ANALYSIS OF THE CAUSATIVE AGENTS OF TURBIDITY IN A GREAT PLAINS RESERVOIR

by

DONALD WILLIAM DUFFORD

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Approved by:

Major Professor

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INTRODUCTION

High turbidity (light extinction coefficient greater than 3.0) is a common limnological feature of reservoirs in the Great Plains of the United States. The biological impact of this feature is suspected but not well documented. Suspended particles tend to reduce the penetration of light into the waters thus reducing primary productivity by suspended phytoplankton. Planktonic plants cannot grow or survive in the absence of light; furthermore, photosynthetic organic production is low at low light intensities and is limited to the upper strata of the reservoir. The reduction of the numbers of photosynthetic organisms reduces the amount of energy available to the higher trophic levels of the food chains within the reservoir.

Berner (1951) indicated that dissolved oxygen in the Missouri River varied inversely with turbidity and suggested that the biochemical oxygen demand of the organic portion of suspended material may have been responsible for dangerously low oxygen levels. Turbidity reduced the productivity of the waters studied by Ellis (1936, 1937), Chandler (1942), and Irwin (1945) by reducing the penetration of light. Buck (1956) found that high turbidities reduced growth and total yield of bass and bluegills, but increased channel catfish production in some Oklahoma waters. Individual catfish grew faster in clear waters, but muddy ponds yielded much greater total weights of channel catfish due to higher rate of survival. Wallen (1951) indicated that montmorillonite clay turbidity was not directly lethal to juvenile or adult fishes at turbidities found in nature; however, Buck (1956) noted that reproductive success of largemouth bass and bluegill was reduced in the more turbid waters.

Turbidity or opaqueness in water is caused by the presence of suspended matter such as clay, silt, finely divided organic matter, or planktonic organisms. Turbidity is an expression of the optical property of the liquid which causes light to be scattered and absorbed rather than transmitted in straight lines (American Public Health Association, 1965). Suspended particles may be autochthonous or allochthonous.

Natural waters vary considerably in the extent to which they absorb light. Birge and Juday (1929, 1930, 1931, 1932) found that transparency was inversely related to both turbidity and color, and extinction of light was logarithmic with depth.

High turbidity was noted as being a characteristic feature of the Blue River, Kansas, prior to impoundment. Clarke (1924) characterized the Kansas River tributaries as very turbid (304-920 ppm). Most of these streams were described as geologically old. They are shallow, meandering streams with broad flood plains and high turbidities at all seasons. Observations of suspended sediments from the U. S. Geological Survey Stream Gaging Station at Randolph, Kansas, during the years 1943 to 1959 (Kansas Water Resources Board, 1964) indicate the average annual suspended sediment load to be about 6,629,000 tons. The per cent distribution of particle sizes of suspended sediment at that station averaged 54 per cent clay, 40 per cent silt, and 6 per cent sand. Large deposits of clay in the plains states furnish a continuous supply of clay particles to the waters of this area (Irwin and Stevenson, 1951).

Tuttle Creek Reservoir has been known for its high turbidity since its impoundment. Cole (1966) found Secchi disc transparency under 25.4 cm throughout most of the spring and summer of 1965. Investigations by the Kansas State Department of Health, Environmental Health Services and the Federal Water Pollution Control Administration during the years 1963 through June 1966 (Department of the Army, Kansas City District, Corps of Engineers, 1966) indicate the presence of very fine suspended sediments. Turbidity was claimed to reduce phytoplankton growth, thus limiting primary production in the reservoir although no data were presented to support these conclusions.

The present study was initiated to determine the agents correlative with turbidity in Tuttle Creek Reservoir, and to develop a predictive model for turbidity level under given conditions using variables regularly collected by the U. S. Army Corps of Engineers.

Because the variables that were collected by the Corps of Engineers were recorded in the English system of measurement, and because the study was designed to develop a predictive model for turbidity using variables routinely collected by the Corps of Engineers, these variables were utilized in the English system. Variables collected by the author are in the metric system. For those individuals so inclined to use only one system, necessary conversion factors are shown in Table 1.

Table 1. English to metric conversion factors.

To get	Multiply	By
Square kilometers	Square miles	0.386
Square kilometers	Acres	247.105
Meters	Feet	3.282
Kilometers	Miles	1.6093
Hectare	Acres	2.471
Metric tons	Tons	1.102

DESCRIPTION OF THE STUDY AREA

Tuttle Creek Dam and Reservoir is a U. S. Army Corps of Engineers project located on the Big Blue River in Riley, Pottawatomie, and Marshall Counties, Kansas. The dam is located 10.0 miles upstream from the confluence of the Kansas and Big Blue Rivers at approximately $39^{\circ}15'30''$ N. latitude, $96^{\circ}35'30''$ longitude. From this point the reservoir is straight with the exception of a gradual approximate 80° bend from the north-northwest to the northeast from approximately 12.4 miles to 15.0 miles upstream from the dam. Tuttle Creek Reservoir was constructed primarily for flood control with secondary considerations being silt retention, water conservation and recreation. Closure was on 21 July 1959, and conservation operation began on 29 April 1963 (Department of the Army, Kansas City District, Corps of Engineers, 1966; Cramer and Marzolf, 1970; Novak, 1969).

The Big Blue River, third largest tributary of the Kansas River, drains an area of 9,696 square miles in north-central Kansas and south-central Nebraska. Seventy-five per cent of the drainage basin lies in Nebraska, 25 per cent in Kansas. The Little Blue River, its major tributary, drains 36 per cent of the total. Soils in the lower part of the basin consist principally of residual and alluvial soils derived from shales and limestones. In the upper part of the basin are loessial soils underlain by glacial fills and alluvial sands. Approximately 76 per cent of the available basin is utilized for cultivated crops, and 18.5 per cent for pasture (Department of Army, 1966).

Normal conservation pool for Tuttle Creek Reservoir is designated at 1075.0 feet above mean sea level (ft. m.s.l.). Gross storage elevation varies from 1,000.0 ft. m.s.l. at minimum sedimentation reserve to 1,136.0 ft. m.s.l. at maximum flood control pool. Surface elevation has varied from 1,060.9 ft. m.s.l. on 11 February 1967 to 1,094.4 ft. m.s.l. on 7 July 1965. At normal conservation pool the reservoir has a surface area of 15,830 acres, a total volume of 425,312 acre feet, a shoreline of 130 miles, a mean depth of 26.8 feet, and a maximum depth of 76.2 feet (Dept. of Army, 1966). The reservoir was arbitrarily divided into six sections for this study (Fig. 1). Data were collected in each of the lower four sections throughout the study.

MATERIALS AND METHODS

A sampling site was selected near the center of each of the four sections below the Randolph Bridge (Fig. 1). Each of these sites was sampled weekly except when weather conditions, reservoir surface

EXPLANATION OF FIG. 1

Tuttle Creek Reservoir, Kansas showing four sampling sites and the river channel.

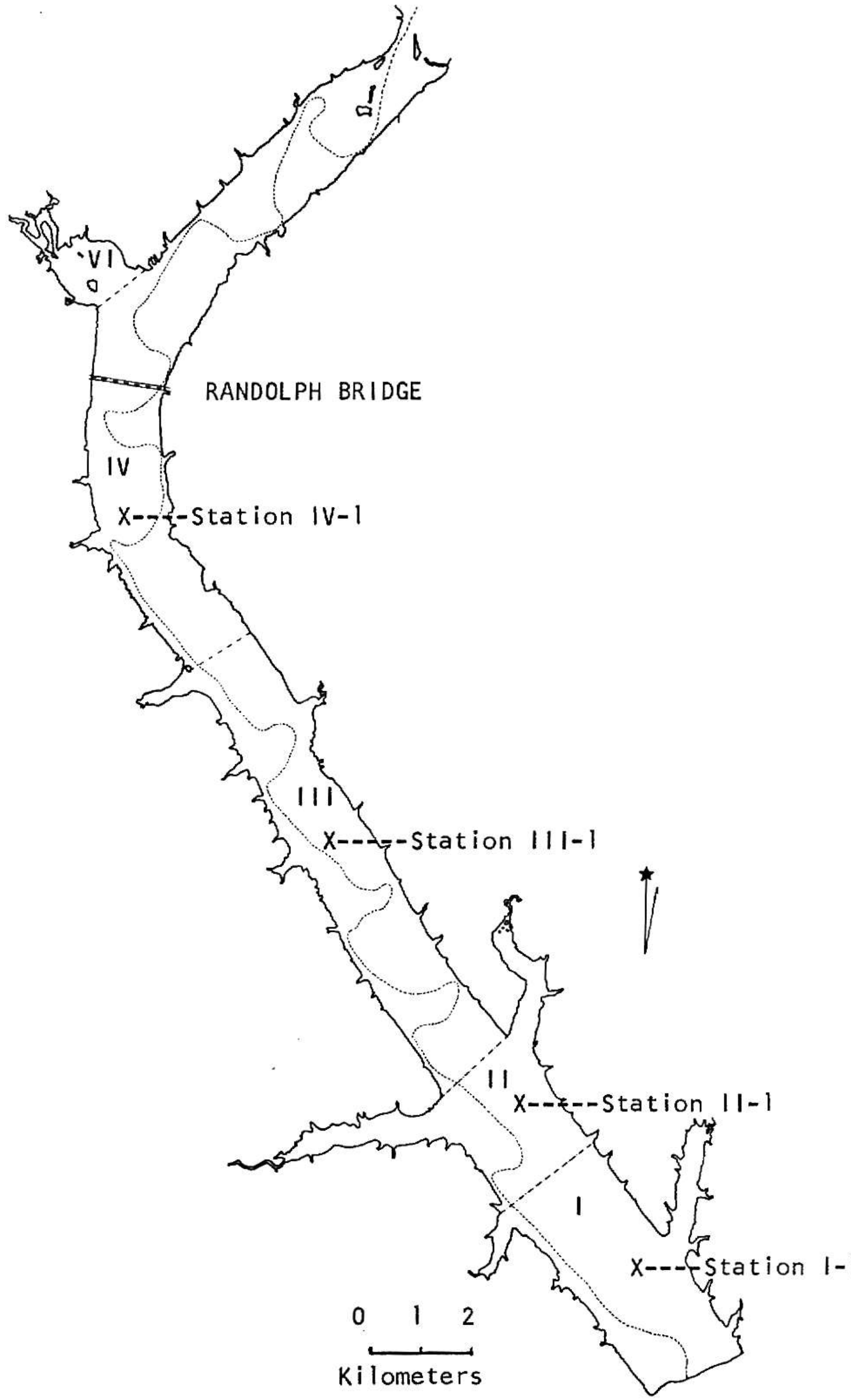


Fig. 1. Tuttle Creek Reservoir.

conditions, or unsafe ice cover made work impossible, from 1 June 1968 to 11 October 1969. With few exceptions, water transparency, light penetration measurements, and a temperature profile were taken at each site. From 23 August 1968 to 22 February 1969, water samples were collected at three meter intervals from the surface of the bottom, with a 3-liter brass Kemmerer sampler. Forty ml of each sample was transferred to a glass sample bottle and returned to the laboratory for turbidity analysis, using a Hach model 1860 nephelometer type turbidimeter.

Water transparency was measured with a 20 cm diameter Secchi disc with black and white quadrants. Light penetration measurements were made with a Whitney underwater daylight meter with amplifier, with a diffusing disc of opaque glass over the cell window. Measurements were made in the air just above the surface, the cell being kept horizontal to the surface, just below the surface, and at one meter intervals to a depth at which no measurable light remained. When no measurable light remained at a depth of one meter, the measurements were made at 50 cm. Light extinction coefficients (K) were calculated using the formula $I_z = I_o e^{-Kz}$ where I_z = light intensity at depth z, z = depth in meters, I_o = surface intensity, e = base of natural logarithms. When solved for K the equation becomes $K = \frac{\ln I_o - \ln I_z}{z}$. Temperature profiles were taken with a Whitney model TC5 underwater thermometer. Both air and water temperatures were recorded.

On 7 and 8 August 1969, a random sample was taken from each section and from coves. The number of sites from each section was weighted according to its relative surface area, 7 in section I, 5 in section II, 10 in section III, 8 in section IV, and 5 in coves. At each site location Secchi disc transparency, light penetration, surface temperature, and turbidity profile were measured. The turbidity profile was measured with a transmissometer consisting of a 10.2 cm General Electric sealed beam bulb number 4416 placed 20 cm from a Weston 856 type RR photovoltaic cell sealed in a water tight plexiglas case. An opaque plexiglas diffusor was used over the cell window. This unit, shielded from ambient light by a series of three 5 mm, flat black, plexiglas baffles connected by four 7 mm hexagon brass rods, was placed in a 61 cm length of 12.8 cm (ID) tuftite polyvinylchloride pipe. A 12 volt battery, the boat electrical system, was used as the power source for the light. The underwater unit was connected to the deck unit with 90 meters of insulated cable. The deck instrumentation consisted of a Tripolet model 327 PL microampmeter with amplifier and 8 shunts (1, 5, 10, 20, 50, 100, 200, and 500). This instrument flushed rapidly permitting many measurements of the turbidity distribution with depth, as well as horizontal and lateral. Measurements within 40 cm (due to instrument length) of the bottom were made at each location. A turbidity profile with this instrument was included in the data collected at each regular scheduled sampling from 8 August 1969 to 11 October 1969.

During the period 1 January 1969 to 22 February 1969, when ice cover was present, measurements were taken through the ice. The wind variables were considered to be zero during this period.

From 31 January 1969 to 2 February 1970, sediment load samples were collected on the Big Blue River near Blue Rapids, Kansas, and on the Black Vermillion River near Frankfort, Kansas, by Corps of Engineers observers. Rate of collection was regulated by river stage. Sampling schedules are shown in Table 2. The bottom withdrawal method for mechanical separation of river silts as discussed by Nelson (1943) and Rentschler (1947) was used to analyze the samples.

Table 2. Sediment inflow sampling schedules for the Big Blue River at Blue Rapids, Kansas, and for the Black Vermillion River at Frankfort, Kansas.

River	River stage (ft m.s.l.)	Discharge (cu ft/sec)	Sampling rate
Big Blue	< 1087.5	< 900	One per week
	1087.5 - 1089	900 - 2000	One per day
	1089.0 - 1092	2000 - 5300	Two per day
	> 1092	> 5300	Three per day
Black Vermillion	< 1105	< 70	One per week
	1105 - 1108	70 - 400	One per day
	1108 - 1112	400 - 1000	Two per day
	> 1112	> 1000	Three per day

Variables routinely collected by the Corps of Engineers along with other variables used in the statistical analysis are listed and explained in Table 3. Wind data were combined to obtain total miles of wind past a point 24, 48, 72, 96, and 120 hours prior to sampling. These five variables were then added together and divided by 15 resulting in a weighted mean wind with day one contributing five times as much as day five.

Table 3. Description of variables used in statistical analysis.

Variable No.	Variable name	Variable description
1	Ext Coef	Light extinction coefficient (K).
2	Secchi	Reciprocal of Secchi disc depth in meters.
3	Turbid	Turbidity as measured in Jackson turbidity units (JTU).
4	Transmis	Direct readings from transmitsometer in microamps.
5	Res Elev	Reservoir elevation in feet above mean sea level at 0800 hours.
6	Outflow0	Mean daily outflow rate (mdor) in cfs during 24 hour period prior to 0800 hours on date of sampling.
7	Inflow00	Mean daily inflow rate (mdir) in cfs during 24 hour period prior to 0800 hours on date of sampling.
8	Avebrf00	Average basin rainfall in inches for 24 hour period up to 0800 hours on date of sampling.
9	Outflo**	The sum of variable number 6, where ** is the number of days prior to date of sampling.
10	Inflow**	The sum of variable number 7, where ** is the number of days prior to date of sampling.
11	Avebrf**	The sum of variable number 8, where ** is the number of days prior to date of sampling.
12	Wind 06	Total miles of wind during the period from midnight to 0600 hours prior to sampling.

Table 3 (continued).

Variable No.	Variable name	Variable description
13	Wind 12	Total miles of wind during the period from 0600 hours to 1200 hours prior to sampling.
14	Wind 18	Total miles of wind during the period from 1200 hours to 1800 hours prior to sampling.
15	Wind 24	Total miles of wind during the period from 1800 hours to 2400 hours prior to sampling.
16	Dirwnd06	Direction of wind of maximum velicity during variable number 12.
17	Dirwnd12	Direction of wind of maximum velocity during variable number 13.
18	Dirwnd18	Direction of wind of maximum velocity during variable number 14.
19	Dirwnd24	Direction of wind of maximum velocity during variable number 15.
20	Wind0day	Total miles of wind for 24 hour period up to 0600 hours on day of sampling.
21	Wind1day	Variable number 20 one day prior to date of sampling.
22	Wind2day	Variable number 20 two days prior to date of sampling.
23	Wind3day	Variable number 20 three days prior to date of sampling.
24	Wind4day	Variable number 20 four days prior to date of sampling.
25	Wind5day	Variable number 20 five days prior to date of sampling.

Table 3 (continued).

Variable No.	Variable name	Variable description
26	Wind6day	Variable number 20 six days prior to date of sampling.
27	2daywind	Sum of variables 20 and 21.
28	3daywind	Sum of variables 20, 21, and 22.
29	4daywind	Sum of variables 20, 21, 22, and 23.
30	5daywind	Sum of variables 20, 21, 22, 23, and 24.
31	6daywind	Sum of variables 20, 21, 22, 23, 24, and 25.
32	7daywind	Sum of variables 20, 21, 22, 23, 24, 25, and 26.
33	Wind bar	$\frac{(5(\#20)\quad 4(\#21)\quad 3(\#22)\quad 2(\#23)\quad 1(\#24))}{15}$
34	Res days	Calculated number of days inflow water had been in the reservoir at each station.
35	1/resdys	The inverse of variable number 34.
36	LnInflo	Natural log of the mean 5 day inflow rate.
37	LnOutflo	Natural log of the mean 21 day outflow rate prior to date of sampling.
38	Sedin**	Sum of the Black Vermillion River (tons silt/day) and the Big Blue River (tons silt/day) sediment loads where ** is the number of days prior to sampling.

Statistical analysis of the data from light penetration, Secchi disc measurements, and turbidity levels consisted of linear regression analysis with light extinction coefficient as the dependent variable. Multiple linear regression analyses were performed for each station, which coupled with an analysis of variance, permitted ranking of reservoir variables in order of contribution to the turbidity levels within the reservoir. Results of light extinction coefficients and routinely collected reservoir variables were reported as simple correlation coefficients, r, which is a measure of how probable a change in one variable results in an exact proportional change in the other variable. Results of the multiple linear regression analyses were reported as multiple linear regression coefficients, R^2 (Fryer, 1966). An R^2 of 1.0 indicates all of the variation in the dependent variable had been accounted for by its linear relationship to the independent variables.

Reservoir volume and outflow rates were combined to calculate residence time, a measure of the number of days that inflow water had remained in the reservoir. Residence time was calculated by utilizing average daily volume and average daily outflow rate times the percentage of total volume above each station. This relation is shown by:

$$\text{Res days} = \frac{\text{Average daily volume (acre ft) x 43.560}}{\text{Average daily discharge rate x 86,400}} \times V \qquad (1)$$

where V = percentage of total volume above the station. Resident days were added to starting inflow date to get the resident date for inflow waters for each station. A Fortran program used to create this variable is shown in Appendix 1.

To reduce heterogenity of variances of K, inflow and outflow variables were transformed with a natural logarithmic transformation. The wind variable used in the analysis was a weighted five day mean. The reciprocal of residence time was used to obtain linearity between K and residence time as assumed with a multiple linear regression analysis.

Paired t tests were utilized on east side versus west side Secchi disc measurements for the period 5 August 1968 to 12 August 1968, and for river channel versus non river channel samples taken on 7 August 1969.

RESULTS

A summary of light extinction coefficients (K) at all four stations is shown in Table 4. A summary of light extinction coefficients versus reciprocal of Secchi disc transparency, turbidity (JTU), and transmissometer measurement regression analyses are shown in Table 5. The relationship between light extinction coefficient and Secchi disc depth (D) is represented by Fig. 2. The curve of this relationship $K = -0.067 + 1.4(\frac{1}{D})$ has been superimposed on Fig. 2. The relationship between K and turbidity in Jackson turbidity units (JTU) is represented by Fig. 3. The equation $K = 0.555 + 0.091$ (JTU) has been superimposed on Fig. 3. The K, transmissometer (uA) relationship and corresponding equation $K = 8.155 - 0.001$ (uA) is shown in Fig. 4. One per cent of the surface light was found to remain at 3.45 times Secchi disc depth in Tuttle Creek Reservoir. The standard deviation of this estimate was 0.527. The mean one per cent light depth was 1.64 meters with a standard deviation of 0.932.

Table 4. Summary of light extinction coefficients (K) for Tuttle Creek Reservoir.

Date	Time	Station			
		I-1	II-1	III-1	IV-1
6 Jun 68	1430-1700	1.09	1.33	1.13	1.46
11 Jun 68	0930-1043	0.93	1.05	1.54	2.34
17 Jun 68	0940-1032	0.91	1.05	1.58	3.00
24 Jun 68	0730-0827	1.28	1.41	2.03	2.65
1 Jul 68	0935-1200	1.47	1.47	1.84	2.61
8 Jul 68	0945-1118	1.24	1.24	1.77	2.30
15 Jul 68	0950-1210	1.44	1.94	2.35	2.85
18 Jul 68					2.53
19 Jul 68	1350-1430			1.66	2.53
22 Jul 68	1030-1150	1.10	1.20	1.61	1.91
24 Jul 68	1400-1615	1.19	1.58	1.85	3.32
25 Jul 68	1410-1510	1.18	1.11	1.50	1.98
26 Jul 68	0925-1040	1.07	1.10	2.18	2.66
27 Jul 68	1200-1345	1.07	1.20	1.96	3.53
29 Jul 68	1055-1205	1.11	1.30	2.32	3.55
31 Jul 68	0920-1030	1.64	2.45	3.31	4.61
3 Aug 68	1130-1300	1.66	1.83	2.77	3.50
5 Aug 68	1015-1109	1.72	1.77	3.11	3.25
7 Aug 68	1015-1145	2.15	1.85	2.27	3.36
9 Aug 68	0940-1120	2.30	2.08	2.78	3.91
12 Aug 68	0940-1100	2.35	2.51	2.82	3.91
14 Aug 68	0940-1035	1.68	2.02	2.28	2.70
16 Aug 68	0920	2.00			
19 Aug 68	0950-1100	2.41	2.98	3.71	3.75
21 Aug 68	1150-1255	3.09	3.15	3.22	5.39
23 Aug 68	1130-1225	2.64	3.00	3.63	6.54
26 Aug 68	0925-1007	2.61	2.82	3.77	5.62
28 Aug 68	1020-1210	2.27	2.65	5.99	6.91
30 Aug 68	0945-1030	3.22	3.37	6.31	7.60
2 Sep 68	0915-1030	2.76	2.98	3.61	5.52
9 Sep 68	0950-1215	3.22	4.32	5.63	6.40

Table 4 (continued)

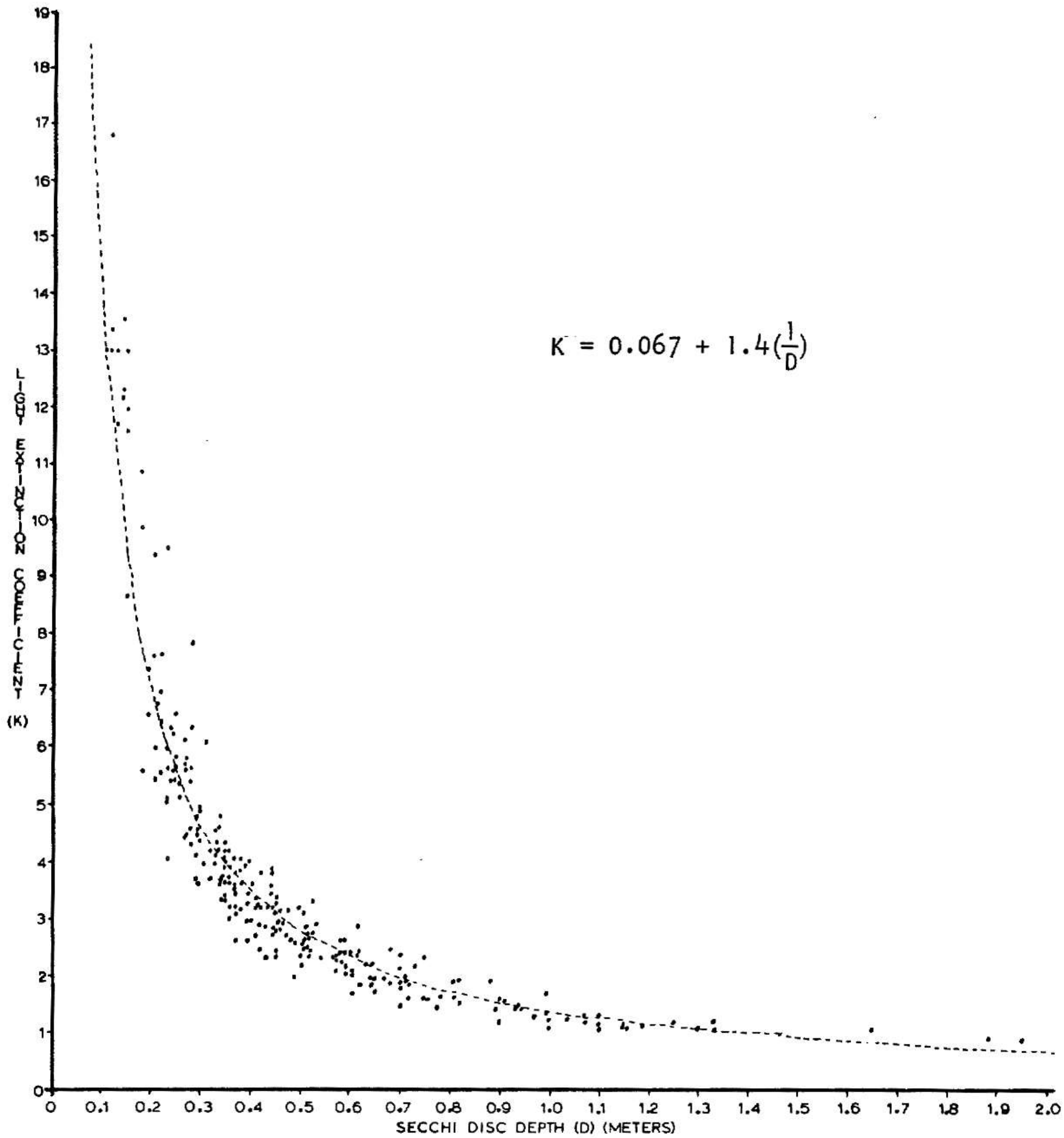
Date	Time	Station I-1	II-1	III-1	IV-1
19 Sep 68	0930-1030	3.97	4.15	4.46	5.93
29 Sep 68	0930-1045	3.79	4.05	4.17	4.47
3 Oct 68	1350-1430	4.09	4.61		
22 Oct 68	0845-0910	4.10	3.65		
2 Nov 68	0940-1110	2.05	2.53	2.80	4.80
9 Nov 68	0930-1037	3.90	3.40	3.60	9.50
16 Nov 68	1025-1115	3.78	3.75	5.45	10.86
23 Nov 68	0900-0955	4.04	4.18	7.82	9.45
30 Nov 68	0900-1055	4.20	3.69	5.67	7.59
7 Dec 68	0850-0915	4.27	4.89		
14 Dec 68	0840	4.38			
1 Jan 69	1105-1245	3.09			2.21
11 Jan 69	0850-1105	2.26	2.41		2.16
25 Jan 69	0840-1120	1.98	1.96		5.55
1 Feb 69	0855-1315	2.30	1.72	1.94	9.79
8 Feb 69	0815-1015	1.35	1.64		5.09
15 Feb 69	0900				4.79
22 Feb 69	0810-0920		2.20		
18 Mar 69	1025-1400	10.66	8.66	10.83	13.00
19 Apr 69	1000-1107	16.76	13.00	13.00	11.60
24 Apr 69	0930-1210	13.37	12.35	13.00	13.00
3 May 69	0920-1010	13.56	12.14	11.98	11.72
15 May 69	0910-1030	6.75	6.24	5.66	5.35
24 May 69	0910-1005	5.79	5.81	4.92	4.51
29 May 69	1025-1115	4.49	5.30	5.72	7.35
5 Jun 69	1030-1515	6.09	6.62	5.32	5.67
13 Jun 69	1000-1210	3.43	3.85	4.16	6.32
23 Jun 69	1045-1145	3.57	3.25	3.69	3.45
27 Jun 69	0940-1130	3.26	4.15	4.01	4.58
3 Jul 69	0955-1135	2.43	2.70	2.85	3.24
11 Jul 69	1045-1155	2.38	2.40	3.17	6.11

Table 4 (concluded).

Date	Time	Station I-1	Station II-1	Station III-1	Station IV-1
17 Jul 69	1015-1140	1.90	2.38	2.91	3.87
24 Jul 69	1100-1220	2.16	2.13	2.63	4.21
31 Jul 69	1135-1250	2.68	3.19	4.00	5.73
7 Aug 69	0920-1430		3.22	3.33	4.06
8 Aug 69	0930	2.51			
14 Aug 69	0900-1140	3.11	2.73	3.98	5.18
21 Aug 69	1100-1225	2.90	2.95	3.22	3.61
28 Aug 69	0925-1155	1.98	2.46	2.87	3.35
4 Sep 69	1000-1135	1.73	1.78	2.24	3.16
20 Sep 69	0900-1100	2.70	3.10	3.10	4.28
27 Sep 69	0910-1035	2.32	2.28	2.45	4.33
4 Oct 69	0910-1115	2.36	2.60	3.42	4.82
11 Oct 69	0955-1045	2.41	2.41	2.45	3.51

EXPLANATION OF FIG. 2

The relationship between light extinction coefficient (K) and Secchi disc depth (D) in Tuttle Creek Reservoir.

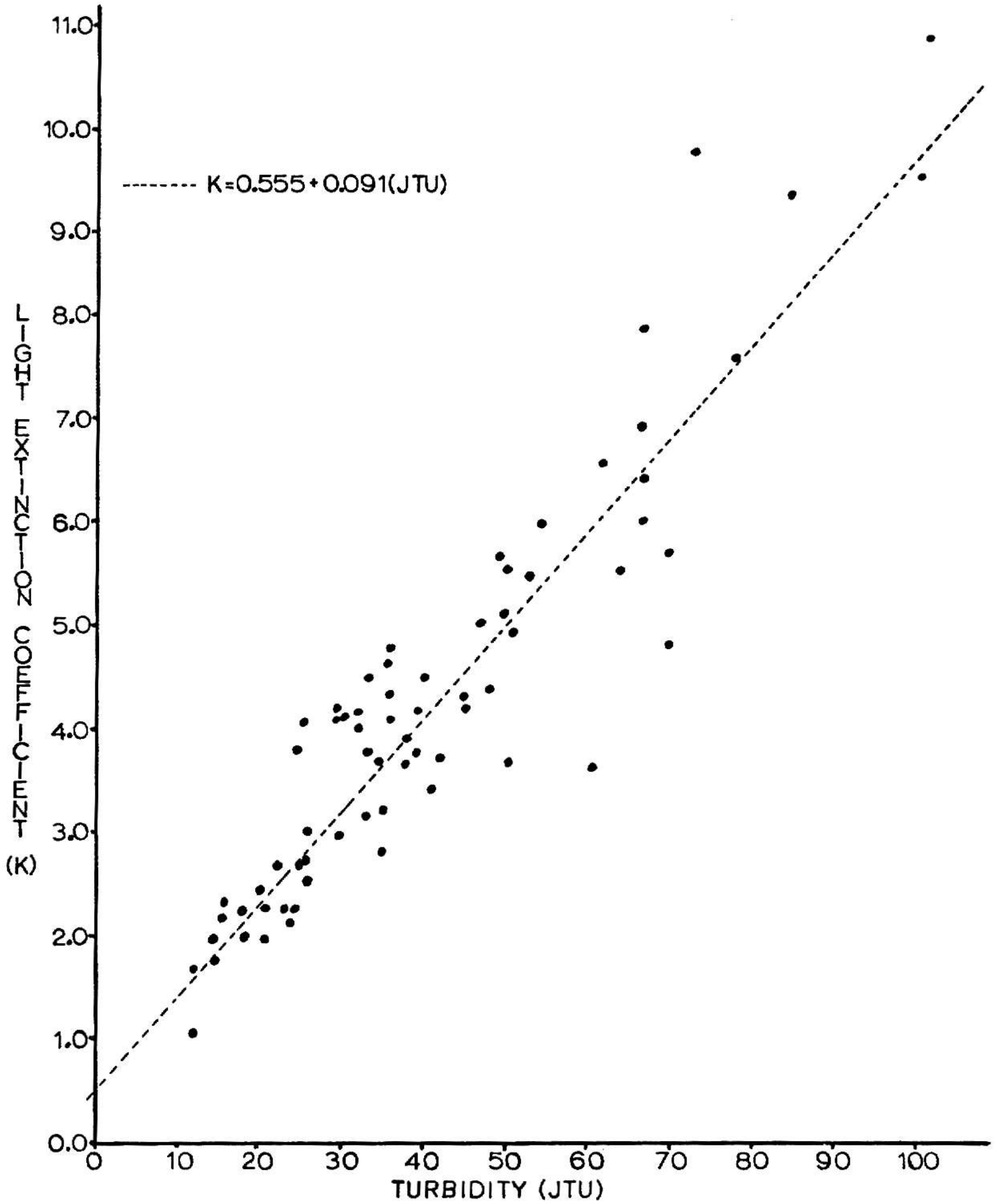


K = 0.067 + 1.4(1/D)
LIGHT EXTINCTION COEFFICIENT (K)
SECCHI DISC DEPTH (D) (METERS)
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
1.1
1.2
1.3
1.4
1.5
1.6
1.7
1.8
1.9
2.0

Fig. 2

EXPLANATION OF FIG. 3

The relationship between light extinction coefficient (K) and turbidity (JTU) in Tuttle Creek Reservoir.

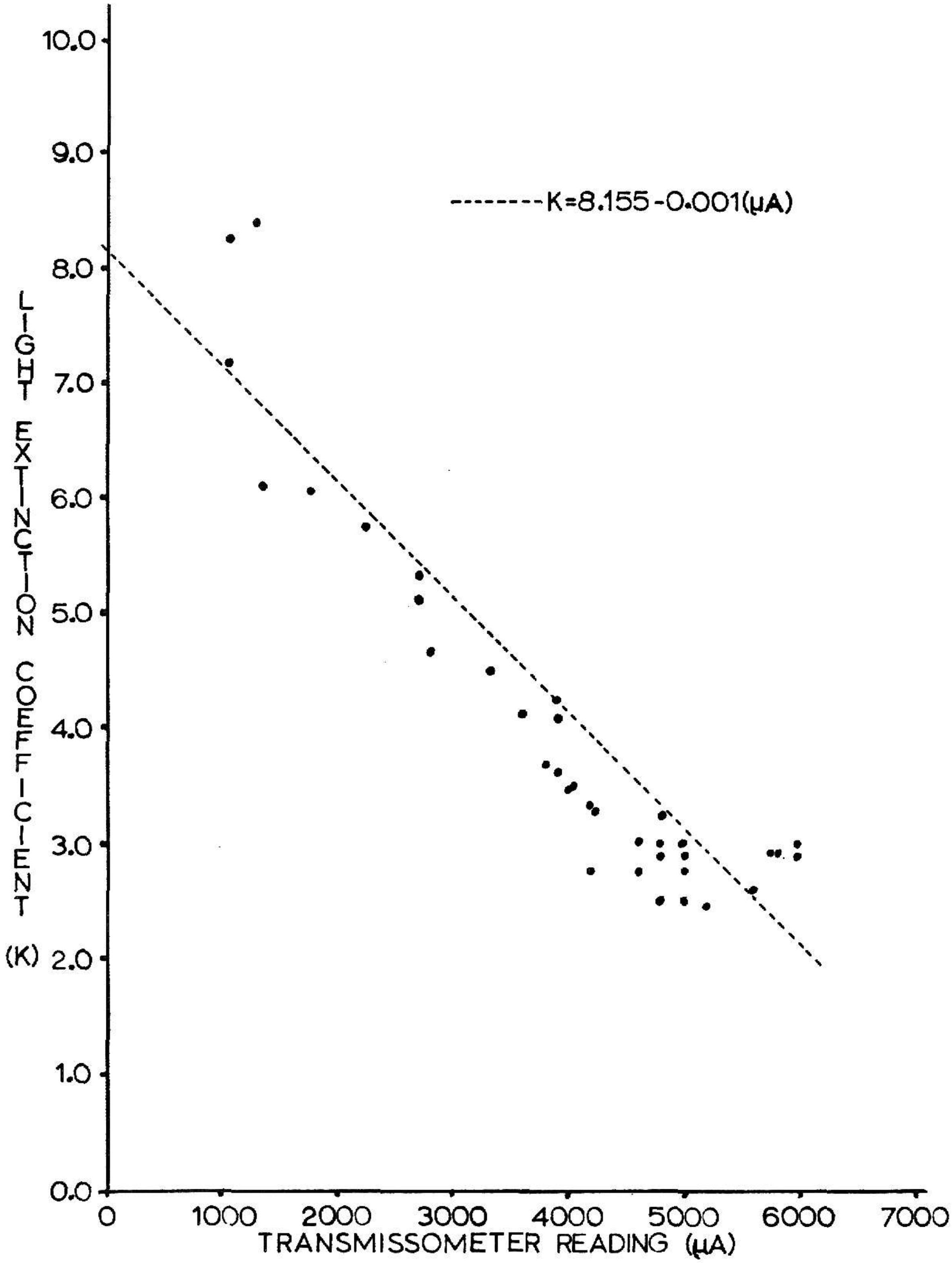


K=0.555+0.091(JTU)
LIGHT EXTINCTION COEFFICIENT (K)
0.0
1.0
2.0
3.0
4.0
5.0
6.0
7.0
8.0
9.0
10.0
11.0
0
10
20
30
40
50
60
70
80
90
100
TURBIDITY (JTU)

Fig. 3

EXPLANATION OF FIG. 4

The relationship between light extinction coefficient (K) and transmissometer readings (uA) in Tuttle Creek Reservoir.



--------K=8.155-0.001(μA)
LIGHT EXTINCTION COEFFICIENT (K)
10.0
9.0
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0.0
0
1000
2000
3000
4000
5000
6000
7000
TRANSMISSOMETER READING (μA)

Fig. 4

Table 5. Summary of light extinction coefficient (Y) versus reciprocal of Secchi disc depth (X_1), turbidity (X_2), and transmissometer measurement (X_3) regression analyses. (* and ** indicate significance at the .05 and .01 levels, respectively.)

Variable	# of Pairs	Min	Max	Mean	Standard deviation	R^2	Regression equation
Y	298	0.91	16.76	4.082	3.191	0.93**	$Y = -0.067 + 1.40(X_1)$
X_1		0.51	20.00	2.804	0.015		
Y	69	1.35	10.86	4.250	2.020	0.85**	$Y = 0.555 + 0.091(X_2)$
X_2		12.0	102.0	40.80	20.57		
Y	35	2.46	8.400	3.990	1.603	0.87**	$Y = 8.155 + 0.001(X_3)$
X_3		1050.	6000.	3914.	1408.		

Results of the linear regression analyses of the Blue River and Black Vermillion River sediment load data, summarized in Table 6, indicate that volume of water or discharge is much more important in determining the tons of sediment entering the reservoir than the weight of sediment per unit of water. It was found that sediment load peaks between six and 12 hours prior to discharge peak. A total of 5,490,291 metric tons of suspended sediment was estimated to have entered Tuttle Creek Reservoir during the period 1 February 1969 and 15 October 1969.

Table 7 shows the correlations of all of the untransformed variables versus light extinction coefficient at each of the four stations. At this point in the analysis it became quite apparent that a flow time or flushing rate variable was required to determine the number of days in residence needed for inflow water to reach the sampling stations.

Volume was related in a linear fashion with reservoir elevation over the range of elevation observed in this investigation (Fig. 5). The equation represented by volume = -17377 + 16.564 (elevation) is superimposed on Fig. 5. The R^2 value was 1.0.

Residence time (days) was found to be inversely related to light extinction coefficient. The maximum residence time from inflow date to outflow date was 133 days. This water entered the reservoir from 27 June to 30 June 1968 and was theoretically discharged from 7 November to 10 November 1968. The minimum residence time was 24 days when inflow water that entered the reservoir from 24 to 26 March 1969 was discharged from 17 to 19 April 1969.

A summary of the multiple linear regression analyses with transformed data at each of the four stations is shown in Table 8.

Table 6. Summary of the Big Blue River and Black Vermillion River discharge (cfs) and sediment load (gms/l.) analyses. The contribution to R^2 for the X_2 variable is after R^2 for X_1 has been entered. (** indicates significance at .01 level.)

	Mean	Standard deviation	Contr. to R^2	Regression equation	R^2
Big Blue River				$Y = 16515 + 4.97(X_1) + 11566(X_2)$	.895**
Discharge (X_1)	3808	4415.3	.781		
Sediment load (X_2)	1.49	1.070	.114		
Tons/day (Y)	19639.	31780.1			
Black Vermillion River				$Y = 2073 + 5.15(X_1) + 1595(X_2)$	.896**
Discharge (X_1)	577.	950.90	.754		
Sediment load (X_2)	1.72	1.660	.142		
Tons/day (Y)	3640.	6611.2			

Table 7. Summary of the correlations of nontransformed variables versus light extinction coefficients at all four stations. (* and ** indicate significance at the .05 and .01 levels, respectively.)

Variable name	Variable number	Station I-1	Station II-1	Station III-1	Station IV-1
Res Elev	5	-.074	-.057	.003	.079
Outflow	6	.405**	.310**	.290*	.493**
Inflow00	7	.191	.234	.205	.261*
Avebrf00	8	-.292	-.154	-.154	-.130
Outflo07	9	.531**	.536**	.543**	.417**
Outflo14	9	.658**	.625**	.642**	.649**
Outflo21	9	.720**	.717**	.723**	.669**
Inflow01	10	.162	.179	.139	.036
Inflow02	10	.117	.131	.106	.175
Inflow03	10	.138	.147	.120	.086
Inflow04	10	.171	.163	.145	.145
Inflow05	10	.229	.218	.205	.222
Inflow06	10	.273*	.248*	.231	.237*
Inflow07	10	.281*	.259*	.248*	.244*
Inflow10	10	.321**	.315**	.311*	.272*
Inflow13	10	.401**	.426**	.405**	.300*
Inflow16	10	.462**	.466**	.447**	.169
Inflow19	10	.498**	.482**	.486**	.198
Inflow22	10	.496**	.484**	.486**	.224
Avebrf07	11	-.056	-.052	-.062	-.117
Avebrf14	11	-.058	-.127	-.061	-.191
Avebrf21	11	-.140	-.142	-.189	-.216

Table 7 (continued).

Variable name	Variable number	Station			
		I-1	II-1	III-1	IV-1
Wind 06	12	.065	.065	-.108	-.055
Wind 12	13	.131	.180	-.049	-.015
Wind 18	14	.140	.175	-.049	-.060
Wind 24	15	-.036	-.005	-.050	-.066
Dirwnd06	16	.102	.082	-.077	-.011
Dirwnd12	17	.215	.177	-.102	-.095
Dirwnd18	18	.234	.294*	.162	.136
Dirwnd24	19	-.129	-.181	-.236	-.318**
Wind0day	20	.242*	.245*	.144	.155
Wind1day	21	.156	.173	.307*	.146
Wind2day	22	.293*	.315**	.283*	.134
Wind3day	23	.305*	.325**	.305*	.156
Wind4day	24	.345**	.353**	.287*	.151
Wind5day	25	.338**	.333**	.300*	.188
Wind6day	26	.352**	.330**	.297*	.191
2daywind	27	.528**	.503**	.517**	.313**
3daywind	28	.555**	.516**	.526**	.286*
4daywind	29	.619**	.553**	.572**	.320**
5daywind	30	.612**	.508**	.542**	.295*
6daywind	31	.634**	.484**	.531**	.301*
7daywind	32	.617**	.463**	.495**	.320**
Sedin01	38	.198	.292	.252	.050
Sedin02	38	.141	.229	.179	.016

Table 7 (concluded).

Variable name	Variable number	Station I-1	II-1	III-1	IV-1
Sedin03	38	.190	.264	.210	.096
Sedin04	38	.218	.281	.226	.147
Sedin05	38	.270	.304	.253	.253
Sedin06	38	.283	.305	.257	.289
Sedin07	38	.299	.274	.231	.264
Sedin10	38	.358	.349	.310	.290
Sedin13	38	.545**	.594**	.547**	.299
Sedin16	38	.658**	.673**	.621**	.387*
Sedin19	38	.705**	.678**	.639**	.556**
Sedin22	38	.648**	.633**	.602**	.530**

EXPLANATION OF FIG. 5

The relationship between volume and reservoir elevation in Tuttle Creek Reservoir.

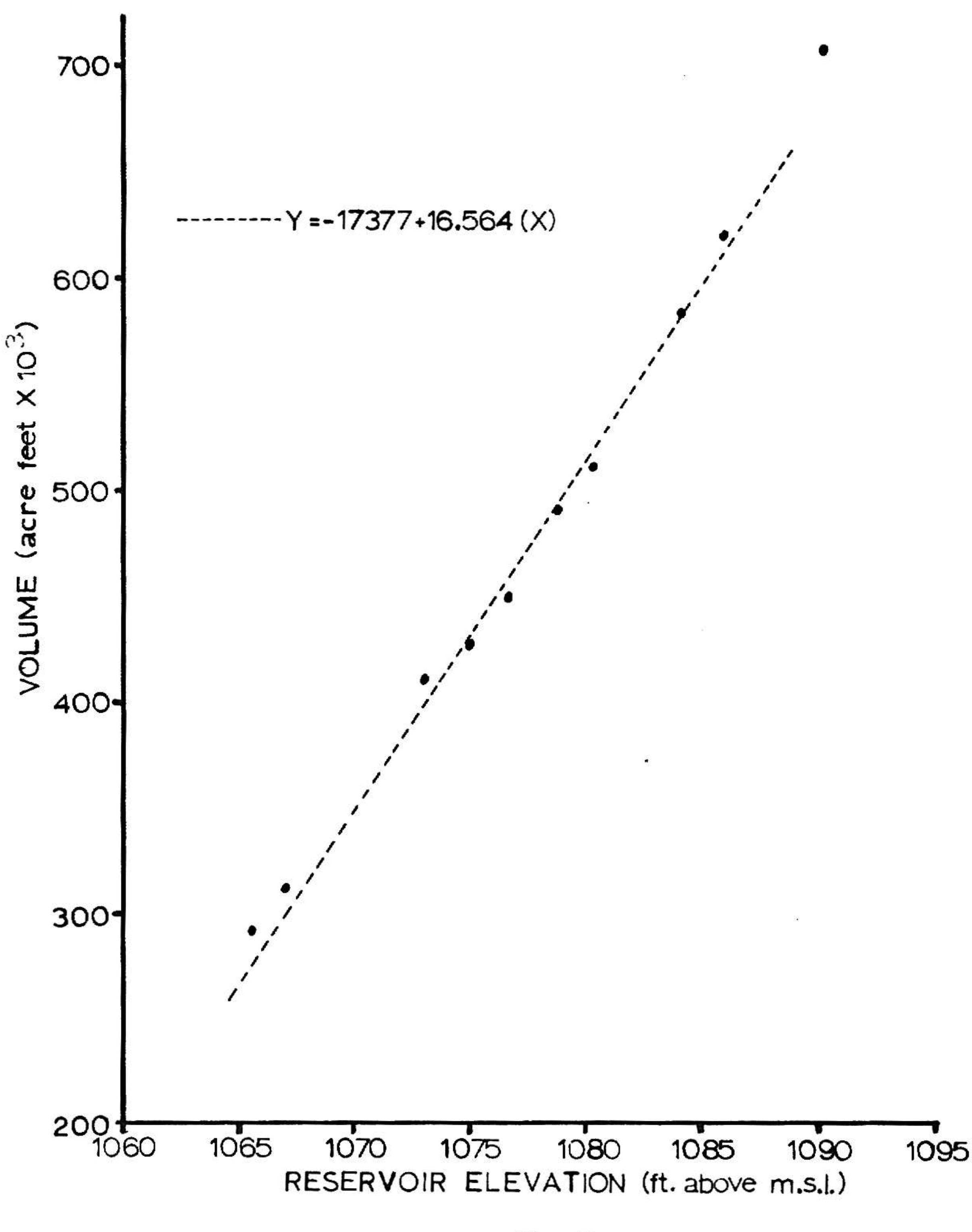

Y = -17377+16.564 (X)
VOLUME (acre feet X 10^3)
700
600
500
400
300
200
1060
1065
1070
1075
1080
1085
1090
1095
RESERVOIR ELEVATION (ft. above m.s.l.)

Fig. 5

Table 8. Summary of multiple linear regression analyses with transformed data at each of the four stations with light extinction coefficients (E) as dependent variable. (* and ** indicate significance at .05 and .01 levels, respectively).

Station	Independent variable #	F/d.f.	R^2	Regression equation
I-1	35,36,33,37	7.98/33**	.492	K = -15.626 + 51.398(1/Res days) + .652(LnInflo) + .009(Wind bar) + 1.523 (LnOutflo)
II-1	35,36,33,37	16.36/40**	.620	K = -17.941 + 27.345(1/Res days) + 1.15(LnInflo) + .005(Wind bar) + 1.445 (LnOutflo)
III-1	35,36,33,37	11.32/36**	.557	K = -21.835 + 3.584(1/Res days) + .992(LnInflo) + .009(Wind bar) + 2.118 (LnOutflo)
IV-1	35,36;33,37	8.58/56**	.380	K = -9.578 + 6.225(1/Res days) + .338(LnInflo) - .001(Wind bar) + 1.571 (LnOutflo)

Ranked in order of contribution at station IV-1 the variables are (i) LnInflow, (ii) LnOutflo, (iii) 1/resdys, and (iv) Wind bar. At stations III-1 and II-1 the order of importance had changed to (i) LnOutflo, (ii) LnInflo, (iii) Wind bar, and (iv) 1/resdys. At station I-1 the order of contribution was (i) LnOutflo, (ii) Wind bar, (iii) 1/resdys, and (iv) LnInflo.

Results of the random sample taken on 7 and 8 August 1969 indicate no significant difference vertically nor laterally within the reservoir.

There was a significant difference between channel and non-channel measurements that were laterally aligned. At the 5 per cent level of significance the five channel measurements were significantly more turbid than the non-channel measurements (t = 2.773). The mean and standard deviation for the channel sample were 3,790 and 1,589.2 microamperes, respectively. The mean and standard deviation for the non-channel sample were 3,070 and 1,427.3 microamperes, respectively.

During the period 5 August 1968 to 12 August 1968, Secchi disc measurements were taken along the east and west shore laterally aligned with each station. At the 5 per cent level of significance the west side was significantly more turbid than the east side (t = 2.672). The mean for the west shore was 41.6 cm, the standard deviation 3.27. The mean for the east shore was 54.8 cm, the standard deviation 3.51.

A predictive model for the lower end of the reservoir to determine the effect of a five day period of inflow on the turbidity level at station I-1 follows. The computerized Fortran program for this model is shown in Appendix 2.

Residence time - At 1,075 ft m.s.l. elevation and 2,000 cfs outflow rate, the residence time is equal to 108 days. Residence time is inversely proportional to outflow rate when reservoir elevation remains constant. Adjust for difference in average outflow rate during residence time (i.e., residence time equals 54 days when outflow rate is 4,000 cfs, residence time equals 10.8 days when average outflow rate is 20,000 cfs, residence time equals 216 days when average outflow rate is 1,000 cfs). Add or subtract 4% to adjusted residence time for each one foot of average reservoir elevation above or below 1,075 ft m.s.l.

Five day mean inflow rate - At an inflow rate of 500 cfs the average sediment load is approximately .5 gms/l. of water and increases up to approximately 5.0 gms/l. of water at an inflow rate of 16,500 cfs. Because this relationship is not linear, calculate an adjustment factor by the following schedule where X = the adjustment factor:

X = 1.0 when average inflow rate is less than 1,500 cfs.

X = 2.0 when average inflow rate is 1,500 cfs or greater but less than 3,500 cfs.

X = 3.0 when average inflow rate is 3,500 cfs or greater but less than 7,500 cfs.

X = 4.0 when average inflow rate is 7,500 cfs or greater but less than 16,500 cfs.

X = 5.0 when average inflow rate is 16,500 cfs or greater.

Adjustment for residence time - The average rate of reduction in light extinction coefficient (K) was 0.03 per day in residence. This varied from no reduction during a six day period with average wind above 15 miles per hour to a rate of 0.28 under ice cover when wind was considered to be zero.

Beta zero from the multiple linear regression equations for the lower end of the reservoir adjusted for average wind values equals -14.0. Maximum K value (A) for station I-1 can be calculated by:

A = -14.0 + (natural logarithm of 5 day mean inflow rate in question times X.)

During the period of study the measured K value did not fall below ten per cent of the calculated maximum K value. It is assumed that this is a function of the colloidal portion of suspended materials. It is also assumed that no unit of water in the reservoir can be clearer than that water with its colloid particles. The calculated K value can be determined by reducing the A value by 3% for each of the number of days in residence or until the calculated K value is equal to 10% of the maximum K value.

The effect of a period of high inflow rate on the light extinction coefficient value can thus be determined by trying different average outflow rates to find the optimum outflow rates that will minimize K without jeopardizing the primary purpose of the reservoir.

The major criterion for any model is its usefulness either for prediction purposes or to lead to a better model. To test the model, all of the periods of inflow with a mean daily inflow rate greater than 10,000 cfs and which theoretically were measured at station I-1, were compared with calculated K values. The results of these analyses are shown in Table 9.

Part of the error is in the calculation of residence time from inflow date to the lower end of the reservoir. Another major source of error is lack of adjustment for wind conditions of less than or greater than average wind. Apparently the model permits the minimum K value to be reduced lower than actually occurs in the reservoir.

Table 9. Comparison of measured K values with predicted K values for periods of inflow with a mean daily inflow rate greater than 10,000 cfs.

Inflow date	Days	Inflow rate	Predicted K value	Measured K value	Error
24 Jul 68	108	4130	1.10	3.90	-2.80
2 Aug 68	114	8156	2.20	3.80	-1.60
12 Aug 68	94	9596	2.27	4.10	-1.83
21 Aug 68	95	6685	1.24	4.04	-2.80
18 Oct 68	101	11250	2.33	2.30	+0.03
21 Apr 69	34	8620	7.90	5.75	+2.15
28 Apr 69	30	7050	5.05	4.50	+0.55
23 May 69	52	13605	4.94	2.00	+2.94

DISCUSSION

Measurement of Light Extinction Coefficient

Secchi Disc. The relationship between the extinction coefficients (K) by photometer and Secchi disc depth (D) is expressed by:

$$K = 0.067 + 1.4 \left(\frac{1}{D}\right) \qquad (2)$$

Poole and Atkins (1929) reported K = 1.7 / D for data collected off of Plymouth, England in the English Channel. K values in that study ranged from 0.088 to 0.203. Their equation for K fits the Atlantic Ocean data of Clarke (1941). Clarke reported extinction coefficients ranging from 0.037 to 0.13 and Secchi measurements from 13.0 to 47.0. The range of

Secchi disc measurements for Tuttle Creek was 0.05 to 1.96 and 0.91 to 16.76 for K. The data collected from Tuttle Creek Reservoir represents a situation of higher turbidity than encountered by the others. Part of the difference between equation 2 and that reported in the literature may be due to differential spectral absorption in the top meter of water. The relative proportion of green light (490 mu to 540 mu) absorbed as compared to the yellow-orange light (590 mu to 610 mu) increases as turbidity increases (Beeton, 1957). Light striking suspended materials is either reflected or absorbed. As turbidity increases the percentage reflected increases for not only the light entering the water from above but also from the Secchi disc back up to the surface. Thus as turbidity increases the percentage of light reflected from the Secchi disc that reaches the surface decreases resulting in Secchi disc measurements relatively shallower in more turbid waters. A study of the relative absorption of the visible spectrum in turbid waters and of the absorption and diffusion in turbid waters of Tuttle Creek Reservoir should prove enlightening.

The use of the Secchi disc as a tool to measure the depth of the euphotic zone has been widely discussed. Jones and Wills (1956), Graham (1966), and Tyler (1968) concluded that conversion factors derived from Secchi disc readings were applicable only to that particular body of water.

Several investigators have reported a value at which Secchi disc measurements could be used to predict the depth at which one per cent of the surface light remained. Verduin (1956) determined that the approximate depth of the euphotic zone in a lake could be calculated by multiplying Secchi disc values by 5.0. Rawson (1950) reported a factor of 4.3 in Great Slave Lake. Strickland (1958) reported that euphotic depth should be about 2.5 times Secchi disc depth. Norden (1968) reported values of 3.1 for two stations in Lake Michigan and 2.1 at a more turbid station in the Milwaukee, Wisconsin harbor.

Error in measurement may account for most of the irregularity in the correlation between light extinction coefficient and Secchi disc depth. A small error in measurement of Secchi disc depth when this depth is 10 cm or less results in a relatively large percentage error. Difficulty in measurement of photocell depth in rough water causes a sacrifice of precision. This error is magnified as turbidity increases.

Measurement of light extinction coefficient through the ice cover was erroneous when a snow cover was present. All five of the measurements under these conditions were higher than calculated from Secchi disc depth and the regression equation (Fig. 2). Measurements under these conditions were made on 1 February 1970, and 15 February 1970, through 21 to 27 cm of ice and up to 21 cm of snow. The resulting K values were 12.1 to 26.9 per cent higher than expected. Comparison of the turbidity, light extinction coefficient relationship (Fig. 3) suggests that Secchi disc measurements were in line and that K values were high, which indicates a shadow effect from the ice-snow cover. All light measurements through ice cover without snow cover were well within the limits of variation such that no deviation from calculated values was noticeable.

Jackson Turbidity Units (JTU). The relationship between light extinction coefficient and turbidity (JTU) was more variable as turbidity increased (Fig. 3). This is partially due to increased percentage error in light measurements. Chandler (1942) found an inverse relationship between turbidity (ppm) and Secchi disc values but chose not to derive one value from the other because the relationship was not constant.

Transmissometer Units. Variation in the correlation between K and transmissometer measurements (Fig. 4) may be accounted for by error in measurement of light values used in the calculation of K. Error in measurement with the transmissometer was considered negligible since the distance between the photocell and light source was fixed, though spectral differences between natural light and the sealed beam bulb represents an uncorrected source of error.

Relationship of Hydrologic Factors to Turbidity

Sediment. Sediment load data were not used in the final analyses because of the eight months of turbidity data for which sediment load data were not available. It was found that river discharge (reservoir inflow) contributed more than 0.75 to the R^2 value whereas sediment load contributed less than 0.15 additional to R^2 (Table 6). This indicates that during the period 1 February 1969 to 15 October 1969, anytime discharge significantly increased it carried along with it an increased sediment load. This relationship was utilized in the final predictive model.

Inflow and Rainfall. Light extinction coefficient (Table 7) was negatively but insignificantly correlated with average basin rainfall. Rainfall within the basin possibly carried organic matter into the reservoir. Mrose (1966) reporting on the results of rain analysis from six sampling stations in Sweden, reported 206 pH measurements ranged from 3.4 to 6.0 and a mean value of 4.5. The yearly mean had not changed since 1958. Cauer (1956) found the pH of rain from rural areas to be lower than in urban areas assuming the reason to be caused by a larger percentage of HNO_3 (from Mrose, 1966). Irwin (1945) and Irwin and Stevenson (1951) found the addition of organic matter or the addition of hydrogen ions cleared impounded waters in Oklahoma by neutralizing the negative ionic charge of colloidal particles permitting coagulation and precipitation. The great influence of periods of high inflow on the turbidity at each station is demonstrated by the significant relationship of most inflow variables to extinction coefficient. Suspended sediment variables were highly correlated with inflow variables.

Wind. Wind variables measured over periods of less than 24 hours were insignificant. This does not agree with the results of Jackson and Starrett (1959) on Lake Chautauqua, Illinois, a shallow lateral reservoir lake along the Illinois River. They reported that the average maximum velocity during the 1-hour period preceding sampling was "better correlated" than the average maximum 5-hour velocity preceding sampling when no vegetation was present. Resuspension, primarily by wind generated currents, of sediment particles, which were originally carried and deposited in the lake by flood waters of the Illinois River, caused the high turbidities in Lake Chautauqua during periods when vegetation levels were low. Chandler (1942) reported that strong winds caused an increase in turbidity in western Lake Erie.

Part of the 24-hour period wind variables were significant ($\alpha = .05$) but none of the r values were above 0.4. Most combined wind variables of more than one day were significant ($\alpha = .01$), indicating that wind is a factor contributing to the turbidity level in Tuttle Creek Reservoir. The primary role of the wind seems to be that of maintenance of materials in suspension rather than resuspension as reported by Jackson and Starrett (1959) and Chandler (1942). This is indicated by the increased contribution by the wind variable in the final analyses at the lower stations where increased depth and a shoreline stabilized by a limestone rock layer would reduce the probability of resuspension. A detailed study of the role of wind in the generation of currents and velocities required to resuspend bottom sediments would be valuable. Schwartz (1970) found areas of bottom containing only original pre-impoundment soil indicating the presence of currents at least strong enough to prevent settling of suspended materials.

Wind direction was found to be insignificant as a causative agent of turbidity in Tuttle Creek Reservoir.

Outflow and Elevation. All of the outflow variables were highly correlated with turbidity levels at all four stations. Reservoir volume and outflow rate determined the number of days that inflow waters were in residence within the reservoir down to the sampling station or until it was discharged from the reservoir. Any time during this study that the outflow rate was increased drastically, more turbid waters were entering or had entered the reservoir at an earlier period. Increased outflow rates resulted in increased gravity flow of more turbid waters from upstream, thus when outflow rate increased, turbidity levels increased. Reservoir elevation alone was an insignificant determinant of extinction coefficient at all four stations. Whenever reservoir elevation changed, a band of higher turbidity along the shoreline was created by wave action on the unstabilized shoreline. This contribution to the overall turbidity level of the reservoir was minor in comparison to the more turbid inflow waters that resulted in the change in elevation.

Residence Time. The created variable, residence time, is based on average daily volume and average daily outflow rate (Equation 1, p. 13). This was a fairly accurate measurement of the time that the initial influence of more turbid water could be measured at each station when outflow rates were not changed drastically during the interim period. A more accurate measure would have been the daily progress made at each day's volume and outflow rate until residence time equaled the progress days, i.e., correct for a variable rate of progress.

The inverse relationship between residence time and light extinction coefficient is significant. When turbid inflow waters were retained at the upper end of the reservoir and permitted to mix with clearer waters and suspended particles permitted to settle, periods of high inflows had less influence on the transparency of the lower end of the reservoir.

The influence of inflow decreased and outflow increased from the upper end to the lower end of the reservoir. The role of wind in the maintenance of suspended particles is borne out by the increased contribution of the weighted five day mean wind variable, from the upper end to the lower end of the reservoir. A more accurate wind variable would consider the 0.28 settling rate when wind was zero, the 0.03 average settling rate for an average wind velocity of 7.3 mph, and the zero settling rate for wind velocity above 15.0 mph for each day in residence. Part of the unexplained contribution to turbidity (Table 8) at each station is the settling of suspended particles during periods of calm wind more than five days prior to sampling. Probably the largest error in the transformed data multiple linear regression analyses is the error in calculation of residence time. The residual influence of high inflow rates at each station is not accounted for.

Currents. The presence of density currents was observed three times during the period of study. On 7 and 8 August 1969, five river channel transmissometer readings were significantly more turbid ($\alpha = .05$) than five laterally paired non-channel measurements. In each of the five pairs the turbidity increased down in the old channel below the maximum depth of the non-channel measurements. No temperature profile was taken so it is uncertain as to whether the increased density was due to temperature, sediment load, or both. The vertical pattern of circulation was apparently mixing the more turbid waters in the channel with clearer waters above the channel. The outflow rate during this period was 5,000 cfs. During the period 5 to 12 August 1968, Secchi disc measurements along the west shoreline were significantly shallower than along the east shoreline ($\alpha = .05$). Outflow rates during this period varied from 200 to 700 cfs. Sullivan (1969) reported that during the 25 March 1969 survey, releases were 12,000 cfs and inflow 22,000 cfs, a very definite current along the right side of the reservoir was indicated by the higher suspended sediment concentrations. Temperatures along the right side were not different from the center or left side of the reservoir. Wiebe (1939) reported density currents due to silt in the Clinch River Sector of Norris Reservoir from the point of origin to a distance of 22 miles below this point. He reports that density currents due to silt are less stable than those due to differences in salinity or temperature.

The Predictive Model

The accuracy of the model is yet to be tested. Its usefulness either for prediction or to lead to a better model has not been challenged. An experimental study of the model which includes manipulation of outflow rates would be valuable. Certainly a study of the effects of low light extinction coefficient values on primary production should be made prior to any artificial attempts to reduce the turbidity in Tuttle Creek Reservoir.

SUMMARY

1. The relationship between light extinction coefficient (K) and Secchi disc depth (D) for 298 pairs in Tuttle Creek Reservoir was found to be: $K = 0.067 + 1.4(\frac{1}{D})$. The range of Secchi disc measurements was 0.05 to 1.96 and 0.91 to 16.76 for K.

2. The depth of the zone receiving 1% or more of surface intensity was found to be 3.45 times Secchi disc depth. This is near the mean of the values reported in the literature.

3. Measurement of K was erroneous through ice cover when snow cover was present. K values under these conditions were from 12.1 to 26.9 per cent higher than expected.

4. The relationship between K and turbidity (JTU) was K = 0.555 + 0.091 (JTU).

5. Residence time, a measure of the number of days that inflow waters had been in the reservoir, was calculated by:

$$\text{days} = \frac{\text{average daily volume (acre ft)} \times 43{,}560}{\text{average daily discharge rate (cfs)} \times 86{,}400} \times V$$

where V = the percentage of total volume above the sampling station. Residence time was found to be reasonably accurate measure of the time required for the initial influence of more turbid waters to reach each sampling station. Residence time was found to be inversely related with K.

6. Density currents were observed three times during the period of study.

7. It is suggested the role of wind in the turbidity level is in the maintenance of particles in suspension as opposed to resuspension. Low outflow rates during periods of high inflow does not prevent the lower end of the reservoir from becoming more turbid, but does reduce the degree of turbidity and regulates the time of arrival of the more turbid water.

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APPENDICES

APPENDIX I

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C THIS PROGRAM CALCULATES THE NUMBER OF DAYS INFLOW WATER IS IN
C RESIDENCE.  F EQUALS THE PER CENT OF TOTAL VOLUME ABOVE EACH OF THE
C FOUR STATIONS AND OUTFLOW DISCHARGE POINT.  INFLOW DATE (IDT) AND
C RESIDENCE DATE (JDT) ARE JULIAN DATES WITH THE LEFT COLUMN EQUAL TO
C THE LAST NUMBER OF THE CALENDAR YEAR.  IDYS EQUALS THE NUMBER OF DAYS
C IN RESIDENCE.  A RESERVOIR CARD CONTAINING ELEVATION (EL), OUTFLOW
C RATE (DIS), AND THE DATE (IDT), WAS INCLUDED FOR EACH DAY OF THE STUDY.
      DIMENSION DIS(504),VOL(505),FLU(504),EI(504),IDT(504),JDT(504),
     2IDYS(504)
      DO 1 I=1,504
      READ(1,10,END=11)IDT(I),EL(I),DIS(I)
   10 FORMAT(4X,I4,F6.2,F5.0)
    1 N=I
   11 NN=N+1
      VOL(NN)=1.0
      DO 2 I=1,N
    2 VOL(I)=(EL(I)*16.564 - 17377.0)*1000.0
      DO 7 II=1,5
      GO TO (31,32,33,34,35),II
   31 F=0.179
      WRITE(3,20)
   20 FORMAT('1','DATE OF INFLOW WITH RESIDENT DATE AT STATION IV-1')
      GO TO 9
   32 F=0.388
      WRITE(3,22)
   22 FORMAT('1','DATE OF INFLOW WITH RESIDENT DATE AT STATION III-1')
      GO TO 9
   33 F=0.602
      WRITE(3,23)
   23 FORMAT('1','DATE OF INFLOW WITH RESIDENT DATE AT STATION II-1')
      GO TO 9
   34 F=0.831
      WRITE(3,24)
   24 FORMAT('1','DATE OF INFLOW WITH RESIDENT DATE AT STATION I-1')
      GO TO 9
   35 F=1.0
      WRITE(3,25)
   25 FORMAT('1','DATE OF INFLOW WITH RESIDENT DATE AT OUTFLOW')
    9 WRITE(3,21)
   21 FORMAT('0',7('DATE  DYS RDATE   '))
      DO 3 I=1,N
      A=0.0
      JJ=0
      VO=0.0
      DI=0.0
      DO 4 J=1,NN
      A=A+1.0
      JJ=JJ+1
      IF(VOL(J).EQ.1.0)GO TO 5
      VO=VO+VOL(J)
```

```
      FLU(I)=((VO/A)/(DI/A))*0.50416*F
      IF(FLU(I).LE.A)GO TO 13
    4 CONTINUE
   13 JDT(I)=IDT(I)+JJ
      IDYS(I)=JJ
      IF(JDT(I).LE.8366)GO TO 3
      IF(IDT(I).GE.9001)GO TO 3
      JDT(I)=JDT(I)+634
      GO TO 3
    5 FLU(I)=999.9
    3 CONTINUE
      M=0
      DO 6 I=1,N,7
      WRITE(3,26)(IDT(M+K),IDYS(M+K),JDT(M+K),K=1,7)
   26 FORMAT(' ',7(I4,I5,I6,3X))
    6 M=M+7
    7 CONTINUE
      STOP
      END
```

APPENDIX 2

```
C THIS PROGRAM IS A PREDICTIVE MODEL FOR TURBIDITY IN TUTTLE CREEK
C RESERVOIR.  IDATE=JULIAN DATE WITH LEFT TWO COLUMNS EQUAL TO THE YEAR.
C EL=AVERAGE RESERVOIR ELEVATION.  AVIN=AVERAGE 5 DAY INFLOW RATE IN
C QUESTION (CFS).  OUT=AVERAGE OUTFLOW RATE PLANNED (CFS).  JDATE IS THE
C JULIAN DATE FOR THE INITIAL IMPACT OF HIGH INFLOW RATES TO REACH MIDLAKE
C OFF OF MCINTIRE COVE.
      WRITE(3,14)
   14 FORMAT(' ','PREDICTED EXT. COEF RESULTING FROM INFLOW RATE, ELEVAT
     2ION, AND OUTFLOW RATE INDICATED'//' ','DATE    DAYS  INFLO CFS  DA
     3TE  EXT COEF  OUT CFS  ELEV')
   16 READ(1,10,END=20)IDATE,EL,AVIN,OUT
   10 FORMAT(I5,F5.1,F6.1,F6.1)
C CALCULATE RESIDENT DAYS
      DYS=1.0/(OUT/2000.0)*108.0
      DYS=DYS+((.04*(EL-1075.0))*DYS)
      IDYS=DYS
C CALCULATE ADJUSTMENT INFLOW FACTOR
      X=1.0
      IF(AVIN.GE.1500.)X=2.0
      IF(AVIN.GE.3500.)X=3.0
      IF(AVIN.GE.7500.)X=4.0
      IF(AVIN.GE.16500.)X=5.0
C CALCULATE MAXIMUM AND MINIMUM K VALUES
      A=-14.0+(ALOG(AVIN)*X)
      B=A*.1
C ADJUST MAXIMUM K FOR MIXING AND SETTLING
      DO 11 I=1,IDYS
      A=A-(.03*A)
      IF(A.LE.B)GO TO 12
   11 CONTINUE
      GO TO 13
   12 A = B
   13 JDATE=IDATE+IDYS
      IF(JDATE.LE.68366)GO TO 17
      IF(JDATE.GE.69001)GO TO 17
      JDATE=JDATE+634
   17 WRITE(3,15)IDATE,IDYS,AVIN,JDATE,A,OUT,EL
   15 FORMAT('0',I5,I6,F11.1,I7,F9.2,F9.0,F8.1)
      GO TO 16
   20 STOP
      END
```

ANALYSIS OF THE CAUSATIVE AGENTS OF TURBIDITY IN A GREAT PLAINS RESERVOIR

by

DONALD WILLIAM DUFFORD

B. S., Kansas State University, 1955
B. S., Kansas State University, 1968

AN ABSTRACT OF A MASTER'S THESIS

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This was a study of the factors causing turbidity in Tuttle Creek Reservoir, Kansas. River inflow was found to be the primary source of suspended materials. Outflow rate and reservoir volume were found to regulate the gravity flow of more turbid water through the reservoir. Reduced outflow rate during periods of high inflows did not prevent the lower end from becoming more turbid but did reduce the degree of turbidity and the time required for the more turbid water to reach the lower end of the reservoir. The primary role of wind was maintenance of particulate matter in suspension as opposed to resuspension. Residence time was calculated using average daily volume, average daily outflow rate and the percentage of total volume above the sampling station. Residence time was found to be inversely related to light extinction coefficient (K).

The relationship of 298 pairs of light extinction coefficient (K), Secchi disc depth (D) data was $K = 0.067 + 1.4 (1.0/D)$. The relationship of 69 paired K, turbidity (JTU) data was $K = 0.555 + 0.091 (JTU)$. The depth of the zone receiving one per cent or more of the surface light intensity was 3.45 times Secchi disc depth. Measurement of K was erroneous through ice cover when snow cover was present. K values under these conditions were from 12.1 to 26.9 per cent higher than expected.