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Comparison of Summer Water Quality Features in Three Grand River Reservoirs, Kansas

by

Carl W. Prophet, Joy E. Prather, and N. Leon Edwards

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Abstract

Water temperature, specific conductance, bicarbonate, dissolved oxygen, phosphate, nitrate-nitrogen, sulfate, calcium, sodium, and potassium were measured in the three Grand River Reservoirs at regular intervals throughout June through August, 1968. In general, physicochemical conditions in Marion Reservoir differed significantly (.05 level) from conditions in Council Grove and John Redmond Reservoirs. There were few significant differences between physicochemical conditions in Redmond and Council Grove reservoirs. Summer mean diversity per individual $\bar{d}$ values based on zooplankton were significantly lower in Redmond and Marion than in Council Grove. Apparently, these two reservoirs were undergoing greater environmental stress than Council Grove. Marion was in the initial stages of flooding during the study and Redmond is subjected to periodic enrichment by commercial feedlot runoff.

Physicochemical conditions in Redmond during its initial five summers (1964-1968) of impoundment were also compared. In general, differences between successive years of individual physicochemical factors were not significant. However, most factors exhibited significant changes during the last year of the study. Dissolved oxygen, phosphate, and nitrate-nitrogen were higher in 1968 than in 1964; other factors measured were lower in 1968 than in 1964. Variations appear related primarily to spring and summer precipitation patterns.

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by

Carl W. Prophet, Joy E. Prather, and N. Leon Edwards *

Introduction

The Grand (Neosho) River originates in east central Kansas and is a member of the Arkansas River System which drains the approximate southern half of the state. Within the past decade, three U. S. Army Corps of Engineers dams, designed primarily as flood control measures, have been constructed in Kansas along the upper Grand River and its major tributary, the Cottonwood River. Council Grove Reservoir is on the Grand River 177 km above John Redmond Reservoir; both were impounded in 1964. Marion Reservoir, on the Cottonwood River 199 km above its confluence with the Grand River, was in the initial stages of filling during the 1968 summer.

Of the three reservoirs, Redmond is unique in that it is subjected to periodic enrichment by livestock wastes. During a given period, up to 70,000 cattle may be confined in five major feedlot operations along the lower reaches of the Cottonwood River between Strong City and Emporia. Wastes introduced into the river by the feedlot runoff move downstream as a pollution slug or front which can be readily detected by its low dissolved oxygen, high ammonia, and high fecal coliform bacteria levels. Fishkills often occur as a front moves downstream and are usually more severe following local precipitation of 2 to 4 cm when the river stage is low. On several occasions pollution fronts have entered the upper basin of Redmond Reservoir, reducing the recreational value of the reservoir (Prophet, 1969).

In June, 1964, a project was initiated to record limnological conditions in Redmond during its early impoundment. Results obtained during the first two years of the project indicated water quality in Redmond was influenced by relative flow in the Cottonwood and upper Grand Rivers (Prophet, et al., 1966). At that time, most of the water entering Redmond was derived from the Cottonwood River which is higher in dissolved solids than the upper Grand River. As a result, some

* Dr. Prophet is Professor of Biology, Kansas State Teachers College, Emporia, Kansas. Mrs. Prather and Mr. Edwards are graduate students, Department of Biology, Kansas State Teachers College, Emporia, Kansas. This project was supported in part by Federal Water Pollution Control Administration Grant WP-00615.

factors such as specific conductance and bicarbonate tended to increase in Redmond during periods of normal or low streamflow but decreased when discharge in the upper Grand River was high. It appeared that regulation of Cottonwood River flow by Marion Dam might result in measurable changes in water quality conditions in Redmond Reservoir. During the 1967 and 1968 summers the project was expanded to include measurements of physicochemical factors in Council Grove and Marion reservoirs in order to compare water quality conditions in reservoirs of different ages and whose drainage basin geochemistry differed.

A comparison of water quality features in the three reservoirs during the 1968 summer is here presented, and variations in limnological conditions recorded in Redmond during the past five years are summarized.

Methods

Data presented were based on measurements and samples taken at weekly intervals from June through August. Sampling sites were established at intervals of approximately 0.8 km along a transect extending from near the outlet to the upper reaches of each reservoir. At each site, water temperatures and specific conductance were measured at each meter from surface to the bottom with the aid of an A.R.A. FT-3 Hydrographic Thermometer and a Beckman RB-3 Solu Bridge. Dissolved oxygen, alkalinity, and pH were determined in the field for the top and bottom meters at each site, with additional measurements at intermediate depths when significant differences between top and bottom samples existed. Dissolved oxygen was measured with a Beckman Model 51 oxygen meter and electrode; pH was determined with a Beckman Model N pH meter. Chemical analyses were conducted according to procedures in *Standard Methods* (APHA, 1960).

Water samples for additional analyses were collected from the top meter at each sampling site on each sampling date and stored in plastic bags under refrigeration until analyses were completed. Calcium, sodium, and potassium were measured by flame photometry. Phosphate was determined by the stanous chloride method and nitrate-nitrogen by the brucine method. Ammonia-nitrogen values were obtained by direct nesslerization.

Results of field measurements and water analyses were recorded on IBM cards for statistical comparisons conducted by the Kansas State Teachers College Data Processing Center. Significance of differences between summer means of factors between reservoirs and between sampling sites within reservoirs was determined by the t-test.

Geology and Morphometry

Although the reservoirs are located in the same region of Kansas, morphometry and geology of their primary drainage basins differ. Redmond is located in an area of Pennsylvanian shales and limestones belonging to the Shawnee Group, while Council Grove is in an area dominated by the Permian Ft. Riley Limestone and Florence Flint. Marion is also in an area of Permian limestones and shales; however, they belong to the younger Summer Group (Moore and Landes, 1937).

Table 1. Morphometry of reservoirs at conservation pool level.

Reservoir	MSL	Drainage km^2	Area ha	Shoreline km	Volume $m^3 \times 10^6$	x Depth m
Redmond	1036	7537	3807	80	69.7	1.9
Council Grove	1270	615	1158	34	47.2	4.4
Marion	1350	500	2430	96	74.0	2.9

Morphometry of the reservoirs is compared in Table 1. In terms of surface area, Redmond is the largest (3807 ha) and Council Grove the smallest (1158 ha). However, the mean depth of Redmond is only 1.9 m compared to 4.4 m in Council Grove. When filled Marion will have the greatest volume (74.01×10^6 m^3) and longest shoreline (96 km), but the smallest drainage area (500 km^2) of the three. Drawdown in both Redmond and Marion is from the surface through gated outlets, while drawdown in Council Grove is from a single bottom outlet.

Thermal Conditions

Although smaller impoundments in east central Kansas usually become thermally stratified by early June and remain so until September (Prophet, 1966), Redmond does not follow this pattern since its basin is shallow and wind action is usually sufficient to maintain circulation. Although the surface stratum heats quickly on calm hot days, temperature differences in the water column are rapidly destroyed by renewed winds. Thermal discontinuity was detected along the river channel in the sheltered upper reaches of Redmond Reservoir during newed winds. Thermal discontinuity was detected along the river channel in the sheltered upper reaches of Redmond Reservoir during August, 1968, but did not extend into the open basin. This condition was probably the result of wedging of cooler more dense inflowing water under the warmer impounded water.

Marion exhibited no evidence of thermal stratification during the 1968 summer; however, it is expected that this reservoir will stratify when filled. Summer thermal conditions in Council Grove are influenced by spring and early summer precipitation. Thermal discontinuity did not become pronounced in this reservoir during the past two summers until late July or August. Apparently, the release of bottom water retarded the onset of stratification during this time since greater than normal precipitation necessitated rapid and almost continuous drawdown throughout spring and early summer. Thermal conditions in reservoirs, unlike most natural lakes, can be affected by rapid inflow and release of large volumes of water as well as by outflow from selected variable depths (Neel, 1963).

Maximum recorded surface temperatures in the three reservoirs during the 1968 summer occurred in late July and August, varying from 30 C in Redmond to 27 C in Marion. Bottom temperatures during this same time tended to be 2 to 3 C lower than surface temperatures. Surface temperatures in all three reservoirs fell within reported ranges for summer temperatures of other impoundments in the central United States (Prophet, et al., 1967; Harris and Silvey, 1940; and Ransom, 1969).

Water Quality

Observations prior to completion of Marion Dam indicated that dissolved solids were higher in the Cottonwood River than in the Grand River (U. S. Geological Survey, 1964; and Scobee and Prophet, 1968). Prophet, et al., (1966) found that certain physicochemical factors in the recently impounded Redmond Reservoir fluctuated depending upon the relative rates of flow in the Cottonwood and upper Grand rivers. In view of these observations it was assumed that water quality conditions in the three reservoirs would differ. A preliminary comparison was made of selected physicochemical factors in the three reservoirs during 1967. As expected, differences were noted; however, it was not known if they were significant or due primarily to the time and number of samples taken and other variables, for although Redmond was being sampled at regular intervals during this time, Marion and Council Grove were visited at irregular intervals.

The following summer steps were taken to reduce possible sources of error due to sampling procedures. It was impossible to obtain simultaneous samples from the three reservoirs but water samples and field measurements were taken during comparable time periods (0900 - 1300 hrs) on each sampling day and reservoirs were usually visited on consecutive days. For example, if Redmond were visited on

Table 2. Comparison of means of physicochemical factors near reservoir outlet, June through August, 1968. Concentrations in mg/liter.

Reservoir	Sp. Cond. micromhos/ cm 25 C	HCO_3	O_2	PO_4	NO_3	NH_3	SO_4	Ca	Na	K
Council Grove	262**	138.6	7.8	.09**	0.95	0.70**	16.7	27.4	7.2	6.2**
Marion	949*	199.8*	5.9*	.18	0.37*	1.00	178.3*	86.4*	17.9	9.4*
John Redmond	348	131.9	7.4	.33***	0.90	0.74	56.4	29.6	6.7***	4.0

* Significantly different from Council Grove and Redmond
** Significantly different from Redmond
*** Significantly different from Marion

Monday, and Council Grove on Tuesday, then Marion was sampled on Wednesday. If events were such that there was more than a one day interruption between days in a sampling set then those data were not used in comparisons.

Although summer means for individual factors varied between sampling sites within each reservoir, differences generally were not significant (0.05 level). On the other hand, there were significant differences between reservoirs. Summer means of physicochemical features at sampling sites located near the outlets of each reservoir are summarized in Table 2. With respect to the factors measured, water quality in Marion was significantly different from that in either Redmond or Council Grove while there were few significant differences between Council Grove and Redmond. Specific conductance, phosphate and potassium were the only factors in Redmond and Council Grove which differed significantly.

One of the major differences in water quality between reservoirs was due to dissolved salts, as reflected by specific conductance. Conductance was greater in Marion than either of the other two reservoirs and was due primarily to high bicarbonate, sulfate, and chloride levels. Chloride, though measured at irregular intervals, was always more than three times as great in Marion as in the other reservoirs. Calcium, sodium, and potassium were also greatest in Marion.

Another difference between impoundments was due to nutrient levels. Phosphate was significantly higher in Redmond than in Marion and Council Grove; Council Grove exhibited the lowest summer mean phosphate level, .09 mg/liter. Although phosphate was higher in Marion than Council Grove, the difference was not significant. Nitrate-nitrogen was lowest in Marion and highest in Council Grove, but there was no significant difference between mean nitrate levels in Council Grove and Redmond. The high nutrient levels in Redmond are attributed, at least in part, to introduction of organic wastes in feedlot runoff since phosphate and nitrate increase in the Cottonwood River during and immediately following periods of runoff. Measurements of phosphate and ammonia-nitrogen in runoff from feedlots located near Emporia consistently yielded concentrations exceeding .75 and 15 mg/liter, respectively. High nitrate in Council Grove was thought due to nitrogen fixation by Cyanophyta. Phytoplankton present at bloom density in this reservoir was dominated by *Anabaena*, a nitrogen-fixer. There is no other important known source of nitrate for this reservoir, and nitrate levels increased over the past two years during which time blue-green blooms occurred. Nutrient levels in all three reservoirs tended to be higher than levels recorded for smaller impoundments in this part of the state but fall within ranges reported for Missouri River main stem impoundments by Benson and Cowell (1967) and other reservoirs and small lakes, some of which are subjected to organic enrichment (Gaufin and McDonald, 1965; Irwin, Symons, and Robeck, 1967; and Neel, 1967).

Although the above comparisons indicated significant differences in physicochemical factors between the three reservoirs, they provided little insight into their possible ecological importances or effects. If these differences are ecologically significant it should be reflected by community structure within each reservoir. Ransom (1969) reported community structure of benthic macroinvertebrates in Keystone Reservoir, Oklahoma, was affected by water quality conditions, and species diversity indices based on benthic macroinvertebrates have been successfully used to evaluate pollution in lotic communities (Wilhm and Dorris, 1968).

A preliminary investigation of zooplankton community structure in the reservoirs was conducted concomitantly with the physicochemical work during the 1968 summer. Community structure of the Cladocera, Copepoda, and Rotifera components of the zooplankton was characterized by species diversity indices following the methods of Wilhm and Dorris (1968) and Patten (1962). Although there was agreement among reservoirs in terms of species composition of zooplankton, there were distinct and significant differences in community structure. Summer mean diversity per individual $\bar{d}$ in Council Grove was 2.86 and was significantly higher (0.05 level, Duncan's Multiple Range Test) than that in either Redmond or Marion. The difference between summer mean d values for Redmond (2.57) and Marion (2.50) was not significant (Prather and Prophet, 1969). Apparently Redmond and Marion were undergoing greater ecological stress than Council Grove. Ecologically, Marion is young and it was not surprising for diversity per individual to be comparatively low. On the other hand, Council Grove and Redmond are approximately the same age. The lower $\bar{d}$ in Redmond is thought to be due to periodic enrichment by feedlot wastes. A more comprehensive study of community structure is planned which may further clarify water quality conditions in these impoundments.

Five Years Trends of Physicochemical Features, Redmond Reservoir

Summer means of selected physicochemical factors in Redmond during the first five years of impoundment are summarized in Table 3. Prophet (1966) reported that during the first two years of impound-

Table 3. Summer means of selected physicochemical conditions near outlet of John Redmond Reservoir (June - August). Concentrations in mg/liter for the top meter.

Year	Sp. Cond. micromhos/cm 25 C	HCO_3	O_2	PO_4	NO_3	ca	Na	K
1964	467	138.0	5.9	0.28	0.46	40.8	9.1	3.7
1965	456	144.5	6.2	0.35	0.55	40.1	10.4	4.5
1966	448	152.1	6.8	0.08	0.29	53.4	16.5	4.6
1967	378	143.3	6.2	0.46	0.99	42.5	17.7	6.1
1868	348	131.9	7.4	0.33	0.90	29.6	6.7	4.0

ment, bicarbonate and specific conductance appeared to decrease as the water mass moved through the basin; and although these factors fluctuated seasonally, it appeared they were gradually increasing in the reservoir. The increase was attributed to the fact that most of the inflowing water during this time was derived from the Cottonwood River which was known to be high in dissolved solids. However, when summer means of factors were statistically compared differences between the upper and lower regions of the reservoir basin, as well as between successive years, were slight and generally not significant (.05 level). None the less some significant changes were detected.

Specific conductance decreased throughout the study and was significantly lower the last two summers than during the initial three years of impoundment. The decrease may have been due to an increase in the proportion of Grand River water in the inflow, resulting from release of water from Council Grove Reservoir.

There was no significant difference between the summer mean bicarbonate for the first and fifth year of the study. Bicarbonate was highest during the third (1966) summer, and lowest the fifth year. The difference between summer means for 1966, 1964 and 1968 was significant.

Dissolved oxygen appeared to fluctuate throughout the project but was significantly higher in 1966 and 1968 than during the other three summers. Low dissolved oxygen during the first year of impoundment was expected because of decomposition of inundated vegetation, but fluctuations observed during the following four years are difficult to explain. The time of day measurements were recorded remained essentially the same from one summer to the next, and obviously there was no shortage of nutrients to limit photosynthesis (Table 3). Overall environmental conditions in Redmond during 1965 and 1967 were similar. On the other hand, there was a marked difference in environmental conditions during 1966 and 1968, when dissolved oxygen was highest. The 1966 spring and summer precipitation was the lowest of the five years, while that of 1968 was the highest. As a result, the water level was lower and storage time was longer in 1966 than during the 1968 summer. It is tempting to attribute the decrease in the summer mean dissolved oxygen in 1967 to decomposition or organic materials introduced in the inflow by feedlot runoff. Seven separate fish-kills were reported along the Grand and Cottonwood rivers above Redmond Reservoir during the first six months of 1967 which were attributed to feedlot runoff, and on two occasions contaminated water was traced downstream until it entered the reservoir. However, one must then ask why dissolved oxygen was higher in 1966, since pollution from feedlot runoff was just as severe during 1966 as in 1967 (Prophet, 1969).

Nutrients were relatively high throughout the five years covered by this study. Feedlots constituted an important source of nutrients for Redmond Reservoir. Evidence to this is based on the decrease in nutrients in the reservoir observed during periods of reduced inflow and their increase during periods of high inflow. Work conducted by this laboratory during the 1968 summer indicated that feedlot runoff generally contained phosphate in excess of 5 mg/liter, ammonia-nitrogen ranging from 10 to 97 mg/liter, and from approximately 1 to 3 mg/liter nitrate-nitrogen. Phosphate and nitrate-nitrogen generally increased in the river following periods of runoff and tended to be highest in the vicinities of the feedlots.

The difference between the summer mean phosphate for 1964 and 1967 was significant; also, mean phosphate for the 1966 summer was significantly different from that of each of the remaining four summers. Nitrate-nitrogen exhibited the same general trend as phosphate, being lowest in 1966 and highest during the 1967 summer. There was a significant difference between the 1966 summer mean and that of each of the other four summers, also mean nitrate-nitrogen during 1967 and 1968 was significantly different from 1964.

With respect to relative concentrations of cations, the relationship $Ca > Na > K$ characterized Redmond Reservoir. Calcium remained relatively constant the first four years of the study and then decreased the last year. The difference between summer means for

1964 and 1968 was significant. Sodium and potassium followed the general trend of increasing during the first four summers and then decreasing. Unlike calcium, differences between their means for 1964 and 1968 were not significant; however, means for 1966 and 1967 were significantly different from 1964.

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