PHYSICOCHEMICAL STRATIFICATION OF KEYSTONE RESERVOIR, OKLAHOMA

By

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PHYSICOCHEMICAL STRATIFICATION OF KEYSTONE
RESERVOIR, OKLAHOMA

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PREFACE

The objectives of the present study of physicochemical stratification of Keystone Reservoir were to: (1) determine the nature and magnitude of seasonal stratification; (2) determine the effects of seasonal stratification on water quality; (3) measure changes in water quality as water flowed through the reservoir; (4) evaluate effects of the discharge of water through the dam from the epilimnion and hypolimnion; and, (5) obtain basic physicochemical data which can be compared with data from future studies to determine effects of hydroelectric power-peaking operations and reservoir aging on stratification and water quality.

Dr. Troy C. Dorris served as major adviser. Dr. Rudolph J. Miller and Dr. Dale W. Toetz served on the advisory committee and criticized the manuscript. Neil E. Carter helped make field collections. Charles Dorris and Mrs. Norman Grimes assisted with drawings and Mrs. Frank Roberts typed the manuscript. The generous assistance of all of these people is appreciated. Special thanks is extended to my wife, Judy, who provided assistance and encouragement throughout the study.

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CHAPTER I

INTRODUCTION

Reservoirs are being built along every major river system in the United States to control flooding and provide water for irrigation, navigation, hydroelectric power and recreational uses. If the maximum benefits of these reservoirs are to be realized, the effects of impoundment on water quality and aquatic life must be understood. Not only must the behavior of existing reservoirs be known, but basic data developed on the limnology of present reservoirs should be used in formulating principles which have predictive value for future reservoirs.

Keystone Reservoir, located in north-central Oklahoma, is typical of many main-stream reservoirs in the southern Great Plains now in existence or to be built in the future. These reservoirs are fed by streams which drain large, semi-arid basins and, consequently, carry high concentrations of dissolved solids. Reservoirs located in the eastern, more humid part of the Plains receive less mineralized, local runoff. Mixing of inflowing waters of different mineralization and, consequently, different densities often produces chemical stratification and density currents in reservoirs.

Worthington and Beadle (1932) first suggested the possibility of rivers introducing salt-heavy water into the hypolimnion of lakes. Smith et al. (1960) described overflowing, interflowing and underflowing density currents due to differences in temperature, salinity and suspended solids in Lake Mead. Temperature and turbidity differences have caused density flows in several TVA reservoirs (Wiebe, 1939, 1941; Lyman, 1944). Some effects of density currents on water quality have been described by Wiebe (1940), Churchill (1957) and Love (1961).

Keystone Reservoir was formed in the fall of 1964 by impounding the Arkansas River at river mile 538.8 in Tulsa County, Oklahoma, and was filled in April, 1965. The impoundment was created by the U. S. Army Corps of Engineers for flood control, hydroelectric power and navigational purposes. The reservoir has two main arms formed above the confluence of the Arkansas and Cimarron Rivers about 2 miles upstream from Keystone Dam (Fig. 1) and receives runoff from a total drainage area of 74,506 square miles. At power pool level (elevation 723.0 MSL) the reservoir has a surface area of 26,300 acres and a gross storage capacity of 663,000 acre-feet. At flood stage (754.0 MSL) the maximum storage capacity is 1,879,000 acre-feet. From June, 1965, until September, 1966, the water level fluctuated within 2 feet of normal (723 MSL) about 80% of the time. Water can be released through the dam from three different elevations. Tainter or flood gates (719.0 MSL) are 1.2 m below power pool level; sluice gates (657.0 MSL) are 20.1 m below power pool level; and power penstocks are 21.5 m below power pool level. All discharges were made through the tainter gates from June, 1965, until July, 1966, except during floods. Since 15 July, 1966, most discharges have been made through the sluice gates. Hydroelectric power generation is scheduled to begin late in 1967.

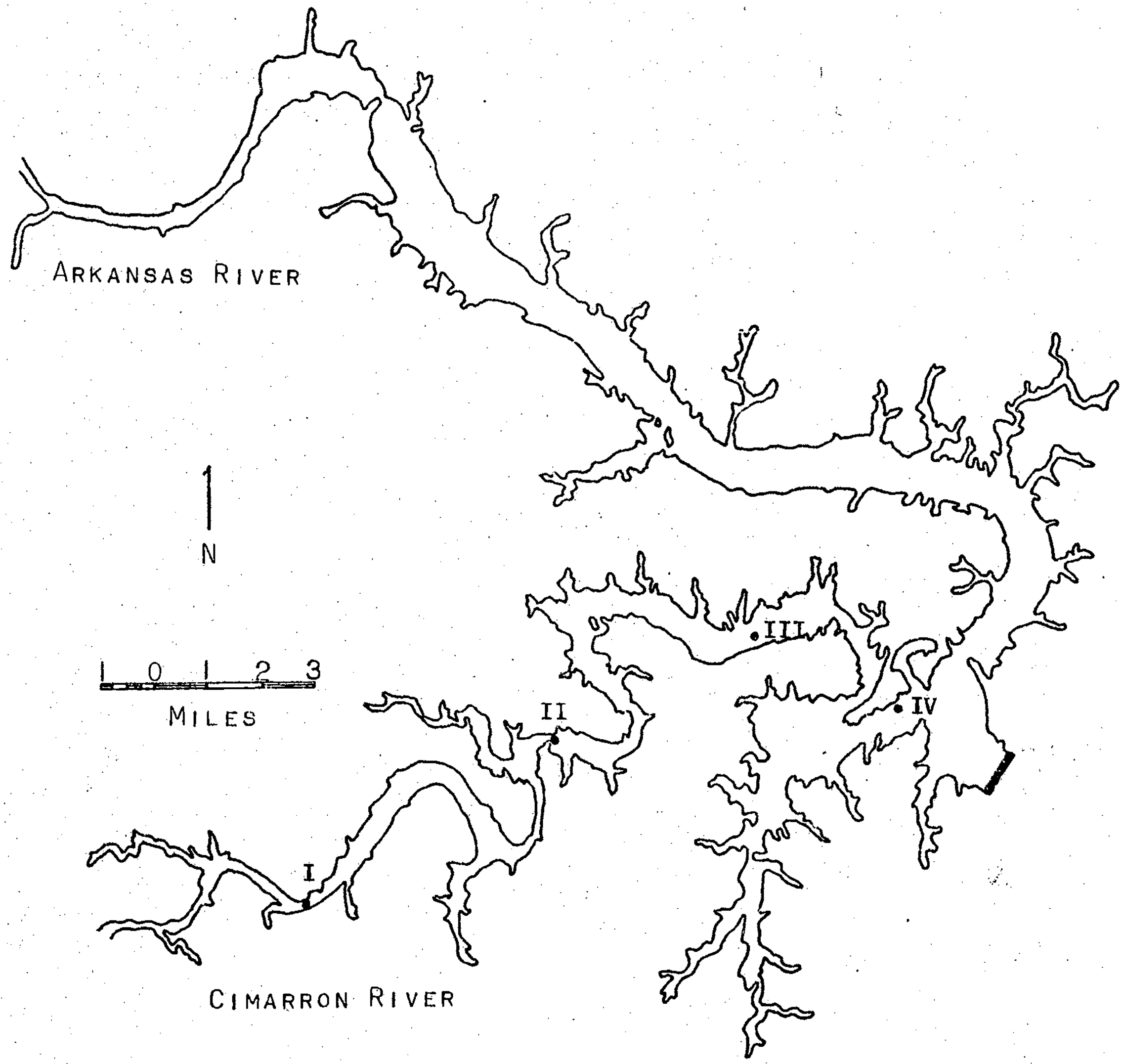

Figure 1. Keystone Reservoir, Oklahoma. Roman numerals indicate locations of sampling stations.

Stable chemical stratification and density currents, caused by salt-heavy water from the Cimarron River, produced unique distributions of temperature, dissolved oxygen, free carbon dioxide and related chemical species in Keystone Reservoir. Effects of physicochemical stratification on water quality during Keystone's first two years of impoundment may be indicative of the early life of future reservoirs constructed under similar geophysical conditions and operated in a similar manner.

CHAPTER II

MATERIALS AND METHODS

Physicochemical parameters were measured monthly at four stations along the Cimarron arm of Keystone Reservoir from September, 1965, through August, 1966 (Fig. 1). When the water surface was at power pool level, station I was 5.5 m deep; station II was 10.1 m deep; station III was 14.0 m deep and station IV was 18.0 m deep. Occasional measurements were made of physicochemical conditions at several points on the Arkansas arm and below Keystone Dam.

Temperature, conductivity, pH, alkalinity, carbon dioxide, specific gravity, oxygen, turbidity and light penetration were determined at each meter of depth at each station. Water temperature was measured using a Yellow Springs tele-thermometer. Micromhos of specific conductance at 25 C were measured in situ using an Industrial Instruments RB Solu-bridge. Depth of light penetration was determined with a Gem submarine photometer. Water samples were taken with a Kemmerer water bottle. Dissolved oxygen samples were fixed in the field by the Alsterberg (Azide) modification of the Winkler method (A.P.H.A., 1960) and were titrated in the lab with 0.01575 N sodium thiosulfate. Oxygen saturation values were determined from a nomograph and corrected for altitude (Rawson, 1944). Hydrogen ion concentration was measured by use of a Hellige Comparator. Phenolpthalein and methyl purple alkalinity were determined by field titration with 0.02 N sulfuric acid (A.P.H.A., 1960). Stoichiometric classification of carbonate and bicarbonate alkalinities is expressed as mg/liter $CaCO_3$. Free carbon dioxide was estimated from a nomograph using pH and bicarbonate alkalinity (Moore, 1939). Turbidity, as measured with a Bausch and Lomb Spectronic 20 Colorimeter calibrated against a Jackson Turbidimeter, is expressed as "Turbidity Units," roughly equivalent to mg/liter. Specific gravity was measured with a hydrometer, and all values were converted to specific gravity at 15 C. Analyses for total dissolved and suspended solids, chlorides, sulfates, sulfides, ammonia, sodium, calcium and magnesium were made according to standard methods (A.P.H.A., 1960).

Seasonal means of monthly physicochemical measurements were determined for each meter of depth and for the entire depth at each of the four sampling stations. The 12 months were divided into four seasons on the basis of differences in the monthly mean temperature of the entire water mass. The fall season included the months of October, November and December; winter included January, February and March; spring included April and May; and summer included June, July, August and September.

CHAPTER III

RESULTS AND DISCUSSION

Keystone Reservoir was chemically stratified during all seasons. Complete mixing occurred only during floods in June and September, 1965. Chemical stratification was re-established within a few weeks after each flood. The chemocline was located at a depth of 12 to 13 m in all seasons except summer, when thermal stratification prevented mixing below 8 m (Fig. 2). Chemical stratification prevented the occurrence of a fall or spring turnover.

Stable chemical stratification resulted from differences in the densities of the Arkansas and Cimarron Rivers. In March, 1966, the Cimarron River contained 5600 mg/l total dissolved solids with a specific gravity at 15 C of 1.0043. The Arkansas River contained only 1400 mg/l total dissolved solids with a specific gravity at 15 C of 1.0013. A high concentration of sodium chloride in the Cimarron River was responsible for most of the density difference between the two rivers (Table I).

Salt-heavy water from the Cimarron underlaid lighter water from the Arkansas and lateral tributaries of the reservoir. Heavy Cimarron water formed a density current which flowed through the Cimarron arm to the region of lowest elevation (650 MSL) above the dam. Since all releases of water were made from the epilimnion during most of 1965 and and the first half of 1966, salt-heavy water in the hypolimnion

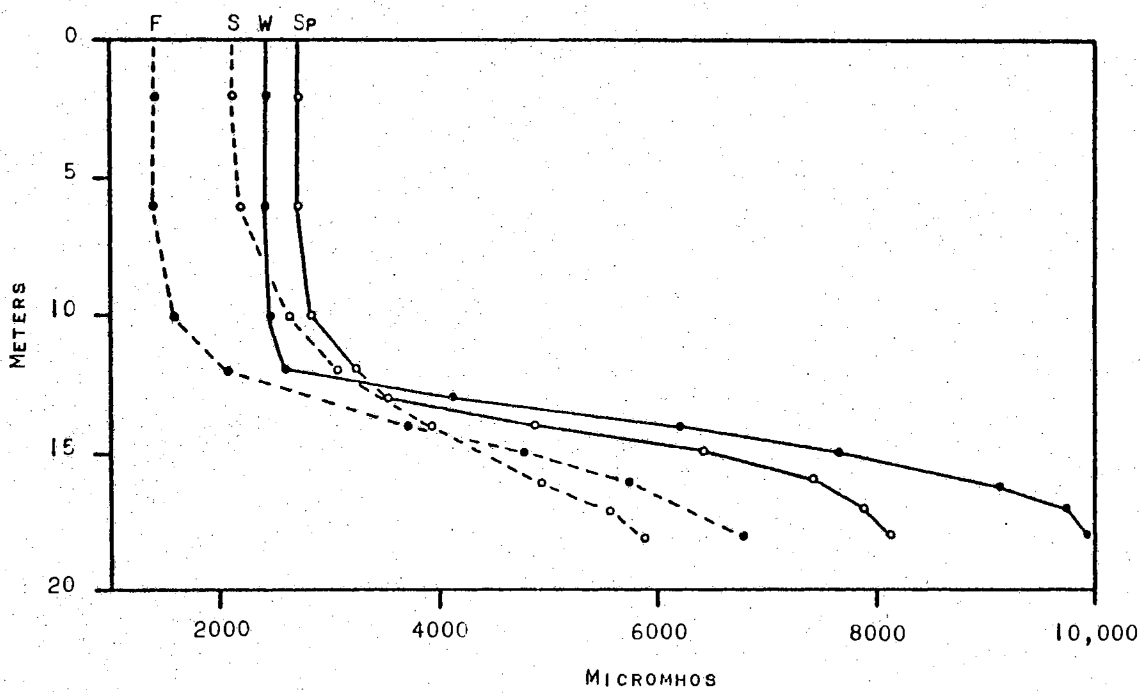

Figure 2. Seasonal Stratification of Conductivity at Sampling Station IV, Keystone Reservoir. F = fall, S = Summer, W = winter, Sp. = spring.

increased in volume and backed up into the Arkansas arm. Conductivity measurements taken in March, 1966, clearly indicate that Cimarron River water had backed up at least 9.5 nautical miles into the Arkansas arm (Fig. 3).

TABLE I

MAJOR DISSOLVED SOLIDS IN THE ARKANSAS AND CIMARRON RIVERS SIX MILES ABOVE KEYSTONE RESERVOIR, MARCH, 1966

	Major Cations (mg/l)			Major Anions (mg/l)	
	Na^+	Ca^{++}	Mg^{++}	Cl^-	$SO_4^=$
Arkansas	163	111	48	425	452
Cimarron	965	147	64	2914	473

Stability of chemical stratification varied seasonally as mineralization of the Cimarron River varied (Fig. 4). During winter, when the drainage basin received only 10% of its total annual rainfall, highly mineralized river water formed an underflowing density current which flowed along the bottom of the old river channel and increased the conductivity of the hypolimnion.

In the summer, when 57% of the drainage basin's total annual rainfall was received, Cimarron River water was less dense than the water in the hypolimnion and formed an interflowing density current. Partial mixing between the interflowing current and the underlying water mass caused the conductivity of the hypolimnion to decrease during the summer.

In addition to chemical stratification, thermal stratification occurred during most of the year (Fig. 5). The relative stability of

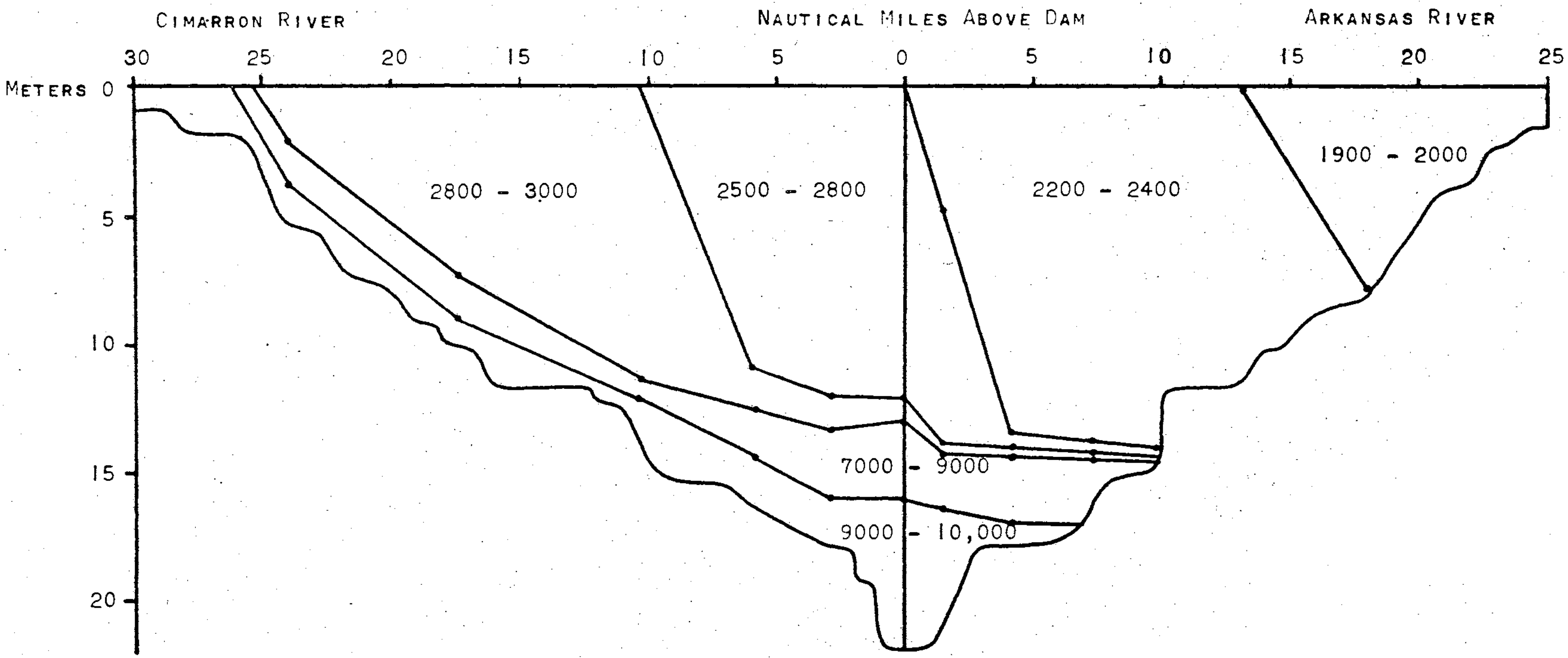

Figure 3. Chemical Stratification and Density Currents in Keystone Reservoir, Oklahoma, 21 March, 1966. Micromhos specific conductance.

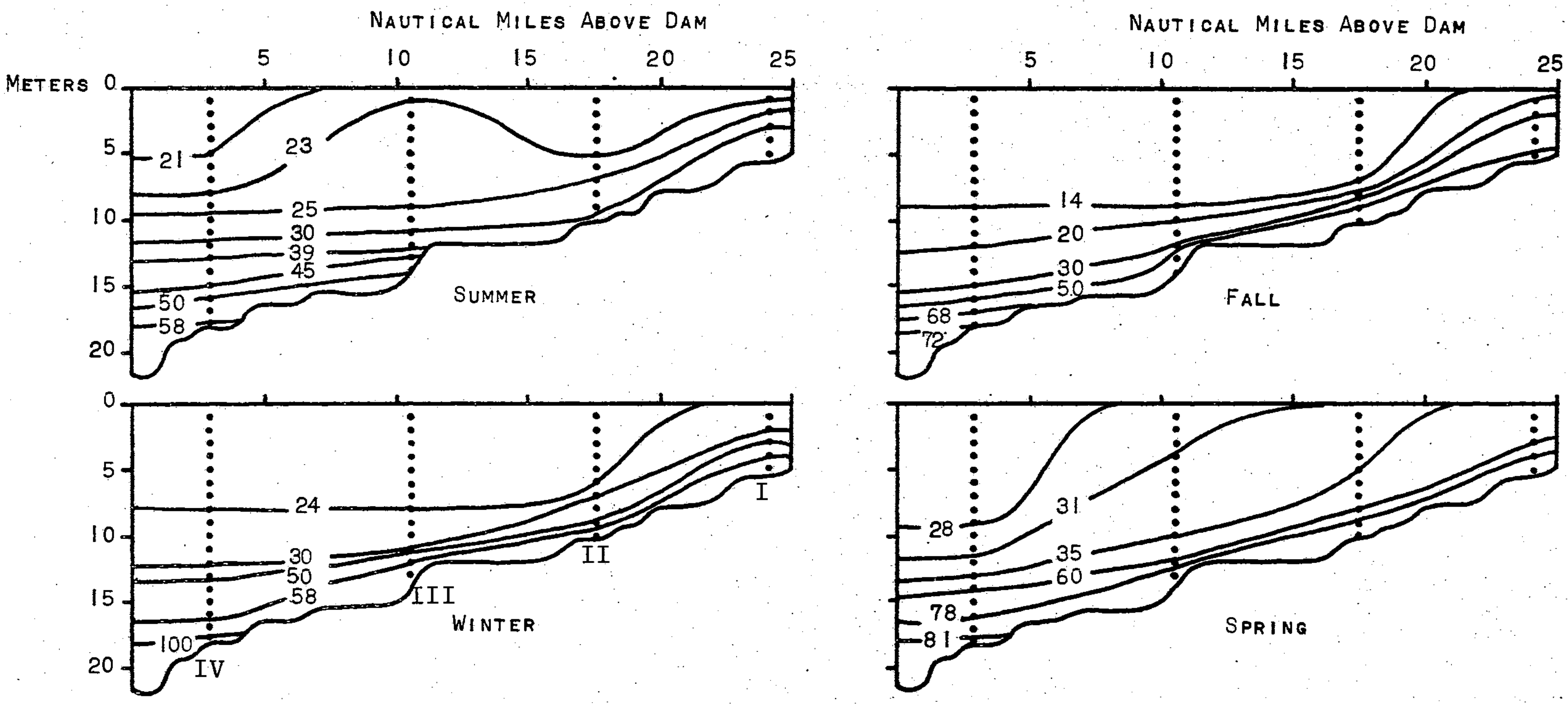

Figure 4. Seasonal Conductivity (10^2 μ mhos), Cimarron Arm, Keystone Reservoir, 1965-66. Dots represent locations of measurements. Station locations are indicated by Roman numerals.

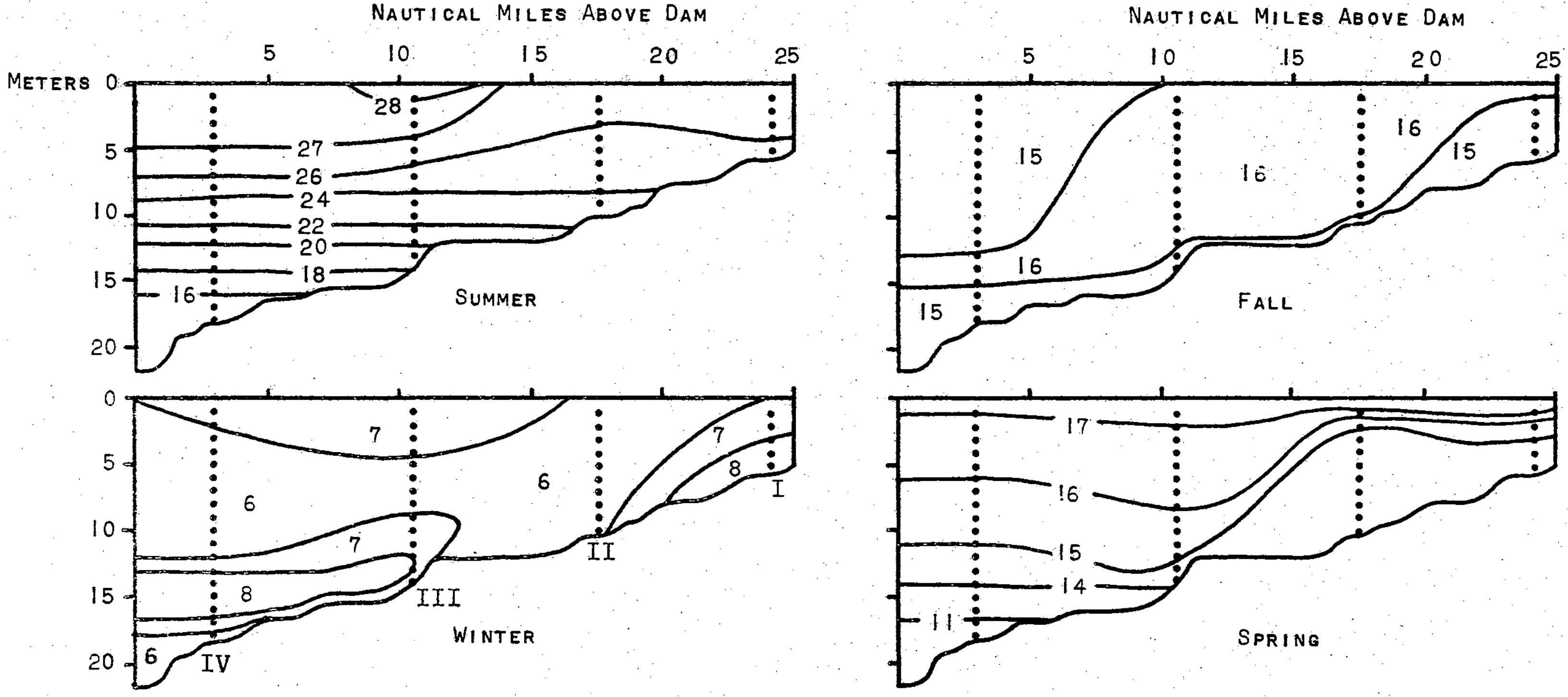

Figure 5. Seasonal Temperature (C), Cimarron Arm, Keystone Reservoir, 1965-66. Dots represent locations of measurements. Station locations are indicated by Roman numerals.

seasonal stratification may be estimated from differences between the average seasonal densities of the epilimnion and hypolimnion (Table II). The contribution of thermal stratification to stability was estimated by subtracting the density of water at the average seasonal temperature of the epilimnion from the density of water at the average seasonal temperature of the hypolimnion. Densities of water as a function of temperature were taken from Hutchinson (1957). Stability due to chemical stratification was determined by subtracting the average seasonal specific gravity of the epilimnion at 15 C from the average seasonal specific gravity of the hypolimnion at 15 C. Stratification was most stable during summer and winter. During the summer, approximately 74% of the total stability was due to thermal stratification. Stability was caused entirely by chemical stratification in the fall and winter when inverse thermal stratification actually reduced stability. Stratification was least stable during spring when mixing by strong winds reduced the density gradient.

Suspended solids were not a factor in formation of density currents except during floods. Siltation of most suspended inorganic solids occurred in the upper 10 miles of the Cimarron arm (Fig. 6). Turbidity was lower during all seasons in the lower half of the Cimarron arm. The euphotic zone, the depth to which 1% of surface light intensity penetrates, was greatest in the winter and least in the fall.

The reservoir was stratified into three distinct layers during winter. A well mixed epilimnion was present above the chemocline at 12 m. The underflowing density current of Cimarron River water brought fresh water into the bottom two meters of the hypolimnion, thus isolating an unmixed layer of water between 13 and 17 m. In January, 1966,

TABLE II

DIFFERENCES BETWEEN THE AVERAGE SEASONAL DENSITIES OF THE EPILIMNION AND HYPOLIMNION AT STATION IV, KEYSTONE RESERVOIR, 1965-66

	Thermally Caused Density Differences*	Chemically Caused Density Differences	Total Density Difference
Summer	+ 0.00171	+ 0.00060	+ 0.00231
Fall	- 0.00003	+ 0.00150	+ 0.00147
Winter	- 0.00001	+ 0.00240	+ 0.00239
Spring	+ 0.00044	+ 0.00070	+ 0.00114

*Positive differences denote higher density in hypolimnion; negative differences denote higher density in epilimnion.

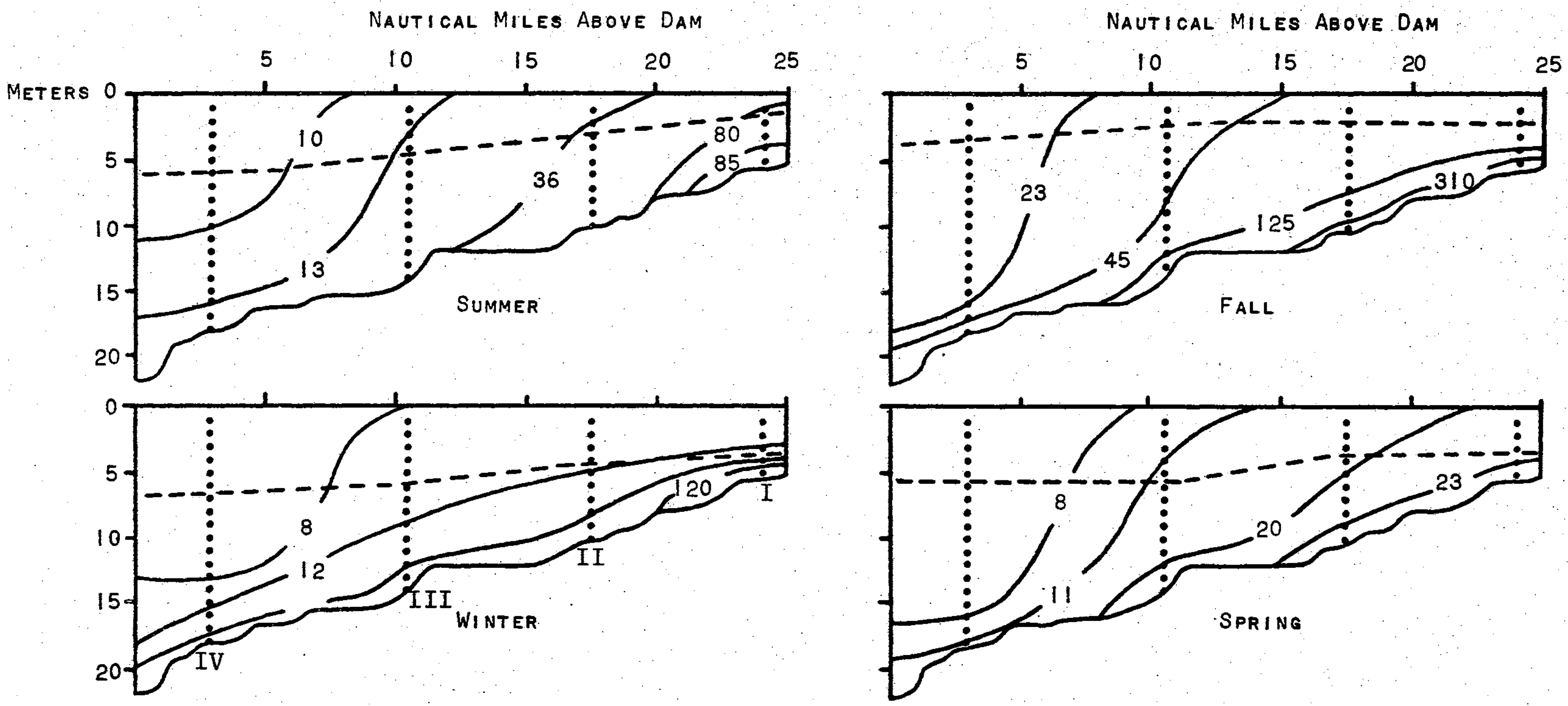

Figure 6. Seasonal Turbidity (Turbidity Units), Cimarron Arm, Keystone Reservoir, 1965-66. Dashed line represents bottom of euphotic zone. Dots represent locations of measurements. Station locations are indicated by Roman numerals.

this intermediate layer was 4 C warmer and contained about 5 mg/l less dissolved oxygen than water above or below it. This layer is clearly shown by the winter distribution of temperature (Fig. 6), dissolved oxygen (Fig. 7), pH (Fig. 8) and free carbon dioxide (Fig. 9).

In the spring, the underflowing density current changed to an interflowing density current, and the influx of fresh water into the bottom of the hypolimnion stopped. Dissolved oxygen below 16 m decreased from 7.2 mg/l on 18 March to 0.0 mg/l on 21 April. Stagnation increased during the spring and summer months, and in July the water mass below 6 m was anoxic and contained 18 mg/l free carbon dioxide. Water samples from the hypolimnion had a strong odor of hydrogen sulfide.

Photosynthetic oxygen production probably was highest in spring, when surface water was 120% saturated with dissolved oxygen, had a pH of 8.6 and contained no free carbon dioxide. Oxygen production probably was at a minimum during fall, when the epilimnion was only 82% saturated with dissolved oxygen, had a pH of 8.1 and contained 1 to 2 mg/l of free carbon dioxide. High oxygen content of the upper layer during the winter was due to an increase in solubility of oxygen in the cooler water. This layer was 98% saturated with dissolved oxygen during the winter.

Based on annual ranges of pH, carbonates, and bicarbonates, Keystone Reservoir can be classified as a medium-hard-water lake (Reid, 1961). In the epilimnion, pH values ranged from 7.8 to 9.1, with a mean of 8.4. The average pH of the entire water mass was 8.2 during 1965-66. Seasonal stratification of carbonates and bicarbonates corresponded to seasonal stratification of pH (Fig. 8). When pH was

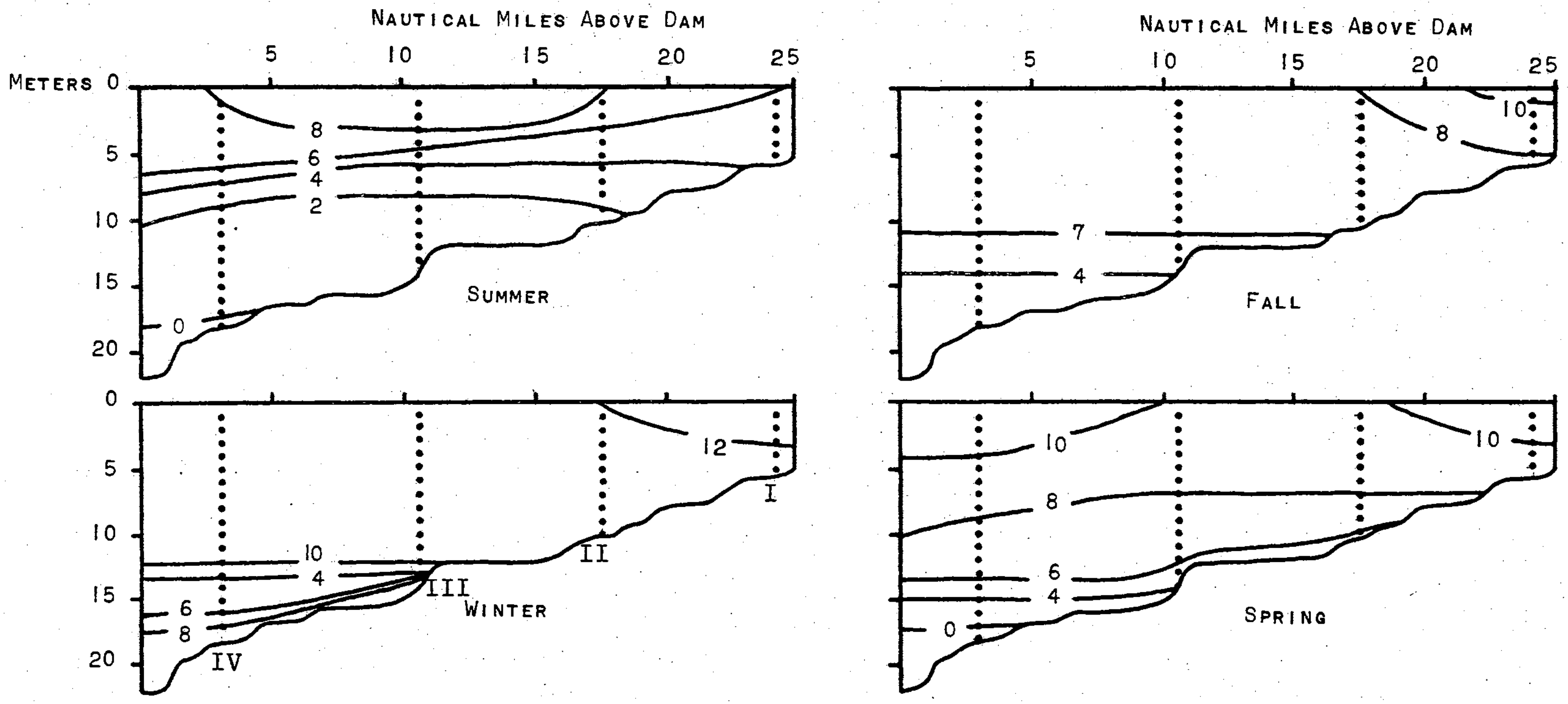

Figure 7. Seasonal Dissolved Oxygen (mg/l), Cimarron Arm, Keystone Reservoir, 1965-66. Dots represent locations of measurements. Station locations are indicated by Roman numerals.

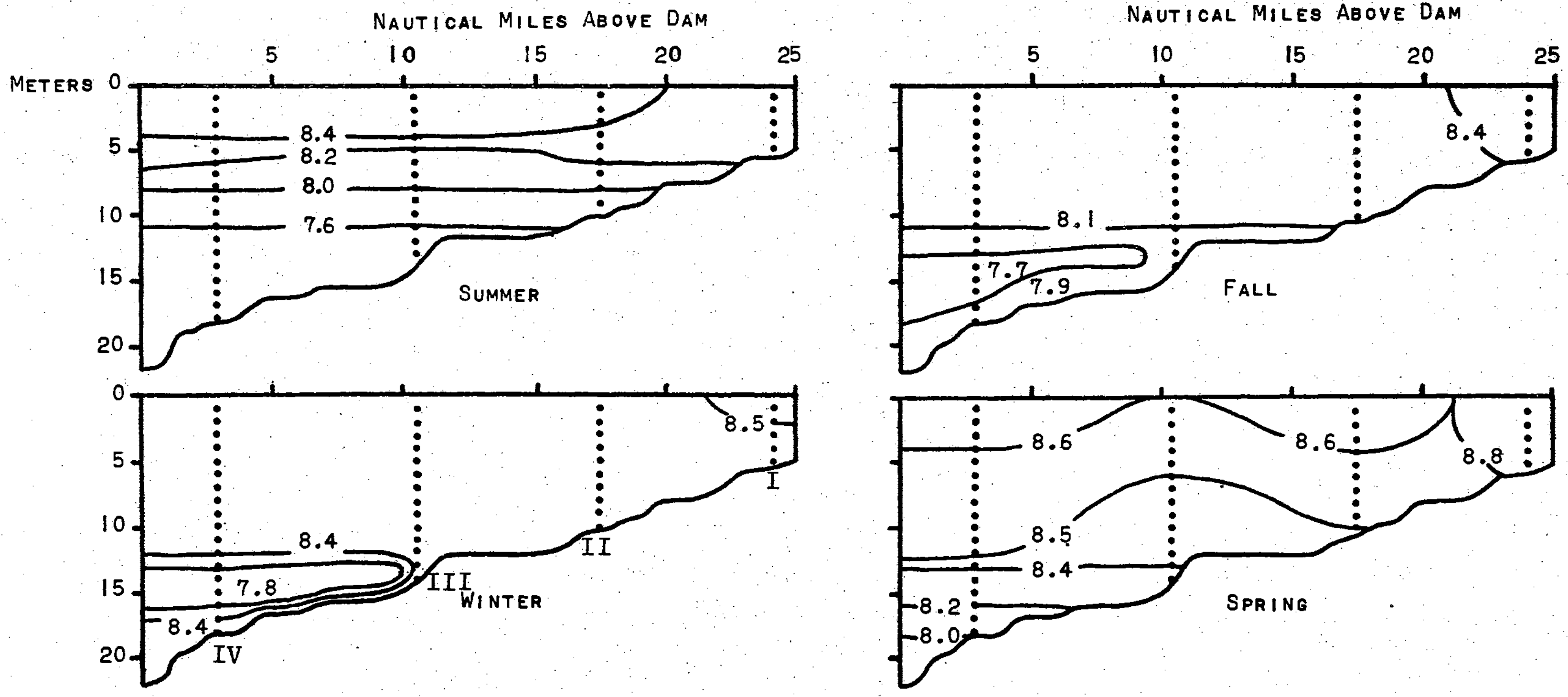

Figure 8. Seasonal pH, Cimarron Arm, Keystone Reservoir, 1965-66. Dots represent locations of measurements. Station locations are indicated by Roman numerals.

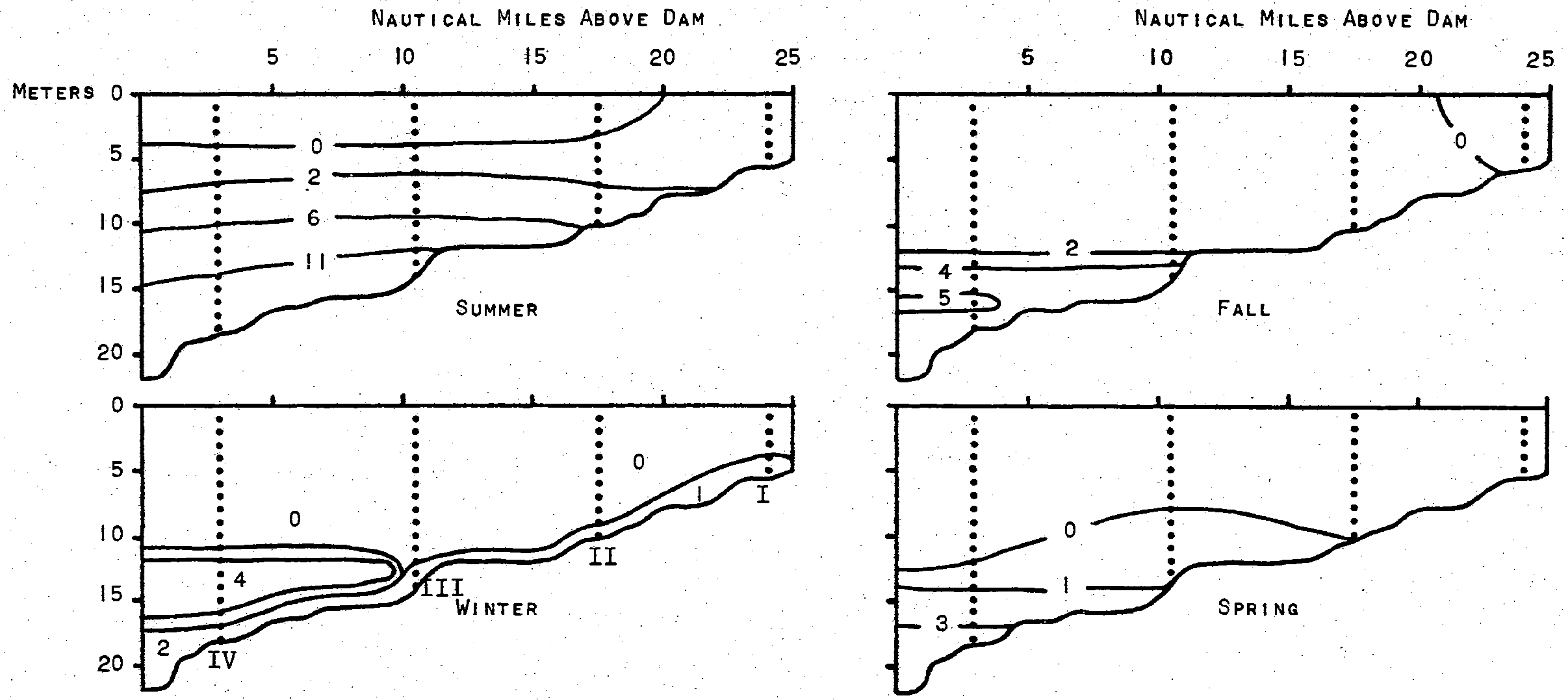

Figure 9. Seasonal Free Carbon Dioxide (mg/l), Cimarron Arm, Keystone Reservoir, 1965-66. Dots represent locations of measurements. Station locations are indicated by Roman numerals.

high (8.3-8.8), carbonates were high (15-56 mg/l), and bicarbonates were low (58-110 mg/l). When pH was low (7.3-8.0), carbonates were low (0-5 mg/l), and bicarbonates were high (130-191 mg/l).

Major floods and continuous release of water from the hypolimnion seemed to be the only forces capable of upsetting the stability of Keystone's stratification. Flood waters entered the Cimarron arm in September, 1965. The discharge of the Cimarron River increased from 425 cfs on 20 September to 41,529 cfs on 22 September. Although flood water was less mineralized because of dilution by runoff, it was cooler and carried a heavy load of suspended solids and, consequently, sank below the lighter reservoir water. Dilution of the salt layer weakened stratification and allowed complete mixing to occur throughout most of the reservoir. During the first 48 hours of flooding, the mean temperature of the water mass at station III decreased from 25.2 to 20.8 C, mean turbidity increased from 40 to 320 turbidity units, mean specific conductance decreased from 2750 to 1450 micromhos, and mean dissolved oxygen decreased from 5.6 to 1.4 mg/l (Carter and Eley, 1967).

Stagnation produced its worst effects in the Cimarron arm of the reservoir in July, 1966. Surface water at stations I and II contained less than 5 mg/l dissolved oxygen and the water was anoxic below 4 m. At stations III and IV, surface water held about 6 mg/l dissolved oxygen, and the water was anoxic below 6 m. Distressed fishes were observed swimming on the surface of the water, and large numbers of less tolerant species, such as gizzard shad, were dying.

When a release of extra water was required to maintain power pool levels in downstream reservoirs, a program to drain off the stagnant hypolimnion was initiated by the U. S. Army Corps of Engineers. Water was released through the sluice gates located near the bottom of the dam. Water also was released from the epilimnion through the tainter gates in an attempt to provide a water mixture of acceptable quality. On 16 July, bottom water composed only 25% of total discharge. By 22 July, this proportion had been increased to 80%; and by 2 August, the total discharge was composed of anoxic bottom water.

Effects of hypolimnetic discharge on downstream water quality are shown in Table III. Temperature of discharged water, rather than original oxygen content, determined the concentration of dissolved oxygen immediately below the dam. As the proportion of anoxic, but cooler, bottom water increased, dissolved oxygen in the tailwaters increased. Energy dissipators in the sluiceways caused discharged water to spray several feet into the air. Because of the method of release and the greater solubility of oxygen in cool water, anoxic bottom water was saturated with dissolved oxygen 50 yards below the dam. During this period of discharge, dissolved oxygen was always higher below the dam than in the epilimnion above the dam. The oxygen demand of discharged bottom water reduced the dissolved oxygen content as water flowed downstream. As the proportion of bottom water increased, oxygen demand in the tailwaters increased.

Hydrogen sulfide escaping from discharged water produced obnoxious odors and caused discoloration of buildings and construction equipment located below the dam. Most of the hydrogen sulfide escaped as water sprayed from the sluice gates and was not present in the tailwaters in quantities lethal to fish.

On 22 July, 12.4 mg/l of ammonia (NH_3) was measured in the water 50 yards below the dam. Numerous fish were dead and many others were

TABLE III

EFFECTS OF THE RELEASE OF STAGNANT WATER BELOW KEYSTONE DAM

Date	Percent of Total Discharge		Distance Below Dam	Temp. C	Dissolved Oxygen		pH	H_2S mg/l	NH_3 mg/l	Dominant Species of Fish Killed
	Sluice Gates	Tainter Gates			mg/l	% Sat.				
16 July	25%	75%	50 yards	25.0	8.3	100%	8.2			gizzard shad
			0.5 miles	25.4	7.8	95%	8.2			gizzard shad
			9 miles	26.7	7.2	90%	8.3			none
22 July	80%	20%	50 yards	18.2	9.5	100%	7.8	0.6	12.4	gizzard shad, gars, channel catfish, flathead catfish
			0.5 miles					0.3	10.7	gizzard shad
			9 miles	21.1	7.5	85%	8.0			none

observed swimming in distress on the water surface. The high concentration of ammonia apparently was responsible for the fish kill, since concentrations as low as 2.5 mg/l NH_3 are harmful in the pH range 7.4 to 8.5 (Ellis, 1947).

Release of bottom water from 15 July to 2 August greatly reduced chemical stratification and allowed mixing of the water mass to occur to a greater depth. Specific conductance of the hypolimnion decreased from 7,000 to 3,500 micromhos during a 12 day period (Fig. 10). Between 2 August and 1 September the temperature of the hypolimnion increased from 16 to 21 C and dissolved oxygen increased from 0 to 5 mg/l.

Effects of chemical and thermal stratification on water quality as water moved through the reservoir are shown by seasonal means for the water mass at the four stations in the Cimarron arm (Figs. 11 and 12). Temperature, conductivity, turbidity, dissolved oxygen, carbonates, and pH generally decreased between stations I and IV during all seasons, while bicarbonates and free carbon dioxide increased.

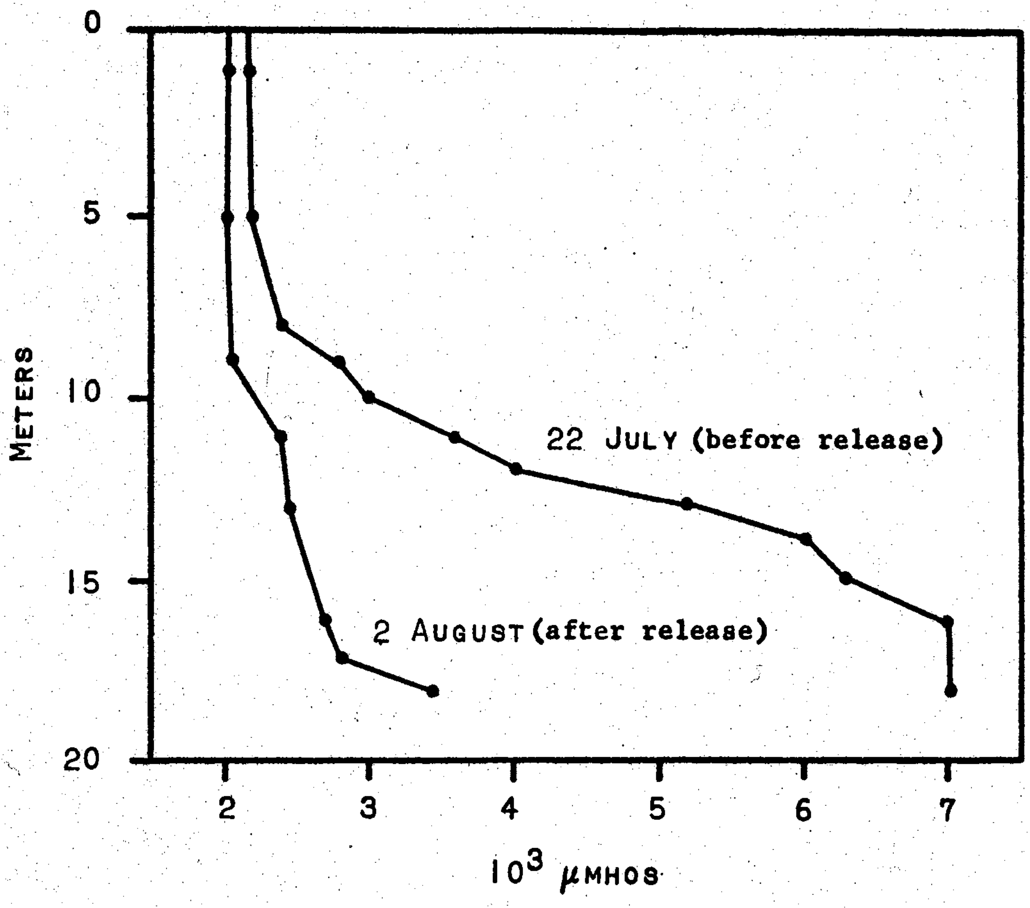

Figure 10. Effect of Release of Hypolimnetic Water on Conductivity in Keystone Reservoir, 1966

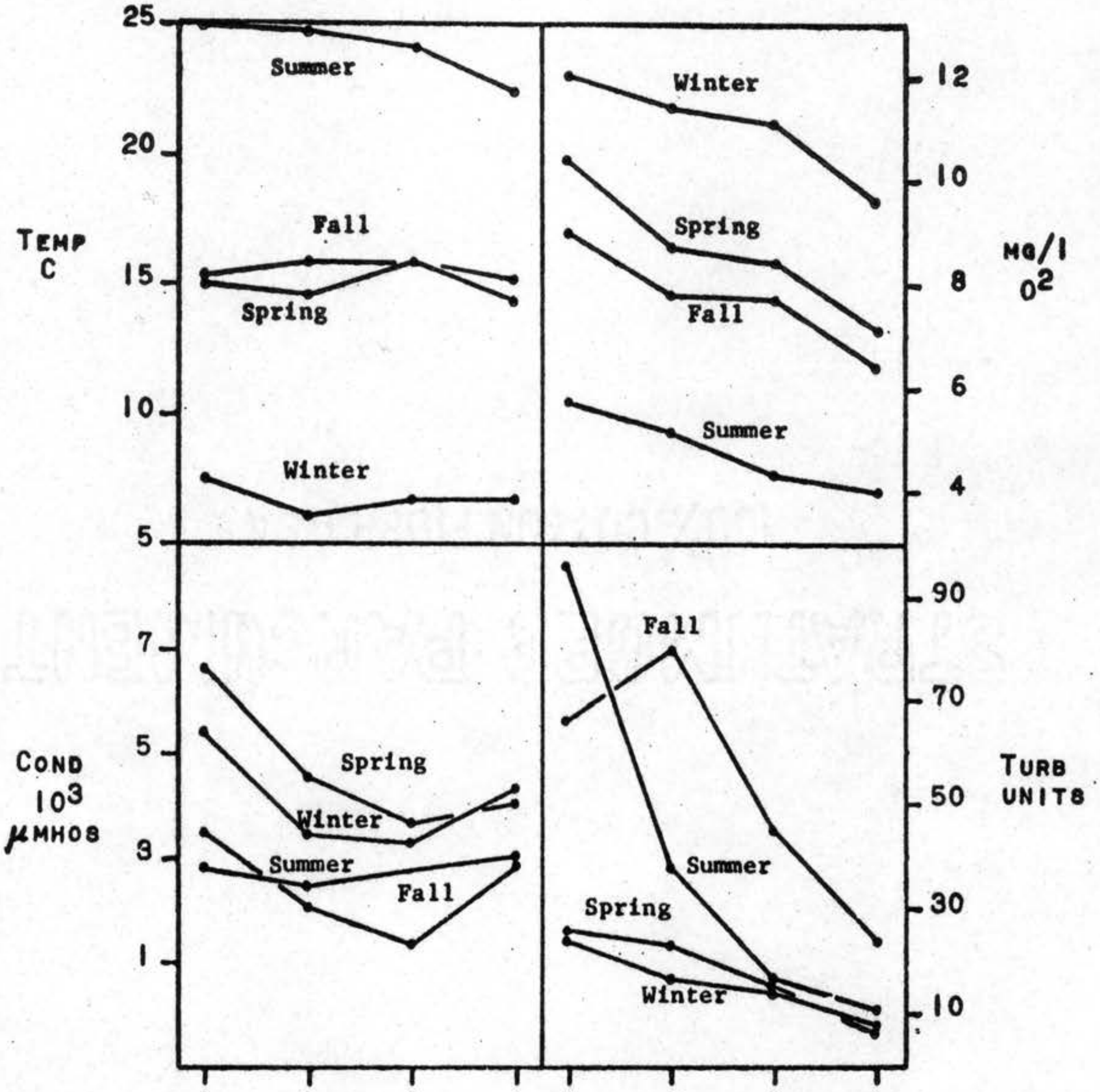

Figure 11. Seasonal Means for Entire Water Mass at Sampling Stations, Cimarron Arm, Keystone Reservoir, 1965-66.

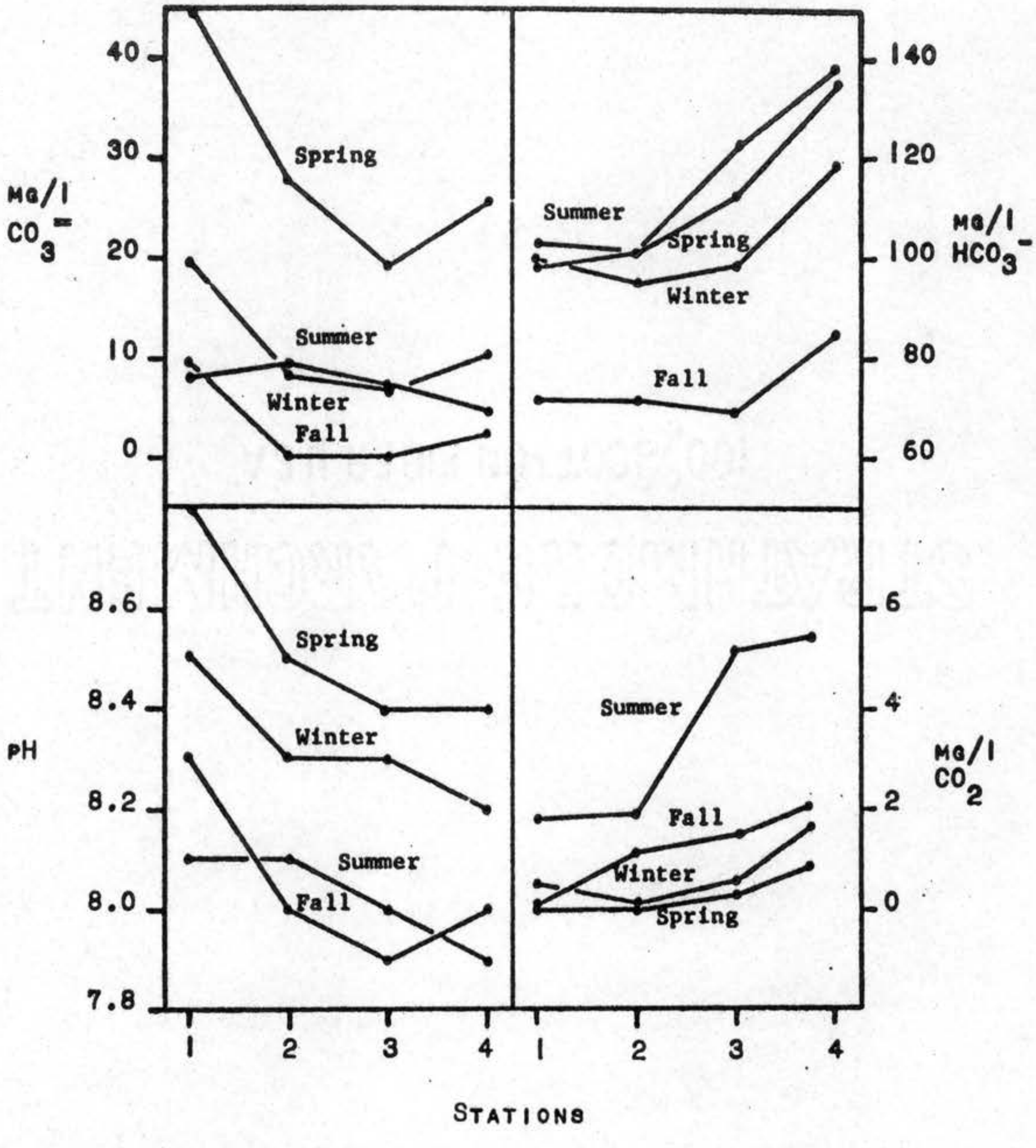

Figure 12. Seasonal Means for Entire Water Mass at Sampling Stations, Cimarron Arm, Keystone Reservoir, 1965-66

CHAPTER IV

SUMMARY AND CONCLUSIONS

Keystone Reservoir was chemically stratified during all seasons. Stable thermal stratification was imposed upon chemical stratification during the summer months. Chemical stratification was caused by salt-heavy Cimarron River water underlying lighter water from the Arkansas River and lateral tributaries of the reservoir. In September, 1965, a flood temporarily disrupted stratification and caused a significant decrease in quality of the entire water mass. In the winter, when surface runoff was low, the highly mineralized Cimarron River formed an underflowing density current which brought fresh water into the bottom of the hypolimnion.

Decomposition of organic matter under anoxic conditions caused an increase of carbon dioxide, hydrogen sulfide and ammonia in the hypolimnion during the summer. During July, 1966, release of hypolimnetic water through the dam produced strong hydrogen sulfide odors and caused a partial fish kill in the tailwaters. Ammonia apparently was responsible for the fish kill. During the period of release, turbulent discharge through sluice gates quickly aerated the cool water, and dissolved oxygen was higher 50 yards below the dam than it was in the epilimnion of the reservoir. When hydroelectric power generation begins late in 1967, water will be released from generators in a less turbulent manner, and reaeration problems so common in the tailrace of other reservoirs (Churchill, 1957) will probably occur.

Draining of the salt-heavy hypolimnion improved water quality of the reservoir by allowing mixing by wind action and convection currents to reoxygenate the hypolimnion. Since the flow of the Arkansas River is about five times greater than the flow of the Cimarron, it will be possible to reduce chemical stratification by continuing the release of water from the hypolimnion. Although thermal stratification might still occur during the summer, its stability will be lessened and anoxic conditions will be confined to a smaller bottom layer. Summer stagnation also will decrease when organic matter which was submerged during impoundment is decomposed.

The reservoir acts as an efficient settling basin for the turbid Cimarron River and produces cooler, less turbid flow in the Arkansas River above Tulsa, Oklahoma, than was present before impoundment. These reductions of temperature and solids will increase the suitability of discharged water for industrial use in the Tulsa area.

LITERATURE CITED

American Public Health Association. 1960. Standard methods for the examination of water and waste water. 11th ed. Amer. Public Health Assn., New York.

Carter, N. E., and R. L. Eley. 1967. Effects of a flood on fish distribution in Keystone Reservoir. Proc. Okla. Acad. Sci. In press.

Churchill, M. A. 1957. Effects of storage impoundments on water quality. J. Sanit. Eng. Div., ASCE. 83: (SA1): Paper 1171. 48 p.

Ellis, M. M. 1937. Detection and measurement of stream pollution (related principally to fish life). U. S. Dept. of Commerce, Bur. of Fisheries Bull. 22.

Hutchinson, G. E. 1957. A treatise on limnology. Vol. 1. Geography, Physics, and Chemistry. John Wiley & Sons, Inc., New York. 1015 p.

Love, K. S. 1961. Relationship of impoundment to water quality. J. AWWA. 53: 559-568.

Lyman, F. E. 1944. Effects of a flood upon temperature and dissolved oxygen relationships in Cherokee Reservoir, Tennessee. Ecology 25 (1): 70-84.

Moore, E. W. 1939. Graphic determination of carbon dioxide and the three forms of alkalinity. J. AWWA. 31: 51.

Rawson, D. S. 1944. The calculation of oxygen saturation values and their correction for altitude. Limnol. Soc. Am., Spec. Publ. No. 15.

Reid, G. K. 1961. Ecology of inland waters and estuaries. Reinhold Publ. Corp., New York. 375 p.

Smith, W. O. et al. 1960. Comprehensive survey of sedimentation in Lake Mead, 1948-49. Professional paper 295, U. S. Geological Survey, Washington, D.C.

U. S. Army Corps of Engineers. 1966. Unpublished discharge data of Keystone Reservoir. Tulsa District, Oklahoma.

Wiebe, A. H. 1939. Density currents in Norris Reservoir. Ecology 20(3): 446-450.

Wiebe, A. H. 1940. The effect of density currents upon the vertical distribution of temperature and dissolved oxygen in Norris Reservoir. J. Tenn. Acad. Sci. 15: 301-308.

________. 1941. Density currents in impounded waters - their significance from the standpoint of fisheries management. Trans. Sixth N. Am. Wildlife Conf. 256-264.

Worthington, E. B. and L. C. Beadle. 1932. Thermoclines in tropical lakes. Nature 129: 55-56.

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