SEASONAL VARIATION OF PARTICULATE ORGANIC MATTER IN TUTTLE CREEK RESERVOIR

by

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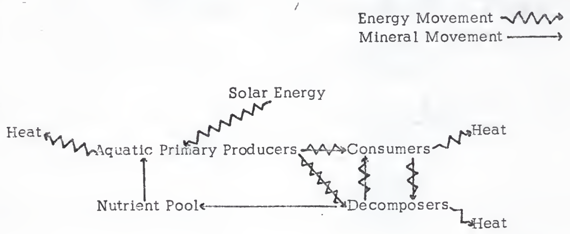
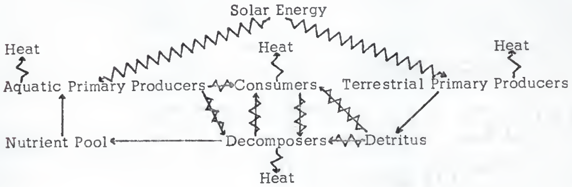
INTRODUCTION

The present study was undertaken to describe the amount of particulate organic matter available in Tuttle Creek Reservoir at various times in an annual cycle, and to assess the relationships between particulate organic matter and several environmental parameters. All life and indeed all living function depends upon an external source of energy, solar energy. Within ecosystems, plants act as primary producers to capture the solar energy and transform it to chemical energy which can be utilized by consumers. A conceptual diagram of the trophic relations of an aquatic ecosystem is shown below.



Within Tuttle Creek Reservoir, a flood control project of the Kansas River Basin in northeast Kansas, a number of factors may be operating to block or greatly reduce the transformation of solar energy to chemical energy by phytoplankton, the primary producers. These include low phytoplankton populations, high turbidity, and wind-generated currents. In the face of these limitations and from observations of large standing crops of zooplankton consumers, it becomes interesting to consider other energy-availing pathways. For that purpose the following diagram is presented as an alternative to the above.



The organic matter which enters the lakes as allochthonous detritus may function in three ways within the lake system according to the diagram proposed. The first is partial or complete decomposition. It is generally accepted that a number of decomposers act upon organic matter to return the substances to simpler forms which may be acted upon by autotrophic organisms. In this manner the decomposers constantly replenish the nutrient pool. Most available and easily accessible organic matter is mineralized within three to ten days (Kuznetsov, 1968).

While this process is important to autotrophic organisms which must rely on the nutrient pool for food substances, a second, more important relationship may evolve from this process, in respect to nourishment of consumers in turbid waters such as Tuttle Creek Reservoir. Darnell (1961) and Kuznetsov (1968) indicate that the biomass of bacteria formed through heterotrophic growth on the detritus can furnish significant nourishment for consumers which feed upon the detritus, and thereby upon the bacteria.

The third fate of the allochthonous detritus is that of direct consumption by consumers. Filter-feeding rotifers, crustacean zooplankters, plus bottom-dwelling invertebrates have feeding structures which allow ingestion of particulate matter. Larger consumers, such as gizzard shad, catfish, and carp may also consume the detritus directly (Darnell, 1961).

In addition to the trophic relationships presented above, it must be recognized that the allochthonous organic matter may have other effects upon the reservoir. Ruttner (1963), Gray and Shah (1964), and Ellis, Westfall, and Ellis (1946) indicate that decomposition of organic matter can appreciably influence the metabolic activity in the water. In 1963 a heavy runoff, as a result of rains in the upper regions of the Tuttle Creek Reservoir drainage basin, carried considerable amounts of silt and organic matter into Tuttle Creek Reservoir. Even with considerable aeration due to wind action the organic matter load imposed upon the reservoir decreased the dissolved oxygen content to near zero in a relatively large area (Gray et al, 1964).

This study reports the seasonal variation in particulate organic matter in Tuttle Creek Reservoir from March, 1967, to July, 1968. The relationships between this parameter and certain others available during the study period were explored through statistical analyses and literature review.

STUDY AREA

The Tuttle Creek Dam and Reservoir is a U. S. Army of Engineers project situated near the apex of the Blue River Drainage Basin. It is a key unit in the Kansas River Basin reservoir system. It provides flood control, augments low water stream flow to the Kansas, lower Missouri and Mississippi rivers, assists in water quality control, and provides recreation. No hydroelectric power is generated.

The earthfill dam is located on the Big Blue River 3.2 km below the mouth of Tuttle Creek, and 19.7 km upstream from the confluence of the Kansas and Big Blue Rivers. It is 9.6 km north of Manhattan, Kansas. At conservation pool the reservoir lies between Pottowatomie and Riley counties, and extends into Marshall County, all in Kansas.

The 2,475,000 hectares of drainage area extends 240 km to the northwest with a maximum width of 205 km. Three-fourths of this drainage area lies within Nebraska, the balance in Kansas.

Most of the land in the drainage basis is used for agricultural purposes, with an estimated 75 per cent cultivated and 15 per cent in pasture.

The soils of the area are classified as to origin into four groups: residual, alluvial, loessial, and glacial. The lower portion of the basin consists mainly of residual and alluvial soils derived from shales and limestones. The upper portion has loessial soils underlain by glacial fills and alluvial sands (Kansas Water Resources Board, 1964).

The sediment loads of tributary streams are heavy. Records (1943-1959) made at the gaging station at Randolf near the head of the reservoir show that the annual suspended sediment load flowing through this station before the reservoir was constructed was about 6,629,000 tons. The particulate size of the suspended sediment averages 54 per cent clay, 40 per cent silt, and 6 per cent sand. The average annual reservoir inflow rate is 49.5 m^3s although instantaneous values have ranged from 1.06 m^3s to 2615 m^3s.

The reservoir lies within a steep-sloped, flat-bottomed valley approximately 1.6 km wide through the main pool of the reservoir. It extends to the north-northwest from the dam for approximately 23.2 km, then deflects to the northeast to continue its course. When at conservation pool the lake has a surface elevation 327.5 m above mean sea level. The total capacity of the reservoir is 0.526 km^3. Its main tributaries are the Big Blue, Little Blue, and the Black Vermillion Rivers (Cramer, 1969).

The shallowness of the lake (average depth of 8 m, maximum depth 25 m), inflowing tributaries, frequent and gusty winds, plus rains are factors which combine to stir the water and prohibit thermal stratification for prolonged periods. These same factors, combined with the heavy sediment inflow, are responsible for turbid conditions. From 20 June 1967, through 20 November 1967, the maximum depth to which the Secchi disc was visible was 45 centimeters. For the period of study the maximum measurement was 180 centimeters, the minimum measurement 5 centimeters. The average of the measurements was 69 cm $\pm$ 7.

The long narrow valley in which the reservoir lies acts as a tube or trough, so that when outflows are high the inflowing waters have little chance to mix with the water present. As the "old" water is drained through the outlets the "new" water advances down the valley. If the inflow is turbid, as during periods of high runoff, the result is two distinct zones, or bodies, of water. As outflow continues these zones progress down the valley, often with the demarkation quite visible during the progression through the entire length of the reservoir.

Water samples during the study were collected at midlake near McIntyre Creek 3 km above the dam. The maximum water depth at this location was 10 m (see Fig. 1).

METHODS AND MATERIALS

Water samples were collected using a 3-liter Kemmerer brass sampler. Duplicates were obtained for both the surface and 5 meter depths. Approximately one liter of water from each sample was transferred to a polyethylene bottle in which it was returned to the laboratory for analysis. Normally the samples were returned within an hour of the sampling time, and were placed in a refrigerator until processed.

The first collection of samples for the study was made on 17 March 1967, with three additional collections made at two or three week intervals. Beginning 23 May 1967, samples were collected on a weekly basis through 8 April

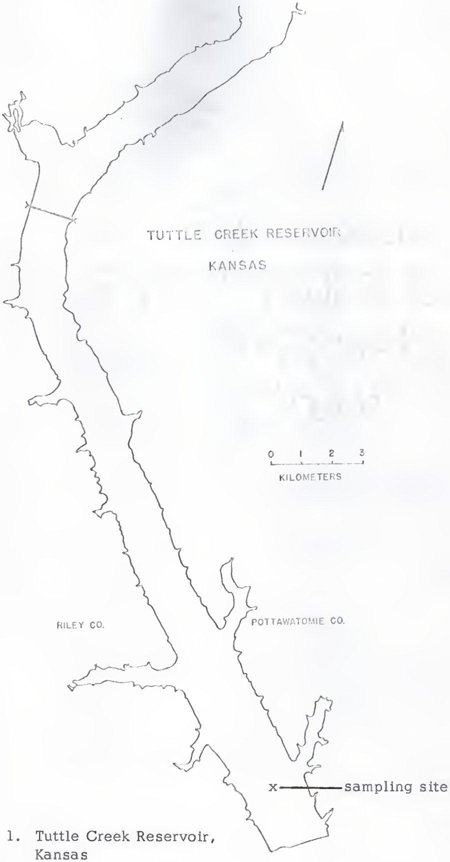


Figure 1. Tuttle Creek Reservoir, Kansas

1968. The sampling was shifted to biweekly at that time and continued to the end of the study. Previous analyses had shown that such a time period would be adequate in describing variations.

The method used for the study was the "wet ashing" method as described by Strickland and Parsons (1960). It involved filtration of water samples onto 47-mm AA Millipore membrane filters which had been treated with a magnesium carbonate suspension. Because of the turbid nature of the water only 250 ml of water was filtered for the analyses. All samples were strained through plankton net (mesh size = 0.076 mm) to remove larger zooplankters before filtration onto the membrane filters.

The residues remaining on the membrane filters were washed into 30 ml beakers and refiltered onto ultrafine (UF) porosity sintered glass discs. These were immersed in a mixture of potassium dichromate and concentrated sulfuric acid and heated for one hour in an over set at 100°C. After cooling the mixtures were transferred to volumetric flasks and diluted with distilled water to the prescribed volume. Blank solutions were also prepared.

The optical density of the samples was measured with a DU Spectrophotometer at a wavelength of 4400 A with a slit width of .10. The cell length used throughout the study was one centimeter.

The particulate organic matter was expressed in terms of milligrams carbon per cubic meter (mgC/m^3), found from the expression:

$$mgC/m^3 = \frac{(E)\ (F)\ (v)}{(V)}$$

where "V" is the volume (in liters) of water filtered, "F" is 280, "v" is the volume (in mililiters) of oxidant used, and "E" is the extinction, corrected for the absorbance of the trivalent chromium by multiplying the value from the spectrophotometer by 1.1.

During the study there was one notable deviation from the procedures as outlined by Strickland and Parsons. They indicated that the particles retained on the membrane filter eventually cause a positive clogging action, so that there is little to be gained in continuing the filtration process once the rate falls below 50 ml per minute. With the first fresh water sample under turbid conditions (Secchi disc measurement = 5 cm) the clogging action was immediate, so that only 50 ml of a 250 ml sample was filtered in twenty minutes at a suction "pressure" of more than twenty pounds per square inch. For lack of a more suitable alternative the samples were frozen for later analysis. This was done for samples collected from 27 June 1967, to 1 August 1967, at which time the Secchi measurement was 15 cm. When the samples were later thawed they were easily filtered, as the clay particles seemed to adhere, forming flakes which did not clog the filter as in the fresh samples.

Samples were collected to analyze the effect of freezing on the organic matter values. Two sets of duplicate samples were taken from the outlet area with one sample from each duplicate processed immediately, the other frozen. Those frozen were processed after one month. No differences were found in the results, thus no effect of freezing was imposed. The values for the samples processed immediately were 560 and 545 mgC/m^3, while those for frozen samples were 560 and 560 mgC/m^3.

The results given by this method are in terms of glucose carbon. The true carbon content of particulate organic material would only approach this value if all the carbon were present as carbohydrates (Strickland and Parsons, 1960). Birge and Juday (1934) indicate that the chemical composition of centrifuge plankton from their investigations of Wisconsin lakes was 59% carbohydrate, 37% crude protein, and 4% ether extract. However, as external organic matter increased within systems, the percentage of protein decreased rapidly. Since ether extract was rather steady, this implied an increase in percentage of carbohydrate.

Strickland and Parsons (ibid) believe the average composition of phytoplankton and detritus to be such that the true carbon content is within 10 to 20 per cent of the "oxidation" value given by their method. In this paper particulate organic matter will be recognized as but a portion of detritus, but will be used as an index to estimate the relative quantitites of detritus to be found in the reservoir.

Analysis of the results of the particulate organic matter analyses consisted of computation of simple correlation coefficients with a number of routinely collected environmental parameters. A multiple regression analysis was also performed coupled with an analysis of variance which allowed ranking of the environmental variables in the order of the contribution to the variation in the organic matter levels in the reservoir.

For the statistical analyses selected parameters were set as dependent

Table 1. Description of the parameters used in the study (sampling date = date organic matter sample was taken).

Number given to parameter	Name given to parameter	Description of the parameters
1	Organic matter	Particulate organic matter retained by AA Millipore membrane filter
2	Inflow 1	Sum of the mean daily inflow rates of the reservoir for the week preceding the sampling date
3	Inflow 2	Sum of the m.d.i.r. for 2nd week preceding sampling date
4	Inflow 3	Sum of the m.d.i.r. for 3rd week preceding sampling date
5	Inflow 4	Sum of the m.d.i.r. for 4th week preceding sampling date
6	Outflow 1	Sum of the mean daily outflow rates for the week preceding the sampling date
7	Outflow 2	Sum of the m.d.o.r. for 2nd week preceding sampling date
8	Outflow 3	Sum of the m.d.o.r. for 3rd week preceding sampling date
9	Outflow 4	Sum of the m.d.o.r. for 4th week preceding sampling date
10	Elevation	Reservoir level (elevation above mean sea level) on sampling date
11	Basin Rainfall	Total basin rainfall for the month preceding sampling date
12	Secchi	Secchi disc measurement on sampling date
13	Freshwater bacteria	Bacterial enumeration on fresh lake water

Table 1. (Continued)

Number given to parameter	Name given to parameter	Description of the parameters
14	Incubated bacteria	Bacterial enumeration from lake water which had been incubated
15	Inflow 1+2	Sum of the m.d.i.r. for two weeks preceding sampling date
16	Inflow 1+2+3	Sum of the m.d.i.r. for three weeks preceding sampling date
17	Inflow 1+2+3+4	Sum of the m.d.i.r. for four weeks preceding sampling date
18	Outflow 1+2	Sum of the m.d.o.r. for two weeks preceding sampling date
19	Outflow 1+2+3	Sum of the m.d.o.r. for three weeks preceding sampling date
20	Outflow 1+2+3+4	Sum of the m.d.o.r. for four weeks preceding sampling date

variables with all, or a number, of other parameters selected as independent variables. The parameters used in these statistical tests are indicated and explained in Table 1.

The results of the multiple regression analyses were reported in terms of the multiple linear correlation coefficient, R^2 (Fryer, 1966). This statistic measures the extent to which other variables "account for" the variations observed in the dependent variable. An R^2 of 1.0 would mean that all variables which account for variation in the dependent variable have been brought into the study.

RESULTS

The results of the wet oxidations are listed in Table 2 and shown in Fig. 2 along with the Secchi disc measurements. Figure 3 shows the weekly sums of mean daily inflow and outflow rates as well as organic matter.

The initial four values of organic matter are high when compared to the values for the same seasonal period of the following year. No apparent reason can be found through comparison with other parameters included in the study. The values from 23 May through 13 June 1967, however, are similar to values obtained for 1968.

During June, 1967, turbid runoff waters from heavy summer rain storms entered the reservoir and flowed through. The associated material reached the sampling site by 20 June 1967, as the organic matter value rose sharply to 812 mgC/m^3. The Secchi measurement at that time was reduced to 19 cm from the 74 cm measurement for the previous week.

Table 2. Organic matter values for each sampling date of the study with variances based upon four samples unless indicated.

Date	Organic Matter (mgC/m^3)	Variance	Date	Organic Matter (mgC/m^3)	Variance
17 III 67	1484	198 (2)	29 VIII	427	70
7 IV	1820	198 (2)	6 IX	378	36
20 IV	1330	115	12 IX	495	212
12 V	1087	685 (3)	21 IX	385	42
23 V	182	13	27 IX	336	56
30 V	420	92	3 X	336	0
6 VI	434	20 (2)	10 X	301	35
13 VI	448	119 (2)	17 X	392	33
20 VI	812	16	26 X	427	53
27 VI	4144	--- (1)	31 X	469	42
5 VII	6720	158	14 XI	322	36
10 VII	5600	202	20 XI	322	28
19 VII	1968	556	28 XI	308	33
25 VII	252	174	5 XII	364	0
1 VIII	915	201	12 XII	280	32
8 VIII	1176	168 (2)	19 XII	273	27
15 VIII	1148	192	9 I 68	289	70
22 VIII	469	77	17 I	259	14

Table 2. (Continued)

Date	Organic Matter (mgC/m^3)	Variance	Date	Organic Matter (mgC/m^3)	Variance
24 I	224	23	26 III 68	595	120
8 II	196	0	3 IV	406	28
14 II	210	28	8 IV	378	59
22 II	289	32	13 V	329	27
27 II	294	28	5 VI	719	48
5 III	385	27	19 VI	315	42
13 III	420	38	3 VII	364	40
19 III	539	27	17 VII	728	0

The full influence of the turbid waters was shown during the next three collections. The organic matter measurements were tenfold the measurements of the previous month, averaging nearly 5,500 mgC/m^3. The Secchi measurements were 5, 9, and 8 cm at this mid-lake sampling site on 27 June, 5 and 10 July, respectively.

Although the sampling site remained turbid throughout the remainder of the summer, the organic matter measurement returned rapidly to 252 mgC/m^3, the approximate level present before the turbid water reached the site.

The return to the lower level was temporary as the level rose to approximately 1000 mgC/m^3 for the next three weeks. Increased inflows (Fig. 3) were experienced at the beginning of this period.

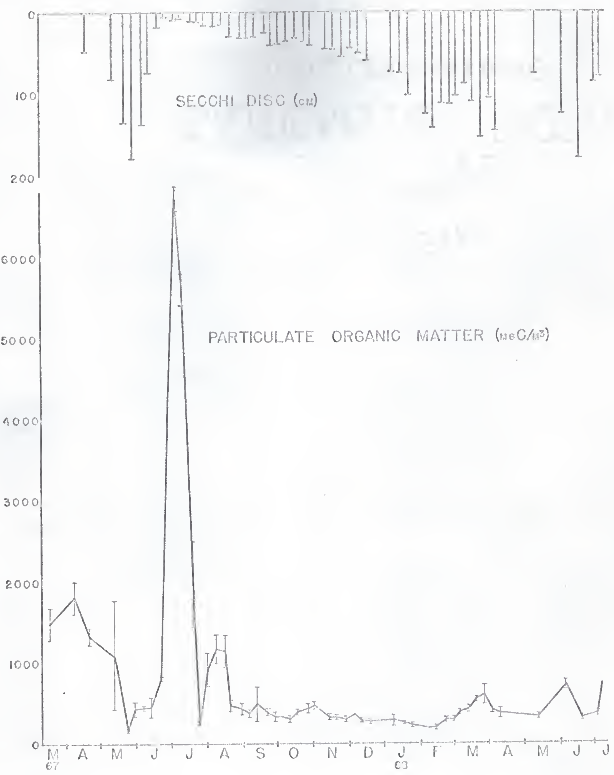


Figure 2. Variations of organic matter and Secchi disc measurements throughout study.

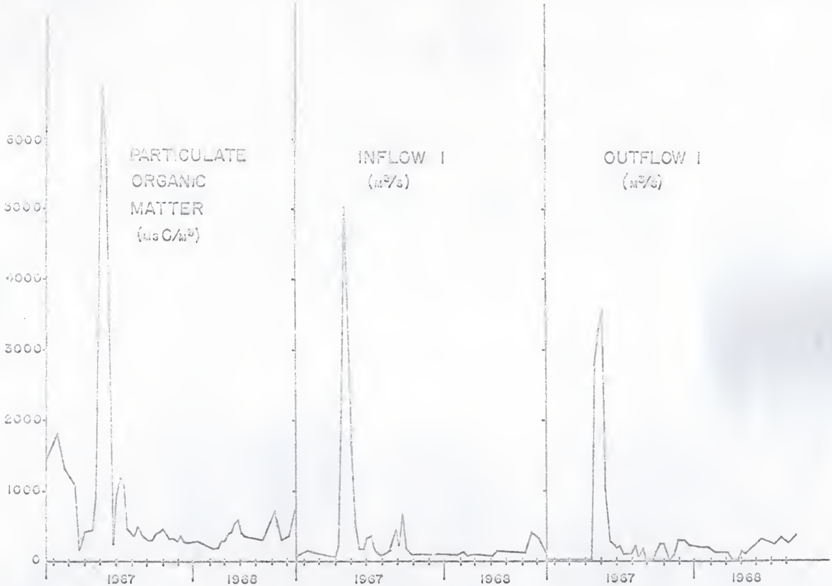


Figure 3. Organic matter, Inflow 1, and Outflow 1 throughout study.

Throughout the remainder of the summer and into the fall the level of organic matter fluctuated between 250 and 500 mgC/m^3. It reached a mid-winter low of 196 mgC/m^3 on 8 February 1968, and increased steadily to 595 mgC/m^3 on 26 March. During this period inflow was relatively constant at 500 cfs.

In the two collections of 3 and 8 April 1968, organic matter decreased. Measurements continued in unpatterned fluctuations through the remainder of the study, the last collection being made 17 July 1968. Inflow and Secchi measurements also show unpatterned fluctuations during this period.

The data were arranged for statistical analysis in six different ways, each arrangement is hereafter referred to as a subset. These six subsets yielded sixteen multiple regression analyses, in addition to the simple correlation tables for each subset of data. Those results are described below.

The first subset of data incorporated 43 sampling dates, from the beginning of the study through 13 March 1968. This included all dates for which there are bacterial counts. It involves all parameters for the maximum number of observations.

The first multiple regression analysis considered organic matter as the dependent variable against all other parameters as independent variables. The second used bacterial counts in fresh water, while the third multiple regression used bacterial counts in incubated water. Examination of graphs of the various parameters suggested that inflow rates, and perhaps outflow rates, were of extreme importance in the influence which they had on the organic matter at the sampling site. The fourth and fifth multiple regressions of Subset I, therefore, eliminated the sums of weekly inflow and outflow rates for the various time intervals preceding sampling. This was done to evaluate the ability of other parameters to account for variability in organic matter, once the weekly inflow and outflow parameters were eliminated. Table 3 summarizes the results of these analyses.

Table 3. Multiple regression analyses for Subset I listing the most important contributions of parameters to R^2. (* and ** indicate significance at the .05 and .01 levels, respectively.)

# of Mult. Regr.	Depend. Param.	Param. Excluded	Most important contributions # Param.	Contr. to R^2	F-test/D.F.	Total Contr. to R^2
1	1	none	4	.895	351/41**	
			3	.036	31/39**	
			10	.022	10/40**	
			12	.013	16/38**	
				Total for all parameters----		.985
2	13	14	16	.659	79/41**	
			6	.065	9/40**	
			7	.019	3/35	
				Total for all parameters----		.785
3	14	13	10	.199	10/41**	
			2	.103	6/40*	
			9	.057	3.7/38	
				Total for all parameters----		.462
4	1	3, 4,	19	.864	260/41**	
		5, 7,	12	.028	26/38**	
		8, 9	10	.047	21/40**	
			20	.020	11/39**	
				Total for all parameters----		.965
5	1	3, 4,	19	.864	260/41**	
		5, 7,	12	.028	26/38**	
		8, 9, 13,	10	.047	21/40**	
		14	20	.020	11/39**	
				Total for all parameters----		.965

Subset II incorporated the observations through 8 February 1968, the time of the mid-winter low in the organic matter level. There were several reasons for using only the observations to that time.

First, since the organic matter had declined to a mid-winter low, it represented a full cycle of the seasonal variation. The year began with sampling dates in March, 1967, and ended with the low in February, 1968.

Second, the steady rise in organic matter after that date appeared to represent autochthonous production of organic matter. Inflow had remained relatively constant since 22 October 1967, implying minimal fluctuations in import of allochthonous organic matter. Thus, the section after 8 February 1968, was isolated for later statistical investigation. The results of the multiple regression analyses performed with this subset were nearly identical to the results of the analyses of Subset I, so the results have not been reproduced in a separate table.

Since no reason could be found for the large values of the initial analyses, Subset III was established with the first five observations eliminated. The previous subsets had not used the observations from the latter portion of the study, so this subset incorporated those observations. It was necessary to remove the bacterial parameters since data was not available for the time after 13 March 1968.

Only two multiple regression analyses were performed, with organic matter as the dependent variable for both. Inflow and outflow weekly sums were eliminated from the second analysis in addition to bacterial parameters.

Table 4 shows that the most important variable in each analysis accounts for an even greater portion of the variability of organic matter than in Subset I. Table 5 is provided to show some of the simple correlations from data in this subset.

Table 4. Multiple regression analyses for Subset III listing the most important contributions of parameters to R^2. (* and ** indicate significance at the .05 and .01 levels, respectively.)

# of Mult. Regr.	Depend. Param.	Param. Excluded	Most important contributions # Param.	Contr. to R^2	F-test/D.F.	Total Contr. to R^2
1	1	13,14	4	.948	829/45**	
			3	.016	20/44**	
			8	.004	5.8/40*	
			11	.003	3.3/43	
				Total for all parameters----		.975
2	1	3,4,	19	.933	622/45**	
		5,7	2	.009	13/40**	
		8,9,13	18	.009	8.7/42**	
		14	6	.008	7.5/43**	
				Total for all parameters----		.971

Table 5. Simple correlations involving pairs of parameters from Subset III.

Organic Matter vs. Parameter	Simple Correlation	Organic Matter vs. Parameter	Simple Correlation
Inflow 2	.7720	Inflow 1+2+3	.8317
Inflow 3	.9739	Inflow 1+2+3+4	.9185
Outflow 2	.9529	Outflow 1+2	.9354
Secchi	-.3547	Outflow 1+2+3	.9657
Inflow 1+2	.6075	Outflow 1+2+3+4	.9657

Subsets IV, V, and VI, were established after the results were available for the first three. Only four multiple regression analyses were performed on these subsets.

Subset IV incorporated the observations during the period when inflow was relatively constant. Since inflow was shown to be highly significant in accounting for variability of organic matter, this time period was chosen to evaluate the effects of other variables. Since the sums of weekly sums of outflow rates had also accounted for much of the variability, these parameters were eliminated. This subset, therefore, tested the remaining parameters for their abilities to account for variation in organic matter and bacteria in the absence of the above mentioned parameters. Organic matter was used as the dependent variable in the first analysis, bacteria in the second. Table 6 summarized the analyses. Figure 4 shows bacterial levels during the study (Chen, 1968).

Table 6. Multiple regression analyses for Subset IV listing the most important contributions of parameters to R^2. (* and ** indicate significance at the .05 and .01 levels, respectively.)

# of Mult. Regr.	Depend. Param.	Param. Excluded	Most important contributions # param.	Contr. to R^2	F-test/D.F.	Total Contr. to R^2
1	1	2, 3, 4	9	.380	9.8/16**	
		5,11, 15	12	.165	5.4/15**	
		16, 17, 18	6	.125	5.3/14*	
		19, 20	10	.084	4.4/13	
				Total for all parameters----		.754
2	13	2, 3, 4	10	.501	16/16**	
		5, 11, 15	9	.108	4.1/15	
		16, 17, 18		Total for all parameters----		.694
		19, 20				

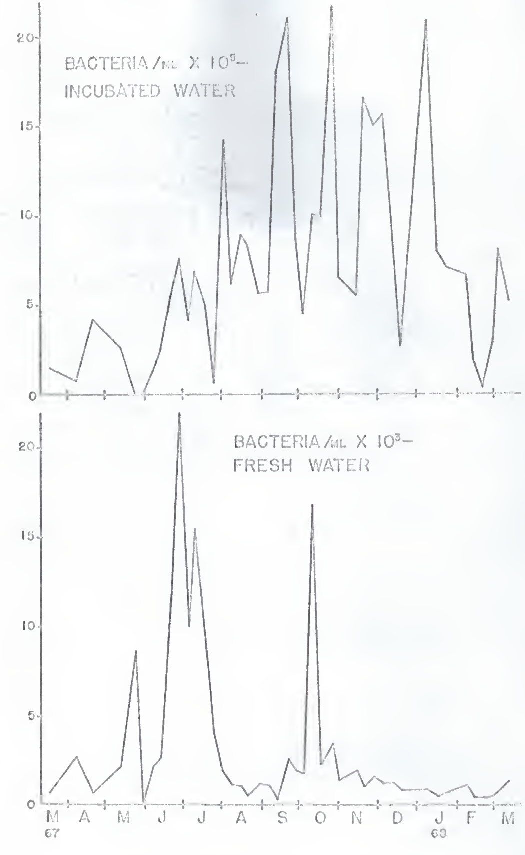


Figure 4. Saprophytic bacterial counts from fresh and incubated lake samples (Chen, 1968).

Subset V covered essentially the same time period, except that it extended beyond the bacterial data to the time when inflow increased. This subset eliminated the bacterial parameters, as well as inflow, but retained all outflow parameters. The results are shown in Table 7. This subset covers the time during which autochthonous production is suspected. It is of particular interest to note the total contribution to R^2 in this case, only .574. This low value suggests that a significant portion of the variability of organic matter is not related to, or accounted for by, the parameters used. Therefore, other parameters should be brought into the study in an attempt to explain the variation. Such parameters might be phytoplankton population, temperature, or wind, for example.

Table 7. Multiple regression analysis for Subset V listing the most important contributions of parameters to R^2. (* and ** indicate significance at the .05 and .01 levels, respectively.)

# of Mult. Regr.	Depend. Param.	Param. Excluded	Most important contributions # param.	Contr. to R^2	F-test/D.F.	Total Contr. to R^2
1	1	2, 3, 4,	20	.437	13/17**	
		5, 11, 13,	6	.074	2.5/15	
		14, 15, 16		Total for all parameters----		.574
		17				

The final subset eliminated the initial observations, as well as those after the bacterial data terminated. The Secchi disc measurements are set against all other parameters except incubated bacteria, in an attempt to evaluate the possible influences or correlations of the parameters. Table 8 gives the results of the analysis. Also included are some of the correlations of interest (Table 9).

Table 8. Multiple regression analysis for Subset VI listing the most important contributions of parameters to R^2. (* and ** indicate significance at the .05 and .01 levels, respectively.)

# of Mult. Regr.	Depend. Param.	Param. Excluded	Most important contributions # param.	Contr. to R^2	F-test/D.F.	Total Contr. to R^2
1	12	14	11	.327	17/36**	
			10	.137	10/34**	
			17	.088	8.3/32**	
			9	.084	5.0/35*	
				Total for all parameters----		.740

Table 9. Simple correlations of interest involving pairs of parameters from Subset VI.

Organic Matter vs. Parameter	Simple Correlations	Organic Matter vs. Parameter	Simple Correlation
Inflow 2	.7694	Incubated Bacteria	-.1092
Inflow 3	.9765	Inflow 1+2+3+4	.9207
Outflow 2	.9567	Outflow 1+2	.9385
Secchi	-.4023	Outflow 1+2+3	.9697
Freshwater Bacteria	.6673	Outflow 1+2+3+4	.8925

DISCUSSION SECTION

Methodology

There are a great number of techniques described for the determination of organic matter with much of the work in wet oxidation pioneered in the field of soil science. Limnological adaptations are often criticized for lacking sensitivity or accuracy, or as being too complicated for routine measurements.

The most common technique for measurement of total organic matter is based on loss in weight upon ignition of a sample that has been evaporated to dryness. This method, however, being an indirect measurement carries an error equal to the amount of inorganic material present, and when large amounts of clay are present the water of hydration leads to inescapable errors. Normally these errors are too large for meaningful interpretation of analytical results. Another method, that of direct estimation of organic energy, involves use of bomb colorimetry. It has the disadvantages, however, of being analytically exacting and of not allowing rapid or multiple simultaneous determinations (Maciolek, 1962).

The method as outlined by Strickland and Parsons (1960) was adopted for this study because the method has the capacity for a wide range of results. This feature was appealing, as little work had been done in this area of study with the type of lake involved.

The technique involves dichromate oxidation of organic matter, a process which yields the original inorganic constituents through reversal of the formation process. As organisms assimilate matter inorganic elements are reduced, requiring energy in proportion to the degree of reduction. When this process is reversed in the oxidation, the oxygen consumed is proportional to the energy content, and is an indirect estimate of the quantity of organic matter oxidized.

The dichromate ions ($Cr_2O_7^{-2}$) form orange colored solutions which reduce to greenish or bluish-violet chromic (Cr^{+3}) derivatives. They are strong oxidizing agents in the presence of free acid, which for the present study was concentrated sulfuric acid. The method of Strickland and Parson has been adapted to spectrophotometry, based upon work by Johnson (1949), so that the change of color of the dichromate solutions can be quantitatively analyzed. The results are then converted to milligrams of carbon per cubic meter of lake water (mgC/m^3).

According to Van Hall, Safranko, and Stenger (1963) and Maciolek (1962), inorganic ions, particularly chlorine, can interfere with wet oxidation techniques and give erroneously high results unless properly regarded. To compensate the method includes a step to eliminate such interference. It involves heating the sintered glass disc in phosphoric acid at 100°C for 30 minutes.

Other oxidants have been used in oxidation techniques, but potassium dichromate, as used by Strickland and Parsons, has the following advantages:

1) it is primary standard;

2) it is very effective at oxidizing most organic compounds under suitable reaction conditions;
3) it is extremely stable in neutral solution and also in acid solution if protected from contamination;
4) it does not decompose spontaneously to any appreciable extent during the reaction even at high temperatures and high acid concentration;
5) it can be measured colorimetrically;
6) it can be used in procedures which require no unusual circumstances (Maciolek, 1960).

Particulate Organic Matter

The most obvious feature of the multiple regression analyses is the degree to which the inflow parameters account for the variability in particulate organic matter during the study. The first multiple regression of Subset III was particularly revealing for the high contribution of the inflow parameter, Inflow 3 (R^2=.948). The F-test shows the result to be very highly significant (α=.01). The next factor in degree of contribution to R^2 was another inflow parameter, Inflow 2. Although the F-test value is not as large as for the third week preceding sampling, it nevertheless shows significance at the (α=.01) level.

These same results are also seen in the first multiple regression of Subset I. The observations used for this subset differ so that the contributions to R^2 are not the same. However, the F-test for the above mentioned parameters again show significance at the (α=.01) level. Correlations of these parameters are seen in Table 5 and Table 9.

It is obvious from the multiple regression analyses and simple correlations that the material being measured is primarily allochthonous detritus carried into the reservoir by tributary streams and creeks. Figure 3 shows that the extremely high measurements for organic matter occurred after the heavy inflows associated with runoff waters.

The reason that the particular parameters, Inflow 3 and Inflow 2, show the greatest contributions to R^2 can be ascertained by noting the location of the sampling site in relation to the headwaters on Fig. 1. Had the sampling site been located at the headwaters of the reservoir, the inflow parameters of the first two weeks preceding sampling would have been expected to show the high contribution to R^2. The effects of inflowing waters in this study were delayed by the length of the valley.

It is axiomatic that the import of large organic loads as occurred in June, 1967, must have considerable effect on the metabolic activity in the lake. Gray and Shah (1964) indicate that with an inflow which effected a five foot rise in the reservoir level in 1963, the organic load created a dissolved oxygen deficit over a relatively large area. In comparison the inflow during June, 1967, caused a fourteen foot rise in the level within seven days. The fact that this water was also laden with organic matter is reflected in the measurements obtained when this water reached the sampling site three weeks after reaching the reservoir. No water chemistry data is available for the period of high inflow in 1967. Ellis, Westfall, and Ellis (1946) indicate that if the dissolved oxygen level is decreased below three parts per million, this condition is considered lethal for fish in most lake and stream environments. Normally a dissolved oxygen level of 5 ppm or more is needed for favorable conditions.

Although the inflow parameters accounted for such a large degree of variation of organic matter in the study, attention should be given to a period from October, 1967, to April, 1968, during which inflow remained relatively constant at 14 m^3s. In effect, the parameters relating to inflow were held constant for this period of nearly six months. Figure 2 shows that organic matter moved through a somewhat irregular decline, reaching a low of 196 mgC/m^3 on 8 February 1968.

The irregular but noticeable decline through 8 February may be attributed to a temperature dependent decrease in metabolic rates within the reservoir during this late fall and winter period. The steady increase through 26 March, however, offers opportunity for interesting speculation.

The one explanation which may be offered is that this represents autochthonous production by phytoplankton within the reservoir in response to the general warming trend of waters. Secchi disc measurements for this period are generally greater than one meter, nearly double the average depth for this study. Henrici (1938) performed studies on Lake Alexander in Minnesota under conditions somewhat similar to those experienced at this time. The unstratified lake was relatively free of runoff contribution. He reported that there was an increase in plankton production during the springtime (not associated with spring turnover, of course, since the lake was unstratified), followed by an increased bacterial population which lagged somewhat. He speculated that the bacterial population was responding to an increased food source in the form of phytoplankton.

Although plankton enumerations are not available for Tuttle Creek Reservoir during this period, and the trend is not clearly evident, it is interesting to speculate that a similar situation was developing in this reservoir. The increase in particulate organic matter during this period cannot be attributed to increased inflow which might carry additional allochthonous detritus. This increase, therefore, may have been the result of increased plankton biomass. Figure 4 shows that bacterial counts began to increase slowly, lagging behind that of particulate organic matter. Unfortunately bacterial data does not extend throughout the remainder of this period, so a trend is not clearly evident.

The second explanation is purely hypothetical, based upon oceanographic work. A number of investigations have been made relating to the particulate organic matter in ocean waters, its formation, and its use (Sheldon, Evelyn, and Parsons, 1967; Baylor and Sutcliffe, 1963; Riley, Van Hempert, and Wangersky, 1965; Riley, Wangersky, and Van Hempert, 1964, and Riley, 1963). The possible connection which can be made to this case is that particulate organic matter has been shown to develop on bubbles, drawing upon the dissolved fraction of the total organic matter. Since the amount of organic matter available in the dissolved state is several times the magnitude of the particulate fraction (Birge and Juday, 1934), such a mechanism might function in a freshwater environment. Certainly the wind-mixed waters of Tuttle Creek Reservoir would provide ample opportunity for bubbles to act as adsorption sites. However, no studies were found in the literature indicating that investigations had been made on this possible formation process in freshwater environments. This explanation must remain in the realm of speculation, but offers possibilities for new studies.

Bacteria

Of particular importance are the counts of saprophytic bacteria. These were enumerated for freshwater counts by immediate plating on appropriate media, and subsequent incubation of the plates for 5 days at $28^{o}C$. Counts for incubated water were obtained by the above plating technique after the water had been incubated at $28^{o}C$ for two days (Chen, 1968).

Examination of inflow patterns vs. freshwater bacterial counts shows that as with organic matter, bacterial numbers were increased greatly with increased inflows. There may be several reasons for this. The first is that there was a great increase of "foreign" bacteria which were washed into the lake from the surrounding watershed. These bacteria would be of a different type, therefore, than the resident bacteria. A second explanation is suggested by Kuznetsov (1968), who reported that bacteria use allochthonous detritus as substrate for heterotrophic growth. The increased import of detrital fragments, therefore, would provide bacteria an unlimited substrate source upon which to grow. Chen (1968) indicates that Bacillus cereus, a common saprophytic bacteria of the reservoir, requires particulate organic matter for its growth. It is reasonable, therefore, that with increased availability of substrate, bacteria would increase in numbers.

Turbidity

An additional parameter available throughout the study was Secchi disc measurement, a visual measure of the light scattering properties and turbidity of the water. As indicated in the introduction to this paper and in the study area description, limitation of the light penetration is the rule and not the exception. Ruttner (1963) indicated the effect on phytoplankton of reduced light penetration in lakes affected by water currents. "As soon as the layers lying below the compensation level are involved in the circulation each individual phytoplankter, having been carried into the depths by eddy-diffusion currents, necessarily exhibits a negative assimilation balance so long as it remains under conditions of insufficient light. With further advancement of the mixing into deep water, these periods of negative balance become progressively longer, and must lead to a deterioration of the total assimilation balance, and to a decline of the plankton population density" (Ruttner, 1963, p. 165). Nalewajko (1966) and Lund (1965) indicate further deleterious effects of light inhibition, such as increased excretion of the products of photosynthesis.

Some investigations have shown that phytoplankton can carry on heterotrophic growth. Danforth (1962) and Wright and Hobbie (1965) indicate that phytoplankton can use dissolved organic substances for this purpose. It should be noted that much of their work is laboratory research, and therefore, must be approached cautiously in considering natural systems. Wright and Hobbie (1966) feel that bacterial populations are probably successful in holding dissolved substances to such low levels that, in practice, phytoplankton are not able to compete for the substances.

The clay particles which contribute predominantly to the turbid condition may have an additional effect on the organic matter of the reservoir. Investigations primarily in the field of soil science have shown that clay particles adsorb organic molecules. In a system such as Tuttle Creek Reservoir where clay particles constitute 54% of the suspended sediment load (U. S. Army Corps of Engineers records, 1963-1966), such adsorption could have an important effect. Button (1969) has indicated that the equilibrium constant between free organics and those bound to suspended sedimentary materials lies far in the direction of the dissolved state. Thus it seems unlikely that in natural systems the level of suspended organisms using small organic molecules may be materially influenced by the level of suspended sedimentary material.

Ecological Implications

The diagram proposed in the introduction to this paper indicated that detritus could be acted upon directly by consumers. Darnell (1961) evaluated consumer nutrition in his study of Lake Pontchartrain, Louisiana. He found that the most abundant copepod in the study area, Acartia tonsa, made considerable use of suspended organic detritus in addition to abundant diatoms. The centers of biological activity, those characterized with the greatest surface zooplankton abundance, were broad subaqueous bars formed by the precipitation of allochthonous plankton and suspended matter carried into the estuary by freshwater passes, and those areas characterized by mixing of water masses, bottom roiling, and the proximity to eroding marshes.

This seems to be in contradiction to work by Claffey (1955) and Cowell (1967). They indicate that in reservoirs of Oklahoma and on the mainstem Missouri River plankton concentrations are highest in waters that are least turbid.

Findings in Tuttle Creek Reservoir in the spring of 1969, indicate that highly turbid waters can support large zooplankton standing crops. Unusually heavy runoff following the spring thaw of winter snows, and additional runoffs from spring rains have combined to keep the reservoir turbid for an extended period. G. R. Marzolf (personal communication) indicates that during this year the zooplankton populations sampled in the headwater area are higher than usually observed in the lake. The Secchi measurements have been extremely low, down to 3 cm.

The implication involved is that since phytoplankton primary production must be low, the zooplankters are either using the allochthonous material carried into the reservoir for direct nourishment, or they are being nourished by some food material associated with the detritus. That leads to an examination of the role which decomposers play in the system.

Marzolf (1965) suggests that a burrowing amphipod in Lake Michigan may actually be nourished more by bacteria on the detritus which it ingests than by the detritus itself. Minshall (1967) notes that detritus within the gut of a herbivore of a woodland springbrook community may remain relatively unchanged from end to end. He postulates that the herbivore may be using the associated microorganisms and not the detritus itself.

The bacterial biomass produced by heterotrophic growth may be substantial, according to Kuznetsov (1968). He indicates that the biomass produced in some cases exceeded that of phytoplankton production within some lakes of northern and central U.S.S.R. The nutritive value would be substantial, since most of the organisms growing upon detritus are in the active state (Rodina, 1963).

Darnell (1961) feels that bacteria are performing intermediate steps between primary production on the one hand and animal nutrition on the other. He considers the heterotrophic bacteria as the "primary consumers" of the Lake Pontchartrain.

The mass of bacteria on detritus is enormous, as they penetrate the particle, filling up all internal spaces, and becoming integral components of the material. Additionally, they extend outside the boundaries overflowing into the surrounding medium, filling accessible space, joining other particles, and cementing them together (Rodina, 1963).

In such a manner bacteria may also make available to the larger consumers this particulate detritus. One such consumer might be the gizzard shad. Darnell indicates that this "mud-loving" consumer procured fine particulate detritus from shallow silty bottoms. Cramer (1969) indicates that the gizzard shad is one of the dominant fish species within many Kansas reservoirs, and according to sources cited in his paper, they may constitute from 80% to 90% of the total fish numbers. Since gizzard shad possess gill rakers capable of filtering off particulate organic matter this food item could constitute a significant food source.

SUMMARY

1. The particulate organic matter during the study period showed a great range, going from 182 mgC/m^3 on 23 May 1967, to 6,720 mgC/m^3 on 5 July 1967. During 1968 a steady increase in level occurred from the midwinter low of 196 mgC/m^3 until late March. It fluctuated irregularly throughout the remainder of the study.

2. Multiple regression analyses showed that inflow parameters accounted for a great deal of the variability in organic matter. The location of the sampling site was the major factor effecting which of the inflow parameters was most significant.

3. When these inflow parameters were removed from consideration in the multiple regression analyses, the cumulative sums of the outflow rates were

found to most effectively account for the variability of organic matter. Thus the importance of parameters dealing with water flow were the most important accounting for the variability of organic matter.

4. During an extended period from October, 1967, to April, 1968, when inflow was essentially constant the parameters included in this study accounted for considerably less of the variability (.754) of organic matter. It was suggested that autochthonous production might have been responsible for a rise in the level of organic matter in the latter portion of that period.

5. The high turbidity caused primarily by clay particles imposed an unfavorable light regime upon phytoplankters. The result in Tuttle Creek Reservoir may be to reduce the population by reducing their photosynthetic capacity and exposing them to prolonged periods during which they suffer a negative assimilation balance.

6. The allochthonous detritus supplied to the reservoir may be consumed directly by the zooplankters or by larger consumers such as gizzard shad.

7. Bacteria which may use the detritus for heterotrophic growth may provide a significant potential energy source for consumers.

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SEASONAL VARIATION OF PARTICULATE ORGANIC MATTER IN TUTTLE CREEK RESERVOIR

by

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This was a study of the seasonal variation of the particulate organic matter in Tuttle Creek Reservoir, Kansas, using an oxidation technique adapted to spectrophotometry, as outlined by Strickland and Parsons (1960). Statistical tests of multiple regression analyses and simple correlations indicated that inflow parameters account for a great amount of the variation observed in particulate organic matter. The factors of low phytoplankton population, high turbidity, and wind-generated water currents combined to impose an unfavorable light regime for primary production by phytoplankton.

The particulate organic matter, considered to be primarily allochthonous detritus during the majority of the period studied, appeared to be a significant source of potential energy for the consumer species within the reservoir. Literature indicated that consumer species may be nourished directly by consumption of particulate organic matter, or they may be nourished by the microorganisms ingested concomitant with particulate detritus. The biomass and potential energy of such a food source may be great.

Since the heterotrophic bacteria may constitute important steps between primary production and animal nutrition in the Lake Pontchartrain estuary (Darnell, 1961), it is appealing to believe the particulate organic matter in Tuttle Creek Reservoir might also be used by bacteria to provide potential energy for consumers.