CONTINUOUS MONITORING OF DISSOLVED OXYGEN CONCENTRATION AND TEMPERATURE AT MULTIPLE DEPTHS IN A RESERVOIR

By

ALLEN RAY FAUST

Bachelor of Science

Oklahoma State University

Stillwater, Oklahoma

1967

Submitted to the faculty of the Graduate College
of the Oklahoma State University
in partial fulfillment of the requirements
for the degree of
Master of Science
May, 1972

CONTINUOUS MONITORING OF DISSOLVED OXYGEN
CONCENTRATION AND TEMPERATURE AT
MULTIPLE DEPTHS IN A RESERVOIR

Thesis Approved:

Troy C. Dorris
Thesis Adviser

Jerry Wilhm

Louis P. Varga

D. Durham
Dean of the Graduate College

PREFACE

The objectives of the present study were to design, construct, and test an apparatus for continuous recording of physicochemical parameters and to determine the value of data collected from several reservoir depths for primary production studies.

Dr. Troy C. Dorris served as major adviser. Drs. Jerry Wilhm and Louis P. Varga served on the advisory committee and criticized the manuscript. Dr. Rex L. Eley made many helpful suggestions with regard to analysis of the data, Doug Carter assisted with the drawings, and Gary K. Rice helped with field work, mechanical maintenance, and computer programming. The typing of the final manuscript was done by Mrs. Gary Rice. I am grateful for the kind assistance of all these people.

This study was supported by a National Defense Education Act Fellowship.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER I

INTRODUCTION

A reservoir is a complex system of interacting physical, chemical, and biological forces influenced by meteorological phenomena (Mackenthun and Ingram, 1967). Like any other ecosystem the reservoir has structure and function, nutrient cycling, and energy flow. If the input and output of physical, chemical, biological, and meteorological factors can be measured; a model can be made that will permit a general prediction of future trends in reservoirs.

Physical, chemical, and meteorological parameters in reservoirs are more easily measured on a continuous basis than are the biological parameters they influence. The evaluation of a continuous physicochemical sampling program of a reservoir is the objective of this study.

Keystone Reservoir, completed and filled by April, 1965, is located just west of Tulsa in north-central Oklahoma. It is a mainstream reservoir constructed by the U. S. Army Corps of Engineers for hydroelectric power generation, flood control, recreation, and control of the Arkansas River navigation system. It is formed by the confluence of the Arkansas and Cimarron Rivers 3.2 km upstream from the dam site (Figs. 1 and 2). Surface area of the reservoir at normal power pool level (220 m Mean Sea Level) is 10,648 ha with a storage capacity of about 8.2 X 10^8 m^3. The two rivers and smaller tributary streams drain large semi-arid plains in southeastern Colorado, southern Kansas, and northern Oklahoma

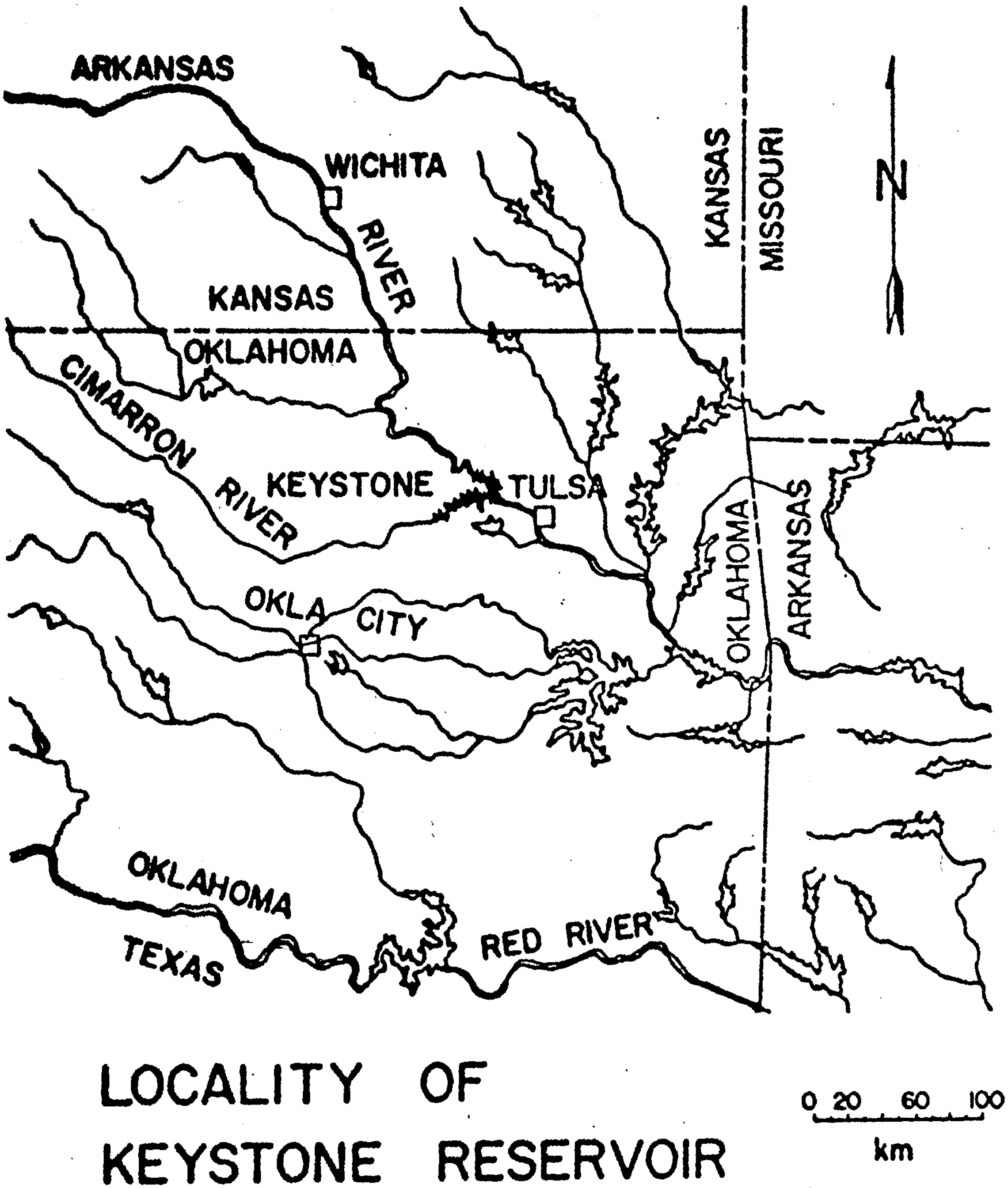

ARKANSAS
WICHITA
RIVER
KANSAS
OKLAHOMA
KANSAS
MISSOURI
N
CIMARRON
RIVER
KEYSTONE
TULSA
OKLA CITY
OKLAHOMA
ARKANSAS
OKLAHOMA
TEXAS
RED RIVER
LOCALITY OF
KEYSTONE RESERVOIR
0 20 60 100
km

Figure 1

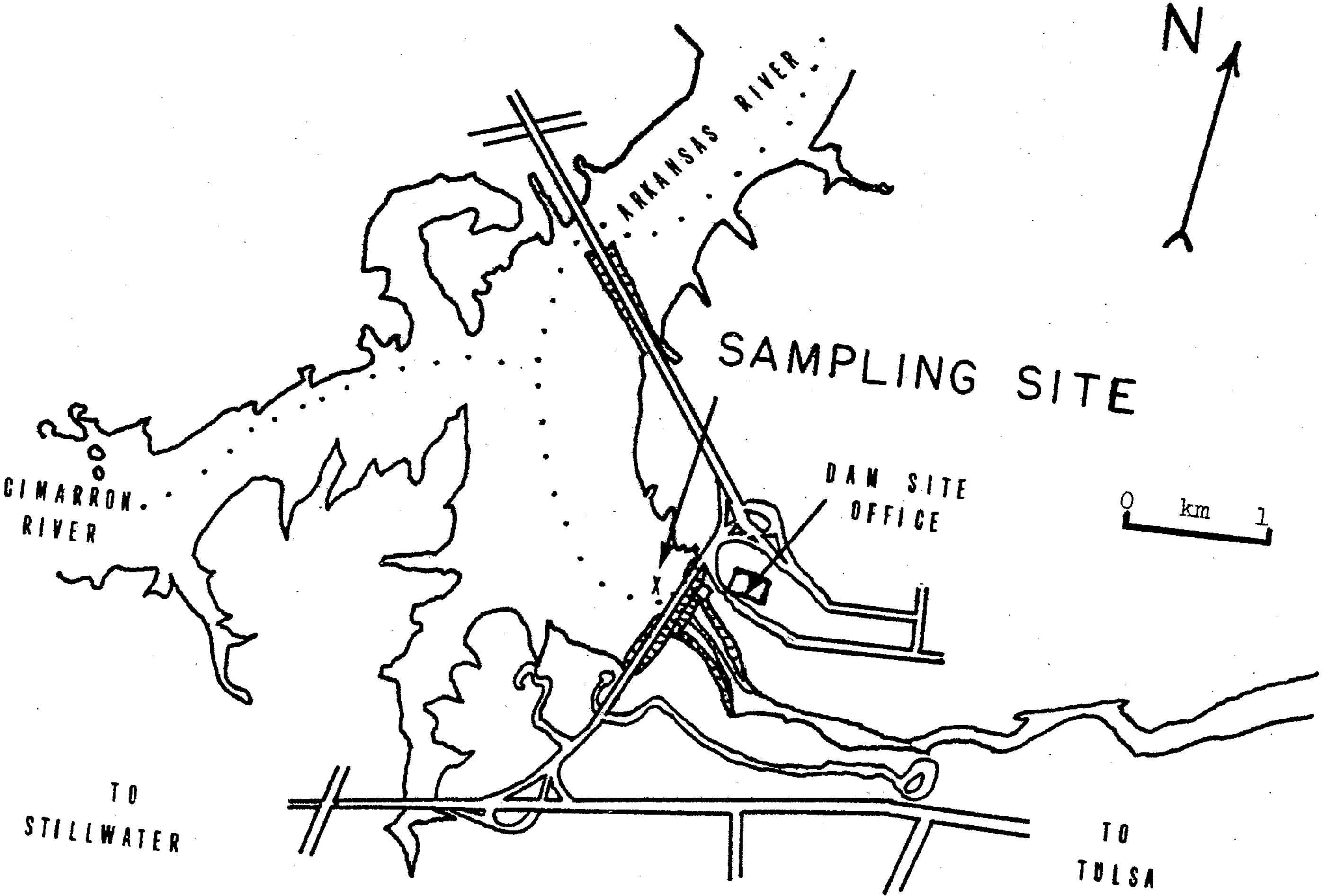


Figure 2. Keystone Dam Area, Showing Location of Sampling Site

(192,970 km^2).

Incoming waters contain variable concentrations of dissolved and suspended inorganic and organic solids. It has been found that the turbid and salt-heavy water of the Cimarron River produces a density current which underflows the clearer and lighter water of the Arkansas River except during mixing by flood waters. However, the Cimarron River contributes only about 17% of the total inflow. During the summer months pronounced thermal and chemical stratification exists (Eley, 1967, 1970).

Continuous monitoring of physicochemical variables can provide immediate data for water quality determinations and aid in the establishment of a predictive mathematical reservoir model. An adequate model can be made if variables such as temperature, oxygen, light and nutrients, which control the distribution of organisms, and turbidity and chemical balances, which influence sedimentation are included (Nicholls and Logan, 1966). In order to make detailed stratification analyses and provide for the most efficient reservoir operation data are also needed on wind, evaporation, quality and quantity of inflow, reservoir topography, circulation, and currents (Leifeste and Popkin, 1968).

It has long been recognized that grab samples are not adequate for detailed oxygen evaluation (Okun, Lamb, and Wells, 1963; Frey, 1967). Recent improvements of in situ oxygen probes and recording devices permit continuous operation with minimal servicing. Ragone and Peters (1967) described the use of continuous oxygen recorders on rafts in reservoir spillways. Operators controlled outflow to prevent anoxic conditions and fish kills below the dams. Leifeste and Popkin (1968) used a pump, hose, and small chamber that contained sensors for measuring temperature, conductance and dissolved oxygen on several Texas reservoirs but without a continuous sampling procedure.

Reservoirs with a high volume turnover, such as Keystone, are kept in a state of low successional maturity by runoff of nutrients from crop lands and urban and natural pollution fed into them (Margalef, 1968). Organic and inorganic nutrients are important in determining biological fluctuations in reservoirs. Continuous recording of ionic chemical species may aid in establishing the extent of transfer of biologically important nutrients through the density gradients of reservoirs (Okun and Weiss, 1963). Other possible predictions from recording ionic species include increases in turbidity, formation of sludge deposits, increases in toxic chemicals, changes to extreme acidity or alkalinity, and production of undesirable aquatic growths (Mackenthun and Ingram, 1967).

Ionic probes must be highly selective and sensitive to low concentrations. Improvement of specific ion electrodes is progressing rapidly particularly for use in laboratory applications. Field application of these electrodes at multiple depths and with continuous recording will make possible much more refined reservoir models.

Monitoring of rapidly changing water conditions has been limited to a few meteorological and chemical parameters and not often continuously or at multiple depths (Okun and Weiss, 1963; Oglesby and Weiss, 1963; Leifeste and Popkin, 1968; and Welch, 1969). Some researchers have obtained data by extending sensing probes to the depths they wished to measure (Pamatmat and Banse, 1969; Eley, 1970). However, most workers have found it acceptable to pump water to a convenient location (Strickland, 1961; Weiss and Oglesby, 1963; Keyser, 1965; Margalef, 1968; and Welch, 1969). Pumping to a central location was found to be a convenient method for the present study since it permitted the use of a single set of sensing probes. Depths were monitored in sequence and simultaneous multiple depth sampling was sacrificed for monetary reasons with minimal loss of data.

CHAPTER II

DESCRIPTION OF THE STUDY AREA

A sampling station was established 130 m upstream from the Keystone Reservoir Dam. Depth of the water at normal power pool level was 19.7 m. Depth during the study varied from 18.5 to 20.5 m because of variable river inflow and discharge through the dam.

Sampled depths were 0.5, 3, 6, 12, and 18 m. Oxygen and temperature were measured every hour at each depth. Oxygen and temperature depth profiles were measured more or less continuously form July 24, 1968, to November 27, 1968. Data from the five measured depths were used to calculate values for each meter of the water column. Sampled depths were closer together in the euphotic zone where more rapid oxygen change was expected than in the relatively stable hypolimnion.

Information on rainfall, river inflow, reservoir depth, and sunlight duration and intensity was provided as daily averages by the Tulsa District Corps of Engineers and the U. S. Weather Bureau, Tulsa, Oklahoma.

The water at three substations 200 m apart near the sampler was homogeneous in respect to stratification, depth, currents, and metabolic activity.

CHAPTER III

METHODS AND MATERIALS

A. Construction of the Floating Sampler

The sampling station was constructed on a raft floated by polystyrene foam logs (Fig. 3). All hoses and fittings were black polyvinyl chloride of 20 mm inside diameter. One hose from each depth connected directly to a solenoid-actuated valve. Water from one depth at a time passed through the valve, a copper tubing manifold, a pump, and into an airtight plexiglas tub which contained the probes (Fig. 4). After flowing through the sampling tub the water was pumped away from the float to minimize mixing with the sample water (Fig. 5).

B. Sampling Control and Recording

An electromechanical controller was constructed to switch the sample depths and to control the probe sequence at each depth. During sampling at each depth the water flushed through the sampling tub for 9 min while the probes equilibrated. Each probe reading was recorded for 30 sec on a Rustrak strip-chart recorder before the controller switched to the next probe. Any depth sequence desired could be monitored.

C. Temperature Sensing

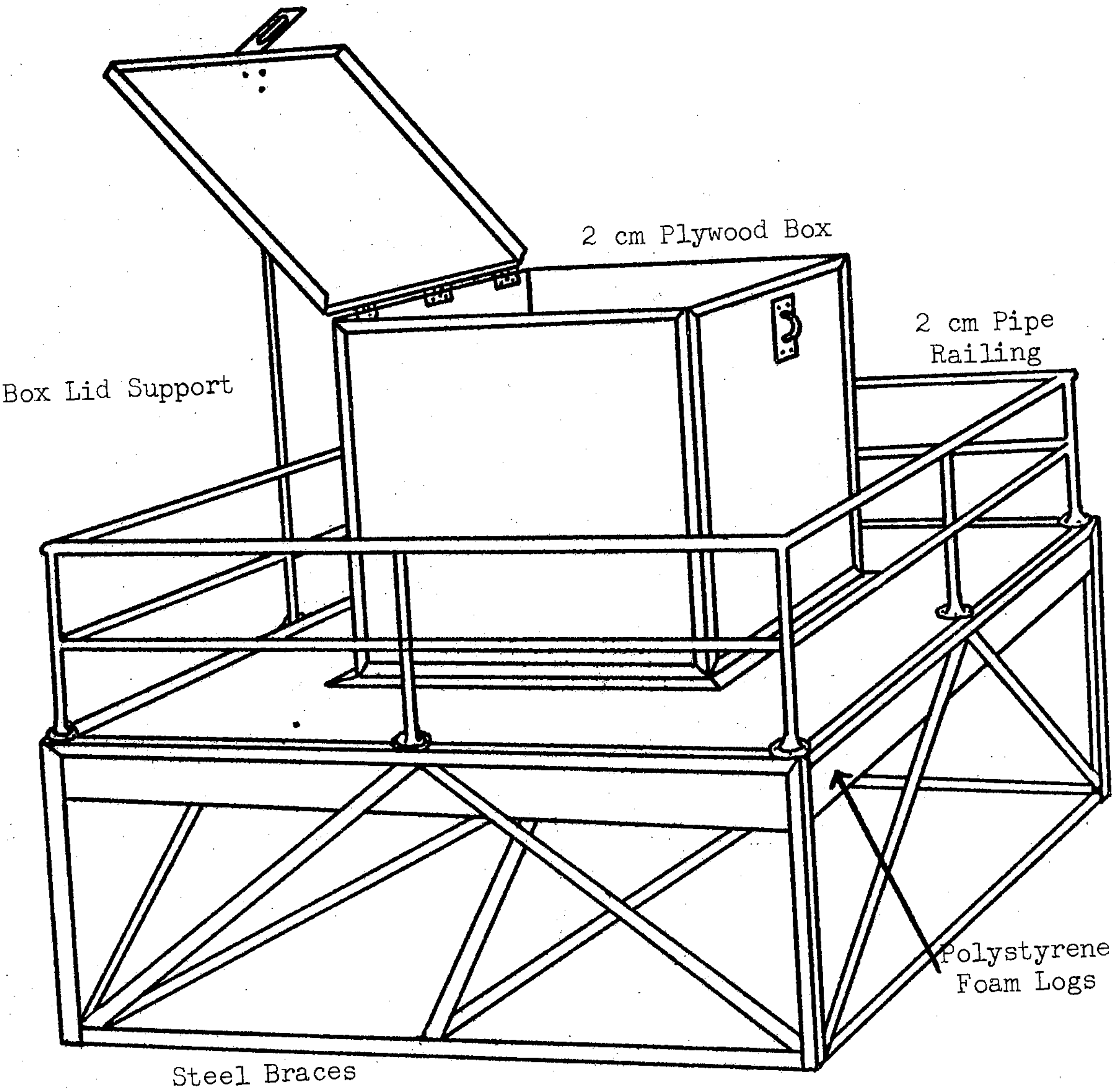


Figure 3. View of Floating Sampler

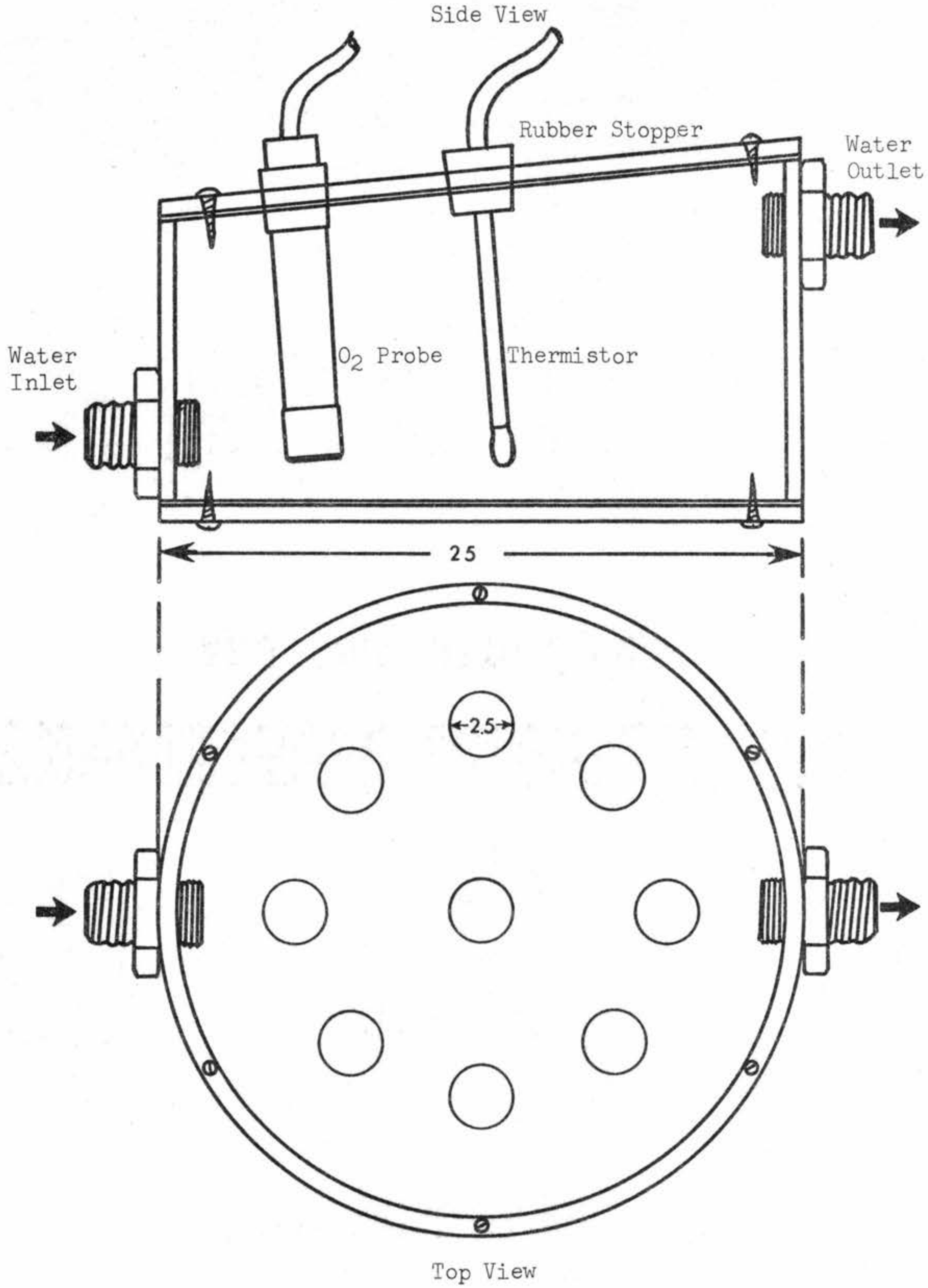


Figure 4. Sampling Tub Dimensions in cm

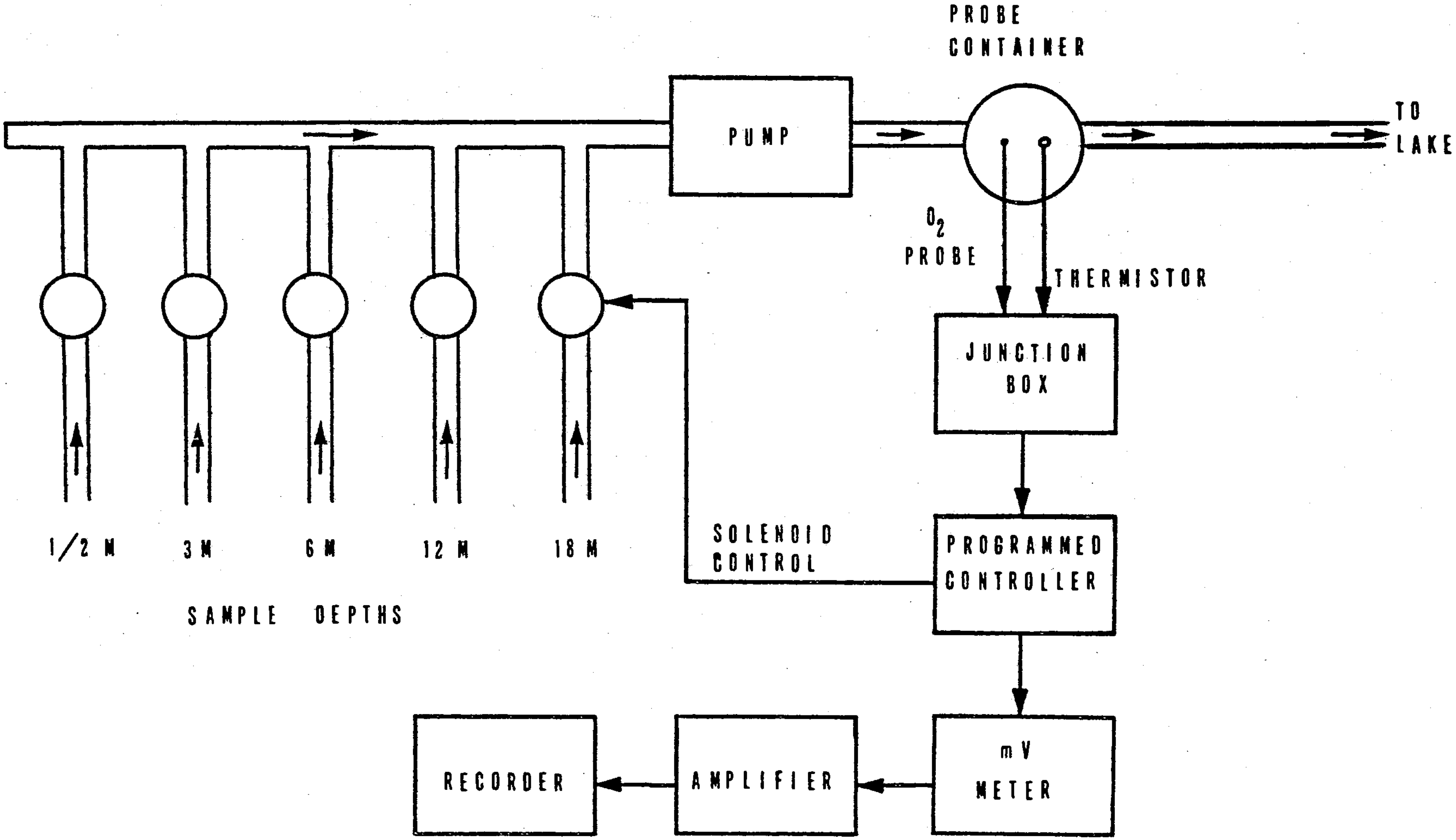


Figure 5. Block Diagram of Sampling Apparatus

The temperature sensor was a shielded, corrosion-proof, plastic-cased thermistor. The thermistor gave a linear response of reduced resistance with increase in temperature. Calibration was accomplished by measuring the millivolt drop across the thermistor over a temperature range of 0 to 35 C as measured by a precision mercury thermometer accurate to ± 0.1 C.

D. Measurement of Oxygen

The oxygen sensor consisted of silver and lead electrodes encased in a porcelain cylinder. The oxygen sensor was placed near the water inlet of the sampling tub to attain the required water current of 30 cm $\sec^{-1}$ over its surface.

The potential produced by oxygen reaction with the electrodes was linear, but probe sensitivity was temperature dependent and changed with time. The sensor was recalibrated after membrane renewal every 2 weeks. For calibration the sensitivity coefficient (γ) was obtained from the ratio of sensor voltage output to oxygen concentration (Equation 1).

$$(1) \qquad \gamma = \frac{\text{mv}}{[O_2] \text{ in g m}^{-3}}$$

Air saturated water was used in calibration (Hutchinson, 1957; Yaakov and Kaplan, 1969). The sensitivity coefficient applied to sensor output gave oxygen concentration of sample water(Equation 2).

$$(2) \qquad [O_2] \text{ of sample water} = \frac{\text{mv}}{\gamma}$$

Functions determined by computer for temperature and oxygen sensor calibrations were made part of a computer conversion program by which millivolt output was converted to degrees C and g O_2 m^{-3}.

Oxygen, temperature, time, and oxygen saturation values output by the conversion program were used in a diurnal oxygen curve analysis program modified from Eley (1970). This program used changes in dissolved oxygen over a 24 hour period, summed for the water column, to calculate gross primary production (Pg), community respiration (Rt), net primary production (Pn = Pg - Rt), Pg/Rt ratio, and diffusion into and out of the reservoir.

Appendix A is a reproduction of the raw data conversion program. Appendix B contains an example of converted data. Appendix C contains representative oxygen curve data and graphs.

E. Operation of the Sampler

Monitoring of oxygen and temperature at several depths with a single set of sensors necessitated a sequential procedure. However, all temperature and oxygen values were considered as having been obtained at the beginning of each hour. Rates of change at the surface were greatest and were measured first. Changes at the bottom were almost negligible because of lack of photosynthetic activity and nearly anoxic conditions and were measured nearly an hour later.

During the 5 months the sampler was in operation, over 100 days of complete data from midnight to midnight was recorded. As many as 21 successive days of recorded data was obtained. A total of 64 days were analyzed for primary production.

F. Data Gathering - Possible Errors

The greatest sources of error in the oxygen curve method are caused by horizontal movement of water masses of different metabolic history and improper estimation of the reaeration constant (Eley, 1970). Further errors enter when oxygen is not measured at sufficiently frequent depths.

Vertical mixing of oxygen is known to occur. Errors in measurement may arise from mixing of water in the thermocline and from interflows. Vertical currents and mixing patterns were not considered in this study.

Seiches of about 6 hour periods were evident from oxygen and temperature recordings at the 12 m depth during summer months. Seiches were created whenever there was high-volume, short-duration outflow. Corrections for seiches could not be incorporated in the primary productivity program since total depths involved were not determined.

Horizontal currents resulted from river inflows and drawdown for hydroelectric power generation and have been described for Keystone Reservoir (Falls, 1969; Eley, 1970).

CHAPTER IV

COMMUNITY METABOLISM

A. Sampling Assumptions and Validity

One station was used partly on the assumption that valid estimates of community metabolism could be made for the immediate vicinity of the sampler whenever water of uniform metabolic history was measured over a 24 hour period (Eley, 1970). He found no significant differences in community metabolism among three to six substations 200 m apart in four areas of the Cimarron River Arm of Keystone Reservoir. Monitored data obtained in the present study when little outflow for power generation occurred was accurate as shown by comparison with grab sample data and the data provided better estimates of production and respiration than on days of high outflow.

Oxygen and temperature data selected from five depths were multiplied by appropriate depth factors for transformation to surface area basis and compared with the data from every meter for production and respiration estimates (Table I). Calculated oxygen changes were compared to observed changes (Table I). A test for paired samples was used to determine the significance level the estimates of Pg, Rt, and Pg/Rt could be considered equivalent. The significance level for Pg was $\alpha = 0.40$, for Rt $\alpha = 0.40$, and for Pg/Rt $\alpha = 0.30$. Calculated changes in net oxygen production were significantly different from

TABLE I

Pg, Rt, AND Pg/Rt RATIOS FROM DATA TAKEN FROM EVERY METER AND FROM FIVE DEPTHS, Pg, Rt AND NET O_2 CHANGE IN g O_2 m^{-2} day^{-1} (ORIGINAL DATA IS FROM ELEY, 1970)

				Every Meter				Five Depths			
Date	Cimarron River Station	km Above Dam	Pg	Rt	Pg/Rt	Calculated Net O_2 Change	Pg	Rt	Pg/Rt	Calculated Net O_2 Change	Observed Net O_2 Change
9/24/66	II	28.0	38.49	45.53	0.90	- 7.04	52.15	58.19	0.90	- 6.04	- 6.00
12/17/66	II	28.0	14.28	4.08	3.50	10.20	11.21	2.77	4.05	8.44	3.40
6/4/67	II	28.0	48.69	39.53	1.23	5.16	43.50	39.40	1.16	4.10	- 7.70
8/1/66	III	17.4	9.35	40.01	0.23	-30.74	0.73	20.34	0.04	-19.61	- 9.80
12/17/66	III	17.4	36.40	12.51	2.91	23.89	43.68	13.39	3.26	30.29	25.10
6/4/67	III	17.4	26.05	18.78	1.39	7.27	28.65	26.93	1.06	1.72	4.80
8/1/66	IV	4.8	21.33	15.12	1.41	6.21	18.03	8.34	2.16	9.69	13.10
12/17/66	IV	4.8	21.88	8.77	2.49	13.11	25.39	11.12	2.28	14.27	7.90
6/4/67	IV	4.8	27.78	30.99	0.90	- 3.21	29.83	32.01	0.93	- 2.18	2.30

observed changes with one exception. Presence of currents at stations along the Cimarron River Arm probably caused the differences. The same method of comparison was used on data from Lake Atitlan, Guatemala by Dorris (unpublished). Agreement existed between observed and calculated net oxygen changes within 0.5 mg $liter^{-1}$ in nineteen of twenty-seven diurnal production studies. In Lake Atitlan no detectable currents exist and the water column is considerably deeper than that of Keystone Reservoir.

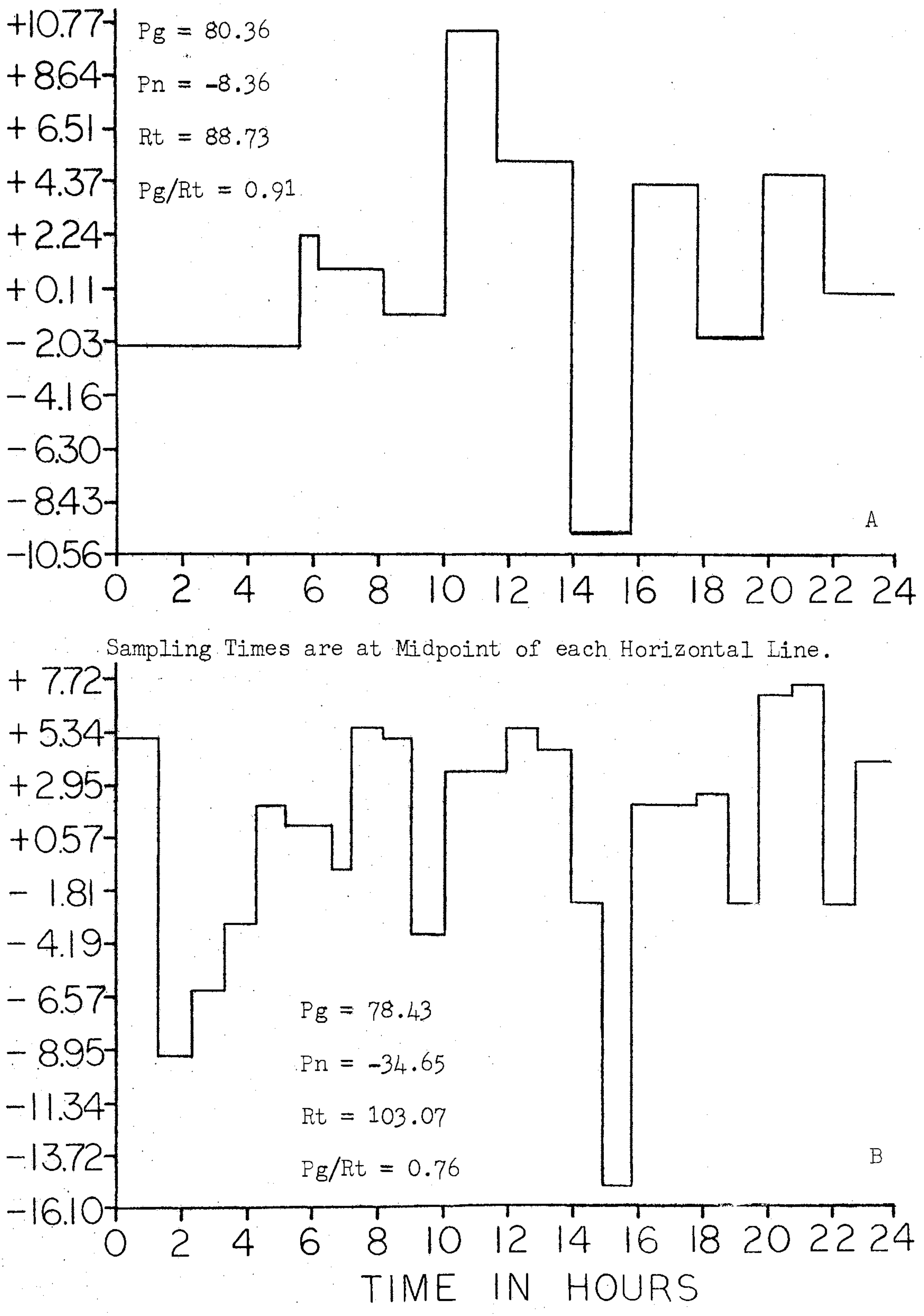
The significant differences between data from five depths and every meter in Pg, Rt, Pg/Rt, and net oxygen changes indicate that more depths should be sampled, perhaps at least at every 2 m. The assumption must also be met that to account for horizontal currents, water of similar metabolic history must be measured over each 24 hour period.

B. Advantage of more Frequent Sampling

More frequent sampling permits greater detail in analyzing oxygen rates of change (Fig. 6). Predawn rates of change progressively increased in Fig. 6 B, but no change occurred in a 5.5 hour period in Fig. 6 A. Infrequent sampling produced estimates with too large positive rates of change and too small negative rates of change. As a result, computed estimates of Pg, Rt, Pn, and Pg/Rt were different between the two sets of data. More frequent sampling permits a more precise picture of rates of change and corresponding production and respiration estimates are more accurate.

C. Production and Respiration Estimates

The correlation coefficient between Pg and Rt was 0.85. The ratio



Sampling Times are at Midpoint of each Horizontal Line.

Figure 6. Comparison of Oxygen Rate of Change Curves from Sampler Data (24 Data Points, Bottom) and from Grab Samples (12 Data Points, Top) for July 27, 1968, in g O_2 m^{-2} day^{-1}

between Pg and Rt was generally considerably less than 1.0 (Fig. 7) and averaged 0.63. The ratio approached 1.0 on only one occasion when Pg was high during a period of clear days in August (Table II). The low ratios indicate that this area of the reservoir was heterotrophic as defined by Odum (1959). This condition is caused by the oxidation of large quantities of organic matter.

Pg and solar intensity were related by: Pg = 0.158 S (Fig. 8) after assuming 15% error and forcing through the origin. A straight line was used because a direct relationship exists between light quanta absorbed and oxygen evolved (Rabinowitch and Govindjee, 1965).

Community metabolism at the dam was compared with data from Eley (1970). Pg, Rt, and Pg/Rt were significantly different from the downstream station (Table III).

D. Differences in Community Metabolism between Clear Days and Cloudy Days

Higher Pg and Rt generally occurred on the clear days (Fig. 9). Minimum Pg occurred on July 26 when solar radiation was at its maximum and inhibiting (Table II). Maximum Pg occurred when solar radiation was 661 g cal cm^{-2} day^{-1}, indicating that this intensity did not seem to be inhibitory, although Hannan (1967) said that 647 g cal cm^{-2} day^{-1} was inhibitory to macrophytes. When solar radiation was high ($\bar{x}$ = 650 g cal cm^{-2} day^{-1}) for 30 clear days, Pg was high. It appeared that the optimum photosynthetic activity occurred at a solar radiation of between 660 and 690 g cal cm^{-2} day^{-1} since intensity as high as 692 g cal cm^{-2} day^{-1} from a single observation seemed to be inhibitory.

During 26 cloudy days solar radiation ($\bar{x}$ = 337 g cal cm^{-2} day^{-1})

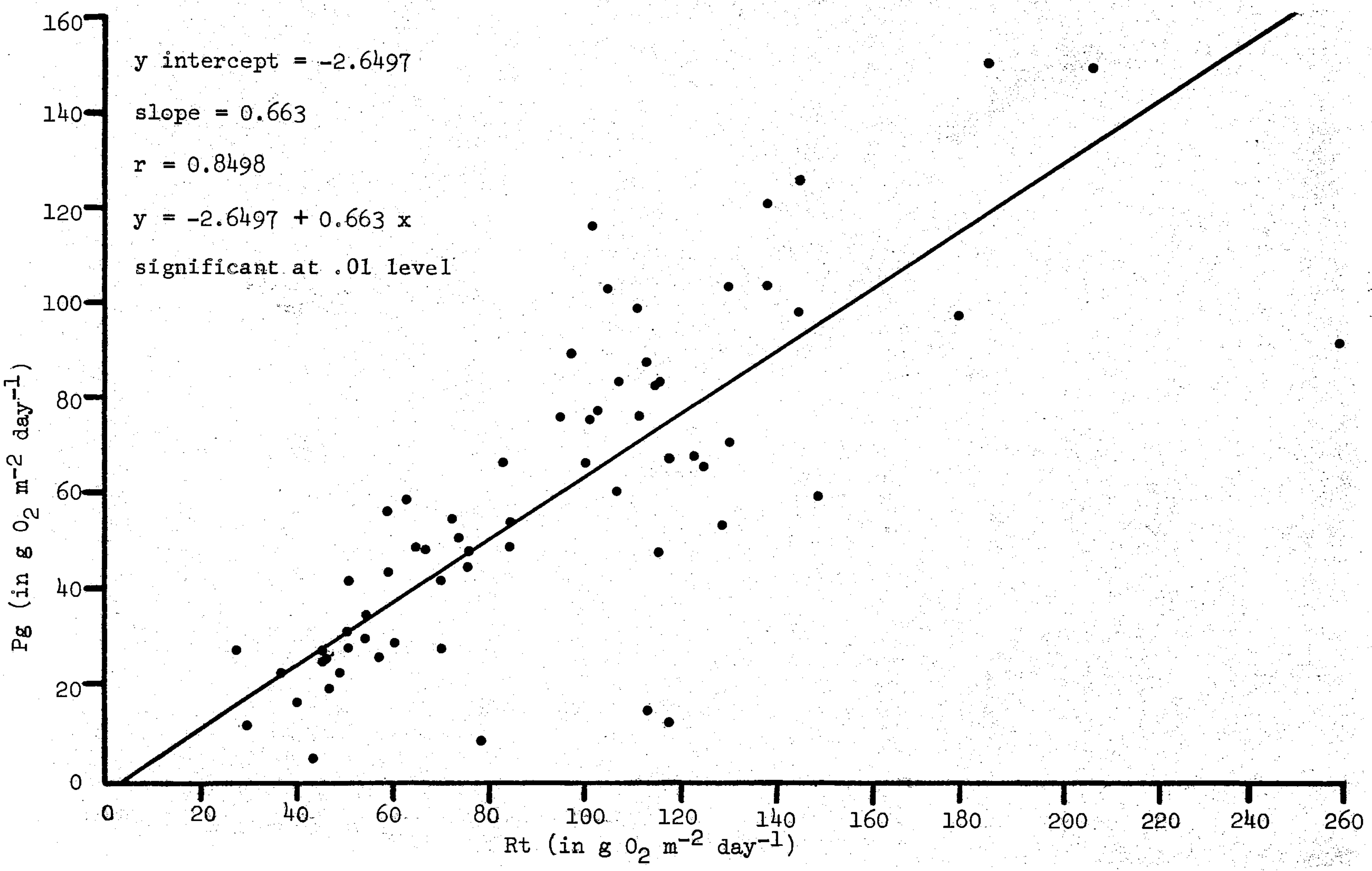


Figure 7. Linear Regression of Pg and Rt

TABLE II

DAILY Pg, Rt, Pn, Pg/Rt, SOLAR INTENSITY (S), EFFICIENCY (F), AND WEATHER (* = CLEAR DAYS, # = PARTLY CLOUDY DAYS, AND – = CLOUDY DAYS)

(1968)	(g O_2 m^{-2} day^{-1})				%	(g cal $cm^{-2}day^{-1}$)	
Date	Pg	Rt	Pn	Pg/Rt	F	S	Weather
7-25	59.27	63.13	- 3.85	0.94	3.41	607	#
7-26	5.01	43.63	- 38.61	0.11	0.25	692	*
7-27	78.42	103.07	- 24.65	0.76	4.10	669	*
7-28	54.50	84.17	- 29.67	0.65	4.91	388	#
7-29	25.16	45.52	- 20.37	0.55	1.31	472	#
7-30	48.48	75.93	- 27.45	0.64	4.04	420	#
8-2	84.65	115.70	- 31.05	0.73	4.35	680	*
8-3	104.79	130.11	- 25.31	0.81	5.42	676	*
8-4	103.47	104.98	- 1.52	0.99	5.53	654	*
8-5	99.55	111.15	- 11.60	0.90	5.47	636	*
8-6	116.60	101.65	14.95	1.15	6.69	610	*
8-7	125.75	144.56	- 18.81	0.87	6.69	657	*
8-8	151.08	184.31	- 33.23	0.82	7.99	661	*
8-9	83.67	114.71	- 31.04	0.73	4.53	648	*
8-13	28.56	70.63	- 42.07	0.40	3.69	270	-
8-14	17.02	39.98	- 22.96	0.43	1.93	308	-
8-17	71.11	130.33	- 59.22	0.55	4.39	566	-
8-18	60.29	148.30	- 88.01	0.41	4.58	460	-
8-19	61.48	105.71	- 44.23	0.58	3.53	608	-
8-20	67.11	124.72	- 57.60	0.54	3.65	643	*
8-21	76.31	100.76	- 24.46	0.76	4.26	626	*
8-22	45.29	76.04	- 30.75	0.60	2.53	625	*
8-23	92.27	258.13	-165.87	0.36	5.32	607	*
8-24	54.85	128.85	- 74.00	0.43	4.57	422	-
8-25	98.94	179.06	- 80.12	0.55	8.97	386	-
8-27	150.27	205.66	- 55.39	0.73	11.17	471	-
8-28	16.12	113.29	- 97.17	0.14	2.64	214	-
8-29	69.04	123.06	- 54.03	0.56	22.58	107	-
8-30	49.47	84.43	- 34.95	0.59	11.54	150	-
9-1	49.35	65.16	- 15.81	0.76	2.75	627	*
9-2	30.40	54.43	- 24.03	0.56	2.12	503	-
9-3	67.14	100.17	- 33.03	0.67	6.27	375	*
9-17	57.35	58.80	- 1.46	0.98	3.97	505	-

TABLE II (CONTINUED)

(1968)	(g O_2 m^{-2} day^{-1})				%	(g cal $cm^{-2}day^{-1}$)	
Date	Pg	Rt	Pn	Pg/Rt	F	S	Weather
9-19	22.79	37.18	- 14.39	0.61	1.48	538	*
9-20	12.04	29.56	- 17.51	0.41	0.86	491	-
9-21	51.46	74.05	- 22.59	0.69	4.27	422	#
9-22	27.65	46.01	- 18.36	0.60	2.03	477	*
9-23	35.08	54.65	- 19.57	0.64	4.61	266	-
9-24	27.36	27.69	- 0.33	0.99	10.88	88	-
9.25	42.71	51.10	- 8.39	0.84	2.73	548	-
9-26	28.20	50.71	- 22.51	0.56	1.88	525	*
9-27	67.13	83.03	- 15.90	0.81	4.50	522	*
9-28	121.46	137.47	- 16.01	0.88	8.24	516	*
9-29	48.86	67.06	- 18.21	0.73	3.35	510	*
9-30	68.40	117.63	- 49.23	0.58	5.16	564	*
10-1	104.30	138.06	- 33.77	0.76	9.24	395	*
10-2	43.89	59.54	- 15.65	0.74	3.17	484	*
10-3	89.89	97.22	- 7.33	0.92	6.32	498	*
10-4	25.99	46.56	- 20.57	0.56	2.19	416	-
10-5	31.58	50.32	- 18.73	0.63	9.53	116	-
10-6	84.62	106.90	- 22.28	0.79	6.14	482	-
10-7	55.43	72.47	- 17.04	0.76	4.10	473	-
10-8	76.32	94.81	- 18.49	0.81	21.20	126	*
10-9	42.52	69.75	- 27.22	0.61	3.29	453	-
10-12	98.89	144.66	- 45.77	0.68	15.45	224	-
10-13	29.54	60.47	- 30.93	0.49	2.61	396	-
10-14	48.65	115.44	- 66.79	0.42	3.99	427	-
10-15	23.32	49.07	- 25.75	0.48	3.52	232	-
10-26	87.71	112.82	- 25.11	0.78	7.38	416	*
10-27	20.16	46.79	- 26.63	0.43	1.67	422	-
11-22	77.54	111.91	- 34.38	0.69	6.78	400	*
11-23	8.87	78.54	- 69.67	0.11	0.78	350	-
11-24	13.57	118.46	-104.90	0.11	1.43	331	-
11-25	26.71	57.43	- 30.72	0.47	3.58	261	*
MEAN	59.48	93.71	- 34.23	0.63	5.27	459	

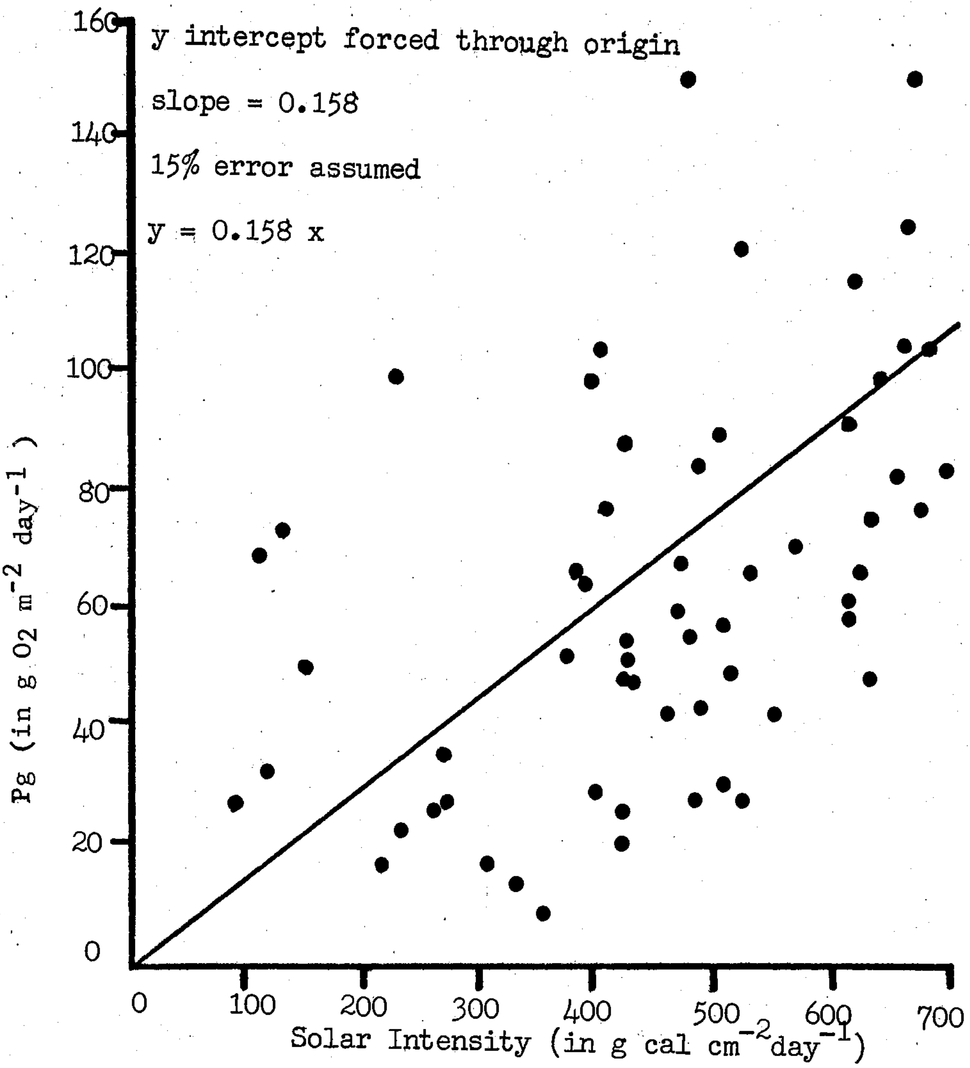


Figure 8. Linear Regression of Pg and Solar Intensity

TABLE III

MEAN Pg, Rt, Pg/Rt, AND EFFICIENCY (F) FOR CIMARRON RIVER STATIONS AND DAM - Pg AND Rt IN g O_2 m^{-2} day^{-1}, F IN %
(DATA FOR STATIONS I-IV IS FROM ELEY, 1970)

Station	km above dam	Pg	Rt	Pg/Rt	F
I	38.7	11.3	11.0	1.02	1.97
		***	***	⊛	
II	28.0	27.4	22.3	1.22	3.87
		***	***	*	
III	17.4	38.6	41.0	0.94	6.35
		**	*		
IV	4.8	49.1	54.1	0.91	8.23
		**	***	***	
dam	0.13	59.5	93.7	0.63	5.27

Asterisks indicate significant differences between means.
***(α = .01), **(α = .05), *(α = .10), ⊛(α = .15).

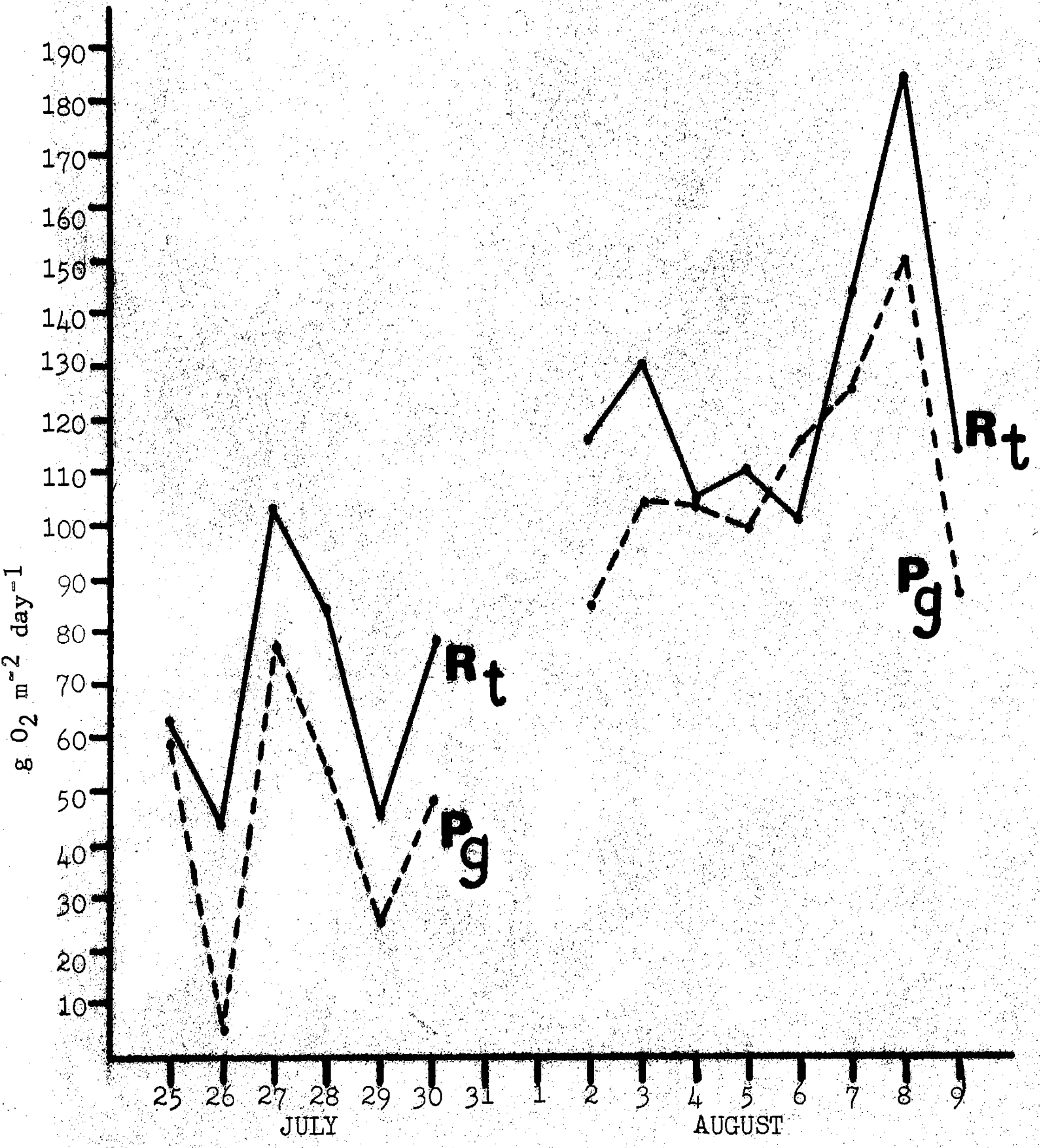


Figure 9. Pg and Rt During 6 Cloudy or Partly Cloudy Days and 8 Consecutive Clear Days

appeared to be limiting or was less than optimal for photosynthetic activity. The difference in productivity between clear and cloudy days was 41% as estimated by the following:

$$\frac{\bar{x}\ \text{Pg (clear days)} - \bar{x}\ \text{Pg (cloudy days)}}{\bar{x}\ \text{Pg (clear days)}} \text{ X } 100 = \%\ \text{difference}$$

Hannan (1967) found that cloudy days were only 52% as productive as clear days. He also found that low light intensity had no obvious effect on community respiration, but that respiration was reduced under conditions of high light intensity. In Keystone Reservoir under low light intensity of cloudy days productivity was reduced considerably more than was respiration (Table IV). High light intensity did not inhibit algal productivity or reduce respiration with the exception of inhibition on July 26.

E. Efficiency of Production

Efficiency of photosynthetic production (Table II) was calculated from solar radiation and Pg according to a formula modified from Oswald (1957):

$$F = \frac{(3500)\ \text{Pg}\ (100)}{(10{,}000)\ S}$$

where F is percent efficiency, Pg is g O_2 m^{-2} day^{-1}, S is solar radiation in g cal cm^{-2} day^{-1}, 10,000 is a factor to convert m^2 to cm^2, and 3500 is the number of cal of solar radiation required to produce 1 g of oxygen according to Kraus (1956).

Mean efficiency for cloudy days was 5.93% while that for clear

TABLE IV

MEAN Pg, Rt, Pn, AND Pg/Rt FOR 30 CLEAR DAYS AND 26 CLOUDY DAYS
Pg, Rt, AND Pn IN g O_2 m^{-2} day^{-1}

parameter	clear days		cloudy days
$\bar{x}$ Pg	78.36	***	46.42
$\bar{x}$ Rt	106.03	*	89.00
$\bar{x}$ Pn	- 27.67	**	- 42.58
$\bar{x}$ Pg/Rt	0.75	***	0.53

Asterisks indicate significant differences between means.
***(α = .005), **(α = .01), *(α = .05).

days was 5.52%. These values were not significantly different at $\alpha = .01$. It appears that under conditions of less than optimal light and lower photosynthetic activity on cloudy days, the algae are able to compensate for low light intensity and be as efficient with less solar energy as on clear days. The correlation between photosynthetic efficiency and light intensity was -0.46 (Fig. 10).

F. Effects of a Flood on Community Metabolism

On August 19, 1968, a large inflow of both Arkansas and Cimarron River water occurred. Before the flood the hypolimnion contained about 1.0 g O_2 m^{-3} (Fig. 11). Salt-heavy flood water of the Cimarron River was well-oxygenated as was interflowing Arkansas River water. The flood increased oxygen content of the entire water column. Stratification was not disrupted. Over a 15 day period the hypolimnion again almost became anoxic. Surface oxygen generally decreased during the first 11 days. A sharp increase in surface oxygen and decrease in oxygen at 18 m occurred during days 11-14, probably caused by a sharp reduction in outflow which allowed a build-up of oxygen at the surface from production and decrease in the hypolimnion from respiration.

No distinct pattern in Pg, Rt, or Pg/Rt could be observed during the flood period (Fig. 12). The great Rt values 4 to 8 days after the flood are indicative of a large amount of allochthonous organic material deposited in the reservoir.

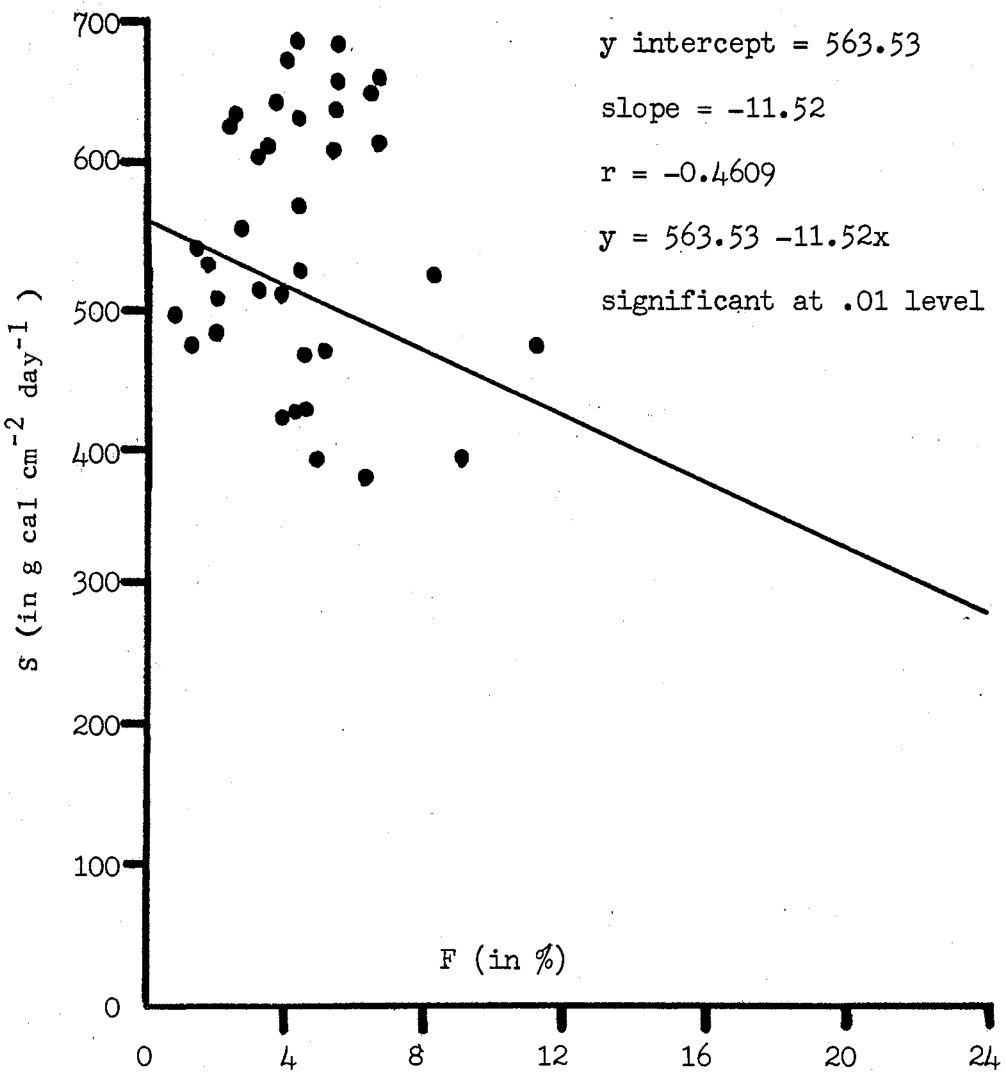


Figure 10. Linear Regression of S and F through September 30, 1968

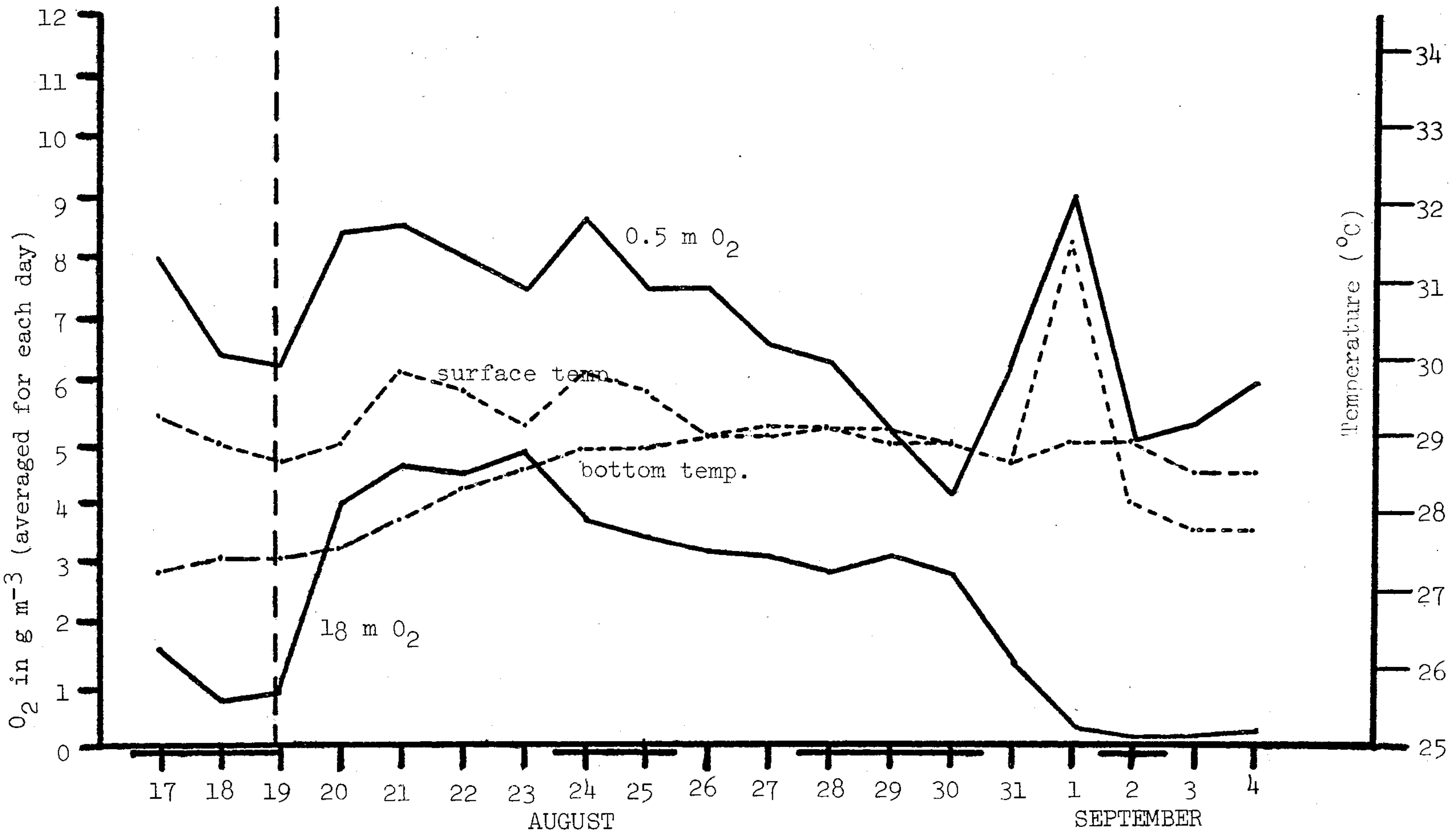


Figure 11. Oxygen and Temperature at Surface and 18 m as a Result of Flooding on August 19, 1968 (Double Line at Bottom Indicates Periods of Cloudiness)

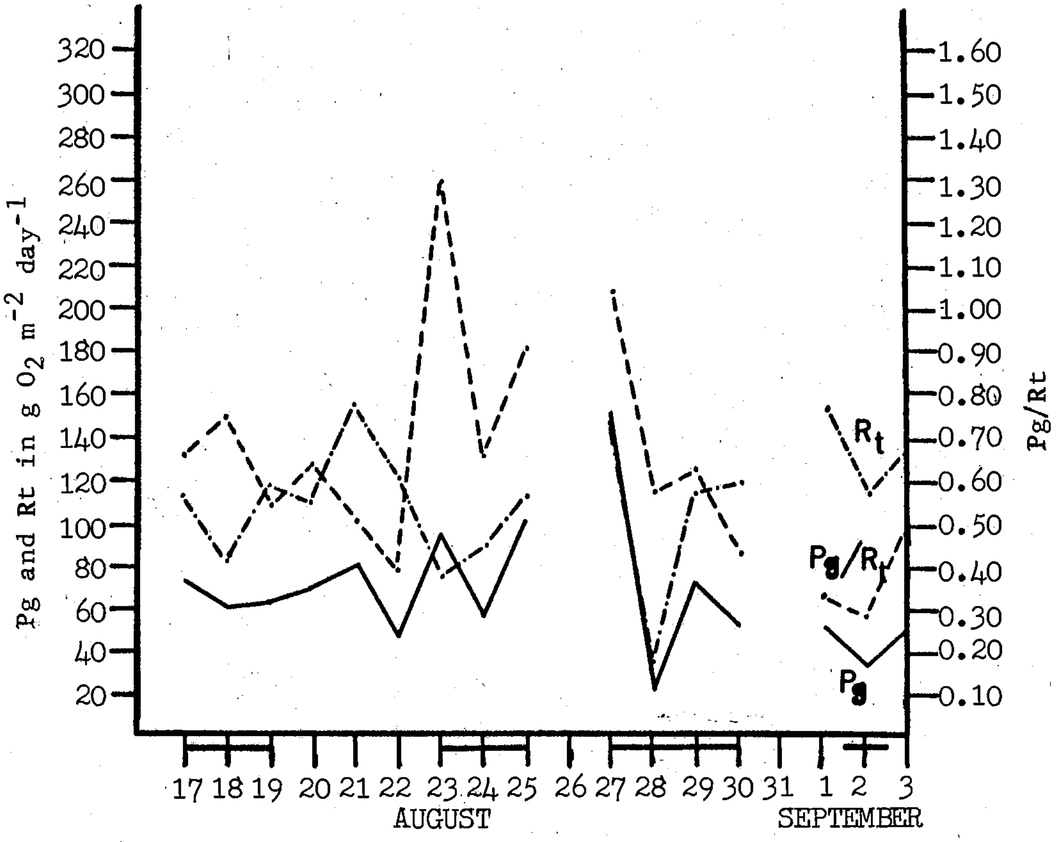


Figure 12. Pg, Rt, and Pg/Rt During and After Flood - August 17 to September 3, 1968 (Double Line at Bottom Indicates Periods of Cloudiness)

CHAPTER V

CONCLUSION

Pumping water to a central location was an acceptable sampling technique and was convenient since it permitted the use of a single set of sensing probes.

At least every 2 m vertically should be monitored. Sample depths should be more frequent in the euphotic zone than in the relatively stable hypolimnion for primary production studies by the diurnal oxygen curve method. The feasibility of using oxygen curve analyses is limited by currents in reservoirs. A complex sampling program which incorporates tracing water masses when interflowing and underflowing currents exist must be developed in order to apply the diurnal oxygen curve dependably.

More frequent sampling during each 24 hour period permitted greater detail in analyzing oxygen rates of change for primary production. One sample every hour appeared to give good results.

At Keystone Reservoir Dam high Pg and low Pg/Rt indicated that much organic matter was being oxidized. Pg and Rt were highly correlated ($r = 0.85$). Mixing of Arkansas and Cimarron River water increased Pg and Rt and reduced the Pg/Rt ratio and efficiency at the dam as compared to four stations on the Cimarron River Arm. The large increase in Rt and decrease in Pg/Rt was probably due to a much larger amount of organic material carried by the Arkansas River than the Cimarron River.

Higher Pg and Rt occurred on clear days. It appeared that the optimum photosynthetic activity occurred at a solar radiation of between 660 and 690 g cal cm^{-2} day^{-1} since intensity as high as 692 g cal cm^{-2} day^{-1} was inhibitory. During cloudy days light was limiting or less than optimal for photosynthetic activity. Under low light on cloudy days productivity was reduced considerably more than respiration.

Efficiency of production between clear and cloudy days was not significantly different. On cloudy days the algae were able to compensate for low light intensity and were as efficient with less solar energy as on clear days.

Flooding oxygenated all water strata but did not always disrupt thermal stratification. It took 15 days after a flood for the hypolimnion to again become anoxic. No distinct patterns in Pg, Rt, or Pg/Rt were observed during the flood period. Great Rt values after the flood are indicative of large amounts of allochthonous organic matter deposited in the reservoir.

BIBLIOGRAPHY

Anonymous. 1968. Climatological Data National Summary. Environ. Sci. Serv. Admin. 19 (7-11).

Burks, S. L. 1969. Organic compounds in Keystone Reservoir. Ph. D. Thesis, Okla. State Univ. 67 p.

Copeland, B. J., and Dorris, T. C. 1964. Community metabolism in ecosystem receiving oil refinery effluents. Limnol. Oceanogr. 9: 431-447.

Duxbury, A. C. 1963. Calibration and use of a galvanic type oxygen electrode in field work. Limnol. Oceanogr. 8: 483-485.

Eley, R. L. 1967. Physicochemical stratification of Keystone Reservoir, Oklahoma. M. S. Thesis, Okla. State Univ. 30 p.

Eley, R. L. 1970. Physicochemical limnology and community metabolism of Keystone Reservoir, Oklahoma. Ph. D. Thesis, Okla. State Univ. 240 p.

Falls, C. P. 1969. Chemical equilibria and dynamics of Keystone Reservoir. Ph. D. Thesis, Okla. State Univ. 155 p.

Findenegg, I. 1966. Factors controlling primary productivity, especially with regard to water replenishment, stratification and mixing. *In* Primary Productivity in Aquatic Environments edited by C. R. Goldman. U. of California Press. p. 110-119.

Frey, D. G. 1967. Reservoir research - objectives and practices with an example from the Soviet Union. Proc. of the Reservoir Fish. Resour. Symp., Amer. Fish. Soc. U. of Georgia Press. p. 26-36.

Hannan, H. H. 1967. Macrophyte standing crop and metabolism in a constant temperature river. Ph. D. Thesis, Okla. State Univ. 47 p.

Hutchinson, G. E. 1957. A treatise on limnology. Vol. I. Geography, Physics and Chemistry. 1015 p.

Ingols, R. S. 1957. Pollutional effects of hydraulic power generation Sewage Ind. Wastes. 29(3): 292-297.

Keyser, A. H. 1965. Dissolved oxygen and related measurements in rivers. ISA p. 26.

Kittrell, F. W. 1959. Effects of impoundments on dissolved oxygen resources. Sewage Ind. Wastes. p. 1065-1078.

Kochsiek, K. A. 1970. Community structure of net zooplankton and related physicochemical limnology in Keystone Reservoir, Oklahoma. Ph. D. Thesis, Okla. State Univ. 58 p.

Kraus, R. W. 1956. Photosynthesis in the algae. Ind. and Eng. Chem., 48: 1449-1458.

Leifeste, D. K. and Popkin, B. 1968. Quality of water and stratification of Possum Kingdom, Whitney, Hubbard Creek, Proctor, and Belton Reservoirs. Report No. 85, Texas Water Development Board. 116 p.

Long, L. H. 1968. The World Almanac and Book of Facts. Doubleday Co.

Love, S. K. and Slack, K. V. 1967. Controls on solution and precipitation in reservoirs. Symp. on Streamflow Regulation for Qual. Contr. P. H. S. Publ. No. 999-WP-30. p. 97-120.

Mackenthun, K. M. and Ingram, W. M. 1967. Biological associated problems in freshwater environments. U. S. Dept. of Interior Rep. 287 p.

Margalef, R. 1968. Perspectives in Ecological Theory. U. of Chicago Press. 111 p.

Nicholls, I. G. and Logan, B. W. 1966. Carbonate sedimentation in Shark Bay, Western Australia, field data gathering and data processing. In CSIRO Symp. of Canberra, Western Australia. John Wiley and Sons, Sydney, Australia. p. 229-248.

Odum, E. P. 1959. Fundamentals of Ecology. W. B. Saunders Co. 546 p.

Odum, H. T. 1965. Primary production in flowing waters. Part of Symp. of Amer. Soc. of Limnol. Oceanogr. at East Lansing, Michigan. p. 102-116.

Odum, H. T. and Wilson. 1962. Further studies on reaeration and metabolism of Texas bays. Publ. Inst. Mar. Sci., Texas, 8: 23-55.

Ohle, W. 1968. Aquatic primary production. Amer. Zool. 8: 31-42.

Okun, D. A., Lamb, J. C., and Wells, C. C. 1963. A waste control program for a river with a highly variable flow. J. Water Pollut. Contr. Fed. p. 1025-1043.

Okun, D. A. and Weiss, C. M. 1963. Organic-biological relationships in reservoirs. Water Works Eng., p. 349-351.

Oswald, W. J., Gotaas, H. B., Golueke, C. G., and Kellen, W. R. 1957. Algae in waste treatment. Sewage Ind. Wastes, 29: 437-455.

Pamatmat, M. M. and Banse, K. 1969. Oxygen consumption by the seabed. II. In situ measurements to a depth of 180 meters. Limnol. Oceanogr. 14(2): 250-259.

Ragone, S. and Peters, B. J. 1967. Water quality monitoring for water quality control. Symp. on Streamflow Regulation for Qual. Contr. P. H. S. Publ. No. 999-WP-30. p. 345-369.

Ransom, J. D. 1969. Community structure of benthic macroinvertebrates and related physicochemical conditions in Keystone Reservoir, Oklahoma. Ph. D. Thesis, Okla. State Univ. 57 p.

Ryther, J. H. 1956. The measurement of primary production. Limnol. Oceanogr. 1(2): 72-83.

Spangler, F. L. 1969. Chlorophyll and carotenoid distribution and phytoplankton ecology in Keystone Reservoir, Tulsa, Oklahoma. Ph. D. Thesis, Okla. State Univ. 61 p.

Strickland, J. D. H. 1966. Measuring the production of marine phytoplankton. Fish. Res. Board of Canada, 172 p.

Strickland, J. D. H. 1968. A comparison of profiles of nutrient and chlorophyll concentrations taken from discrete depths and by continuous recording. Limnol. Oceanogr. 13(2): 388-391.

Talling, J. F. 1961. Photosynthesis under natural conditions. Annu. Rev. of Plant Physiol., 12: 133-154.

Vollenweider, R. A. 1966. Calculation models of photosynthesis-depth curves and some duplications regarding day rate estimates in primary production estimates. In Primary Production in Aquatic Environments edited by C. R. Goldman. p. 425-457.

Weiss, C. M. and Oglesby, R. T. 1963. Instrumentation for monitoring water quality in reservoirs. J. Amer. Water Works Ass. 55(9): 1213-1219.

Welch, H. E. 1968. Use of modified diurnal curves for the measurement of metabolism in standing water. Limnol. Oceanogr. 13(4): 679-687.

Wilhm, J. L. and Dorris, T. C. 1968. Biological parameters for water quality criteria. Bioscience. 18(6): 477-481.

Yaakov, S. B. and Kaplan, I. R. 1968. pH-temperature profiles in ocean and lakes using an in situ probe. Limnol. Oceanogr. 13(4): 688-693.

Rabinowitch, E. I. and Govindjee 1965. The role of chlorophyll in photosynthesis. Sci. Amer. 213 (1): 74-83.

APPENDIX A

REPRODUCTION OF CONVERSION PROGRAM

```
C  THIS PROGRAM CALCULATES O2 CONCENTRATION AND TEMPERATURE FROM RUSTRAK STRIP
C    CHART RECORDER DATA READ IN AS LINE NUMBERS ON CHART PAPER PRODUCED BY THE
C    RESERVOIR CONTINUOUS MONITORING SYSTEM.  RECALIBRATION OF PROBES AND OF
C    BOTTOM DEPTH CONSTANT IS DONE AUTOMATICALLY AS THE DATA IS CONVERTED, THE
C    ONLY REQUIREMENT BEING THAT ALL NECESSARY DATA BE PRESENT AND THAT EACH
C    DATA SET BE IN CHRONOLOGICAL ORDER.
C  SURFACE SATURATION AND O2 CONCENTRATIONS ARE SUMMED OVER THE WATER COLUMN
C    FOR FURTHER UTILIZATION BY PERIPHERAL PROGRAMS.
C  OUTPUT IS RECORDED ON MAGNETIC TAPE UNIT 4 AND PRINTED IN TABULAR FORM.
     DIMENSION ITIME(24), TEMP(24,5), O2(24,5), ZERO(24,5), CON(5),
    *HUTCH(36,10), PSAT(24), SUM(24), MONTH(24), IDAY(24), IYEAR(24),
    *CON5(200),RINTCP(200),SLOPE(200),IYEARX(200),MONTHX(200),
    *IDAYX(200),ITIMEX(200),IYEARC(200),MONTHC(200),IDAYC(200),
    *ITIMEC(200),NPROBE(200),IX2(200),ITIMEA(200),IC2(200),ITIMEB(200)
     COMMON WORD(6)
   1 FORMAT (10(F4.2, 4X))
   2 FORMAT (3I3, 2X, I4, 5(F5.1, F4.1, F4.1))
   3 FORMAT (F3.2,46X,3I2,I4,20X,I1)
   4 FORMAT (8X, E13.6, 3X, E13.6,6X,3I2,I4,21X,I2,3X,I1)
   8 FORMAT('1',T60, 'DATE', I4, '/', I2, '/', I2 // 8X, '0.5 M', 4X,
    *'3.0 M', 4X, '6.0 M', 4X, '12.0 M', 3X, '18.0 M', 5X, '0.5 M',
    *3X, '3.0 M', 3X, '6.0 M', 3X, '12.0 M', 3X, '18.0 M', 13X,
    *'SURFACF' / 1X, 'TIME', 2X, 'TEMP(1)', 2X, 'TEMP(2)', 2X,
    *'TEMP(3)', 2X, 'TEMP(4)', 2X, 'TEMP(5)', 5X, 'O2(1)', 3X, 'O2(2)',
    *3X, 'O2(3)', 3X, 'O2(4)',4X, 'O2(5)', 3X, 'SUM O2', 4X,        '
    *SATURATION',/  ( 1X, I4, F8.2, F9.2, F9.2, F9.2, F9.2, F11.2,
    *F8.2, F8.2, F8.2, F8.2, F9.2, F11.2))
  22 FORMAT  (1X,T61,'CON(5) DATA'/////35X,'CON(5)',46X,'TIME CODE'//
    *(36X,F4.2,47X,3I2,I4))
  23 FORMAT ('1',T54,'O2 PROBE CALIBRATION DATA'/////38X,'INTERCEPT',
    *8X,'SLOPE',12X,'TIME',6X,'PROBE NO.'//(35X,E13.6,3X,E13.6,5X,3I2,
    *I4,5X,I3))
  24 FORMAT (/////' DIURNAL IS COMPLETE')
  25 FORMAT (' CON(5) CHANGED TO',F5.2,' AT',I5)
  26 FORMAT (/' CON(5)    EQUALS  ',F5.2,' AT',I5)
  28 FORMAT (/' O2 PROBE NO.',I3,' BEING USED AT',I5)
  30 FORMAT (' O2 PROBE CHANGED TO NO.',I3,' AT',I5)
  51 FORMAT (' ****CAPACITY OF ARRAY NOT ENOUGH TO STORE CALIBRATION DA
    *TA/     READ 200 DATA CARDS')
  52 FORMAT (3(2A3,4X))
  53 FORMAT (I4,3I3/(I4,12F6.2))
  54 FORMAT (F5.2)
  55 FORMAT (F5.2,I5)
  57 FORMAT ('-MORE THAN 10 CON5 VALUES PER DAY * * * PROGRAM TERMINATE
    &D')
  59 FORMAT (1X)
  60 FORMAT (I5)
  61 FORMAT (2I5)
  63 FORMAT ('-MORE THAN 10 O2 PROBES PER DAY * * * PROGRAM TERMINATED'
    &)
  72 FORMAT (I3)
  73 FORMAT      (F5.2,I5)
  74 FORMAT      (2I5)
     REWIND 4
     NCARD=0
C  READ ALPHABETIC CHARACTERS INTO COMMON FOR SUBROUTINE TIMCHK
     READ (5,52) (WORD(I),I=1,6)
C  READ IN HUTCHIN'S SATURATION TABLE
```

APPENDIX A (CONTINUED)

```
      ~~READ(5,1) ((HUTCH(I,J), J = 1, 10), I = 1, 36)~~
C   READ BOTTOM DEPTH CONSTANTS (CON5)
      DO 20 I = 1,200
      READ (5,3) CON5(I),IYEARC(I),MONTHC(I),IDAYC(I),ITIMEC(I),ISIG
      IF (ISIG .EQ. 9) GO TO 9
C   CHECK DEPTH CONSTANT DATA FOR TIME CODE ERRORS
   20 CALL TIMCHK (IYEARC(I),MONTHC(I),IDAYC(I),ITIMEC(I),I,1)
      GO TO 50
    9 NC = I-1
C   LIST CON5 DATA
      WRITE (6,22) (CON5(I),IYEARC(I),MONTHC(I),IDAYC(I),ITIMEC(I),
     *I = 1,NC)
C   READ O2 PROBE CALIBRATION DATA
      DO 21 I = 1,200
      READ (5,4) RINTCP(I),SLOPE(I),IYEARX(I),MONTHX(I),IDAYX(I),
     *ITIMEX(I),NPROBE(I),ISIG
      IF (ISIG .EQ. 9) GO TO 10
C   CHECK O2 PROBE DATA FOR TIME CODE ERRORS
   21 CALL TIMCHK (IYEARX(I),MONTHX(I),IDAYX(I),ITIMEX(I),I,3)
      GO TO 50
   10 NX = I-1
C   WRITE O2 PROBE DATA
      WRITE (6,23) (RINTCP(I),SLOPE(I),IYEARX(I),MONTHX(I),IDAYX(I),
     *ITIMEX(I),NPROBE(I),I=1,NX)
C   INITIALIZE VARIABLES
      DATA CON(1),C3N(2),CON(3),CON(4)/1.75,3.25,4.50,6.00/,ISTOP,IC1,
     &IX1,IX4,MCON5,MO2/0,2,2,1,1,1/,IC2(1),IX2(1)/1,1/
      CON(5)=CON5(1)
   15 I = 0
   31 NCON5 = 0
      NO2 = 0
   13 I = I+1
C   READ RUSTRAK DATA
      READ (5,2,END=17) MONTH(I),IDAY(I),IYEAR(I),ITIME(I),(TEMP(I,J),
     *O2(I,J),ZERO(I,J), J=1,5)
      NCARD=NCARD+1
C   CHECK RUSTRAK DATA FOR TIME CODE ERRORS
      CALL TIMCHK (IYEAR(I),MONTH(I),IDAY(I),ITIME(I),NCARD,5)
   35 ISIG = 0
      NSIG = 0
C   IF DATA IS FOR A DIFFERENT DAY, STORE IT AND FINISH CALCULATIONS FOR THE DAY
      IF (IDAY(I) .NE. IDAY(1)) GO TO 16
C   CHANGE BOTTOM DEPTH CONSTANT IF TIME CODE OF RUSTRAK DATA IS .GE. TIME CODE
C     OF NEXT CON5 VALUE
   32 IF (IC1 .GT. NC) GO TO 11
      IF (IYEAR(I)-IYEARC(IC1)) 11,42,45
   42 IF (MONTH(I)-MONTHC(IC1)) 11,43,45
   43 IF (IDAY(I)-IDAYC(IC1)) 11,44,45
   44 IF (ITIME(I)-ITIMEC(IC1)) 11,45,45
   45 IF (ISIG .EQ. 0) NCON5 = NCON5+1
      CON(5) = CON5(IC1)
      IC2(NCON5) = IC1
      ITIMEB(IC1) = ITIME(I)
      IC1 = IC1+1
      ISIG = 1
C   CHANGE O2 PROBE CALIBRATION IF TIME CODE OF RUSTRAK DATA IS .GE. TIME CODE
C     OF NEXT O2 PROBE CALIBRATION
      GO TO 32
```

```
   11 IF (IX1 .GT. NX) GO TO 12
      IF (IYEAR(I)-IYEARX(IX1)) 12,38,39
   38 IF (MONTH(I)-MONTHX(IX1)) 12,40,39
   40 IF (IDAY(I)-IDAYX(IX1)) 12,41,39
   41 IF (ITIME(I)-ITIMEX(IX1)) 12,39,39
   39 IF (NSIG .EQ. 0) NO2 = NO2+1
      IX2(NO2) = IX1
      ITIMEA(IX1) = ITIME(I)
      IX4 = IX1
      IX1 = IX1+1
      NSIG = 1
C   INDICATE IF CON5 OR O2 WAS NOT CHANGED DURING THE DAY
      GO TO 11
   12 IF (NCON5 .EQ. 0) GO TO 46
      IF (I .EQ. 1) MCON5 = IC2(NCON5)
   46 IF (NO2 .EQ. 0) GO TO 36
      IF (I .EQ. 1) MO2 = IX2(NO2)
C   CONVERT RUSTRAK DATA TO TEMP. IN DEG. C AND O2 CONC. IN MG/L O2
C     APPROX. EQUAL TO GRAM/(CUBIC METER) O2
   36 DO 5 J = 1, 5
      TEMP(I,J) = (ZERO(I,J) - TEMP(I,J))*28.0*(-0.0669758) + 55.6132
    5 O2(I,J) = (ZERO(I,J) - O2(I,J))*28.0/(SLOPE(IX4)*TEMP(I,J)+RINTCP
     *(IX4))
C   USING HUTCHINSON'S TABLE CALCULATE % SAT. OF SURFACE WATER (PSAT)
      K = INT(TEMP(I,1)) + 1
      L = INT(TEMP(I,1)*10.0001) - (K -1)*10 + 1
    6 PSAT(I) = O2(I,1)/(HUTCH(K,L)*1.03)
C   SUM O2 CONC. TO GET (G O2)/(SQ. M LAKE SURFACE)
      SUM(I) = 0.0
      DO 7 J = 1, 5
    7 SUM(I) = O2(I,J)*CON(J) + SUM(I)
C   IF 24 RUSTRAK DATA CARDS WEREN'T READ, READ ANOTHER ONE
      IF (ISTOP .EQ. 1) GO TO 84
      IF (I .NE. 24) GO TO 13
   84 N=I
      GO TO 18
   16 N = I-1
C   WRITE CALCULATED DATA ONTO TAPE WITH ITS TIME CODE
   18 WRITE (4,53) N,IYEAR(1),MONTH(1),IDAY(1),(ITIME(M),(TEMP(M,J),
     &J=1,5),(O2(M,J),J=1,5),SUM(M),PSAT(M),M=1,N)
C   PAD UNUSED TAPE RECORDS WITH BLANKS
      M=24-N
      IF (M .EQ. 0) GO TO 66
      DO 67 MPAD=1,M
   67 WRITE (4,59)
C   WRITE CON5 VALUES USED FOR THE DAY ONTO TAPE
   66 WRITE (4,54) CON5(MCON5)
      NCOKNT=0
      IF (NCON5 .EQ. 0) GO TO 48
C   LIMITED TO 10 CON5 VALUES PER DAY
      IF (NCON5 .GT. 10) GO TO 56
      DO 83 M=1,NCON5
      IC3=IC2(M)
      IF (IC3 .EQ. MCON5) GO TO 83
      NCOKNT = NCOKNT+1
   83 CONTINUE
C   WRITE NUMBER OF TIMES O2 PROBES WERE CHANGED DURING THE DAY
      WRITE (4,72) NCOKNT
```

APPENDIX A (CONTINUED)

```
      DO 47 M=1,NCON5
      IC3 = IC2(M)
      IF (IC3 .EQ. MCON5) GO TO 47
      WRITE (4,55) CON5(IC3),ITIMEB(IC3)
   47 CONTINUE
      GO TO 49
   48 IF (IC1 .EQ. 2) MCON5 = IC2(1)
      WRITE (4,72) NCOKNT
      GO TO 27
   49 MCON5 = IC2(NCON5)
C   PAD UNUSED TAPE RECORDS WITH BLANKS
   27 M=10-NCOKNT
      IF (M .EQ. 0) GO TO 49
      DO 58 MPAD=1,M
   58 WRITE (4,59)
C   WRITE O2 PROBE CALIBRATION NUMBERS USED FOR THE DAY ONTO TAPE
      WRITE (4,60) NPROBE(MO2)
      NO2KNT=0
      IF (NO2 .EQ. 0) GO TO 34
C   LIMITED TO 10 NPROBE VALUES PER DAY
      IF (NO2 .GT. 10) GO TO 62
      DO 82 M=1,NO2
      IX3=IX2(M)
      IF (IX3 .EQ. MO2) GO TO 82
      NO2KNT=NO2KNT+1
   82 CONTINUE
C   WRITE NUMBER OF TIMES O2 PROBES WERE CHANGED DURING THE DAY
      WRITE (4,72) NO2KNT
      DO 33 M=1,NO2
      IX3 = IX2(M)
      IF (IX3 .EQ. MO2) GO TO 33
      WRITE (4,61) NPROBE(IX3),ITIMEA(IX3)
   33 CONTINUE
      GO TO 37
   34 IF (IX1 .EQ. 2) MO2 = IX2(1)
      WRITE (4,72) NO2KNT
      GO TO 29
   37 MO2 = IX2(NO2)
C   PAD UNUSED TAPE RECORDS WITH BLANKS
   29 M=10-NO2KNT
      IF (M .EQ. 0) GO TO 37
      DO 64 MPAD=1,M
   64 WRITE (4,59)
C   N .EQ. I WHEN 24 VALUES/DAY WERE CALCULATED (COMPLETE DIURNAL)
      IF (ISTOP .EQ. 1) GO TO 69
      IF (N .EQ. I) GO TO 15
C   TRANSFER STORED VALUES FOR THE NEXT DAY INTO DATA POSITION ONE OF EACH
C     RESPECTIVE ARRAY
      IDAY(1) = IDAY(I)
      MONTH(1) = MONTH(I)
      IYEAR(1) = IYEAR(I)
      ITIME(1) = ITIME(I)
      DO 19 J = 1,5
      TEMP(1,J) = TEMP(I,J)
      O2(1,J) = O2(I,J)
   19 ZERO(1,J) = ZERO(I,J)
C   INITIALIZE VARIABLES AND GO BACK TO BEGINNING
      I = 1
```

APPENDIX A (CONTINUED)

```
      NCON5=0
      NO2=0
      GO TO 35
   17 IF (I .EQ. 1) GO TO 69
      ISTOP = 1
      GO TO 35
C   WRITE ERRORS DETECTED BY PROGRAM AND TERMINATE (SEE RESPECTIVE FORMATS FOR
C     MESSAGE WRITTEN)
   50 WRITE (6,51)
      STOP
   56 WRITE (6,57)
      STOP
   62 WRITE (6,63)
      STOP
   69 ENDFILE 4
      REWIND 4
C   AT THIS POINT ALL DATA IS CALCULATED AND ON TAPE, THE REMAINING STATEMENTS
C     READ BACK THE TAPE DATA AND PRODUCE PRINTED OUTPUT
   81 READ (4,53,END=76) N,IYEAR(1),MONTH(1),IDAY(1),(ITIME(M),
     &(TEMP(M,J),J=1,5),(O2(M,J),J=1,5),SUM(M),PSAT(M),M=1,N)
C   SKIP BLANK RECORDS
      M=24-N
      IF (M .EQ. 0) GO TO 77
      DO 70 MPAD=1,M
   70 READ (4,59)
   77 WRITE(6,8)MONTH(1),IDAY(1),IYEAR(1),(ITIME(M),(TEMP(M,J),
     &J=1,5),(O2(M,J),J=1,5),SUM(M),PSAT(M),M=1,N)
      IF(N .EQ. 24)WRITE (6,24)
C   READ AND WRITE CON5 VALUE USED AT FIRST READING
      READ (4,54) CON5(1)
      WRITE (6,26) CON5(1)     ,ITIME(1)
C   READ AND WRITE CON5 VALUES CHANGED DURING THE DAY AND THE TIME THEY WERE
C     CHANGED
      READ (4,72) NCOKNT
      IF (NCOKNT .EQ. 0) GO TO 79
      READ (4,73)       (CON5(IC3),ITIMEB(IC3),IC3=1,NCOKNT)
      WRITE (6,25)(CON5(IC3),ITIMEB(IC3),IC3=1,NCOKNT)
C   SKIP BLANK RECORDS
   79 M=10-NCOKNT
      IF (M .EQ. 0) GO TO 80
      DO 71 MPAD=1,M
   71 READ (4,59)
C   READ AND WRITE O2 PROBE NUMBER USED AT FIRST READING
   80 READ (4,60) NPROBE(1)
      WRITE (6,28) NPROBE(1)   ,ITIME(1)
C   READ AND WRITE O2 PROBE NUMBERS CHANGED DURING THE DAY AND THE TIME THEY
C     WERE CHANGED
      READ (4,72) NO2KNT
      IF (NO2KNT .EQ. 0) GO TO 78
      READ (4,74)      (NPROBE(IX3),ITIMEA(IX3),IX3=1,NO2KNT)
      WRITE (6,30)(NPROBE(IX3),ITIMEA(IX3),IX3=1,NO2KNT)
C   SKIP BLANK RECORDS
   78 M=10-NO2KNT
      DO 75 MPAD=1,M
   75 READ (4,59)
      GO TO 81
   76 REWIND 4
      STOP
```

APPENDIX A (CONTINUED)

```
      SUBROUTINE TIMCHK (IYEAR,MONTH,IDAY,ITIME,I,IX)
C    SUBPROGRAM TO CHECK DATA FOR PROPER TIME SEQUENCING AND GROSS TIME ERRORS
      COMMON WORD(6)
      IN=I-1
      IY=IX+1
C     CHECK FOR UNREALISTIC TIME DATA
      IF ((IYEAR .LT. 68) .OR. (IYEAR .GT.70)) GO TO 17
      IF ((MONTH .LT. 1) .OR. (MONTH .GT. 12)) GO TO 17
      IF ((IDAY .LT. 1) .OR. (IDAY .GT. 31)) GO TO 17
      IF ((ITIME .LT. 0000) .OR. (ITIME .GT. 2400)) GO TO 17
      IF (I .EQ. 1) GO TO 2
C     CHECK FOR PROPER TIME SEQUENCE
      IF (IYEAR.LT.IYEARX) GO TO 13
      IF (MONTH.LT.MONTHX) GO TO 6
    5 IF (IDAY.LT.IDAYX) GO TO 4
   10 IF (ITIME.LE.ITIMEX) GO TO 12
      GO TO 2
    6 ASSIGN 5 TO N
    8 IF (IYEAR.GT.IYEARX) GO TO N, (5,2)
      GO TO 13
    4 ASSIGN 10 TO M
      MZ=10
   15 IF (MONTH.GT.MONTHX) GO TO M, (10,2)
      ASSIGN 10 TO N
      IF (MZ .EQ. 2) ASSIGN 2 TO N
      GO TO 8
   12 IF (IDAY.GT.IDAYX) GO TO 2
      MZ=2
      ASSIGN 2 TO M
      GO TO 15
    2 IYEARX=IYEAR
      MONTHX=MONTH
      IDAYX=IDAY
      ITIMEX=ITIME
      RETURN
C    WRITE MESSAGES AND TERMINATE
   13 WRITE(6,7)IN,MONTHX,IDAYX,IYEARX,ITIMEX,I,MONTH,IDAY,IYEAR,ITIME,
     *(WORD(IW),IW=IX,IY)
    7 FORMAT('-ERROR DETECTED WHILE COMPARING CARD',I9,10X,3I3,I6/26X,
     *' WITH CARD',I9,10X,3I3,I6,10X,2A3)
      STOP
   17 WRITE (6,18)  I,MONTH,IDAY,IYEAR,ITIME,(WORD(IW),IW=IX,IY)
   18 FORMAT ('-UNREALISTIC DATA ENCOUNTERED ON CARD',I8,10X,3I3,I6,10X,
     *2A3)
      STOP
      END
```

APPENDIX B

REPRESENTATIVE CONVERTED DATA

```
                                                                   DATE   7/25/68

        0.5 M    3.0 M    6.0 M    12.0 M   18.0 M     0.5 M    3.0 M    6.0 M    12.0 M   18.0 M              SURFACE
TIME   TEMP(1)  TEMP(2)  TEMP(3)  TEMP(4)  TEMP(5)     O2(1)    O2(2)    O2(3)    O2(4)    O2(5)    SUM O2    SATURATION
 100    28.42    28.23    27.48    27.30    26.92       9.25     7.57     7.77     1.63     0.25    86.77       1.17
 200    28.42    27.86    28.61    27.41    26.92       9.02     7.75     7.48     1.48     0.25    84.71       1.14
 300    28.80    28.05    27.86    27.11    26.73       9.06     7.54     7.43     1.07     0.25    81.44       1.15
 400    28.61    27.86    27.86    27.11    27.11       9.19     7.83     7.35     1.64     0.25    85.67       1.16
 500    28.23    28.05    28.05    27.11    27.11       9.39     7.38     7.30     1.15     0.25    81.40       1.18
 600    28.23    28.98    27.48    26.92    27.30       8.60     8.00     7.61     1.07     0.08    82.13       1.08
 700    28.23    28.42    27.86    27.11    27.11       8.05     8.15     7.43     0.33     0.16    76.80       1.01
 800    28.42    28.23    27.67    27.11    26.73       8.31     8.28     8.20     0.25     0.25    81.09       1.05
 900    27.86    27.67    28.61    26.92    27.30       8.71     8.60     7.95     0.25     0.08    80.85       1.09
1000    28.61    28.23    28.42    26.55    26.92       9.27     9.23     8.23     0.75     0.25    89.01       1.17
1100    29.36    28.80    28.80    27.11    27.48       9.50     9.37     8.90     0.41     0.16    90.40       1.21
1200    29.17    29.36    28.80    27.67    27.11      10.63     9.96     8.21     0.80     0.25    93.94       1.35
1300    29.92    29.73    28.42    27.48    26.73      10.52    10.36     8.47     0.89     0.25    96.78       1.36
1400    28.42    29.55    27.86    27.48    27.30      10.43    10.50     8.15     1.05     0.41    97.39       1.31
1500    30.86    29.92    27.86    27.48    26.92      10.65    10.38     7.83     0.40     0.33    91.67       1.39
1600    30.67    28.05    27.86    27.30    26.92      10.94     9.69     7.43     0.73     0.17    89.27       1.42
1700    29.92    28.61    27.86    27.11    26.92      11.27     9.19     7.35     0.57     0.08    86.53       1.45
1800    29.92    28.80    27.86    27.30    26.36      11.05     9.06     7.43     0.33     0.34    85.84       1.42
1900    30.11    27.86    28.42    27.30    26.55      10.98     9.27     7.29     0.33     0.17    84.93       1.42
2000    30.48    28.05    27.86    27.30    26.73      10.78     8.97     7.51     0.33     0.08    84.18       1.40
2100    30.30    28.23    27.48    27.30    26.73      11.14     8.68     7.45     0.24     0.17    83.49       1.44
2200    31.05    28.61    27.86    27.67    26.92      10.81     8.57     7.35     0.40     0.08    82.67       1.41
2300    30.30    28.42    28.42    27.30    26.92      10.77     8.70     7.13     1.63     0.25    90.24       1.39
2400    30.11    28.42    28.42    27.30    26.73      10.83     8.70     7.45     1.38     0.25    90.30       1.40


DIURNAL IS COMPLETE

CON(5)   EQUALS   4.98 AT  100

O2 PROBE NO.  2 BEING USED AT  100
```

APPENDIX C

REPRESENTATIVE OXYGEN CURVE DATA

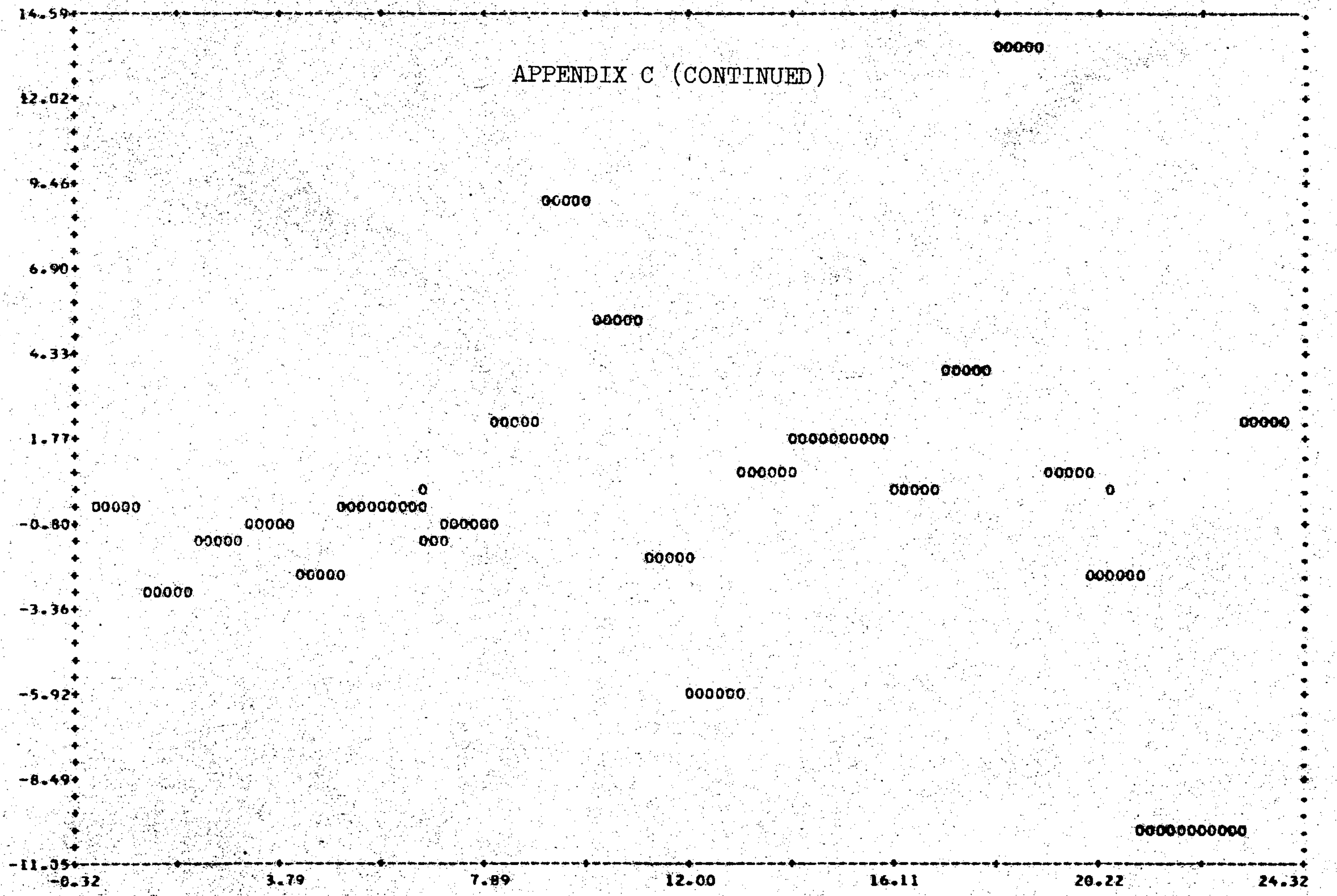
```
VALUES ADJUSTED ACCORDING TO CLASS(3,2)
RESPIRATION LINE BEGINS AT      6.60 HOURS  AND ENDS  AT       21.00HOURS

        TIME  INTERVAL      RATE

        0.0       1.00      -0.25
        1.00      1.00      -3.03
        2.00      1.00      -1.25
        3.00      1.00      -0.91
        4.00      1.00      -2.35
        5.00      1.60      -0.33
        6.60      0.40      -1.43
        7.00      1.00      -1.04
        8.00      1.00       2.15
        9.00      1.00       8.95
       10.00      1.00       5.59
       11.00      1.00      -1.90
       12.00      1.00      -5.85
       13.00      1.00       0.55
       14.00      1.00       1.67
       15.00      1.00       1.91
       16.00      1.00       0.07
       17.00      1.00       3.87
       18.00      1.00      13.76
       19.00      1.00       0.64
       20.00      1.00      -2.51
       21.00      1.00     -10.25
       22.00      1.00     -10.25
       23.00      1.00       2.13

GROSS PROD =      103.47  G OF O2/M**2/24HR          DIFFUSION-OUT =    3.55  G OF O2/M**2/24HR
TOTAL RESP =      104.98  G OF O2/M**2/24HR          DIFFUSION-IN  =   -0.0   G OF O2/M**2/24HR
NET PROD   =       -1.52  G OF O2/M**2/24HR
PROD/RESP  =        0.99                             DIFFUSION CONSTANT (K)  =  -1.00  SUPPLIED FOR ENTIRE SET
```

APPENDIX C (CONTINUED)



Y-AXIS = RATE OF CHANGE IN GRAMS-OF-OXYGEN/M**2/HOUR
KEYSTONE RESERVOIR

X-AXIS = TIME IN HOURS
STATION 1 SUBSTATION 1 DATE 8/ 4/68

SUNRISE= 6.60 SUNSET=20.40

APPENDIX C (CONTINUED)

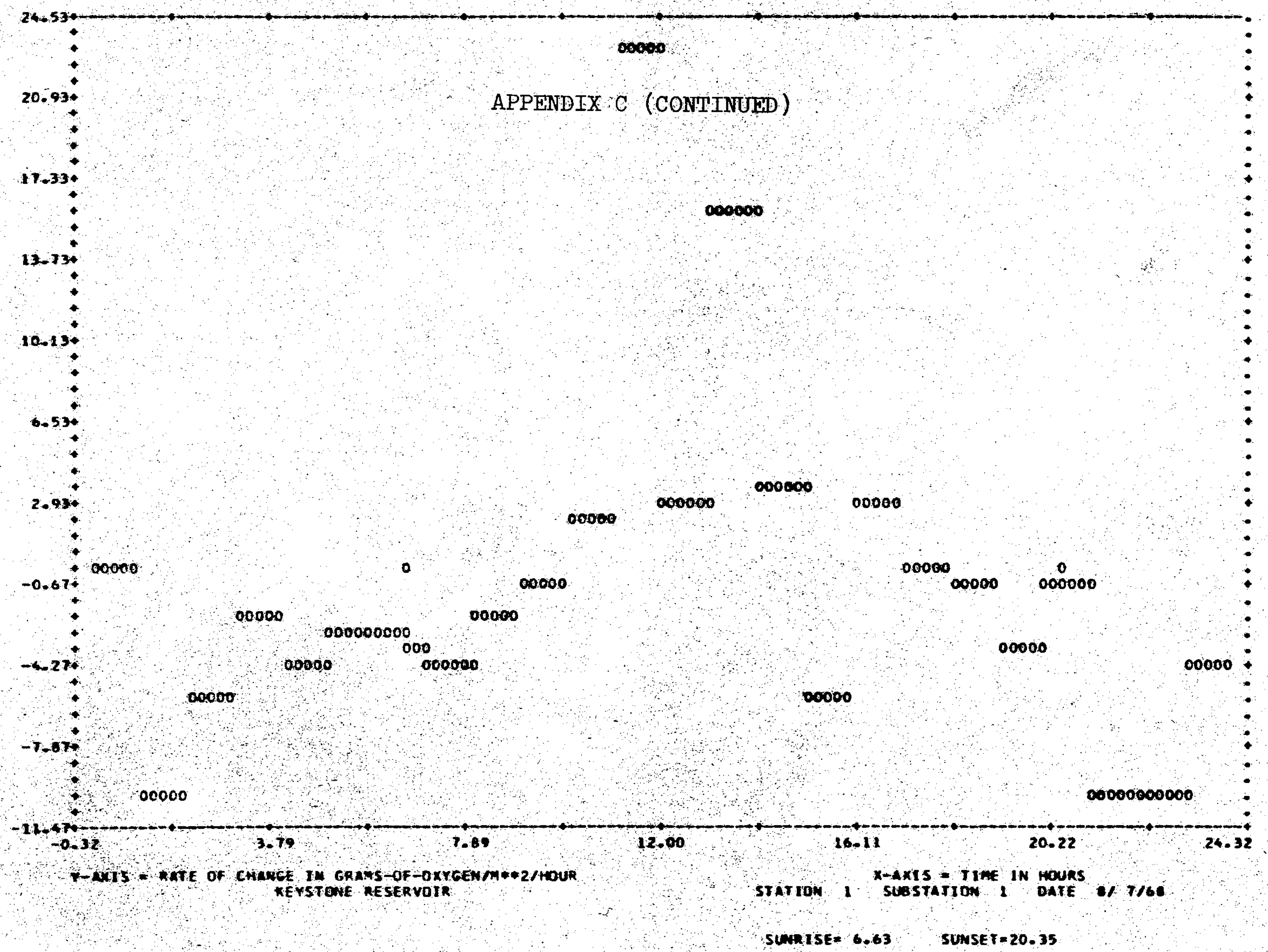
```
VALUES ADJUSTED ACCORDING TO CLASS(3.2)
RESPIRATION LINE BEGINS AT      6.63 HOURS  AND ENDS  AT      21.00HOURS

        TIME   INTERVAL       RATE

        0.0       1.00      -0.09
        1.00      1.00     -10.35
        2.00      1.00      -5.94
        3.00      1.00      -1.90
        4.00      1.00      -4.57
        5.00      1.63      -3.02
        6.63      0.37      -3.76
        7.00      1.00      -4.54
        8.00      1.00      -1.78
        9.00      1.00      -0.79
       10.00      1.00       2.18
       11.00      1.00      23.36
       12.00      1.00       3.17
       13.00      1.00      15.85
       14.00      1.00       3.77
       15.00      1.00      -5.43
       16.00      1.00       2.85
       17.00      1.00       0.04
       18.00      1.00      -0.67
       19.00      1.00      -3.47
       20.00      1.00      -0.38
       21.00      1.00      -9.92
       22.00      1.00      -9.92
       23.00      1.00      -3.99

GROSS PROD =      125.75  G OF O2/M**2/24HR          DIFFUSION-OUT =     0.16  G OF O2/M**2/24HR
TOTAL RESP =      144.56  G OF O2/M**2/24HR          DIFFUSION-IN  =     3.23  G OF O2/M**2/24HR
NET PROD   =      -18.81  G OF O2/M**2/24HR
PROD/RESP  =        0.87                             DIFFUSION CONSTANT (K)  =  -1.00  SUPPLIED FOR ENTIRE SET
```

APPENDIX C (CONTINUED)



APPENDIX C (CONTINUED)

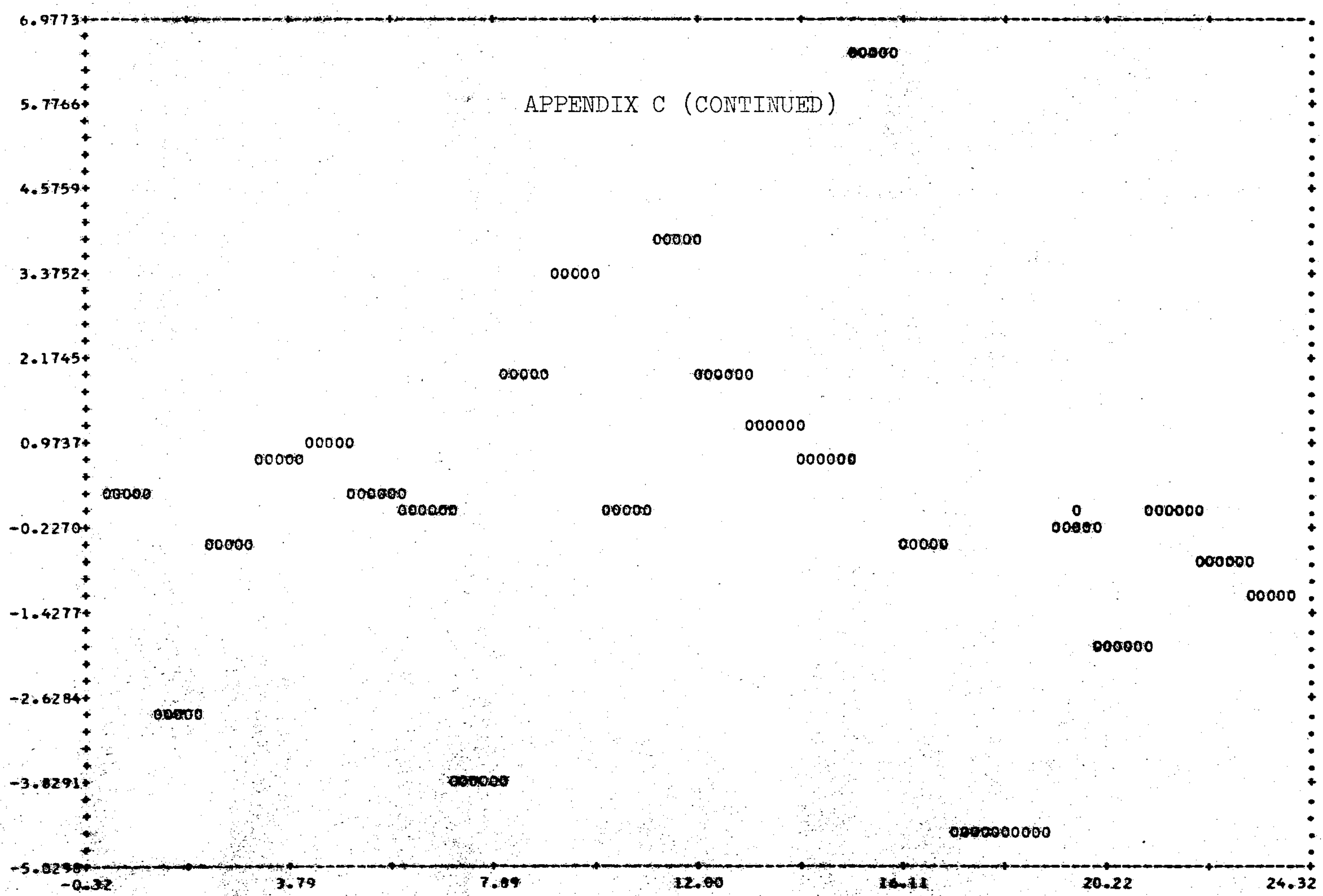
```
VALUES ADJUSTED ACCORDING TO CLASS(I,J)
RESPIRATION TIME BEGINS AT     8.00 HOURS AND ENDS AT     18.00HOURS

      TIME   INTERVAL      RATE

      0.0       1.00       0.20
      1.00      1.00      -2.95
      2.00      1.00      -0.39
      3.00      1.00       0.79
      4.00      1.00       0.96
      5.00      1.00       0.26
      6.00      1.00       0.81
      7.00      1.00      -3.08
      8.00      1.00       1.67
      9.00      1.00       3.47
     10.00      1.00      -0.09
     11.00      1.00       3.88
     12.00      1.00       2.03
     13.00      1.00       1.27
     14.00      1.00       0.68
     15.00      1.00       6.59
     16.00      1.00      -0.45
     17.00      1.00      -4.59
     18.00      1.00      -4.65
     19.00      1.00      -0.31
     20.00      1.00      -1.98
     21.00      1.00       0.06
     22.00      1.00      -0.75
     23.00      1.00      -1.27

GROSS PROD =      57.35  G OF O2/M**2/24HR          DIFFUSION-OUT =     0.14  G OF O2/M**2/24HR
TOTAL RESP =      58.80  G OF O2/M**2/24HR          DIFFUSION-IN  =     0.56  G OF O2/M**2/24HR
NET PROD   =      -1.46  G OF O2/M**2/24HR
PROD/RESP  =       0.98                             DIFFUSION CONSTANT (K)  =  -1.00  SUPPLIED FOR ENTIRE SET
```

APPENDIX C (CONTINUED)



Y-AXIS = RATE OF CHANGE IN GRAMS-OF-OXYGEN/M**2/HOUR
KEYSTONE RESERVOIR

X-AXIS = TIME IN HOURS
STATION 1 SUBSTATION 1 DATE 9/17/68

SUNRISE= 7.16 SUNSET=19.50

APPENDIX C (CONTINUED)

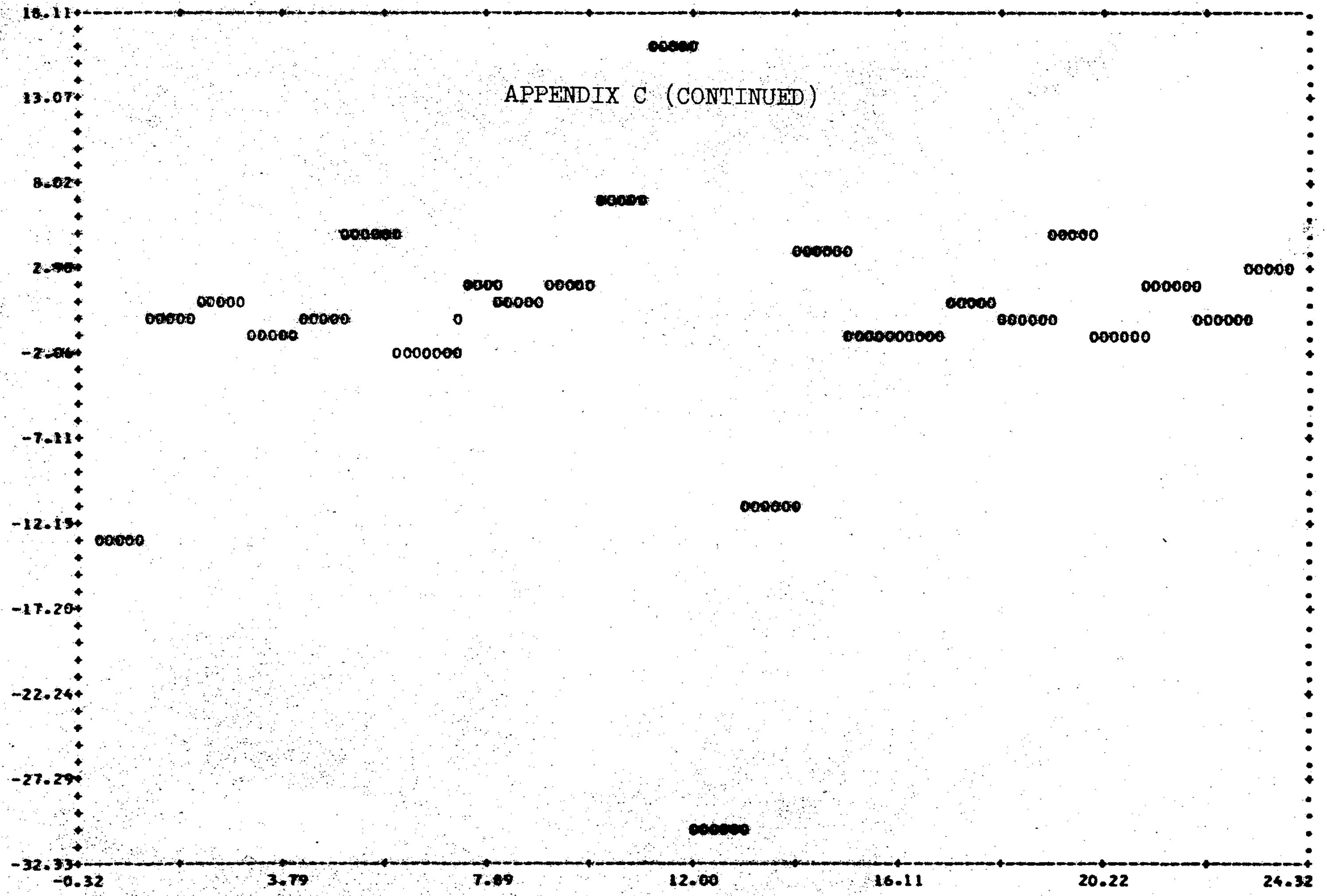
```
VALUES ADJUSTED ACCORDING TO CLASSES.13
RESPIRATION LINE BEGINS AT      7.35 HOURS  AND ENDS  AT      12.00HOURS

       TIME  INTERVAL      RATE

       0.0      1.00    -12.66
       1.00     1.00     -0.19
       2.00     1.00      0.93
       3.00     1.00     -0.79
       4.00     1.00     -0.06
       5.00     1.00      5.47
       6.00     1.35     -2.11
       7.35     0.65      2.43
       8.00     1.00      1.03
       9.00     1.00      2.05
      10.00     1.00      6.73
      11.00     1.00     16.48
      12.00     1.00    -30.75
      13.00     1.00    -10.79
      14.00     1.00      3.59
      15.00     1.00     -1.34
      16.00     1.00     -1.20
      17.00     1.00      0.94
      18.00     1.00     -0.21
      19.00     1.00      4.59
      20.00     1.00     -0.75
      21.00     1.00      2.17
      22.00     1.00      0.93
      23.00     1.00      3.44

GROSS PROD =     104.30  G OF O2/M**2/24HR          DIFFUSION-OUT =    0.71  G OF O2/M**2/24HR
TOTAL RESP =     138.06  G OF O2/M**2/24HR          DIFFUSION-IN  =    0.04  G OF O2/M**2/24HR
NET PROD   =     -33.77  G OF O2/M**2/24HR
PROD/RESP  =       0.76                             DIFFUSION CONSTANT (K)  =  -1.00  SUPPLIED FOR ENTIRE SET
```

APPENDIX C (CONTINUED)



Y-AXIS = RATE OF CHANGE IN GRAMS-OF-OXYGEN/M**2/HOUR
KEYSTONE RESERVOIR

X-AXIS = TIME IN HOURS
STATION 1 SUBSTATION 1 DATE 10/ 1/68

SUNRISE= 7.35 SUNSET=19.16

APPENDIX C (CONTINUED)

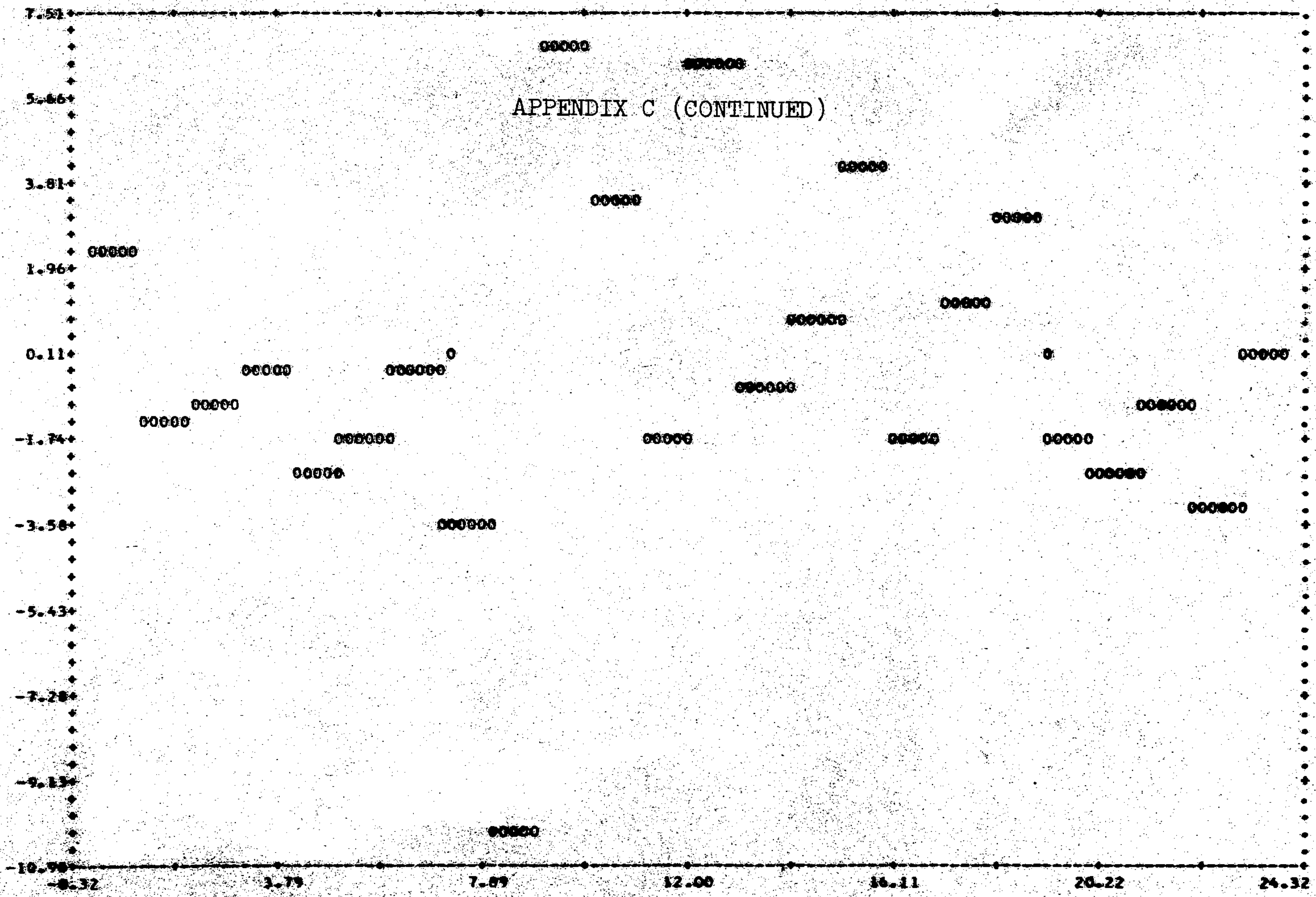
```
 VALUES ADJUSTED ACCORDING TO CLASS(1,2)
 RESPIRATION LINE BEGINS AT     9.00 HOURS  AND ENDS  AT      20.00HOURS

        TIME  INTERVAL      RATE

       0.0      1.00       2.51
       1.00     1.00      -1.35
       2.00     1.00      -0.97
       3.00     1.00      -0.14
       4.00     1.00      -2.39
       5.00     1.00      -1.72
       6.00     1.00      -0.24
       7.00     1.00      -3.54
       8.00     1.00     -10.40
       9.00     1.00       6.91
      10.00     1.00       3.46
      11.00     1.00      -1.90
      12.00     1.00       6.27
      13.00     1.00      -0.72
      14.00     1.00       0.94
      15.00     1.00       4.11
      16.00     1.00      -1.71
      17.00     1.00       1.31
      18.00     1.00       2.93
      19.00     1.00      -1.76
      20.00     1.00      -2.33
      21.00     1.00      -0.94
      22.00     1.00      -3.14
      23.00     1.00      -0.02

GROSS PROD =      89.89  G OF O2/M**2/24HR          DIFFUSION-OUT =    1.77  G OF O2/M**2/24HR
TOTAL RESP =      97.22  G OF O2/M**2/24HR          DIFFUSION-IN  =   -0.0   G OF O2/M**2/24HR
NET PROD   =      -7.33  G OF O2/M**2/24HR
PROD/RESP  =       0.92                             DIFFUSION CONSTANT (K)  =  -1.00  SUPPLIED FOR ENTIRE SET
```

APPENDIX C (CONTINUED)



Y-AXIS = RATE OF CHANGE IN GRAMS-OF-OXYGEN/M**2/HOUR
KEYSTONE RESERVOIR

X-AXIS = TIME IN HOURS
STATION 1 SUBSTATION 1 DATE 10/ 3/68

SUNRISE= 7.30 SUNSET=19.11

VITA

Allen Ray Faust

Candidate for the Degree of

Master of Science

Thesis: CONTINUOUS MONITORING OF DISSOLVED OXYGEN CONCENTRATION AND TEMPERATURE AT MULTIPLE DEPTHS IN A RESERVOIR

Major Field: Zoology

Biographical:

Personal Data: Born in Clinton, Oklahoma, January 11, 1945, the son of Jacob S. and Elvira L. Faust.

Education: Graduated from Midwest City High School, Midwest City, Oklahoma, in 1963; received the Bachelor of Science Degree, Oklahoma State University, Stillwater, Oklahoma, May, 1967, with a major in Zoology; completed requirements for Master of Science Degree in May, 1972, at Oklahoma State University.

Professional Experience: Undergraduate research assistant, Cooperative Fishery Unit, Oklahoma State University, 1967; graduate research assistant for Reservoir Research Center, Oklahoma State University, June, 1967 - January, 1969; biomedical research technician, U. S. Army Aeromedical Research Laboratory, Fort Rucker, Alabama, April, 1969 - November, 1970; graduate research assistant for Reservoir Research Center, Oklahoma State University, January, 1971 - May, 1972.

Member: American Society of Limnology and Oceanography, American Society of Ichthyology and Herpetology, Phi Sigma Society, American Institute of Biological Sciences, Water Pollution Control Federation, Red Rose.