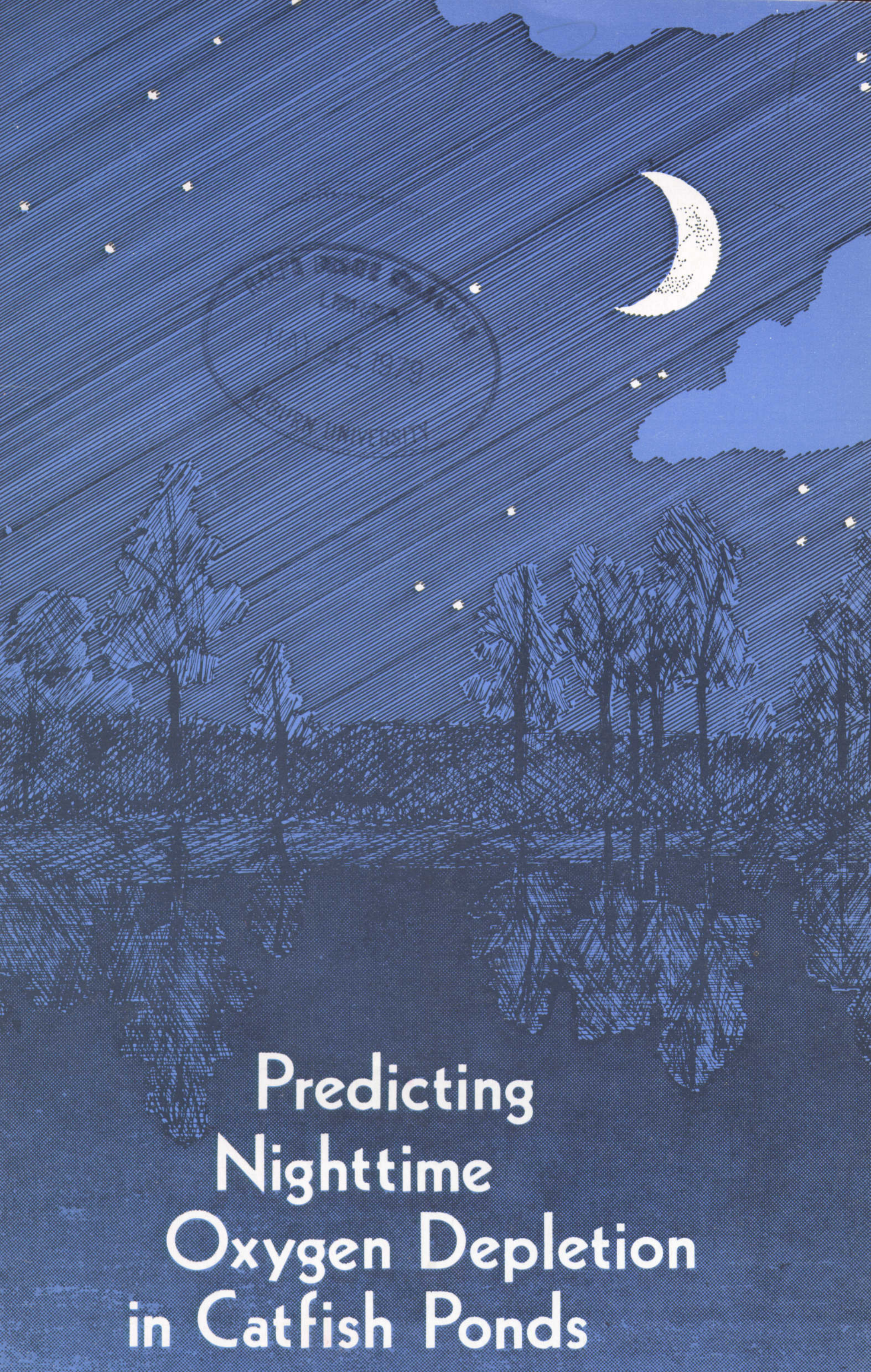

Predicting Nighttime Oxygen Depletion in Catfish Ponds

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CONTENTS

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Predicting Nighttime Oxygen Depletion in Catfish Ponds[1]

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INADEQUATE CONCENTRATION of dissolved oxygen (DO) has long been recognized as a critical factor in the intensive production of channel catfish *(Ictalurus punctatus)* in ponds. Depletion of DO may cause fish kills resulting in serious economic losses to the producer. Moreover, fish do not feed or grow well and may become predisposed to diseases in ponds with sudden or chronically low concentrations of DO.

Emergency aeration should be initiated in ponds when the DO concentration declines to less than 2.0 parts per million (ppm). Presently, fish culturists have no reliable technique for predicting if DO will fall below this critical level during the night. Therefore, the culturist must make DO measurements at intervals during the night or rely upon experience or 'rules of thumb' provided by fish culture researchers or other fish farmers. Consequently, emergency aeration is frequently used when not required, and in some cases, it is not used when needed. Either situation is a wasteful practice and increases the cost of producing catfish.

The data herein provide the culturist with two practical methods for predicting at dusk (or shortly thereafter) if DO depletion is likely to occur in a pond during any given night, thereby allowing time to prepare for emergency aeration.

NIGHTTIME DISSOLVED OXYGEN MODEL

Research at Auburn University has led to the development of a practical simulation model for predicting the nighttime loss in DO caused principally by respiration of the biota in channel catfish ponds. The basic equation for predicting nighttime DO decline is:

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[1]Research supported by the Office of Water Research and Technology of the Department of the Interior through the Water Resources Research Institute of Auburn University under provision of the Water Research Act of 1964.

[2]Graduate Research Assistant and Professor, respectively, Department of Fisheries and Allied Aquacultures.

$DO_t = DO_{dusk} \pm DO_{df} - DO_f - DO_m - DO_p$

DO_t = DO concentration after t hours of darkness,

DO_{dusk} = DO concentration at dusk,

DO_{df} = gain or loss of O_2 to diffusion,

DO_f = O_2 used by fish,

DO_m = loss of O_2 to mud respiration,

DO_p = O_2 consumed by the planktonic community.

A computer program written in the simulation language CSMP-III (Continuous System Modeling Program-III) is used to solve the nighttime DO equation from data on O_2 consumption by plankton (8), organisms in the mud (10, 11) and channel catfish (3), and O_2 diffusion data from Schroeder (11).

Evaluation of the nighttime DO equation gave highly reliable predictions of early morning DO concentrations when Secchi disk visibility was used to estimate oxygen consumption by the plankton community, table 1. Similar results were obtained when the chemical oxygen demand (COD) was used to estimate oxygen consumption by the plankton, table 2.

APPLICATION

To make the nighttime DO prediction equation practical, a computer algorithm was used to prepare tables of minimum acceptable (critical) Secchi disk visibilities (Appendix I, tables 1A-1H) and maximum permissable (critical) COD concentrations (Appendix I, tables 2A-2H) required to maintain a DO concentration above 2.0 ppm (± 0.1 ppm) at dawn. Smaller

TABLE 1. COMPARISONS OF MEASURED DO CONCENTRATIONS AT DAWN IN CHANNEL CATFISH PONDS WITH DO CONCENTRATIONS CALCULATED BY COMPUTER SIMULATION. OXYGEN CONSUMPTION BY PLANKTON PREDICTED FROM SECCHI DISK VISIBILITY. AFTER BOYD ET AL. (8)

Date[1]	Fish[2] (lb/acre)	Secchi disk visibility (cm)	DO at dusk (ppm)	DO at dawn (ppm)		Difference (ppm)
				measured	calculated	
5/25/74	251	84	10.13	8.32	8.17	−0.17
6/29/74	504	46	9.70	7.49	7.10	−0.39
7/30/74	965	49	6.69	4.15	3.18	−0.97
9/11/74	1851	30	7.30	4.27	4.00	−0.27
8/29/75	2161	27	7.80	2.40	1.85	−0.55

[1]Beginning of period of measurement.

[2]Estimated from stocking rate and average weight gain for the particular feeding rate.

TABLE 2. COMPARISONS OF MEASURED DO CONCENTRATIONS AT DAWN IN CHANNEL CATFISH PONDS WITH DO CONCENTRATIONS CALCULATED BY COMPUTER SIMULATION. OXYGEN CONSUMPTION BY PLANKTON PREDICTED FROM CHEMICAL OXYGEN DEMAND (COD). AFTER BOYD ET AL. (8)

Date[1]	Fish[2] (lb/acre)	COD (ppm)	DO at dusk (ppm)	DO at dawn (ppm) measured	DO at dawn (ppm) calculated	Difference (ppm)
5/25/74	251	38.9	10.13	8.32	7.73	−0.59
6/29/74	504	41.2	9.70	7.49	7.55	+0.06
7/30/74	965	37.5	6.69	4.15	4.16	+0.01
9/11/74	1851	47.9	7.30	4.27	4.76	+0.51
8/29/75	2161	72.3	7.80	2.40	2.13	−0.27

[1]Beginning of period of measurement.
[2]Estimated from stocking rate and average weight gain for the particular feeding rate.

Secchi disk values or larger COD values than those found in the tables for any combination of water temperature, fish density and DO concentration at dusk would cause the DO to fall below 2.0 ppm by dawn. Where Secchi disk or COD entries are designated safe (S), the DO concentration at dawn would not be expected to drop below 2.0 ppm. The nighttime DO model revealed that in ponds containing up to 4,000 pounds of catfish per acre no DO problems should be encountered when the average DO concentration at dusk exceeds 12.0 ppm. Careful monitoring of DO is recommended, however, when Secchi disk visibilities are less than 20 centimeters (cm)[3] or COD values exceed 100 ppm, regardless of the DO concentration at dusk. Studies have shown an increased likelihood of incurring oxygen related problems in ponds with a Secchi disk visibility less than 20 cm or where the COD exceeds 100 ppm (6, 7, 8, 12). Likewise, these prediction tables are not applicable for ponds during periods in which massive algal die-offs have occurred.

Certain information is required to use the tables. This includes Secchi disk visibility or COD, water temperature and DO concentration at dusk, and the standing crop of fish (pounds per acre) in the pond on the date of measurement. The standing crop of fish in the pond may be estimated from stocking data and feeding rate or from stocking data and average weight of fish in seine hauls. For convenience, the expected standing crop of channel catfish (pounds per acre) at the beginning of each month during a typical 210-day growing season (March through September) is given for three common stocking rates, table 3. An error of ± 500 pounds of fish per acre

[3]1 centimeter = 0.394 inch.

TABLE 3. EXPECTED MONTHLY STANDING CROP OF CHANNEL CATFISH (POUNDS/ACRE) FOR PONDS STOCKED AT THREE RATES WITH 5-INCH FINGERLINGS ON MARCH 1. DATA ASSUMES THE FISH ARE FED AT 3% OF THEIR BODY WEIGHT DAILY, 7 DAYS A WEEK, WITH FEED READJUSTMENTS MADE BIWEEKLY

Date	Stocking rate (No./acre)		
	2,000	3,000	4,000
March 1	74	111	148
April 1	119	173	227
May 1	195	278	357
June 1	326	453	571
July 1	535	726	898
August 1	895	1184	1436
September 1	1495	1930	2295
October 1	2300	2970	3401

will not seriously affect critical Secchi disk or COD values.

Water temperature and DO concentration should be measured within ± 1 hour of dusk. Temperature and DO determinations may be made with a polarographic DO meter, figure 1. However, reliable DO values may be obtained with a water analysis kit, figure 2, if a DO meter is not available (4,5). Temperature and DO determinations should be made at the surface, 30, 60, and 90 cm depths and the average of the four measurements taken as the correct reading.

FIG. 1. Polarographic dissolved oxygen (DO) meter.

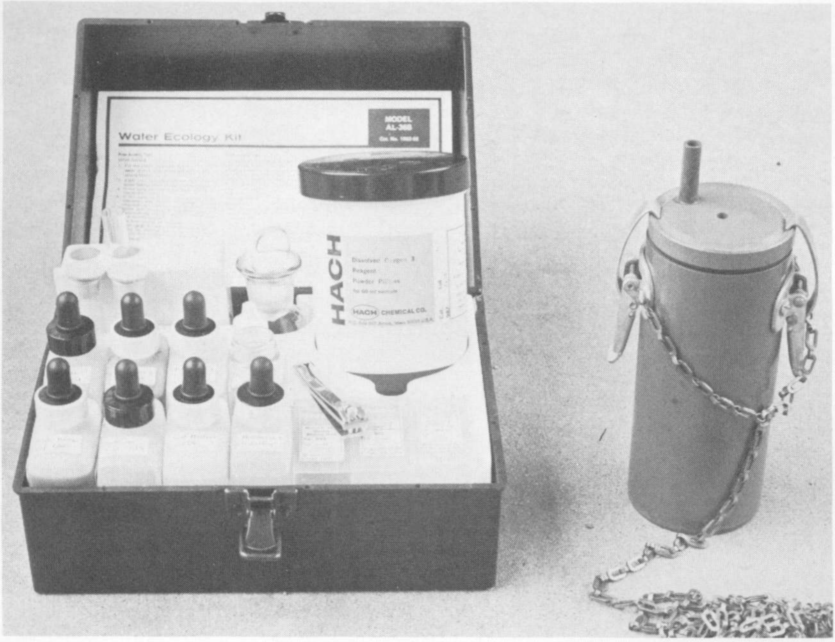

FIG. 2. Dissolved oxygen (DO) kit.

Secchi disk visibility or COD must be measured, preferably between 10:00 a.m. and 4:00 p.m. Secchi disk visibility should be measured with a 20-cm (8-inch) diameter disk with alternate black and white quadrants, figure 3. The Secchi disk visibility is obtained by lowering the disk in pond water until it disappears and the depth recorded. The disk is then raised and the depth of reappearance noted. The average of the depth of disappearance and the depth of reappearance is taken as the correct reading. A partial list of suppliers of DO meters, water analysis kits, and Secchi disks is given in Appendix II.

The Secchi disk visibility tables will provide a reliable prediction of the critical DO concentration in ponds where plankton is the major source of turbidity. In well managed fish ponds, plankton is usually the most important source of turbidity (1). Generally, a careful observer can distinguish between plankton turbidity and other sources of turbidity. In ponds containing appreciable clay turbidity, however, the COD tables should be used to predict critical DO levels. Research stations and fish farms can afford to make COD analyses, but the use of COD will not be practical in most other fish culture operations. Readers can find the analytical procedure of standard COD determination in *Standard Methods for the Examination of Water and Wastewater* (2).

To illustrate the use of the Secchi disk and COD tables consider the following two examples. In a pond with an average depth of 100-cm (3.28 feet) containing 1,500 pounds of catfish per acre, suppose a DO concentration and water temperature of 7.0 ppm and 30°C[4], respectively, were measured at dusk and a Secchi disk visibility of 36 cm recorded that afternoon. The critical Secchi disk value from Appendix I. Table 1-C is 53 cm. Since the measured value of 36 cm is less than 53 cm, the culturist could expect the DO concentration to fall below 2.0 ppm by dawn. This advanced warning would allow time to prepare for emergency aeration during the night. Had the measured Secchi disk visibility exceeded 53 cm the DO would not have been expected to drop below 2.0 ppm by dawn and emergency aeration would not likely be necessary.

Consider the same pond later in the growing season contained 2,000 pounds catfish per acre but appreciable clay turbidity required that a COD determination be made. Suppose the measured COD was 78 ppm and the recorded temperature and DO concentration at dusk was 27°C and 9.0 ppm, respec-

[4] °C = 5/9 (° F − 32)

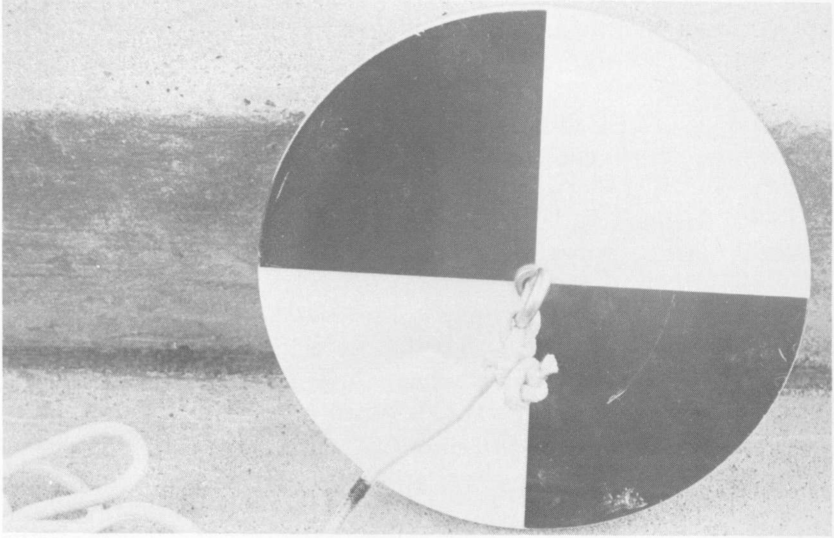

FIG. 3. The Secchi disk is a 20-cm (8-inch) diameter disk with alternate black and white quadrants on the upper surface and black on the bottom. An I-bolt fixed at the center of the upper surface provides attachment for a graduated rope and the bottom is weighted to facilitate sinking. A Secchi disk may be purchased (Appendix II) or easily constructed from metal or plastic and other materials readily available.

tively. Reference to Appendix I. Table 2-D gives a critical COD value of 114 ppm. Since the measured value of 78 ppm is less than 114 ppm, no DO problems would likely be encountered. However, had the measured COD been greater than 114 ppm, then the DO concentration would have likely declined below 2.0 ppm by dawn.

Five channel catfish production ponds on the Auburn University Fisheries Research Unit were visited 40 times during the 1978 growing season (June through September) to evaluate the Secchi disk visibility tables. The ponds ranged from 1.4 to 22 acres in size and were stocked at a standard rate of 3,000 fingerling catfish in March, 1978.

Results disclosed that the tables gave reliable and consistent predictions of eminent DO problems the afternoon before they actually occurred. On 25 occasions, the tables predicted that the DO would be 2.0 ppm or less the following dawn. Measured DO concentration at dawn were observed to be less than 2.0 ppm on 20 of these visits. The measured DO at dawn ranged from 2.5 to 3.5 ppm on the other five occasions. More importantly, on no occasion was the DO at dawn observed to be less than 2.0 ppm when the tables had predicted the ponds to be safe from DO problems (i.e., DO at dawn greater than 2.0 ppm).

PROJECTION METHOD

Where ponds are muddy and COD analyses are not possible an alternative method exists for predicting nighttime decline in DO. The decline in DO during the night is essentially linear with respect to time. If DO is measured at dusk and again after 2 or 3 hours, the two DO concentrations can be plotted versus time and a straight line through the two points projected to estimate DO at other times during the night or dawn. The projection method when evaluated was found to be almost as

TABLE 4. COMPARISONS OF MEASURED DO CONCENTRATIONS AT DAWN IN CHANNEL CATFISH PONDS WITH DO CONCENTRATIONS CALCULATED BY THE PROJECTION METHOD. AFTER BOYD ET AL. (8)

Date	DO at dusk (ppm)	DO at dawn (ppm) measured	DO at dawn (ppm) calculated	Difference (ppm)
5/25/74	10.13	8.32	9.35	+0.97
6/29/74	9.70	7.49	7.60	+0.11
7/30/74	6.69	4.15	4.82	+0.67
9/11/74	7.30	4.27	4.92	+0.65
8/29/75	7.80	2.40	2.90	+0.50

reliable as the computer simulation model in predicting DO concentrations at dawn, table 4. To illustrate the method (graph paper will be needed) suppose the DO concentration at dusk was 8.0 ppm and the measured value 3 hours later 5.7 ppm. According to figure 4 the projected DO concentration at dawn would be less than 2.0 ppm and thus emergency aeration would likely be required.

The projection technique for predicting DO decline in ponds is simpler to use than tables based on computer simulation. Unfortunately, since the projection technique requires no knowledge of fish density or plankton respiration one has no advanced warning of whether or not O_2 depletion is likely, and estimates of DO decline cannot be made until 2 or 3 hours after dark. Therefore, logistical problems may arise once one decides to use emergency aeration. The projection technique will be useful where Secchi disk visibility cannot be used to estimate O_2 consumption by plankton and COD cannot be measured.

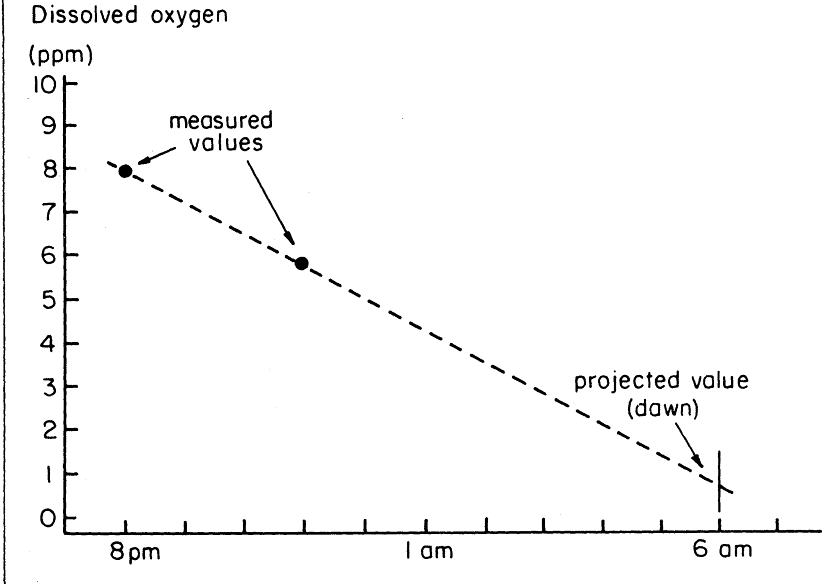

FIG. 4. Illustration of the method for calculating DO concentration at dawn by projecting DO measurements made at dusk and 3 hours later.

EMERGENCY MEASURES TO PREVENT OXYGEN-RELATED FISH KILLS

If either the table method or the projection technique indicates DO depletion is likely by dawn, emergency measures should be initiated to prevent a possible fish kill. Swingle (12) suggested pumping water from a depth of 1.6 to 2.3 feet and discharging it with force at an acute angle against the pond surface. If other ponds are located nearby, fresh, oxygenated water may be pumped into a pond with low DO.

Various types of mechanical agitators are also commercially available and may be used to improve DO concentrations in localized areas (6). Small agitators are often used in small ponds such as those found at fish hatcheries and research stations. Small agitators (0.33 HP) will maintain the DO concentration of small ponds (0.1 to 0.25 acre) at a safe level. Large agitators and lift pumps are available for emergency use in large ponds.

Treatment of ponds with up to 6.0 ppm of potassium permanganate is frequently recommended to alleviate problems of low DO (9). However, recent studies have shown that potassium permanganate treatment is totally ineffective in treating DO problems (13). In fact, potassium permanganate treatment retards oxygen production by phytoplankton, thus prolonging DO depletion.

COMPUTER PROGRAMS

The computer program for solving the nighttime predictive DO equation can be found in Appendix III. The associated computer algorithm for calculating critical Secchi disk and COD values is given in Appendix IV. Note that these programs are presented for reference only and are not required for the practical use of the Secchi disk visibility or COD tables in Appendix I.

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APPENDIX I

TABLE 1-A. CRITICAL SECCHI DISK VALUES (CM) FOR 100-CM (3.28 FT) DEEP PONDS CONTAINING 500 LBS/ACRE OF CHANNEL CATFISH. A SMALLER SECCHI DISK VALUE FOR ANY COMBINATION OF TEMPERATURE AND DO CONCENTRATION AT DUSK WILL CAUSE DO TO FALL BELOW 2.0 PPM AT DAWN. DO CONCENTRATION WILL NOT DROP TO 2.0 PPM REGARDLESS OF SECCHI DISK VALUES FOR ENTRIES DESIGNATED SAFE (S)

	DO concentration at dusk (ppm)										
°C	2	3	4	5	6	7	8	9	10	11	12
	Secchi disk values (cm)										
20	26	S	S	S	S	S	S	S	S	S	S
21	48	21	S	S	S	S	S	S	S	S	S
22	58	32	S	S	S	S	S	S	S	S	S
23	80	48	26	S	S	S	S	S	S	S	S
24	85	58	37	21	S	S	S	S	S	S	S
25	90	69	48	29	S	S	S	S	S	S	S
26	100	74	53	37	21	S	S	S	S	S	S
27	100	79	63	45	32	18	S	S	S	S	S
28	100	85	69	53	37	26	16	S	S	S	S
29	100	90	71	58	45	32	21	S	S	S	S
30	100	90	74	63	50	37	26	18	S	S	S
31	100	93	79	66	53	42	34	24	16	S	S
32	100	95	82	69	58	48	40	29	21	13	S

TABLE 1-B. CRITICAL SECCHI DISK VALUES (CM) FOR 100-CM (3.28 FT) DEEP PONDS CONTAINING 1,000 LBS/ACRE OF CHANNEL CATFISH. A SMALLER SECCHI DISK VALUE FOR ANY COMBINATION OF TEMPERATURE AND DO CONCENTRATION AT DUSK WILL CAUSE DO TO FALL BELOW 2.0 PPM AT DAWN. DO CONCENTRATION WILL NOT DROP TO 2.0 PPM REGARDLESS OF SECCHI DISK VALUES FOR ENTRIES DESIGNATED SAFE (S)

	DO concentration at dusk (ppm)										
°C	2	3	4	5	6	7	8	9	10	11	12
	Secchi disk values (cm)										
20	37	S	S	S	S	S	S	S	S	S	S
21	58	26	S	S	S	S	S	S	S	S	S
22	79	42	21	S	S	S	S	S	S	S	S
23	90	58	32	16	S	S	S	S	S	S	S
24	100	69	42	26	S	S	S	S	S	S	S
25	100	79	53	37	21	S	S	S	S	S	S
26	100	85	63	48	32	16	S	S	S	S	S
27	100	90	69	53	37	26	S	S	S	S	S
28	100	95	74	58	45	32	21	S	S	S	S
29	100	95	79	63	53	40	29	18	S	S	S
30	100	100	85	69	58	45	34	26	16	S	S
31	100	100	87	74	63	50	40	32	21	S	S
32	100	100	90	79	66	55	45	37	29	18	S

TABLE 1-C. CRITICAL SECCHI DISK VALUES (CM) FOR 100-CM (3.28 FT) DEEP PONDS CONTAINING 1,500 LBS/ACRE OF CHANNEL CATFISH. A SMALLER SECCHI DISK VALUE FOR ANY COMBINATION OF TEMPERATURE AND DO CONCENTRATION AT DUSK WILL CAUSE DO TO FALL BELOW 2.0 PPM AT DAWN. DO CONCENTRATION WILL NOT DROP TO 2.0 PPM REGARDLESS OF SECCHI DISK VALUES FOR ENTRIES DESIGNATED SAFE (S)

	DO concentration at dusk (ppm)										
°C	2	3	4	5	6	7	8	9	10	11	12
	Secchi disk values (cm)										
20	48	16	S	S	S	S	S	S	S	S	S
21	69	37	S	S	S	S	S	S	S	S	S
22	90	48	26	S	S	S	S	S	S	S	S
23	100	63	37	21	S	S	S	S	S	S	S
24	100	79	53	32	16	S	S	S	S	S	S
25	100	85	63	42	26	S	S	S	S	S	S
26	100	90	69	53	37	21	S	S	S	S	S
27	100	100	79	58	42	32	16	S	S	S	S
28	100	100	85	66	53	37	26	16	S	S	S
29	100	100	90	74	58	45	34	24	S	S	S
30	100	100	93	77	63	53	40	32	21	S	S
31	100	100	95	79	69	58	48	37	26	18	S
32	100	100	98	85	74	61	53	42	34	24	16

TABLE 1-D. CRITICAL SECCHI DISK VALUES (CM) FOR 100-CM (3.28 FT) DEEP PONDS CONTAINING 2,000 LBS/ACRE OF CHANNEL CATFISH. A SMALLER SECCHI DISK VALUE FOR ANY COMBINATION OF TEMPERATURE AND DO CONCENTRATION AT DUSK WILL CAUSE DO TO FALL BELOW 2.0 PPM AT DAWN. DO CONCENTRATION WILL NOT DROP TO 2.0 PPM REGARDLESS OF SECCHI DISK VALUES FOR ENTRIES DESIGNATED SAFE (S)

	DO concentration at dusk (ppm)										
°C	2	3	4	5	6	7	8	9	10	11	12
	Secchi disk values (cm)										
20	58	21	S	S	S	S	S	S	S	S	S
21	79	37	16	S	S	S	S	S	S	S	S
22	100	58	32	S	S	S	S	S	S	S	S
23	100	69	48	26	S	S	S	S	S	S	S
24	100	85	58	37	21	S	S	S	S	S	S
25	100	90	69	48	32	16	S	S	S	S	S
26	100	100	79	58	42	26	S	S	S	S	S
27	100	100	85	63	48	34	21	S	S	S	S
28	100	100	90	74	58	42	32	18	S	S	S
29	100	100	95	79	63	50	37	26	18	S	S
30	100	100	100	85	69	55	45	34	26	16	S
31	100	100	100	87	74	63	53	42	32	24	S
32	100	100	100	90	79	66	58	48	37	29	18

TABLE 1-E. CRITICAL SECCHI DISK VALUES (CM) FOR 100-CM (3.28 FT) DEEP PONDS CONTAINING 2,500 LBS/ACRE OF CHANNEL CATFISH. A SMALLER SECCHI DISK VALUE FOR ANY COMBINATION OF TEMPERATURE AND DO CONCENTRATION AT DUSK WILL CAUSE DO TO FALL BELOW 2.0 PPM AT DAWN. DO CONCENTRATION WILL NOT DROP TO 2.0 PPM REGARDLESS OF SECCHI DISK VALUES FOR ENTRIES DESIGNATED SAFE (S)

	DO concentration at dusk (ppm)										
°C	2	3	4	5	6	7	8	9	10	11	12
	Secchi disk values (cm)										
20	69	26	S	S	S	S	S	S	S	S	S
21	90	48	21	S	S	S	S	S	S	S	S
22	100	63	37	16	S	S	S	S	S	S	S
23	100	79	48	26	S	S	S	S	S	S	S
24	100	90	63	42	21	S	S	S	S	S	S
25	100	100	74	53	34	18	S	S	S	S	S
26	100	100	85	63	45	29	16	S	S	S	S
27	100	100	90	69	53	37	26	S	S	S	S
28	100	100	95	79	63	48	34	24	S	S	S
29	100	100	100	85	69	53	42	32	21	S	S
30	100	100	100	90	74	61	48	40	29	18	S
31	100	100	100	93	79	66	55	45	37	26	16
32	100	100	100	95	84	71	61	53	42	32	24

TABLE 1-F. CRITICAL SECCHI DISK VALUES (CM) FOR 100-CM (3.28 FT) DEEP PONDS CONTAINING 3,000 LBS/ACRE OF CHANNEL CATFISH. A SMALLER SECCHI DISK VALUE FOR ANY COMBINATION OF TEMPERATURE AND DO CONCENTRATION AT DUSK WILL CAUSE DO TO FALL BELOW 2.0 PPM AT DAWN. DO CONCENTRATION WILL NOT DROP TO 2.0 PPM REGARDLESS OF SECCHI DISK VALUES FOR ENTRIES DESIGNATED SAFE (S)

	DO concentration at dusk (ppm)										
°C	2	3	4	5	6	7	8	9	10	11	12
	Secchi disk values (cm)										
20	79	32	S	S	S	S	S	S	S	S	S
21	100	53	26	S	S	S	S	S	S	S	S
22	100	69	42	21	S	S	S	S	S	S	S
23	100	90	58	32	16	S	S	S	S	S	S
24	100	100	69	48	26	S	S	S	S	S	S
25	100	100	79	58	37	21	S	S	S	S	S
26	100	100	90	69	48	32	21	S	S	S	S
27	100	100	95	74	58	42	29	16	S	S	S
28	100	100	100	85	66	53	37	26	16	S	S
29	100	100	100	90	74	58	48	34	26	16	S
30	100	100	100	95	79	63	53	42	32	21	S
31	100	100	100	98	85	71	58	50	40	29	21
32	100	100	100	100	90	77	66	55	48	37	26

TABLE 1-G. CRITICAL SECCHI DISK VALUES (CM) FOR 100-CM (3.28 FT) DEEP PONDS CONTAINING 3,500 LBS/ACRE OF CHANNEL CATFISH. A SMALLER SECCHI DISK VALUE FOR ANY COMBINATION OF TEMPERATURE AND DO CONCENTRATION AT DUSK WILL CAUSE DO TO FALL BELOW 2.0 PPM AT DAWN. DO CONCENTRATION WILL NOT DROP TO 2.0 PPM REGARDLESS OF SECCHI DISK VALUES FOR ENTRIES DESIGNATED SAFE (S)

	DO concentration at dusk (ppm)										
°C	2	3	4	5	6	7	8	9	10	11	12
	Secchi disk values (cm)										
20	90	37	S	S	S	S	S	S	S	S	S
21	100	58	26	S	S	S	S	S	S	S	S
22	100	79	48	21	S	S	S	S	S	S	S
23	100	100	58	37	16	S	S	S	S	S	S
24	100	100	74	53	32	16	S	S	S	S	S
25	100	100	90	63	42	26	S	S	S	S	S
26	100	100	95	74	53	37	21	S	S	S	S
27	100	100	100	79	63	48	32	21	S	S	S
28	100	100	100	90	69	55	42	32	21	S	S
29	100	100	100	95	79	63	50	40	29	18	S
30	100	100	100	100	85	69	58	48	37	26	16
31	100	100	100	100	90	74	63	53	42	34	24
32	100	100	100	100	93	79	69	61	50	40	32

TABLE 1-H. CRITICAL SECCHI DISK VALUES (CM) FOR 100-CM (3.28 FT) DEEP PONDS CONTAINING 4,000 LBS/ACRE OF CHANNEL CATFISH. A SMALLER SECCHI DISK VALUE FOR ANY COMBINATION OF TEMPERATURE AND DO CONCENTRATION AT DUSK WILL CAUSE DO TO FALL BELOW 2.0 PPM AT DAWN. DO CONCENTRATION WILL NOT DROP TO 2.0 PPM REGARDLESS OF SECCHI DISK VALUES FOR ENTRIES DESIGNATED SAFE (S)

	DO concentration at dusk (ppm)										
°C	2	3	4	5	6	7	8	9	10	11	12
	Secchi disk values (cm)										
20	100	48	16	S	S	S	S	S	S	S	S
21	100	69	37	S	S	S	S	S	S	S	S
22	100	90	53	26	S	S	S	S	S	S	S
23	100	100	69	42	21	S	S	S	S	S	S
24	100	100	79	58	37	18	S	S	S	S	S
25	100	100	90	69	48	32	16	S	S	S	S
26	100	100	100	79	58	42	26	S	S	S	S
27	100	100	100	85	69	53	37	24	S	S	S
28	100	100	100	95	74	58	48	38	24	S	S
29	100	100	100	100	85	69	53	42	32	21	S
30	100	100	100	100	90	74	63	50	40	29	18
31	100	100	100	100	95	79	69	58	48	37	26
32	100	100	100	100	98	85	74	63	53	45	34

TABLE 2-A. CRITICAL CHEMICAL OXYGEN DEMAND (COD) VALUES IN PPM FOR 100-CM (3.28 FT) DEEP PONDS CONTAINING 500 LBS/ACRE OF CHANNEL CATFISH. A LARGER COD VALUE FOR ANY COMBINATION OF TEMPERATURE AND DO CONCENTRATION AT DUSK WILL CAUSE DO TO FALL BELOW 2.0 PPM AT DAWN. DO CONCENTRATION WILL NOT DROP TO 2.0 PPM REGARDLESS OF COD VALUES FOR ENTRIES DESIGNATED SAFE (S)

	DO concentration at dusk (ppm)										
°C	2	3	4	5	6	7	8	9	10	11	12
	COD values (ppm)										
20	60	114	S	S	S	S	S	S	S	S	S
21	43	71	136	S	S	S	S	S	S	S	S
22	38	59	93	158	S	S	S	S	S	S	S
23	29	49	71	103	180	S	S	S	S	S	S
24	24	43	60	87	125	180	S	S	S	S	S
25	21	38	54	75	103	136	S	S	S	S	S
26	18	33	49	65	87	114	147	S	S	S	S
27	16	30	43	60	79	98	125	158	S	S	S
28	16	27	43	57	73	93	109	136	158	S	S
29	16	27	40	54	71	84	101	120	142	S	S
30	16	27	38	51	67	79	93	110	125	169	179
31	16	27	38	49	62	76	87	103	119	147	158
32	16	27	38	49	60	73	87	98	112	136	148

TABLE 2-B. CRITICAL CHEMICAL OXYGEN DEMAND (COD) VALUES IN PPM FOR 100-CM (3.28 FT) DEEP PONDS CONTAINING 1,000 LBS/ACRE OF CHANNEL CATFISH. A LARGER COD VALUE FOR ANY COMBINATION OF TEMPERATURE AND DO CONCENTRATION AT DUSK WILL CAUSE DO TO FALL BELOW 2.0 PPM AT DAWN. DO CONCENTRATION WILL NOT DROP TO 2.0 PPM REGARDLESS OF COD VALUES FOR ENTRIES DESIGNATED SAFE (S)

	DO concentration at dusk (ppm)										
°C	2	3	4	5	6	7	8	9	10	11	12
	COD values (ppm)										
20	49	93	S	S	S	S	S	S	S	S	S
21	38	64	103	S	S	S	S	S	S	S	S
22	27	49	82	114	S	S	S	S	S	S	S
23	21	43	65	93	136	S	S	S	S	S	S
24	17	32	54	76	103	158	S	S	S	S	S
25	13	30	49	65	87	114	158	S	S	S	S
26	10	27	43	59	75	103	125	169	S	S	S
27	10	24	38	54	71	89	114	136	169	S	S
28	8	22	35	49	65	82	99	120	147	178	S
29	8	21	32	46	60	76	93	107	125	153	180
30	8	19	32	44	56	71	84	98	115	136	158
31	8	19	30	43	54	67	79	93	109	123	147
32	8	19	30	41	51	65	75	87	101	114	136

TABLE 2-C. CRITICAL CHEMICAL OXYGEN DEMAND (COD) VALUES IN PPM FOR 100-CM (3.28 FT) DEEP PONDS CONTAINING 1,500 LBS/ACRE OF CHANNEL CATFISH. A LARGER COD VALUE FOR ANY COMBINATION OF TEMPERATURE AND DO CONCENTRATION AT DUSK WILL CAUSE DO TO FALL BELOW 2.0 PPM AT DAWN. DO CONCENTRATION WILL NOT DROP TO 2.0 PPM REGARDLESS OF COD VALUES FOR ENTRIES DESIGNATED SAFE (S)

	DO concentration at dusk (ppm)										
°C	2	3	4	5	6	7	8	9	10	11	12
	COD values (ppm)										
20	38	75	S	S	S	S	S	S	S	S	S
21	32	60	93	S	S	S	S	S	S	S	S
22	17	43	71	103	S	S	S	S	S	S	S
23	16	38	54	82	114	S	S	S	S	S	S
24	11	29	49	71	93	136	S	S	S	S	S
25	9	24	38	59	82	103	147	S	S	S	S
26	8	21	35	54	71	93	114	158	S	S	S
27	7	18	32	49	63	82	103	125	158	S	S
28	5	16	29	43	57	73	93	109	131	158	S
29	5	16	27	40	54	68	84	98	114	136	169
30	5	14	27	38	49	62	76	93	106	125	147
31	5	13	24	35	47	59	71	84	98	114	136
32	5	13	24	35	46	57	68	79	93	107	125

TABLE 2-D. CRITICAL CHEMICAL OXYGEN DEMAND (COD) VALUES IN PPM FOR 100-CM (3.28 FT) DEEP PONDS CONTAINING 2,000 LBS/ACRE OF CHANNEL CATFISH. A LARGER COD VALUE FOR ANY COMBINATION OF TEMPERATURE AND DO CONCENTRATION AT DUSK WILL CAUSE DO TO FALL BELOW 2.0 PPM AT DAWN. DO CONCENTRATION WILL NOT DROP TO 2.0 PPM REGARDLESS OF COD VALUES FOR ENTRIES DESIGNATED SAFE (S)

	DO concentration at dusk (ppm)										
°C	2	3	4	5	6	7	8	9	10	11	12
	COD values (ppm)										
20	38	71	136	S	S	S	S	S	S	S	S
21	27	49	81	136	S	S	S	S	S	S	S
22	16	38	60	93	158	S	S	S	S	S	S
23	12	32	49	76	103	180	S	S	S	S	S
24	8	23	43	60	87	114	180	S	S	S	S
25	5	21	36	53	74	98	125	180	S	S	S
26	5	16	32	49	65	82	109	136	179	S	S
27	5	14	27	43	57	74	93	114	140	180	S
28	5	10	24	38	52	65	82	103	120	147	S
29	5	10	21	35	49	60	76	93	109	131	158
30	5	10	21	32	43	57	71	82	98	114	136
31	5	10	20	30	43	54	65	78	93	106	125
32	5	10	19	30	41	51	62	73	87	98	114

TABLE 2-E. CRITICAL CHEMICAL OXYGEN DEMAND (COD) VALUES IN PPM FOR 100-CM (3.28 FT) DEEP PONDS CONTAINING 2,500 LBS/ACRE OF CHANNEL CATFISH. A LARGER COD VALUE FOR ANY COMBINATION OF TEMPERATURE AND DO CONCENTRATION AT DUSK WILL CAUSE DO TO FALL BELOW 2.0 PPM AT DAWN. DO CONCENTRATION WILL NOT DROP TO 2.0 PPM REGARDLESS OF COD VALUES FOR ENTRIES DESIGNATED SAFE (S)

	DO concentration at dusk (ppm)										
°C	2	3	4	5	6	7	8	9	10	11	12
	COD values (ppm)										
20	32	60	114	S	S	S	S	S	S	S	S
21	21	43	71	136	S	S	S	S	S	S	S
22	14	33	57	87	136	S	S	S	S	S	S
23	8	27	43	71	103	158	S	S	S	S	S
24	8	21	38	60	82	114	158	S	S	S	S
25	5	16	31	48	71	93	120	158	S	S	S
26	5	12	27	43	59	76	103	125	169	S	S
27	5	10	21	38	54	71	88	109	136	169	S
28	5	8	21	33	49	61	76	93	114	136	175
29	5	7	18	30	43	57	71	85	103	120	147
30	5	6	17	27	40	54	65	76	93	109	129
31	5	6	16	27	38	49	61	71	85	98	120
32	5	6	16	25	35	47	57	68	82	93	109

TABLE 2-F. CRITICAL CHEMICAL OXYGEN DEMAND (COD) VALUES IN PPM FOR 100-CM (3.28 FT) DEEP PONDS CONTAINING 3,000 LBS/ACRE OF CHANNEL CATFISH. A LARGER COD VALUE FOR ANY COMBINATION OF TEMPERATURE AND DO CONCENTRATION AT DUSK WILL CAUSE DO TO FALL BELOW 2.0 PPM AT DAWN. DO CONCENTRATION WILL NOT DROP TO 2.0 PPM REGARDLESS OF COD VALUES FOR ENTRIES DESIGNATED SAFE (S)

	DO concentration at dusk (ppm)										
°C	2	3	4	5	6	7	8	9	10	11	12
	COD values (ppm)										
20	27	54	93	S	S	S	S	S	S	S	S
21	16	38	71	114	S	S	S	S	S	S	S
22	10	25	49	82	125	S	S	S	S	S	S
23	5	21	43	65	93	136	S	S	S	S	S
24	5	16	33	52	76	103	147	S	S	S	S
25	5	12	27	43	63	82	114	158	S	S	S
26	5	10	21	38	54	71	93	120	158	S	S
27	5	8	19	33	49	64	82	103	125	158	S
28	5	5	16	30	43	60	73	89	109	131	158
29	5	5	16	27	40	54	65	82	96	114	136
30	5	5	13	24	35	49	60	73	87	103	120
31	5	5	10	21	32	45	56	67	82	93	111
32	5	5	10	21	32	43	54	62	75	87	103

TABLE 2-G. CRITICAL CHEMICAL OXYGEN DEMAND (COD) VALUES IN PPM FOR 100-CM (3.28 FT) DEEP PONDS CONTAINING 3,500 LBS/ACRE OF CHANNEL CATFISH. A LARGER COD VALUE FOR ANY COMBINATION OF TEMPERATURE AND DO CONCENTRATION AT DUSK WILL CAUSE DO TO FALL BELOW 2.0 PPM AT DAWN. DO CONCENTRATION WILL NOT DROP TO 2.0 PPM REGARDLESS OF COD VALUES FOR ENTRIES DESIGNATED SAFE (S)

	DO concentration at dusk (ppm)										
°C	2	3	4	5	6	7	8	9	10	11	12
	COD values (ppm)										
20	21	49	82	S	S	S	S	S	S	S	S
21	13	38	60	93	S	S	S	S	S	S	S
22	8	27	49	71	114	S	S	S	S	S	S
23	5	19	38	60	82	125	S	S	S	S	S
24	5	13	30	49	71	93	136	S	S	S	S
25	5	10	25	38	60	82	103	136	S	S	S
26	5	6	19	32	49	71	87	114	136	S	S
27	5	5	16	30	43	60	76	93	114	147	S
28	5	5	13	27	38	54	71	82	103	125	147
29	5	5	10	21	35	49	60	76	93	109	131
30	5	5	10	21	32	43	57	68	82	100	114
31	5	5	8	19	30	41	51	62	76	87	103
32	5	5	8	19	27	38	49	60	71	82	100

TABLE 2-H. CRITICAL CHEMICAL OXYGEN DEMAND (COD) VALUES IN PPM FOR 100-CM (3.28 FT) DEEP PONDS CONTAINING 4,000 LBS/ACRE OF CHANNEL CATFISH. A LARGER COD VALUE FOR ANY COMBINATION OF TEMPERATURE AND DO CONCENTRATION AT DUSK WILL CAUSE DO TO FALL BELOW 2.0 PPM AT DAWN. DO CONCENTRATION WILL NOT DROP TO 2.0 PPM REGARDLESS OF COD VALUES FOR ENTRIES DESIGNATED SAFE (S)

	DO concentration at dusk (ppm)										
°C	2	3	4	5	6	7	8	9	10	11	12
	COD values (ppm)										
20	16	43	82	S	S	S	S	S	S	S	S
21	10	32	54	93	S	S	S	S	S	S	S
22	5	21	43	71	103	S	S	S	S	S	S
23	5	16	32	54	82	114	S	S	S	S	S
24	5	10	27	43	65	87	125	S	S	S	S
25	5	6	21	38	54	76	98	125	175	S	S
26	5	5	16	30	46	65	82	103	131	169	S
27	5	5	10	27	38	54	71	87	109	136	175
28	5	5	10	21	35	49	65	79	93	114	142
29	5	5	8	19	32	43	57	71	87	103	125
30	5	5	6	16	27	41	51	65	76	93	109
31	5	5	6	16	27	38	49	60	71	84	98
32	5	5	5	13	24	35	43	54	65	76	93

APPENDIX II

A Partial List of Suppliers

Dissolved Oxygen Meters: VWR Scientific Company, P. O. Box 20158, Atlanta, Ga. 30325, (404) 351-3872; Arthur H. Thomas Company, Vine Street at 3rd, Philadelphia, Pa. 19106, (215) 574-4555; Fisher Scientific Company, 711 Forbes Avenue, Pittsburgh, Pa. 15219; Cole-Parmer Instrument Company, 7425 North Oak Park Avenue, Chicago, IL. 60648, (312) 647-0272; The Garcia Corporation, Teaneck, New Jersey 07666

Dissolved Oxygen Kits and Thermometers: Fisher Scientific Company, 711 Forbes Avenue, Pittsburg, Pa. 15219; Cole-Parmer Instrument Company, 7425 North Oak Park Avenue, Chicago, Illinois 60648, (312) 647-0272; Hach Chemical Company, P. O. Box 907, Ames, Iowa 50010, (515) 232-2533; McCrarys's Farm Supply, 114 Park Street, Lonoke, Arkansas 72086, (501) 676-2766; Ecologic Instrument, 132 Wilbur Place, Bohemia, N.Y. 11716, (516) 567-9000

Secchi Disk: Wildco Instruments, 301 Cass Street, Saginaw, Michigan 48602, (517) 799-8100

APPENDIX III

Computer Program for Solving the Nighttime Predictive DO Equation Including a Sample of Computer Output

To calculate nighttime DO levels using COD values to estimate oxygen consumption by the plankton community, substitute the following cards in the computer program:

```
INITIAL SECTION

    PARAMETER COD=
for PARAMETER SDISK=

DYNAMIC SECTION

    DOPL = (-1.005719 - .0014827 * COD - .0000125 * COD *
           COD + .0765502 * T - .0014427 * T * T
           + .0002527 * COD * T)/60.0

for DOPL = (-1.133331 + .0038082 * SDISK + .0000145 *
           SDISK * SDISK + .0812387 * T - .0007486 *
           T * T - .0003490 * SDISK * T)/60.0
```

```
$$$CONTINUOUS SYSTEM MODELING PROGRAM  III   V1M3   TRANSLATOR OUTPUT$$$

* SIMULATION PROGRAM FOR PREDICTING NIGHTTIME DISSOLVED OXYGEN (DO)
* LEVELS IN CHANNEL CATFISH PONDS.  THIS COMPUTER PROGRAM IS MODIFIED
* AFTER A COMPUTER ALGORITHM DEVELOPED BY DR. CHARLES BUSCH, DEPT.
* OF AGRICULTURAL ENGINEERING, AUBURN UNIVERSITY,AUBURN AL 36830

INITIAL


* WT - CHARTS CHANNEL CATFISH GROWTH FROM 7.7 GRAMS (G) AT DAY 69
*      OF THE YEAR TO 440.4 G ON DAY 320
FUNCTION WT = (69,7.7),(164,55.8),(192,91.3),(224,177.5),...
              (263,315.5),(320,440.4)

* DEGR - CHARTS WATER TEMPERATURE (°C) ON SEVERAL DATES DURING
*        THE GROWING SEASON
FUNCTION DEGR = (179,30.),(179.46,27.8),...
                (187,32.3),(187.46,28.),...
                (240,30.6),(240.46,27.2)

* DIFFUSE - GAIN OR LOSS OF DISSOLVED OXYGEN (DO) TO
*           DIFFUSION  - MG/L/HOUR
FUNCTION DIFFUS = (0,.212),(25,.177),(50,.129),(75,.079),...
                  (100,.025),(125,-.040),(150,-.098),...
                  (175,-.146),(200,-.181),(225,-.209),...
                  (250,-.225)

* DOBTH - LOSS OF DO TO MUD RESPIRATION, MG/L/MIN
PARAMETER DOBTH = 0.000694

* RISE - SELECTS TIME SUNRISE OCCURS
FUNCTION RISE = (186,5.0),(188,6.0)

* SET - SELECTS TIME SUNSET OCCURS
FUNCTION SET = (186,19.0),(188,19.0)


* FISHNO - NUMBER OF FISH IN THE POND; PONVOL - POND VOLUME IN LITERS
PARAMETER FISHNO=3000., PONVOL=3912000.

* TIME - STARTING TIME FOR SIMULATION = DUSK
INCON TIME=0.0000

* DAYRUN - SELECTS DAY OF THE YEAR BEING ANALYZED; JULY 6
*          IS USED IN THIS EXAMPLE
PARAMETER DAYRUN = 187

* SDISK - SECCHI DISK VISIBILITY (CM)
PARAMETER SDISK = 32.0

*ICDOX - MEASURED DO CONCENTRATION AT DUSK, MG/L
INCON ICDOX = 8.2

* TEMP - MEASURED WATER TEMPERATURE AT DUSK (°C)
PARAMETER TEMP= 32.3

* MEAS - RECORD OF MEASURED DO VALUES TO COMPARE WITH CALCULATED VALUES
FUNCTION MEAS = (187,8.2),(187.23,4.4),(187.46,2.3)
```

```
DYNAMIC

DAY = DAYRUN + TIME

HOUR = TIME*24.

* SRISE - TIME SUNRISE WILL OCCUR
SRISE=AFGEN(RISE,DAYRUN)

*SSET - TIME SUNSET WILL OCCUR
SSET=AFGEN(SET,DAYRUN)

NIGHT = (24.-(SSET-SRISE))/24.

* T - WATER TEMPERATURE (°C)
T =AFGEN(DEGR,DAY)

* DOSAT - SATURATION OXYGEN LEVEL FOR STANDARD PRESSURE, MG/L
DOSAT = 14.652 - .41022*TEMP + .007991*TEMP*TEMP...
- .000078*TEMP*TEMP*TEMP

* SATCON - SATURATED OXYGEN LEVEL CORRECTED FOR ELEVATION, MG/L
 SATCON = (DOSAT)*(0.973)

* PERSAT - PERCENT OXYGEN SATURATION OF POND WATER
PERSAT = (ICDOX/SATCON)*100.0

* DODIFF - RATE OF GAIN OR LOSS OF DO TO DIFFUSION, MG/L/MIN
DODIFF = NLFGEN(DIFFUS,PERSAT)/60.0

* UNITWT - AVERAGE WEIGHT OF FISH IN GRAMS
UNITWT = NLFGEN(WT,DAY)

* LOGFOX - LOG10 RESPIRATION VALUES FOR CHANNEL CATFISH AS A
*          FUNCTION OF WEIGHT AND TEMPERATURE, LOG10 MG/G/HOUR
LOGFOX=-.999099-.0009572*UNITWT+.0000006*UNITWT*UNITWT...
       +.0327044*T-.0000087*T*T+.0000003*UNITWT*T

* FISHOX - DO CONSUMED BY FISH, MG/G/MIN
FISHOX=(10.**(LOGFOX))/60.

*FISHWT - TOTAL WEIGHT OF FISH IN POND, GM.
FISHWT = UNITWT*FISHNO

* DOFISH - COMBINDED SOLID WASTE BOD AND FISHOX, MG/L/MIN
DOFISH = (.00143 + FISHOX)*FISHWT/PONVOL


* DOPL - OXYGEN CONSUMED BY THE PLANKTONIC COMMUNITY, MG/L/MIN
DOPL=(-1.133331+.0038082*SDISK+.0000145*SDISK*SDISK+.0812387*T...
      -.0007486*T*T-.0003490*SDISK*T)/60.0

* DODT - DO CHANGE, MG/L/24 HR
DODT = (DODIFF-DOFISH-DOPL-DOBTH)*1440.

* DOCALC - CALCULATED DO CONCENTRATION AT TIME 'T'
DOCALC=INTGRL(ICDOX,DODT)
```

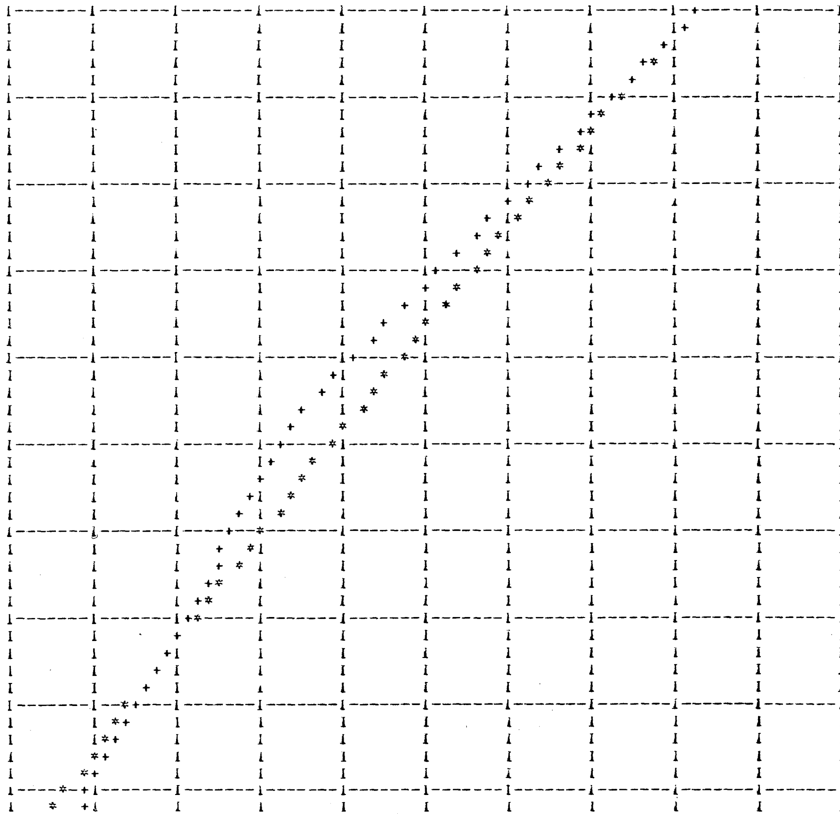
```
DIFFDO=DODIFF*1440.

FISHDO=DOFISH*1440.

PLDO=DOPL*1440.

BBOD=DOBTH*1440.

* DIFFO - CUMULATIVE O2 GAIN OR LOSS TO DIFFUSION, MG/L
DIFFO=INTGRL(0.0,DIFFDO)

* BTHO - CUMULATIVE O2 CONSUMED BY ORGANISMS IN THE MUD, MG/L
BTHO=INTGRL(0.0,BBOD)

* PLANO - CUMULATIVE O2 CONSUMED BY THE PLANKTONIC COMMUNITY, MG/L
PLANO=INTGRL(0.0,PLDO)

* FISHO - CUMULATIVE O2 CONSUMED BY THE FISH POPULATION, MG/L
FISHO=INTGRL(0.0,FISHDO)

* DOMEAS - MEASURED DO VALUES FOR COMPARISON WITH PREDICTED DO
DOMEAS = AFGEN(MEAS,DAY)


TERMINAL


TIMER DELT=.01,  FINTIM=0.6, PRDEL=0.01, OUTDEL=0.01
FINISH TIME = NIGHT
METHOD SIMP
PRINT DOMEAS, DOCALC, DIFFO, BTHO, PLANO, FISHO, T
OUTPUT DOCALC, DOMEAS
LABEL CALCULATED DO VS MEASURED DO
LABEL DATE: JULY 6, 1977
LABEL        3000 CHANNEL CATFISH/ACRE
PAGE NPLOT=2, SYMBOL=(*,+), GROUP=2
END
STOP

OUTPUT VARIABLE SEQUENCE
DOSAT  SATCON PERSAT DODIFF DAY    UNITWT T      LOGFOX FISHOX FISHWT
DOFISH DOPL   DODT   DOCALC DIFFDO DIFFO  BBOD   BTHO   PLDO   PLANO
FISHDO FISHO  HOUR   SSET   SRISE  NIGHT  DOMEAS
```

CSMP III VERSION V1M3 SIMULATION OUTPUT

TIME	DOMEAS	DOCALC	DIFFO	BTHO	PLANO	FISHO	T
0.0	8.2000	8.2000	0.0	0.0	0.0	0.0	32.300
1.0000000D-02	8.0347	8.0525	-5.30622E-03	9.99359E-03	0.11631	1.58395E-02	32.207
2.0000000D-02	7.8696	7.9057	-1.06124E-02	1.99872E-02	0.23214	3.15809E-02	32.113
3.0000000D-02	7.7043	7.7594	-1.59187E-02	2.99808E-02	0.34747	4.72251E-02	32.020
4.0000000D-02	7.5391	7.6137	-2.12249E-02	3.99744E-02	0.46230	6.27727E-02	31.926
5.0000000D-02	7.3740	7.4686	-2.65311E-02	4.99680E-02	0.57663	7.82244E-02	31.833
6.0000000D-02	7.2085	7.3242	-3.18373E-02	5.99615E-02	0.69046	9.35807E-02	31.739
7.0000000D-02	7.0435	7.1803	-3.71435E-02	6.99551E-02	0.80379	0.10884	31.646
8.0000000D-02	6.8784	7.0370	-4.24497E-02	7.99487E-02	0.91661	0.12401	31.552
9.0000000D-02	6.7129	6.8943	-4.77560E-02	8.99422E-02	1.0289	0.13908	31.459
1.0000000D-01	6.5479	6.7522	-5.30622E-02	9.99358E-02	1.1407	0.15407	31.365
0.110000	6.3828	6.6108	-5.83684E-02	0.10993	1.2520	0.16895	31.272
0.120000	6.2173	6.4699	-6.36746E-02	0.11992	1.3627	0.18375	31.178
0.130000	6.0522	6.3297	-6.89808E-02	0.12992	1.4729	0.19846	31.085
0.140000	5.8867	6.1901	-7.42869E-02	0.13991	1.5826	0.21308	30.991
0.150000	5.7217	6.0511	-7.95931E-02	0.14990	1.6918	0.22760	30.898
0.160000	5.5566	5.9127	-8.48993E-02	0.15990	1.8004	0.24204	30.804
0.170000	5.3911	5.7750	-9.02055E-02	0.16989	1.9085	0.25639	30.711
0.180000	5.2261	5.6379	-9.55117E-02	0.17988	2.0161	0.27065	30.617
0.190000	5.0610	5.5014	-0.10082	0.18988	2.1231	0.28482	30.524
0.200000	4.8955	5.3655	-0.10612	0.19987	2.2295	0.29891	30.430
0.210000	4.7305	5.2303	-0.11143	0.20986	2.3355	0.31291	30.337
0.220000	4.5652	5.0957	-0.11674	0.21986	2.4408	0.32683	30.244
0.230000	4.3999	4.9618	-0.12204	0.22985	2.5456	0.34066	30.150
0.240000	4.3086	4.8285	-0.12735	0.23985	2.6499	0.35441	30.057
0.250000	4.2173	4.6959	-0.13265	0.24984	2.7535	0.36807	29.963
0.260000	4.1257	4.5639	-0.13796	0.25983	2.8567	0.38165	29.870
0.270000	4.0347	4.4325	-0.14327	0.26983	2.9592	0.39514	29.776
0.280000	3.9431	4.3019	-0.14857	0.27982	3.0612	0.40856	29.683
0.290000	3.8521	4.1718	-0.15388	0.28981	3.1626	0.42189	29.589
0.300000	3.7607	4.0424	-0.15919	0.29981	3.2634	0.43514	29.496
0.310000	3.6692	3.9137	-0.16449	0.30980	3.3636	0.44831	29.402
0.320000	3.5781	3.7857	-0.16980	0.31979	3.4633	0.46140	29.309
0.330000	3.4868	3.6583	-0.17510	0.32979	3.5624	0.47442	29.215
0.340000	3.3955	3.5316	-0.18041	0.33978	3.6608	0.48735	29.122
0.350000	3.3042	3.4056	-0.18572	0.34977	3.7587	0.50020	29.028
0.360000	3.2129	3.2802	-0.19102	0.35977	3.8560	0.51298	28.935
0.370000	3.1216	3.1555	-0.19633	0.36976	3.9527	0.52568	28.841
0.380000	3.0303	3.0315	-0.20164	0.37976	4.0488	0.53830	28.748
0.390000	2.9390	2.9082	-0.20694	0.38975	4.1443	0.55085	28.654
0.400000	2.8477	2.7855	-0.21225	0.39974	4.2391	0.56332	28.561
0.410000	2.7563	2.6636	-0.21755	0.40974	4.3334	0.57571	28.468
0.420000	2.6650	2.5423	-0.22286	0.41973	4.4270	0.58804	28.374
0.430000	2.5737	2.4217	-0.22817	0.42972	4.5200	0.60028	28.281
0.440000	2.4824	2.3019	-0.23347	0.43972	4.6124	0.61245	28.187
0.450000	2.3911	2.1827	-0.23878	0.44971	4.7042	0.62455	28.094
0.460000	2.2998	2.0642	-0.24408	0.45970	4.7954	0.63658	28.000

CALCULATED DO VS MEASURED DO
DATE: JULY 6, 1977
3000 CHANNEL CATFISH/ACRE

1.600 '+'=DOMEAS 9.600
1.600 '*'=DOCALC 9.600



TIME	DOCALC	DOMEAS
0.0	8.2000	8.2000
1.00000E-02	8.0525	8.0347
2.00000E-02	7.9057	7.8696
3.00000E-02	7.7594	7.7043
4.00000E-02	7.6137	7.5391
5.00000E-02	7.4686	7.3740
6.00000E-02	7.3242	7.2085
7.00000E-02	7.1803	7.0435
8.00000E-02	7.0370	6.8784
9.00000E-02	6.8943	6.7129
0.10000	6.7522	6.5479
0.11000	6.6108	6.3828
0.12000	6.4699	6.2173
0.13000	6.3297	6.0522
0.14000	6.1901	5.8867
0.15000	6.0511	5.7217
0.16000	5.9127	5.5566
0.17000	5.7750	5.3911
0.18000	5.6379	5.2261
0.19000	5.5014	5.0610
0.20000	5.3655	4.8955
0.21000	5.2303	4.7305
0.22000	5.0957	4.5652
0.23000	4.9618	4.3999
0.24000	4.8285	4.3086
0.25000	4.6959	4.2173
0.26000	4.5639	4.1257
0.27000	4.4325	4.0347
0.28000	4.3019	3.9431
0.29000	4.1718	3.8521
0.30000	4.0424	3.7607
0.31000	3.9137	3.6692
0.32000	3.7857	3.5781
0.33000	3.6583	3.4868
0.34000	3.5316	3.3955
0.35000	3.4056	3.3042
0.36000	3.2802	3.2129
0.37000	3.1555	3.1216
0.38000	3.0315	3.0303
0.39000	2.9082	2.9390
0.40000	2.7855	2.8477
0.41000	2.6636	2.7563
0.42000	2.5423	2.6650
0.43000	2.4217	2.5737
0.44000	2.3019	2.4824
0.45000	2.1827	2.3911
0.46000	2.0642	2.2998

APPENDIX IV

Computer Program for Calculating Critical Secchi Disk Values Including a Sample of Computer Output

To calculate critical COD values the following card substitutions must be made in the computer program:

```
INITIAL SECTION

     INCON MAXCOD = 180.0, MINCOD = 5.0, COD = 92.5
for  INCON MIDISK =   5.0, MXDISK = 175.0, SDISK = 90.0

DYNAMIC SECTION

     DOPL = (-1.005719-.0014827*COD-.0000125*COD*COD
            + .0765502*T-.0014427*T*T+.0002527*COD*
            T)/60.0
for  DOPL = (-1.133331+.0038082*SDISK+.0000145*SDISK*
            SDISK+.0812387*T-.0007486*T*T
            -.0003490*SDISK*T)/60.0

TERMINAL SECTION

     MINCOD = COD
for  MXDISK = SDISK

     COD = (MAXCOD + COD)/2.0
for  SDISK = (MIDISK + SDISK)/2.0

     MAXCOD = COD
for  MIDISK = SDISK

     COD = (MINCOD + COD)/2.0
for  SDISK = (MXDISK + SDISK)/2.0

     WRITE (6,4) ICDOX, T, DOCALC, UNITWT, COD
for  WRITE (6,4) ICDOX, T, DOCALC, UNITWT, SDISK

     3X, 'UNITWT =', F 6.1, /,5X, 'COD =' F 6.2)
for  3X, 'UNITWT =', F 6.1, /,5X, 'SDISK =', F 6.2)

     2 MAXCOD = 180.0
for  2 MIDISK =   5.0

     MINCOD = 5.0
for  MXDISK = 175.0

     COD = (MAXCOD + MINCOD)/2.0
for  SDISK = (MXDISK + MIDISK)/2.0
```

```
$$$CONTINUOUS SYSTEM MODELING PROGRAM  III   V1M3   TRANSLATOR OUTPUT$$$

* SIMULATION MODEL FOR CALCULATING CRITICAL SECCHI DISK
* VISIBILITIES (CM) FOR 100-CM (3.28 FT) DEEP PONDS CONTAINING
* 3000 CHANNEL CATFISH PER ACRE.  CRITICAL VALUES WILL BE
* GENERATED FOR 500-4000 LBS/ACRE IN 500 LBS/ACRE INCREMENTS.

INITIAL

* DIFFUSE - GAIN OR LOSS OF DISSOLVED OXYGEN (DO) TO
*           DIFFUSION  - MG/L/HOUR
FUNCTION DIFFUS = (0,.212),(25,.177),(50,.129),(75,.079),...
                  (100,.025),(125,-.040),(150,-.098),...
                  (175,-.146),(200,-.181),(225,-.209),...
                  (250,-.225)

* T - WATER TEMPERATURE AT DUSK(°C); ICDOX - DO AT DUSK, MG/L
INCON T=20.0, ICDOX=2.0

* MXDISK, MIDISK, SDISK - MAXIMUM, MINIMUM, AND AVERAGE SECCHI
*                         DISK VISIBILITY (CM) - THESE VALUES
*                         SHOULD NOT BE CHANGED
INCON MIDISK = 5.0, MXDISK = 175.0, SDISK = 90.0

* DOBTH - LOSS OF DO TO MUD RESPIRATION, MG/L/MIN
PARAMETER DOBTH = 0.000694

* UNITWT - INDIVIDUAL FISH WEIGHT, GM
PARAMETER UNITWT = 75.67

* FISHNO - NUMBER OF FISH/ACRE; PONVOL - POND VOLUME IN LITERS
PARAMETER FISHNO=3000., PONVOL=3912000.

* TIME - STARTING TIME FOR SIMULATION = DUSK
INCON TIME=0.0000

DYNAMIC

* DOSAT - SATURATION OXYGEN LEVEL FOR STANDARD PRESSURE, MG/L
* DOSAT - SATURATION OXYGEN LEVEL FOR STANDARD PRESSURE, MG/L
DOSAT = 14.652 - .41022*T + .007991*T*T - .000078*T*T*T

* SATCON - SATURATED OXYGEN LEVEL CORRECTED FOR ELEVATION, MG/L
 SATCON = (DOSAT)*(0.973)

* PERSAT - PERCENT OXYGEN SATURATION OF POND WATER
PERSAT = (ICDOX/SATCON)*100.0

* DODIFF - RATE OF GAIN OR LOSS OF DO TO DIFFUSION, MG/L/MIN
DODIFF = NLFGEN(DIFFUS,PERSAT)/60.0

* LOGFOX - LOG10 RESPIRATION VALUES FOR CHANNEL CATFISH AS A
*          FUNCTION OF WEIGHT AND TEMPERATURE, LOG10 MG/G/HOUR
LOGFOX=-.999099-.0009572*UNITWT+.0000006*UNITWT*UNITWT...
       +.0327044*T-.0000087*T*T+.0000003*UNITWT*T
* FISHOX - DO CONSUMED BY FISH, MG/G/MIN
FISHOX=(10.**(LOGFOX))/60.

*FISHWT - TOTAL WEIGHT OF FISH IN POND, GM.
```

```
FISHWT = UNITWT*FISHNO

* DOFISH - COMBINDED SOLID WASTE BOD AND FISHOX, MG/L/MIN
DOFISH = (.00143 + FISHOX)*FISHWT/PONVOL

* DOPL - OXYGEN CONSUMED BY THE PLANKTONIC COMMUNITY, MG/L/MIN
DOPL=(-1.133331+.0038082*SDISK+.0000145*SDISK*SDISK+.0812387*T...
     -.0007486*T*T-.0003490*SDISK*T)/60.0

DODT = (DODIFF-DOFISH-DOPL-DOBTH)*1440.

* DOCALC - CALCULATED DO CONCENTRATION AT DAWN
DOCALC=INTGRL(ICDOX,DODT)

DIFFDO=DODIFF*1440.
FISHDO=DOFISH*1440.
PLDO=DOPL*1440.
BBOD=DOBTH*1440.

DIFFU=INTGRL(0.0,DIFFDO)
FISHU=INTGRL(0.0,FISHDO)
PLANU=INTGRL(0.0,PLDO)
BTHU=INTGRL(0.0,BBOD)

TERMINAL

* FINTIM - FINISHING TIME FOR SIMULATION = DAWN
TIMER DELT=.01, FINTIM=0.46
METHOD SIMP

* ALGORITHM FOR GENERATING CRITICAL SECCHI DISK VALUES

      IF (ABS(DOCALC-2.0) .LT. 0.1) GO TO 9
      NUMRUN = NUMRUN + 1
      IF(NUMRUN .LE. 10) GO TO 3
      NUMRUN = 0
      WRITE(6,99)
   99 FORMAT('0',5X,'CONVERGENCE CRITERIA NOT MET')
      CALL DEBUG (24, 0.00)
      GO TO 2
    3 CONTINUE
      IF(DOCALC .LT. 2.0) GO TO 5
      MXDISK=SDISK
      SDISK = (MIDISK+SDISK)/2.0
      GO TO 8
    5 CONTINUE
      MIDISK=SDISK
      SDISK = (MXDISK+SDISK)/2.0
    8 CONTINUE
      CALL RERUN
      GO TO 40
    9 CONTINUE
      WRITE(6,4)ICDOX, T, DOCALC, UNITWT, SDISK
    4 FORMAT(5X,'ICDOX =',F4.1,3X,'T =',F5.1,3X,'DOCALC =',F6.3,...
      3X,'UNITWT =',F6.1,/,5X,'SDISK =',F6.2)
    2 MIDISK = 5.0
      MXDISK = 175.0
      SDISK = (MXDISK+MIDISK)/2.0
      NUMRUN=0
```

```
      IF (T .GE. 32.) GO TO 10
      T=T + 1.0
      CALL RERUN
      GO TO 40
   10 CONTINUE
      T=20.0
      IF (ICDOX .GE. 14.0) GO TO 30
      ICDOX=ICDOX + 1.0
      CALL RERUN
      GO TO 40
   30 CONTINUE
      ICDOX=2.0
      IF (UNITWT .GE. 605.34) GO TO 40
      UNITWT=UNITWT + 75.67
      CALL RERUN
   40 CONTINUE

 END

OUTPUT VARIABLE SEQUENCE
DOSAT  SATCON PERSAT DODIFF LOGFOX FISHOX FISHWT DOFISH DOPL   DODT
DOCALC DIFFDO DIFFU  FISHDO FISHU  PLDO   PLANU  BBOD   BTHU   ZZ1009
NUMRUN NUMRUN MXDISK SDISK  MIDISK SDISK  MIDISK MXDISK SDISK  NUMRUN
T      T      ICDOX  ICDOX  UNITWT

 $$$ TRANSLATION TABLE CONTENTS $$$        CURRENT          MAXIMUM

   MACRO AND STATEMENT OUTPUTS            41                 600
   STATEMENT INPUT WORK AREA              72                1900
   INTEGRATORS+MEMORY BLOCK OUTPUTS        5 +  0            300
   PARAMETERS+FUNCTION GENERATORS         12 +  1            400
   STORAGE VARIABLES+INTEGRATOR ARRAYS     0 +  0/2           50
   HISTORY AND MEMORY BLOCK NAMES         21                  50
   MACRO DEFINITIONS AND NESTED MACROS     6                  50
   MACRO STATEMENT STORAGE                13                 125
   LITERAL CONSTANT STORAGE                0                 100
   SORT SECTIONS                           1                  20
   MAXIMUM STATEMENTS IN SECTION          21                 600



$$$END OF TRANSLATOR OUTPUT$$$
```

```
$$$ CONTINUOUS SYSTEM MODELING PROGRAM III   V1M3    EXECUTION OUTPUT $$$

 FUNCTION DIFFUS = (0,.212),(25,.177),(50,.129),(75,.079),...
                   (100,.025),(125,-.040),(150,-.098),...
                   (175,-.146),(200,-.181),(225,-.209),...
                   (250,-.225)
 INCON T=20.0, ICDOX=2.0
 INCON MIDISK = 5.0, MXDISK = 175.0, SDISK = 90.0
 PARAMETER DOBTH = 0.000694
 PARAMETER UNITWT = 75.67
 PARAMETER FISHNO=3000., PONVOL=3912000.
 INCON TIME=0.0000
 TIMER DELT=.01, FINTIM=0.46
 METHOD SIMP
 END

TIMER VARIABLES      SIMP    INTEGRATION       START TIME  = 0.0
   DELT          DELMIN       FINTIM        PRDEL         OUTDEL         DELMAX
 1.00000D-02 4.60000D-08 0.46000      0.0           0.0           0.46000
$$$ SIMULATION HALTED FOR FINISH CONDITION  TIME    0.46000
$$$ SIMULATION HALTED FOR FINISH CONDITION  TIME    0.46000
$$$ SIMULATION HALTED FOR FINISH CONDITION  TIME    0.46000
    ICDOX = 2.0   T = 20.0   DOCALC = 1.923   UNITWT =  75.7
    SDISK = 26.25
$$$ SIMULATION HALTED FOR FINISH CONDITION  TIME    0.46000
$$$ SIMULATION HALTED FOR FINISH CONDITION  TIME    0.46000
    ICDOX = 2.0   T = 21.0   DOCALC = 2.014   UNITWT =  75.7
    SDISK = 47.50
$$$ SIMULATION HALTED FOR FINISH CONDITION  TIME    0.46000
$$$ SIMULATION HALTED FOR FINISH CONDITION  TIME    0.46000
$$$ SIMULATION HALTED FOR FINISH CONDITION  TIME    0.46000
$$$ SIMULATION HALTED FOR FINISH CONDITION  TIME    0.46000
    ICDOX = 2.0   T = 22.0   DOCALC = 1.901   UNITWT =  75.7
    SDISK = 58.13
$$$ SIMULATION HALTED FOR FINISH CONDITION  TIME    0.46000
$$$ SIMULATION HALTED FOR FINISH CONDITION  TIME    0.46000
$$$ SIMULATION HALTED FOR FINISH CONDITION  TIME    0.46000
$$$ SIMULATION HALTED FOR FINISH CONDITION  TIME    0.46000
    ICDOX = 2.0   T = 23.0   DOCALC = 2.092   UNITWT =  75.7
    SDISK = 79.38
$$$ SIMULATION HALTED FOR FINISH CONDITION  TIME    0.46000
$$$ SIMULATION HALTED FOR FINISH CONDITION  TIME    0.46000
$$$ SIMULATION HALTED FOR FINISH CONDITION  TIME    0.46000
$$$ SIMULATION HALTED FOR FINISH CONDITION  TIME    0.46000
$$$ SIMULATION HALTED FOR FINISH CONDITION  TIME    0.46000
    ICDOX = 2.0   T = 24.0   DOCALC = 1.985   UNITWT =  75.7
    SDISK = 84.69
$$$ SIMULATION HALTED FOR FINISH CONDITION  TIME    0.46000
    ICDOX = 2.0   T = 25.0   DOCALC = 1.925   UNITWT =  75.7
    SDISK = 90.00
$$$ SIMULATION HALTED FOR FINISH CONDITION  TIME    0.46000
$$$ SIMULATION HALTED FOR FINISH CONDITION  TIME    0.46000
$$$ SIMULATION HALTED FOR FINISH CONDITION  TIME    0.46000
$$$ SIMULATION HALTED FOR FINISH CONDITION  TIME    0.46000
    ICDOX = 2.0   T = 26.0   DOCALC = 2.053   UNITWT =  75.7
    SDISK =100.63
$$$ SIMULATION HALTED FOR FINISH CONDITION  TIME    0.46000
$$$ SIMULATION HALTED FOR FINISH CONDITION  TIME    0.46000
$$$ SIMULATION HALTED FOR FINISH CONDITION  TIME    0.46000
$$$ SIMULATION HALTED FOR FINISH CONDITION  TIME    0.46000
```