installed around the penstock intakes would force the water to the surface of the reservoir in the vicinity of the dam and would increase reaeration.

3. Submerged Weirs: Several versions are possible.

4. Tailrace Aeration: The installation of mechanical aerators to increase the turbulence of waters in the tailrace possibly could increase the oxygen content immediately downstream.

5. Supplemental High Quality Spills: Spilling high quality surface water (upper 2-3 feet) and mixing it with water discharged through turbines would increase downstream water quality. However, it should be noted that these five methods only improve downstream water quality and not the entire lake or reservoir.

Since the deterioration of water quality in impoundments is due largely to thermal stratification, only through breakage of stratification patterns, called destratification, can good quality water be maintained throughout the entire water mass. Destratification can be achieved by artificial means through using mechanical pumps or compressed air.

Lake Thunderbird and Water Quality Problems

Lake Thunderbird is located in Cleveland County, Oklahoma, approximately 12 miles east of Norman and 25 miles southeast of Oklahoma City. It was built by U.S. Bureau of Reclamation for flood control, recreation, and a municipal and industrial water supply for Norman, Del City, and Midwest City. The earth-fill dam was completed in 1965 across Little River, just downstream from the mouth of Hog Creek. The Central Oklahoma Master Conservatory District is the controlling agency of the lake and is composed of members from Del City, Norman, and Midwest City.

Lake pool elevations and morphometry data are listed in Table 2. At the normal (conservation) elevation of 1039 feet above sea level, the reservoir has an area of 6,070 acres and a capacity of 119,600 acre-feet. The maximum depth of the conservation pool is 69 feet (21 meters)(sediment build-up not accounted for) in the area just northwest of the dam. However, the mean depth of the conservation pool is only 19.7 feet (6 meters).

Lake Thunderbird is a U-shaped lake. Prevailing southerly winds keep the reservoir well-mixed. Vertical temperature stratification in 40

TABLE 2

LAKE THUNDERBIRD MORPHOMETRY

Normal pool elevation	1,039.0 msl
Maximum pool elevation	1,049.4 msl
Length of pool	13.5 miles
Length of shoreline	86.0 miles
Surface area	6,070 acres
Volume	119,600 acre - feet
Maximum depth	69.0 feet
Average depth	19.7 feet
Maximum length	27,750 feet (measured N.E. by S.W. or N-S)
Maximum width	27,750 feet
Direction of major axis	N-S; E-W

Source: Reservoirs of Oklahoma, Oklahoma Department of Wildlife Conservation, Bulletin No. 11, January 1973, pp. 123-124.

feet of water has not exceeded 4-5°C. Chemical analyses reveal very little difference from one sample location to the next, with the possible occasional exception of the upper reaches of the Little River and Hog Creek arms. Water temperatures vary from a winter low of near freezing to a summer high of 30°C. Table 3 (Keeley, 1971) lists approximate ranges for some typical water quality parameters.

The water quality of the lake is generally good. Although the DO concentration is usually near saturation, low lake bottom values have been recorded in the summer. The nutrient levels at the lake are variable, but are at or above the threshold for occurrence of troublesome algal blooms. This is evidenced by algal blooms during the late summer.

Climate

The climate of Cleveland County is controlled by the interaction of tropical and polar air masses, and most precipitation is brought about by the chilling of warm, moist Gulf air by cooler air from the north. Most of the annual precipitation is due to rainfall, with very little attributed to hail, sleet, and/or snow.

Rain from regional cyclonic storms and local thunderstorms occurs throughout the year, but is greatest during the spring and summer months. The average annual precipitation at Norman is 33 inches. The average annual temperature is 60°F (15.6°C). However, as can be seen from Tables 4, 5, and 6, the Central Oklahoma area is characterized by wide ranges in temperature and wide deviations from average annual precipitation values. An annual temperature range of 110°F (43.3°C) is not unusual in this area.

TABLE 3

LAKE THUNDERBIRD WATER QUALITY

Dissolved Oxygen	Near Saturation
pH	8.0 - 8.5
Turbidity	5 - 500 J. T. U.
TDS	250 - 300 mg/l
Iron	0 - 0.1 mg/l
Total Phosphate	0.2 - 0.3 mg/l
Ortho Phosphate	0.01 - 0.15 mg/l
Alkalinity	150 - 200 mg/l

TABLE 4

*AVERAGE TEMPERATURE AND PRECIPITATION

IN CENTRAL OKLAHOMA

MONTH	AVERAGE TEMPERATURE °F	°C	AVERAGE PRECIPITATION (In.)
January	38.8	3.80	1.43
February	43.0	6.10	1.58
March	49.3	9.60	2.08
April	61.1	16.20	3.44
May	69.0	20.55	5.44
June	72.8	22.67	4.46
July	81.0	27.20	3.07
August	82.1	27.83	2.69
September	69.5	20.83	3.35
October	63.9	17.72	2.93
November	49.7	9.83	1.81
December	41.3	5.17	1.53
ANNUAL	60.1	15.61	33.81

*72 Years Average (from 1891 to 1963)

Source: Wood, P.R. and Burton, L.C. "Ground water resources in Cleveland and Oklahoma Counties, Oklahoma," Oklahoma Geological Survey, Circular 71, 1968.

TABLE 5

AVERAGE TEMPERATURE AND PRECIPITATION

YEAR 1974

MONTH	AVERAGE TEMPERATURE °F	°C	AVERAGE PRECIPITATION (In.)
January	38.1	3.39	0.14
February	47.8	8.78	1.64
March	58.2	14.55	1.77
April	63.6	17.55	2.78
May	73.8	23.22	4.19
June	75.3	24.05	2.23
July	83.7	28.72	0.36
August	79.5	26.39	5.22
September	66.7	19.28	4.57
October	64.2	17.89	6.04
November	50.8	10.44	1.83
December	40.7	4.83	1.36
ANNUAL	61.9°F	16.6°C	31.13

Source: Temperature: National Weather Service, OKC, OK
Precipitation: City of Norman, Norman, OK

TABLE 6

AVERAGE TEMPERATURE AND PRECIPITATION

YEAR 1975

MONTH	AVERAGE TEMPERATURE °F	°C	AVERAGE PRECIPITATION (In.)
January	42.1	5.60	2.34
February	39.6	4.20	2.33
March	48.5	9.20	2.76
April	61.6	16.40	2.51
May	70.1	21.20	10.48
June	75.1	23.90	4.70
July	78.0	25.55	6.94
August	80.1	26.70	1.09
September	68.3	20.20	3.14
October	63.4	17.40	0.88
November	50.7	10.40	2.04
December	41.8	5.40	1.16
ANNUAL	59.9°F	15.5°C	40.38

Source: Temperature: National Weather Service, OKC, OK
Precipitation: City of Norman, Norman, OK

Likewise, rain fall intensities have been known to vary from a few hundreths of an inch per 24 hours to 10-12 inches per 24 hours.

Southerly winds prevail over the region throughout the year with the exception of January and February when northerly winds prevail. This shift in wind direction is due to the passing of winter storm centers. The wind speed normally ranges from 10-15 miles per hour and wind speeds in the 70 to 80 miles per hour range have been recorded. Severe storms such as tornadoes are very common from April until the end of June. The wind velocity data from May, 1974, to October, 1975, is given in Table 7.

Artificial Destratification in Lake Thunderbird

A destratification unit using compressed air was started on June 4, 1974. A 25 hp electrically-driven rotary compressor housed atop the dam delivered 100 cfm of compressed air. The air was delivered to the water by 1000 ft of 1-in galvanized pipe. The diffuser section consisted of 100 ft of galvanized pipe with 3/32 - in holes on 6 - in centers. The diffuser section was placed in the lake bottom in the deepest part of the lake close to the dam. Aeration has been 24 hrs/day since the starting date.

Objectives of this Study

When aeration of Lake Thunderbird was started, it was hoped that the resultant mixing would improve the general quality of the water. It was also anticipated that mixing would: (1) eliminate thermal stratification and establish isothermal conditions throughout the lake, (2) bring about uniform dissolved oxygen concentrations from surface to bottom by increasing bottom concentrations and eliminating anaerobic conditions, and (3) eliminate troublesome algal blooms.

TABLE 7

WIND VELOCITY DATA FOR MAY 1974-OCTOBER 1975

	Month	Average mph	Fastest mph	Fastest Direction	Fastest Date
1974	May	13.0	38	N	23
	June	10.2	37	S	8
	July	9.5	27	SW	2
	August	9.9	34	N	1
	September	9.5	44	NE	1
	October	10.6	33	SW	4
	November	12.0	35	S	2
	December	11.0	38	NW	18
1975	January	12.9	49	N	19
	February	15.0	38	NE	22
	March	15.6	37	SE	26
	April	15.5	35	NW	2
	May	11.5	39	SW	19
	June	11.5	43	NW	6
	July	8.0	26	SW	19
	August	7.4	23	SW	29,30
	September	8.9	33	N	11
	October	10.3	26	SW	12,13

Source: National Weather Service, OKC,OK

The objectives of this investigation were to study the water quality changes due to artificial destratification and find out whether aeration of Lake Thunderbird had: (1) eliminated thermal stratification and established isothermal conditions in the summer months, (2) eliminated anaerobic conditions at the lake bottom and brought about uniform DO concentrations throughout the lake, and (3) improved the overall water quality of the lake.

To study the water quality changes due to artificial destratification the following physical and chemical parameters were measured:

Physical

1. Temperature
2. Turbidity
3. Total Dissolved Solids (TDS)

Chemical

4. Dissolved Oxygen (DO)
5. pH
6. Alkalinity
7. Dissolved phosphate
8. Nitrogen: Nitrite
Nitrate
Kjeldahl's Nitrogen
9. Iron

The base-line for the water quality of the lake was established

by

1. measurement of water quality before the destratification, and
2. collection of all the data available for the lake from various

local and state agencies plus the data available from the School of Civil Engineering and Environmental Science and Department of Zoology at the University of Oklahoma.

Sampling Station Selection and Sampling Dates

Figure 1 is a location map of Lake Thunderbird, with the sampling station numbers noted by circles. Five sampling stations were selected as follows:

I. Located between the beach and east shore on Hog Creek arm (water depth - 10 meters)

II. Located near the dam in the deepest part of the lake. This station is also near the aeration site (water depth - 15 meters).

III. Located near the water intake structure. It is also close to the Clear Creek arm of the lake (water depth - 10 meters).

IV. Located midway between Stations III and V. It is close to the Blue Creek arm of the lake (water depth - 6 meters).

V. Located close to the Alameda Street bridge. This is near the Little River arm of the lake (water depth - 4 meters).

Originally the sampling was planned for twice monthly starting in May, 1974. Due to equipment and weather difficulties sampling was accomplished only once during the following months: May, 1974; June, 1974; November, 1974; February, 1975; and September, 1975. No sampling was done in July, 1974.

The temperature was measured every meter from the surface to the bottom of the lake. The water samples for the chemical analyses were collected at 3 meter intervals from the surface to the lake bottom. During the months when the lake was completely mixed, three samples (surface,

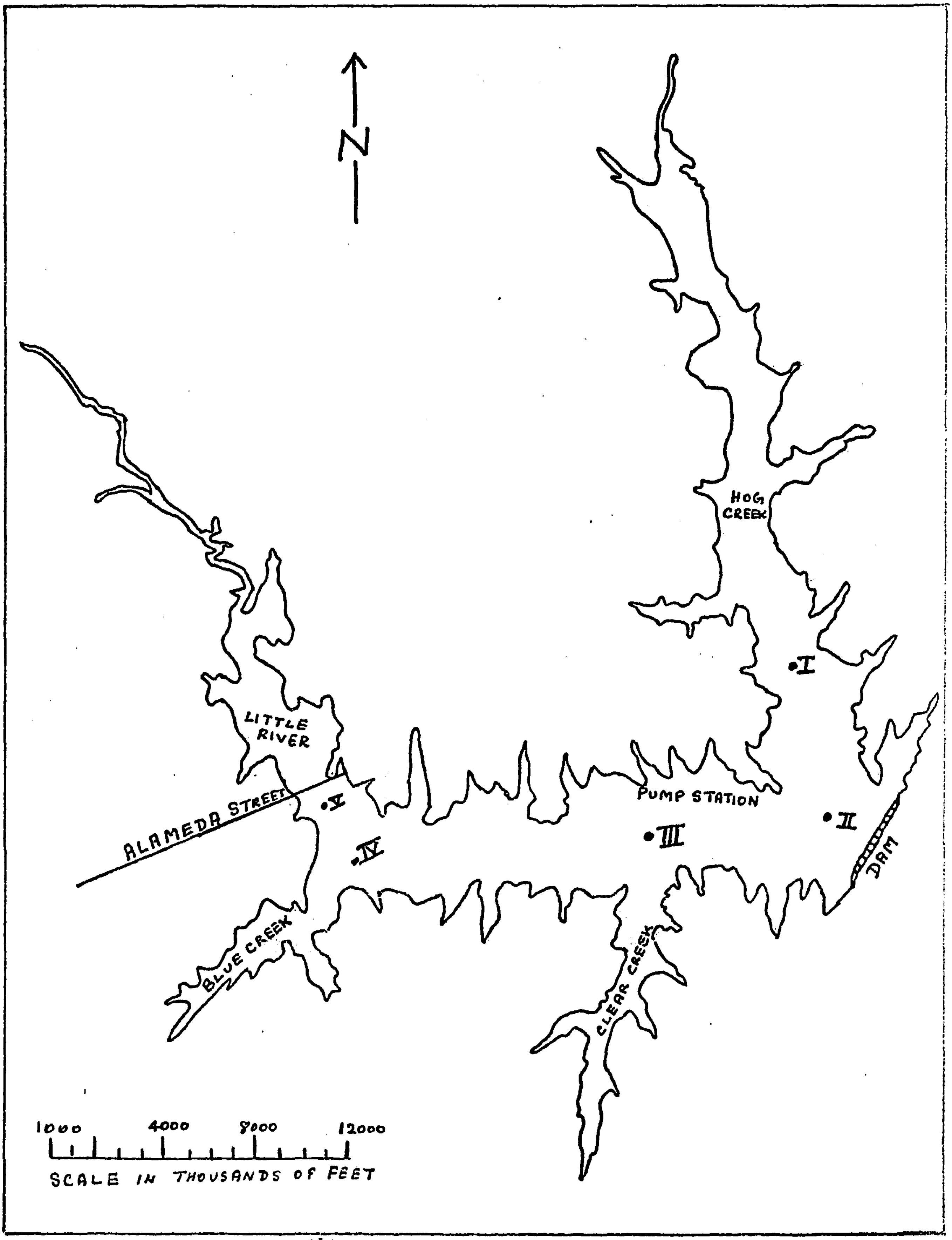

Figure 1. Location Map of Lake Thunderbird

middle, and bottom) were collected at Stations I, II, and III, and two samples (surface and bottom) were collected at Stations IV and V. Sampling was discontinued on October 19, 1975, when the lake was completely mixed with respect to temperature and dissolved oxygen.

Water samples were collected 27 times starting May 10, 1974, with the sampling dates as follows:

1974	1975
May 10	January 21
June 11	February 28
August 4	March 17
August 25	March 30
September 10	April 12
September 29	April 28
October 16	May 9
October 31	May 26
November 12	June 8
December 12	June 26
December 27	July 12
	July 30
	August 16
	August 31
	September 25
	October 19

CHAPTER II

LITERATURE REVIEW

The effects of impoundments on water quality have been studied for many years. There are several articles written concerning the quality of water in impoundments. Churchill (1957), Love (1961), Wang and Evans (1970) and others have detailed the possible beneficial and detrimental water quality effects that may be realized when a free flowing stream is damned. Beneficial effects include: reduced turbidity caused by low velocities and long detention times; reduced hardness caused by algal assimilation of caron dioxide and subsequent precipitation of calcium carbonate; reduced color and BOD caused by long detention times permitting biodegradation; reduced indicator organism density caused by increased detention time permitting natural die-off; evening out of sharp variations in dissolved minerals, pH and alkalinity; and equalizing action smoothing large concentrations of various incoming pollutants. Detrimental effects that may occur when water is impounded include: less mixing caused by non-uniform waste distribution; less atmospheric reaeration caused by low velocities and increased depths; accumulation of pollutants caused by evaporation; increased algal problems, primarily appearing as aesthetically displeasing scums or tastes and odors in water, both of which are caused by increased detention times; no bottom scour because of increased depths; and thermal stratification.

Thermal stratification can occur in both natural lakes and man-made reservoirs. In the late winter or early spring the impoundment water is cold, has relatively high density, is easily mixed by wind action, and has a uniform vertical temperature. As the season advances and the atmospheric temperature becomes higher, both the inflowing tributary water and the surface water in the impoundment become warmer. This warm water tends to remain at the surface, absorbs more heat, and thus a stable condition tends to be established. However, evaporation will always cool the surface layer, setting up convection currents. Surface cooling and hence convection will be enhanced by back radiation and conduction losses, especially at night. Wind stresses on the water surface will cause mixing whenever a neutral or unstable density gradient is established by surface cooling. These processes of heating, cooling, and wind action lead to the development of warm circulating, turbulent upper region, called the "epilimnion."

The epilimnion may be 5 to 50 feet deep depending on impoundment depth and other factors. The impoundment is mixed to this depth by wind-induced currents, and this layer has a uniform temperature. Below the epilimnion is the "thermocline," which may be 5 to 20 feet deep. The thermocline is a stratum in which the temperature decreases rapidly as depth increases. A thermocline has been defined for convenience, though on a strictly arbitrary basis, as a stratum of water in which the temperature decreases 1.0°C or more in depth of 1 meter, or 0.55°F per foot. The decrease in temperature down to 4.0°C is accompanied by an increase in density, with a corresponding increase in resistance to mixing. In the temperate regions of the northern hemisphere the epilimnion water reaches its maximum temperature during June, July or August, and the thermocline becomes sharply defined. Below the thermocline the water which extends to the bottom has low and nearly uniform temperatures. This lowest layer is called the "hypolimnion." In the hypolimnion water is protected from the atmosphere by the overlying thermocline and epilimnion; therefore, very little increase in temperature occurs after stratification is established.

In the southern portion of the United States the temperature of the epilimnion may rise as high as 85°F or even a few degrees higher. The hypolimnion consists of water that was stored during winter or early spring. The temperature of the hypolimnion may remain as low as 45 to 50°F in some reservoirs (Posey and Dewitt, 1970).

Summer stratification persists until fall when influent water becomes cooler. Toward the end of August the strength and duration of solar radiation declines and the average air temperature tends to decrease. Heat losses by conduction to the atmosphere and evaporation from the surface then begin to exceed heat gains. The epilimnion water cools, and as the surface water becomes cooler than that below, it sinks. The slightest wind can cause circulation in the epilimnion under these conditions, and as a result, the epilimnion becomes cooler throughout and extends down further and further into the thermocline layer, gradually eliminating it. The date at which the difference in temperature between the epilimnion and hypolimnion becomes insignificant depends on weather conditions and the temperature the hypolimnion reached before stratification became effective; usually, however, conditions of instability have been reached by the end of September. Only a moderate wind is then required to cause a complete circulation of the whole body of water, the commencement of which may happen quite suddenly, and is known as "Autumn or Fall Overturn."

During the winter in the northern United States a different type of stratification occurs. When water temperature drops below 4°C (39.2°F) the density trend is reversed and the water becomes lighter. The denser 4°C (39.2°F) water sinks to the bottom, while the colder but lighter water in the range between 32.0°F and 39.2°F remains on the surface. There are only two strata. The top stratum is quite thin with a temperature drop in relation to depth similar to that of the summer thermocline. This condition frequently exists in conjunction with an ice cover. Inverse stratification in the winter is not very stable because of small density differences and even moderate winds can produce currents which soon extend to the bottom of the lake. The ensuing circulation which brings bottom waters to the surface, and thoroughly mixes all the water in the lake, is called the "Spring Overturn."

One of the reasons for stratification is the peculiar temperature-density relationship for water shown in Figure 2 (Symons, 1969). The fact that the density changes more rapidly at higher temperatures than it does at lower ones is especially important. The difference in density between 25.0°C and 30.0°C (1.4 mg/ml) is 2.34 times larger than the difference in density between 10.0°C and 15.0°C (0.6 mg/ml). The change in density between 24.0°C and 25.0°C is thirty times greater than between 4.0°C and 5.0°C. This means that even if an impoundment showed a rather modest temperature gradient than never reaches the intensity of a thermocline, it could still be density stratified. Warmer waters generally stratify with a smaller temperature difference than colder waters.

Thermal stratification has been thoroughly reviewed by Thompson (1954), Kittrell (1959), Posey and Dewitt (1970), and others. Hutchinson

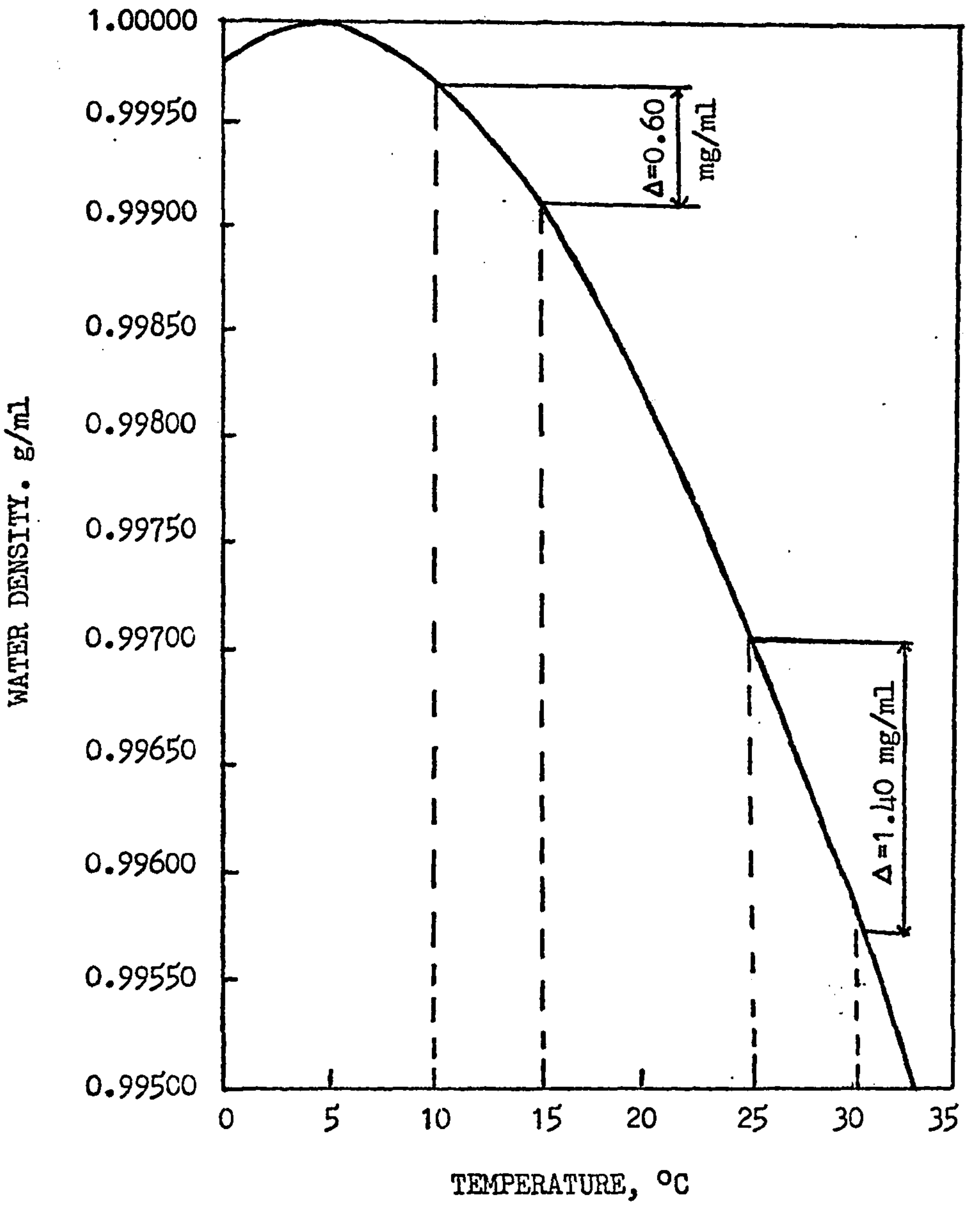

Figure 2. Temperature - Density Relationship

(1957), Hammer (1971), and Unni (1971-72) report that deeper lakes tend to warm up and cool off more slowly than shallow lakes. This is also true for deep and shallow stations in the same lake or reservoir. This indicates that stratification will occur and disappear more quickly in shallow lakes, and persist for a longer time in deeper lakes. In any case, the rate of warming and cooling is influenced considerably by meterological factors such as air temperature and wind speeds. The effect of a cold spell is more immediate and great in shallow lakes. Begg (1970), McCombe (1959), Munavar (1970), and Rao (1971) report a direct relationship between monthly mean air temperature and water temperature. The tendency for lakes to stratify is usually prevented as a result of almost constant winds. Yount (1961) reports that in Florida heavy rainfalls and wind gusts can overturn shallow lakes. He also states that wind only can initiate overturns in small shallow lakes.

Thermal stratification has a profound effect on lake water quality. A major related interest is chemical stratification. Chemical stratification can occur even when thermal stratification does not exist. For example, when a highly mineralized and denser influent flows along the bottom of a large impoundment, chemical stratification exists.

In a thermally stratified situation the lighter warm water forms a cover over the denser bottom waters and prevents their receiving atmospheric reaeration. The lid also prevents the bottom water from circulating to the surface. The natural oxygen demand of this dense water removes the dissolved oxygen (DO) from solution and the DO concentration is gradually reduced to zero. This results in the hypolimnion becoming anaérobic and because of anaerobic decomposition of organic matter there is an increase in the concentration of carbon dioxide which lowers the pH of the hypolimnitic waters. The depletion of oxygen combined with low pH makes the hypolimnion a chemically-reducing environment.

Under anaerobic conditions changes tend to occur which further decrease water quality. McMahon (1969), Myers (1961), Walesh (1967), Weiss (1962), and Zafar (1964) studied the distribution of iron and manganese in lake waters and their findings can be summarized as follows:

(1) Acid waters hold more iron and manganese in solution and there is an inverse relationship between pH and the concentration of these elements.

(2) The relative solubility of iron and manganese varies with the oxidation-reduction potential of the solvent system. They are soluble in a reduced state and only slightly soluble in an oxidized state.

(3) The concentrations of iron and manganese in bottom waters are maximum before spring and fall circulation.

(4) The concentrations of iron and manganese increase from surface to bottom in a lake.

(5) Iron and manganese accumulate in deep, deoxygenated waters and are derived from the sediment, being released to the water when sufficient reducing conditions are established.

(6) Low concentrations of iron are helpful in accelerating the decomposition of organic compounds. In the presence of large amounts of organics and iron, chelation occurs and chelating compounds are precipitated.

A summary of the iron cycle according to Stumm and Morgan (1970) is given in Figure 3.

In addition to iron and manganese there are several other chemical constituents which undergo changes in concentrations in stratified

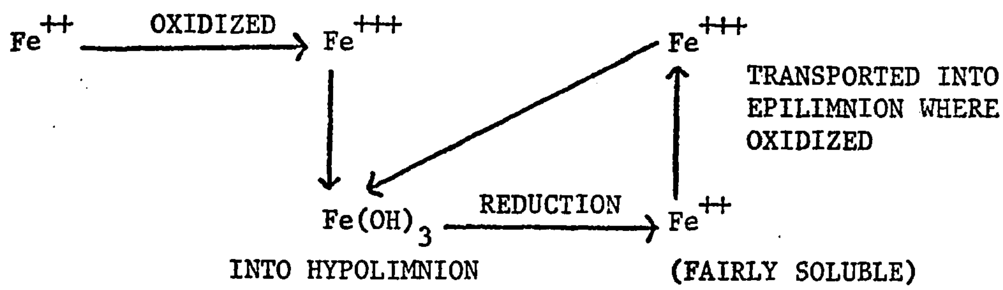

Figure 3. Iron Cycle

waters. Some of these are summarized as follows:

(1) The concentration of sulfates is higher in the epilimnion and the concentration decreases with depth. Sulfate is reduced to sulfide in the hypolimnion and this could result in taste and odor problems in water. Hydrogen sulfide in the hypolimnion is responsible for an increase in alkalinity and the possible precipitation of iron as ferrous sulfide.

(2) Several changes take place in the alkalinity of water. In the hypolimnion the alkalinity is higher and the pH is lower. Hutchinson (1957), Mann (1958), Munavar (1970), Rao (1971), Ruttner (1963), and Seenaya (1971) state that the high alkalinity is due to the presence of the carbonate cycle in water. According to Mann (1958) the fluctuations on bicarbonate are partly due to the removal of carbon dioxide during photosynthesis and the action of H_2SO_4 when the sulfide is oxidized in the winter. The carbonate system can be depicted as follows:

$$CO_2 + H_2O \rightleftharpoons H_2CO_3$$

$$H_2CO_3 \rightleftharpoons H^+ + HCO_3^-$$

$$HCO_3^- \rightleftharpoons H^+ + CO_3^=$$

When CO_2 is removed from the water due to algal photosynthesis the pH of the water increases according to

$$HCO_3^- + H^+ \rightleftharpoons H_2CO_3 \rightleftharpoons CO_2 + H_2O$$

This will also result in a decrease in the concentrations of $CO_3^=$ and HCO_3^-. However HCO_3^- can split according to

$$2HCO_3^- \longrightarrow CO_3^= + CO_2 + H_2O$$

The $CO_3^=$ combines with Ca^{++} to form $CaCO_3$ which is precipitated. The precipitated $CaCO_3$ reaches the hypolimnion and in the hypolimnion excess CO_2 is available due to anaerobic decomposition of organic compounds. The CO_2 reacts with $CaCO_3$ and forms $Ca(HCO_3)_2$ according to

$$CaCO_3 + CO_2 + H_2O \rightleftharpoons Ca(HCO_3)_2$$

This accounts for the increase in the alkalinity in the hypolimnion.

Mann (1958) states that the period of low oxygen concentration coincides with high bicarbonate and low sulfate; during the period of increasing oxygen saturation, the alkalinity decreases.

(3) The phosphorus content of the hypolimnion is higher. This is in part due to decomposition of plankton, but is primarily caused by liberation of phosphate from ferric phosphate in the sediments. Ferrous iron and phosphate react in the presence of oxygen in alkaline medium to form insoluble ferric phosphate, which is deposited in the lake sediments. When there is lack of oxygen in the sediments the iron is reduced from the ferric to ferrous state releasing phosphorus into water.

(4) Austin (1973), Seenaya (1971), Venkateswaralu (1969), Wang and Evans (1970), and Zafar (1964) report that there is an increase in ammonia content and a decrease in the nitrate concentrations in the summer months. The ammonia content is higher in the hypolimnion due to lower oxygen content and the nitrate content is minimum.

In addition to the above changes in hypolimnetic water quality anaerobic decomposition may produce some undesirable organics. These organics are undesirable because of taste and odor, and occasionally because of toxicity. Even the cold temperatures of these bottom waters can be considered polluting in that they might adversely affect downstream water uses.

Water quality deterioration in stratified reservoirs can be prevented by mixing the water either naturally or artificially. Supplemental aeration and mixing of lakes and reservoirs is complicated by stratification and the tremendous volume of water that must be moved. A method of oxygenation must provide for distribution of oxygen throughout the body of water or the water must be mixed to bring it in contact with oxygen at the surface. Most methods of supplemental aeration of impounded waters rely on mixing alone and do not attempt to add oxygen directly. Mixing brings the oxygen-deficient hypolimnion into contact with the atmosphere, where it absorbs oxygen naturally, breaks up stratification, and enables natural wind forces to contribute to further mixing action with the entire depth of water.

Until recently few attempts have been made to artifically control thermal stratification. One of the first attempts to mix a body of water was described by Hooper, Ball and Tanner (1952), and it involved pumping of water from the hypolimnion and returning it to the epilimnion. This small natural lake in Michigan has a volume of 3,151,000 cu-ft (89,100 cu.m.or 72 acre-ft), a mean depth of 20.3 ft and a maximum depth of 42.0 ft. A centrifugal pump powered by a 4 cylinder gasoline motor at the edge of the lake drew water with a temperature of 51°F from a depth of 39 ft. The water was returned to the surface of the lake near the middle by flowing over the edges of a barge that supported the pump discharge line. This rather crude mixing device was completely effective in mixing the cold hypolimnion water with the 76°F epilimnion water, and no cold water was detected returning to the bottom. Recirculation of about one-fifth of the volume of water in the lake over 10 days (244 hrs) lowered the upper limit of the thermocline from 13 to 25 ft (4m to 7.6m) below the surface of the lake. The mean temperature of the lake did not change significantly, but the epilimnion temperature dropped about 5°F. At the start of the pumping DO was about 8 mg/l from the surface to a depth of 27 ft. From a depth of 34 ft to the bottom (41 ft) the DO was zero. At the end of the pumping the depth of water with 8 mg/l DO was increased to 35 ft and the DO was more than 5 mg/l at all depths. There was an increase in the alkalinity of surface waters and no significant changes in turbidity in the epilimnion.

Most successful attempts to destroy stratification have used compressed air. The compressed air is not primarily intended to aerate the water but to create upward currents and to lift the bottom waters to the surface where they can absorb oxygen from the atmosphere. This technique was tried by Derby (1956) in 1953 in the Lower Hollywood Reservoir (area of 82 acres, volume of 4000 acre-ft) and the Encino Reservoir (area of 80 acres, volume of 3000 acre-ft). Compressed air was introduced from the bottom through perforated hoses. The thermocline was lowered in both reservoirs.

Riddick (1957) reported the first highly successful attempt of using compressed air to mix a reservoir. Using only an 8 horsepower compressor to supply 160 cfm of air at a depth of 7.5 ft (2.3 m) to a floating aerator, an 80 million gallon (246 acre-ft) reservoir at Ossining, New York, was completely destratified and recirculated almost twice a day. The DO content at the 20 ft (6.1 m) depth increased from 1 mg/l to 6 mg/l in two days. The DO content at the 25 ft (7.6 m) depth increased from 0.4 to 7 mg/l in 7 days. Initially the epilimnion was about 95 to 100 percent saturated. Riddick also reported a uniform pH of 6.9 from surface to bottom. The concentrations of carbon dioxide, color, iron and phytoplankton decreased in the bottom.

Compressed air was also used to destratify polluted Swedish lakes beginning in 1959. Lake Langsjon was mixed by compressed air from a 500 meter long perforated plastic hose laid on the bottom of the lake. Heath (1961) reported that in less than three weeks the oxygen content of the water increased from zero to 57 percent saturation, new plant life appeared, and the original temperature differential of 12°F disappeared.

One of the most successful trials of compressed air mixing, from the standpoint of quick results for the air used, was reported by Ford (1963). Lake Wohlford in California covers 222 acres (90 hectares) and is long and narrow, 7000 ft (2100 m) by 1200 ft (370 m). It contains 7,000 acre-ft (8,640,000 cu.m.) and has a maximum depth of 80 ft (24 m). A single perforated 1.5 inch plastic pipe was placed about 1200 ft (370 m) above the dam, perpendicular to the long axis of the lake, and suspended 5 ft (1.5 m) off the bottom. An air compressor powered by a 50 hp electric motor installed on the lake side supplied 210 cfm of air. After only six days of intermittent operation, about 40 percent of the time, stratification was completely eliminated throughout the lake. The top to bottom temperature differential dropped from 16.5°F to 2.0°F and the entire lake then contained about 8 mg/l of oxygen. All taste and odor problems disappeared and the chlorine demand decreased. The lake was kept in circulation throughout the summer by intermittent mixing.

While some attempts of mixing were most successful, one of the unsuccessful experiments was described by Patriarche (1961). He described the mixing of two shallow Michigan lakes with compressed air pumped through a perforated rubber hose. He found this treatment ineffective in preventing depletion of DO.

The Cincinnati Water Research Laboratory conducted a series of experiments between 1964 and 1966 on artificial destratification using both mechanical pumping and compressed air. Irwin, Symons and Robeck (1966) conducted destratification experiments at four different lakes in Ohio varying in volume from 98 to 1,260 acre-ft. The maximum depth varied between 17 to 30 ft. All four lakes were well-protected from the wind by hills and trees. Each impoundment was thermally and chemically stratified in early sping and remained stratified until the fall. The mixing device was a 2,880 gpm (13 acre-ft per day) mixed-flow pump driven by a 16 hp gasoline engine. The pump, which was mounted on a raft positioned over the deepest part of each lake, drew water from just above the bottom and discharged it at the surface. The 1260 acre-ft lake was pumped for about 200 hours in a semi-continuous fashion, while the pumping time for the other lakes varied between 8 and 35 hours. From these experiments conducted in the summer of 1964 the following conclusions were drawn:

(1) temperature was nearly isothermal in all lakes,

(2) some DO appeared at all depths,

(3) impoundments thermally restratify after pumping is stopped (completed) and

(4) an entire lake could be destratified with on pumping location.

In August, 1965 the mechanical pumping device was placed in Boltz Lake in northern Kentucky. The lake has a surface area of 96 acres and a volume of about 2,900 acre-ft. Bullock Pen Lake, a lake with a similar size and shape (142 surface acres and about 3,200 acre-ft volume) a few miles from Boltz Lake was chosen as a "control" for the experiment.

Important water quality parameters were measured weekly at various depths at the pump site in the test lake and near the dam in the control lake throughout the summer of 1965. The gasoline engine size used was 26 hp. The test lake was pumped for five weeks between August 6 and September 10, 1965. Symons, Irwin and Robeck (1967) stated that artificial destratification warmed the lower layers of the test lake and DO was present at all depths. The pumping operation added DO to the lower layers of the test lake and caused oxidation of sulfides and manganese in the bottom. Mixing did not bring large quantities of nutrients of the surface and did not cause algal blooms. Blue-green algae counts were reduced more than green algae counts.

To reduce the energy imput, a diffused-air pump was used in the spring and summer of 1966. In addition to the change in the equipment, in the 1966 test Symons, Irwin, Robinson and Robeck (1967) investigated the technique of water quality maintanence by early and periodic mixing instead of water quality improvement by one late mixing. Also another test lake, Falmouth Lake (area 225 acres and volume 4,600 acre-ft) was added to the experiment. The equipment used was a 22.4 kilowatt-hour portable air compressor that delivered about 115 cfm of air at 30 to 40 psi. The air was released through 16 porous ceramic diffusers spaced at 3-foot intervals in a cross pattern. From the 1966 experiments the following conclusions were drawn:

1. Mixing caused a sharp temperature rise in lower waters and some temperature decline in surface waters.

2. Stratification was eliminated during mixing.

3. Nitrate, ammonia and soluble phosphorus concentrations at the surface increased; however, no algal blooms occurred.

4. The DO concentrations in the bottom waters were increased.

5. High Mn^{+2} concentrations in lower waters were avoided.

6. Mixing did not affect the concentrations of Fe^{+2}, conductivity, sulfate and alkalinity.

7. Green algae predominated instead of blue-green algae.

Symons, Carswell and Robeck (1970) summarized the results of the artificial destratification experiments conducted from 1964 through 1966 as follows:

1. Artificial destratification by a mechanical or diffused air pump was an effective method of improving water quality in reservoirs or maintaining good quality water in reservoirs, or both.

2. Artificial destratification created a uniform temperature throughout the reservoir depth; added DO to the water; oxidized the reduced materials such as sulfide, reduced iron, and manganese, or prevented their formation; and did not impair the clarity of water.

3. Although some nitrogen and phosphorus was brought to the surface during artificial destratification, increased algal populations did not occur. Plankton populations decreased temporarily and shifted in predominance toward green algae.

4. Periodic mixing maintained water quality more effectively than one mixing.

5. Reservoir water quality control should begin in the spring or early summer and be continued throughout the summer to minimize quality deterioration.

Since the work by Symons, et al, destratification has been tried in several reservoirs. One of the methods used is the "Air-Aqua" system designed and engineered by Hinde Engineering Co. The system consists of specially formulated polyethylene aeration tubing which has been machine processed to die-form thousands of check values, polyethylene headered feeder tubing, and a compressor which supplies oil-less compressed air. The aeration tubing has a continuous strip of lead "Keel" encapsulated with a flexible sheath to keep the check valves in an upright position. Air is supplied continuously and released through the check valves in a stream of pin point bubbles which rise to form linear screens. Because of the introduction of air in the hypolimnion, vertical circulation is created and the water is mixed.

The "Air-Aqua" system was studied in the Laurel Run Reservoir and Milcreek Reservoir in the summer of 1965 by Ogborn (1966). Laurel Run Reservoir has a volume of 75 million gallons and Milcreek Reservoir has a volume of 55 million gallons. Both reservoirs stratified in the summer and oxygen depletion and septic conditions occurred in the hypolimnia. After adding 22 cfm of air for 45 hours in the Laurel Run Reservoir, the temperature gradient was reduced form 17.1°F to 1.5°F and the DO in the bottom waters increased from 0 to 6.5 mg/l. After 67 hours of aeration (14.8 cfm of air), in the Milcreek Reservoir the temperature difference was reduced from 12.0°F to 4.4°F, the DO in the surface changed from 8.5 to 6.5 mg/l, and the DO in the bottom increased from 2.8 to 5.8 mg/l. Ogborn (1966) stated that the taste and odor problems and undesirable color and turbidity were eliminated due to aeration.

Burns (1966) fed compressed air at approximately 30 lbs. pressure into the Escondido Reservoir in California from 40 ft below the surface. The operation lasted for 34 hours over a two-week period. He stated that the surface to bottom temperature difference was reduced from 12-14°F to 0.5°F. The chlorine use in the water treatment plant was reduced from 140 lbs to 40 lbs per million gallons.

Bernhardt (1967) used the "Diffused Air Bubble" method and hypolimnion aeration in the aeration of Wahnbach Reservoir. This reservoir has an area of 530 acres and a volume of 33,740 acre-feet. In 1964, 210 cfm of air was added to the bottom water. Aeration was accomplished from January 11 to November 11, 1964. From July 7 to November 14, 1966, the hypolimnion aeration method was used. During hypolimnion aeration the reservoir was not completely mixed; only the hypolimnion was oxygenated. This kept the bottom water cold and the temperature profile of the reservoir was not affected. Both aeration methods improved the water quality of the reservoir. During operation with both techniques the oxygen concentration was maintained above zero in the hypolimnion and the Mn(II) concentration was maintained near zero throughout the summer.

Brezonik, Delfino and Lee (1969) used six aerator guns or aero hydraulic guns in destratification experiments at Cox Hollow Lake in Wisconsin. It has an area of 96 acres and a maximum depth of 9 meters. Six aerator guns were operated continuously for one month starting on July 1, 1966. According to the authors the lake was completely destratified and there was no evidence of stable thermal stratification after initial destratification. The DO was available at all depths and a marked decrease occurred in the hypolimnetic manganese content.

Destratification experiments were conducted at Lake Maarsseveen near Rotterdam, Netherlands by Knoppert, Rook, Hofkner and Oskam in the summer of 1967. Lake Maarsseveen covers 150 acres and has a volume of 6500 acre-feet. An air input of 88 cfm was used between August 3 and September 18, 1967. Surface temperatures were decreased and complete isothermal conditions were achieved on September 18, 1967. The authors reported high DO concentrations and decreases in alkalinity, ammonia and nitrates.

Laverty and Nielsen (1970) aerated Lafayette Reservoir, a 1.385 billion gallon artificial lake. They used a gasoline engine compressor with a discharge pressure of 50 psig and air flow of approximately 60 cfm. Aeration was started in December, 1967, and stopped in January, 1969, with a break between March 15 and March 31, 1968. They reported that stratification was completely eliminated and the surface and bottom temperatures were the same by August, 1968. According to the authors a modest increase in aeration time during the months of April, May and June could have produced isothermal conditions much earlier than August. They arrived at the following conclusions:

1. The reservoir surface temperature was lowered, thus resulting in reduced evaporation losses, and

2. The DO concentration started to increase after approximately three weeks of aeration, and by late July the DO concentrations of the surface and bottom waters were nearly equal. The authors stated that "a reservoir with a history of taste and odor problems relative to water quality degradation can, if properly aerated and managed, be used as a domestic water supply with minimal aeration cost."

In 1968 and 1969 Casitas Reservoir in California was destratified using compressed air (Barnett, 1971). In 1968 the reservoir storage was 128,000 acre-ft, the surface area was 1,750 acres, and the maximum depth was 210 feet. The reservoir had a history of stratification starting in May and reaching a maximum in August. The hypolimnion extended from 30 feet and near anaerobic conditions existed in the hypolimnion. The concentrations of manganese and hydrogen sulfide were very high in the hypolimnion. The reservoir was aerated from the bottom using a 600-cfm diesel operated rotary compressor for air supply. Six diffusers were used. The 24 hr/day aeration was started on June 20, 1968 and stopped on November 20, 1968. In 1969 the storage was 197,000 acre-ft, and aeration was 12 hrs/day from May 5 to 26, and 24 hrs/day from May 27 to October 17. Aeration was accomplished using a floating feeder system with the 600 cfm air compressor. Four diffusers containing 3/16 in. diameter holes each were set at a depth of 130 ft (120 ft above reservoir bottom). As a result of aeration no significant amount of manganese was found in the upper 120 ft of the lake. An excess of 3 mg/l dissolved oxygen was present in the upper 50 ft and a measurable amount was present down to the 100 ft level. Chemical characteristics such as TDS and hardness were not affected. Taste and odor threshold numbers did not exceed 2. In 1970 the aeration was from April 7 to October 16 and the results were very similar to those obtained in 1969.

Rapoza (1971) used an "Air-Aqua" system designed by Hinde Engineering Co. to aerate the Greenville Reservoir in New Hampshire. This reservoir has a capacity of 750 million gallons. Air was supplied by eight 3/4 hp electric motor driven compressors, each delivering 4.3 cfm of air. The aeration system was installed in the winter of 1970. The DO was increased from 0 to 11.4 mg/l in the bottom, while iron, manganese and turbidity were reduced. Uniform temperatures were achieved throughout the 23-ft reservoir.

Biederman and Fulton (1971) destratified the Waco Reservoir in Waco, Texas, using a gasoline-powered air compressor which delivered 110 cfm of air. The Waco Reservoir has a volume of 104,100 acre-ft and an area of 7,270 acres. It has a maximum depth of 85 ft and an average depth of 35 ft. The reservoir remains stratified between May and October and no oxygen is available below 35 ft. The entire reservoir was destratified by the air introduction and DO was maintained throughout the major portion. No algal blooms occurred and no severe taste and odor problems were noted. The concentrations of iron and manganese were reduced. Artificial destratification had no effect on pH, alkalinity, hardness and chlorides.

Shuler (1972) used an "Air-Aqua" system designed by Hinde Engineering Co. to destratify the 273-million gallon Rankin Lake. Air was supplied by nine-3/4 hp compressors each delivering 4.4 cfm of air at 30 psi. Due to the aeration, taste and odor problems were elininated. DO became available at all depths, and less chlorine was required in the lake water treatment plant.

Weiss and Breedlove (1973) used an "Air-Aqua" system to destratify the University Lake at Chapell Hill, North Carolina. During the first year of their experiment (1970) 1/2 hp compressors were used and during the second year (1971) 3/4 hp compressors were used. The air lift pattern was concentrated in the deepest portion (30 ft) of the lake and four diffusers were used. They reported that the temperature difference between the epilimnion and the hypolimnion was decreased from 10°C to 1-2°C. The DO was available at all depths. The epilimnion pH showed a downward trend, and the turbidity, ammonia, soluble phosphorus, iron and manganese were reduced in the bottom waters. There was a shift in the phytoplankton population from blue-green to green algae.

The Union Carbide research department (Anonymous, 1974) attempted hypolimnion aeration using direct aeration with compressors and Side Stream

Pumping (SSP) using diffusers and pure oxygen. The experiments were conducted in August, 1972 and July, 1973. Direct aeration was tried using a "Limno" aerator manufactured by Atlas Copco Co., Sweden, in two small lakes in New York with surface areas of 66 and 132 acres. Compressed air from a shore-based compressor was carried through a submerged plastic pipe to two porous diffusers at the lake bottom. The air compressor supplied 280 cfm of air to two diffusers. The SSP was tried in a small lake in New York (11 acres) and in Ohio (2 acres). A pump on shore pumped water from the hypolimnion, raising the pressure. Oxygen in the gas phase was introduced into the water discharge line of the pump. The pressurized water together with the oxygen was discharged to a preselected location in the hypolimnion. All four lakes showed stratification during summer and the hypolimnion oxygen concentration was close to zero. Because of the oxygenation of the hypolimnion either by direct aeration or by the SSP, it was possible to increase the DO of the hypolimnion water without increasing the temperature to a great extent. Other changes which took place include a higher pH in the hypolimnion and a decrease of phosphates and turbidity in the hypolimnion. Alkalinity and nitrogen forms were not affected.

Leach, Duffer and Harlin (1970) studied hypolimnion aeration in Lake Eufaula (volume 2,800,000 acre-ft, area 102,500 acres) in Oklahoma in the summer of 1968. The central pool where the major portion of the research was conducted had a surface area of 10,800 acres and a volume of 570,000 acre-ft. An electric compressor placed on the top of the dam delivered 1200 cfm of air to the distributor system on the lake bottom. The distributor system was located 750 ft upstream of the power penstock intakes. Prior to this aeration Lake Eufaula exhibited thermal stratification beginning in July. The dissolved oxygen concentration was constant to a depth of about 30 ft. and then decreased rapidly to zero at the 60 to 70 ft. depth. The dissolved oxygen concentration in the power releases was reduced to 3 mg/l. The authors reported that after 25 days of continuous aeration the temperature differential between the surface and the bottom was reduced from 10°C to 7°C, and the DO concentrations increased below the 40 ft. depth. The authors also reported that because of aeration, the DO concentration was increased in down-stream releases between 55 and 80 percent above the concentration during static stratified conditions.

Garton, Rice and Steichen (1976) destratified a small stratified lake (volume of 115 ha-m, area of 40 ha) using a low power, high-volume axial flow pump by moving oxygen-rich surface water to the bottom to induce mixing of the lake. The lake had no DO below four meters during the summer. They stated that within two weeks the pump completely destratified the lake thermally, but longer time was required to destratify the DO. A uniform pH was also obtained throughout the body of water.

The AWWA's Quality Control in Reservoir Committee recently sent out questionnaires to 37 water utility managers who used artificial destratification (JAWWA, September 1971). A total of 79 percent responded and supplied data on 29 different reservoirs. One-third of the units were operated continuously, one-third continuously during the summer and one-third intermittently during the summer. Destratification was used to overcome the classical problems of quality degradation associated with anaerobic conditions in reservoir hypolimnia. A total of 86 percent of the respondents considered that destratification was a success and reported some combination of improved water treatment, improved raw water quality, improved finished water quality, and improved aesthetics in the reservoirs. Continuation of mixing operations were planned by 90 percent of the respondents.

CHAPTER III

WATER QUALITY FOR LAKE THUNDERBIRD PRIOR TO JUNE, 1974

Lake Thunderbird has been under investigation since 1967 by Oklahoma State Department of Health (OSDH). From May 1967 to June, 1974, the surface water of the lake was sampled 15 times by OSDH. Faculty and students from the Department of Zoology and the School of Civil Engineering and Environmental Science at the University of Oklahoma, Norman, Oklahoma, have conducted several water quality studies of Lake Thunderbird. Klehr (1967-68) and DeNoylles (1973) performed depth sampling of the lake. Canter (1973) conducted a water quality study from June through November, 1973, and reported monthly averages of various water quality parameters. In order to utilize this base-line information on water quality for Lake Thunderbird, the sampling locations of previous studies were used in selecting the sampling stations of the present study. Base-line water quality data are presented in Tables 8 A-D.

Due to the wide variance of the reported values (Tables 8 A-D) of each water quality parameter, it is difficult to arrive at the overall water quality of the lake. However, it is possible to derive value ranges for each water quality parameter and these are reported in Tables 9 A-D and discussed as follows.

TABLE 8-A

WATER QUALITY FOR LAKE THUNDERBIRD--FALL
(September, October & November)

DATE	Depth meters	Temperature °C	DO mg/1	DO % Saturation	pH	Alkalinity mg/1 as $CaCo_3$	Turbidity J.T.U.	TDS mg/1	Ortho $Po_4^{\equiv}$ mg/1	Total $Po_4^{\equiv}$ mg/1	NO_2^- mg/1	NO_3^- mg/1	NH_3 mg/1	Org.N. mg/1	Iron mg/1
STATION 1															
10/20/67	0				8.6	182	46	280							
9/26/68	1	23.5	7.1	85.3	7.9	180	30	240	.18						.25
	7	23.0	7.0	83.5	7.9	180	38	240	.24			.45			.30
10/1/68	0				8.3	170		230							0
9/25/69	0				8.2	208		320							.10
10/12/72	0	22.0			8.0	180	15	280		.01	.01	.10	.10	.50	.40
10/28/73	0	18.0			7.95		12	290	.002			2.1			.43
	3				8.10		25								.21
	7				8.20		48								.04

TABLE 8-A

WATER QUALITY FOR LAKE THUNDERBIRD--FALL
(September, October & November)
(Continued)

DATE	Depth meters	Temperature °C	DO mg/1	DO % Saturation	pH	Alkalinity mg/1 as $CaCo_3$	Turbidity J.T.U.	TDS mg/1	Ortho $Po_4^{\equiv}$ mg/1	Ortho $Po_4^{\equiv}$ mg/1	NO_2^- mg/1	NO_3^- mg/1	NH_3 mg/1	Org.N mg/1	Iron mg/1
STATION II															
10/20/67	0				8.6	52	26	240							
11/15/67	0	12.6	10.9	106	8.6	180	19.8	278	.028	.28	.01	.166	.54K*		<.1
	3	12.0	10.7	102	8.6	180	24	280	.02	.32	.01	.490	.60K		<.1
	6.5	12.0	10.3	98.7	8.6	180	25	281	.01	.22	.01	.090	.60K		<.1
	9	12.0	10.4	99.7	8.6	180	32	270	.04	.44	.01	1.20	.66K		<.1
9/26/68	1	23.0	7.1	84.7	7.8	176	45	240	.12			.10			.25
	11	23.0	6.5	77.6	7.8	172	51	220	.18			.15			.30
10/4/68	0				8.1	162		230							0.1
9/25/69	0				8.2	204		330							0.5
10/12/72	0	22	10	119	7.9	185	9	270		.01	.01	.10		.30	.15

*Kjeldhal's nitrogen

TABLE 8-A

WATER QUALITY FOR LAKE THUNDERBIRD--FALL
(September, October & November)
(Continued)

DATE	Depth meters	Temperature °C	DO mg/1	DO % Saturation	pH	Alkalinity mg/1 as $CaCo_3$	Turbidity J.T.U.	TDS mg/1	Ortho $Po_4^{\equiv}$ mg/1	Total $Po_4^{\equiv}$ mg/1	NO_2^- mg/1	NO_3^- mg/1	NH_3 mg/1	Org.N mg/1	Iron mg/1
STATION II (CONT.)															
10/27/73	0	19.3	7.7	85.9											
	B	19.3	7.5	83.7											
10/28/73	0	18.7	7.0	77.3	8.0		35	270	.0032			2.07			.09
	3		5.5		8.15		30								.43
	6		6.8		8.15		25								.21
	10		6.7		8.20		27								.21
Avg. Sept.		25.5	6.35	78.9	8.23		9	223	.034			.84			.43
Oct.		20.0	5.60	63.3	8.70		25	230	.003			1.53			4.5
Nov.		18.7	7.0	77.3	8.10		35	200	.0022			2.07			.09

TABLE 8-A

WATER QUALITY FOR LAKE THUNDERBIRD--FALL
(September, October & November)
(Continued)

DATE	Depth meters	Temperature °C	DO mg/l	DO % Saturation	pH	Alkalinity mg/l as $CaCo_3$	Turbidity J.T.U.	TDS mg/l	Ortho $Po_4^{\equiv}$ mg/l	Total $Po_4^{\equiv}$ mg/l	NO_2^- mg/l	NO_3^- mg/l	NH_3 mg/l	Org.N mg/l	Iron mg/l
<u>STATION III</u>															
10/20/67	0				8.6	56	70	250							
9/26/68	1	23.0	7.2	86.0	7.8	180	60	240	.17			0			.30
	5	23.0	6.9	82.3	7.8	180	60	240	.17			.05			.30
	9	23.0	6.9	82.3	7.8	174	70	240	.20			.225			.30
10/1/70	0				7.0	142	28								.14
11/2/70	0				7.7	140	25								.15
10/12/72	0	22.0	10.0	117	8.5	188	93	270		.01	.01	0	.20	.60	.15
9/5/73	S		6.0												
	B		6.0												
9/7/73	S		6.8												

TABLE 8-A

WATER QUALITY FOR LAKE THUNDERBIRD--FALL
(September, October & November)
(Continued)

DATE	Depth meters	Temperature °C	DO mg/1	DO % Saturation	pH	Alkalinity mg/1 as $CaCo_3$	Turbidity J.T.U.	TDS mg/1	Ortho $Po_4^{\equiv}$ mg/1	Total $Po_4^{\equiv}$ mg/1	NO_2^- mg/1	NO_3^- mg/1	NH_3 mg/1	Org.N mg/1	Iron mg/1
STATION III (Cont.)															
9/7/73	B		6.4												
9/12/73	S		8.0												
	B		3.75												
9/14/73	S		6.4												
	B		5.9												
10/27/73	S	20.0	7.7	87.1											
	B	20.0	7.5	84.8											
10/28/73	0	18.3	6.2	67.9	8.2		23	280	.0015			3.06			.13
	3		6.8		8.25		21								.23
	6		6.8		8.2		28								.93
	10		5.1		8.25		45								.19
Avg. Sept.	0	26.17	6.8	85.4	8.5		15	207	.033			1.14			.38
73 Oct.	0	20.0	6.4	72.3	8.7		29	220	.0026			1.43			.171
Nov.	0	18.3	6.2	67.9	8.25		23	240	.0015			3.06			.130

TABLE 8-A

WATER QUALITY FOR LAKE THUNDERBIRD--FALL
(September, October & November)
(Continued)

DATE	Depth-meters	Temperature °C	DO mg/1	DO %Saturation	pH	Alkalinity mg/1 as $CaCo_3$	Turbidity mg/1	TDS mg/1	Ortho $Po_4^{\equiv}$ mg/1	Total $Po_4^{\equiv}$ mg/1	NO_2^- mg/1	NO_3^- mg/1	NH_3 mg/1	Org.N mg/1	Iron mg/1
STATION IV															
9/26/68	3	22.0			7.5	174	190	200	.32			.50			.65
STATION V															
9/25/69	0				8.3	220		310							.70
10/28/73	0	18.0			8.1		68	270	.0031			2.68			.21
Avg. Sept.	0	24.0	7.1	86.1	8.3		54	218	.0058			1.45			2.68
1973 Oct.	0	21.75	7.00	82.2	8.6		25	417.5	.0061			3.03			1.85
Nov.	0	18.0			8.3		68	270	.0031			2.68			0.21

TABLE 8-B

WATER QUALITY FOR LAKE THUNDERBIRD--WINTER

(December, January and February)

DATE	Depth-meters	Temperature °C	DO mg/1	DO % Saturation	pH	Alkalinity mg/1 as $CaCo_3$	Turbidity mg/1	TDS mg/1	Ortho $Po_4^{\equiv}$ mg/1	Total $Po_4^{\equiv}$ mg/1	NO_2^- mg/1	NO_3^- mg/1	NH_3 mg/1	Org.N mg/1	Iron mg/1
STATION I															
12/18/67	0	5.0	12.1	97.8	8.3	186	21	300	.06	.11	.02	.60	0.56K*		.05
	6	5.0	12.2	98.6	8.3	190	23	300	.09	.16	.01	.30	0.50K		.05
12/12/73	0	8.0	9.5	82.8	7.5	173	16	255		.01	.01	.30		1.0	.40
1/30/74	0	4.4	10.5	79.5	8.1	179	3.6	279		<.01	.01	<.10		.6K	.10
STATION II															
12/18/67	0	5.0	12.1	97.8	8.3	188	23	300	.09	.14	.01	.30	.50K		.06
	9	5.0	12.0	97.0	8.3	192	32	290	.06	.13	.01	.40	.56K		.07
12/7/68	0	7.0	11.8	100	8.4	198									
	2	7.0	11.7	99.5	8.2	194									

*Kjeldhal's nitrogen

TABLE 8-B

WATER QUALITY FOR LAKE THUNDERBIRD--WINTER
(December, January and February)
(Continued)

DATE	Depth-meters	Temperature °C	DO mg/1	DO % Saturation	pH	Alkalinity mg/1 as $CaCo_3$	Turbidity J.T.U.	TDS mg/1	Ortho $Po_4^{\equiv}$ mg/1	Total $Po_4^{\equiv}$ mg/1	NO_2^- mg/1	NO_3^- mg/1	NH_3 mg/1	Org.N mg/1	Iron mg/1
STATION II (Cont.)															
12/7/68	4	7.0	11.5	97.8	8.2	194									
	6	7.0	11.7	99.5	8.3	190									
	8	7.0	11.4	97.0	7.8	191									
	10	7.0	11.5	97.8	8.1	176									
1/8/68	0	3.2	12.9	99.4	8.1	180	8.6	307	.116	.146	.01	.15	$.50^K$		.06
	3	3.5	12.8	99.5	8.2	178	8.5	305	.115	.145	.01	.19	$.545^K$		.05
	6	3.5	12.8	93.8	8.1	180	22	315	.110	.170	.01	.19	$.560^K$		.10
	8	2.5	12.4	93.8	8.2	176	5	320	.140	.070	.01	.19	$.560^K$		.05
12/19/73	0				7.9	171	7.5	249		.010	.01	.30		.60	.08
1/30/74	0	2.8	12.5	99.5	8.1	176	3.2	264		<.01	<.01	.20		.5K	.10

TABLE 8-B
WATER QUALITY FOR LAKE THUNDERBIRD--WINTER
(December, January and February)
(Continued)

DATE	Depth-meters	Temperature °C	DO mg/l	DO % Saturation	pH	Alkalinity mg/l as $CaCo_3$	Turbidity J.T.U.	TDS mg/l	Ortho $Po_4^{\equiv}$ mg/l	Total $Po_4^{\equiv}$ mg/l	No_2^- mg/l	No_3^- mg/l	NH_3 mg/l	Org.N mg/l	Iron mg/l
STATION III															
12/18/67	0	4.5	12.3	98.1	8.3	188	22	300	.04	.22	.01	.40	$.66^K$		.07
	2	4.5	12.2	97.3	8.3	190	23	300	.04	.22	.01	.30	$.56^K$		.05
	4	4.5	12.3	98.1	8.3	190	35	300	.04	.21	.01	.30	$.53^K$		.06
1/28/69	0				8.3	164		230							0
12/1/70	0				7.6	140	12								.11
1/25/71	0				7.9	144	8								.07
2/23/71	0				7.8	146	8								.04
12/19/73	0	9	11.0	98.3	7.8	169	8.5	235		.01	.01	.30		.50	.08
1/30/74	0	3.3	12.0	92.7	7.5	196	3	309		<.01	.02	<.1		.6K	.13
STATION IV															
12/18/67	3.5	3.5	12.4	96.3	8.3	210	29	320	.06	.22	.01	.20	$.56^K$		.07
STATION V															
12/19/73	0	8.0	11.5	100	7.8	173	15	243		.30	.01	.30		.80	.15
1/30/74	0	4.4	11.0	87.5	8.2	201	46	297		.04	.02	.30		.80	.10

TABLE 8-C

WATER QUALITY FOR LAKE THUNDERBIRD--SPRING

(March, April and May)

DATE	Depth-meters	Temperature °C	DO mg/1	DO % Saturation	pH	Alkalinity mg/1 as $CaCo_3$	Turbidity J.T.U.	TDS mg/1	Ortho $Po_4^{\equiv}$ mg/1	Total $Po_4^{\equiv}$ mg/1	No_2^- mg/1	No_3^- mg/1	NH_3 mg/1	Org.N mg/1	Iron mg/1
STATION I															
5/23/67	0					136		260							
4/24/68	0	18.0	8.2	89.3	7.6	172	80	280	0			.20	1.0^{K}		
	7	17.0	8.2	87.5	7.8	172	90	280	0			.30	0.92^{K}		
5/5/69	0				8.4	220		320							.10
5/6/70	0				8.5	188		294							.40
3/10/71	0				8.0	165		280							.09
3/10/72	0	10.0	11.0	87.5	7.5	167	17	310		.05	.01	.05	.10	.30	.13
5/17/73	0	17.0	10.0	107	8.4	160	12	240		.25	.01	.20		1.7K	.18
STATION II															
4/24/68	0	18.0	8.3	90.4	7.7	176	120	285	0		.01	.30	$.77^{K}$		

TABLE 8-C
WATER QUALITY FOR LAKE THUNDERBIRD--SPRING
(March, April and May)
(Continued)

DATE	Depth-meters	Temperature °C	DO mg/l	DO % Saturation	pH	Alkalinity mg/l as $CaCo_3$	Turbidity J.T.U.	TDS mg/l	Ortho $Po_4^{\equiv}$ mg/l	Total $Po_4^{\equiv}$ mg/l	No_2^- mg/l	No_3^- mg/l	NH_3 mg/l	Org.N mg/l	Iron mg/l
STATION II (Cont.)															
4/24/68	12	16.0	8.2	85.8	7.9	172	135	285	.02			.40	.77[K]		
5/5/69	0				8.4	228		320							0.1
5/6/70	0				8.5	180		282							.04
3/10/71	0				8.4	78		280		.01		.40			.11
3/10/72	0	9.0	11.0	98.3	8.4	178	17	290		.003	.01	.05	.10	.65	.15
5/15/73	0	28.0	9.0	116		177				.02		.10			
STATION III															
3/11/68	0				8.4	182	40	280							.10
3/5/69	0				7.8	174		260							.20
3/26/69	0					184		1260							.90

TABLE 8- C
WATER QUALITY FOR LAKE THUNDERBIRD--SPRING
(March, April and May)
(Continued)

DATE	Depth-meters	Temperature °C	DO mg/1	DO % Saturation	pH	Alkalinity mg/1 as $CaCo_3$	Turbidity J.T.U.	TDS mg/1	Ortho $Po_4^{\equiv}$ mg/1	Total $Po_4^{\equiv}$ mg/1	No_2^- mg/1	No_3^- mg/1	NH_3 mg/1	Org.N mg/1	Iron mg/1
STATION III (Cont.)															
3/10/71	0				8.0	165		270							.18
3/22/71	0				7.7	140	6								.07
4/29/71	0				7.7	240		380							.04
4/13/73	0	12.0	10.7	103	8.0	160	36	235							
	2	11.8	9.8	93.5	7.9	158	28	235							
	4	11.7	9.9	94.3	7.9	160	30	240							
	6	11.6	9.8	93.1	8.0	160	22	240							
	8	11.5	9.9	93.8	8.0	160		240							
	10	10.5	9.2	85.2	8.0	164		240							
4/19/73	0	14.4	9.7	98.1		157		234							

TABLE 8-C
WATER QUALITY FOR LAKE THUNDERBIRD--SPRING
(March, April and May)
(Continued)

DATE	Depth-meters	Temperature °C	DO mg/1	DO % Saturation	pH	Alkalinity mg/1 as $CaCo_3$	Turbidity J.T.U.	TDS mg/1	Ortho $Po_4^{\equiv}$ mg/1	Total $Po_4^{\equiv}$ mg/1	No_2^- mg/1	No_3^- mg/1	NH_3 mg/1	Org.N mg/1	Iron mg/1
STATION III (Cont)															
4/19/73	2	14.2	9.7	97.7		155		238							
	4	14.2	9.6	96.7		160		238							
4/20/73	0	15.3	9.8	101	8.2	164		230							
	2	14.7	9.7	98.7	8.3	162		230							
	4	14.2	9.7	97.7	8.4	160		230							
	6	13.4	9.4	93.0	8.4	160		234							
	8	12.9	9.0	88.1	8.4	158		237							
	10	12.6	9.0	87.5	8.4	155		238							
STATION IV															
4/24/68	3	16.0	8.2	85.8	7.9	198	400	210							
STATION V															
5/5/69	0				8.0	256		360							.10
5/6/70	0				8.3	176		277							.04
3/10/72	0	11.0	11.0	103	8.4	201	22	320		.013	.01	.05	.10	.65	.17
5/15/73	0					193				.010					
5/17/73	0	17	10	107	8.1	184	27	200			.01	.30		1.3K	.40

TABLE 8-D

WATER QUALITY FOR LAKE THUNDERBIRD--SUMMER

(June, July and August)

DATE	Depth-meters	Temperature °C	DO mg/1	DO % Saturation	pH	Alkalinity mg/1 as $CaCo_3$	Turbidity J.T.U.	TDS mg/1	Ortho $Po_4^{\equiv}$ mg/1	Total $Po_4^{\equiv}$ mg/1	No_2^- mg/1	No_3^- mg/1	NH_3 mg/1	Org.N mg/1	Iron mg/1
STATION I															
6/12/68	0	28.5	9.4	122	8.6	228	40	245	.02			.60	.77K		
	9.5	22.8	2.5	29.7	8.6	168	70	200	.06			.40	.83K		
7/25/68	0	29.0	7.8	102	8.8	208	20	240	.11			.50	.56K		
	8.5	26.0	1.0	12.5	8.6	208	50	245	.09			.50	.86K		
7/7/70	0				8.1	207		321							.11
7/29/71	0	18.0	11.0	119.8	8.3	195		300		.39	.01	.10	.10	.10	.15
6/27/73	1	26.8	7.5	95	8.2	157.5	20	220	.01						.14
	4	26.8	7.8	98.8	8.4	156	12	215	.01						.15
	8	26.4													
	9	22.0	6.2	72.7	7.8	155	17	215	.015						.30
8/15/73	0	29.0	9.5	124	8.1	174	9.5	256		.01	.01	.60		.70	.13
July '73	0	29.0	6.65	87.0	8.38		13	211	1.31	1.31		.61			.45
Aug '73	0	26.66	6.03	76.3	8.30		17.5	201	.018	.018		1.61			.56

TABLE 8-D
WATER QUALITY FOR LAKE THUNDERBIRD--SUMMER
(June, July and August)
(Continued)

DATE	Depth-meters	Temperature °C	DO mg/1	DO % Saturation	pH	Alkalinity mg/1 as $CaCo_3$	Turbidity J.T.U.	TDS mg/1	Ortho $Po_4^{\equiv}$ mg/1	Total $Po_4^{\equiv}$ mg/1	No_2^- mg/1	No_3^- mg/1	NH_3 mg/1	Org.N mg/1	Iron mg/1
STATION II															
6/12/68	0	26.0	10.2	127.6	8.8	180	45	240	.04			.50	.72K		
	11.5	21.0	.15	1.7	8.3	186	350	170	.12			.50	1.1K		
7/25/68	0	28.5	7.9	102.7	8.6	204	15	245	.14			.30	.66K		
	11	26.0	1.3	16.3	8.6	216	100	220	.16			.50	1.93K		
6/2/72	0		3.0		8.3	171	9	280		.04				.30	.08
6/27/73	1	26.2	7.6	95.5	8.4	155	18	210	0						.20
	4	26.0	7.5	93.9	8.4	156.5	18	210	0						.12
	9	22.8	7.4	88.0	8.3	157.5	19	218	0						.14
	11	21.5	0.2	2.3	7.4	147	65	210	0						.29
8/15/73	0	9.0	10	89.4	7.8	166	4.1	244		.01	.01	.10		.80	.05

TABLE 8-D
WATER QUALITY FOR LAKE THUNDERBIRD--SUMMER
(June, July and August)
(Continued)

DATE	Depth-meters	Temperature °C	DO mg/l	DO % Saturation	pH	Alkalinity mg/l as $CaCo_3$	Turbidity J.T.U.	TDS mg/l	Ortho $Po_4^{\equiv}$ mg/l	Total $Po_4^{\equiv}$ mg/l	No_2^- mg/l	No_3^- mg/l	NH_3 mg/l	Org.N mg/l	Iron mg/l
STATION II (Cont.)															
Avg. July 73	0	28.66	6.87	89.6	8.31		12.5	231		1.45		.60			.33
Aug	0	28.66	5.96	77.7	8.66		10.0	202		.091		1.3			1.01
STATION III															
8/11/69	0				8.0	200		290							.05
7/7/70	0				8.0	203		333							.14
6/21/72	0		3.0		8.3	173	5	300		.01				1.3	.08
6/27/73	1	26.5	8.1	102.3	8.4	157	17	200	0						<.1
	4	26.0	7.7	96.4	8.4	155	26	215	0						.15
	6	25.8													
	8	23.8													
	9	22.8	1.8	22	7.8	156.5	59	220	.01						.25
Avg. July 73	0	29.0	6.75	88.3	8.36		15	215	1.52	1.52		.78			.225
Aug	0	26.66	6.0	75.9	8.73		10	212	.026	.026		1.61			.190

TABLE 8-D
WATER QUALITY FOR LAKE THUNDERBIRD--SUMMER
(June, July and August)
(Continued)

DATE	Depth-meters	Temperature °C	DO mg/1	DO % Saturation	pH	Alkalinity mg/1 as $CaCo_3$	Turbidity J.T.U.	TDS mg/1	Ortho $Po_4^{\equiv}$ mg/1	Total $Po_4^{\equiv}$ mg/1	No_2^- mg/1	No_3^- mg/1	NH_3 mg/1	Org.N mg/1	Iron mg/1
STATION IV															
6/12/68	3	24.5	1.8	22	8.6	56	70	205	.30			.60	1.2K		
7/25/68	2.5	29.0	2.1	27.5	8.6	240	50	270	.12			.40	.82K		
STATION V															
7/7/70	0				8.3	203		312							.01
7/29/71	0	17.0			8.4	185		290		.23	.01	.20	.01		.25
6/2/72	0		3.0		8.9	182	33	290		.01				1.5	.35
8/15/73	0	29.0	9.0	117.8	8.1	184	36	276		.10	.01	.10		.90	.23
73 Avg. July	0	30.5	6.55	87.7	8.03		30	231	2.3	2.3		.49			.819
Aug	0		5.4		8.13		60	280	.013	.013		1.10			5.4

TABLE 9-A

WATER QUALITY FOR LAKE THUNDERBIRD

prior to June, 1974

FALL (September, October and November)

PARAMETER	UPPER	MIDDLE	DAM
Temperature (°C)	18-24	18-23.5	12-25.5
Dissolved Oxygen (mg/l)	7.0-7.1	3.75-10	5.5-10.9
pH (pH units)	7.5-8.6	7.0-8.7	7.8-8.7
Alkalinity (mg/l as $CaCo_3$)	174-220	56-208	52-204
TDS (mg/l)	200-417.5	207-320	200-300
Turbidity (JTU)	25-190	12-93	9-51
Phosphate (mg/l)	.0031-.32	.0015-.24	.0022-.18
Nitrite (mg/l)	.01	.01	.01
Nitrate (mg/l)	0.5 - 3.03	0-3.06	0.1-2.07
Ammonia (mg/l)	----	.1-.20	----
Organic Nitrogen (mg/l)	----	.5-.60	.54-.66
Iron (mg/l)	0.21-2.68	0 - 0.93	<.1-4.5

Upper: → Stations IV and V

Middle: → Stations I and III

Dam: → Station II

TABLE 9-B

WATER QUALITY FOR LAKE THUNDERBIRD

prior to June, 1974

WINTER (December, January and February)

PARAMETER	UPPER	MIDDLE	DAM
Temperature (°C)	3.5-8.0	3.3-9.0	2.5-7.0
Dissolved Oxygen (mg/l)	11.0-12.4	9.5-12.3	11.4-12.9
pH (pH units)	7.8-8.3	7.5-8.3	7.8-8.4
Alkalinity (mg/l as $CaCo_3$)	173-210	140-190	171-198
TDS (mg/l)	243-320	230-309	249-320
Turbidity (JTU)	15-46	3-25	3.2-32
Phosphate (mg/l)	.06	.04-.09	.06-.14
Nitrite (mg/l)	.01-.02	.01-.02	.01
Nitrate (mg/l)	.20-.30	<.1-.60	.15-.40
Ammonia (mg/l)	----	----	
Organic Nitrogen (mg/l)	.56-.80	.50-1.0	.5-.60
Iron (mg/l)	.07-.15	0-.40	.05-.10

Upper: → Stations IV and V

Middle: → Stations I and III

Dam: → Station II

TABLE 9-C

WATER QUALITY FOR LAKE THUNDERBIRD

prior to June, 1974

SPRING (March, April, and May)

PARAMETER	UPPER	MIDDLE	DAM
Temperature (°C)	11.0-17.0	10.0-18.0	9-28.0
Dissolved Oxygen (mg/l)	8.2-11.0	8.2-11.0	8.2-11.0
pH (pH units)	7.9-8.4	7.6-8.5	7.7-8.5
Alkalinity (mg/l as $CaCo_3$)	176-256	136-220	78-228
TDS (mg/l)	200-360	230-320	280-320
Turbidity (JTU)	22-400	12-90	17-135
Phosphate (mg/l)	----	----	0-.02
Nitrite (mg/l)	.01	.01	.01
Nitrate (mg/l)	.05-.30	.05-.30	.05-.40
Ammonia (mg/l)	.10	.10	.10
Organic Nitrogen (mg/l)	.65-1.3	.30-1.7	.65-.77
Iron (mg/l)	.04-.40	.09-.40	.04-.15

Upper: → Stations IV and V

Middle: → Stations I and III

Dam: → Station II

TABLE 9-D

WATER QUALITY FOR LAKE THUNDERBIRD

prior to June, 1974

SUMMER (June, July and August)

PARAMETER	UPPER	MIDDLE	DAM
Temperature (°C)	17-30.5	18.0-29.0	21.5-29.0
Dissolved Oxygen (mg/l)	1.8-9.0	1.0-11.0	0.15-10.2
pH (pH units)	8.03-8.6	7.8-8.8	7.4-8.8
Alkalinity (mg/l as $CaCo_3$)	56-240	155-228	147-216
TDS (mg/l)	205-312	200-333	170-245
Turbidity (JTU)	30-70	5-59	4.1-350
Phosphate (mg/l)	.013-2.3	0-1.52	0-1.45
Nitrite (mg/l)	.01	.01	.01
Nitrate (mg/l)	0.1-1.1	0.1-1.61	0.1-1.3
Ammonia (mg/l)	.10	.10	.10
Organic Nitrogen (mg/l)	0.8-1.5	0.7-1.3	0.66-1.93
Iron (mg/l)	0.01-5.4	<0.1-0.56	.05-1.01

Upper: → Stations IV and V

Middle: → Stations I and III

Dam: → Station II

Temperature

In Oklahoma the maximum and the minimum air temperatures occur in July and January, respectively (Table 4). The surface water temperature of the lake is directly proportional to the air temperature. The previous water quality studies of Lake Thunderbird indicated that the maximum water temperature was reached in July and the minimum water temperature occurred in January of each year. The temperature range was 2.5 to 30.5°C. The maximum water temperature of Lake Thunderbird did not exceed the water quality standards for Little River. The water quality standards for Little River in central Oklahoma are given in Table 10 (Oklahoma Water Resources Board, September 1973). The surface water temperature increased from January until July or August. In September the surface water temperature showed a decline indicating the beginning of a cooling trend in the lake.

From the temperature data available for Lake Thunderbird, it can be seen that the temperatures of the surface and the bottom waters were almost the same in fall and winter and for most of the spring. Temperature differences between different layers of water began to appear by the end of spring (May). In the summer the temperature difference between the surface and the bottom waters increased; however, the temperature differences were not very large (2.0 to 5.0°C). Lake Thunderbird normally stratifies from May to August; however, it is not very intense.

Dissolved Oxygen (DO)

The temperature and the DO content of water are directly related to each other. Water holds more oxygen at low temperatures than at high temperatures. In Lake Thunderbird the DO content of the surface water was high (80% saturation to super saturation) in all four seasons. When the

TABLE 10

WATER QUALITY STANDARDS FOR LITTLE RIVER IN CENTRAL OKLAHOMA

PARAMETER	STANDARD
Total Dissolved Solids	2802 mg/l
Turbidity (other than natural)	50 JTU
Temperature (°C)	Max. temp. ≤ 90°F (32.2°C)
Dissolved Oxygen	5 mg/l
pH	6.5-8.5

SOURCE: Oklahoma Water Resources Board: "Oklahoma Water Quality Standards--1973," Publ. 52, Oklahoma City, Sept. 1973.

lake was isothermal (September to April) the DO values were almost the same from surface to bottom. When the lake was thermally stratified, the DO value was high at the surface (90% saturation to super saturation), decreased from surface to bottom, and was near zero at the bottom. For example, on June 27, 1973, at Station II (Dam) the DO concentration decreased from 7.4 mg/l (95.5% saturation) at the surface to 0.15 mg/l (2.3% saturation) at 11 meters. Since thermal stratification was more intense in July and August one would expect a more pronounced DO stratification and the existence of anaerobic conditions in the bottom.

The water quality standards for Little River (Table 10) indicate that the dissolved oxygen shall not be less than 5 mg/l. This standard is met in the surface water; however, in the summer months the bottom waters are of poor quality.

pH

The pH values varied from 7.4 to 8.9 in Lake Thunderbird; most of the values were between 7.9 and 8.6. The pH of the surface waters was slightly higher in the summer than in other seasons. From the available data it was difficult to arrive at any conclusion about the pH of Lake Thunderbird. For example, the pH values for October varied from 7.9 in 1972 to 8.6 in 1967 and other months also showed similar variations. The available pH values also failed to show any seasonal trends. In 1973 the average pH value at the surface was 8.7 in August and October and average pH range for June through November was 8.1 to 8.7. In some instances, the pH value was lower when the DO value was lower and in other instances no relationship was noted. On June 27, 1973, the pH value decreased from 8.4 at the surface to 7.4 at the bottom and the DO values were 7.6 mg/l at the surface and 0.2 mg/1 at the bottom. However, on June 25, 1968, the pH at the surface and the bottom was 8.6, the DO concentration at the surface and the bottom was 7.9 and 1.3 mg/1, respectively.

The Little River water quality standards (Table 10) indicate that the pH should be between 6.5 and 8.5. The pH values in the winter and spring are within acceptable ranges. In the summer and fall, most of the pH values are within acceptable range; however, some of the reported pH values are more than 8.5.

Alkalinity

The alkalinity values also had a wide range (52 to 256 mg/1 as $CaCO_3$), although most of them were between 150 and 190 mg/1 as $CaCO_3$. The alkalinity values appeared to be unaffected by changes in temperature and DO. The alkalinity range showed little seasonal variation. There are no alkalinity standards for Lake Thunderbird.

Turbidity

The turbidity range was from 3.2 to 400 J.T.U., with most of the values from 5 to 100 J.T.U. The turbidity values in the spring were higher than the turbidity values in other seasons. The turbidity values at Station V were generally higher in comparison with other sampling stations due to car and foot traffic on Alameda Street bridge and the influent turbidity from Little River. Generally, the turbidity values were low at the surface and increased with the depth.

The turbidity values in the winter meet the Little River water quality standards. In other seasons the turbidity values at the bottom are higher than the acceptable standard of 50 J.T.U. (Table 10).

Total Dissolved Solids (TDS)

The range for TDS was from 130 to 1260 mg/l; however, the majority of the values were between 200 and 300 mg/l. The TDS values did not show any seasonal variation. The TDS values meet the Little River water quality standard of 2802 mg/l (Table 10).

Orthophosphates

There are very few values for orthophosphates available before 1974. Where data existed the phosphate values increased with depth. The range was from 0 to 0.3 mg/l. Most of the phosphate values were for the surface waters, and the amount of dissolved phosphorus in surface waters was low due to the high oxygen content. No orthophosphates standards exist for Little River and Lake Thunderbird.

Nitrites

The nitrite concentration in Lake Thunderbird was very low. Most of the nitrite values were reported as less than 0.1 mg/l and were for surface waters. The nitrite concentrations were low due to the high oxygen content of the surface waters. Nitrites are very unstable and in the presence of oxygen are oxidized to nitrates. No nitrite water quality standard exists for Little River and Lake Thunderbird.

Nitrates

Nitrate concentrations ranged from 0 to 3.06 mg/l as NO_3^-, with most of the reported values being between 0 and 0.6 mg/l. The nitrate concentrations at Station V were higher than other sampling stations and it was probably because Station V was the Little River inflow station. Also, the nitrate concentrations in the fall and summer were higher than in the spring and winter and this was probably due to higher surface run off. No nitrate water quality standard exists for Little River and Lake Thunderbird.

Ammonia

Only very small quantities of ammonia were present in Lake Thunderbird. All of the reported concentrations were less than 0.1 mg/l. No ammonia water quality standard exists for Little River and Lake Thunderbird.

Organic Nitrogen

Compared to other forms of nitrogen, the organic nitrogen concentrations were higher, ranging from 0.5 to 1.6 mg/l. No organic nitrogen water quality standard exists for Little River and Lake Thunderbird.

Iron

The concentration of iron varied widely in Lake Thunderbird, with the minimum and maximum reported concentration being 0 and 5.4 mg/l, respectively. In some cases during the summer the iron concentrations increased with depth due to anaerobic conditions in the bottom waters. Most of the iron concentrations were in the range from 0 to 0.5 mg/l. No water quality standard exists for iron in Little River and Lake Thunderbird.

Water Quality Problems in Lake Thunderbird

The water quality of Lake Thunderbird is generally good and meets the water quality standards for Little River. The lake water quality deteriorates in the late spring and the summer (May through August) due to thermal stratification. The thermal stratification resulted in low or zero oxygen concentration at the lake bottom. The concentrations of phosphates and iron were increased at the bottom and the pH was reduced. The nutrient levels at the lake are variable, but are sufficient to cause troublesome algal blooms.

CHAPTER IV

DISCUSSION OF RESULTS

This chapter will be divided into two parts. In the first part each water quality parameter measured in this study will be discussed separately for each of the five sampling stations. For example, the temperature changes in the lake will be discussed separately for all five sampling stations. In the second part, the effect of artificial destratification on the water quality of Lake Thunderbird will be summarized.

Discussion of Sampling Data

Temperature

Temperature changes in Lake Thunderbird waters are due primarily to climatic phenomena. Heat is gained by water primarily through direct absorption of solar radiation and to a lesser extent through transfer of heat from the air or from the bottom. The loss of heat from water takes place through radiation, evaporation and through conduction to the air and the bottom. Temperature is an important parameter because temperature establishes limiting or controlling conditions for many of the chemical and biological changes in water. Increased temperature results in increased oxygen demand and may cause increases in the growth of undesirable aquatic plants.

The temperature measurements made in this study were accomplished in the field through the use of a thermister probe. The temperature readings were taken every meter from the surface to the bottom. The temperature measurements are presented in Tables 11 A-E.

Station I

In 1974 the maximum water temperature of 28.8°C was reached on August 4 and the minimum water temperature of 5.7°C was reached on December 27.

The first temperature measurements were made on May 10, 1974 and at that time the aeration of Lake Thunderbird had not begun. On that date the temperature difference between the surface and the bottom was 2.3°C. The temperature slowly decreased from 20.8°C at the surface to 19.5°C at 9 meters, and there was 1.0°C temperature difference between 9 and 10 meters. The temperature gradient was not well defined.

On June 11 the surface water temperature increased due to higher air temperature (Table 12), and the difference between the surface and the bottom was only 2.0°C. There was a temperature difference of 1.0°C between 1 and 2 meters and between 2 and 4 meters. Below 4 meters the temperature remained constant. Although the temperature difference between the surface and the bottom was small, a typical thermal startification curve was exhibited.

The maximum temperature of the water was reached on August 4. The difference in temperature between the surface and the bottom was only 1.1°C, and thermal stratification was not well-defined. On August 25 the difference between the surface and the bottom temperature was only 0.4°C, and the temperature drop between successive one meter depths was only 0.1°C. Station I was almost isothermal by the end of August.

TABLE 11-A

TEMPERATURE VALUES IN LAKE THUNDERBIRD

Temperature °C

	1	2	3	4	5	6	7	8	9
STATION I Depth-meters	May 10, 1974	June 11, 1974	August 4, 1974	August 25, 1974	Sept. 10, 1974	Sept. 29, 1974	Oct. 16, 1974	Oct. 31, 1974	Nov. 12, 1974
Surface(0)	20.8	25.0	28.8	27.2	23.5	20.9	19.6	18.5	14.2
1	20.4	25.0	29.0	27.2	23.5	21.0	19.4	18.5	14.2
2	20.3	24.0	28.9	27.2	23.4	21.0	19.4	18.5	14.2
3	20.2	23.5	28.8	27.2	23.4	21.0	19.3	18.5	14.2
4	20.2	23.0	28.5	27.1	23.3	21.0	19.2	18.5	14.2
5	20.2	23.0	28.5	27.1	23.2	21.0	19.1	18.5	14.2
6	20.2	23.0	28.3	27.1	23.2	21.0	19.1	18.5	14.2
7	20.0	23.0	28.3	27.0	23.2	21.0	19.1	18.5	14.2
8	19.9	23.0	28.1	27.0	23.2	21.0	18.9	18.5	14.2
9	19.5	23.0	27.8	26.9	23.2	21.0	18.6	18.5	14.2
10	18.5	23.0	27.7	26.8	23.1	21.0	18.6	18.5	14.1

TABLE 11-A

TEMPERATURE VALUES IN LAKE THUNDERBIRD

Temperature °C
(Continued)

	10	11	12	13	14	15	16	17	18
STATION I (Cont.) Depth-meters	Dec.12, 1974	Dec. 27, 1974	Jan. 21, 1975	Feb. 28, 1975	March 27, 1975	March 30, 1975	April 12, 1975	April 28, 1975	May 9, 1975
Surface(0)	6.2	5.9	4.7	8.5	7.3	10.5	15.2	20.0	22.0
1	5.9	5.9	4.8	7.5	7.3	10.5	14.0	20.0	22.0
2	5.9	5.9	4.8	7.0	7.3	10.5	12.4	19.8	22.0
3	5.9	5.9	4.8	7.0	7.3	10.5	12.2	19.5	21.8
4	5.9	5.9	4.8	7.0	7.3	10.5	12.2	19.0	21.0
5	5.9	5.9	4.8	7.0	7.3	10.5	12.2	19.0	20.8
6	5.9	5.9	4.8	7.0	7.3	10.5	12.2	18.5	20.0
7	5.9	5.7	4.8	7.0	7.3	10.5	12.2	18.5	19.0
8	5.9	5.7	4.8	7.0	7.3	10.5	12.0	18.5	19.0
9	5.9	5.7	4.8	7.0	7.3	10.5	12.0	18.5	19.0
10	5.9	5.7	4.8	7.0	7.3	10.4	12.0	18.5	18.0

TABLE 11-A

TEMPERATURE VALUES IN LAKE THUNDERBIRD

Temperature °C
(Continued)

STATION I (Cont.) Depth-meters	19 May 26, 1975	20 June 8, 1975	21 June 26, 1975	22 July 12, 1975	23 July 30, 1975	24 August 16, 1975	25 August 31,1975	26 Sept. 25, 1975	27 Oct. 19, 1975
Surface(0)	23.2	25.3	26.9	28.4	28.0	28.7	28.0	21.5	19.8
1	23.4	25.2	26.7	28.4	27.5	28.7	28.0	21.5	20.0
2	23.4	24.9	26.5	28.3	27.0	28.7	28.0	21.5	20.0
3	23.4	24.9	26.4	28.3	27.0	28.7	28.0	21.5	20.0
4	23.4	24.2	26.3	27.3	26.0	28.7	28.0	21.5	20.0
5	23.4	23.8	26.2	26.7	26.0	28.4	28.0	21.5	20.0
6	23.4	23.8	26.2	26.2	26.0	27.9	27.8	21.5	20.0
7	23.4	23.2	26.1	26.1	26.0	27.7	27.5	21.5	20.0
8	23.2	23.1	26.1	25.9	25.0	27.3	27.4	21.0	20.0
9	21.9	23.0	25.1	25.5	25.0	27.0	27.2	21.0	20.0
10	21.3	22.6	24.5	25.4	25.0	26.9	27.1	21.0	20.0
11	21.1	22.1							

TABLE 11-B

TEMPERATURE VALUES IN LAKE THUNDERBIRD

Temperature °C

	1	2	3	4	5	6	7	8	9
STATION II Depth-meters	May 10, 1974	June 11, 1974	August 4, 1974	August 25,1974	Sept. 10, 1974	Sept. 29, 1974	Oct. 16, 1974	Oct. 31, 1974	Nov. 11, 1974
Surface(0)	20.8	25.0	28.9	27.5	23.4	21.2	19.8	18.7	14.9
1	20.6	24.5	29.1	27.5	23.4	21.1	19.6	18.5	14.9
2	20.4	24.0	29.0	27.5	23.5	21.0	19.2	18.5	14.9
3	20.2	24.0	28.8	27.5	23.6	21.0	19.0	18.5	14.9
4	20.2	23.5	28.7	27.5	23.6	21.0	19.0	18.5	14.9
5	20.1	23.5	28.7	27.5	23.6	21.0	19.0	18.5	14.9
6	20.0	23.5	28.7	27.5	23.6	21.0	19.0	18.5	14.9
7	19.4	23.5	28.7	27.5	23.6	21.0	18.9	18.5	14.9
8	19.2	23.0	28.3	27.5	23.6	21.0	18.9	18.5	14.9
9	19.0	23.0	28.1	27.5	23.6	21.0	18.9	18.5	14.9
10	18.5	23.0	27.7	27.4	23.6	20.9	18.9	18.4	14.9
11	18.2	23.0	27.1	27.4	23.6	20.9	18.9	18.4	14.9
12	18.0	23.0	27.0	27.3	23.5	20.9	18.9	18.4	14.9
13	17.9	23.0	26.9	27.0	23.5	20.9	18.8	18.4	14.9
14	17.6	23.0	26.8	26.8	23.4	20.9	18.7	18.4	14.9
15	17.0	23.0	26.8	26.8	23.4	20.9	18.6	18.4	14.8

TABLE 11-B
TEMPERATURE VALUES IN LAKE THUNDERBIRD
Temperature °C
(Continued)

	10	11	12	13	14	15	16	17	18
STATION II (Cont.) Depth-meters	Dec. 12, 1974	Dec. 27, 1974	Jan. 21, 1975	Feb. 28, 1975	March 17, 1975	March 30, 1975	April 12, 1975	April 28, 1975	May 9, 1975
Surface(0)	6.9	6.0	4.8	7.4	7.3	10.5	13.7	19.0	22.0
1	6.8	6.0	4.8	7.5	7.3	10.5	12.8	19.0	22.0
2	6.7	5.9	4.8	7.0	7.3	10.5	12.5	18.8	21.7
3	6.6	5.9	4.8	7.0	7.3	10.5	12.3	18.8	20.9
4	6.6	5.9	4.8	6.8	7.3	10.5	12.3	18.8	20.3
5	6.6	5.8	4.8	6.8	7.3	10.5	12.3	18.8	19.8
6	6.5	5.8	4.8	6.8	7.3	10.5	12.2	18.8	19.8
7	6.5	5.7	4.8	6.8	7.3	10.5	12.1	18.5	19.5
8	6.5	5.7	4.8	6.8	7.3	10.5	12.1	18.5	19.3
9	6.5	5.7	4.8	6.8	7.3	10.5	12.0	18.5	19.1
10	6.5	5.7	4.8	6.8	7.3	10.5	12.0	18.5	18.8
11	6.4	5.7	4.8	6.8	7.3	10.5	12.0	18.0	18.7
12	6.4	5.6	4.8	6.8	7.3	10.5	12.0	18.0	18.7
13	6.4	5.6	4.8	6.8	7.3	10.5	12.0	17.0	18.4
14	6.4	5.6	4.8	6.8	7.3	10.4	12.0	17.0	18.1
15	6.4	5.6	4.8	6.8	7.3	10.4	12.0	17.0	17.8

TABLE 11-B
TEMPERATURE VALUES IN LAKE THUNDERBIRD
Temperature °C
(Continued)

	19	20	21	22	23	24	25	26	27
STATION II (Cont.) Depth-meters	May 26, 1975	June 8, 1975	June 26, 1975	July 12, 1975	July 30, 1975	August 16,1975	August 31,1975	Sept. 25, 1975	Oct. 19, 1975
Surface(0)	22.9	24.0	26.9	29.0	27.5	28.2	28.0	21.8	19.6
1	22.9	24.0	26.5	28.5	27.5	28.2	27.8	21.8	19.8
2	22.9	24.0	26.0	28.5	27.0	28.2	27.8	21.8	20.0
3	22.9	23.8	25.8	28.0	27.0	28.2	27.5	21.8	20.0
4	22.9	23.6	25.5	28.0	27.0	28.0	27.5	21.8	20.0
5	22.9	23.4	25.3	28.0	27.0	28.0	27.5	21.8	20.0
6	22.5	23.2	25.1	27.0	27.0	27.8	27.2	21.8	20.0
7	22.0	23.1	24.8	26.0	26.5	27.0	27.2	21.8	20.0
8	21.8	22.9	24.8	25.5	26.3	26.6	27.0	21.8	20.0
9	21.8	22.9	24.8	25.0	26.2	26.2	27.0	21.8	20.0
10	21.3	22.7	24.7	24.5	26.1	25.9	27.0	21.8	20.0
11	20.9	22.2	24.5	24.5	25.9	25.6	26.9	21.8	20.0
12	20.7	21.9	24.2	24.5	25.1	25.6	26.9	21.8	20.0
13	20.6	21.9	23.9	24.3	24.9	25.4	26.6	21.8	20.0
14	20.3	21.9	23.7	24.0	24.6	25.1	26.2	21.8	20.0
15	20.3	21.9	23.1	24.0	24.3	24.3	26.0	21.8	19.9
16	19.9	21.7				23.9			

TABLE 11-C

TEMPERATURE VALUES IN LAKE THUNDERBIRD

Temperature °C

	1	2	3	4	5	6	7	8	9
STATION III Depth-meters	May 10, 1974	June 11, 1974	August 4,1974	August 25, 1974	Sept. 10, 1974	Sept. 29, 1974	Oct. 16, 1974	Oct. 31, 1974	Nov. 12, 1974
Surface(0)	20.8	24.5	29.5	27.8	24.2	21.5	19.7	18.7	14.5
1	20.8	24.2	29.4	27.8	24.1	21.5	19.7	18.4	14.5
2	20.5	23.8	29.4	27.8	24.1	21.4	19.1	18.4	14.5
3	20.4	23.4	29.3	27.7	24.1	21.4	19.1	18.4	14.4
4	20.4	23.1	29.2	27.7	24.1	21.3	19.1	18.4	14.4
5	20.4	23.1	29.2	27.6	24.1	21.3	19.1	18.4	14.4
6	20.0	23.0	29.2	27.6	24.1	21.3	19.1	18.4	14.3
7	19.6	23.0	29.1	27.6	24.1	21.3	19.1	18.4	14.3
8	19.0	23.0	29.0	27.5	24.1	21.3	19.1	18.3	14.2
9	18.8	22.8	28.6	27.4	24.0	21.2	19.1	18.3	14.2
10	18.2	22.8	27.7	27.3	24.0	21.2	19.1	18.3	14.1

TABLE 11-C
TEMPERATURE VALUES IN LAKE THUNDERBIRD
Temperature °C
(Continued)

	10	11	12	13	14	15	16	17	18
STATION III (Cont.) Depth-meters	Dec. 12, 1974	Dec. 27, 1974	Jan. 21, 1975	Feb. 28, 1975	March 17, 1975	March 30, 1974	April 12, 1975	April 28, 1975	May 9, 1975
Surface(0)	7.3	6.1	4.9	9.5	7.3	10.5	14.5	19.0	22.4
1	7.2	6.1	4.9	8.0	7.3	10.5	13.8	18.8	21.9
2	7.1	6.0	4.9	7.0	7.3	10.5	13.0	18.8	21.7
3	7.1	5.9	4.9	7.0	7.3	10.5	12.9	18.8	21.3
4	7.0	5.9	4.9	7.0	7.3	10.5	12.8	18.8	21.1
5	7.0	5.9	4.9	7.0	7.3	10.5	12.5	18.5	20.6
6	6.9	5.9	4.9	7.0	7.3	10.5	12.2	18.5	20.3
7	6.9	5.9	4.9	7.0	7.3	10.5	12.2	18.4	20.2
8	6.9	5.8	4.9	7.0	7.3	10.5	12.2	18.2	19.8
9	6.8	5.8	4.9	6.8	7.3	10.5	12.1	17.5	19.5
10	6.8	5.8	4.9	6.8	7.3	10.5	12.0	17.3	18.9

TABLE 11-C
TEMPERATURE VALUES IN LAKE THUNDERBIRD
Temperature °C
(Continued)

	19	20	21	22	23	24	25	26	27
STATION III (Cont.) Depth-meters	May 26, 1975	June 8, 1975	June 26, 1975	July 12, 1975	July 30, 1975	Aug. 16, 1975	Aug. 31, 1975	Sept. 25, 1975	Oct. 19, 1975
Surface(0)	23.1	24.2	27.0	28.5	27.5	28.5	28.0	22.0	19.8
1	23.1	24.1	26.8	28.5	27.5	28.5	27.8	21.9	20.0
2	23.1	24.0	26.5	28.5	27.0	28.2	27.8	21.8	20.0
3	23.1	23.9	26.3	28.5	27.0	28.2	27.5	21.8	20.0
4	23.1	23.8	26.2	28.0	27.0	28.0	27.2	21.8	20.0
5	23.1	23.7	26.0	27.0	27.0	27.8	27.1	21.8	20.0
6	23.1	23.7	25.6	26.0	27.0	27.5	27.0	21.8	20.0
7	22.8	23.5	25.5	26.0	26.5	27.0	27.0	21.8	20.0
8	22.2	23.4	25.2	25.5	26.0	26.8	27.0	21.8	20.0
9	21.7	22.8	24.4	25.0	26.0	26.2	27.0	21.8	19.8
10	21.4	22.1	24.2	25.0	25.5	25.6	26.8	21.8	19.5
11	21.1	22.0			25.0		26.5		

TABLE 11-D

TEMPERATURE VALUES IN LAKE THUNDERBIRD

Temperature °C

	1	2	3	4	5	6	7	8	9
STATION IV Depth-meters	May 10, 1974	June 11, 1974	August 4, 1974	August 25,1974	Sept. 10, 1974	Sept. 9, 1974	Oct. 16, 1974	Oct. 31, 1974	Nov. 12, 1974
Surface(0)	21.5	25.0	28.9	28.4	24.6	21.3	19.4	18.8	14.0
1	21.5	24.9	28.9	28.4	24.6	21.2	19.3	18.7	14.0
2	21.2	24.9	28.9	28.1	24.6	21.1	19.0	18.5	14.0
3	21.2	24.9	28.8	27.9	24.6	20.9	18.8	18.5	13.8
4	21.0	24.9	28.8	27.9	24.6	20.7	18.6	18.5	13.8
5	20.5	24.9	28.8	27.8	24.5	20.7	18.6	18.5	13.7
6	19.0	23.2	28.7	27.8	24.5	20.6	18.6	18.5	13.6

TABLE 11-D
TEMPERATURE VALUES IN LAKE THUNDERBIRD
Temperature °C
(Continued)

	10	11	12	13	14	15	16	17	18
STATION IV (Cont.) Depth-meters	Dec. 12, 1974	Dec. 27, 1974	Jan. 21, 1975	Feb. 28, 1975	March 17, 1975	March 30, 1975	April 12, 1975	April 28, 1975	May 9, 1975
Surface(0)	6.9	6.0	4.8	9.5	7.4	10.5	15.0	19.0	23.0
1	6.8	5.9	4.8	9.0	7.4	10.5	14.0	18.9	22.9
2	6.7	5.8	4.8	8.0	7.4	10.5	13.2	18.8	22.3
3	6.6	5.8	4.8	7.5	7.4	10.5	13.1	18.5	22.1
4	6.5	5.7	4.8	7.5	7.4	10.5	13.0	18.5	22.0
5	6.4	5.7	4.8	7.2	7.4	10.5	12.9	18.5	21.3
6	6.3	5.6	4.8	7.2	7.4	10.5	12.6	18.5	21.3

TABLE 11-D
TEMPERATURE VALUES IN LAKE THUNDERBIRD
Temperature °C
(Continued)

	19	20	21	22	23	24	25	26	27
STATION IV (Cont.) Depth-meters	May 26, 1975	June 8, 1975	June 26, 1975	July 12, 1975	July 30, 1975	Aug. 16, 1975	Aug. 31, 1975	Sept. 25, 1975	Oct. 19, 1975
Surface(0)	24.3	24.8	27.6	29.0	28.0	28.6	28.0	21.5	19.9
1	24.0	24.7	27.4	29.0	28.0	28.5	27.8	21.5	19.9
2	23.8	24.4	26.7	29.0	27.5	28.2	27.5	21.2	19.9
3	23.8	24.3	26.7	28.5	26.0	28.0	27.2	21.2	19.9
4	23.6	24.3	26.4	28.0	26.0	28.0	27.0	21.0	19.9
5	23.4	24.3	26.3	27.5	26.0	27.9	27.0	21.0	19.9
6	23.4	24.1	26.0	27.0	26.0	27.8	27.0	21.0	19.9
7	22.6	23.8							
7.5	22.0								

TABLE 11-E

TEMPERATURE VALUES IN LAKE THUNDERBIRD

Temperature °C

	1	2	3	4	5	6	7	8	9
STATION V Depth-meters	May 10, 1974	June 11, 1974	Aug. 4, 1974	Aug. 25, 1974	Sept. 10, 1974	Sept. 29, 1974	Oct. 16, 1974	Oct. 31, 1974	Nov. 12, 1974
Surface(0)	22.0	26.0	28.0	28.9	25.4	21.6	19.5	18.9	13.2
1	22.0	26.0	27.4	28.9	25.2	21.3	19.4	18.8	13.1
2	21.8	25.4	27.5	28.8	24.9	21.0	18.8	18.8	13.0
3	21.8	25.0	27.8	28.1	24.4	20.8	18.4	18.7	12.7
4	20.8	24.0	27.8	28.1	24.3	20.7	18.3	17.5	12.4

TABLE 11-E

TEMPERATURE VALUES IN LAKE THUNDERBIRD
Temperature °C
(Continued)

	10	11	12	13	14	15	16	17	18
STATION V (Cont.) Depth-meters	Dec. 12, 1974	Dec. 27, 1974	Jan. 21, 1975	Feb. 28, 1975	March 17, 1975	March 30, 1975	April 12, 1975	April 28, 1975	May 9, 1975
Surface(0)	5.6	4.6	4.4	10.6	7.5	10.0	15.8	19.3	24.0
1	5.5	4.5	4.5	10.5	7.4	10.0	14.8	19.0	23.5
2	5.4	4.5	4.5	10.2	7.4	10.0	14.0	18.8	22.2
3	5.3	4.4	4.5	8.0	7.3	10.0	13.6	18.8	21.0
4	5.2	4.4	4.5	8.0	7.3	10.0	13.4	18.6	21.0

TABLE 11-E
TEMPERATURE VALUES IN LAKE THUNDERBIRD
Temperature °C
(Continued)

	19	20	21	22	23	24	25	26	27
STATION V (Cont.) Depth-meters	May 26, 1975	June 8, 1975	June 26, 1975	July 12, 1975	July 30, 1975	Aug. 16, 1975	Aug. 31, 1975	Sept. 25, 1975	Oct. 19, 1975
Surface(0)	24.6	25.0	27.9	28.8	28.0	29.0	29.0	21.0	18.5
1	24.3	25.0	27.8	28.8	28.0	28.8	28.0	20.8	18.5
2	24.1	24.8	27.8	28.2	28.0	28.4	27.8	20.5	18.5
3	23.6	24.7	26.4	28.0	26.0	28.2	27.0	20.0	18.5
4	23.4	24.7	26.2	28.0	26.0	28.0	27.0	19.5	18.5
5	23.0	24.6							

TABLE 12

AIR-TEMPERATURE AND WATER-TEMPERATURE RELATIONSHIP

	STATION I			STATION II		
DATE	TIME	AIR TEMP. °C	WATER TEMP. °C	TIME	AIR TEMP. °C	WATER TEMP. °C
5/10/74	11:00am	24.5	20.8	12:00pm	24.5	20.8
6/11/74	2:30pm	28.0	25.0	3:45pm	28.0	25.0
8/4/74	4:20pm	31.0	28.8	3:00pm	31.0	28.9
8/25/74	9:45am	28.0	27.2	11:00am	29.0	27.5
9/10/74	9:10am	22.5	23.5	10:05am	23.0	23.4
9/29/74	8:40am	16.0	20.9	9:30am	15.0	21.2
10/16/74	1:35pm	21.5	19.6	2:10pm	22.0	19.8
10/31/74	10:00am	19.0	18.5	10:30am	20.0	18.7
11/12/74	8:00am	6.5	14.2	9:00am	9.8	14.9
12/12/74	7:45am	4.0	6.2	8:45am	7.5	6.9
12/27/74	9:00am	6.0	5.9	9:50am	6.0	6.0
1/21/75	8:35am	4.5	4.7	9:10am	5.2	4.8
2/28/75	2:00pm	16.0	8.5	2:30pm	16.5	9.5
3/17/75	11:20am	10.0	7.3	10:55am	8.0	7.3
3/30/75	11:00am	7.0	10.5	10:30am	9.0	10.5
4/12/75	4.30pm	17.0	15.2	1:00pm	16.0	13.7
4/28/75	2:45pm	23.5	20.0	3:45pm	23.5	19.0
5/9/75	9:50am	24.0	22.0	10:25am	24.8	22.0
5/26/75	10:10am	19.3	23.2	10:45am	20.5	22.9
6/8/75	10:10am	25.0	25.3	10:45am	25.0	24.0
6/26/75	2:00pm	30.0	26.9	2:30pm	30.0	26.9
7/12/75	2:50pm	29.0	28.4	3:30pm	30.0	29.0
7/30/75	8:30am	25.0	28.0	10:00am	28.0	27.5
8/16/75	9:15am	27.0	28.7	9:45am	26.0	28.2
8/31/75	9:25am	28.0	28.0	10:10am	28.5	28.0
9/25/75	9:45am	14.0	21.5	10:25am	17.0	21.8
10/19/75	9:20am	12.0	19.8	9:50am	13.0	19.6

TABLE 12

AIR-TEMPERATURE AND WATER-TEMPERATURE RELATIONSHIP
(Continued)

	STATION III			STATION IV		
DATE	TIME	AIR TEMP. °C	WATER TEMP. °C	TIME	AIR TEMP. °C	WATER TEMP. °C
5/10/74	11:15am	25.0	20.8	2:30pm	26.0	21.5
6/11/74	4:00pm	28.0	24.5	4:15pm	28.0	25.0
8/4/74	1:45pm	31.0	29.5	11:45am	30.5	28.9
8/25/74	2:20pm	30.0	27.8	2:00pm	32.0	28.4
9/10/74	11:15am	23.7	24.2	12:10pm	25.0	24.6
9/29/74	10:30am	17.5	21.5	11:30am	20.0	21.3
10/16/74	3:00pm	23.0	19.7	3:35pm	25.5	19.4
10/31/74	11:15am	20.5	18.7	12:00pm	20.5	18.8
11/12/74	9:45am	9.4	14.8	10:15am	11.0	14.0
12/12/74	9:30am	7.5	7.3	10:25am	7.3	6.9
12/27/74	11:10am	7.0	6.1	11:50am	7.0	6.0
1/21/75	9:40am	6.5	4.9	10:10am	7.0	4.8
2/28/75	3:10pm	16.5	9.5	3:40pm	17.5	9.4
3/17/75	10:25am	7.5	7.3	10:00am	7.0	7.4
3/30/75	9:50am	8.0	10.5	9:30am	7.5	10.5
4/12/75	2:00pm	17.0	14.5	3:00pm	17.0	15.0
4/28/75	4:15pm	23.5	19.0	4:45pm	23.0	19.0
5/9/75	11:00am	24.5	22.4	11:45am	28.0	23.0
5/26/75	11:25am	22.0	23.1	1:05pm	26.0	24.3
6/8/75	4:10pm	25.0	24.2	4:45pm	25.0	24.8
6/26/75	3:00pm	30.0	27.0	3:45pm	30.0	27.6
7/12/75	4:20pm	30.0	28.5	5:00pm	30.0	29.0
7/30/75	11:25am	28.0	27.5	12:00pm	32.0	28.0
8/16/75	10:20am	29.0	28.5	11:20am	30.0	28.6
8/31/75	10:55am	30.0	28.0	11:35am	33.0	28.0
9/25/75	11:05am	20.0	22.0	11:40am	20.0	21.5
10/19/75	10:40am	17.0	19.8	11:15am	18.0	19.9

TABLE 12

AIR-TEMPERATURE AND WATER-TEMPERATURE RELATIONSHIP
(Continued)

	STATION V		
DATE	TIME	AIR TEMP. °C	WATER TEMP. °C
5/10/74	3:30pm	26.0	22.0
6/11/74	4:30pm	28.0	26.0
8/4/74	10:45am	29.5	28.0
8/25/74	2:20pm	32.0	28.9
9/10/74	12:40pm	25.2	25.4
9/29/74	11:55am	21.0	21.6
10/16/74	4:05pm	24.5	19.5
10/31/74	12:20pm	20.5	18.9
11/12/74	11:00am	10.8	13.2
12/12/74	11:00am	8.0	5.6
12/27/74	12:20pm	7.0	4.6
1/21/75	10:25am	7.0	4.4
2/28/75	4:05pm	17.5	10.6
3/17/75	9:40am	7.0	7.5
3/30/75	9:00am	7.0	10.0
4/12/75	3:30pm	17.0	15.8
4/28/75	5:10pm	22.5	19.3
5/9/75	12:05pm	28.0	24.0
5/26/75	1:40pm	26.5	24.6
6/8/75	5:05pm	25.0	25.0
6/26/75	4:10pm	30.0	27.9
7/12/75	5:25pm	29.5	28.8
7/30/75	12:25pm	33.0	28.0
8/16/75	11:45am	31.0	29.0
8/31/75	12:05pm	33.0	29.0
9/25/75	12:00pm	20.0	21.0
10/19/75	11:35am	18.0	18.5

After August the water temperature fell steadily every month and the lowest water temperature for 1974 was reached by the end of December. Between September and December 1974 the difference between the surface and the bottom temperatures was insignificant. Station I remained in an isothermal condition.

In 1975 the highest water temperature of 28.7°C was reached on August 16, and the lowest water temperature of 4.7°C was reached on January 21. On February 28 the surface water temperature was 8.5°C indicating the beginning of a warming trend. In February and March the temperature differences between the surface and the bottom were insignificant. The isothermal conditions at Station I continued until March. In April small differences in temperatures between the surface and the bottom began to appear and the temperature decreased slowly from the surface to the bottom.

On May 9 the surface water temperature was 22.0°C and the bottom temperature was 4.0°C lower. The temperature difference between the surface and 6 meters was 2.0°C. This sampling date was almost a year from the beginning of this study. On May 10, 1974, the temperature difference between the surface and the bottom was 2.3°C and the difference increased to 4.0°C on May 4, 1975. At Station I the thermal stratification began to develop at the same time in 1974 and 1975.

On May 26 the temperature difference between the surface and the bottom was only 2.1°C--lower in comparison to May 9. The temperature was almost the same up to 8 meters and the bottom temperature was 2.1°C lower. More than 8 inches of rain fell on the lake between May 10 and May 23 which resulted in an increase in the lake level. Because of the rains, mixing occurred which resulted in more uniform temperatures in the lake.

On June 8 the surface water temperature was higher than on May 26 and the temperature decreased slowly from the surface to the bottom. The temperature difference between the surface and the bottom was 3.2°C and there was 1.0°C difference between 8 meters and the bottom. Several rains occurred between June 8 and June 26; on June 26 the lake once again started to thermally stratify. The temperature difference between the surface and the bottom was 2.4°C, and between 8 meters and the bottom it was 1.6°C.

On July 12, 1975, the surface water temperature was almost equal to that of August 4, 1974. The maximum, minimum and the average air temperatures of these two sampling dates were almost the same. The water temperature was almost the same until 4 meters, and from 4 meters to the bottom a temperature gradient was present. The difference between the surface and the bottom temperatures was 3.0°C, and there was 1.0°C difference in temperature between 3 and 4 meters and 8 and 9 meters. On July 30 the surface water temperature was slightly less, but the difference between surface and bottom temperatures of the water was the same (3.0°C). The temperature dropped by 1.0°C between 3 and 4 meters and between 7 and 8 meters.

On August 16 the water temperature reached its maximum for 1975. The water temperature was constant until 4 meters, then slowly decreased with depth. The temperature difference between the surface and the bottom was only 1.8°C. On August 31 the surface water temperature was less and the bottom temperature was slightly more in comparison to August 16. Also the temperature difference between the surface and the bottom was only 1.0°C. A slight temperature gradient was present below 5 meters.

On September 25 the surface water temperature was only 21.5°C and the temperature remained constant until 7 meters. Even below 7 meters the temperature drop to the bottom was only a small one (0.5°C). Therefore, the water temperature at Station I was nearly isothermal.

On October 19 the water temperature decreased further and the surface and the bottom temperatures were almost the same. The lake was in a completely mixed state (isothermal).

The temperature profiles indicated that the seasonable behavior of the lake was almost the same for both 1974 and 1975. The small differences in actual surface water temperatures between the two years are due to differences in air temperatures and the time of day when sampling was accomplished.

Station II

Station II was located near the dam and was close to the aeration site. Station II had a depth of 15 meters and was the deepest of all the sampling stations.

The temperature behavior of Station II was similar to that of Station I. Like Station I, the surface water temperatures closely followed the air temperatures. In 1974 the maximum water temperature of 28.9°C and the minimum water temperature of 5.6°C were reached on August 4 and December 27, respectively. In 1975 they were 29.0°C on July 12 and 4.8°C on January 21.

On May 10, 1974, the temperature difference between the surface and the bottom was 3.8°C, which was slightly higher than at Station I. The biggest temperature difference (0.6°C) was between the 6 meter and the 7 meter depth. From 7 meters to the bottom the temperature dropped by at least 1.0°C every 3 meter depth. On June 11 the difference between surface and bottom temperatures was only 2.0°C. The maximum difference between two successive one meter depths was 0.5°C--between 3 and 4 meters and 7 and 8 meters. Below the 8 meter depth the temperature was constant. The temperature curve resembled a well-defined stratification curve. On August 4 the surface water temperature was 28.9°C (maximum for 1974) and a difference of 2.1°C existed between surface and bottom water. The thermal stratification curve was well-defined once again. On August 25 the surface water temperature was less, which indicated a cooling trend. The water temperature was almost constant until the 12 meter depth, and even between 12 meters and the bottom the temperature difference was very small.

After August the surface water temperature decreased on each sampling date. The cooling trend continued until March 30, 1975, when the water temperature showed an increase at the surface as compared to the previous sampling date (March 17, 1975). The higher surface water temperature on February 28 was due to an unseasonably high air temperature. From the end of March the surface water temperature was higher every month until July 12, 1975 when the maximum water temperature for the year 1975 was reached. From September, 1974, to April, 1975, the water temperature between the surface and the bottom was the same or exhibited only very small differences, thus isothermal conditions existed at Station II.

On May 9, 1975, the surface water temperature was 22.0°C and the difference between the surface and the bottom temperature was 4.0°C. The temperature profile was approaching a typical stratification curve obtainable during summer months. On May 26, 1975, the temperature difference between the surface and the bottom decreased to 3.0°C and on June 8, 1975, to 2.0°C despite a higher surface water temperature. This differential reduction was probably due to some mixing by heavy rains prior to June 8. The temperature gradient began at a depth of 5 meters on May 26 and 2 meters on June 8.

On June 26 the surface and the bottom temperature showed a higher difference (3.8°C). On July 12 the surface water temperature of 29.0°C was the highest for the year 1975. The bottom temperature was 5.0°C lower than the surface temperature and the temperature difference between 5 and 6 meters and between 6 and 7 meters was 1.0°C. There was a temperature gradient from the surface to the bottom and the temperature profile indicated a well-defined, thermal stratification pattern. The temperature gradient continued to exist until the end of August. On August 31, 1975, the temperature difference was only 2.0°C between surface and bottom, and on September 25 the water temperature was constant from surface to bottom. Station II was also isothermal on October 19.

Like Station I, Station II temperature measurements indicated that it was isothermal from the end of August or beginning of September until the end of April. Thermal stratification began to develop in May and became more intense as the water temperature increased, and it reached the highest intensity during July or August. The general temperature patterns for Station II was the same for both 1974 and 1975.

Station III

Station III had a maximum depth of 10 meters and the thermal behavior of this sampling station was similar to that of Station I. In 1974 the maximum water temperature of 29.5°C and the minimum water temperature of 5.8°C was reached on August 4 and December 27, respectively. In 1975 they were 28.5°C on July 12 and August 16, and 4.9°C January 21.

Station III also showed the existence of isothermal conditions from September to April. Thermal stratification existed during the last spring and summer months (May, June, July and August), and the intensity reached a maximum in July. The maximum difference between the surface and the bottom water temperatures was 3.5°C on May 10, 1974, and July 12, 1975. The temperature behavior of Station III was almost the same for both 1974 and 1975.

Station IV

This was one of the shallow stations, with a depth of only 6 meters. The water temperature range for this station was 4.8°C to 29.0°C. The minimum and maximum water temperature was reached on January 21, 1975, and July 12, 1975, respectively.

On May 10, 1974, the temperature difference between the surface and the bottom was 2.5°C. The temperature was nearly constant to a depth of 5 meters, and between 5 meters and the bottom the temperature decreased by 1.5°C. On June 11, 1974, the temperature was constant until 5 meters, and the difference in temperature between 5 meters and the bottom was 1.7°C. In 1974, except for these two sampling dates, the temperature differences between the surface and the bottom were insignificant.

Like the other sampling stations Station IV was isothermal until the end of March. There was only one exception and it occurred on February 28, 1975. Because of the unusually high air temperature (Table 12), the temperature of the water at the surface was 9.5°C, and it was 8.0°C at 2 meters. Below 2 meters the temperature was constant. The unusually high difference in temperature (2.3°C) between the surface and the bottom was due to the high air temperature of 17.5°C and the lack of high winds.

Station IV also exhibited a temperature gradient in May, June and July. The temperature difference between the surface and the bottom was small, the maximum difference of 2.0°C occurred in July. Beginning in August the temperature differences between the surface and the bottom decreased, and in September isothermal conditions were established.

Station V

Station V was the shallowest of all the sampling stations; it was only 4 meters deep. Station V was located near the Alameda Street bridge. The water temperature range was 4.4 to 29.0°C, with the minimum and maximum occurring in January and July. Because of the shallow nature of this station, the temperature differences between the surface and the bottom were small, even during summer months. The maximum temperature difference between the surface and the bottom was only 2.0°C, and this occurred on July 12, 1975. This station exhibited a small temperature difference between surface and bottom waters during May through August, and was isothermal in other months.

Monthly Average Temperatures: Stations I - V

Table 13 A-E contains the monthly average water temperatures from May, 1974 to October, 1975. Each temperature value was the average of two temperature values when the measurements were made twice a month, the same as the temperature of the sampling date when the measurements were made only once a month.

From the monthly average temperatures it can be readily seen that the heating period for the lake begins in February and continues until July or August, when the water reaches its maximum temperature. After August the cooling period starts and the minimum water temperature is reached in January, which is the coldest month. Thermal stratification started in May when significant differences in temperatures between different depths began to appear. Thermal stratification was most intense during July and August. From September until March or April, the temperature differences between the surface and the bottom were small and, in most cases, isothermal conditions exist. The shallow stations (IV and V) showed small differences in temperatures between surface and bottom waters during summer months. The thermal behavior of the lake appeared to be the same for the years 1974 and 1975.

Dissolved Oxygen (DO)

Dissolved Oxygen (DO) is the amount of oxygen dissolved in water and expressed in milligrams per liter (mg/l). The sources of dissolved oxygen in water are algal photosynthesis and atmospheric oxygen. The solubility of oxygen is directly proportional to the temperature of water and decreases in a non-linear manner with increasing temperature. The solubility of atmospheric oxygen in fresh waters range from 14.6 mg/l

TABLE 13-A

MONTHLY AVERAGE TEMPERATURES - STATION I

Temperature °C

1974

Depth-meters	MAY	JUNE	JULY	AUGUST	SEPTEMBER	OCTOBER	NOVEMBER	DECEMBER
Surface	20.8	25.0		28.0	22.2	19.0	14.2	6.0
1	20.4	25.0		28.1	22.2	18.9	14.2	5.9
2	20.3	24.0		28.0	22.2	18.9	14.2	5.9
3	20.2	23.5		28.0	22.2	18.9	14.2	5.9
4	20.2	23.0		27.8	22.1	18.8	14.2	5.9
5	20.2	23.0		27.8	22.1	18.8	14.2	5.9
6	20.2	23.0		27.7	22.1	18.8	14.2	5.9
7	20.0	23.0		27.6	22.1	18.8	14.2	5.8
8	19.9	23.0		27.5	22.1	18.7	14.2	5.8
9	19.5	23.0		27.3	22.1	18.5	14.2	5.8
10	18.5	23.0		27.2	22.0	18.5	14.1	5.8

TABLE 13-A

MONTHLY AVERAGE TEMPERATURES - STATION I

Temperature °C
(Continued)

1975

Depth-meters	JANUARY	FEBRUARY	MARCH	APRIL	MAY	JUNE	JULY	AUGUST	SEPTEMBER	OCTOBER
Surface	4.7	8.5	8.9	17.6	22.6	26.1	28.2	28.3	21.5	19.8
1	4.8	7.5	8.9	17.0	22.7	25.9	27.9	28.3	21.5	20.0
2	4.8	7.0	8.9	16.1	22.7	25.7	27.6	28.3	21.5	20.0
3	4.8	7.0	8.9	15.8	22.6	25.6	27.6	28.3	21.5	20.0
4	4.8	7.0	8.9	15.6	22.2	25.2	26.6	28.3	21.5	20.0
5	4.8	7.0	8.9	15.6	22.1	25.0	26.3	28.2	21.5	20.0
6	4.8	7.0	8.9	15.3	21.7	25.0	26.1	27.8	21.5	20.0
7	4.8	7.0	8.9	15.3	21.2	24.6	26.0	27.6	21.5	20.0
8	4.8	7.0	8.9	15.2	21.1	24.6	25.4	27.3	21.0	20.0
9	4.8	7.0	8.9	15.2	20.4	24.0	25.2	27.1	21.0	20.0
10	4.8	7.0	8.8	15.2	19.5	23.3	25.2	27.0	21.0	20.0

TABLE 13-B

MONTHLY AVERAGE TEMPERATURES - STATION II

Temperature °C

1974 Depth-meters	MAY	JUNE	JULY	AUGUST	SEPTEMBER	OCTOBER	NOVEMBER	DECEMBER
Surface	20.8	25.0		28.2	22.3	19.2	14.9	6.5
1	20.6	24.5		28.3	22.3	19.0	14.9	6.4
2	20.4	24.0		28.2	22.3	18.8	14.9	6.3
3	20.2	24.0		28.1	22.3	18.7	14.9	6.2
4	20.2	23.5		28.1	22.3	18.7	14.9	6.2
5	20.1	23.5		28.1	22.3	18.7	14.9	6.2
6	20.0	23.5		28.1	22.3	18.7	14.9	6.2
7	19.4	23.5		28.1	22.3	18.7	14.9	6.1
8	19.2	23.0		27.9	22.3	18.7	14.9	6.1
9	19.0	23.0		27.8	22.3	18.7	14.9	6.1
10	18.5	23.0		27.5	22.3	18.7	14.9	6.1
11	18.2	23.0		27.2	22.3	18.6	14.9	6.1
12	18.0	23.0		27.1	22.2	18.6	14.9	6.0
13	17.9	23.0		26.9	22.2	18.6	14.9	6.0
14	17.6	23.0		26.8	22.1	18.5	14.9	6.0
15	17.0	23.0		26.8	22.1	18.5	14.8	6.0

TABLE 13-B

MONTHLY AVERAGE TEMPERATURES - STATION II

Temperature °C
(Continued)

1975

Depth-meters	JANUARY	FEBRUARY	MARCH	APRIL	MAY	JUNE	JULY	AUGUST	SEPTEMBER	OCTOBER
Surface	4.8	9.5	8.9	16.3	22.4	25.4	28.2	28.1	21.8	19.6
1	4.8	7.5	8.9	15.9	22.4	25.2	28.0	27.9	21.8	19.8
2	4.8	7.0	8.9	15.6	22.3	25.0	27.7	27.9	21.8	20.0
3	4.8	7.0	8.9	15.5	21.9	24.8	27.5	27.8	21.8	20.0
4	4.8	6.8	8.9	15.5	21.6	24.5	27.5	27.7	21.8	20.0
5	4.8	6.8	8.9	15.5	21.3	24.4	27.5	27.7	21.8	20.0
6	4.8	6.8	8.9	15.5	21.1	24.1	27.0	27.5	21.8	20.0
7	4.8	6.8	8.9	15.3	20.7	23.9	26.2	27.1	21.8	20.0
8	4.8	6.8	8.9	15.3	20.5	23.8	25.9	26.8	21.8	20.0
9	4.8	6.8	8.9	15.2	20.4	23.8	25.6	26.6	21.8	20.0
10	4.8	6.8	8.9	15.2	20.0	23.7	25.3	26.4	21.8	20.0
11	4.8	6.8	8.9	15.0	19.8	23.3	25.2	26.4	21.8	20.0
12	4.8	6.8	8.9	15.0	19.7	23.0	24.8	26.2	21.8	20.0
13	4.8	6.8	8.9	14.5	19.5	22.9	24.6	26.0	21.8	20.0
14	4.8	6.8	8.8	14.5	19.2	22.8	24.3	25.6	21.8	20.0
15	4.8	6.8	8.8	14.5	18.8	22.4	24.1	24.9	21.8	19.9

TABLE 13-C

MONTHLY AVERAGE TEMPERATURES - STATION III

Temperature °C

1974 Depth-meters	MAY	JUNE	JULY	AUGUST	SEPTEMBER	OCTOBER	NOVEMBER	DECEMBER
Surface	20.8	24.5		28.6	22.8	19.2	14.5	6.7
1	20.8	24.2		28.6	22.8	19.0	14.5	6.6
2	20.5	23.8		28.6	22.8	18.7	14.5	6.5
3	20.4	23.4		28.5	22.7	18.7	14.4	6.5
4	20.4	23.1		28.4	22.7	18.7	14.4	6.4
5	20.4	23.1		28.4	22.7	18.7	14.4	6.4
6	20.0	23.0		28.4	22.7	18.7	14.3	6.4
7	19.6	23.0		28.3	22.7	18.7	14.3	6.4
8	19.0	23.0		28.2	22.7	18.7	14.2	6.3
9	18.8	22.8		28.0	22.6	18.7	14.2	6.3
10	18.2	22.8		27.5	22.6	18.7	14.1	6.3

TABLE 13-C

MONTHLY AVERAGE TEMPERATURES - STATION III

Temperature °C
(Continued)

1975 Depth-meters	JANUARY	FEBRUARY	MARCH	APRIL	MAY	JUNE	JULY	AUGUST	SEPTEMBER	OCTOBER
Surface	4.9	9.5	8.9	16.7	22.7	25.6	28.0	28.2	22.0	19.8
1	4.9	8.0	8.9	16.3	22.5	25.4	28.0	28.1	21.9	20.0
2	4.9	7.0	8.9	15.9	22.4	25.2	27.7	28.0	21.8	20.0
3	4.9	7.0	8.9	15.8	22.2	25.1	27.7	27.8	21.8	20.0
4	4.9	7.0	8.9	15.8	22.1	25.0	27.5	27.6	21.8	20.0
5	4.9	7.0	8.9	15.5	21.8	24.8	27.0	27.4	21.8	20.0
6	4.9	7.0	8.9	15.3	21.7	24.6	26.5	27.2	21.8	20.0
7	4.9	7.0	8.9	15.3	21.5	24.5	26.1	27.0	21.8	20.0
8	4.9	7.0	8.9	15.2	21.0	24.3	25.7	26.9	21.8	20.0
9	4.9	6.8	8.9	14.8	20.6	23.6	25.5	26.6	21.8	19.8
10	4.9	6.8	8.9	14.1	20.0	23.1	25.0	26.0	21.8	19.5

TABLE 13-D

MONTHLY AVERAGE TEMPERATURES - STATION IV

Temperature °C

1974 Depth-meters	MAY	JUNE	JULY	AUGUST	SEPTEMBER	OCTOBER	NOVEMBER	DECEMBER
Surface	21.5	25.0		28.6	22.9	19.1	14.0	6.4
1	21.5	24.9		28.6	22.9	19.0	14.0	6.3
2	21.2	24.9		28.5	22.8	18.8	14.0	6.2
3	21.2	24.9		28.3	22.7	18.6	13.8	6.2
4	21.0	24.9		28.3	22.7	18.6	13.8	6.1
5	20.5	24.9		28.3	22.6	18.5	13.7	6.0
6	19.0	23.2		28.2	22.5	18.5	13.6	6.0

TABLE 13-D

MONTHLY AVERAGE TEMPERATURES - STATION IV

Temperature °C
(Continued)

1975 Depth-meters	JANUARY	FEBRUARY	MARCH	APRIL	MAY	JUNE	JULY	AUGUST	SEPTEMBER	OCTOBER
Surface	4.8	9.5	8.9	17.0	23.6	26.2	28.5	28.3	21.5	19.9
1	4.8	9.0	8.9	16.4	23.4	26.0	28.5	28.1	21.5	19.9
2	4.8	8.0	8.9	16.0	23.0	25.5	28.2	27.8	21.2	19.9
3	4.8	7.5	8.9	15.8	22.9	25.5	27.2	27.6	21.2	19.9
4	4.8	7.5	8.9	15.7	22.8	25.3	27.0	27.5	21.0	19.9
5	4.8	7.2	8.9	15.7	22.3	25.3	26.7	27.4	21.0	19.9
6	4.8	7.2	8.9	15.5	21.6	24.9	26.5	27.4	21.0	19.9

TABLE 13-E

MONTHLY AVERAGE TEMPERATURES - STATION V

Temperature °C

1974 Depth-meters	MAY	JUNE	JULY	AUGUST	SEPTEMBER	OCTOBER	NOVEMBER	DECEMBER
Surface	22.0	26.0		28.4	23.5	19.2	13.2	5.1
1	22.0	26.0		28.1	23.2	19.1	13.1	5.0
2	21.8	25.4		28.1	22.9	18.8	13.0	4.9
3	21.8	25.0		27.9	22.6	18.5	12.7	4.8
4	20.8	24.0		27.9	22.5	17.9	12.4	4.8

TABLE 13-E

MONTHLY AVERAGE TEMPERATURES - STATION V

Temperature °C
(Continued)

1975 Depth-meters	JANUARY	FEBRUARY	MARCH	APRIL	MAY	JUNE	JULY	AUGUST	SEPTEMBER	OCTOBER
Surface	4.4	10.6	8.7	17.5	24.3	26.4	28.4	29.0	21.0	18.5
1	4.5	10.6	8.7	16.9	23.9	26.4	28.4	28.4	20.8	18.5
2	4.5	10.2	8.7	16.8	23.1	26.3	28.1	28.1	20.5	18.5
3	4.5	8.0	8.6	16.2	22.3	25.5	27.0	27.6	20.0	18.5
4	4.5	8.0	8.6	16.0	22.0	25.4	27.0	27.5	19.5	18.5

at 0°C to about 7.0 mg/l at 35.0°C under 1 atmosphere of pressure. The cirtical conditions related to DO deficiency in water occur during summer months when the temperatures are high and solubility of oxygen is at a minimum.

All living organisms are dependent upon oxygen to maintain metabolic processes that produce energy for growth and reproduction. Adequate dissolved oxygen is necessary for aerobic and facultative aquatic organisms.

The water samples for DO measurements in this study were collected with BOD bottles. The DO measurements were made immediately in the field by the Azide Modification of the Winkler Method. The DO values are presented in Tables 14 A-E.

Station I

The DO concentration range at Station I was 0.2 to 12 mg/l. The highest DO concentration was observed on January 21, 1975, and February 28, 1975. Generally, the DO concentration was higher when the water temperature was lower. On January 21, 1975, the water temperature was the lowest for 1975. Even when the surface water temperature was above 20.0°C, the DO concentration was generally 7.0 mg/l or higher.

On May 10, 1974, the DO concentration at the surface was 8.6 mg/l and there was no change in the DO concentration down to the 6 meter depth. Between 6 meters and the bottom the DO concentration was reduced by 1.6 mg/l, the bottom DO concentration was 7.0 mg/l. On June 11, 1974, the surface DO was 7.9 mg/l and the decrease in the DO concentration at the surface was probably due to the higher water temerature. The DO

TABLE 14-A

TEMPERATURE AND DISSOLVED OXYGEN IN LAKE THUNDERBIRD

STATION I

DATE	SURFACE		3 Meters		6 Meters		9 Meters		BOTTOM (10 Meters)	
	Temp. °C	DO mg/1	Temp. °C	DO mg/1	Temp. °C	DO mg/1	Temp. °C	DO mg/1	Temp. °C	DO mg/1
May 10, 1974	20.8	8.6	20.2	8.5	20.2	8.4	19.5	7.2	18.5	7.0
June 11, 1974	25.0	7.9	23.5	7.8	23.0	7.2	23.0	7.0	23.0	7.0
August 4, 1974	28.8	6.1	28.8	6.1	28.3	5.1	27.8	4.5	27.7	3.2
August 25, 1974	27.2	7.6	27.2	7.2	27.1	5.3	26.9	3.1	26.8	2.1
Sept. 10, 1974	23.5	6.8	23.4	6.8	28.2	5.1	23.2	4.4	23.1	3.2
Sept. 29, 1974	20.9	7.6	21.0	7.6	21.0	7.6	21.0	7.5	21.0	7.5
Oct. 16, 1974	19.6	8.2	19.3	8.2	19.1	8.2	18.6		18.6	8.0
Oct. 31, 1974	18.5	8.0	18.5		18.5	7.8	18.5		18.5	7.8
Nov. 12, 1974	14.2	8.5	14.2		14.2	8.5	14.2		14.1	8.5
Dec. 12, 1974	6.2	10.8	5.9		5.9	10.8	5.9		5.9	10.8
Dec. 27, 1974	5.9	11.2	5.9		5.8	11.0	5.7		5.7	11.0
Jan. 21, 1975	4.7	12.0	4.8		4.8	12.0	4.8		4.8	11.9
Feb. 28, 1975	8.5	12.0	7.0		7.0	12.0	7.0		7.0	11.7
March 17, 1975	7.3	11.5	7.3		7.3	11.5	7.3		7.3	11.3
March 30, 1975	10.5	10.4	10.5		10.5	10.4	10.5		10.4	10.3
April 12, 1975	15.2	10.6	12.2		12.2	10.2	12.0		12.0	10.0

TABLE 14-A

TEMPERATURE AND DISSOLVED OXYGEN IN LAKE THUNDERBIRD

STATION I
(Continued)

	SURFACE		3 Meters		6 Meters		9 Meters		BOTTOM (10 Meters)	
DATE	Temp. °C	DO mg/1	Temp. °C	DO mg/1	Temp. °C	DO mg/1	Temp. °C	DO mg/1	Temp. °C	DO mg/1
April 28, 1975	20.0	8.4	19.5		18.5	8.4	18.5		18.5	8.4
May 9, 1975	22.0	9.3	21.8	9.3	20.0	7.7	19.0	7.3	18.0	6.8
May 26, 1975	23.2	7.6	23.4	7.6	23.4	7.4	21.9	6.8	21.1	4.5
June 8, 1975	25.3	7.6	24.9	7.6	23.8	6.7	23.0	5.6	22.1	4.8
June 26, 1975	26.9	7.3	26.4	7.2	26.2	7.2	25.1	5.0	24.5	4.5
July 12, 1975	28.4	7.6	28.3	6.9	26.2	1.6	25.5	0.5	25.4	0.4
July 30, 1975	28.0	7.3	27.0	7.2	26.0	1.9	25.0	1.2	25.0	0.2
August 16, 1975	28.7	6.7	28.7	6.7	27.9	5.9	27.0	0.9	26.9	0.3
August 31. 1975	28.0	7.3	28.0	7.3	27.8	7.1	27.2	5.0	27.1	4.8
Sept. 25, 1975	21.5	7.5	21.5	7.3	21.5	7.2	21.0	7.2	21.0	7.0
Oct. 19, 1975	19.8	7.5	20.0	7.5	20.0	7.4	20.0	7.3	20.0	7.3

TABLE 14-B

TEMPERATURE AND DISSOLVED OXYGEN IN LAKE THUNDERBIRD

STATION II

	SURFACE		3 Meters		6 Meters		9 Meters		12 Meters		BOTTOM (15 Meters)	
DATE	Temp. °C	DO mg/1	Temp. °C	DO mg/1	Temp. °C	DO mg/1	Temp. °C	DO mg/1	Temp. °C	Do mg/1	Temp. °C	DO mg/1
May 10, 1974	20.8	8.6	20.2	8.5	20.0	8.3	19.0	8.1	18.0	7.1	17.0	5.8
June 11, 1974	25.0	7.9	24.0	7.8	23.5	7.8	23.0	7.2	23.0	7.2	23.0	4.0
Aug. 4, 1974	28.9	6.5	28.8	6.5	28.7	6.0	28.1	5.3	27.0	0.9	26.8	0.3
Aug. 25, 1974	27.5	6.9	27.5	6.7	27.5	6.0	27.5	5.3	27.3	4.9	26.8	0.2
Sept. 10, 1974	23.4	6.7	23.6	6.7	23.6	5.9	23.6	5.8	23.6	5.1	23.4	3.7
Sept. 29, 1974	21.2	7.3	21.0	7.3	21.0	7.3	21.0	7.3	20.9	7.3	20.9	7.1
Oct. 16, 1974	19.8	8.1	19.0		19.0		19.0	7.9	18.9		18.6	7.9
Oct. 31, 1974	18.7	8.0	18.5		18.5		18.5	8.0	18.4		18.4	7.6
Nov. 12, 1974	15.0	8.5	14.9		14.9		14.9	8.5	14.9		14.8	8.5
Dec. 12, 1974	6.9	10.8	6.6		6.5		6.5	10.8	6.4		6.4	10.8
Dec. 27, 1974	6.0	11.2	5.9		5.8		5.7	11.1	5.6		5.6	11.1
Jan. 21, 1975	4.8	12.0	4.8		4.8		4.8	11.9	4.8		4.8	11.9
Feb. 28, 1975	9.5	12.0	7.0		6.8		6.8	11.9	6.8		6.8	11.9
March 17,1975	7.3	11.4	7.3		7.3		7.3	11.3	7.3		7.3	11.2
March 30,1975	10.5	10.4	10.5		10.5		10.5	10.4	10.5		10.4	10.3
April 12, 1975	13.7	10.5	12.3		12.2		12.0	10.2	12.0		12.0	10.1

TABLE 14-B

TEMPERATURE AND DISSOLVED OXYGEN IN LAKE THUNDERBIRD

STATION II
(Continued)

	SURFACE		3 Meters		6 Meters		9 Meters		12 Meters		BOTTOM (15 Meters)	
DATE	Temp. °C	DO mg/1	Temp. °C	DO mg/1	Temp. °C	DO mg/1	Temp. °C	DO mg/1	Temp. °C	DO mg/1	Temp. °C	DO mg/1
April 28, 1975	19.0	8.7	18.8		18.8		18.5	8.4	18.0		17.0	7.5
May 9, 1975	22.0	9.4	20.9	9.4	19.8	7.7	19.1	7.3	18.7	6.3	17.8	6.2
May 26, 1975	22.9	7.4	22.9	7.3	22.5	7.3	21.8	6.8	20.7	4.7	19.9	4.0
June 8, 1975	24.0	7.2	23.8	7.1	23.2	6.7	22.9	5.5	21.9	4.5	21.7	2.8
June 26, 1975	26.9	7.5	25.8	7.1	25.1	6.2	24.8	5.4	24.2	4.6	23.1	1.6
July 12, 1975	29.0	7.5	28.0	7.5	27.0	6.4	25.0	2.0	24.5	0.2	24.0	0.1
July 30, 1975	27.5	7.0	27.0	6.7	27.0	3.5	26.2	2.4	25.1	0.2	24.3	0.1
Aug. 16, 1975	28.2	6.5	28.2	6.5	27.8	6.2	26.6	2.0	25.6	0.2	23.9	0
Aug. 31, 1975	28.0	7.1	27.5	6.9	27.2	6.0	27.0	4.6	26.9	1.9	26.0	0.1
Sept. 25, 1975	21.8	7.2	21.8	7.0	21.8	7.0	21.8	7.0	21.8	6.9	21.8	6.9
Oct. 19, 1975	19.6	7.5	20.0	7.5	20.0	7.4	20.0	7.4	20.0	7.3	19.9	7.3

TABLE 14-C

TEMPERATURE AND DISSOLVED OXYGEN IN LAKE THUNDERBIRD

STATION III

	SURFACE		3 Meters		6 Meters		9 Meters		BOTTOM (10 Meters)	
DATE	Temp. °C	DO mg/l	Temp. °C	DO mg/l	Temp. °C	DO mg/l	Temp. °C	DO mg/l	Temp. °C	DO mg/l
May 10, 1974	20.8	8.5	20.4	8.5	20.0	7.8	18.8	6.8	18.2	3.2
June 11, 1974	24.5	8.2	23.4	8.0	23.0	7.8	23.0	6.5	22.8	6.5
August 4, 1974	29.5	6.2	29.3	5.8	29.2	5.0	28.6	4.8	27.7	1.8
August 25, 1974	27.8	7.4	27.7	7.4	27.6	6.4	27.4	4.3	27.0	2.2
Sept. 10, 1974	24.2	7.4	24.1	7.1	24.1	6.8	24.0	6.6	24.0	6.3
Sept. 29, 1974	21.5	7.6	21.4	7.4	21.3	7.3	21.2	7.3	21.2	7.2
Oct. 16, 1974	19.7	8.3	19.1		19.1	8.0	19.1		19.1	7.9
Oct. 31, 1974	18.7	8.1	18.4		18.4	7.8	18.3		18.3	7.8
Nov. 12, 1974	14.5	8.7	14.4		14.3	8.7	14.2		14.1	8.7
Dec. 12, 1974	7.3	11.0	7.1		6.9	10.9	6.8		6.8	10.9
Dec. 27, 1974	6.1	11.3	6.0		5.9	11.3	5.8		5.8	11.3
Jan. 21, 1975	4.9	12.0	4.9		4.9	12.0	4.9		4.9	11.9
Feb. 28, 1975	9.5	11.9	7.0		7.0	11.8	6.8		6.8	11.8
March 17, 1975	7.3	11.3	7.3		7.3	11.3	7.3		7.3	11.3
March 30, 1975	10.5	10.5	10.5		10.5	10.4	10.5		10.5	10.4
April 12, 1975	14.5	10.6	12.9		12.2	10.2	12.1		12.0	10.0

TABLE 14-C

TEMPERATURE AND DISSOLVED OXYGEN IN LAKE THUNDERBIRD

STATION III
(Continued)

	SURFACE		3 METERS		6 METERS		9 METERS		BOTTOM (10 METERS)	
DATE	Temp. °C	DO mg/l	Temp. °C	DO mg/l	Temp. °C	DO mg/l	Temp. °C	DO mg/l	Temp. °C	DO mg/l
April 28, 1975	19.0	8.7	18.8		18.5	8.7	17.5		17.3	8.1
May 9, 1975	22.4	9.3	21.3	9.3	20.3	8.9	19.5	7.4	18.9	6.6
May 26, 1975	23.1	7.6	23.1	7.4	23.1	7.0	21.7	6.0	21.1	4.5
June 8, 1975	24.2	8.0	23.9	8.0	23.7	7.3	22.8	4.8	22.0	3.2
June 26, 1975	27.0	7.6	26.3	7.6	25.6	7.1	24.4	3.7	24.2	3.4
July 12, 1975	28.5	7.5	28.5	7.4	26.0	3.8	25.0	0.7	25.0	0.2
July 30, 1975	27.5	7.3	27.0	7.2	27.0	6.1	26.0	3.5	25.0	0.8
August 16, 1975	28.5	6.7	28.2	6.7	27.5	4.4	26.2	0.3	25.6	0
August 31, 1975	28.0	7.1	27.5	7.0	27.0	5.0	27.0	4.2	26.5	3.2
Sept. 25, 1975	22.0	7.3	21.8	7.1	21.8	7.1	21.8	7.0	21.8	7.0
Oct. 19, 1975	19.8	7.6	20.0	7.5	20.0	7.4	19.8	7.4	19.5	7.0

TABLE 14-D

TEMPERATURE AND DISSOLVED OXYGEN IN LAKE THUNDERBIRD

STATION IV

DATE	SURFACE		3 METERS		BOTTOM (6 METERS)	
	Temp. °C	DO mg/1	Temp. °C	DO mg/1	Temp. °C	DO mg/1
May 10, 1974	21.5	8.8	21.2	8.8	19.0	7.2
June 11, 1974	25.0	8.5	24.9	8.3	23.2	7.2
August 4, 1974	28.9	6.0	28.8	5.8	28.7	5.5
August 25, 1974	28.4	7.9	27.9	7.9	27.8	6.9
September 10, 1974	24.6	7.6	24.6	7.6	24.5	7.6
September 29, 1974	21.3	7.9	20.9	7.6	20.6	7.5
October 16, 1974	19.4	9.0	18.8		18.6	8.0
October 31, 1974	18.8	8.2	18.5		18.5	8.0
November 12, 1974	14.0	8.8	13.8		13.6	8.7
December 12, 1974	6.9	11.3	6.6		6.3	11.3
December 27, 1974	6.0	11.5	5.8		5.6	11.5
January 21, 1975	4.8	12.1	4.8		4.8	12.0
February 28, 1975	9.5	12.3	7.5		7.2	12.1
March 17, 1975	7.4	11.4	7.4		7.4	11.3
March 30, 1975	10.5	10.5	10.5		10.5	10.5
April 12, 1975	15.0	10.7	13.1		12.6	10.7
April 28, 1975	19.0	8.7	18.5		18.5	8.4
May 9, 1975	23.0	9.3	22.1	9.3	21.3	8.3
May 26, 1975	24.3	7.4	23.8	7.4	22.0	6.7
June 8, 1975	24.8	8.4	24.3	7.5	23.8	5.6
June 26, 1975	27.6	7.9	26.7	7.8	26.0	7.2
July 12, 1975	29.0	7.2	28.5	7.0	27.0	3.8
July 30, 1975	28.0	8.2	26.0	8.2	26.0	5.5
August 16, 1975	28.6	7.0	28.0	6.8	27.8	5.3
August 31, 1975	28.0	7.4	27.2	6.5	27.0	5.1
September 25, 1975	21.5	7.7	21.2	7.6	21.0	7.2
October 19, 1975	19.9	7.9	19.9	7.9	19.9	7.9

TABLE 14-E

TEMPERATURE AND DISSOLVED OXYGEN IN LAKE THUNDERBIRD

STATION V

DATE	SURFACE		3 METERS		BOTTOM (4 METERS)	
	Temp. °C	DO - mg/l	Temp°C	DO-mg/l	Temp°C	DO-mg/l
5/10/74	22.0	8.3	21.8	8.0	20.8	7.2
6/11/74	26.0	7.4	25.0	7.4	24.0	7.4
8/4/74	28.0	6.1	27.8	4.8	27.9	4.8
8/25/74	28.9	7.9	28.1	7.9	28.1	7.8
9/10/74	25.4	8.0	24.4	7.8	24.3	7.5
9/29/74	21.6	8.2	20.8	8.1	20.7	8.0
10/16/74	19.5	8.9	18.4		18.3	8.0
10/31/74	18.9	7.6	18.7		17.5	7.2
11/12/74	13.2	8.8	12.7		12.4	8.7
12/12/74	5.6	11.8	5.3		5.2	11.8
12/27/74	4.6	11.6	4.4		4.4	11.6
1/21/75	4.4	12.1	4.5		4.5	12.1
2/28/75	10.6	12.6	8.0		8.0	12.4
3/17/75	7.5	11.4	7.3		7.3	11.4
3/30/75	10.0	10.5	10.0		10.0	10.5
4/12/75	15.8	10.8	13.6		13.4	10.8
4/28/75	19.3	8.7	18.8		18.6	8.7
5/9/75	24.0	8.8	21.0	8.4	21.0	7.6
5/26/75	24.6	6.3	23.6	6.3	23.0	4.5
6/8/75	25.0	6.9	24.7	6.9	24.6	6.7
6/26/75	27.9	8.0	26.4	7.5	26.2	6.8
7/12/75	28.8	6.5	28.0	5.3	28.0	4.5
7/30/75	28.0	8.2	26.0	8.1	26.0	7.9
8/16/75	29.0	7.6	28.2	7.0	28.0	4.4
8/31/75	29.0	7.9	27.0	6.6	27.0	6.0
9/25/75	21.0	8.0	20.0	7.5	19.5	7.5
10/19/75	18.5	7.8	18.5	7.7	18.5	7.7

concentration at the bottom was the same as on May 10 (7.0 mg/l).

On August 4, 1974, the DO concentration at the surface and 3 meters was 6.1 mg/l; it dropped by 1.0 mg/l at 6 meters, and the bottom DO was only 3.2 mg/l. The gradual decrease in DO values from the surface to the bottom indicated DO stratification. On August 25, 1974, the DO concentration showed a decrease at 9 meters and the bottom--the DO concentration at the bottom was only 2.1 mg/l. Once again, DO stratification was present. On September 10, 1974, the temperature profile was entirely uniform; however, the DO profile ranged from 6.8 mg/l at the surface to 3.2 mg/l at the bottom. More time was required to raise the DO to a uniform level than was necesary to make the lake isothermal. This was probably due to the high organic content of the lake. On September 29, 1974, the DO concentration was almost the same from the surface to the bottom.

From September 29, 1974, until the end of February, 1975, the DO values at the surface showed an increasing trend due to reduction in temperatures. From September 29, 1974, until the end of April, 1975, the DO concentrations from the surface to the bottom were the same, or the difference in DO values were small. During this period the lake was isothermal and homogeneous with respect to oxygen.

On May 9, 1975, the DO concentration showed a significant difference between the surface and the bottom. The DO concentration at the bottom was 6.8 mg/l and the difference between the surface and the bottom DO value was 2.5 mg/l. The bottom DO was almost the same as on May 10, 1974. On May 26, 1975, the bottom DO was further reduced to only 4.5 mg/l. This DO concentration was less than the minimum water quality standard for Little River (5.0 mg/l). In June, on both sampling dates, the DO concentrations were lower at the 9 meter depth and the bottom DO concentrations were almost the same.

On July 12, 1975, the DO values ranged from 7.6 mg/l at the surface to 0.4 mg/l at the bottom. The DO concentration dropped by 5.3 mg/l from 3 meters to 6 meters, and below 6 meters the available DO was less than 1.6 mg/l. On July 30, 1975, the DO concentration below 6 meters was still less than 2.0 mg/l, and the bottom DO was only 0.2 mg/l. On August 16, 1975, the DO at the 6-meter depth increased, but 9 meter and bottom DO values were only 0.9 mg/l and 0.3 mg/l respectively. In July and part of August near anaerobic conditions existed below 9-meter depth, and water of poor quality existed below the 6 meter depth. On August 31, 1975, the DO concentration at the bottom increased to 4.8 mg/l, and other depths also showed an increase.

On September 25, 1975, the DO concentration at 9 meters and at the bottom increased and were almost equal to the surface DO concentration. On October 19, 1975, once again the surface and the bottom DO concentrations were the same, indicating that the lake was homogeneous.

Station II

Station II was located near the aeration site. The DO concentration range at Station II was 0 to 12.0 mg/l. The maximum DO concentration was obtained on January 21, 1975, and February 28, 1975.

The DO behavior at Station II was similar to the DO behavior at Station I. On May 10, 1974, the DO concentration dropped from 8.6 mg/l at the surface to 5.8 mg/l at the bottom. The DO value decreased 0.5 mg/l from the surface to a depth of 9 meters. There was a drop of 1 mg/l in DO between 9 meters and 12 meters and 1.3 mg/l between 12 meters and the bottom; therefore, the DO stratification was beginning to develop at Station II. On June 11, 1974, similar DO values were obtained, but the bottom DO was only 4 mg/l. On August 4, 1974, the DO concentration decreased at all depths and there was a 4.4 mg/l difference between 9 and 12 meters. The DO concentration at the 12-meter depth was only 0.9 mg/l, and at the bottom it was only 0.3 mg/l, thus the DO stratification was more intense. On August 25, 1974, the bottom DO was almost the same, but the DO concentration at 12 meters increased to 4.9 mg/l. On August 25, 1974, the difference between the surface and 9-meter DO concentration was only 0.9 mg/l. In August, 1974, near anaerobic conditions existed at the bottom.

On September 10, 1974, the DO concentration increased at 12 meters and the bottom. The temperature was uniform, the DO concentration ranged from 6.7 mg/l at the surface to 3.7 mg/l at the bottom. On September 29, 1974, the DO concentration was almost the same from the surface to the bottom, and Station II was homogeneous with respect to DO.

From the end of September until the end of April the DO concentrations were uniform from surface to bottom. The surface DO variation on different sampling dates were due to changes in water temperatures.

On May 9, 1975, there was a 3.2 mg/l difference in the DO value between the surface and the bottom. The DO concentration decreased with depth and the bottom DO was only 6.2 mg/l. On May 26, the DO concentration was decreased at all depths and the bottom DO was only 4.0 mg/l. On June 8, 1975, there was a significant reduction in the DO concentration below 9 meters. The DO concentration was 7.2 mg/l until 6 meters, dropped by 1.2 mg/l at 9 meters, dropped to 4.5 mg/l at 12 meters, and at the bottom it was only 2.8 mg/l. On June 26, 1975, the DO concentration showed similar differences between depths, and at the bottom it was reduced to 1.6 mg/l. In 1975, May and June DO values were lower than the DO values of May and June in 1974.

On July 12, 1975, the DO concentration dropped more rapidly below the 6-meter depth (4.4 mg/l difference between 6 and 9 metes, 1.8 mg/l difference between 9 and 12 meters), and the bottom DO concentration was only 0.1 mg/l. On July 30 the DO concentration range was from 7.0 mg/l at the surface to 0.1 mg/l at the bottom and the DO concentration at the 6-meter depth was reduced from 6.4 mg/l (on July 12) to 3.5 mg/l.

The DO stratification continued in August and on August 16, the DO concentration was less than 2.0 mg/l below the 9 meter depth; it was 0.2 mg/l at 12 meters and zero at the bottom. On August 31, the DO concentrations at the 9 and 12 meter depths increased slightly; however, the bottom DO was still only 0.1 mg/l.

Station II remained in a stratified condition during May, June, July and August. In July and August the DO concentration below 9 meters did not meet the Oklahoma water quality standards. Water below the 12-meter depth was anaerobic. In September and October the DO values did not vary much between surface and bottom, thus Station II became homogeneous with respect to oxygen.

<u>Station III</u>

The DO concentration range at Station III was 0 to 12.0 mg/l. The surface water had the maximum DO concentration on January 21, 1975, and February 28, 1975. On August 16, 1975, the DO concentration at the bottom was zero.

The DO profiles at Station III were similar to those at Stations I and II. On May 10, 1974, the DO at the surface was 8.5 mg/l and the bottom water had an oxygen content of only 3.2 mg/l. The DO concentration decreased from the surface to the bottom, the DO difference was 3.6 mg/l between 9 meters and the bottom. On June 11, 1974, the DO content was almost the same as that on May 10, down to 9 meters, but the bottom DO value increased to 6.5 mg/l. On August 4, 1974, the DO concentration at the surface was only 6.2 mg/l (due to higher water temperature) and the DO content decreased from the surface to the bottom; the bottom DO was only 1.8 mg/l. On August 25, 1974, the DO at each level increased over that on August 4; the bottom DO also showed a small increase. On September 10, 1974, the surface and the bottom DO concentrations showed a difference of only 1.1 mg/l. On September 29, 1974, the oxygen content at the surface and the bottom was almost the same, and Station III was homogeneous with respect to oxygen. The surface and the bottom DO varied little from September until the end of April.

On May 9, 1975, the differences in DO concentrations between different depths began to appear; the bottom DO was 6.6 mg/l. The DO content at the 9-meter depth and the bottom decreased with each sampling date until the middle of August. The same was true for 6 meter depths in some cases. On two occasions (July 12 and July 30), the bottom was near anaerobic and the DO concentration was zero on August 16, 1975. On August 31, 1975, the DO at all levels increased over those on August 16; the DO at the bottom increased to 3.2 mg/l. On September 25 and October 19 the DO concentration from surface to bottom showed only a small difference. Beginning on September 19, 1975, Station III was homogeneous in terms of DO concentrations at all levels.

Station IV

The DO concentration range at Station IV was from 3.8 to 12.3 mg/l. The surface DO was 12.3 mg/l on February 28, 1975, and the bottom DO was 3.8 mg/l on July 30, 1975.

On most sampling dates there was very little variation in DO concentration from surface to bottom, thus Station IV was homogeneous. This was probably due to greater wind mixing of the water because of the shallow depth of this sampling station. In some cases there were marked differences in the DO values between the surface and the bottom. The difference in DO between 3 meters and the bottom on June 8, 1975, was 1.9 mg/l; on July 12, 1975, it was 3.2 mg/l; on July 30, 1975, it was 2.7 mg/l; on August 16, 1975, it was 1.5 mg/l; and on August 31, 1975, it was 1.4 mg/l. The DO concentration at the bottom during July and August was lower in comparison with other months.

Station V

The DO concentration range at Station V was from 4.4 to 12.6 mg/l. On February 28, 1975, the surface DO was the maximum and the minimum DO occurred at the bottom on August 16, 1975.

On most sampling dates the DO concentration from the surface to the bottom was almost the same, thus Station V was homogeneous. Like Station IV, this was probably due to greater wind mixing because of the shallow depth of Station V. On only a few occasions did the DO concentration between the surface and the bottom waters show marked differences. This occurred during the summer months. For example, on July 12, 1975, the DO concentration at the surface was 6.5 mg/l and at the bottom it was 4.5 mg/1. On August 16, 1975, the DO difference between 3 meters and the bottom was 2.6 mg/1.

Monthly Average DO Values - Stations I - V

The monthly average DO values from May, 1974, through October, 1975, are presented in Tables 15 A-E. The monthly average DO values were computed in the same manner as the monthly average temperatures. The monthly average DO concentrations showed that the differences in oxygen content between different depths began to appear in May; however, the bottom still had plenty of oxygen. The oxygen stratification which began in May intensified in July and August. During July there were large differences in DO values between the surface and the bottom. The bottom DO concentrations during July and August were zero, or close to zero, in Stations I, II and III, and the DO values below 6 meters were much less compared to the period when the lake was homogeneous. The average DO concentrations began to increase in August although the oxygen stratification was still intense. In September the DO was relatively uniform throughout. Sampling Stations I, II and III were homogeneous with respect to oxygen from September until April. Sampling Stations IV and V had low oxygen concentration at the bottom during July and August and, except for 3 or 4 occasions during the summer months, the DO content was almost the same at different depths. This was probably due to greater wind mixing because of the shallow depth of these two sampling stations.

pH

The term pH is used to express the intensity of acid or alkaline conditions of water. It is a way of expressing hydrogen-ion concentration

TABLE 15-A

MONTHLY AVERAGE TEMPERATURE AND DISSOLVED OXYGEN VALUES--STATION I

1974

MONTH	SURFACE		3 Meters		6 Meters		9 Meters		BOTTOM (10 Meters)	
	Temp. °C	DO mg/1	Temp. °C	DO mg/1	Temp. °C	DO mg/1	Temp. °C	DO mg/1	Temp. °C	DO mg/1
May	20.8	8.6	20.2	8.5	20.2	8.4	19.5	7.2	18.5	7.0
June	25.0	7.9	23.5	7.8	23.0	7.2	23.0	7.0	23.0	7.0
August	28.0	6.8	28.0	6.6	27.7	5.2	27.3	3.8	27.2	2.6
September	22.2	7.2	22.2	7.2	22.1	6.3	22.1	5.9	22.0	5.3
October	19.0	8.1	18.9		18.8	8.0	18.5		18.5	7.9
November	14.2	8.5	14.2		14.2	8.5	14.2		14.1	8.5
December	6.0	11.0	5.9		5.8	10.9	5.8		5.8	10.9

TABLE 15-A

MONTHLY AVERAGE TEMPERATURE AND DISSOLVED OXYGEN VALUES--STATION I

1975
(Continued)

MONTH	SURFACE		3 METERS		6 METERS		9 METERS		BOTTOM (10 METERS)	
	Temp. °C	DO mg/l	Temp. °C	DO mg/l	Temp. °C	DO mg/l	Temp. °C	DO mg/l	Temp. °C	DO mg/l
January	4.7	12.0	4.8		4.8	12.0	4.8		4.8	11.9
February	8.5	12.0	7.0		7.0	12.0	7.0		7.0	11.7
March	8.9	10.9	8.9		8.9	10.9	8.9		8.8	10.8
April	17.6	9.5	15.8		15.3	9.3	15.2		15.2	9.2
May	22.6	8.4	22.6	8.4	21.7	7.5	20.4	7.0	19.5	5.6
June	26.1	7.4	25.6	7.4	25.0	6.9	24.0	5.3	23.3	4.6
July	28.2	7.4	27.6	7.0	26.1	1.7	25.2	0.8	25.2	0.3
August	28.3	7.0	28.3	7.0	27.8	6.5	27.1	2.9	27.0	2.5
September	21.5	7.5	21.5	7.3	21.5	7.2	21.0	7.2	21.0	7.0
October	19.8	7.5	20.0	7.5	20.0	7.4	20.0	7.3	20.0	7.3

TABLE 15-B

MONTHLY AVERAGE TEMPERATURE AND DISSOLVED OXYGEN VALUES--STATION II

1974

MONTH	SURFACE		3 METERS		6 METERS		9 METERS		12 METERS		BOTTOM (15 METERS)	
	Temp. °C	DO mg/1	Temp. °C	Do mg/1	Temp. °C	DO mg/1	Temp. °C	DO mg/1	Temp. °C	Do mg/1	Temp. °C	DO mg/1
May	20.8	8.6	20.2	8.5	20.0	8.3	19.0	8.1	18.0	7.1	17.0	5.8
June	25.0	7.9	24.0	7.8	23.5	7.8	23.0	7.2	23.0	7.2	23.0	4.0
August	28.2	6.7	28.1	6.6	28.1	6.0	27.8	5.3	27.1	2.9	26.8	0.2
September	22.3	7.0	22.3	7.0	22.3	6.6	22.3	6.5	22.2	6.2	22.1	5.4
October	19.2	8.0	18.7		18.7		18.7	7.9	18.6		18.5	7.7
November	14.9	8.5	14.9		14.9		14.9	8.5	14.9		14.8	8.5
December	6.5	11.0	6.2		6.1		6.1	10.9	6.0		6.0	10.9

TABLE 15-B

MONTHLY AVERAGE TEMPERATURE AND DISSOLVED OXYGEN VALUES--STATION II

1975

(Continued)

MONTH	SURFACE		3 METERS		6 METERS		9 METERS		12 METERS		BOTTOM (15 METERS)	
	Temp. °C	DO mg/l	Temp. °C	DO mg/l	Temp. °C	DO mg/l	Temp. °C	DO mg/l	Temp. °C	DO mg/l	Temp. °C	DO mg/l
January	4.8	12.0	4.8		4.8		4.8	11.9	4.8		4.8	11.9
February	9.5	12.0	7.0		6.8		6.8	11.9	6.8		6.8	11.9
March	8.9	10.9	8.9		8.9		8.9	10.8	8.9		8.8	10.7
April	16.3	9.6	15.5		15.5		15.2	9.3	15.0		14.5	8.8
May	22.4	8.4	21.9	8.3	21.1	7.5	20.4	7.0	19.7	5.5	18.8	5.1
June	25.4	7.3	24.8	7.1	24.1	6.4	23.8	5.4	23.0	4.5	22.4	2.2
July	28.2	7.2	27.5	7.1	27.0	4.9	25.6	2.2	24.8	0.2	24.1	0.1
August	28.1	6.8	27.8	6.7	27.5	6.1	26.8	3.3	26.2	1.0	24.9	0.5
September	21.8	7.2	21.8	7.0	21.8	7.0	21.8	7.0	21.8	6.9	21.8	6.9
October	19.6	7.5	20.0	7.5	20.0	7.4	20.0	7.4	20.0	7.3	19.9	7.3

TABLE 15-C

MONTHLY AVERAGE TEMPERATURE AND DISSOLVED OXYGEN VALUES--STATION III

1974

MONTH	SURFACE		3 METERS		6 METERS		9 METERS		BOTTOM (10 METERS)	
	Temp. °C	DO mg/l	Temp. °C	DO mg/l	Temp. °C	Do mg/l	Temp. °C	Do mg/l	Temp. °C	Do mg/l
May	20.8	8.5	20.4	8.5	20.0	7.8	18.8	6.8	18.2	3.2
June	24.5	8.2	23.4	8.0	23.0	7.8	23.0	6.5	22.8	6.5
August	28.6	6.8	28.5	6.6	28.4	5.7	28.0	4.5	27.5	2.0
September	22.8	7.5	22.7	7.2	22.7	7.0	22.6	6.9	22.6	6.7
October	19.2	8.2	18.7		18.7	7.9	18.7		18.7	7.8
November	14.5	8.7	14.4		14.3	8.7	14.2		14.1	8.7
December	6.7	11.1	6.5		6.4	11.1	6.3		6.3	11.1

TABLE 15-C

MONTHLY AVERAGE TEMPERATURE AND DISSOLVED OXYGEN VALUES--STATION III

1975
(Continued)

MONTH	SURFACE		3 METERS		6 METERS		9 METERS		BOTTOM (10 METERS)	
	Temp. °C	DO mg/1	Temp. °C	DO mg/1	Temp. °C	DO mg/1	Temp. °C	DO mg/1	Temp. °C	DO mg/1
January	4.9	12.0	4.9		4.9	12.0	4.9		4.9	11.9
February	9.5	11.9	7.0		7.0	11.8	6.8		6.8	11.8
March	8.9	10.9	8.9		8.9	10.8	8.9		8.9	10.8
April	16.7	9.6	15.8		15.3	9.4	14.8		14.1	9.0
May	22.7	8.4	22.2	8.3	21.7	7.9	20.6	6.7	20.0	5.5
June	25.6	7.8	25.1	7.8	24.6	7.2	23.6	4.2	23.1	3.3
July	28.0	7.4	27.7	7.3	26.5	4.9	25.5	2.1	25.0	0.5
August	28.2	6.9	27.8	6.8	27.2	4.7	26.6	2.2	26.0	1.6
September	22.0	7.3	21.8	7.1	21.8	7.1	21.8	7.0	21.8	7.0
October	19.8	7.6	20.0	7.5	20.0	7.4	19.8	7.4	19.5	7.0

TABLE 15-D

MONTHLY AVERAGE TEMPERATURE AND DISSOLVED OXYGEN VALUES--STATION IV

1974

MONTH	SURFACE		3 METERS		BOTTOM (6 METERS)	
	Temp. °C	DO mg/1	Temp. °C	DO mg/1	Temp. °C	DO mg/1
May	21.5	8.8	21.2	8.8	19.0	7.2
June	25.0	8.5	24.9	8.3	23.2	7.2
August	28.6	6.9	28.3	6.8	28.2	6.2
September	22.9	7.7	22.7	7.6	22.5	7.5
October	19.1	8.6	18.6		18.5	8.0
November	14.0	8.8	13.8		13.6	8.7
December	6.4	11.4	6.2		6.0	11.4

TABLE 15-D

MONTHLY AVERAGE TEMPERATURE AND DISSOLVED OXYGEN VALUES--STATION IV

1975
(Continued)

MONTH	SURFACE		3 METERS		BOTTOM (6 METERS)	
	Temp. °C	DO mg/l	Temp. °C	DO mg/l	Temp. °C	DO mg/l
January	6.0	12.1	5.8		5.6	12.0
February	4.8	12.3	4.8		4.8	12.1
March	8.9	10.9	8.9		8.9	10.9
April	17.0	9.7	15.8		15.5	9.5
May	23.6	8.3	22.9	8.3	21.6	7.5
June	26.2	8.1	25.5	7.6	24.9	6.4
July	28.5	7.7	27.2	7.6	26.5	4.6
August	28.3	7.2	27.6	6.6	27.4	5.2
September	21.5	7.7	21.2	7.6	21.0	7.2
October	19.9	7.9	19.9	7.9	19.9	7.9

TABLE 15-E

MONTHLY AVERAGE TEMPERATURE AND DISSOLVED OXYGEN VALUES--STATION V

1974

MONTH	SURFACE		3 METERS		BOTTOM (4 METERS)	
	Temp. °C	DO mg/1	Temp. °C	DO mg/1	Temp. °C	DO mg/1
May	22.0	8.3	21.8	8.0	20.8	7.2
June	26.0	7.4	25.0	7.4	24.0	7.4
August	28.6	7.0	28.0	6.3	28.0	6.3
September	23.5	8.1	22.6	7.9	22.5	7.7
October	19.2	8.2	18.5		17.9	7.6
November	13.2	8.8	12.7		12.4	8.7
December	5.1	11.7	4.8		4.8	11.7

TABLE 15-E

MONTHLY AVERAGE TEMPERATURE AND DISSOLVED OXYGEN AVLUES--STATION V

1975
(Continued)

MONTH	SURFACE		3 METERS		BOTTOM (4 METERS)	
	Temp. °C	DO mg/1	Temp. °C	DO mg/1	Temp. °C	DO mg/1
January	4.6	12.1	4.4		4.4	12.1
February	4.4	12.6	4.5		4.5	12.4
March	8.7	10.9	8.6		8.6	10.9
April	17.5	9.7	16.2		16.0	9.7
May	24.3	7.5	22.3	7.3	22.0	6.0
June	26.4	7.4	25.5	7.2	25.4	6.7
July	28.4	7.3	27.0	6.7	27.0	6.2
August	29.0	7.7	27.6	6.8	27.5	5.2
September	21.0	8.0	20.0	7.5	19.5	7.5
October	18.5	7.8	18.5	7.7	18.5	7.7

or hydrogen-ion activity. The pH is an important factor in coagulation, disinfection, corrosion control and water softening. In biological treatment processes, pH must be controlled within a range favorable to the particular organisms involved.

The pH of lakes varies from 1.7 in some volcanic lakes containing free H_2SO_4 to 12 or more in some closed alkaline lakes rich in soda. The pH of most natural waters falls within the range 6-9. Most natural waters have a pH greater than 7 due to the presence of carbonates and bicarbonates. There is usually a slight fall in pH in the hypolimnion of lakes exhibiting a clinograde oxygen curve during summer stratification due to a higher carbon dioxide content and the presence of organic acids formed during decomposition.

The pH measurements in this study were made in the field with a portable pH meter. In some cases the pH measurements were made in the laboratory within 2 to 3 hours of the sample collection and this was done during the winter due to the cold weather. The pH values are given in Tables 16 A-E.

Station I

The pH range at the surface was from 8.1 to 8.6, and at the bottom it was from 7.6 to 8.6. On May 10, 1974, the pH at the surface was 8.5 and there was a difference of 0.3 unit between the surface and the bottom. On June 11, 1974, the bottom pH was reduced to 7.9 and it was 0.4 unit less than at the surface. In August, 1974, the pH of the bottom water was 7.6, and the difference between surface and bottom pH was 0.6 unit. The biggest drop in pH occurred between 6 and 9 meters. From September, 1974, to April, 1975, the surface pH showed variation,

TABLE 16-A

pH AND ALKALINITY IN LAKE THUNDERBIRD

STATION I

DATE	SURFACE		3 METERS		6 METERS		9 METERS		BOTTOM (10 METERS)	
	pH	Alk.mg/1 as CaCo3	pH	Alk.mg/1 as CaCo3	pH	Alk.mg/1 as CaCo3	pH	Alk.mg/1 as CaCo3	pH	Alk.mg/1 as CaCo3
May 10, 1974	8.50	170	8.50	170	8.40	172	8.40	172	8.20	174
June 11, 1974	8.30	180	8.25	183	8.10	182	8.00	184	7.90	184
August 4, 1974	8.30	152	8.20	162	8.00	172	7.70	172	7.60	172
August 31,1974	8.35	170	8.10	170	7.90	170	7.70	172	7.60	174
Sept. 10, 1974	8.25	170	8.25	170	8.20	172	8.20	172	8.15	172
Sept. 29, 1974	8.30	166	8.25	166	8.25	166	8.25	170	8.25	170
Oct. 16, 1974	8.30	170	8.30	172	8.30	172	8.30	174	8.30	174
Oct. 31, 1974	8.35	160			8.35	166			8.35	166
Nov. 12, 1974	8.45	156			8.35	160			8.35	160
Dec. 12, 1974	8.60	160			8.60	164			8.60	164
Dec. 27, 1974	8.40	160			8.40	166			8.40	166
Jan. 21, 1975	8.55	170			8.55	170			8.55	170
Feb. 28, 1975	8.60	166			8.55	166			8.55	172
March 17, 1975	8.45	164			8.30	168			8.30	168
March 30, 1975	8.30	168			8.25	168			8.25	170
April 12, 1975	8.40	160			8.35	170			8.30	172
April 28, 1975	8.55	172			8.50	171			8.40	171

TABLE 16-A

pH AND ALKALINITY IN LAKE THUNDERBIRD

STATION I
(Continued)

DATE	SURFACE		3 METERS		6 METERS		9 METERS		BOTTOM (10 METERS)	
	pH	Alk.mg/l as $CaCo_3$	pH	Alk.mg/l as $CaCo_3$	pH	Alk.mg/l as $CaCo_3$	pH	Alk.mg/l as $CaCo_3$	pH	Alk.mg/l as $CaCo_3$
May 9, 1975	8.60	166	8.60	172	8.40	174	8.40	174	8.20	176
May 26, 1975	8.60	168	8.60	168	8.60	158	8.50	158	8.25	150
June 8, 1975	8.30	160	8.25	158	8.20	160	7.95	160	7.90	160
June 26, 1975	8.30	162	8.30	161	8.25	162	8.10	162	8.00	162
July 12, 1975	8.40	160	8.40	160	7.90	162	7.80	162	7.80	162
July 30, 1975	8.50	160	8.30	158	8.00	160	7.80	160	7.80	160
Aug. 16, 1975	8.40	154	8.40	156	8.40	158	8.00	158	7.90	160
Aug. 31, 1975	8.40	160	8.35	160	8.30	162	8.25	162	8.25	162
Sept. 25, 1975	8.40	160	8.40	160	8.30	158	8.30	158	8.25	158
Oct. 19, 1975	8.10	158	8.10	160	8.10	162	8.10	162	8.10	162

TABLE 16-B

pH AND ALKALINITY IN LAKE THUNDERBIRD

STATION II

DATE	SURFACE		3 METERS		6 METERS		9 METERS		12 METERS		BOTTOM (15 METERS)	
	pH	Alk.mg/1 as $CaCo_3$	pH	Alk.mg/1 as $CaCo_3$	pH	Alk.mg/1 as $CaCo_3$	pH	Alk.mg/1 as $CaCo_3$	pH	Alk.mg/1 as $CaCo_3$	pH	Alkmg/1 as $CaCo_3$
5/10/74	8.50	170	8.50	170	8.40	172	8.30	176	8.25	176	8.20	180
6/11/74	8.30	178	8.30	176	8.25	180	8.30	178	8.25	183	8.20	183
8/4/74	8.0	170	8.00	170	8.0	170	7.90	170	7.75	172	7.40	171
8/25/74	8.0	170	8.00	172	7.95	172	7.85	172	7.80	172	7.40	172
9/10/74	8.05	170	8.05	170	8.05	170	7.95	170	7.85	170	7.75	172
9/29/74	8.15	168	8.10	168	8.10	168	8.05	168	8.05	168	7.95	170
10/16/74	8.40	174					8.20	174			8.20	174
10/16/74	8.30	168					8.30	170			8.25	170
11/12/74	8.35	164					8.35	166			8.35	166
12/12/74	8.50	164					8.45	162			8.45	162
12/27/74	8.45	172					8.35	170			8.30	170
1/21/75	8.60	168					8.55	168			8.55	170
2/28/75	8.30	170					8.30	170			8.25	170

TABLE 16-B

pH AND ALKALINITY IN LAKE THUNDERBIRD

STATION II
(Continued)

DATE	SURFACE		3 METERS		6 METERS		9 METERS		12 METERS		BOTTOM (15 METERS)	
	pH	Alk. mg/l as $CaCo_3$	pH	Alk. mg/l as $CaCo_3$	pH	Alk. mg/l as $CaCo_3$	pH	Alk. mg/l as $CaCo_3$	pH	Alk. mg/l as $CaCo_3$	pH	Alk. mg/l as $CaCo_3$
3/17/75	8.30	168					8.25	170			8.25	170
3/30/75	8.30	168					8.25	170			8.25	170
4/12/75	8.35	172					8.35	174			8.30	174
4/28/75	8.45	175					8.45	175			8.30	175
5/9/75	8.60	172	8.55	172	8.40	174	8.40	176	8.25	176	8.20	176
5/26/75	8.60	176	8.60	176	8.55	177	8.45	178	8.35	180	8.25	180
6/8/75	8.20	160	8.20	160	8.20	160	8.15	159	7.95	158	7.80	158
6/26/75	8.30	162	8.25	160	8.25	162	8.15	162	8.05	164	7.95	164
7/12/75	8.35	164	8.35	166	8.35	166	7.90	166	7.70	166	7.70	166
7/30/75	8.30	162	8.30	160	8.25	160	7.90	160	7.75	162	7.75	168
8/16/75	8.45	158	8.45	158	8.40	160	8.0	162	7.80	164	7.80	164
8/31/75	8.30	162	8.30	162	8.25	162	8.25	162	7.90	164	7.85	164
9/25/75	8.35	158	8.35	160	8.30	160	8.25	158	8.25	160	8.25	162
10/19/75	8.10	160	8.10	160	8.10	160	8.10	160	8.00	160	8.00	162

TABLE 16-C

pH AND ALKALINITY IN LAKE THUNDERBIRD

STATION III

DATE	SURFACE		3 METERS		6 METERS		9 METERS		BOTTOM (10 METERS)	
	pH	Alk.mg/1 as $CaCo_3$	pH	Alk.mg/1 as $CaCo_3$	pH	Alk.mg/1 as$CaCo_3$	pH	Alk.mg/1 as$CaCo_3$	pH	Alk.mg/1 as $CaCo_2$
5/10/74	8.50	170	8.50	170	8.45	170	8.40	172	8.30	176
6/11/74	8.35	182	8.35	182	8.25	182	8.25	182	8.20	178
8/4/74	8.10	170	8.00	170	8.00	169	7.70	171	7.40	176
8/25/74	8.00	170	8.00	172	7.90	172	7.60	172	7.40	172
9/10/74	8.05	168	8.05	170	7.95	172	7.95	172	7.95	172
9/29/74	8.00	168	7.95	168	7.95	170	7.90	170	7.85	170
10/16/74	8.30	172			8.20	172			8.10	174
10/31/74	8.35	168			8.25	168			8.25	170
11/12/74	8.35	164			8.35	164			8.35	164
12/12/74	8.40	164			8.35	164			8.35	164
12/27/74	8.40	170			8.30	170			8.30	168
1/21/75	8.30	170			8.30	170			8.30	170
2/28/74	8.30	170			8.30	170			8.30	170
3/17/75	8.35	172			8.35	172			8.30	168

TABLE 16-C

pH AND ALKALINITY IN LAKE THUNDERBIRD

STATION III
(Continued)

DATE	SURFACE		3 METERS		6 METERS		9 METERS		BOTTOM (10 METERS)	
	pH	Alk.mg/1 as $CaCo_3$	pH	Alk.mg/1 as$CaCo_3$	pH	Alk.mg/1 as$CaCo_3$	pH	Alk.mg/1 as$CaCo_3$	pH	Alk.mg/1 as$CaCo_3$
3/30/75	8.30	162			8.30	170			8.25	172
4/12/75	8.40	172			8.35	172			8.35	171
4/28/75	8.40	175			8.35	175			8.35	175
5/9/75	8.55	174	8.55	174	8.40	176	8.25	176	8.25	180
5/26/75	8.60	174	8.60	174	8.50	176	8.40	176	8.25	178
6/8/75	8.30	160	8.25	160	8.25	162	8.00	164	7.90	164
6/26/75	8.30	162	8.30	161	8.25	162	8.10	162	8.00	162
7/12/75	8.30	160	8.25	164	8.05	164	7.60	166	7.60	166
7/30/75	8.35	160	8.35	160	8.30	160	8.25	158	8.00	158
8/16/75	8.40	160	8.40	160	8.20	160	7.80	160	7.80	162
8/31/75	8.40	162	8.30	162	8.25	162	8.00	162	7.95	162
9/25/75	8.30	158	8.30	158	8.25	158	8.25	162	8.25	162
10/19/75	8.20	160	8.20	160	8.20	162	8.15	162	8.15	162

TABLE 16-D

pH AND ALKALINITY IN LAKE THUNDERBIRD

STATION IV

DATE	SURFACE		3 METERS		BOTTOM (6 METERS)	
	pH	Alk.mg/1 asCaCo3	pH	Alk.mg/1 asCaCo3	pH	Alk.mg/1 as CaCo3
5/10/74	8.50	178	8.50	178	8.45	180
6/11/74	8.40	181	8.40	179	8.30	180
8/4/74	8.20	168	8.20	171	8.05	173
8/25/74	8.00	172	7.60	172	7.50	172
9/10/74	8.30	176	8.25	176	8.25	176
9/29/74	8.00	164	7.90	166	7.90	166
10/16/74	8.40	172			8.20	172
10/31/74	8.35	164			8.25	166
11/12/74	8.35	154			8.25	156
12/12/74	8.40	164			8.35	164
12/27/74	8.40	172			8.35	170
1/21/75	8.55	172			8.50	172
2/28/75	8.40	172			8.40	172
3/17/75	8.30	170			8.30	172
3/30/75	8.25	172			8.25	172
4/12/75	8.40	176			8.40	176
4/28/75	8.50	178			8.40	178
5/9/75	8.50	174	8.40	174	8.40	180
5/26/75	8.40	174	8.40	174	8.40	176
6/8/75	8.35	160	8.30	162	8.30	164
6/26/75	8.40	164	8.40	164	8.40	164
7/12/75	8.35	166	8.30	166	8.25	166
7/30/75	8.40	156	8.35	158	8.30	158
8/16/75	8.40	160	8.40	160	8.30	162
8/31/75	8.35	162	8.25	162	8.25	166
9/25/75	8.40	160	8.40	162	8.35	162
10/19/75	8.10	162	8.10	162	8.10	162

TABLE 16-E

pH AND ALKALINITY IN LAKE THUNDERBIRD

STATION V

DATE	SURFACE		3 METERS		BOTTOM (4 METERS)	
	pH	Alk. mg/1 as $CaCo_3$	pH	Alk. mg/1 as $CaCo_3$	pH	Alk. mg/1 as $CaCo_3$
5/10/74	8.40	184	8.40	184	8.35	190
6/11/74	8.45	185	8.40	183	8.40	182
8/4/74	8.20	172	8.20	172	8.15	172
8/25/74	7.70	172	7.70	176	7.50	176
9/10/74	8.30	172	8.25	174	8.25	174
9/29/74	8.05	166	8.05	166	8.05	170
10/16/74	8.45	170			8.35	172
10/31/74	8.25	158			8.25	162
11/12/74	8.25	156			8.25	156
12/12/74	8.40	166			8.35	166
12/27/74	8.40	172			8.40	172
1/21/75	8.55	186			8.55	186
2/28/75	8.35	180			8.35	180
3/17/75	8.30	172			8.30	172
3/30/75	8.30	172			8.30	170
4/12/75	8.40	180			8.40	180
4/28/75	8.50	180			8.45	178
5/9/75	8.50	186	8.50	184	8.40	190
5/26/75	8.35	154	8.30	150	8.25	150
6/8/75	8.35	158	8.35	162	8.30	162
6/26/75	8.40	170	8.40	168	8.35	172
7/12/75	8.35	168	8.30	170	8.30	170
7/30/75	8.50	160	8.50	160	8.50	160
8/16/75	8.40	160	8.30	160	8.30	162
8/30/75	8.40	162	8.30	164	8.25	166
9/25/75	8.40	162	8.40	162	8.35	164
10/19/75	8.20	164	8.15	164	8.15	164

but the pH values from the surface to the bottom showed only small differences; in most cases the surface and bottom pH values were the same.

In May, 1975, the pH values decreased from the surface to the bottom. The pH of the bottom water continued to decrease, and on July 30, 1975, the pH of the bottom water was 7.8. The difference in pH between surface and bottom waters increased from 0.4 unit in May, 1975, to 0.7 unit in July, 1975. In August there was also a difference in the pH values between the surface and the bottom; however, the difference was less than in July. The period when there were pH differences with depth coincided with the periods of thermal and oxygen stratification. In September the pH values were almost the same from the surface to the bottom, and in October the pH was uniform with depth.

Stations II and III

For Stations II and III, the pH range at the surface was from 8.0 to 8.6, and at the bottom it was from 7.4 to 8.55 for Stations II and III. The pH difference between the surface and the bottom was small in May and it increased from May to July, with July exhibiting the greatest difference. At Station II the bottom pH decreased from 8.2 in May to 7.7 on July 12, 1975. Station III also had similar pH values. From September to April the pH values were almost the same from surface to bottom, thus Stations II and III were homogeneous.

Stations IV and V

The pH range at the surface and the bottom was from 8.0 to 8.5 and 7.5 to 8.45 for Station IV, respectively; and it was from 7.7 to 8.55 for Station V. The pH values at these two stations varied little from surface to bottom, and it was probably due to wind mixing. The only exception was on August 25, 1974, when the bottom pH at Station IV was 7.5 and the difference between surface and bottom pH was 0.5 unit.

Monthly Average pH Values--Stations I - V

The monthly average pH values are given in Tables 17 A-E. The range for the monthly average pH was from 7.4 to 8.6. The surface pH values varied from one sampling date to another, and did not exhibit any pattern. From May to August the pH decreased slowly from the surfact to the bottom; the pH at the bottom was lowest in July. The difference between the pH at the surface and the bottom was the highest in July. From September to April the pH was almost the same at all depths, and the lake was well mixed. The period of pH stratification coincided with the period of thermal and oxygen stratification. Due to their shallow depths, Stations IV and V showed only very small differences in pH values between the surface and the bottom throughout the year.

Alkalinity

The alkalinity of water is a measure of its capacity to neutralize acids. The alkalinity of natural waters is mainly due to the salts of weak acids, although weak or strong bases may also contribute. Bicarbonates represent the major form of alkalinity. They are formed in considerable amounts from the action of carbon dioxide upon basic materials in soil. The formation is:

$$CO_2 + CaCO_3 + H_2O \rightarrow Ca(HCO_3)_2$$

Other salts of weak acids, such as borates, silicates and phosphates, may be present in small amounts. A few organic acids that are resistant to

TABLE 17-A

MONTHLY AVERAGE pH AND ALKALINITY VALUES

STATION I

MONTH	SURFACE		3 METERS		6 METERS		9 METERS		BOTTOM (10 METERS)	
	pH	Alk.mg/1 as $CaCo_3$	pH	Alk.mg/1 as $CaCo_3$	pH	Alk mg/1 as $CaCo_3$	pH	Alk.mg/1 as $CaCo_3$	pH	Alk.mg/1 as $CaCo_3$
1974										
MAY	8.50	170	8.50	170	8.40	172	8.40	172	8.20	174
JUNE	8.30	180	8.25	183	8.10	182	8.00	181	7.90	184
AUGUST	8.35	161	8.10	166	7.90	171	7.70	172	7.60	173
SEPTEMBER	8.27	168	8.25	168	8.22	168	8.22	171	8.20	171
OCTOBER	8.32	165			8.32	169			8.32	170
NOVEMBER	8.45	156			8.35	160			8.35	160
DECEMBER	8.50	160			8.50	165			8.50	165
1975										
JANUARY	8.55	170			8.55	170			8.55	170
FEBRUARY	8.60	166			8.55	166			8.55	172
MARCH	8.37	166			8.27	168			8.27	169
APRIL	8.47	166			8.42	170			8.35	171
MAY	8.60	167	8.60	170	8.50	170	8.45	166	8.22	163
JUNE	8.30	161	8.27	160	8.22	161	8.02	161	7.95	161
JULY	8.45	160	8.35	159	7.95	161	7.80	161	7.80	161
AUGUST	8.40	157	8.37	158	8.35	159	8.12	160	8.07	161
SEPTEMBER	8.40	160	8.40	160	8.30	158	8.30	158	8.25	158
OCTOBER	8.10	158	8.10	160	8.10	160	8.10	162	8.10	162

TABLE 17-B

MONTHLY AVERAGE pH AND ALKALINITY VALUES

STATION II

MONTH	SURFACE		3 METERS		6 METERS		9 METERS		12 METERS		BOTTOM (15 METERS)	
	pH	Alk.mg/1 as $CaCo_3$	pH	Alk.mg/1 as $CaCo_3$	pH	Alk.mg/1 as $CaCo_3$	pH	Alk.mg/1 as $CaCo_3$	pH	Alk.mg/l as$CaCo_3$	pH	Alk.mg/1 as $CaCo_3$
<u>1974</u>												
MAY	8.50	170	8.50	170	8.40	172	8.30	176	8.25	176	8.20	180
JUNE	8.30	178	8.30	176	8.25	181	8.30	178	8.25	183	8.20	183
AUGUST	8.00	170	8.00	171	7.95	171	7.85	171	7.80	172	7.40	172
SEPT.	8.10	169	8.07	169	8.07	169	8.00	169	7.95	169	7.85	171
OCT.	8.35	171					8.25	172			8.22	172
NOV.	8.35	164					8.35	166			8.35	166
DEC.	8.47	168					8.40	166			8.37	166
<u>1975</u>												
JAN.	8.60	168					8.55	168			8.55	170
FEB.	8.30	170					8.30	170			8.25	170
MARCH	8.30	168					8.25	170			8.25	170
APRIL	8.40	173					8.40	174			8.30	174
MAY	8.60	174	8.57	174	8.47	176	8.42	177	8.30	178	8.22	178
JUNE	8.25	161	8.22	161	8.22	161	8.15	161	8.00	161	7.87	161
JULY	8.32	163	8.32	163	8.30	163	7.90	163	7.72	164	7.72	167
AUG.	8.37	160	8.36	160	8.32	161	8.12	162	7.85	164	7.82	164
SEPT.	8.35	158	8.35	160	8.30	160	8.25	158	8.25	160	8.25	162
OCT.	8.10	160	8.10	160	8.10	160	8.10	160	8.00	160	8.00	162

TABLE 17-C

MONTHLY AVERAGE pH AND ALKALINITY VALUES

STATION III

MONTH	SURFACE		3 METERS		6 METERS		9 METERS		BOTTOM (10 METERS)	
	pH	Alk.mg/1 as $CaCo_3$	pH	Alk.mg/1 as $CaCo_3$	pH	Alk.mg/1 as $CaCo_3$	pH	Alk.mg/1 as $CaCo_3$	pH	Alk.mg/1 as $CaCo_3$
1974										
MAY	8.50	170	8.50	170	8.45	170	8.40	172	8.30	176
JUNE	8.35	182	8.35	182	8.25	182	8.25	182	8.20	178
AUGUST	8.00	170	8.00	171	7.90	171	7.60	172	7.40	174
SEPTEMBER	8.00	169	8.00	171	7.95	171	7.92	171	7.90	171
OCTOBER	8.32	170		170	8.22	170			8.17	172
NOVEMBER	8.35	164		164	8.35	164			8.35	162
DECEMBER	8.40	167		167	8.32	167			8.32	166
1975										
JANUARY	8.30	170			8.30	170			8.30	170
FEBRUARY	8.30	170			8.30	170			8.30	170
MARCH	8.32	167			8.32	170			8.27	170
APRIL	8.40	173			8.35	173			8.35	173
MAY	8.57	174	8.57	174	8.45	176	8.32	176	8.25	179
JUNE	8.30	161	8.27	161	8.25	162	8.05	163	7.95	163
JULY	8.32	160	8.30	162	8.17	162	7.92	162	7.80	162
AUGUST	8.40	161	8.35	161	8.22	161	7.90	161	7.87	162
SEPTEMBER	8.30	158	8.30	158	8.25	158	8.25	162	8.25	162
OCTOBER	8.20	160	8.20	160	8.20	162	8.15	162	8.15	162

TABLE 17-D

MONTHLY AVERAGE pH AND ALKALINITY VALUES

STATION IV

MONTH	SURFACE		3 METERS		BOTTOM (6 METERS)	
	pH	Alk.mg/l as $CaCo_3$	pH	Alk.mg/l as$CaCo_3$	pH	Alk.mg/l as$CaCo_3$
1974						
MAY	8.50	178	8.50	178	8.45	180
JUNE	8.40	181	8.40	179	8.30	180
AUGUST	8.00	170	7.60	172	7.50	173
SEPTEMBER	8.15	170	8.07	171	8.07	171
OCTOBER	8.37	168			8.22	169
NOVEMBER	8.35	154			8.25	156
DECEMBER	8.40	168			8.35	167
1975						
JANUARY	8.55	172			8.50	172
FEBRUARY	8.40	172			8.40	172
MARCH	8.27	171			8.27	172
APRIL	8.45	177			8.40	177
MAY	8.45	174	8.40	174	8.40	178
JUNE	8.37	162	8.35	163	8.35	164
JULY	8.37	161	8.32	162	8.27	162
AUGUST	8.37	161	8.32	161	8.27	164
SEPTEMBER	8.40	160	8.40	162	8.35	162
OCTOBER	8.10	162	8.10	162	8.10	162

TABLE 17-E

MONTHLY AVERAGE pH AND ALKALINITY VALUES

STATION V

MONTH	SURFACE		3 METERS		BOTTOM (4 METERS)	
	pH	Alk.mg/1 as $CaCo_3$	pH	Alk.mg/1 as $CaCo_3$	pH	Alk.mg/1 as $CaCo_3$
1974						
MAY	8.40	184	8.40	184	8.35	190
JUNE	8.45	185	8.40	183	8.40	182
AUGUST	8.20	172	8.20	173	8.15	174
SEPTEMBER	8.18	169	8.15	170	8.15	172
OCTOBER	8.35	164			8.30	167
NOVEMBER	8.25	156			8.25	156
DECEMBER	8.40	169			8.37	169
1975						
JANUARY	8.55	186			8.55	186
FEBRUARY	8.35	180			8.35	180
MARCH	8.30	172			8.30	171
APRIL	8.45	180			8.42	179
MAY	8.42	170	8.40	167	8.32	170
JUNE	8.37	164	8.37	165	8.32	167
JULY	8.42	164	8.40	165	8.40	165
AUGUST	8.40	161	8.30	162	8.27	164
SEPTEMBER	8.40	162	8.40	162	8.35	164
OCTOBER	8.20	164	8.15	164	8.15	164

biological oxidation form salts that add to the alkalinity of natural waters; humic acid is an example. In some cases, ammonia or hydroxides may make a contribution to the total alkalinity of water. Under certain conditions natural waters may contain appreciable amounts of carbonate and hydroxide alkalinity, such as in surface waters where algae are flourishing. Alkalinity data is useful in chemical coagulation. It is also important in water softening and corrosion control.

The alkalinity measurements in this study were made in the laboratory by the Methyl Orange Indictor Method on the same day of sample collection. The alkalinity values reported are the average of two measurements for each water sample. Tables 16 A-E contain the average alkalinity values.

Stations I - V

The range for alkalinity was from 150 to 190 mg/l as $CaCO_3$. Most of the alkalinity values fell in the range of from 160 to 180 mg/l as $CaCO_3$. In the majority of cases, alkalinity values showed very little variation from the surface to the bottom. In some cases (during the summer months), the alkalinity values increased from the surface to the bottom. On a given sampling date, the alkalinity did not vary appreciably from one sampling station to another.

Monthly Average Alkalinity--Stations I - V

The monthly average alkalinity values are given in Tables 17 A-E. The average alkalinity values had a range of from 156 to 186 mg/l as $CaCO_3$. The average alkalinity values were almost the same from the surface to the bottom. In some instances during the summer months, the alkalinity at the bottom was slightly higher than the surface alkalinity.

Turbidity

The term "Turbid" is applied to waters containing suspended matter that interferes with the passage of light through the water, or in which visual depth is restricted. Turbidity is caused by organic and inorganic particulate matter in suspension. Turbidity is also caused by silt, clay, plankton and other microscopic organisms.

A highly turbid water is undesirable due to the following reasons: (1) it is aesthetically displeasing, (2) it is difficult and expensive to filter, (3) it decreases the effectiveness of disinfection, and (4) it interferes with natural stream purification.

The turbidity measurements in this study were made in the field with a Hach field kit. The turbidity values are given in Tables 18 A-E.

Stations I - V

The turbidity values at each station exhibited wide ranges as follows:

	Turbidity Range
Station I	5 - >500 J.T.U.
Station II	2 - 75 J.T.U.
Station III	3 - 125 J.T.U.
Station IV	8 - 70 J.T.U.
Station V	5 - 475 J.T.U.

The turbidity values at all sampling stations were lowest at the surface and increased with depth. Despite the wide range of turbidity values obtained in this study, most of the turbidity values were in the range of from 2 to 70 J.T.U. Generally, the turbidity values at Station V were the highest, with the high values probably due to its closeness to

TABLE 18-A

TURBIDITY AND TOTAL DISSOLVED SOLIDS IN LAKE THUNDERBIRD

STATION I

DATE	SURFACE		3 METERS		6 METERS		9 METERS		BOTTOM (10 METERS)	
	Turb. J.T.U.	TDS mg/1	Turb. J.T.U.	TDS mg/1	Turb. J.T.U.	TDS mg/1	Turb. J.T.U.	TDS mg/1	Turb. J.T.U.	TDS mg/1
5/11/74	6	215	7	215	7	215	11	215	15	215
6/11/74	8	270	8	280	8	290	11	295	15	295
8/4/74	4	225	3.5	190	3.5	190	4.8	230	5.0	240
8/25/74	6	220	6	220	6	225	14	230	18	230
9/10/74	11	245	11	245	16	245	43	245	55	245
9/29/74	25	220	28	240	30	240	28	240	28	240
10/16/74	35	225	36	225	35	225		225	38	225
10/31/74	28	250			30	240			45	240
11/12/74	38	220			39	225			42	225
12/12/74	15	210			18	210			25	210
12/27/74	12	200			13	210			18	210
1/21/75	18	210			25	210			27	210
2/28/75	15	210			21	245			36	210
3/17/75	20	245			19	245			19	245
3/30/75	30	245			30	245			35	250
4/12/75	30	240			32	245			32	245
4/28/75	15	245			18	245			18	250
5/9/75	11	250	13	250	21	250	24	255	42	255
5/26/75	35	250	35	250	40	250	160	225	>500	200
6/8/75	8	230	8	230	12	230	18	225	35	225
6/26/75	18	215	22	215	28	220	35	225	35	225
7/12/75	5	235	5	225	10	225	15	225	20	225
7/30/75	5	220	9	220	20	220	20	225	60	225
8/16/75	8	225	8	225	10	225	10	230	12	230
8/31/75	5	220	10	220	10	220	18	220	23	220
9/25/75	18	225	18	235	20	240	22	240	24	240
10/19/75	24	225	24	225	24	225	24	230	28	230

TABLE 18-B

TURBIDITY AND TOTAL DISSOLVED SOLIDS IN LAKE THUNDERBIRD

STATION II

DATE	SURFACE		3 METERS		6 METERS		9 METERS		12 METERS		BOTTOM (15 METERS)	
	Turb. J.T.U.	TDS mg/1	Turb. J.T.U.	TDS mg/1	Turb. J.T.U.	TDS mg/1	Turb. J.T.U.	TDS mg/1	Turb. J.T.U.	TDS mg/1	Turb. J.T.U.	TDS mg/1
5/10/74	6	215	6	215	6	215	6	215	9	215	23	225
6/11/74	7	275	7	275	8	275	8	275	14.5	310	--	---
8/4/74	2	220	2.5	225	3	240	3	225	17	230	18	250
8/25/74	6	220	6	220	6	240	7	230	10	240	22	190
9/10/74	15	240	26	240	35	240	35	240	36	240	51	250
9/29/74	25	240	30	240	30	240	35	240	38	240	48	245
10/16/74	30	225					35	225			55	225
10/31/74	25	235					25	240			32	240
11/12/74	15	235					18	235			20	235
12/12/74	15	210					15	210			18	215
12/27/74	8	210					8	210			50	210
1/21/75	18	210					25	210			25	215
2/28/75	15	210					15	210			15	210
3/17/75	15	250					15	245			17	250
3/30/75	30	245					32	245			35	245
4/12/75	28	245					32	245			42	245
4/28/75	7	245					12	245			38	250
5/9/75	9	255	9	255	17	255	17	255	35	255	45	260
5/26/75	15	240	18	240	18	245	20	250	25	255	48	255
6/8/75	8	225	8	225	12	230	18	240	35	240	75	240
6/26/75	8	215	10	215	10	220	18	220	28	225	40	230
7/12/75	2	225	5	225	8	225	10	225	28	230	47	250
7/30/75	3	220	10	220	15	220	17	225	29	230	33	245
8/16/75	4	225	4	230	6	230	10	230	24	235	70	240
8/31/75	6	215	6	215	6	220	8	225	14	225	47	225
9/25/75	18	240	19	240	20	240	20	240	20	240	22	240
10/19/75	25	230	26	230	26	230	27	230	28	230	50	240

TABLE 18-C

TURBIDITY AND TOTAL DISSOLVED SOLIDS IN LAKE THUNDERBIRD

STATION III

DATE	SURFACE		3 METERS		6 METERS		9 METERS		BOTTOM (10 METERS)	
	Turb. J.T.U.	TDS mg/l	Turb. J.T.U.	TDS mg/l	Turb. J.T.U.	TDS mg/l	Turb. J.T.U.	TDS mg/l	Turb. J.T.U.	TDS mg/l
5/10/74	6	220	6	220	6	225	8	230	8	230
6/11/74	8	340	10	340	10	320	13		13	335
8/4/74	3	220	3	220	3	230	5	240	15	210
8/25/74	7	220	7	220	7	220	21	230	32	230
9/10/74	18	240	20	250	22	250	28	250	32	250
9/29/74	45	240	45	240	48	240	48	240	58	240
10/16/74	28	220			28	225			55	225
10/31/74	28	240			28	240			35	240
11/12/74	15	230			17	225			17	225
12/12/74	16	210			18	210			18	215
12/27/74	10	210			10	215			13	215
1/21/75	20	210			22	210			25	215
2/28/75	10	210			15	210			15	210
3/17/75	10	245			10	245			15	245
3/30/75	18	245			22	245			25	250
4/12/75	26	250			28	250			32	250
4/28/75	12	245			12	245			28	255
5/9/75	8	250	8	250	8	250	15	255	18	255
5/26/75	15	245	20	245	30	245	90	225	125	225
6/8/75	12	225	15	225	15	225	25	240	70	240
6/26/75	5	210	8	215	8	215	25	215	42	220
7/12/75	4	245	6	225	12	225	20	220	20	225
7/30/75	5	220	8	220	8	220	10	215	70	210
8/16/75	8	225	8	225	8	230	18	230	70	235
8/31/75	10	220	10	220	10	220	10	220	20	225
9/25/75	20	240	20	240	23	240	28	240	28	240
10/19/75	22	235	25	235	25	235	30	235	55	235

TABLE 18-D

TURBIDITY AND TOTAL DISSOLVED SOLIDS IN LAKE THUNDERBIRD

STATION IV

DATE	SURFACE		3 METERS		BOTTOM (6 METERS)	
	Turb. J.T.U.	TDS mg/1	Turb. J.T.U.	TDS mg/1	Turb. J.T.U.	TDS mg/1
5/10/74	10	225	10	225	11	225
6/11/74	9.5	310	11	310	11	310
8/4/74	8	225	9	215	11	210
8/25/74	13	230	13	225	16	220
9/10/74	28	250	35	245	38	250
9/29/74	38	240	48	240	52	240
10/16/74	28	215			38	220
10/31/74	48	235			55	240
11/12/74	22	230			60	220
12/12/74	15	210			16	210
12/27/74	5	215			8	215
1/21/75	18	215			18	215
2/28/75	18	215			20	215
3/17/75	13	250			17	260
3/30/75	18	250			22	250
4/12/75	30	260			42	260
4/28/75	18	255			18	255
5/9/75	8	260	12	260	25	260
5/26/75	25	240	25	240	45	240
6/8/75	8	230	12	230	32	240
6/26/75	18	215	25	220	30	220
7/12/75	8	215	10	220	70	220
7/30/75	15	215	18	220	21	220
8/16/75	5	220	7	225	20	240
8/31/75	17	220	19	220	23	225
9/25/75	25	240	28	240	42	240
10/19/75	28	240	28	240	31	240

TABLE 18-E

TURBIDITY AND TOTAL DISSOLVED SOLIDS IN LAKE THUNDERBIRD

STATION V

DATE	SURFACE		3 METERS		BOTTOM (4 METERS)	
	Turb. J.T.U.	TDS mg/1	Turb. J.T.U.	TDS mg/1	Turb. J.T.U.	TDS mg/1
5/10/74	20	225	22	225	33	225
6/11/74	12	330	12	330	19	330
8/4/74	21	230	23	235	25	220
8/25/74	22	230	22	230	24	230
9/10/74	48	250	48	250	52	250
9/29/74	58	240	58	240	62	240
10/16/74	38	220			45	220
10/31/74	125	215			>150	170
11/12/74	45	215			65	210
12/12/74	17	210			38	210
12/27/74	5	215			5	215
1/21/75	18	215			22	215
2/28/75	20	215			25	215
3/17/75	19	250			19	260
3/30/75	22	270			25	270
4/12/75	32	275			40	275
4/28/75	28	285			32	290
5/9/75	12	275	22	275	32	280
5/26/75	185	210	190	205	475	190
6/8/75	25	240	25	240	30	240
6/26/75	40	225	52	225	70	230
7/12/75	30	220	50	225	75	225
7/30/75	20	220	27	220	30	220
8/16/75	28	225	30	230	55	240
8/31/75	40	225	42	225	57	230
9/25/75	48	240	56	240	70	245
10/19/75	55	240	55	240	85	240

Alameda Street bridge and the inflow point from Little River. Stations I and III had higher turbidity values than Stations II and IV because they were closer to the shore and in more shallow water. On May 26, 1975, the turbidity values at all the sampling stations were high due to preceding heavy rains.

Monthly Average Turbidity Values

The monthly averages are given in Tables 19 A-E. The average turbidity values had a range from 2.5 to 271 J.T.U. The average turbidity values at the surface were higher in September, October and November. This was probably due to the turnover of the lake in September; the turnover brought turbid materials from the bottom. The average turbidity values at all stations increased with the depth.

Total Dissolved Solids (TDS)

Total Dissolved Solids (TDS) represents the total concentration of dissolved substances or minerals in natural water. Dissolved solids consist of carbonates, bicarbonates, chlorides, sulfates, phosphates and nitrates of calcium, magnesium, sodium and potassium. TDS is determined by evaporating a filtered quantity of water at 103 to 105°C, and is expressed as mg/l.

The amount of dissolved solids present in water is a consideration in its suitability for domestic use. Highly mineralized water is also unsuitable for many industrial applications. Waters with higher solids content often have a laxative and sometimes the reverse effect upon people whose bodies are not adjusted to them. Corrosion control is frequently accomplished by production of stabilized water through pH

TABLE 19-A

MONTHLY AVERAGE TURBIDITY AND TOTAL DISSOLVED SOLIDS VALUES

STATION I

MONTH	SURFACE		3 METERS		6 METERS		9 METERS		BOTTOM (10 METERS)	
	Turb. J.T.U.	TDS mg/1	Turb. J.T.U.	TDS mg/1	Turb. J.T.U.	TDS mg/1	Turb. J.T.U.	TDS mg/1	Turb. J.T.U.	TDS mg/1
1974										
MAY	6	215	7	215	7	215	11	215	15	215
JUNE	8	270	8	280	8	290	11	295	15	295
AUGUST	5	222.5	4.7	205	4.7	207.5	9.4	230	11.5	235
SEPTEMBER	18	232.5	19.5	242.5	23	242.5	35.5	242.5	41.5	242.5
OCTOBER	31.5	237.5			32.5	232.5			43.5	232.5
NOVEMBER	38	220			39	225			42	225
DECEMBER	13.5	205			15.5	210			22.5	210
1975										
JANUARY	18	210			25	210			27	210
FEBRUARY	15	210			21	210			36	210
MARCH	25	245			24.5	245			27	247.5
APRIL	22.5	242.5			25	245			25	247.5
MAY	23	250	24	250	30.5	250	92	240	271	227.5
JUNE	13	222.5	15	222.5	20	225	26.5	225	35	225
JULY	5	227.5	7	222.5	15	222.5	17.5	225	40	225
AUGUST	6.5	222.5	9	222.5	10	222.5	14	225	17.5	225
SEPTEMBER	18	225	18	235	20	240	22	240	24	240
OCTOBER	24	225	24	225	24	225	24	230	28	230

TOTAL 19-B

MONTHLY AVERAGE TURBIDITY AND TOTAL DISSOLVED SOLIDS VALUES

STATION II

MONTH	SURFACE		3 METERS		6 METERS		9 METERS		12 METERS		BOTTOM (15 METERS)	
	Turb. J.T.U.	TDS mg/1	Turb. J.T.U.	TDS mg/1	Turb. J.T.U.	TDS mg/1	Turb. J.T.U.	TDS mg/1	Turb. J.T.U.	TDS mg/1	Turb. J.T.U.	TDS mg/1
1974												
MAY	6	215	6	215	6	215	6	215	9	215	23	225
JUNE	7	275	7	275	8	275	8	275	14.5	310		
AUG.	4	220	4.2	222.5	4.5	240	5	227.5	13.5	235	20	220
SEPT.	20	240	28	240	32.5	240	35	240	37	240	49.5	247.5
OCT.	27.5	230					30	232.5			43.5	232.5
NOV.	15	235					18	235			20	235
DEC.	11.5	210					11.5	210			34	212.5
1975												
JAN.	18	210					25	210			25	215
FEB.	15	210					15	210			15	210
MARCH	17.5	247.5					18.5	245			26	247.5
APRIL	17.5	245					22	245			40	247.5
MAY	12	247.5	13.5	247.5	17.5	247.5	18.5	252.5	30	255	46.5	257.5
JUNE	8	220	9	220	11	225	18	230	31.5	232.5	57.5	235
JULY	2.5	222.5	7.5	222.5	11.5	222.5	18.5	225	28.5	230	40	247.5
AUG.	5	220	5	222.5	6	225	9	227.5	19	230	59	232.5
SEPT.	18	240	19	240	20	240	20	240	20	240	22	240
OCT.	25	230	26	230	26	230	27	230	28	230	50	240

TABLE 19-C

MONTHLY AVERAGE TURBIDITY AND TOTAL DISSOLVED SOLIDS VALUES

STATION III

MONTH	SURFACE		3 METERS		6 METERS		9 METERS		BOTTOM (10 METERS)	
	Turb. J.T.U.	TDS mg/1	Turb. J.T.U.	TDS mg/1	Turb. J.T.U.	TDS mg/1	Turb. J.T.U.	TDS mg/1	Turb. J.T.U.	TDS mg/1
1974										
MAY	6	220	6	220	6	225	8	230	8	230
JUNE	8	340	10	340	10	320	13		13	335
AUGUST	5	220	5	220	5	225	13	235	23.5	220
SEPTEMBER	31.5	240	32.5	245	35	245	38	245	45	245
OCTOBER	28	230			28	232.5			45	232.5
NOVEMBER	15	230			17	225			17	225
DECEMBER	13	210			14	212.5			15.5	215
1975										
JANUARY	20	210			22	210			25	215
FEBRUARY	12	210			15	210			15	210
MARCH	14	245			16	245			20	247.5
APRIL	19	247.5			20	247.5			30	252.5
MAY	11.5	247.5	14	247.5	19	247.5	52.5	240	71.5	240
JUNE	8.5	217.5	11.5	220	11.5	220	25	232.5	56	230
JULY	4.5	232.5	7	222.5	10	222.5	15	217.5	45	222.5
AUGUST	9	222.5	9	222.5	9	225	14	225	45	230
SEPTEMBER	21	240	21	240	23	240	28	240	28	240
OCTOBER	22	235	23	235	25	235	31	235	55	235

TABLE 19-D

MONTHLY AVERAGE TURBIDITY AND TOTAL DISSOLVED SOLIDS VALUES

STATION IV

MONTH	SURFACE		3 METERS		BOTTOM (6 METERS)	
	Turb. J.T.U.	TDS mg/1	Turb. J.T.U.	TDS mg/1	Turb. J.T.U.	TDS mg/1
1974						
MAY	10	225	10	225	11	225
JUNE	9.5	310	11	310	11	310
AUGUST	10.5	227.5	11	220	13.5	215
SEPTEMBER	33	245	41.5	242.5	45	245
OCTOBER	38	225			46.5	230
NOVEMBER	22	230			60	220
DECEMBER	18.5	212.5			38	212.5
1975						
JANUARY	18	215			18	215
FEBRUARY	18	215			20	215
MARCH	15.5	250			19.5	255
APRIL	24	257.5			30	257.5
MAY	16.5	250	18.5	250	35	250
JUNE	13	222.5	18.5	225	31	230
JULY	11.5	215	14	220	45.5	220
AUGUST	11	220	13	222.5	21.5	232.5
SEPTEMBER	25	240	28	240	42	240
OCTOBER	28	240	28	240	31	240

TABLE 19-E

MONTHLY AVERAGE TURBIDITY AND TOTAL DISSOLVED SOLIDS VALUES

STATION V

MONTH	SURFACE		3 METERS		BOTTOM (4 METERS)	
	Turb. J.T.U.	TDS mg/1	Turb. J.T.U.	TDS mg/1	Turb. J.T.U.	TDS mg/1
1974						
MAY	20	225	22	225	33	225
JUNE	12	330	12	330	19	330
AUGUST	21.5	230	22.5	232.5	24.5	225
SEPTEMBER	53	245	53	245	57	245
OCTOBER	81.5	217.5			97.5	195
NOVEMBER	45	215			65	210
DECEMBER	31	212.5			51.5	212.5
1975						
JANUARY	18	215			22	215
FEBRUARY	20	215			25	215
MARCH	20.5	260			22	265
APRIL	30	280			36	282.5
MAY	98.5	242.5	106	240	253.5	235
JUNE	32.5	232.5	38.5	232.5	50	235
JULY	25	220	38.5	222.5	52.5	222.5
AUGUST	34	225	36	232.5	56	235
SEPTEMBER	48	240	56	240	70	245
OCTOBER	55	240	55	240	85	240

adjustments; the pH stabilization depends upon the total solids present in addition to temperature and alkalinity.

The TDS measurements were made in the field through the use of a Myron Meter, and the TDS values are given in Tables 18 A-E.

Stations I - V

The TDS values at each sampling station exhibited wide ranges as follows:

Station I	190 - 295 mg/1
Station II	190 - 310 mg/1
Station III	210 - 340 mg/1
Station IV	210 - 310 mg/1
Station V	170 - 330 mg/1

Despite the extremes found in the TDS values, most of the concentrations for Stations I through IV were between 210 and 250 mg/1. The TDS values for Station V were the highest.

The TDS values exhibited only small variations from the surface to the bottom, and this was true even during periods of thermal stratification. In most cases, the TDS values at the surface were slightly lower than the TDS values at the bottom. The higher TDS values at the bottom were probably due to chemical precipitation and resuspension of bottom deposits. The TDS values did not follow any discernable seasonal patterns.

Monthly Average TDS--Stations I - V

The monthly average TDS values are given in Tables 19 A-E. The monthly average values ranged from 210 to 340 mg/1. Most of the average

TDS values for Stations I through IV were in the range of 210 to 250 mg/l, and, in June, 1974, the values were the highest. The TDS values were slightly higher at Station V due to the influence of car and foot traffic on the Alameda Street bridge and the inflow from Little River.

Nitrates

Nitrates represent the most highly oxidized phase in the nitrogen cycle, and normally reach important concentrations in the final stages of biological oxidation. Nitrates serve as a fertilizer for plants and the excess nitrates not used by the plants are carried away in water percolating through the soil, thus frequently resulting in high concentrations of nitrates in ground water. The concentrations of nitrates in natural waters is usually small since nitrates are nutrients for all types of plants and are converted to protein. In excessive amounts, nitrates cause methemoglobinemia in infants.

The water samples collected for nitrate determinations were filtered using a 0.45μ membrane filter, and the filtrate was preserved at 4.0°C using 40 mg $HgCl_2$ per liter. The nitrate concentrations were determined within 24 hours after sample collection by the Cadmium Reduction Method. In three instances the filtrate was kept in a freezer and the nitrate concentrations were determined within a week. The nitrate concentrations are given in Tables 20 A-E.

Station I

The nitrate concentration range at Station I was from 0.02 to 0.35 mg/l as N. The maximum and minimum nitrate concentrations were obtained on June 8, 1975,and August 16, 1975, respectively.

TABLE 20-A

NITRATES AND NITRITES IN LAKE THUNDERBIRD

STATION I

DATE	SURFACE		3 METERS		6 METERS		9 METERS		BOTTOM (10 METERS)	
	NO_3^- mg/l	NO_2^- µg/l	NO_3^- mg/l	NO_2^- µg/l	NO_3^- mg/l	NO_2^- µg/l	NO_3^- mg/l	NO_2^- µg/l	NO_3^- mg/l	NO_2^- µg/l
5/10/74										
6/11/74										
8/4/74	.3170	0.44	.3126	0.51	.2732	0.95	.2266	0.95	.2260	0.95
8/25/74	.3030	2.47	.3042	2.40	.2782	11.70	.2049	10.30	.1884	10.30
9/10/74	.1924	2.47	.1810	2.40	.1727	7.86	.1610	14.41	.1372	18.42
9/29/74	.2571	1.02	.2533	1.20	.2461	1.10	.2280	1.00	.2244	1.00
10/16/74	.1888	6.60			.1768	7.80			.1745	6.30
10/31/74	.1760	2.40			.1759	2.60			.1701	2.90
11/12/74	.1818	7.90			.1810	8.00			.1836	7.90
12/12/74	.1556	2.10			.1538	2.10			.1464	2.20
12/27/74	.1743	1.60			.1768	1.60			.1744	1.82
1/21/75	.0964	1.24			.0960	1.00			.0966	1.00
2/28/75	.1142	2.40			.1138	2.40			.1071	2.60
3/17/75	.1126	2.55			.1100	2.55			.1108	2.55
3/30/75	.1137	2.55			.1137	2.55			.1082	2.55
4/12/75	.1055	2.77			.1061	2.91			.1044	3.13
4/28/75	.0910	2.30			.0891	2.38			.0849	2.62
5/9/75	.1393	2.97	.1285	3.29	.1008	3.29	.0678	7.20	.0442	9.32
5/26/75	.1666	5.30	.1188	5.60	.1015	5.76	.0676	5.82	.0585	5.88
6/8/75	.3522	3.23	.2722	4.53	.1834	4.64	.1546	4.64	.1124	4.68
6/26/75	.1838	2.26	.1743	2.76	.1653	2.67	.1596	3.61	.1151	3.78
7/12/75	.1626	0.50	.1562	0.80	.1138	2.06	.0395	2.06	.0393	2.26
7/30/75	.2277	0.12	.1300	0.35	.1182	0.44	.0468	0.91	.0275	11.64
8/16/75	.0756	0.10	.0719	0.18	.0323	0.47	.0196	0.85	.0196	0.86
8/31/75	.1090	0.26	.1082	0.26	.0882	0.26	.0689	1.76	.0660	1.76
9/25/75	.1173	2.15	.1165	2.26	.1132	2.26	.1080	2.10	.1029	2.10
10/19/75	.1378	9.76	.1350	9.76	.1326	11.41	.1315	11.26	.1214	11.30

TABLE 20-A

NITRATES AND NITRITES IN LAKE THUNDERBIRD

STATION I

DATE	SURFACE		3 METERS		6 METERS		9 METERS		BOTTOM (10 METERS)	
	NO_3^- mg/l	NO_2^- µg/l	NO_3^- mg/l	NO_2^- µg/l	NO_3^- mg/l	NO_2^- µg/l	NO_3^- mg/l	NO_2^- µg/l	NO_3^- mg/l	NO_2^- µg/l
5/10/74										
6/11/74										
8/4/74	.3170	0.44	.3126	0.51	.2732	0.95	.2266	0.95	.2260	0.95
8/25/74	.3030	2.47	.3042	2.40	.2782	11.70	.2049	10.30	.1884	10.30
9/10/74	.1924	2.47	.1810	2.40	.1727	7.86	.1610	14.41	.1372	18.42
9/29/74	.2571	1.02	.2533	1.20	.2461	1.10	.2280	1.00	.2244	1.00
10/16/74	.1888	6.60			.1768	7.80			.1745	6.30
10/31/74	.1760	2.40			.1759	2.60			.1701	2.90
11/12/74	.1818	7.90			.1810	8.00			.1836	7.90
12/12/74	.1556	2.10			.1538	2.10			.1464	2.20
12/27/74	.1743	1.60			.1768	1.60			.1744	1.82
1/21/75	.0964	1.24			.0960	1.00			.0966	1.00
2/28/75	.1142	2.40			.1138	2.40			.1071	2.60
3/17/75	.1126	2.55			.1100	2.55			.1108	2.55
3/30/75	.1137	2.55			.1137	2.55			.1082	2.55
4/12/75	.1055	2.77			.1061	2.91			.1044	3.13
4/28/75	.0910	2.30			.0891	2.38			.0849	2.62
5/9/75	.1393	2.97	.1285	3.29	.1008	3.29	.0678	7.20	.0442	9.32
5/26/75	.1666	5.30	.1188	5.60	.1015	5.76	.0676	5.82	.0585	5.88
6/8/75	.3522	3.23	.2722	4.53	.1834	4.64	.1546	4.64	.1124	4.68
6/26/75	.1838	2.26	.1743	2.76	.1653	2.67	.1596	3.61	.1151	3.78
7/12/75	.1626	0.50	.1562	0.80	.1138	2.06	.0395	2.06	.0393	2.26
7/30/75	.2277	0.12	.1300	0.35	.1182	0.44	.0468	0.91	.0275	11.64
8/16/75	.0756	0.10	.0719	0.18	.0323	0.47	.0196	0.85	.0196	0.86
8/31/75	.1090	0.26	.1082	0.26	.0882	0.26	.0689	1.76	.0660	1.76
9/25/75	.1173	2.15	.1165	2.26	.1132	2.26	.1080	2.10	.1029	2.10
10/19/75	.1378	9.76	.1350	9.76	.1326	11.41	.1315	11.26	.1214	11.30

TABLE 20-B

NITRATES AND NITRITES IN LAKE THUNDERBIRD

STATION II

DATE	SURFACE		3 METERS		6 METERS		9 METERS		12 METERS		BOTTOM (15 METERS)	
	NO_3^- mg/1	NO_2^- μg/1	NO_3^- mg/1	NO_2^- μg/1	NO_3^- mg/1	NO_2^- μg/1	NO_3^- mg/1	NO_2^- μg/1	NO_3^- mg/1	NO_2^- μg/1	NO_3^- mg/1	NO_2^- μg/1
5/10/74												
6/11/74												
8/4/74	.3171	0.95	.2393	0.73	.1803	0.95	.1702	0.98	.1559	1.67	.1538	1.65
8/25/74	.3056	3.90	.3045	6.70	.2955	7.40	.2821	7.30	.2090	8.40	.1978	19.70
9/10/74	.1968	1.67	.1969	1.53	.1899	2.02	.1776	2.69	.1748	5.68	.1350	18.78
9/29/74	.2822	1.45	.2457	1.54	.2493	1.62	.2466	1.36	.2456	1.65	.2490	1.87
10/16/74	.1919	7.20					.1959	8.70			.1947	8.00
10/31/74	.1992	4.90					.1881	5.10			.1904	5.70
11/12/74	.1834	8.00					.1800	7.90			.1800	8.00
12/12/74	.1591	2.30					.1592	2.20			.1635	1.50
12/27/74	.1794	2.00					.1795	2.00			.1829	2.80
1/21/75	.1029	1.30					.1007	1.30			.1044	1.20
2/28/75	.1267	2.30					.1100	2.40			.1102	2.70
3/17/75	.1187	2.62					.1082	2.62			.1063	2.62
3/30/75	.1165	2.70					.1117	2.70			.1117	2.70
4/12/75	.1010	2.84					.1042	2.91			.1052	3.49
4/28/75	.0790	2.26					.0837	2.26			.1046	4.10
5/9/75	.1502	3.38	.1255	3.38	.1217	5.35	.1021	5.30	.0748	8.60	.0748	15.80
5/26/75	.2180	6.53	.1760	6.64	.1706	6.67	.0967	6.69	.0704	6.32	.0704	7.50
6/8/75	.3364	4.50	.3361	4.88	.1704	4.97	.1277	5.06	.1134	5.06	.1134	5.56
6/26/75	.2037	2.41	.2015	2.82	.1263	2.67	.1230	2.70	.1048	5.35	.1048	10.78
7/12/75	.1305	0.59	.1290	0.59	.1261	0.65	.0467	3.70	.0226	11.35	.0226	16.82
7/30/75	.1636	0.94	.1316	0.97	.1279	0.97	.0495	1.10	.0296	7.47	.0296	11.32
8/16/75	.0873	0.10	.0793	0.10	.0384	0.15	.0287	0.44	.0124	0.50	.0124	0.77
8/31/75	.0922	0.29	.0871	0.29	.0757	0.82	.0571	2.38	.0128	4.82	.0128	4.91
9/25/75	.1467	3.03	.1464	3.03	.1362	3.03	.1376	3.03	.1406	2.90	.1406	2.94
10/19/75	.1837	7.41	.1808	7.41	.1699	7.41	.1655	7.41	.1569	7.38	.1569	6.44

TABLE 20-C

NITRATES AND NITRITES IN LAKE THUNDERBIRD

STATION III

DATE	SURFACE		3 METERS		6 METERS		9 METERS		BOTTOM (10 METERS)	
	NO_3^- mg/l	NO_2^- µg/l	NO_3^- mg/l	NO_2^- µg/l	NO_3^- mg/l	NO_2^- µg/l	NO_3^- mg/l	NO_2^- µg/l	NO_3^- mg/l	NO_2^- µg/l
5/10/74										
6/11/74										
8/4/74	.1795	0.66	.1750	0.80	.1561	1.16	.1520	1.31	.1250	1.02
8/25/74	.3056	3.60	.3050	4.30	.3012	5.20	.2940	13.20	.2771	12.5
9/10/74	.1994	0.80	.1956	1.02	.1936	1.24	.1893	1.89	.1906	2.40
9/29/74	.2680	1.15	.2570	1.18	.2570	1.24	.2568	1.31	.2386	1.33
10/16/74	.1896	5.75			.1754	5.40			.1771	7.50
10/31/74	.1832	7.60			.1748	7.60			.1745	7.90
11/12/74	.1799	9.90			.1776	10.40			.1792	10.60
12/12/74	.1560	1.80			.1560	1.80			.1540	1.90
12/27/74	.1810	1.82			.1781	1.82			.1795	1.82
1/21/75	.0953	1.20			.0953	1.20			.0953	1.20
2/28/75	.1174	2.50			.1083	2.50			.0974	2.50
3/17/75	.1119	2.55			.1133	2.55			.1082	2.62
3/30/75	.1128	2.70			.1117	2.70			.1100	2.62
4/12/75	.0916	2.77			.0851	2.77			.0800	3.13
4/28/75	.0716	2.03			.0683	2.47			.1051	3.56
5/9/75	.1846	2.82	.1767	3.14	.0860	3.14	.0715	4.20	.0639	4.20
5/26/75	.1970	7.56	.1657	7.94	.1285	8.79	.0924	14.23	.0868	14.73
6/8/75	.1907	4.62	.1891	6.35	.1875	6.44	.1620	10.00	.1491	10.12
6/26/75	.2094	4.07	.2091	4.44	.1801	4.32	.1708	4.53	.1503	5.03
7/12/75	.1760	0.60	.1756	0.60	.1386	1.20	.0398	1.78	.0299	9.17
7/30/75	.1430	0.41	.1320	0.53	.1386	1.26	.0585	1.62	.0310	8.00
8/16/75	.0721	0.12	.0732	0.32	.0634	0.32	.0147	0.60	.0157	1.06
8/31/75	.0790	0.38	.0717	0.38	.0559	2.82	.0164	4.20	.0141	6.64
9/25/75	.1258	3.17	.1095	2.73	.1088	2.73	.1026	2.76	.0987	3.00
10/19/75	.1566	6.85	.1566	6.85	.1557	6.85	.1492	6.94	.1365	7.26

TABLE 20-D

NITRATES AND NITRITES IN LAKE THUNDERBIRD

STATION IV

DATE	SURFACE		3 METERS		BOTTOM (6 METERS)	
	NO_3^- mg/1	NO_2^- μg/1	NO_3^- mg/1	NO_2^- μg/1	NO_3^- mg/1	NO_2^- μg/1
5/10/74						
6/11/74						
8/4/74	.1433	0.51	.1412	0.80	.1224	1.38
8/25/74	.3067	0.60	.3053	0.60	.3056	0.60
9/10/74	.1920	0.95	.1906	2.40	.1917	1.31
9/29/74	.2604	1.36	.2498	1.03	.2422	1.33
10/16/74	.1156	3.30			.1008	4.30
10/31/74	.1643	4.10			.1185	5.50
11/12/74	.1534	12.8			.1440	17.2
12/12/74	.1541	1.75			.1558	1.90
12/27/74	.1742	1.70			.1747	1.90
1/21/75	.0882	1.40			.0879	1.40
2/28/75	.0904	2.20			.0904	2.20
3/17/75	.0891	2.40			.0887	2.40
3/30/75	.0877	2.70			.0862	2.70
4/12/75	.0589	2.80			.0581	2.84
4/28/75	.0606	1.67			.0563	2.41
5/9/75	.0986	2.26	.0932	2.56	.0885	2.85
5/26/75	.1326	8.29	.1135	9.29	.0971	9.29
6/8/75	.1522	4.91	.1464	5.29	.1657	6.06
6/26/75	.0608	3.56	.0589	3.94	.0544	4.10
7/12/75	.0749	0.85	.0697	0.94	.0637	4.23
7/30/75	.0666	0.38	.0506	0.38	.0288	10.26
8/16/75	.0784	0.23	.0754	0.30	.0679	0.53
8/31/75	.0715	0.56	.0749	0.82	.0648	3.06
9/25/75	.0796	2.10	.0767	2.10	.0622	2.00
10/19/75	.1349	3.94	.1313	3.94	.1258	3.73

TABLE 20-E

NITRATES AND NITRITES IN LAKE THUNDERBIRD

STATION V

DATE	SURFACE		3 METERS		BOTTOM (4 METERS)	
	NO_3^- mg/l	NO_2^- µg/l	NO_3^- mg/l	NO_2^- µg/l	NO_3^- mg/l	NO_2^- µg/l
5/10/74						
6/11/74						
8/4/74	.1551	1.46	.1507	2.33	.1440	1.67
8/25/74	.2355	0.70	.2358	0.40	.2330	0.70
9/10/74	.1950	1.67	.1942	1.67	.1890	6.04
9/29/74	.2457	1.50	.2421	1.50	.2310	1.70
10/16/74	.1058	2.80			.0980	2.55
10/31/74	.1720	2.90			.1272	4.10
11/12/74	.1522	17.90			.1485	20.0
12/12/74	.1527	1.40			.1535	2.40
12/27/74	.1735	1.20			.1741	1.40
1/21/75	.4673	1.40			.4673	1.40
2/28/75	.0585	2.40			.0582	2.80
3/17/75	.0863	2.70			.0853	2.60
3/30/75	.0750	3.00			.0746	3.00
4/12/75	.0581	2.47			.0573	2.47
4/28/75	.0592	1.21			.0524	1.23
5/9/75	.1260	2.82	.0912	3.12	.0774	4.12
5/26/75	.1561	6.53	.1385	7.85	.1363	8.29
6/8/75	.2031	6.85	.1881	7.06	.1701	9.11
6/26/75	.0733	8.67	.0733	8.70	.0585	8.92
7/12/75	.0863	1.88	.0779	3.06	.0665	4.35
7/30/75	.0771	0.10	.0523	0.10	.0683	0.10
8/16/75	.1332	0.06	.0931	0.12	.0828	1.47
8/31/75	.1248	1.20	.0990	1.59	.0758	3.76
9/25/75	.1338	2.41	.0901	2.44	.0625	2.44
10/19/75	.0900	3.73	.0875	3.65	.0856	3.76

In August, 1974, the nitrate concentration was higher at the surface than at the bottom. From September to April the nitrate concentration varied from one sampling date to another, but the nitrate concentration on a particular sampling date was essentially constant from surface to the bottom. This corresponds with the previously established homogeneous conditions in the lake from September to April.

In 1975 the nitrate concentration once again showed a decrease from the surface to the bottom from May through August. In May, July and August the nitrate concentration at the bottom was less than 0.1 mg/l. In September and October the nitrate concentration was almost the same from surface to bottom. On August 16, 1975, the nitrate concentration was uniformly low at all depths, but still there was a drop in concentrations from the surface to the bottom. From May through August the average nitrate concentration at the surface was 0.20 mg/l and at the bottom it was only 0.06 mg/l.

Station II

The nitrate concentration range at Station II was from 0.01 to 0.34 mg/l. The maximum nitrate concentration was at the surface on June 8, 1975, and the minimum nitrate concentration was at the bottom on August 16, 1975.

The nitrate concentration at Station II showed very little difference from the surface to the bottom from September through April. From May through August the nitrate concentration decreased with the depth. As was the case for Station I, at Station II the concentration of nitrates below the 9-meter depth in July and August was also low. From May through August the nitrate concentration at the surface averaged

0.20 mg/l and at the bottom the average was only 0.08 mg/l.

Station III

The nitrate concentration range at Station III was from 0.01 to 0.31 mg/l. The nitrate behavior of Station III was similar to that of Stations I and II. From May to August the average nitrate concentration at the surface was 0.17 mg/l, and at the bottom it was only 0.09 mg/l.

Station IV

The nitrate concentration range at Station IV was from 0.06 to 0.31 mg/l. The nitrate concentration at this station was somewhat lower than the nitrate concentrations at the other sampling stations. Also at this station the nitrate concentrations varied only slightly from the surface to the bottom throughout the year. This was because this sampling station was in a homogeneous state throughout the year. The average surface and bottom nitrate concentrations differed by only 0.01 mg/l throughout the year.

Station V

The nitrate concentration range at Station V was from 0.10 to 0.47 mg/l. The nitrate concentration was higher at this station in comparison with other sampling stations and it was probably because this was the Little River inflow station. The nitrate concentration varied only slightly from the surface to the bottom throughout the year. The average nitrate concentration at the surface and the bottom differed by only 0.02 mg/l.

Monthly Average Nitrate Concentrations

The monthly average nitrate concentrations are given in Tables 21 A-E. The average nitrate concentration range was from 0.01 to 0.31 mg/l. The monthly average nitrate concentrations also showed a decrease from the surface to the bottom during the period of thermal stratification (from May to August). From September to April the average nitrate concentration was almost the same at all depths.

Nitrites

Nitrites are the intermediate compounds in the nitrogen cycle. Nitrites may occur in water as a result of biological decomposition of proteinaceous materials. Nitrites are very unstable and the concentration of nitrites in water is usually very low.

The water samples collected for nitrite determinations were filtered through a 0.45μ membrane filter, and the filtrates were preserved at 4.0°C using 40 mg/l $HgCl_2$. The nitrite concentrations were determined within 24 hours after the collection of samples by the Diazotization Method. The nitrite concentrations are presented in Tables 20 A-E.

Stations I - V

The concentration of nitrites present in Lake Thunderbird was very low, with the range as follows:

Station I	0.1 - 18.4 μg/l
Station II	0.2 - 19.7 μg/l
Station III	0.1 - 14.7 μg/l
Station IV	0.2 - 17.2 μg/l
Station V	0.1 - 20 μg/l

From September to April, when the lake was in a mixed state, the nitrite contentrations varied very little with depth. From May to August, when the lake was thermally stratified, the nitrite concentrations increased from the surface to the bottom at Stations I, II, and III. Stations IV and V showed little vertical variation in nitrite concentrations throughout the year. Generally, the nitrites tended to accumulate at the bottom during summer months due to the reduction of nitrates to nitrites under anaerobic conditions; however, even then the nitrite concentrations were very low at the bottom.

Average Nitrite Concentrations

The monthly average nitrite concentrations are given in Tables 21 A-E. The monthly average nitrite concentration had a range from 0.2 to 20 μg/l. The average nitrite values from September to April were almost the same from surface to bottom. From May to August the nitrite concentrations increased from the surface to the bottom, and there was an accumulation of nitrites at the bottom. At Stations IV and V the nitrite concentrations did not show much variation from the surface to the bottom even during the summer months.

Total Kjeldahl Nitrogen

The term "total Kjeldahl nitrogen" is applied to the ammonia nitrogen and organic nitrogen. Ammonia is the chief microbial decomposition product from plant and animal proteins. The free ammonia content of natural waters is derived in part from bacterial decomposition of proteins, and in part from deamination also involving bacteria. Ammonia nitrogen is present in many surface and ground waters and occurs in relatively small quantities. The organic nitrogen content of water is

TABLE 21-A

MONTHLY AVERAGE NITRATES AND NITRITES VALUES

STATION I

MONTH	SURFACE		3 METERS		6 METERS		9 METERS		BOTTOM (10 METERS)	
	NO_3^- mg/l	NO_2^- µg/l	NO_3^- mg/l	NO_2^- µg/l	NO_3^- mg/l	NO_2^- µg/l	NO_3^- mg/l	NO_2^- µg/l	NO_3^- mg/l	NO_2^- µg/l
1974										
MAY										
JUNE										
AUGUST	.310	1.45	.308	1.45	.276	6.30	.216	5.62	.207	5.62
SEPTEMBER	.225	1.74	.217	1.80	.209	4.48	.194	7.70	.181	9.71
OCTOBER	.182	4.50			.176	5.20			.172	4.60
NOVEMBER	.182	7.90			.181	8.00			.184	7.90
DECEMBER	.165	1.85			.165	1.85			.160	2.01
1975										
JANUARY	.096	1.24			.096	1.00			.097	1.00
FEBRUARY	.114	2.40			.114	2.40			.107	2.60
MARCH	.113	2.55			.112	2.55			.109	2.55
APRIL	.098	2.53			.098	2.64			.095	2.87
MAY	.153	4.23	.124	4.44	.101	4.52	.068	6.51	.051	7.60
JUNE	.268	2.74	.223	3.64	.174	3.65	.157	4.12	.114	4.23
JULY	.181	0.30	.143	0.56	.116	1.25	.043	1.48	.033	6.95
AUGUST	.092	0.20	.090	0.22	.060	0.37	.044	1.31	.043	1.31
SEPTEMBER	.117	2.15	.116	2.26	.113	2.26	.108	2.10	.103	2.10
OCTOBER	.138	9.76	.135	9.76	.132	11.41	.131	11.26	.121	11.30

TABLE 21-B

MONTHLY AVERAGE NITRATES AND NITRITES VALUES

STATION II

MONTH	SURFACE		3 METERS		6 METERS		9 METERS		12 METERS		BOTTOM (15 METERS)	
	NO_3^- mg/l	NO_2^- µg/l	NO_3^- mg/l	NO_2^- µg/l	NO_3^- mg/l	NO_2^- µg/l	NO_3^- mg/l	NO_2^- µg/l	NO_3^- mg/l	NO_2^- µg/l	NO_3^- mg/l	NO_2^- µg/l
1974												
MAY												
JUNE												
AUGUST	.311	2.42	.272	3.71	.238	4.17	.226	4.14	.182	5.03	.176	10.68
SEPT.	.239	1.56	.221	1.53	.220	1.82	.212	2.03	.210	3.66	.192	10.33
OCT.	.196	6.05					.192	6.70			.192	6.85
NOV.	.183	8.00					.180	7.90			.180	8.00
DEC.	.171	2.15					.180	2.10			.172	2.15
1975												
JAN.	.103	1.30					.101	1.30			.104	1.20
FEB.	.127	2.30					.110	2.40			.110	2.70
MARCH	.118	2.66					.110	2.66			.109	2.66
APRIL	.090	2.55					.094	2.58			.105	3.80
MAY	.184	4.95	.151	5.01	.146	6.01	.099	6.00	.092	7.46	.070	11.65
JUNE	.270	3.45	.269	3.85	.148	3.82	.125	3.88	.122	5.20	.104	8.17
JULY	.147	0.76	.130	0.78	.127	0.81	.048	2.40	.037	9.41	.026	14.07
AUGUST	.090	0.20	.083	0.20	.057	0.48	.043	1.41	.020	2.66	.013	2.84
SEPT.	.147	3.03	.146	3.03	.136	3.03	.138	3.03	.139	2.90	.141	2.94
OCT.	.184	7.41	.181	7.41	.170	7.41	.165	7.41	.160	7.38	.157	6.44

TABLE 21-C

MONTHLY AVERAGE NITRATES AND NITRITES VALUES

STATION III

MONTH	SURFACE		3 METERS		6 METERS		9 METERS		BOTTOM (10 METERS)	
	NO_3^- mg/l	NO_2^- µg/l	NO_3^- mg/l	NO_2^- µg/l	NO_3^- mg/l	NO_2^- µg/l	NO_3^- mg/l	NO_2^- µg/l	NO_3^- mg/l	NO_2^- µg/l
<u>1974</u>										
MAY										
JUNE										
AUGUST	.242	2.13	.240	2.55	.229	3.18	.223	7.25	.201	6.76
SEPTEMBER	.234	0.97	.226	1.10	.225	1.24	.223	1.60	.215	1.87
OCTOBER	.181	6.67			.176	6.50			.177	7.70
NOVEMBER	.180	9.90			.178	10.40			.179	10.60
DECEMBER	.168	1.81			.167	1.81			.167	1.86
<u>1975</u>										
JANUARY	.095	1.20			.095	1.20			.095	1.20
FEBRUARY	.117	2.50			.108	2.50			.097	2.50
MARCH	.112	2.62			.112	2.62			.109	2.62
APRIL	.082	2.40			.077	2.62			.092	3.34
MAY	.191	5.19	.171	5.54	.107	5.96	.084	9.21	.075	9.46
JUNE	.200	4.34	.199	5.39	.184	5.38	.166	7.26	.150	7.57
JULY	.159	0.50	.154	0.56	.139	1.23	.049	1.70	.030	8.58
AUGUST	.075	0.25	.072	0.35	.060	1.57	.016	2.39	.015	3.85
SEPTEMBER	.126	3.17	.109	2.73	.109	2.73	.103	2.76	.099	3.00
OCTOBER	.157	6.85	.156	6.85	.156	6.85	.149	6.94	.136	7.26

TABLE 21-D

MONTHLY AVERAGE NITRATES AND NITRITES VALUES

STATION IV

MONTH	SURFACE		3 METERS		BOTTOM (6 METERS)	
	NO_3^- mg/1	NO_2^- µg/1	NO_3^- mg/1	NO_2^- µg/1	NO_3^- mg/1	NO_2^- µg/1
1974						
MAY						
JUNE						
AUGUST	.225	0.56	.223	0.70	.214	1.00
SEPTEMBER	.226	1.15	.220	1.72	.217	1.32
OCTOBER	.140	3.70			.110	4.90
NOVEMBER	.153	12.80			.144	17.20
DECEMBER	.164	1.72			.165	1.90
1975						
JANUARY	.088	1.40			.088	1.40
FEBRUARY	.090	2.20			.090	2.20
MARCH	.088	2.55			.087	2.55
APRIL	.060	2.23			.057	2.62
MAY	.116	5.27	.103	5.92	.093	6.07
JUNE	.106	4.23	.103	4.61	.110	5.07
JULY	.071	0.62	.060	0.66	.046	7.24
AUGUST	.075	0.40	.075	0.56	.066	1.79
SEPTEBMER	.080	2.10	.077	2.10	.062	2.00
OCTOBER	.135	3.94	.131	3.94	.126	3.73

TABLE 21-E

MONTHLY AVERAGE NITRATES AND NITRITES VALUES

STATION V

MONTH	SURFACE		3 METERS		BOTTOM (4 METERS)	
	NO_3^- mg/1	NO_2^- µg/1	NO_3^- mg/1	NO_2^- µg/1	NO_3^- mg/1	NO_2^- µg/1
1974						
MAY						
JUNE						
AUGUST	.195	1.08	.193	1.36	.189	1.19
SEPTEMBER	.220	1.59	.218	1.04	.210	3.87
OCTOBER	.139	2.85			.113	3.32
NOVEMBER	.152	17.90			.148	20.00
DECEMBER	.163	1.30			.164	1.90
1975						
JANUARY	.047	1.40			.047	1.40
FEBRUARY	.058	2.40			.058	2.80
MARCH	.081	2.85			.080	2.80
APRIL	.059	1.84			.055	1.85
MAY	.141	4.67	.115	5.48	.107	6.20
JUNE	.138	7.76	.127	7.88	.114	9.01
JULY	.082	1.00	.065	1.58	.067	2.22
AUGUST	.129	0.63	.096	0.85	.079	2.61
SEPTEMBER	.134	2.41	.090	2.44	.062	2.44
OCTOBER	.090	3.73	.087	3.65	.086	3.76

contributed in various degrees by amino acids, polypeptides and proteins which are the products of biological processes.

The kjeldahl nitrogen determinations were carried out within one week after the sample collection by the Distillation Method. The water samples were preserved using 40 mg/l $HgCl_2$ and the samples were kept in a freezer. The kjeldahl nitrogen concentrations were measured only for the surface and the bottom waters. Table 22 contains the kjeldahl nitrogen values.

Stations I - V

The total kjeldahl nitrogen range for Lake Thunderbird was from 0.728 to 1.79 mg/l. At all sampling stations the kjeldahl nitrogen was less than 1.0 mg/l from January to April, and it was slightly higher the rest of the year. From September to April the kjeldahl nitrogen values at the surface and the bottom were almost the same, with this being due to homogeneous conditions in the lake.

From May to August Stations IV and V did not show much difference in kjeldahl nitrogen values from the surface to the bottom and this was once again due to the homogeneous conditions existing at these stations because of their shallow depths. Stations I, II and III showed differences in kjeldahl nitrogen values at the surface and the bottom from May to August; the differences were slightly higher in July and August than in May and June. The bottom kjeldahl nitrogen concentrations at Stations I, II and III were the highest on August 16, 1975, being greater than 1.6 mg/l.

According to the data available from other sources, the amount of ammonia in Lake Thunderbird was very small (0.1 mg/l or less). The

TABLE 22

KJELDHAL'S NITROGEN IN LAKE THUNDERBIRD--STATIONS I-V
mg/l

DATE	STATION I		STATION II		STATION III		STATION IV		STATION V	
	SURFACE	BOTTOM	SURFACE	BOTTOM	SURFACE	BOTTOM	SURFACE	BOTTOM	SURFACE	BOTTOM
5/10/74	0.952	1.064	1.008	1.232	1.064	1.232	1.120	1.120	1.176	1.176
6/11/74	1.064	1.120	1.008	1.288	1.064	1.176	1.008	1.064	1.176	1.176
8/4/74	1.120	1.400	1.120	1.512	1.120	1.456	1.288	1.400	1.288	1.568
8/25/74	1.064	1.456	1.120	1.624	1.008	1.400	1.176	1.232	1.176	1.232
9/10/74	1.288	1.288	1.288	1.512	1.232	1.512	1.120	1.120	1.120	1.176
9/29/74	1.232	1.288	1.232	1.400	1.232	1.344	1.008	1.120	1.008	1.120
10/16/74	1.232	1.288	1.344	1.288	1.400	1.400	1.232	1.176	1.176	1.120
10/31/74	1.232	1.288	1.288	1.400	1.344	1.400	1.176	1.120	1.176	1.232
11/12/74	1.176	1.176	1.176	1.176	1.176	1.232	1.008	1.120	1.120	1.120
12/12/74	1.176	1.176	1.176	1.176	1.176	1.176	1.120	1.120	1.344	1.344
12/27/74	1.176	1.176	1.232	1.344	1.176	1.232	1.120	1.120	1.232	1.232
1/22/75	1.064	1.120	0.784	0.784	0.840	0.840	0.784	0.784	0.840	0.840
2/27/75	0.840	0.840	0.952	0.952	0.896	0.896	0.952	0.868	1.008	0.896
3/17/75	0.896	0.896	0.896	0.868	0.868	1.008	0.868	0.868	0.896	0.896
3/30/75	0.840	0.812	0.896	0.896	0.812	0.812	0.840	0.812	0.784	0.840
4/12/75	0.784	0.840	0.840	0.840	0.672	0.784	0.840	0.840	0.728	0.812
4/28/75	0.896	0.896	0.896	0.896	0.896	0.840	0.840	0.840	0.840	0.896
5/9/75	0.896	1.008	0.980	1.120	1.008	1.008	1.008	1.008	1.008	1.176
5/26/75	0.952	1.064	1.008	1.120	1.064	1.064	1.120	1.120	1.176	1.008
6/8/75	0.952	1.120	1.008	1.232	1.120	1.232	1.064	1.232	1.064	1.176
6/26/75	0.840	1.008	1.176	1.288	1.120	1.120	0.840	0.952	1.008	1.008
7/12/75	1.232	1.568	1.232	1.680	1.120	1.568	1.288	1.400	1.344	1.400
7/30/75	1.176	1.568	1.232	1.680	1.232	1.456	1.232	1.232	1.400	1.400
8/16/75	1.288	1.624	1.120	1.792	1.288	1.736	1.344	1.400	1.372	1.400
8/30/75	1.176	1.344	1.008	1.624	1.062	1.176	1.456	1.456	1.372	1.456
9/25/75	1.288	1.344	1.120	1.120	1.288	1.232	1.680	1.736	1.400	1.372
10/19/75	1.176	1.232	1.120	1.232	1.176	1.176	1.176	1.344	1.288	1.232

concentrations of kjeldahl nitrogen at the surface and the bottom were the same when the lake was homogeneous. Therefore, part of the increase in the kjeldahl nitrogen value at the bottom from May through August was due to an increase in the ammonia content at the bottom, and part of it was due to an increase in the organic nitrogen content. The organic nitrogen was due to biological activity and it was higher during the summer months. It could be concluded that during the summer months the organic and ammonia nitrogen concentration at the bottom increased, and from September to April their levels were the same throughout the lake.

Monthly Average Kjeldahl Nitrogen

The monthly average kjeldahl nitrogen values are given in Table 23 and they range from 0.784 to 1.74 mg/l. The monthly average kjeldahl nitrogen values were higher at the bottom in July and August. From September through April the kjeldahl nitrogen values were small and almost the same at the surface and the bottom. There was some difference in kjeldahl nitrogen values between the surface and the bottom from May through August; the differences were higher in July and August. Stations I, II and III showed differences in Kjeldahl nitrogen values between the surface and the bottom in the summer months. Even during the summer months Stations IV and V showed only small differences in kjeldahl nitrogen values between the surface and the bottom.

Phosphates

Phosphorus is an important nutrient for the growth and reproduction of algae. It is present only in small amounts in natural waters. Algae can take up more phosphorus than it needs for growth, and the excess phosphorus is stored. Phosphorus is lost rapidly from the open waters of a lake due to storage by phytoplankton, Zooplankton and Littoral vegetation.

TABLE 23

MONTHLY AVERAGE KJELDHAL'S NITROGEN VALUES--STATIONS I-V
mg/l

DATE	STATION I		STATION II		STATION III		STATION IV		STATION V	
	SURFACE	BOTTOM	SURFACE	BOTTOM	SURFACE	BOTTOM	SURFACE	BOTTOM	SURFACE	BOTTOM
1974										
MAY	0.952	1.064	1.008	1.232	1.064	1.232	1.120	1.120	1.176	1.176
JUNE	1.064	1.120	1.008	1.288	1.064	1.176	1.008	1.064	1.176	1.176
AUGUST	1.092	1.428	1.120	1.568	1.064	1.428	1.232	1.316	1.232	1.400
SEPTEMBER	1.260	1.288	1.260	1.456	1.232	1.428	1.064	1.120	1.064	1.148
OCTOBER	1.232	1.288	1.316	1.344	1.372	1.400	1.204	1.148	1.176	1.176
NOVEMBER	1.176	1.176	1.176	1.176	1.176	1.232	1.008	1.120	1.120	1.120
DECEMBER	1.120	1.176	1.204	1.260	1.176	1.204	1.120	1.120	1.288	1.288
1975										
JANUARY	1.064	1.120	0.784	0.784	0.840	0.840	0.784	0.784	0.840	0.840
FEBRUARY	0.840	0.840	0.952	0.952	0.896	0.896	0.952	0.868	1.008	0.896
MARCH	0.868	0.854	0.896	0.854	0.840	0.910	0.854	0.840	0.840	0.868
APRIL	0.840	0.868	0.868	0.868	0.784	0.812	0.840	0.840	0.784	0.854
MAY	0.924	1.036	0.994	1.120	1.036	1.036	1.064	1.064	1.092	1.092
JUNE	0.896	1.064	1.094	1.260	1.120	1.176	0.952	1.092	1.036	1.092
JULY	1.204	1.568	1.232	1.680	1.176	1.512	1.260	1.316	1.372	1.400
AUGUST	1.232	1.484	1.064	1.708	1.176	1.456	1.400	1.428	1.372	1.428
SEPTEMBER	1.288	1.344	1.120	1.120	1.288	1.232	1.680	1.736	1.400	1.372
OCTOBER	1.176	1.232	1.120	1.232	1.176	1.176	1.176	1.344	1.288	1.232

Natural water contains different forms of phosphorus, including soluble phosphate phosphorus, soluble organic phosphorus and particulate organic phosphorus. Phosphorus gets into water from the soil, body wastes and detergents. Since phosphorus is one of the important nutrients for algal growth, excessive phosphorus present in water results in algal blooms. Algal blooms can clog water treatment plant filters and cause taste and odor problems. Phosphate determinations are important in assessing the potential biological productivity of surface waters. Phosphates occur in bottom sediments of impounded waters both as precipitated inorganic forms and incorporated into organic forms.

The water samples collected for phosphate determinations were filtered using a 0.45μ membrane filter and the filtrate was kept in a freezer. Phosphate concentrations were measured in the laboratory within 24 hours after sample collection by the Ascorbic Acid Method. The phosphorus concentrations are presented in Tables 24 A-E.

<u>Station I</u>

The dissolved phosphorus range at the surface was from 0.9 to 30.6 μg/l as P, and at the bottom it was from 1.22 to 34.6 μg/l as P. The dissolved phosphorus concentrations varied widely. The dissolved phosphorus values differed from the surface to the bottom during the summer months. There were differences in the concentrations of phosphorus between the surface and the bottom even during periods when the lake was in a mixed state. The difference in concentrations between the surface and the bottom was higher during the summer months, with the bottom water having the higher concentration. From May through August the average phosphate concentration at the surface was 6.8μg/l, and at the bottom it was 9.5μg/l.

TABLE 24-A

PHOSPHATES AND IRON IN LAKE THUNDERBIRD

STATION I

DATE	SURFACE		3 METERS		6 METERS		9 METERS		BOTTOM (10 METERS)	
	$Po_4^{\equiv}$ µg/1	Fe mg/1	$Po_4^{\equiv}$ µg/1	Fe mg/1	$Po_4^{\equiv}$ µg/1	Fe mg/1	$Po_4^{\equiv}$ µg/1	Fe mg/1	$Po_4^{\equiv}$ µg/1	Fe mg/1
5/10/74	2.40	.109	2.60	.112	3.00	.114	2.40	.116	4.10	.185
6/11/74	1.22	.110	1.22	.112	1.22	.116	1.22	.185	1.22	.255
8/4/74	30.6	.110	30.2	.150	28.7	.150	28.0	.252	26.4	.352
8/25/74	28.4	.170	28.5	.180	32.8	.180	34.4	.310	34.6	.420
9/10/74	1.07	.210	5.34	.210	6.87	.300	20.2	.575	20.2	.580
9/29/74	14.2	.220	10.6	.220	10.20	.310	10.2	.330	10.4	.350
10/16/74	9.25	.230			8.02	.295			7.00	.380
10/31/74	2.90	.280			3.80	.280			6.90	.320
11/12/74	7.60	.140			8.30	.140			8.90	.146
12/12/74	4.90	.120			4.90	.205			4.90	.200
12/27/74	2.00	.171			1.70	.265			1.85	.265
1/21/75	6.20	.205			6.20	.252			6.50	.230
2/28/75	1.70	.123			1.70	.120			2.00	.180
3/17/75	1.54	.124			1.54	.127			1.54	.137
3/30/75	1.54	.114			1.23	.114			1.23	.114
4/12/75	0.90	.100			1.08	.127			1.08	.120
4/28/75	4.47	.240			5.09	.251			5.09	.252
5/9/75	2.01	.110	2.94	.118	3.56	.179	3.56	.218	6.20	.285
5/26/75	2.94	.280	3.10	.300	3.72	.254	4.50	.750	6.04	1.03
6/8/75	2.01	.128	2.32	.126	2.94	.141	4.34	.230	4.40	.350
6/26/75	2.32	.250	2.40	.250	2.48	.250	4.80	.315	4.95	.330
7/12/75	3.10	.107	3.56	.107	3.87	.140	4.96	.240	6.51	.545
7/30/75	2.01	.106	2.80	.110	5.30	.195	11.80	.220	11.20	.585
8/16/75	2.01	.100	2.01	.117	3.41	.183	5.12	.220	5.27	1.30
8/31/75	2.32	.104	2.32	.103	2.86	.107	3.41	.147	3.72	.148
9/25/75	3.41	.142	3.25	.140	2.80	.143	2.80	.150	2.20	.158
10/19/75	5.42	.130	5.00	.130	5.00	.133	5.30	.133	5.73	.158

TABLE 24-B

PHOSPHATES AND IRON IN LAKE THUNDERBIRD

STATION II

DATE	SURFACE		3 METERS		6 METERS		9 METERS		12 METERS		BOTTOM (15 METERS)	
	$PO_4^{\equiv}$ µg/1	Fe mg/1	$PO_4^{\equiv}$ µg/1	FE mg/1	$PO_4^{\equiv}$ µg/1	Fe mg/1	$PO_4^{\equiv}$ µg/1	Fe mg/1	$PO_4^{\equiv}$ µg/1	Fe mg/1	$PO_4^{\equiv}$ µg/1	Fe mg/1
5/10/74	2.44	.109	2.44	.114	2.44	.120	2.75	.170	2.75	.165	4.43	.190
6/11/74	1.98	.240	1.68	.235	1.68	.235	1.22	.240	0.76	.310	1.20	.420
8/4/74	19.50	.104	24.90	.136	24.90	.150	29.20	.150	50.8	.495	74.8	.495
8/25/74	18.90	.146	25.0	.156	24.70	.156	30.40	.170	34.5	.225	52.4	.375
9/10/74	22.0	.200	26.0	.200	32.80	.300	34.50	.335	50.4	.420	52.7	.490
9/29/74	12.3	.300	12.30	.330	12.30	.340	12.60	.342	13.4	.480	13.90	.485
10/16/74	8.20	.140					9.70	.396			11.0	.340
10/31/74	7.60	.265					7.40	.265			7.40	.293
11/12/74	8.60	.120					9.40	.135			9.40	.250
12/12/74	6.00	.208					6.00	.173			6.80	.180
12/27/74	2.20	.220					3.20	.261			4.20	.295
1/21/75	6.20	.200					6.20	.210			6.20	.310
2/28/75	1.40	.124					2.20	.124			2.20	.156
3/17/75	1.54	.120					1.70	.124			2.00	.127
3/30/75	1.38	.107					1.38	.107			1.54	.130
4/12/75	1.54	.110					1.70	.120			2.47	.144
4/28/75	3.40	.174					4.00	.225			9.70	.345
5/9/75	2.00	.150	2.00	.166	2.00	.210	2.50	.210	8.70	.290	12.1	.290
5/26/75	3.41	.210	3.10	.210	3.10	.210	3.72	.230	9.14	.250	25.1	.362
6/8/75	2.00	.127	2.32	.132	2.48	.154	4.50	.230	9.76	.340	15.5	.460
6/26/75	1.86	.141	1.86	.165	2.17	.240	3.72	.234	5.90	.295	9.95	.370
7/12/75	1.55	.084	1.70	.085	1.86	.085	4.34	.141	15.65	.295	30.70	.450
7/30/75	1.70	.116	2.20	.100	4.30	.136	10.20	.210	10.80	.255	123.2	.500
8/16/75	2.01	.067	2.01	.067	2.48	.072	16.43	.156	24.33	.325	138.3	1.36
8/31/75	2.32	.100	2.63	.094	2.63	.100	2.63	.102	8.80	.161	20.3	.530
9/25/75	4.65	.143	4.96	.144	4.96	.146	4.96	.146	5.10	.142	5.27	.160
10/19/75	7.44	.137	7.75	.137	7.91	.142	7.91	.136	8.22	.136	8.22	.173

TABLE 24-C

PHOSPHATES AND IRON IN LAKE THUNDERBIRD

STATION III

DATE	SURFACE		3 METERS		6 METERS		9 METERS		BOTTOM (10 METERS)	
	$Po_4^{\equiv}$ µg/l	Fe mg/l	$Po_4^{\equiv}$ µg/l	Fe mg/l	$Po_4^{\equiv}$ µg/l	Fe mg/l	$Po_4^{\equiv}$ µg/l	Fe mg/l	$Po_4^{\equiv}$ µg/l	Fe mg/l
5/10/74	2.44	.100	2.60	.120	2.90	.120	3.97	.100	5.34	.200
6/11/74	0.80	.150	0.80	.150	0.80	.240	1.20	.300	1.37	.300
8/4/74	28.70	.132	31.0	.132	36.30	.132	42.0	.144	60.80	.460
8/25/74	27.0	.166	27.2	.190	26.6	.150	26.7	.365	35.0	.465
9/10/74	3.00	.230	3.80	.230	5.30	.285	5.60	.285	5.60	.300
9/29/74	12.50	.312	12.60	.360	12.60	.370	13.70	.370	17.0	.380
10/16/74	6.50	.135			7.70	.145			8.60	.240
10/31/74	6.30	.340			6.80	.330			6.70	.300
11/12/74	10.3	.220			10.8	.230			11.3	.250
12/12/74	5.70	.195			4.90	.195			4.70	.245
12/27/74	1.00	.120			1.70	.150			1.70	.195
1/21/75	6.00	.144			6.00	.160			6.00	.310
2/28/75	1.85	.180			1.85	.160			1.85	.205
3/17/75	1.23	.110			1.23	.110			1.23	.110
3/30/75	1.23	.124			1.23	.137			1.23	.137
4/12/75	1.08	.110			1.08	.120			1.08	.123
4/28/75	2.31	.210			2.47	.265			7.25	.320
5/9/75	2.00	.130	2.80	.147	2.80	.146	2.80	.200	3.10	.240
5/26/75	2.17	.200	2.94	.200	2.94	.250	3.72	.500	4.34	.655
6/8/75	2.48	.125	2.63	.120	3.72	.120	5.27	.235	10.85	.420
6/26/75	2.63	.180	2.63	.174	3.41	.180	6.82	.295	8.06	.600
7/12/75	1.86	.087	3.25	.087	3.56	.172	4.50	.174	14.70	.300
7/30/75	2.48	.120	2.48	.108	2.32	.108	3.25	.109	17.05	.480
8/16/75	2.63	.072	4.03	.074	4.03	.075	9.76	.156	21.23	1.28
8/31/75	2.63	.110	2.01	.101	2.01	.100	4.18	.130	4.18	.161
9/25/75	4.65	.150	3.88	.153	3.88	.160	3.88	.161	4.03	.167
10/19/75	6.51	.128	7.20	.128	8.34	.128	8.68	.140	8.84	.205

TABLE 24-D

PHOSPHATES AND IRON IN LAKE THUNDERBIRD

STATION IV

DATE	SURFACE		3 METERS		BOTTOM (6 METERS)	
	$PO_4^{\equiv}$ µg/l	Iron mg/l	$PO_4^{\equiv}$ µg/l	Iron mg/l	$PO_4^{\equiv}$ µg/l	Iron mg/l
5/10/74	4.28	.072	5.96	.160	6.87	.160
6/11/74	0.46	.210	0.46	.280	0.46	.290
8/4/74	27.2	.300	29.5	.300	34.0	.455
8/25/74	26.3	.290	27.6	.320	34.5	.390
9/10/74	5.30	.380	4.60	.280	4.60	.280
9/29/74	14.5	.350	13.0	.350	12.3	.360
10/16/74	2.85	.154			5.40	.180
10/31/74	8.20	.380			5.90	.385
11/12/74	18.3	.295			19.1	.465
12/12/74	1.70	.205			1.70	.295
12/27/74	1.10	.104			1.10	.146
1/21/75	6.00	.220			6.00	.240
2/28/75	1.40	.160			1.40	.180
3/17/75	1.10	.120			1.10	.200
3/30/75	1.23	.141			1.23	.141
4/12/75	0.80	.110			1.23	.171
4/28/75	2.31	.174			3.24	.235
5/9/75	2.00	.140	2.60	.232	2.60	.336
5/26/75	2.48	.025	2.94	.290	2.94	.410
6/8/75	2.94	.163	3.10	.210	8.06	.350
6/26/75	3.01	.280	3.26	.300	3.87	.350
7/12/75	3.56	.140	4.34	.143	6.35	.400
7/30/75	1.86	.145	2.94	.140	3.25	.270
8/16/75	2.01	.070	2.32	.070	2.63	.177
8/31/75	2.32	.160	2.79	.147	3.10	.164
9/25/75	4.03	.160	2.95	.170	2.80	.255
10/19/75	7.44	.136	7.13	.134	7.00	.142

TABLE 24-E

PHOSPHATES AND IRON IN LAKE THUNDERBIRD

STATION V

DATE	SURFACE		3 METERS		BOTTOM (4 METERS)	
	$PO_4^{\equiv}$ µg/l	Iron mg/l	$PO_4^{\equiv}$ µg/l	Iron mg/l	$PO_4^{\equiv}$ µg/l	Iron mg/l
5/10/74	9.10	.320	9.40	.450	9.93	.455
6/11/74	1.98	.170	0.46	.280	0.46	.465
8/4/74	31.0	.470	31.60	.500	35.60	.500
8/25/74	26.0	.340	26.20	.390	26.90	.515
9/10/74	5.00	.415	6.00	.360	6.90	.415
9/29/74	13.1	.360	13.4	.360	18.80	.430
10/16/74	3.10	.163			4.70	.255
10/31/74	23.6	.650			56.30	.620
11/12/74	23.9	.325			44.10	.476
12/12/74	0.80	.210			2.30	.305
12/27/74	1.10	.100			1.20	.161
1/21/75	6.00	.305			6.00	.310
2/28/75	1.20	.220			1.20	.220
3/17/75	1.00	.133			1.00	.154
3/30/75	1.70	.139			2.70	.154
4/12/75	1.08	.141			1.23	.166
4/28/75	3.55	.340			3.55	.346
5/9/75	2.60	.210	3.10	.260	3.10	.350
5/26/75	2.48	1.16	2.94	1.165	3.72	1.90
6/8/75	4.65	.360	5.27	.370	8.21	.370
6/26/75	4.34	.380	4.87	.390	4.95	.490
7/12/75	4.03	.295	6.67	.350	9.61	.395
7/30/75	2.48	.225	2.80	.227	2.80	.240
8/16/75	3.87	.230	3.87	.250	4.50	.295
8/31/75	2.17	.200	3.10	.220	3.72	.240
9/25/75	2.17	.220	3.57	.200	4.82	.290
10/19/75	7.90	.174	9.00	.176	11.47	.355

Station II

The dissolved phosphorus concentration at Station II was higher than at Station I, and the range was from 1.2 μg/l to 0.138 mg/l. The phosphate concentrations during the summer months were high at the bottom. On August 4, 1974, the phosphate concentration increased from 19.5 μg/l at the surface to 74.5 μg/l at the bottom, with most of the increase occurring below 9 meters. On August 25, 1974, the bottom phosphorus concentration was 52.4 μg/l, and the difference between the surface and the bottom was more than 30 μg/l. Even on September 10, 1974, the bottom water exhibited a high phosphate concentration.

In May and June of 1975 the phosphorus concentration showed only a modest increase from the surface to the bottom. In July and August the increase in phosphate concentration with depth was substantial. On July 12, 1975, the phosphorus content increased gradually until the 9-meter depth, and then there was a difference of 26 μg/l between 9 meters and the bottom. On July 30, 1975, the phosphate concentration at the bottom was 0.12 mg/l with the phosphate concentration increasing by more than 100 μg/l below the 9-meter depth. The phosphate concentration at the bottom remained high on August 16, 1975, when it was 0.14 mg/l. On August 31, 1975, the phosphate concentration at the bottom decreased to 20 μg/l. In September and October the phosphorus content increased only by a small amount from surface to bottom. From May through August the surface waters had an average of 4.9 μg/l phosphate and at the bottom it was 42.3 μg/l. From September to April the average difference between the surface and the bottom phosphate concentrations was only 3.0 μg/l.

Station III

The phosphorus concentration range was from 0.8 to 61.0 μg/l. The lowest phosphate concentration was at the surface on June 11, 1974, and the highest was at the bottom on August 4, 1974. In August, 1974, the phosphorus content was high at all depths and increased from the surface to the bottom. Station III also had a wide range of phosphorus values, and during the summer months the phosphate concentrations increased from the surface to the bottom. In May and June of 1975 the difference in phosphate concentrations between the surface and the bottom was small; July and August had a higher difference. From May through August the bottom waters had an average of 8.0 μg/l phosphorus more than the surface. From September through April the phosphate concentration was almost the same from the surface to the bottom.

Station IV

The dissolved phosphorus range was from 0.5 to 34.5 μg/l. On June 11, 1974, the phosphate concentration at the surface was the lowest and on August 25, 1974, the phosphate concentration at the bottom was the highest. The phosphate concentrations at Station IV varied little from surface to bottom. From May through August the surface and the bottom concentrations differed by 2.0 μg/l and the difference was only 1.0 μg/l for the rest of the year.

Station V

The dissolved phosphorus range at Station V was from 0.5 to 56.3 μg/l. The phosphate concentrations at Station V were generally high. In most cases the phosphate concentrations between surface and bottom showed only a small increase. The average phosphate concentration at the surface was 7.4 μg/1, and at the bottom it was 10.7 μg/1.

Monthly Average Phosphates

The monthly average phosphorus concentrations are given in Tables 25 A-E. The average phosphate concentration range was from 0.5 to 74.3 μg/1. With the exception of Station V, all the sampling stations had maximum phosphate at the bottom in August. Stations I and III showed only small increases in phosphate concentrations from the surface to the bottom; for Station II it was higher. The phosphate concentrations varied minimally from the surface to the bottom at Stations IV and V.

Iron

Iron is found widely in nature either as bivalent Fe^{++} or trivalent Fe^{+++}. The bivalent, ferrous, state is soluble, but only under anaerobic conditions. In the presence of oxygen the ferric form is present as a colloidal complex in combination with other inorganic ions. Iron occurs in natural waters in varying but small amounts. If anaerobic conditions develop in the hypolimnion of a stratified impoundment, iron can occur in appreciable quantities as soluble ferrous bicarbonate. The epilimnion contains only small quantities of iron which is present as colloids or as a supersaturated solution.

Water containing iron is aesthetically unacceptable because, when exposed to air, it becomes turbid due to Fe^{+++} which forms a colloidal precipitate. Iron imparts stains to plumbing fixtures, laundry and porcelain, and cause difficulties in distribution systems by supporting the growth of iron bacteria.

TABLE 25-A

MONTHLY AVERAGE PHOSPHATES AND IRON VALUES

STATION I

MONTH	SURFACE		3 METERS		6 METERS		9 METERS		BOTTOM (10 METERS)	
	$Po_4^{\equiv}$ µg/l	Iron mg/l	$Po_4^{\equiv}$ µg/l	Iron mg/l	$Po_4^{\equiv}$ µg/l	Iron mg/l	$Po_4^{\equiv}$ µg/l	Iron mg/l	$Po_4^{\equiv}$ µg/l	Iron mg/l
1974										
MAY	2.40	.109	2.60	.112	3.00	.114	2.40	.116	4.10	.185
JUNE	1.22	.110	1.22	.112	1.22	.116	1.22	.185	1.22	.255
AUGUST	29.50	.140	29.35	.165	30.75	.165	31.20	.281	30.50	.386
SEPTEMBER	7.63	.215	7.97	.215	8.53	.305	15.20	.452	15.30	.465
OCTOBER	6.07	.255			5.91	.287			6.90	.350
NOVEMBER	7.60	.140			8.30	.140			8.90	.146
DECEMBER	3.45	.145			3.30	.235			3.37	.233
1975										
JANUARY	6.20	.205			6.20	.252			6.50	.230
FEBRUARY	1.70	.123			1.70	.120			2.00	.180
MARCH	1.54	.119			1.39	.120			1.39	.125
APRIL	2.68	.170			3.08	.189			3.08	.186
MAY	2.47	.195	3.02	.209	3.64	.216	4.03	.484	6.12	.657
JUNE	2.16	.189	2.36	.188	2.71	.195	4.57	.272	4.67	.340
JULY	2.55	.106	3.18	.108	4.58	.167	8.38	.230	8.85	.565
AUGUST	2.16	.102	2.16	.110	3.13	.145	4.26	.183	4.50	.724
SEPTEMBER	3.41	.142	3.25	.140	2.80	.143	2.80	.150	2.20	.158
OCTOBER	5.42	.130	5.00	.130	5.00	.133	5.30	.133	5.73	.158

TABLE 25-B

MONTHLY AVERAGE PHOSPHATES AND IRON VALUES

STATION II

MONTH	SURFACE		3 METERS		6 METERS		9 METERS		12 METERS		(15 METERS)	
	$Po_4^{\equiv}$ µg/l	Iron mg/l	$Po_4^{\equiv}$ µg/l	Iron mg/l	$Po_4^{\equiv}$ µg/l	Iron mg/l	$Po_4^{\equiv}$ µg/l	Iron mg/l	$Po_4^{\equiv}$ µg/l	Iron mg/l	$Po_4^{\equiv}$ µg/l	Iron mg/l
1974												
MAY	2.44	.109	2.44	.114	2.44	.120	2.75	.170	2.75	.165	4.43	.190
JUNE	1.98	.240	1.68	.235	1.68	.235	1.22	.240	0.76	.310	1.20	.420
AUGUST	19.20	.173	24.95	.178	24.80	.228	29.80	.252	42.65	.322	63.45	.432
SEPT.	11.65	.250	14.15	.265	22.55	.320	23.55	.338	31.90	.450	33.30	.487
OCT.	7.90	.202					8.55	.330			8.40	.316
NOV.	8.60	.120					9.40	.135			9.40	.250
DEC.	4.10	.214					7.70	.217			8.10	.237
1975												
JAN.	6.20	.200					6.20	.210			6.20	.310
FEB.	1.40	.124					2.20	.124			2.20	.156
MARCH	1.46	.113					1.59	.115			1.77	.128
APRIL	2.47	.142					2.85	.172			6.08	.245
MAY	2.70	.180	2.55	.188	2.55	.210	3.11	.220	8.92	.270	18.55	.326
JUNE	1.93	.134	2.09	.148	2.32	.197	4.11	.232	7.83	.317	12.72	.415
JULY	1.62	.100	1.95	.092	3.08	.110	7.27	.175	13.22	.275	76.95	.475
AUG.	2.16	.083	2.37	.080	2.55	.086	9.53	.129	16.56	.243	79.30	.945
SEPT.	4.65	.143	4.96	.144	4.96	.146	4.96	.146	5.10	.142	5.27	.160
OCT.	7.44	.137	7.75	.137	7.91	.142	7.91	.136	8.22	.136	8.22	.173

TABLE 25-C

MONTHLY AVERAGE PHOSPHATES AND IRON VALUES

STATION III

MONTH	SURFACE		3 METERS		6 METERS		9 METERS		BOTTOM (10 METERS)	
	$PO_4^{\equiv}$ µg/l	Fe mg/l	$PO_4^{\equiv}$ µg/l	Fe mg/l	$PO_4^{\equiv}$ µg/l	Fe mg/l	$PO_4^{\equiv}$ µg/l	Fe mg/l	$PO_4^{\equiv}$ µg/l	Fe mg/l
1974										
MAY	2.44	.100	2.60	.120	2.90	.120	3.97	.100	5.34	.200
JUNE	0.80	.150	0.80	.150	0.80	.240	1.20	.300	1.37	.300
AUGUST	27.85	.149	29.10	.161	31.45	.141	34.35	.254	47.90	.462
SEPTEMBER	7.75	.271	8.20	.295	8.95	.327	9.65	.327	11.30	.340
OCTOBER	6.40	.237			7.25	.237			7.65	.270
NOVEMBER	10.30	.220			10.80	.230			11.30	.250
DECEMBER	3.35	.157			3.30	.172			3.20	.220
1975										
JANUARY	6.00	.144			6.00	.160			6.00	.310
FEBRUARY	1.85	.180			1.85	.160			1.85	.205
MARCH	1.23	.117			1.23	.123			1.23	.123
APRIL	1.70	.160			1.78	.192			4.16	.221
MAY	2.08	.165	2.87	.173	2.87	.198	3.26	.350	2.72	.447
JUNE	2.55	.152	2.63	.147	3.56	.150	6.04	.265	9.45	.510
JULY	2.17	.103	2.86	.097	2.94	.140	3.87	.141	15.87	.390
AUGUST	2.63	.091	3.02	.087	3.02	.087	6.97	.143	12.70	.720
SEPTEMBER	4.65	.150	3.88	.153	3.88	.160	3.88	.161	4.03	.167
OCTOBER	6.51	.128	7.20	.128	8.34	.128	8.68	.140	8.84	.205

TABLE 25-D

MONTHLY AVERAGE PHOSPHATES AND IRON VALUES

STATION IV

MONTH	SURFACE		3 METERS		BOTTOM (6 METERS)	
	$PO_4^{\equiv}$ µg/l	Fe mg/l	$PO_4^{\equiv}$ µg/l	Fe mg/l	$PO_4^{\equiv}$ µg/l	Fe mg/l
1974						
MAY	4.28	.072	5.96	.160	6.87	.160
JUNE	0.46	.210	0.46	.280	0.46	.290
AUGUST	26.75	.295	28.55	.310	34.25	.422
SEPTEMBER	9.90	.365	8.80	.315	8.45	.320
OCTOBER	5.52	.267			5.65	.282
NOVEMBER	18.30	.295			19.10	.465
DECEMBER	1.40	.154			1.40	.220
1975						
JANUARY	6.00	.220			6.00	.240
FEBRUARY	1.40	.160			1.40	.180
MARCH	1.16	.130			1.16	.170
APRIL	1.55	.142			2.23	.203
MAY	2.24	.082	2.77	.262	2.77	.373
JUNE	2.97	.221	3.18	.255	5.97	.350
JULY	2.71	.142	3.64	.142	4.80	.335
AUGUST	2.16	.115	2.55	.108	2.86	.170
SEPTEMBER	4.03	.160	2.95	.170	2.80	.255
OCTOBER	7.44	.136	7.13	.134	7.00	.142

TABLE 25-E

MONTHLY AVERAGE PHOSPHATES AND IRON VALUES

STATION V

MONTH	SURFACE		3 METERS		BOTTOM (4 METERS)	
	$Po_4^{\equiv}$ µg/1	Fe mg/1	$Po_4^{\equiv}$ µg/1	Fe mg/1	$Po_4^{\equiv}$ µg/1	Fe mg/1
1974						
MAY	9.10	.320	9.40	.450	9.93	.455
JUNE	1.98	.170	0.46	.280	0.46	.465
AUGUST	28.50	.405	28.90	.445	31.25	.507
SEPTEMBER	9.05	.387	9.70	.360	12.85	.422
OCTOBER	13.35	.406			30.50	.437
NOVEMBER	23.90	.325			44.10	.476
DECEMBER	0.95	.155			1.75	.233
1975						
JANUARY	6.00	.305			6.00	.310
FEBRUARY	1.20	.220			1.20	.220
MARCH	1.35	.136			1.85	.154
APRIL	2.32	.240			2.39	.256
MAY	2.54	.685	3.02	.712	3.41	1.12
JUNE	4.50	.370	5.07	.380	6.58	.430
JULY	3.25	.260	4.73	.288	6.20	.317
AUGUST	3.02	.215	3.48	.235	4.11	.267
SEPTEMBER	2.17	.220	3.57	.200	4.82	.290
OCTOBER	7.90	.174	9.00	.176	11.47	.355

Iron measurements were made in the laboratory by the Phenanthroline Method. Tables 24 A-E contain the iron results from this study.

Station I

The iron concentration range was from 0.1 to 1.3 mg/l. The iron concentrations increased from the surface to the bottom throughout the year with a few exceptions. From September through April the iron concentrations showed a modest increase from the surface to the bottom and from May through August the iron concentrations showed an even higher increase from the surface to the bottom. The iron concentration at the bottom was high in July and August. On August 16, 1975, the bottom waters had 1.3 mg/l of iron. From May through August the average concentration of iron at the surface and the bottom differed by 0.3 mg/l, and from September through April the difference was only 0.01 mg/l.

Station II

The iron concentration range was from 0.07 to 1.36 mg/l. From September through April the differences in iron concentrations between the surface and the bottom were minimal. From May through August the iron concentrations substantially increased from the surface to the bottom. On August 16, 1975, the bottom iron concentration was the highest for the year--1.36 mg/l. From May to August the average iron concentration at the surface was 0.14 mg/l and at the bottom it was 0.46 mg/l. From September through April the iron concentration increased only by 0.035 mg/l from the surface to the bottom.

Station III

The iron concentration range was from 0.07 to 1.28 mg/l. On August 16, 1975, the surface had the minimum iron content and the bottom had the maximum value. From September through April the iron concentration was almost the same from the surface to the bottom with few exceptions. From May through August on the average the iron concentration increased by 0.3 mg/l from the surface to the bottom; the increase in iron concentration was only 0.05 mg/l the rest of the year.

Station IV

The iron concentration range was from 0.02 to 0.46 mg/l. The concentration of iron at Station IV was lower in comparison with other sampling stations. Station IV also showed an increase in the iron concentration from the surface to the bottom during the summer. This increase also occurred on occasion when the lake was in a mixed state. From May through August the iron concentration was 0.14 mg/l higher at the bottom than at the surface.

Station V

The range for iron concentration at Station V was from 0.1 to 1.9 mg/l. The iron concentrations at Station V were much higher compared to other sampling stations. The higher iron values at this sampling station were probably due to bridge corrosion. From September through April the distribution of the iron was uniform from surface to bottom and there were few exceptions. From May through August the iron values increased from the surface to the bottom, although the increase was small. The iron values increased by 0.4 mg/l from the surface to the bottom during the summer months, while the increase was only 0.03 mg/l the rest of the year.

Monthly Average Iron

The monthly average iron concentrations are presented in Tables 25 A-E. The range for the monthly average iron concentration was from 0.08 to 1.12 mg/l. In all sampling stations the iron concentrations showed a modest increase from the surface to the bottom when the lake was in a mixed state. When the lake was thermally stratified the iron concentrations showed a much higher increase from the surface to the bottom. The iron concentrations at Station V were highest, and this was probably due to bridge corrosion.

The iron concentrations varied widely because of several possible chemical reactions. The iron concentration can decrease due to chemical precipitation of $Fe(OH)_3$, or due to the formation of iron-organic complexes. Whenever iron is transferred from the bottom sediments to the water, the iron concentration increases and the iron is distributed throughout the water. It takes a fairly long time for the distributed iron to settle, precipitate and thus so the iron concentration varies at different depths even when the lake is completely mixed.

The Effect of Artificial Destratification on the Water Quality of Lake Thunderbird

One way to determine the effect of artificial destratification on the water quality of Lake Thunderbird is to compare the water quality before and after aeration. The aeration of Lake Thunderbird began on June 4, 1974. The water quality of the lake prior to aeration is available from various sources. The current study of the lake began on May 10, 1974.

Another way to determine the effect of artificial destratification is to find out whether the expected water quality changes due to aeration have taken place in the lake. The water quality changes in an impoundment due to artificial destratification have been discussed fully in Chapter II (Literature Review). Some of the water quality changes which are anticipated (based on the information available from the literature) can be summarized as follows:

1. Artificial destratification eliminated thermal stratification and established isothermal conditions by providing uniform temperatures throughout the lake.

2. Artificial destratification added oxygen to the water at the bottom and eliminated anaerobic conditions. The DO content became uniform throughout the lake.

3. Due to the addition of oxygen to the water, the reduced materials were either oxidized or their formation was prevented.

4. The pH of the water became uniform.

5. The turbidity of the water was reduced.

6. The concentrations of soluble phosphorus and iron in the bottom water were decreased.

7. Taste and odor problems were eliminated by preventing eutrophic conditions in the lake.

8. The overall water quality was improved.

9. The TDS and alkalinity were not affected.

The results of this study will be discussed by (1) comparing the results with the water quality data available prior to June, 1974, and (2) determining whether predicted water quality changes (based on the literature) have taken place. Study results are summarized in Table 26 and discussed as follows.

TABLE 26

COMPARISON OF WATER QUALITY OF LAKE THUNDERBIRD
BEFORE AND AFTER ARTIFICIAL DESTRATIFICATION

PARAMETER	BEFORE DESTRATIFICATION	EXPECTED EFFECT FROM LITERATURE	AFTER DESTRATIFICATION
Temperature	Range: 4.4 to 29.0 °C Isothermal conditions from September through April. Beginning of thermal stratification in May and intense thermal stratification (higher temperature differences between the surface and the bottom) in the summer months.	Small temperature differences between the surface and the bottom in the summer. Isothermal conditions throughout the year.	Range: 4.4 to 29.5°C Isothermal conditions from September through April. Beginning of thermal stratification in May, intensified in the summer. <u>Conclusion</u> Artificial destratification failed to establish isothermal conditions throughout the year.
Dissolved Oxygen	Range: 0.15 to 12.9 mg/1 DO concentrations same (or very small differences) from the surface to the bottom when the lake was isothermal. Small differences in the DO concentrations between the surface and the bottom in May. Marked differences in DO concentrations between the surface and the bottom	Increased bottom DO concentrations. Homogeneous with respect to DO throughout the year.	Range: 0 to 12.6 mg/1 Homogeneous with respect to DO in the fall, winter and most of the spring. Small differences in the DO concentrations between the surface and the bottom in May. Very low or zero bottom DO concentrations in the summer and intense DO stratification.

TABLE 26

COMPARISON OF WATER QUALITY OF LAKE THUNDERBIRD

BEFORE AND AFTER ARTIFICIAL DESTRATIFICATION

(Continued)

PARAMETER	BEFORE DESTRATIFICATION	EXPECTED EFFECT FROM LITERATURE	AFTER DESTRATIFICATION
Dissolved Oxygen (Continued)	in the summer. Very low bottom DO concentration in July (0.15 to 0.2 mg/l).		<u>Conclusion</u> Artificial destratification failed to increase bottom DO concentrations in the summer. Failed to create homogeneous DO concentrations throughout the year.
pH	Range: 7.4 to 8.9. No seasonal trends. Only surface pH values for the fall, winter and the spring. Lower pH values at the bottom in the summer and pH differences between the surface and the bottom.	Uniform pH from the surface to the bottom.	Range: 7.4 to 8.6. Uniform pH from the surface to the bottom in the fall, winter and spring. Small differences between the surface and the bottom pH values in June and higher differences in July and August. <u>Conclusion</u> Artificial destratification failed to eliminate pH differences in the summer and create uniform pH throughout the year.

TABLE 26

COMPARISON OF WATER QUALITY OF LAKE THUNDERBIRD

BEFORE AND AFTER ARTIFICIAL DESTRATIFICATION

(Continued)

PARAMETER	BEFORE DESTRATIFICATION	EXPECTED EFFECT FROM LITERATURE	AFTER DESTRATIFICATION
Alkalinity	Range: 52 to 256 mg/1 as $CaCo_3$. (Most 150 to 200 mg/1 as $CaCo_3$) All the values for the surface waters. No seasonal trends.	No effect	Range: 150 to 190 mg/1 as $CaCo_3$. No seasonal patterns. Alkalinity almost the same from the surface to the bottom with few exceptions. In the summer slightly higher alkalinity in the bottom. <u>Conclusion</u> Artificial destratification did not have any discernible effect.
Turbidity	Range: 3.2 to 400 J.T.U. Low turbidity values at the surface and the turbidity increased with depth. Higher turbidity values in spring and fall.	Turbidity can increase or decrease from the surface to the bottom.	Range: 2 to >500 J.T.U. Turbidity increased from the surface to the bottom. High turbidity in the spring and fall seasons. <u>Conclusion</u> Artificial destratification had no effect.

TABLE 26

COMPARISON OF WATER QUALITY OF LAKE THUNDERBIRD

BEFORE AND AFTER ARTIFICIAL DESTRATIFICATION

(Continued)

PARAMETER	BEFORE DESTRATIFICATION	EXPECTED EFFECT FROM LITERATURE	AFTER DESTRATIFICATION
TDS	Range: 130 to 1260 mg/1 (most 200 to 260 mg/1) No seasonal pattern. Very small differences in the surface and the bottom TDS values.	No effect.	Range: 170 to 340 mg/1 (most 200 to 250 mg/1) No seasonal patterns. TDS values almost the same from the surface to the bottom with few exceptions in the summer. Bottom TDS slightly higher. Conclusion Artificial destratification did not affect TDS.
Nitrates	Range: 0 to 0.7 mg/1 as N. (mostly 0 to 0.40 mg/1 as N) No discernible pattern. No seasonal trends.	Homogeneous conditions throughout or increased surface nitrate concentrations.	Range: 0.01 to 0.57 mg/1 as N. No seasonal trends. Nitrate concentrations almost the same from the surface to the bottom when the lake was isothermal. Small differences in the nitrate concentrations between the surface and the bottom and lower bottom concentrations in the summer.

TABLE 26

COMPARISON OF WATER QUALITY OF LAKE THUNDERBIRD
BEFORE AND AFTER ARTIFICIAL DESTRATIFICATION
(Continued)

PARAMETER	BEFORE DESTRATIFICATION	EXPECTED EFFECT FROM LITERATURE	AFTER DESTRATIFICATION
Nitrates (Continued)			Conclusion Did not have any appreciable effect. Lower bottom values due to anaerobic conditions. Aeration should have increased bottom nitrate concentration.
Nitrites	Range: 0 to <0.1 mg/l. Surface nitrites values. No trend.	None (not addressed)	Range: 0.1 to 18 μg/l as N Same concentrations from the surface to the bottom from September through May. Very small increases in the bottom nitrite concentrations in the summer. Conclusions No discernible effects.

TABLE 26

COMPARISON OF WATER QUALITY OF LAKE THUNDERBIRD

BEFORE AND AFTER ARTIFICIAL DESTRATIFICATION

(Continued)

PARAMETER	BEFORE DESTRATIFICATION	EXPECTED EFFECT FROM LITERATURE	AFTER DESTRATIFICATION
Kjeldahl Nitrogen	Range: 0.5 to 1.6 (ammonia <0.1 mg/l) No seasonal trend. Higher organic nitrogen at the bottom.	Low ammonia and organic nitrogen in the bottom.	Range: 0.7 to 1.8 mg/l. No variation between the surface and the bottom values from September through April; very small differences in the summer. Bottom Kjeldahl nitrogen values were higher in the summer. <u>Conclusion</u>: Artificial destratification did not reduce ammonia and/or organic nitrogen at the lake bottom.
Dissolved Phosphorus	Range: 0 to 0.75 mg/l as P (Mostly 0 to 0.1 mg/l as P) Only few values available. No noticeable trend.	Uniform phosphorus concentrations.	Range: 0.8 μg/l to 0.14 mg/l as P. Uniform phosphate concentrations in the fall, winter and spring. Increase in concentrations from the surface to the bottom in the summer. Very high bottom concentrations in the summer.

TABLE 26

COMPARISON OF WATER QUALITY OF LAKE THUNDERBIRD

BEFORE AND AFTER ARTIFICIAL DESTRATIFICATION

(Continued)

PARAMETER	BEFORE DESTRATIFICATION	EXPECTED EFFECT FROM LITERATURE	AFTER DESTRATIFICATION
Dissolved Phosphorus (Continued)			Conclusion: Artificial destratification failed to create uniform phosphate concentrations in the lake.
Iron	Range: 0 to 5.4 mg/l (Mostly 0 to 0.5 mg/l) No seasonal trend. Increased iron concentration with depth in the summer.	Low and uniform concentrations throughout the year.	Range: 0.01 to 1.9 mg/l. (Mostly 0.1 to 0.5 mg/l) No seasonal patterns. Higher bottom concentrations in the summer and concentrations increased with depth. Conclusion: Artificial destratification failed to create low and uniform iron concentrations.

Temperature

Most of the previous studies on Lake Thunderbird give temperature measurements only for surface water; however, depth sampling was accomplished by Klehr (1967 - 68) and Denoylles (1973). On June 12, 1968, a temperature gradient existed in the lake. The temperature difference between the surface and the bottom was between 4.0°C and 5.0°C. The lake was isothermal in April, 1968, and September, 1968. On June 27, 1973, the temperature difference between the surface and the bottom was 5.0°C; the temperature decreased gradually from the surface to the bottom. The temperature difference between the surface and the bottom was eliminated on October, 1973. The lake was also isothermal in December, 1973. The temperature measurements on May 10, 1974, indicated the presence of thermal stratification.

The aeration of Lake Thunderbird began on June 4, 1974, and was continuous (24 hrs/day). One week later (June 11, 1974) the temperature difference still persisted and the temperature decreased from the surface to the bottom at Stations I, II and III. The temperature profiles on June 11, 1974, resembled a classical thermal stratification curve. The density profiles clearly indicated the existence of different density layers in the lake. The temperature and density differences between the surface and the bottom waters also existed in August, 1974. By the end of August the temperature differences between the surface and the bottom were reduced. July was the hottest month in 1974 and the average temperature was 28.72°C (Table 5). Water sampling was not accomplished in July, 1974, due to equipment breakdown. If temperature measurements had been taken in July, 1974, the surface and the bottom waters would have shown temperature differences and thermal stratification would have existed. The temperature differences between the surface and the bottom waters disappeared completely in September, 1974, and the temperature became uniform throughout the lake. This condition continued until the end of April, 1975.

In 1975 the temperature differences between the surface and the bottom began to develop in May. On May 9, 1975, all five sampling stations exhibited a temperature difference of about 4.0°C between the surface and the bottom. Therefore, in May, 1975, after 11 months of continuous aeration, thermal stratification began to develop. This was the same month when thermal stratification began in previous years. On May 26, 1975, the temperature difference between the surface and the bottom had decreased and thermal stratification was partly destroyed. Between the two sampling dates in May, 1975, the lake received heavy rains (8.24 inches). On May 24, 1975, alone 4.8 inches of rain fell on the drainage area of the lake. The rain was probably responsible for mixing the lake. This rain mixing in May, plus more rain in June, 1975, made the temperature differences between different depths smaller in June. Yount (1961) reported that heavy rainfall can overturn a stratified lake. The temperature differences between the surface and the bottom once again appeared in July. The temperature differences continued in August, 1975; however, by the end of August they became smaller. In September the temperature differences between the surface and the bottom disappeared and the lake became isothermal.

Although lake aeration was continuous for more than a year and thermal stratification developed in May and continued through August in both 1974 and 1975, isothermal conditions existed in the lake from September to April. This was the same pattern followed by Lake Thunderbird in previous years. Previous destratification studies in different lakes resulted in isothermal conditions within a few months and, in some cases, within a few days (Chapter II). In this study the aeration did not have any appreciable effect on the temperature profiles of Lake Thunderbird.

In Central Oklahoma the wind speed averages from 7 to 15 mph with intermittent wind gusts (Table 7). Wind gusts up to 50 to 60 mph are not uncommon. In addition to wind gusts there were several thunderstorms recorded from May through August in both 1974 and 1975--23 in 1974 and 35 in 1975. Ruttner (1963) and Yount (1961) showed that strong winds (from 10 to 15 mph) and heavy rainfall can mix a lake continuously and prevent stratification. In spite of the adverse conditions for stratification (strong winds, heavy rainfall and thunderstorms), Lake Thunderbird developed temperature differences between the surface and bottom waters. Aeration did not prevent the development of thermal stratification and did not narrow the temperature differences between the surface and the bottom waters. Aeration did not even affect Station II which was located near the aeration site. If aeration had been effective, the lake would have remained isothermal throughout the year, or at least the temperature differences between the surface and bottom waters would have been minimized in the summer.

Dissolved Oxygen

The DO concentrations at the lake surface exhibited variations because of the relationship between solubility of oxygen in water and water temperature. From the available oxygen data prior to June, 1974, it was possible to conclude that DO concentration was the same from the surface to the bottom from September through April; and this was the same period when the lake was well mixed or isothermal.

From the present study it was determined that in May the DO concentration exhibited differences at different depths. On May 10, 1974, the DO concentration at the surface was high and at the bottom it was less; however, the DO concentration at the bottom was still fairly high. It was evident from the DO values of June 12, 1968, and June 27, 1973, that DO concentrations differed at the surface and the bottom. Bottom DO concentrations decreased further in July. On July 25, 1968, there was a difference of 6.8 mg/1 in the DO concentration between the surface and the bottom. At Station I the DO concentration at 8.5 meters was only 1.0 mg/1. Therefore, from the DO values prior to June, 1974, it can be seen that the DO concentrations at the surface and the bottom began to show differences in May, and the differences increased until July. The DO concentrations at the bottom decreased from May to July.

On May 10, 1974, the DO concentration at the bottom was 7.0 mg/1 at Station I, 5.8 mg/1 at Station II and 3.2 mg/1 at Station III. On June 11, 1974, after one week of aeration, the DO concentration at the bottom was still essentially the same at Stations I and III; however, it had decreased at Station II. On August 4, 1974, the DO concentrations at all sampling stations had decreased considerably. On August 4, 1974, at Station II, the DO concentration at 12 meters was only 0.9 mg/1, and it was further reduced to 0.3 mg/1 at the bottom. On August 25, 1974, the DO concentration at the bottom remained the same at Station III, while Stations I and II showed further decreases. At Station II the bottom DO concentration was only 0.2 mg/1. On August 25, 1974, the lake had been aerated continuously for more than 2 1/2 months; however, DO stratification was present.

It is interesting to note that Station II was located near the aeration site, and even at Station II there was no evidence of water mixing due to aeration. Below 9 meters at Station II the DO concentration was very low; near anaerobic conditions existed at the bottom.

From September until the end of April the DO concentrations were almost the same from the surface to the bottom, and the lake was well-mixed. In May, 1975, the surface and bottom DO concentrations again exhibited differences. This DO stratification coincided with the beginning of thermal stratification. The bottom DO decreased as the summer progressed; during July and August the concentrations below 6 meters were extremely low at all sampling stations. Station II exhibited a DO concentration of 0.2 mg/l or less below the 12-meter depth during both July and August. On August 16, 1975, the DO concentration at the bottom at Stations II and III was zero. In September the DO differences between the surface and the bottom decreased, and the concentrations at all levels showed an increase. By the end of September the DO concentrations were almost the same from the surface to the bottom.

By August, 1975, the lake had been aerated for 15 months; however, the DO concentrations decreased from the surface to the bottom and DO stratification was still present. The DO stratification which began in May ended in September when the lake became isothermal. Water quality studies of Lake Thunderbird prior to June, 1974, also indicated DO stratification from May through August. Therefore, aeration did not change the DO behavior in the lake even after 15 months of continuous operation. Aeration also failed to add oxygen to the water at lower levels and make the DO concentrations uniform throughout the lake. Aeration did not prevent the development of anaerobic conditions near the bottom, even at Station II which was located near the aeration site.

pH

From the previous water quality studies of Lake Thunderbird, it was difficult to determine any consistent seasonal trends in pH values, even at the surface. However, from the Klehr (1968) and DeNoylles (1973) studies it was shown that in June the pH values decreased from the surface to the bottom.

In this study the pH range for all stations was from 7.4 to 8.6. From September to April when the lake was isothermal and homogeneous with respect to DO, there were minimal variations in pH from the surface to the bottom. On the average the pH values between the surface and the bottom differed by less than 0.1 unit. From May to August when the lake was thermally stratified the pH differences between the surface and the bottom were higher than the rest of the year. The pH values at the bottom were lower than the pH values at the surface. In May and June the pH difference between the surface and the bottom were about 0.4 units; in July and August they were higher (0.60 to 0.75 units).

In July and August the pH values at the bottom were the lowest for the year. This coincided with very low to zero DO values at the lake bottom.

The aeration of the lake should have smoothed out the differences in pH values at different levels (depths) and made the pH values uniform throughout the lake. But the pH values during the summer months were different at different levels, and the pH decreased from the surface to the bottom. Therefore aeration did not create uniform pH values in the lake.

Total Alkalinity

The alkalinity values exhibited a wide range and did not follow any seasonal patterns; this occurred both before and after aeration. Most of the alkalinity values fell in the range of 150 to 190 mg/l as $CaCO_3$. In most cases the alkalinity values showed very little difference between surface and bottom samples. In some instances during the summer months the alkalinity values showed an increase from the surface to the bottom; with the highest alkalinity values obtained at the bottom. Higher alkalinity values at the bottom during the summer months were due to CO_2 from biological decomposition. Alkalinity values were not affected by aeration. The literature review also indicated that there was no evidence that aeration affected alkalinity values.

Turbidity

There was a wide variation in turbidity values both before and after aeration. Generally, the turbidity values were low at the surface and increased from the surface to the bottom. In the summer the turbidity values at the surface were low, and they were high at the bottom. The turbidity values at the surface during the fall and spring were higher. This was probably due to mixing in the fall (fall turnover) and precipitation run off in the spring. The differences in turbidity values between the surface and the bottom during the non-summer period were less than the differences during the summer months. Since turbidity is caused by inorganic and organic materials and microorganisms, it was difficult to form any conclusion about the turbidity values since biological parameters were not measured in this study. It was also difficult to form any conclusions about the effect of artificial destratification on turbidity values in this study.

In the literature there was evidence to support both an increase and decrease in turbidity values due to artificial mixing.

Total Dissolved Solids (TDS)

The TDS values measured in this study exhibited wide ranges (from 170 to 340 mg/1), but most of the values were in the range of 200 to 250 mg/1. The TDS values before June, 1974, also exhibited a wide range with most of the values between 200 to 260 mg/1. The TDS ranges were almost the same before and after aeration. In most cases the TDS values were the same from the surface to the bottom; however, in some samples the TDS values increased from the surface to the bottom. The literature review indicated that artificial destratification does not affect the TDS in water.

Nitrates

The concentration of nitrates prior to June, 1974, ranged from 0 to 3.06 mg/1 as NO_3 (0 to 0.7 mg/1 as N). Most of the nitrate values were less than 0.4 mg/1 as N.

In this study the nitrate concentrations at the surface varied between 0.1 and 0.5 mg/1 as N. When the lake was isothermal the nitrate concentrations from the surface to the bottom were almost the same. In the summer months the nitrate concentrations were higher at the surface compared to the bottom. The nitrate concentrations at the bottom during July and August were lower; this was probably due to the low DO content of the water. During the summer the average concentration of nitrates at the bottom was 0.1 mg/1 less than the surface concentrations. Aeration should have increased the nitrate concentration at the bottom, and the nitrate concentrations should have been equal throughout the lake. Neither of these effects occurred.

Nitrites

Most of the nitrite values available before June, 1974, were for surface water only. The reported nitrite values were 0.1 mg/l or less. In the present study nitrite concentrations are reported as μg/l-N. The nitrite content of Lake Thunderbird was low, with the maximum nitrite concentration being only 20 μg/l. From September through April when the lake was isothermal the nitrite concentrations were almost the same from the surface to the bottom. When the lake was thermally stratified (from May to August) the nitrite concentrations increased slightly from the surface to the bottom. Even during this period the nitrite concentrations at the bottom were only 4-5 μg/l higher than at the surface. The effect of artificial destratification on nitrite values has not been addressed in the published literature. No discernible effects were noted from this survey.

Kjeldahl Nitrogen

The extant organic nitrogen values available in most cases were for surface water. Before June, 1974, the organic nitrogen concentration range was from 0.7 to 1.6 mg/l. The ammonia content was low and usually less than 0.1 mg/l.

In the present study Kjeldahl nitrogen values for both the surface and the bottom had a range of 0.7 to 1.8 mg/l. When Lake Thunderbird was isothermal kjeldahl nitrogen values showed very small or no variation from the surface to the bottom. When the lake was thermally stratified the kjeldahl nitrogen was higher at the bottom than at the surface. The increase in kjeldahl nitrogen values at the bottom could be due to increases in either ammonia or organic nitrogen values. In some cases, the kjeldahl nitrogen values were almost the same at the surface and the bottom during thermal stratification. Aeration should have kept the organic nitrogen and ammonia concentrations low at the bottom. Also aeration should have made the kjeldahl nitrogen values equal in the vertical plane. However, aeration failed to accomplish these effects in Lake Thunderbird.

Dissolved Phosphorus

The dissolved phosphorus will be discussed only with the results of this study. The dissolved phosphorus values were fairly constant at all depths when the lake was isothermal. The dissolved phosphorus concentrations at the bottom were high when the lake was thermally stratified. On July 30, 1975, and August 16, 1975, Station II had bottom concentrations of 1.23 mg/l and 1.38 mg/l as P, respectively. These values were very high when compared with the bottom dissolved phosphorus values on other sampling dates. The high dissolved phosphorus concentrations at the bottom coincided with zero or near zero DO. These concentrations were probably due to the release of phosphorus from iron compounds (ferric phosphate and iron-organic complexes). Aeration should have reduced the dissolved phosphorus concentrations by creating an oxidizing environment at the bottom; however, aeration failed to create uniform phosphate concentrations throughout the lake.

Total Iron

The iron values before June, 1974, had a range from 0 to 5.4 mg/l. The iron values did not follow any seasonal trends. When iron values were reported for different depths they were highest at the lake bottom.

In this study iron concentrations varied widely, with the range from 0.01 to 1.9 mg/l. When the lake was isothermal the iron concentrations exhibited only a small variation from the surface to the bottom and, in most cases, the concentrations were almost the same in the vertical section. When the lake was thermally stratified the iron concentrations increased from the surface to the bottom. On August 16, 1975, the bottom iron concentrations at Stations I, II, and III were in excess of 1.3 mg/l. These high iron values were due to the anaerobic conditions at the lake bottom which resulted in the release of iron from the sediments to the water. Lake aeration should have minimized the bottom iron concentrations; however, iron concentrations were high throughout the summer months. Aeration did not influence iron concentrations.

Overall Water Quality

When the overall water quality of Lake Thunderbird before aeration is compared with the water quality during aeration, no significant differences are noted. Aeration did not seem to have any effect on the water quality of the lake. It can also be pointed out that Canter (1973) found that Lake Thunderbird had sufficient phosphate and nitrate concentrations to cause algal blooms. In a preliminary environmental impact statement for Norman, published in 1976, the Environmental Protection Agency classified Lake Thunderbird as eutrophic (EPA Statement No. 7417, 1976).

Artificial destratification of Lake Thunderbird was not effective in improving the water quality and this was primarily due to insufficient air input. Table 27 contains the information on the ratios of cfm to volume, area, and maximum depth for several lakes where destratification by aeration has been attempted. The air input per unit volume was higher in the lakes where aeration was successful than it was in Lake Thunderbird. The cfm/volume ratio was higher (1.3 to 812) in all the successful lakes in comparison with the cfm/volume ratio for Lake Thunderbird. The cfm/area ratio was also higher (24 to 283) in all the lakes (with the exception of Waco Reservoir) in comparison with the cfm/area ratio for Lake Thunderbird. Of the eight lakes for which data was available, four exhibited cfm/maximum depth ratio greater than that in Lake Thunderbird and two had ratios less than in Lake Thunderbird.

Waco Reservoir in Texas can be compared closely with Lake Thunderbird in Oklahoma. The maximum depths of Waco Reservoir and Lake Thunderbird were 85 ft and 69 ft, respectively. The lesser depth of Lake Thunderbird is another contributing factor for the failure of artificial destratification; in deeper lakes a better circulation pattern is established. Even in the Waco Reservoir complete isothermal conditions were established only after two months of aeration, and homogeneous DO concentrations throughout the reservoir were never achieved in the summer months. Aeration kept the bottom waters from becoming anaerobic (the DO concentration in the bottom was increased from 0 to 15% saturation).

From Table 27 it can be concluded that the success of artificial destratification depends on several factors--cfm/volume, cfm/area, cfm/maximum depth, and the maximum depth of the lake.

TABLE 27

AIR INPUT, VOLUME, AREA AND MAXIMUM DEPTH DATA FOR LAKES

NAME AND LOCATION OF THE LAKE	VOLUME ACRE-FT	AREA ACRES	MAXIMUM DEPTH FT	AIR INPUT cfm	RATIO cfm / VOLUME	RATIO cfm / MAXIMUM DEPTH
Ossining, New York	246	X*	30	160	0.65	X
Lake Oscaleta, New York	1400	60	X	280	0.20	4.70
Laurelrun, Pennsylvania	230	X	X	22	0.096	X
Milcreek, Pennsylvania	169	X	X	14.8	0.088	X
Lake Waccabuc, New York	3300	132	X	280	0.085	2.10
Escondido, California	3400	X	X	210	0.062	X
Rankin Lake, North Carolina	838	75	X	40	0.048	0.53
Boltz Lake, Kentucky	2900	96	62	115	0.040	1.20
Lake Wohlford, California	7000	222	80	210	0.030	0.95
Falmouth Lake, Kentucky	4600	225	42	115	0.025	0.51
Greenville, New Hampshire	2302	X	X	34.4	0.015	X
Lafayette, Indiana	4252	130	X	60	0.014	0.46
Lake Maarsseven, Netherlands	6500	150	98	88	0.014	0.59
Wanbach, California	33,740	530	141	210	0.0060	0.40
Waco Reservoir, Texas	104,100	7270	85	110	0.0011	0.015
Lake Thunderbird, Oklahoma	119,600	6070	69	100	0.0008	0.016

*X denotes data not available.

TABLE 27

AIR INPUT, VOLUME, AREA AND MAXIMUM DEPTH DATA FOR LAKES

(Continued)

NAME AND LOCATION OF THE LAKE	RATIO cfm / MAXIMUM DEPTH	cfm/VOLUME RATIO TO LAKE THUNDERBIRD	cfm/AREA RATIO TO LAKE THUNDERBIRD	cfm/DEPTH RATIO TO LAKE THUNDERBIRD	RESULT
Ossining, New York	5.33	812	X*	3.7	S*
Lake Oscaleta, New York	X	250	283	X	S
Laurelrun, Pennsylvania	X	120	X	X	S
Milcreek, Pennsylvania	X	110	X	X	S
Lake Waccabuc, New York	X	106	129	X	S
Escondido, California	X	77	X	X	S
Rankin Lake, North Carolina	X	60	32	X	S
Boltz Lake, Kentucky	1.85	50	73	1.3	S
Lake Wohlford, California	2.62	37	57	1.8	S
Falmouth Lake, Kentucky	2.74	31	31	1.9	S
Greenville, New Hampshire	X	19	X	X	S
Lafayette, Indiana	X	18	28	X	S
Lake Maarsseven, Netherlands	0.90	18	35	0.6	S
Wanbach, California	1.49	8.0	24	1.0	S
Waco Reservoir, Texas	1.30	1.3	0.94	0.9	LS*
Lake Thunderbird, Oklahoma	1.45	1.0	1.0	1.0	US*

*X denotes data not available.
S = Artificial destratification successful.
LS = Artificial destratification Limited Success.
US = Artificial destratification Unsuccessful.

CHAPTER V

CONCLUSIONS

Artificial destratification of Lake Thunderbird using compressed air was expected to improve the general quality of water by eliminating thermal stratification (establishing isothermal conditions throughout the lake) and bringing about uniform dissolved oxygen concentrations from the surface to the bottom. The initial base-line for the lake's water quality was established by the measurement of the water quality prior to destratification and collection of available data from the School of Civil Engineering and Environmental Science and the Department of Zoology at the University of Oklahoma and from various state and local agencies. To study the water quality changes from artificial destratification, eleven different physical and chemical parameters (temperature, dissolved oxygen, pH, alkalinity, turbidity, total dissolved solids, nitrates, nitrites, kjeldahl's nitrogen, dissolved phosphorus, and iron) were measured at selected depths at five sampling stations. The temperature was measured at one-meter intervals from the surface to the bottom of the lake, while the water samples for chemical analyses were collected at three-meter intervals from the surface to the lake bottom. The lake was sampled 27 times beginning on May 10, 1974, and ending on October 19, 1975. The following conclusions were drawn from this study:

1. Artificial destratification failed to prevent the formation of thermal stratification in the summer months. It did not eliminate thermal stratification and establish isothermal conditions in the summer.

2. Artificial destratification did not prevent the formation of anaerobic conditions in the bottom waters during the summer months. It also failed to elininate oxygen stratification in the summer.

3. Artificial destratification did not create uniform pH throughout the lake during the summer months.

4. Artificial destratification failed to eliminate chemical stratification during the summer months. The concentrations of dissolved phosphorus and iron increased from the surface waters to the bottom waters during the summer.

5. Artificial destratification did not have any discernible effects on total dissolved solids and alkalinity.

6. Artificial destratification did not have any appreciable effect on the overall water quality of Lake Thunderbird.

7. Artificial destratification was ineffective in Lake Thunderbird primarily because of insufficient air input per unit volume of the lake.

BIBLIOGRAPHY

Anonymous. Oxygenation of the Hypolimnion. Public Works, 105: 85-88. Feb., 1974.

Austin, R.E. and G.F. Lee. Nitrogen Release from Lake Sediments. Jour. Water Pollut. Control Fed., 45: 870-79. May, 1973.

Barnett, R.H. Reservoir Destratification Improves Water Quality. Public Works, 102: 60-65. June, 1971.

Begg, G.W. Limnilogical Observations on Lake Kariba During 1967 with Some Emphasis on Some Special Features. Limnol. and Oceangr., 15: 776-88. 1970.

Bernhardt, H. Aeration of Wahnbach Reservoir Without Changing the Temperature Profile. Jour. Am. Water Works Assoc., 59: 943-64. Aug., 1967.

Biederman, W.J. and E.E. Fulton. Destratification Using Air. Jour. Am. Water Works Assoc., 59: 943-64. Aug., 1967.

Brezonik, P.L.; J.J. Delfino; and G.F. Lee. Chemistry of Nitrogen and Manganese in Cox Hollow Lake, Wisconsin following Destratification. Jour. Sanit. Eng. Div., Proc. Am. Soc. Civil Eng., 95(SA5): 929-40. Oct., 1969.

Burns, J.M., Jr. Reservoir Turnover Improves Water Quality. Water and Wastes Eng., 3: 81. May, 1966.

Canter, L.W. Environmental Study of Little River State Park, Final Report. Div. State Parks, Oklahoma City, Oklahoma, 1973.

Canter, L.W. Environmental Impacts of Recreational Use of Reservoirs. Oklahoma Reservoir Resources Symposium. Published by Oklahoma Geological Society, University of Oklahoma, Norman, Oklahoma. 1976. pp. 69-78.

Churchill, M.A. Effects of Storage Impoundments on Water Quality. Jour. Sanit. Eng. Div., Proc. Am. Soc. Civil Eng., 83 (SAI): Paper 1171. Feb., 1977.

City of Norman, Norman, Oklahoma. Personal Communication. 1974-75.

Committee Report. Artificial Destratification in Reservoirs. Jour. Am. Water Works Assoc., 63: 597-604. Sept., 1971.

DeNoyelles, J. Personal Communication. 1973.

Derby, R.L. Chlorination of Deep Reservoirs for Taste and Odor Control. Jour. Am. Water Works Assoc., 48: 775-80. July, 1956.

Environmental Impact Statement for Norman, 1976. Impact Statement No. 7417. Environmental Protection Agency, Region VI, Dallas, Texas.

Ford, M.E., Jr. Air Injection for Control of Reservoir Limnology. Jour. Am. Water Works Assoc., 55: 267-74. March, 1963.

Garton, J.E.; C.E. Rice; and J.M. Steichen. Modification of Reservoir Water Quality by Artificial Destratification. Oklahoma Reservoir Resources Symposium. Published by Oklahoma Geological Society, University of Oklahoma, Norman, Oklahoma. 1976. pp. 47-56.

Hammer, U.T. Limnological Studies of Lakes and Streams of Upper Qu'Apple River System. Hydrobiologia, 37: 473-507. 1971.

Heath, W.A. Compressed Air Revives Polluted Swedish Lakes. Water and Sewage Works, 108: 200. May, 1961.

Hooper, F.F.; R.C. Ball; and H.A. Tanner. An Experiment in the Artificial Circulation of a Small Michigan Lake. Trans. Am. Fisheries Soc. 82: 222-41. July, 1952.

Hutchinson, E. A Treatise on Limnology, Vol. I. Geography, Physics, and Chemistry. John Wiley and Sons, New York. 1957.

Ingels, R.S. Effects of Impoundment on Downstream Water Quality, Catawba River. Jour. Am. Water Works Assoc., 51: 42-46. Jan., 1959.

Irwin, W.H.; J.M. Symons; and G.G. Robeck. Impoundment Destratification by Mechanical Pumping. Jour. Sanit. Eng. Div., Proc. Am. Soc. Civil Eng., 92 (SA6): 21-40. Dec., 1966. Closure, 94 (SA1): 176-78. Feb., 1968.

Keeley, J.W. A Feasibility Study of a Laboratory Model as a Research Tool for Impoundment Water Quality Investigations. Ph.D. Thesis, University of Oklahoma, Norman, Oklahoma. 1971.

Kittrell, F.W. Effects of Impoundments on Dissolved Oxygen Resources. Sewage and Ind. Wastes, 31: 1065-78. Sept., 1959.

Klehr, E.H. Personal Communication. 1968.

Knoppert, P.L.; J.J. Rook; T.J. Hofker; and G. Oskam. Destratification Experiments at Rotterdam. Jour. Am. Water Works Assoc., 62: 448-54. July, 1970.

Laverty, G.L. and H.L. Nelson. Quality Improvements by Reservoir Aeration. Jour. Am. Water Works Assoc., 62: 711-15. Nov., 1970.

Leach, L.E.; W.R. Duffer; and C.C. Harlin. Induced Hypolimnion Aeration for Water Quality Improvement of Power Rleases. Robert S. Kerr Water Research Center. Federal Water Pollution Control Administration, USDI, Ada, Oklahoma. Oct., 1970.

Love, S.K. Relationships of Impoundments to Water Quality. Jour. Am. Water Works Assoc., 53: 559-68. May, 1961.

Mann, K.H. Annual Fluctuations in Sulfate and Bicarbonate Hardness in Ponds. Limnol. and Oceanogr., 3: 418-22. 1958.

McCombe, A.M. Some Relations between Air Temperature and Surface Water Temperatures of Lakes. Limnol. and Oceanogr., 4: 252. 1959.

Munavar, M. Limnological Studies on Fresh Water Ponds of Hydrabad, India. Hydrobiologia, 35: 127-62. 1970.

National Weather Service, Oklahoma City, Oklahoma. 1974-75.

Ogborn, C.M. Aeration System Keeps Water Testing Fresh. Public Works, 97: 84-86. April, 1966.

Oklahoma State Department of Health, Water Quality Control Division, Water Quality Reports. 1967-1974.

Oklahoma Water Resources Board, Oklahoma's Water Quality Standards--1973. Publ. 52, Oklahoma City, Oklahoma. Sept., 1973.

Patriarche, M.H. Air Induced Water Circulation of Two Shallow Michigan Lakes. Jour. Wildlife Management, 25: 282-89. July, 1961.

Posey, F.H., Jr. and J.W. Dewitt. Effects of Reservoir Impoundment on Water Quality. Jour. Power Div., Proc. Am. Soc. Civil Engr., 96 (PO1): 173-85. Jan., 1970.

Rao, V.S. Ecological Study of Three Fresh Water Ponds of Hydrabad, India. Hydrobiologica, 38: 213-24. 1971. 39: 351-72. 1972.

Rapoza, D. Reservoir Aeration Improved Water Quality. Public Works, 102: 86-87. May, 1971.

Reservoirs of Oklahoma, Oklahoma Department of Wildlife Conservation, Bulletin No. 11, Jan., 1973. pp. 123-24.

Riddick, T.M. Forced Circulation of Reservoir Waters. Water and Sewage Works, 104: 231-37. June, 1957. Also published as: Forced Circulation of Large Bodies of Water. Jour. Sanit. Eng. Div., Proc. Am. Soc. Civil Engr., 84 (SA4): Paper 1703. July, 1958.

Ruttner, F. Fundamentals of Limnology. University of Toranto Press, Toranto. 1963.

Seenaya, V.S. Ecological Studies in the Plankton of Certain Fresh Water Ponds in India. Hydrobiologia, 37: 7-31. 1971.

Shuler, J. How a Lake Aeration System Overcame Consumer Complaints. Public Works, 103: 92-93. May, 1972.

Standard Methods for the Examination of Waste Water. Am. Pub. Health Assoc., Water Works Assoc., and Water Pollut. Control Fed., 13th Ed., New York. 1971.

Stum, W. and J.J. Morgan. Aquatic Chemistry. John Wiley and Sons, New York. 1970.

Symons, J.M. Water Quality Behavior in Reservoirs. U.S. Dept. of Health, Education, and Welfare, Public Health Publ. No. 1930. 1969.

Symons, J.M.; W.H. Irwin; and G.G. Robeck. Impoundment Destratification by Mechanical Pumping. Jour. Sanit. Eng. Div., Proc. Am. Soc. Civil Eng., 92 (SA6): 21-40. Dec., 1966. Closure, 94 (SA1): 176-78. Feb., 1968.

Symons, J.M.; W.H. Irwin; and G.G. Robeck. Impoundment Water Quality changes Caused by Mixing. Jour. Sanit. Eng. Div., Proc. Am. Soc. Civil Eng., 93 (SA2): 1-20. Apr., 1967.

Symons, J.M.; W.H. Irwin; E.L. Robinson; and G.G. Robeck. Impoundment Destratification for Raw Water Quality Control using either Mechanical or Diffused Air Pumping. Jour. Am. Water Works Assoc., 59: 1268-91. Oct., 1967.

Thompson, R.W.L. Stratification and Overturn in Lakes and Reservoirs. Jour. Inst. Water Engrs., 8: 19-52. Feb., 1954.

Unni, S. Horizontal and Vertical Distribution of Different Chemical Constituents. Hydrobiologia, 38: 479-87. 1971.

Unni, S. An Ecological Study of Malrophyte Vegetation of Doodhari Lake, Raipur, U.P., India. Three Chemical Factors. Hydrobiologia, 40: 25-36. 1972.

Venkateswaralu, V. An Ecological Study of Algae of River Moosi, Hydrabad with Special Reference to Water Pollution. Hydrobiologia, 33: 117-128. 1969.

Wang and Evans. Nutrients and Quality in Impounded Waters. Jour. Am. Water Works Assoc., 62: 511-520. 1970.

Weiss, C.M.; and B. Breedlove. Water Quality Changes in an Impoundment as a Consequence of Artificial Destratification. Dept. of Env. Sc. and Eng., University of North Carolina, Chapel Hill, N.C. ESE Publication No. 322. Jan., 1973.

Wood, P.R. and L.C. Burton. Ground-Water Resources, Cleveland and Oklahoma Counties. Oklahoma Geological Survey Circular 71. 1968.

Yount, J. A Note on Stability in Central Florida Lakes with Discussion of the Effects of Hurricanes. Limnol. and Oceanogr., 6: 322. 1961.

Zafar, A.R. An Ecology of Algae in Certain Fish Ponds of Hydrabad, India. Hydrobiologia, 23: 179-95. 1964.