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**Limnology of
John Redmond Reservoir,
Kansas**

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Limnology of John Redmond Reservoir, Kansas

by
Carl W. Prophet*

ABSTRACT

John Redmond Reservoir was constructed by the U. S. Army Corps of Engineers primarily as a flood control measure for the Neosho (Grand) River in East Central Kansas. Partial impoundment was commenced during 1964, and in June of that year measurement of limnological conditions within the basin was begun. During the early stages of impoundment, conditions varied depending upon the relative discharges of the upper Neosho and Cottonwood Rivers. Except for periods of excessive rainfall, most of the inflow was of Cottonwood River origin and the chemistry of the reservoir became more similar to that of Cottonwood water. Although the reservoir appears to operate as a single water mass, when various conditions were compared between upstream and downstream locations within the basin the impounded water appeared to undergo some chemical change. The change was associated to biological activity and storage time.

In general, nutrients and primary production were higher in the reservoir than was the case in other impoundments in the vicinity of the reservoir. Overall, values for the chemical conditions studied tended to be higher during the second year of impoundment. At conservation level, approximately 75% of the basin is less than three meters deep. Because of its shallow nature and exposure to the prevailing southerly winds, thermal stratification is not expected to become a problem in this reservoir.

INTRODUCTION

In the past, there were relatively few aquatic communities in Kansas to attract the attention of limnologists; however, the situation is now rapidly changing, for the number and diversity of man-made impoundments in this state are increasing from year to year. In addition to more than 100,000 small farm ponds, numerous large reservoirs have been constructed in Kansas for recreation, water supply, flood control, and other uses. Scattered throughout the state are 37 lakes which were constructed by the Kansas Forestry, Fish and Game Commission. These lakes were developed primarily for fishing and vary in size from approximately 12 to 1200 hectares, only a few have been studied.

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Andrews and Breukelman (1952) conducted a preliminary survey of several of the state lakes. Although their study gave an indication of the variation in some of the chemical features between lakes, their data for any one lake were limited. Considerable information relating the variations in such features as water temperatures, dissolved oxygen, and alkalinity in Flint Hills farm ponds was published by Tiemeier and Moorman (1957) and Tiemeier and Elder (1957). Since March, 1963, the limnology laboratory at Kansas State Teachers College has been recording the changes in the water chemistry, primary productivity, and zooplankton in Lyon County State Lake. This lake was drained during the 1962 summer as an initial step in rehabilitating its fisheries; the limnological conditions in the lake during the first year of reflooding were summarized by Prophet (1965), and the data recorded since that time will be presented in a future paper. Although the above cited references are by no means the only publications of a limnological nature concerning Kansas waters, they represent the types of studies that have been conducted to date.

At the close of 1965, approximately 20 large federal reservoirs were either impounding water or were in some stage of development in Kansas. With the completion of these reservoirs, the flow in virtually all of the major river systems in the state will be regulated by one or more large dams, and the surface area of this impounded water in Kansas will be increased to more than 52,000 hectares. The effects of these large dams on the biological and chemical features of rivers are not totally understood, and the government agencies responsible for water quality control and pollution abatement have become increasingly concerned about the lack of understanding. The 1961 amendment to the Federal Water Pollution Control Act (Public Law 660) directed federal agencies engaged in the planning of new reservoirs to include in their plans additional water storage which would be used for the regulation of streamflow. This amendment made it clear that the federal government depended heavily on streamflow regulation as a means of improving and controlling water quality in our rivers. However, as pointed out by Symons, et al. (1964), the success of the streamflow regulation program depends on the ability of the responsible agencies to forecast the quality of the impounded water, since it will be used to maintain downstream flow as well as to dilute the downstream water. In spite of the vast limnological literature that has been published in recent years, relatively little has concerned the problems of impoundment behavior and change in water quality during impoundment.

The current study was initiated to record the seasonal and annual changes in some of the limnological conditions in the John Redmond Reservoir during its early impoundment. The results of this study may provide some insight into the changes in the chemical characteristics of the water during its impoundment, and they will serve as a basis for determining changes in the limnological features of the reservoir following the completion of upstream reservoirs.

DESCRIPTION OF THE UPPER NEOSHO RIVER SYSTEM OF RESERVOIRS

The Grand, more commonly known as the Neosho River in Kansas, has its origin in Morris and Southwestern Wabaunsee counties in a region underlaid by Permian shales and limestones of the Chase and Council Grove Groups. From its origin, it flows 452 km in a southeasterly course to its confluence with the Arkansas River near Muskogee, Oklahoma. Its major tributary above the John Redmond Reservoir is the Cottonwood River whose source is in Marion County in a region of Permian formations belonging to the Summer Group. Together, the upper Neosho and Cottonwood rivers drain an area of approximately 3,015 square miles (Schoewe, 1952). Both rivers are relatively sluggish and meandering with gradients that rarely exceed one meter per kilometer.

John Redmond Reservoir

The John Redmond Reservoir is located in the southeast corner of Coffey County, approximately 3 km northwest of Burlington, Kansas. It was authorized by Congress on May 17, 1950, and construction was started by the U. S. Army Corps of Engineers during 1959; the structure was completed during early 1965. The project was initially planned as a flood control measure for the upper Grand (Neosho) River, which has flooded approximately 58 times during the past 36 years; however, provisions for additional storage capacity were made before its completion for streamflow regulation purposes.

The dam is an earthen structure about 6 km long with fourteen 40 x 35-foot gates to control spillway discharges; low-flow discharge is controlled by two 30-inch gated pipes. The basin is located in an area of Pennsylvania shales and limestones. Currently, at conservation level the impoundment has a surface area of 3,157 hectares and a gross storage capacity of $69.70 \times 10^6 \text{ m}^3$; at flood pool level the surface area would be 12,829 hectares, with maximum storage of $79.54 \times 10^7 \text{ m}^3$. Within a few years the top of the conservation pool in John Redmond Reservoir might be raised about one meter, increasing the surface area at conservation level to 3,804 hectares. (U.S. Corps of Engineers, Personal Communication).

Upstream Reservoirs

The Cottonwood joins the Neosho River just east of Emporia or approximately 48 kilometers above the John Redmond Dam. Currently, the U.S. Army Corps of Engineers is constructing a dam on the South Fork of the Cottonwood River near Marion, Kansas, about 72 kilometers west of Emporia. The resulting reservoir, due for completion in 1968, will have a surface area of 2,428 hectares. Another reservoir is proposed for the Cottonwood drainage near Cedar Point, Kansas, located between Marion and Emporia.

The Council Grove Dam, completed during 1965, is located on the Neosho River approximately 64 kilometers above its confluence with the Cottonwood River. This dam forms an impoundment of 1,214 hectares and regulates flow in the upper Neosho River.

METHODS

Chemical analyses of water samples were conducted according to the procedures outlined in Standard Methods (A.P.H.A. 1960). Measurements of physical conditions were made in the field at the time the samples were collected. For chemical analyses requiring laboratory facilities, water samples were returned to the laboratory and kept under refrigeration until analyses could be completed. During the summer months, measurements were recorded every 2-3 days and at weekly intervals during the remaining months, weather permitting. Results presented in this paper are based on more than 300 separate measurements and analyses.

Water samples were collected from four main locations in the basin (Fig. 1). Stations referred to as Ottumwa and Hickory Creek were located in the upstream or upper region of the basin. The remaining two stations, East Point and Redmond Cove, were located in the lower or downstream portion of the basin. Periodic samples were collected from other regions of the basin to check for differences in limnological conditions. However, since most changes appeared to be of a longitudinal nature only the results from the above four sampling sites were included in this paper.

On each sampling date at each of the four stations, water samples for dissolved oxygen, alkalinity, and pH were collected from the top, middle, and bottom meters of water. All other chemical analyses were based on a composite water sample which consisted of 14 liters of water collected from throughout the depth of the euphotic zone with a Kemmerer water sampler and placed in a large polyethylene carboy. Sub-samples were withdrawn from the composite sample and returned to the laboratory for analysis of chlorophyll, phosphate, nitrate, calcium, sodium, potassium, and detergents.

Water temperatures were measured with the aid of a Whitney underwater electrical resistance thermometer and were recorded at intervals of one foot from the surface to the bottom. Specific conductance was determined by measuring the electrical resistance of a sample with a model RC-7 Industrial Instruments conductivity bridge and converting the resistances to reciprocal micromhos/cm corrected to 25°C. Dissolved oxygen was measured by the Alsterberg modification of the Winkler Method. Alkalinity was measured by titrating water samples with N/50 H₂SO₄ to endpoints of pH 8.3 and 4.6 and converting the results to carbonate and bicarbonate alkalinity. A Beckman Model N pH meter was used to determine pH. Nitrate nitrogen was estimated by the brucine method and orthophosphate was measured by the stannous chloride method. Calcium, sodium, and potassium concentrations were determined by flame photometry. A Coleman Model 21 Flame Photometer with a Coleman Model 6D Junior Spectrophotometer as the read-out instrument was used.

The depth of the euphotic zone was determined by estimating the depth to which 1% of the surface illumination penetrated. Light penetration was either measured directly with a Whitney underwater photometer

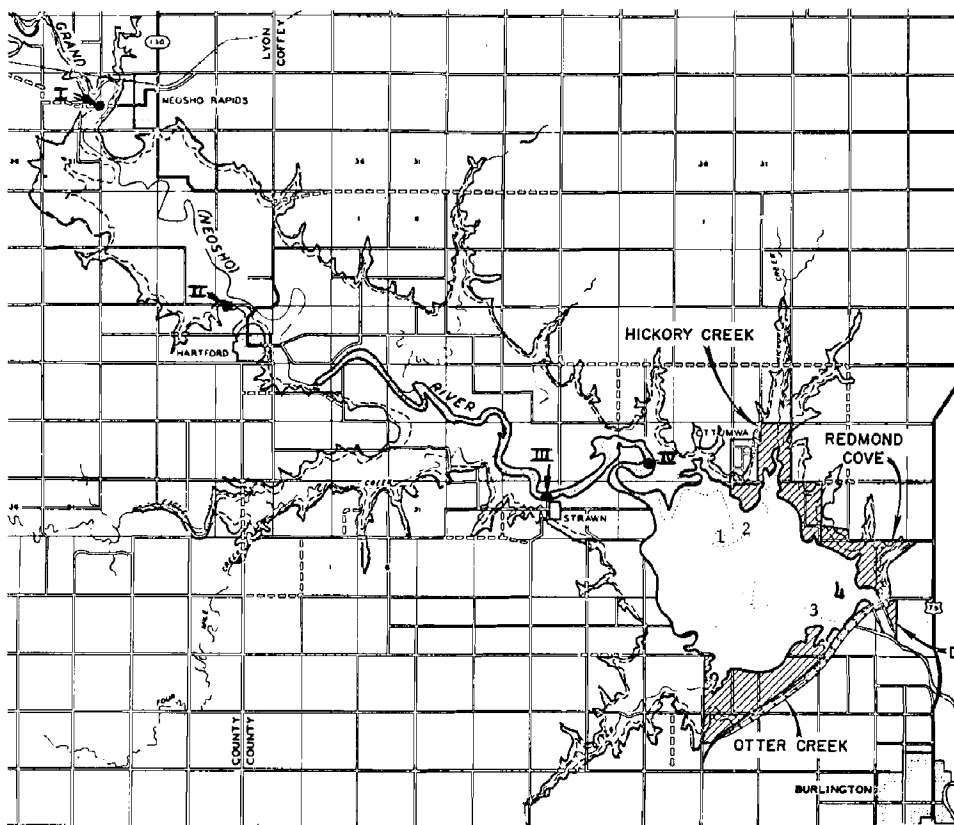


Figure 1. Map of John Redmond Reservoir (U.S. Army Corps of Engineers) showing location of sampling stations within the basin. 1 = Ottumwa; 2 = Hickory Creek; 3 = East Point; and 4 = Redmond Cove. Pre-impoundment data below the confluence were recorded at locations indicated by Roman Numerals. Scale $\frac{1}{2}$ " = 1 mile.

or estimated with the aid of a six inch Secchi disc. In the latter instances the Secchi readings were compared with the results of the photometer. Generally, the depth to which 1% of the surface illumination penetrated was equal to four times the Secchi depth.

Initially, one liter of each composite sample was returned to the laboratory for chlorophyll analyses and centrifuged in a Foerst Plankton centrifuge. The centrifugate was then washed into a 15 ml conical centrifuge tube and centrifuged in a clinical centrifuge for 10 minutes, decanted, and then extracted in 90% acetone under refrigeration for 18-24 hours. Since September, 1964, phytoplankton has been removed by filtering a 250 ml sample through a type AA Millipore Filter and dissolving the filter in 90% acetone. In either case, the contents were periodically mixed to aid in the extraction. The samples were then brought to room temperature and again centrifuged in the clinical centrifuge and the extract decanted. The absorbance of the extract was measured at 665, 645, and 630 mmicrons with a Beckman Model B spectrophotometer.

These values were then used to estimate the concentration of chlorophyll after the method of Richards and Thompson (1952).

Photosynthetic activity (gross primary production) was estimated by comparing the oxygen change in paired light and dark bottles. Glass-stoppered 250 ml bottles were filled with water from the composite sample. Care was taken to overflow each bottle with a sufficient volume of water to lessen the possibility of aeration and trapping of air bubbles in the bottles. Additional samples were collected to measure the concentration of dissolved oxygen in the composite sample at the start of each run. The paired bottles were then suspended from an anchored float, which consisted of a rubber inner tube to which was attached a chain and anchor. Cross bars from which the bottles could be suspended at given depths were attached to the chain. One pair of bottles was maintained just below the surface and additional pairs were suspended at intervals of 0.5 m throughout the depth of the euphotic zone. The samples were then incubated for a period of 4 to 6 hours during the period of maximum insolation, usually between 0900 and 1600 hours. After incubation the concentration of dissolved oxygen in each bottle was measured. The difference between values in the light and dark bottles represented gross primary production. The values obtained at each depth were summed and the average production per liter of euphotic zone was determined. Measurements were not attempted on heavily overcast days, but when they were conducted duplicate runs were made at the Hickory Creek and East Point stations.

RESULTS AND DISCUSSION

Reservoir Stage

The river flow was diverted through the low flow works in the structure during September, 1963, and for the next 12 months the reservoir was operated as a detention basin only. However, by April, 1964, the water surface elevation in the basin had risen to within one meter of the proposed conservation level (1036 msl). It remained at approximately that stage until November, 1964, during which time considerable precipitation was received in the drainage causing the water level to rise above conservation level. Following official impoundment in September, 1964, there were four periods characterized by a rise in the water surface elevation. As can be seen in Tables 1 and 2, excessive precipitation occurred during November, 1964, and March, June, and September, 1965, which resulted in a marked increase in the inflow and a rise in the water surface elevation within the basin. These periods were characterized by marked fluctuations in some of the chemical conditions in the reservoir.

Thermal Conditions

Depth and wind exposure appeared to have an important influence on the thermal conditions in John Redmond Reservoir. The reservoir is relatively shallow; at conservation level, approximately 78% of the im-

Table 1. Total recorded and normal monthly precipitation at John Redmond Reservoir; June, 1964, through February, 1966.

Month	Inches of precipitation			Month	Inches of precipitation		
	1964	Normal	1965		1965	Normal	1966
June	5.55	4.72	11.76	Jan.	0.74	0.96	0.05
July	1.15	3.96	2.92	Feb.	0.81	1.15	0.69
August	4.35	3.68	2.47	Mar.	1.75	2.06	
Sept.	2.50	3.83	8.29	Apr.	2.98	2.96	
Oct.	1.00	2.49	0.26	May	2.65	4.60	
Nov.	5.40	1.56	0.01				
Dec.	0.75	1.25	2.04				

pounded water is less than four meters deep. The prevailing southerly winds have a fetch of at least 4 km across much of the basin. Thus, except for extended periods of hot, calm weather, holomixis persists and water temperatures are essentially the same from the surface to the bottom. The effect of inflow and subsequent discharge of large volumes of water on the thermal conditions was apparent during the 1965 summer. Rainfall exceeding 34 cm occurred in the reservoir drainage during June resulting in flooding. The entrance of the flood waters into the basin raised the water level in the reservoir about 8 m above conservation level (Table 2) and the inflow and discharge of the flood water continued into July. The comparatively short storage time during this period as well as the mixing effect of inflow and drawdown was sufficient to prevent the establishment of thermal stratification during the 1965 summer. Other smaller impoundments in the vicinity of the reservoir not affected by the flooding were observed to stratify as usual.

Weather conditions were considerably different during the 1964 summer, and the reservoir exhibited a tendency to stratify on several different occasions. This tendency was first noted during the period between June 24 and July 10, and again during the last two weeks of July.

On June 24, the water temperature dropped from about 24° to 23° C in the top meter but was relatively uniform throughout the remaining six meters. During the next week, the water mass warmed so that by July 1, there was about 3° C difference in water temperature between the surface and bottom, with the greatest temperature change occurring within the second meter. During this period dissolved oxygen in the bottom meter was reduced to zero. The water continued to heat the following two days but temperature change with increased depth became less pronounced. Wind velocities then increased and mixing occurred. By July 10, the difference between top and bottom temperatures was slight, and the mixing had raised the dissolved oxygen content in the bottom meter to 4.2 mg/liter. On July 13, there was an indication of a tendency for temperature differences to develop again in the water column. This trend was short lived, however, for on July 15, the reservoir was again essentially homothermous from top to bottom. Calm,

Table 2. Monthly variations in the inflow and water surface elevation. Data from U.S. Army Corps of Engineers, District Office, Tulsa, Oklahoma.

Month	Water Surface Elevation (+1000msl)		Inflow (cfs.)	
	Max.	Min.	Max.	Min.
1963				
Sept.	21.7	9.0	700	50
Oct.	26.3	22.0	1,240	75
Nov.	26.2	25.2	145	45
Dec.	25.3	24.2	85	50
1964				
Jan.	24.2	23.7	80	60
Feb.	23.8	23.4	110	65
Mar.	23.4	22.5	175	55
Apr.	34.8	22.6	7,000	150
May	34.5	33.2	3,200	180
June	35.0	33.3	5,750	200
July	33.3	32.5	340	130
Aug.	32.6	31.9	5,900	170
Sept.	33.0	32.1	1,200	70
Oct.	32.9	32.5	850	20
Nov.	39.9	32.7	11,500	100
Dec.	36.8	36.0	2,500	600
1965				
Jan.	36.4	36.0	2,600	200
Feb.	36.3	36.0	2,000	300
Mar.	38.0	36.0	12,250	550
Apr.	39.5	35.9	6,900	300
May	36.2	36.0	1,000	110
June	62.4	36.0	48,000	300
July	50.3	36.1	7,000	300
Sept.	44.8	36.1	18,000	400
Oct.	39.0	35.9	3,900	400
Nov.	36.2	36.1	300	280
Dec.	37.7	36.0	3,450	200
1966				
Jan.	36.8	36.0	1,170	280
Feb.	36.7	36.1	2,000	280

hot conditions again prevailed during the last part of July. The surface waters heated to a maximum temperature of approximately 31.5° by July 22, and oxygen in the bottom meter was reduced to zero. Thermal conditions were again relatively uniform from top to bottom by July 31. Although there were slight differences between top and bottom temperatures during August, they were never as great as just described, and oxygen depletion in the bottom meter was not observed.

Table 3. Monthly mean top and bottom water temperatures in degrees C.

Month	Ottumwa		Hickory Creek		Redmond Cove		East Point	
	Top	Bottom	Top	Bottom	Top	Bottom	Top	Bottom
1964								
June	24.4	23.1	23.8	22.0	24.9	24.2	25.0	25.0
July	28.0	25.8	28.2	26.3	27.8	25.7	27.6	25.5
Aug.	26.0	24.4	25.6	23.7	25.0	24.3	25.0	24.3
Sept.	23.9	23.3	24.8	23.2	24.1	23.6	23.8	22.8
Oct.	15.4	13.7	15.1	13.4	14.9	14.2	14.8	13.8
Nov.	9.3	8.9	8.4	8.0	8.5	8.5	8.7	9.1
Dec.	1.4	0.3	0.4	1.0	1.3	1.4	"	"
1965								
Jan.	2.2	2.2	2.5	2.7	"	"	2.9	2.9
Feb.	6.2	6.0	3.7	3.6	"	"	"	"
Mar.	3.8	4.0	3.3	3.2	3.8	3.4	3.3	3.2
Apr.	15.0	14.1	14.5	13.5	15.0	14.5	15.0	14.1
May	21.2	19.9	20.7	20.4	21.0	20.3	20.7	20.2
June	23.7	23.2	24.0	23.5	24.2	22.0	23.7	22.9
July	27.4	25.6	27.3	26.6	26.7	25.5	26.4	25.2
Aug.	25.2	24.2	25.4	25.1	25.2	24.8	25.3	24.6
Sept.	"	"	23.6	23.1	23.3	23.2	23.4	22.9
Oct.	17.3	16.0	17.5	16.5	17.6	16.0	17.8	16.6
Nov.	11.2	11.0	11.0	11.4	11.1	11.0	11.1	11.2
Dec.	6.7	6.7	5.9	5.8	7.5	7.1	7.4	7.4
1966								
Jan.	1.8	1.8	1.8	1.8	2.2	2.2	2.3	2.4
Feb.	"	"	1.7	2.2	2.1	2.3	"	"

"Weather conditions prevented measurements.

With the exception of the periods described, temperature differences were generally slight between top and bottom throughout the year. Maximum water temperatures occurred during July and August while minimum temperatures occurred during December and January (Table 3). Slight differences were noted in the water temperatures from one sampling station to another. However, these differences were attributed primarily to the time of day that the temperatures were recorded. Thin ice covers frequently formed during the winter months, but air temperatures rarely stayed low for long periods so that a thick ice cover could persist throughout the winter. The estimated annual heat budget for the reservoir during 1964 was 9,396 gram calories compared to 8,748 gram calories for 1965.

Dissolved Oxygen

As pointed out in the previous section, dissolved oxygen was depleted in the bottom meter on several occasions during the 1964 summer. These instances were attributed to decomposition of the recently submerged vegetation as well as to thermal stratification. During other periods, dissolved oxygen at all depths tended to exceed 4.0 mg/liter. As would be expected, dissolved oxygen concentrations were greatest during the colder months of the year and least during the warmer months. The monthly average concentration of dissolved oxygen in the top and bottom meters of water as well as the monthly averages of other chemical conditions at the four sampling stations are given in Tables 5-8.

Hydrogen-ion Concentration and Alkalinity

The hydrogen-ion concentration most generally varied from pH 7.0 to 8.3, hence, total alkalinity was usually equal to bicarbonate alkalinity. There was little difference between the bicarbonate alkalinity in the top and bottom meters at any of the sampling stations. The overall trend since June, 1964, has been for bicarbonate alkalinity to increase (Fig. 2). This increase was probably due to the relative rates of flow in the Cottonwood and upper Neosho Rivers. Alkalinity in the Cottonwood is usually greater than 200 mg/l. compared to less than 150 mg/l. in the Neosho above their confluence, and most of the flow below the confluence to the vicinity of the reservoir in past years has been from the Cottonwood River (Surface Water Records of Kansas, 1964). In addition, there could have been some dissolution of bicarbonates from the soils in the basin, although in this case their effect on the alkalinity of the impounded water was probably negligible.

Periods of high inflow were characterized by marked decreases in the alkalinity. As seen in Table 2, inflow during November-December, 1964, and March, June, and September, 1965, greatly increased. During these periods alkalinity decreased. Apparently, the inflow tended to dilute the impounded water.

When conditions between the two upstream and the two downstream stations were compared, there was an apparent decrease in the bicarbonate alkalinity as the water moved through the reservoir. That is, the bicarbonate alkalinity in the upper end of the reservoir was usually greater than in the lower part of the basin (Fig. 2). This decrease was probably related to utilization of bicarbonates by phytoplankters as a source of CO₂ for photosynthesis.

Specific Conductance

Specific conductance varied from station to station on any one date (Tables 5-8); however, when the average conductance in the top meter at the two upstream stations was compared to the average conductance at the two downstream stations, a pattern similar to that exhibited by alkalinity was observed. Conductance was highest during the colder months. This reflected the increases observed during this time in al-

Table 4. Monthly average bicarbonate alkalinity, orthophosphates, and dissolved oxygen prior to impoundment at four locations below the confluence of the Cottonwood and Neosho Rivers, June, 1963-March, 1964.

NR - Neosho Rapids
H - Hartford

S - Strawn
O - Ottumwa

Month	HCO ₃ Alkalinity mg/L				PO ₄ mg/L				Diss. O ₂ mg/L			
	NR	H	S	O	NR	H	S	O	NR	H	S	O
June	187	209	188	210	.40	.92	.70	.92	5.8	4.7	7.8	6.5
July	180	166	165	162	.47	.57	.46	.43	7.4	4.7	7.0	6.1
Aug.	180	174	183	180	1.00	.60	.34	.34	7.4	6.6	10.2	9.8
Sept.	160	195	193	175	.52	.53	.34	.37	12.4	9.2	9.2	11.6
Oct.	180	197	191	192	.76	.61	1.02	.73	7.1	6.1	6.1	7.9
Nov.	199	171	170	160	.86	.70	.46	.46	8.4	9.0	9.7	8.4
Dec.	271	264	256	241	.62	.76	.82	.68	16.9	12.6	14.6	15.0
Jan.	225	324	283	288	1.10	.67	.21	.30	14.0	15.2	15.4	16.0
Feb.	229	227	240	215	.75	.68	.81	.62	13.9	14.0	14.2	13.4
Mar.	241	215	200	200	.96	.81	.54	.66	17.2	17.8	15.6	-----

kalinity, phosphate, nitrate, and other solutes. Such increases were probably the result of a decreased utilization of these materials by plankters during the winter. Specific conductance in the top meter ranged from 305 to 752 micromhos/cm during the period covered by this paper.

Calcium, Sodium, and Potassium

Fluctuations in the amounts of calcium, sodium, and potassium present in the euphotic zone were similar. All values appeared to increase during the summer; this was especially true for calcium and sodium. Although the amounts of these cations appeared to vary with the amount of inflow, there was no apparent change in sodium or potassium between the upper and lower basin stations. The monthly mean calcium content ranged from 21 to 77 mg/liter; the monthly average for sodium usually exceeded 10 mg/liter; and potassium tended to average less than 6 mg/liter.

Alkyl Benzene Sulfonate

The concentration of ABS (more specifically, the total methylene blue active substances) in water samples exceeded 0.1 mg/liter in only nine of 168 samples analyzed. These levels were well below concentrations that produce taste and odor problems in water supplies. Cohen (1963) reported that ABS concentrations on the order of 1000 mg/liter were required before odor was detected and that none of a 21 member panel detected the taste of ABS at concentrations as low as 4 mg/liter.

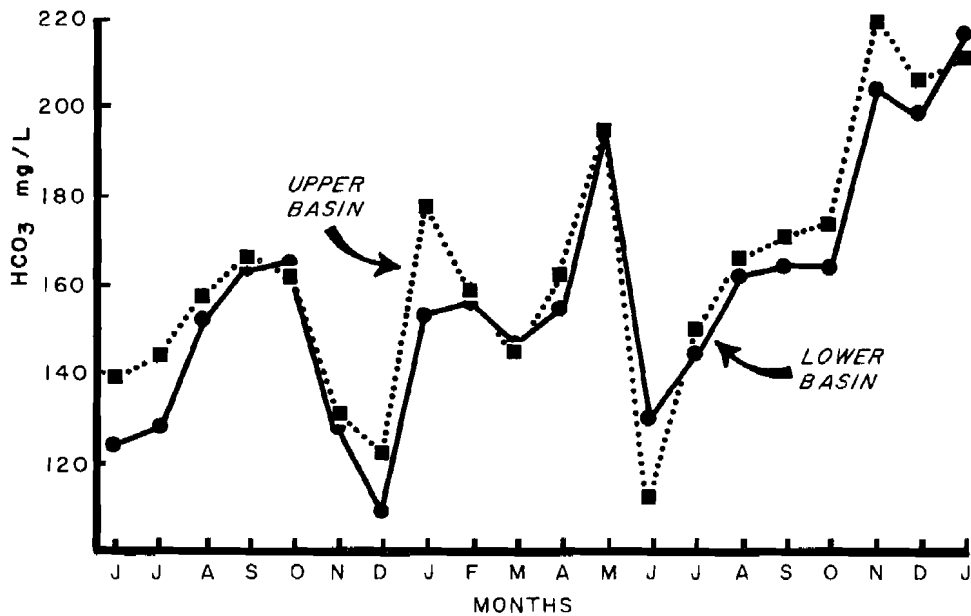


Figure 2. Variations in bicarbonate alkalinity between the upper and lower regions of John Redmond Reservoir from June, 1964, through January, 1966.

Table 5. Monthly mean conditions of some chemicals at Ottumwa.

Month	Diss. O ₂ mg/l		HCO ₃ mg/l		Sp. Cond. umhos/cm		PO ₄ mg/l	NO ₃ mg/l	Ca mg/l	Na mg/l	K mg/l
	Top	Bot.	Top	Bot.	Top	Bot.					
June '64	5.7	4.4	131	122	359	344	.52	----	----	----	----
July	5.9	2.4	148	150	378	385	.22	.33	46	12	2
Aug.	6.0	4.1	158	162	406	411	.17	.38	41	9	5
Sept.	6.3	5.6	167	171	440	450	.13	.37	40	10	6
Oct.	9.0	7.5	163	158	472	483	.12	.28	37	7	3
Nov.	7.9	7.4	132	132	443	404	.33	.60	29	0	3
Dec.	9.8	-----	124	-----	444	-----	.67	.44	43	9	10
Jan. '65	9.3	7.9	178	169	-----	-----	.51	.30	64	14	8
Feb.	14.8	12.6	151	171	694	763	.28	.60	80	25	6
Mar.	11.3	11.1	144	146	507	519	.29	.94	29	3	1
Apr.	8.6	8.4	172	179	481	500	.21	.99	61	12	3
May	9.8	7.7	193	190	556	568	.37	.14	46	11	3
June	5.9	5.5	112	117	305	310	.50	.51	20	7	5
July	6.4	5.7	150	160	379	400	.31	.79	44	10	5
Aug.	6.4	6.1	169	172	455	459	.24	.51	57	12	5
Sept.	"	"	"	"	"	"	"	"	"	"	"
Oct.	8.2	7.9	173	176	433	460	.35	.53	53	10	6
Nov.	6.8	6.3	226	235	474	515	.05	.05	70	16	4
Dec.	10.0	9.7	232	230	704	704	.09	.20	72	19	5
Jan. '66	12.6	12.4	212	214	733	679	.04	.02	75	19	4

"Sampling prevented due to weather conditions.

Table 6. Monthly mean conditions of some chemicals at Hickory Creek.

Month	Diss. O ₂ mg/l		HCO ₃ mg/l		Sp. Cond. umhos/cm		PO ₄ mg/l	NO ₃ mg/l	Ca mg/l	Na mg/l	K mg/l
	Top	Bot.	Top	Bot.	Top	Bot.					
June '64	5.9	4.3	148	120	405	330	.37	----	----	---	---
July	5.5	2.9	137	146	348	363	.19	.32	43	11	3
Aug.	6.0	8.0	156	156	401	408	.16	.49	41	8	5
Sept.	6.6	5.6	167	163	449	437	.14	.21	39	6	6
Oct.	9.0	7.6	164	164	495	483	.11	.16	34	4	4
Nov.	8.1	7.0	129	130	435	392	.34	.55	30	1	3
Dec.	11.9	-----	122	-----	526	-----	.33	.25	42	9	9
Jan. '65	10.3	9.7	161	157	-----	-----	.42	.17	50	12	9
Feb.	16.1	16.3	151	157	687	769	.76	.60	73	21	6
Mar.	11.7	11.9	155	155	595	571	.23	.82	46	54	16
Apr.	8.6	8.1	171	172	461	472	.42	1.20	60	12	3
May	7.4	8.1	190	191	522	518	.33	.56	39	9	3
June	6.3	5.5	125	123	330	326	.47	.27	21	8	4
July	5.8	5.2	152	151	406	400	.26	.69	48	11	5
Aug.	6.7	6.2	167	167	442	452	.19	.60	57	12	5
Sept.	7.1	6.9	147	147	450	437	.09	.38	66	14	5
Oct.	8.3	7.8	161	165	407	423	.26	.40	47	10	8
Nov.	7.2	6.6	215	215	610	598	.07	.15	68	15	4
Dec.	10.4	11.1	237	236	712	712	.05	.20	77	20	5
Jan. '66	11.8	12.3	211	212	711	741	.06	.20	77	19	5

Phosphate and Nitrate

Both nitrate and phosphate in the reservoir were high when compared with the values from other smaller impoundments in East Central Kansas. According to Neel (1963) nutrients in newly impounded reservoirs are characteristically high during the first year or two of impoundment. Usually the high values are attributed to decomposition of the inundated vegetation. However, at the 1965 American Fisheries Society meeting in Tulsa, Oklahoma, James Mullan and Richard Applegate (Bureau of Sport Fisheries and Wildlife, Fayetteville, Arkansas) reported there was no significant difference in the nutrient base of the 14-year old Bull Shoals Reservoir and the newly impounded Beaver Reservoir. They suggested that the occurrence of an initial flush of nutrients in a newly impounded reservoir may be influenced by a combination of factors, such as time of impoundment, filling time, and thermal and light properties.

Although there was undoubtedly an addition of nitrate and phosphate from decomposition of submerged vegetation, these materials were also introduced into the reservoir from upstream sources. Phosphate levels in the rivers have generally been greater than 0.5 mg/l (Table 4). In addition to effluents from sewage treatment plants of at least

Table 7. Monthly mean conditions of some chemicals at East Point.

Month	Diss. O ₂ mg/l		HCO ₃ mg/l		Sp. Cond. umhos/cm		PO ₄ mg/l	NO ₃ mg/l	Ca mg/l	Na mg/l	K mg/l
	Top	Bot.	Top.	Bot.	Top	Bot.					
June '64	7.3	6.4	110	130	327	334	.31	----	----	----	----
July	5.9	3.0	130	128	331	335	.25	.40	39	11	2
Aug.	6.2	4.8	153	152	395	398	.20	.27	38	8	4
Sept.	6.9	5.5	165	167	445	443	.10	.19	39	9	6
Oct.	8.9	8.0	169	166	476	483	.10	.20	33	6	3
Nov.	7.1	7.4	130	128	436	436	.22	.05	30	0	3
Jan. '65	10.3	10.2	145	141	-----	-----	.49	.44	48	12	12
Mar.	11.7	11.7	137	141	504	495	.35	1.29	37	3	1
Apr.	8.6	8.4	155	156	461	500	.42	1.40	54	11	3
May	7.7	6.7	189	186	535	537	.34	.59	40	9	3
June	6.4	5.6	130	131	346	343	.05	.34	23	9	4
July	6.1	5.1	143	142	368	369	.35	.55	43	9	4
Aug.	7.2	6.5	164	163	435	447	.26	.52	57	12	5
Sept.	8.0	7.7	168	166	495	495	.20	.40	72	----	5
Oct.	9.1	7.8	141	126	388	366	.27	.70	36	8	6
Nov.	6.6	6.4	208	210	591	576	.08	.25	66	14	4
Dec.	9.7	9.5	237	239	709	704	.05	.20	76	20	5
Jan. '66	12.5	12.7	217	218	736	719	.02	.10	79	20	4

five upstream communities, run-off from fertilized cropland and livestock feeding lots enters the rivers. Ordinary sewage is rich in both nitrogen and phosphorus (Sawyer, 1952), and the run-off from fertilized land and feed lots should also be high.

The monthly mean phosphate content in the euphotic zone reached a peak during the first winter of impoundment, averaging 0.6 mg/liter during February, 1965 (Fig. 3). Although phosphate fluctuated during the following year, the overall trend was for the concentration to decrease. Nitrates followed a similar pattern (Fig. 4).

There were slight differences in the relative amounts of nitrate and phosphate between the upper and lower regions of the basin. From June to December, 1964, values for nitrate and phosphate tended to be higher in the upper region of the basin, but during the next 12 months the converse tended to be the case.

The increase in both nitrate and phosphate during the winter and early spring of the first year was probably due primarily to decomposition of submerged vegetation. The water level of the reservoir was raised approximately two meters during the latter half of November, 1964, flooding a large area of the shoreline. This, coupled with the decreased uptake of nutrients by the phytoplankters during the colder months, would probably account for the build up of both nitrate and phosphate. The marked fluctuations of nitrate and phosphate during July and October, 1965, were thought to be due to a combination of

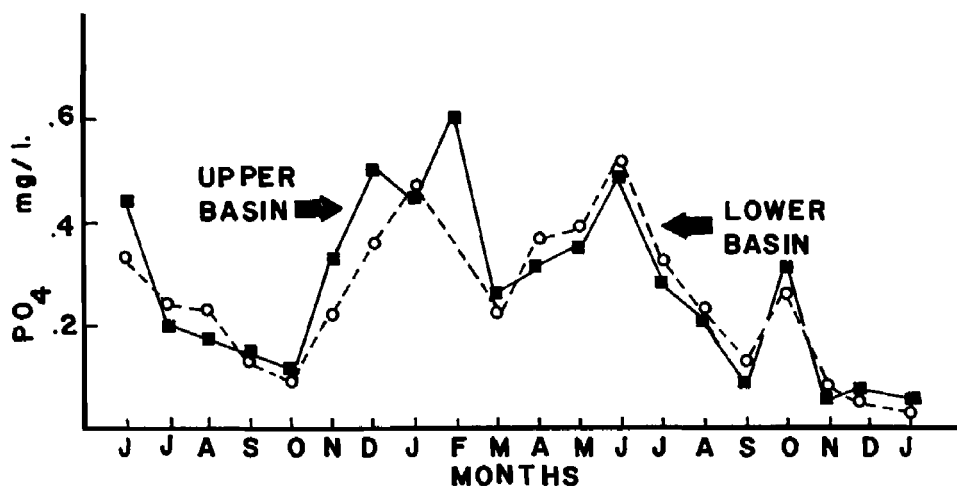


Figure 3. Variation in phosphate content in the euphotic zone between the upper and lower basin of John Redmond Reservoir from June, 1964 through January, 1966.

Table 8. Monthly mean conditions of some chemicals at Redmond Cove.

Month	Diss. O ₂ mg/l		HCO ₃ mg/l		Sp. Cond. umhos/cm		PO ₄ mg/l	NO ₃ mg/l	Ca mg/l	Na mg/l	K mg/l
	Top	Bot.	Top	Bot.	Top	Bot.					
June	6.1	5.9	139	127	366	390	.36	----	----	----	----
July	5.9	3.9	128	116	326	330	.23	.58	42	11	2
Aug.	6.1	5.2	153	151	393	386	.26	.22	38	7	5
Sept.	6.7	5.8	165	163	441	437	.19	.36	40	9	7
Oct.	9.1	8.3	161	169	492	478	1.72	.10	35	4	3
Nov.	7.2	7.2	122	128	457	440	.22	.50	36	0	3
Dec.	9.9	-----	99	-----	500	-----	.36	.20	28	7	9.
Jan. '65	11.4	10.8	153	144	-----	-----	.46	.59	55	12	9
Mar.	11.9	11.8	146	145	515	489	.22	.89	39	4	2
Apr.	8.6	8.6	157	155	448	444	.33	.60	53	11	3
May	7.7	7.4	193	193	517	531	.33	.56	41	9	3
June	6.7	4.6	131	130	350	353	.54	.46	24	9	4
July	7.1	5.6	143	143	370	365	.32	.67	45	9	4
Aug.	6.9	6.1	164	168	446	435	.24	.52	57	12	5
Sept.	6.7	6.8	166	161	513	508	.06	.30	76	15	5
Oct.	8.3	7.8	162	158	393	394	.26	.62	44	9	5
Nov.	6.7	6.4	207	207	581	567	.08	.30	65	14	4
Dec.	9.9	10.2	230	235	752	758	.05	.20	74	19	5
Jan. '66	12.8	12.6	216	218	733	731	.06	.00	79	21	4

flushing out and an inflow of organic material into the basin due to the excessive run off occurring during those periods. Throughout the period covered by this study, nitrate and phosphate levels were well above the levels necessary for the development of algal blooms as suggested by Sawyer (1952).

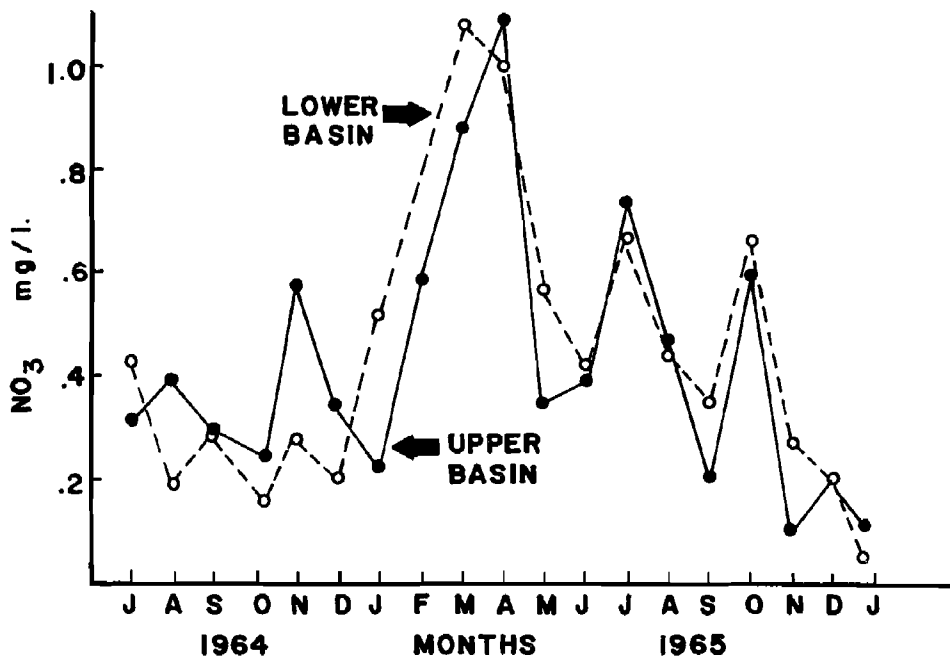


Figure 4. Variation in nitrate-nitrogen in the euphotic zone between the upper and lower basin from June, 1964, through January, 1966.

Chlorophyll

The monthly mean concentration of chlorophyll in the euphotic zone varied inversely with amounts of phosphate and nitrate present. In general, chlorophyll was lowest during the winter, usually less than 10 mg/m^3 , and then gradually increased throughout the spring and summer, reaching a maximum of approximately 25 mg/m^3 during the fall. Small (1964) stated that chlorophyll concentrations of 30 mg/m^3 or greater during the growing season indicated eutrophic conditions in lakes. On this basis, if the present trend continues, this condition could present some serious problems to management of the reservoir. Even though the relative amounts of nitrate and phosphate decreased during the second year, levels were still sufficient to maintain a large phytoplankton population. With the continuous introduction of nutrients in the inflow it does not seem likely that nitrate or phosphate will become limiting.

Based on the relative amounts of chlorophyll present in the euphotic zone, the phytoplankton density in the reservoir was slightly greater during the second year of impoundment (Fig. 5). Flooding may have prevented the 1965 summer chlorophyll values from being greater than they were. It appears that the phytoplankton density was adversely affected by the high inflow and drawdown. The drop in chlorophyll values during June, July, and October, 1965, was thought to be due to the diluting and flushing affect of the increased inflow that occurred during those periods.

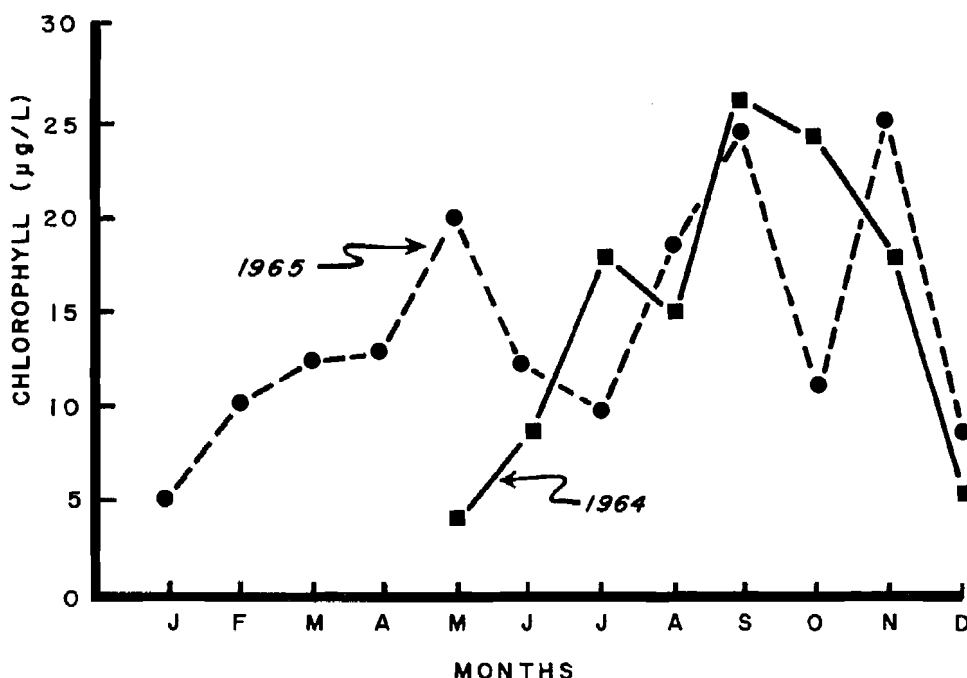


Figure 5. Monthly mean chlorophyll concentrations in the euphotic zone during 1964 and 1965.

The concentration of chlorophyll often differed from one part of the reservoir to another and was probably due to dispersal of the standing crop of phytoplankters by the wind action (Small, 1964).

Although no attempt was made to quantitate the species composition of the phytoplankters, examination of tow net samples indicated a predominance of desmids, mainly *Pediastrum*, and blue-green algae, especially *Oscillatoria*, during this study.

Primary Production

In most biotic communities photosynthesis is the primary means of energy fixation. Energy must be continually available if the biota is to grow and reproduce; and since the availability of energy in a community influences the rate and direction of succession, it is not surprising that limnologists have long been interested in the problems concerning the measurement of photosynthesis in lakes and rivers. In fact, the bulk of published literature on this subject is now great enough and so varied that the related terminology used by different investigators is becoming confusing, and some authors have stressed the need for standardizing the terminology (Davis, 1963). However, as Steeman Nielsen (1965) points out, care must be taken to avoid flooding the literature with a myriad of unnecessary terms. Perhaps the confusion could best be eliminated if authors more clearly defined the terms they used. In the following presentation the term "gross primary production" is used to designate the rate of photosynthesis by phytoplankters during the period of maximum daily insolation as estimated from changes in the dissolved oxygen concentrations in paired light and dark bottles. Pro-

duction by rooted plants and benthic organisms was not included in the estimations.

More than 115 separate measurements of gross primary production were recorded during the period from May, 1964, through February, 1966, of which approximately 50% were made during the months of June, July, and August. Although an attempt was made to obtain measurements at least once per week during the fall, winter and spring, it was often not possible. During the late fall and early winter, skies were frequently overcast on the days the reservoir was visited and measurements were not attempted since a means to adequately measure insolation was not available.

There was often considerable variation in the primary production from one date to another, depending upon such factors as turbidity, concentration of chlorophyll, and insolation. Measured primary production ranged from 17 to 483 micrograms O_2 /liter of euphotic zone/hour but values were most commonly near the middle of this range. As can be seen in Table 9 nearly 75% of the measurements yielded values which exceeded 100 micrograms O_2 /liter/hour, and 45% of all measurements fell within the range of 100-199 micrograms O_2 /liter/hour.

Gross primary production in John Redmond Reservoir averaged approximately 153 micrograms O_2 /liter/hour during the period covered by this study. In general, production increased during the spring and reached maximum values during the late summer and early fall. The apparent exception to this trend occurred during February, 1965, when two measurements averaged 282 micrograms O_2 /liter/hour (190-375 micrograms O_2 /liter/hour). Perhaps a part of the explanation for the higher rate of photosynthesis rests in the fact that the transparency of the water greatly increased as water temperatures decreased. For example, the Secchi disc depths usually varied from about 0.25 to 0.40 meter during most of the year, but, during January and February, the depths ranged from 0.75 to 1.0 meter. Thus, the volume of the euphotic zone during these months was greatly increased; and, also, wave action was less thereby facilitating light penetration. The recorded primary production during the following winter was less than that recorded during 1965, but still relatively high as compared with the production observed during other months of the year (Table 10). These winter averages were based on only a few measurements and may not be truly characteristic of the reservoir during the winter. Numerous studies have drawn attention to seasonal variations in primary production which is to be expected in view of the changes in daily isolation during the different seasons of the year. Local conditions, other than insolation, will also influence photosynthesis: For example, maximum production during 1964 occurred during July and September, but the following year production was relatively low during the summer and did not reach a peak until October. In this case the low production during the 1965 summer was due primarily to the entrance of flood water into the reservoir during June and July. Goldman and Wetzel (1963) reported a bimodal photosynthesis pattern for Clear Lake, California, with primary production reaching peaks during the early summer and again during the fall. It was lowest during the winter. Williams and

Table 9. Comparison of estimated gross primary production in euphotic zone of John Redmond Reservoir.

% Measurements	Photosynthesis $\mu\text{gO}_2/\text{L}/\text{hr.}$
5.3	0-49
20.0	50-99
26.3	100-149
18.9	150-199
29.5	200 or greater

Table 10. Comparison of monthly average chlorophyll concentration and gross primary production in John Redmond Reservoir.

Month	Chlorophyll $\mu\text{g}/\text{L}$	Gross Production $\mu\text{gO}_2/\text{L}/\text{hr}$	Photosynthesis per unit of Chlorophyll $\mu\text{mole O}_2/\mu\text{gChl}/\text{hr}$
1964			
May	3.55	125	1.10
June	8.85	85	.30
July	17.42	232	.42
Aug.	14.55	126	.27
Sept.	25.47	211	.26
Oct.	23.42	131	.17
Nov.	18.41	119	.20
1965			
Feb.	11.20	282	.77
Mar.	13.37	111	.26
Apr.	13.77	60	.13
May	20.00	130	.20
June	12.52	109	.27
July	8.75	154	.54
Aug.	17.64	157	.28
Sept.	23.24	194	.26
Oct.	10.61	234	.69
Nov.	23.9	80	.10
Dec.	-----	133	-----
1966			
Jan.	30.23	157	.16
Feb.	6.7	160	.75

Murdoch (1966) reported that photosynthesis in Beaufort Channel also exhibited a pronounced seasonal cycle of high values during the summer and early fall and low values during the winter, and Verduin (1960) found that photosynthesis gradually increased throughout the summer in Western Lake Erie.

Compared with other smaller impoundments in East Central Kansas, gross primary production in John Redmond Reservoir was relatively high. Measurements of gross primary production in Lyon County Lake 16 km northeast of Emporia ranged from 5 to 153 micrograms O_2 /liter/hour from October, 1963, through June, 1965. These measurements were recorded during the period this lake was being reflooded. It had been drained by the Kansas Fish and Game Commission during October, 1962, as the initial step in rehabilitating the fisheries. Another small impoundment, Chase County Lake about 40 km west of Emporia, exhibited values of 50 to 160 micrograms O_2 /liter/hour during the 1964 summer. On the other hand, when compared with the photosynthetic rates in a shallow North Carolina estuary (Williams and Murdoch, 1966), Canyon Ferry Reservoir in Montana (Wright, 1959), Western Lake Erie (Verduin, 1960), and Clear Lake, California (Goldman and Wetzel, 1963), the values from John Redmond Reservoir fall in the lower range of the results reported for the above communities.

Photosynthesis per unit of chlorophyll varied from 0.10 to 1.10 micromole O_2 /microgram Chlorophyll/hour but was usually around 0.25 micromole/microgram chlorophyll/hour. Production was not always greatest when chlorophyll values were highest, indicating that the relationship between chlorophyll and photosynthesis is complex. Light, age, and condition of the phytoplankters, and, perhaps, numerous other conditions will influence photosynthesis (Wright, 1959; and Williams and Murdoch, 1966).

FUTURE CHANGES IN THE RESERVOIR

The general limnological features of the reservoir may undergo considerable change during the next few years. There are some distinct differences between the water chemistry of the upper Neosho and the Cottonwood River. During the current study it was evident that the chemistry of the reservoir was greatly influenced by the relative flow in these two rivers. After the upstream dams are completed, it should be possible to regulate, at least partially, the flow in the two rivers and thereby control some of the chemical features of the water entering the reservoir.

The morphometry of John Redmond Reservoir is such that the reservoir operates as a single water mass. Differences between the upstream and downstream regions of the basin are not expected to become more pronounced or even to continue to be evident unless something happens to change the general physical features of the reservoir. It is possible in the future that the Corps of Engineers will increase the conservation pool by approximately 20%. Such an increase would extend the storage time of the impounded water allowing greater modification by biological activity. Depth would also be increased and this might allow

the reservoir to become more strongly stratified than was evidenced during the first two years of impoundment. The detection of chemical change during storage will require numerous and frequent sampling of the water mass as it moves through the basin.

Nutrient levels have been relatively high since impoundment; and, in view of the amounts of nutrients known to be in the inflowing water during the past three years, it appears probable that the reservoir will continue to be characterized by relatively high nutrient values. As a result, phytoplankters and rooted aquatics are likely to develop dense populations. In fact, dense growths of *Polygonum coccineum* have developed in many parts of the basin during the summer. The area and density of these stands were great enough to prevent the passage of small motor boats through them. Their presence detracts from the recreational value of the reservoir, and, should they continue to develop and expand, they will become a serious problem to the management of the reservoir.

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