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ABSTRACT

This document is the appendix for a series of documents developed by the National Training and Operational Technology Center describing operational control procedures for the activated sludge process used in wastewater treatment. Categories discussed include: control test data, trend charts, moving averages, semi-logarithmic plots, probability plot examples, testing equipment and symbols and terminology. (CS)

EPA-430/9-74-001d

NATIONAL WASTE TREATMENT CENTER
CINCINNATI

OPERATIONAL CONTROL PROCEDURES for the ACTIVATED SLUDGE PROCESS

APPENDIX

MARCH 1974

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY
OFFICE OF WATER PROGRAM OPERATIONS

EQUIVALENTS USED FOR ACTIVATED SLUDGE CALCULATIONS

ft	x	0.3048	=	m
inches	x	2.540	=	cm
m	x	3.28083	=	ft
m	x	39.37	=	in
sq ft	x	0.0929	=	sq m
sq m	x	10.7639	=	sq ft
cu ft	x	28.3170	=	liter
cu ft	x	0.028317	=	cu m
cu ft	x	7.48052	=	gal
cu m	x	1000.0	=	liter
cu m	x	35.3145	=	cu ft
cu m	x	264.179	=	gal
gal	x	3.785	=	liter
gal	x	0.003785	=	cu m
liter	x	0.26417	=	gal
mgd	x	3785	=	cu m/day
cu m/day	x	0.000264	=	mgd
gpd/sq ft	x	0.0408	=	cu m/day/sq m
cu m/day/sq m	x	24.51	=	gpd/sq ft
lb	x	0.453592	=	kg
lb	x	453.592	=	g
kg	x	2.20462	=	lb
kg	x	1000.0	=	g
lbs/1000 cu ft	x	16.0	=	g/cu m
g/cu m	x	0.0625	=	lbs/1000 cu ft
cu ft (H_2O)	x	62.4	=	lb (H_2O)
gal (H_2O)	x	8.345	=	lb (H_2O)
liter (H_2O)	x	1.000	=	kg (H_2O)

lb/day = mgd x mg/l x 8.345

kg/day = cu m/day x mg/l /1000

lb = English SLU x (WCR*/1198)

kg = Metric SLU x (WCR/10)

English SLU = Metric SLU x 264.2

Metric SLU = English SLU x 0.003785

*WCR = sludge weight (mg/l)/centrifuged concentration (%)

NATIONAL WASTE TREATMENT CENTER - CINCINNATI

OPERATIONAL CONTROL PROCEDURES
FOR THE
ACTIVATED SLUDGE PROCESS

APPENDIX

by

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MARCH 1974
(Revised Nov.,1975)

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY

OFFICE OF WATER PROGRAM OPERATIONS

FOREWORD

The National Waste Treatment Center (Cincinnati) is developing a series of pamphlets describing Operational Control Procedures for the Activated Sludge Process. This series, describing the "NWTC Procedures", will include Part I OBSERVATIONS, Part II CONTROL TESTS, Part III CALCULATION PROCEDURES, Part IV SLUDGE QUALITY, Part V PROCESS CONTROL and an APPENDIX. Each of these individual parts will be released for distribution as soon as it is completed, though not necessarily in numerical order. The original five-part series may then be expanded to include case histories and refined process evaluation and control techniques.

This pamphlet has been developed as a reference for Activated Sludge Plant Control lectures I have presented at training sessions, symposia, and workshops. It is based on my personal conclusions reached while directing the operation of dozens of different activated sludge plants. This pamphlet is not necessarily an expression of Environmental Protection Agency policy or requirements.

The mention of trade names or commercial products in this pamphlet is for illustrative purposes and does not constitute endorsement or recommendation for use by the Environmental Protection Agency.

Alfred W. West

TABLE OF CONTENTS

CONTROL TEST DATA

DAY [illegible]

DATE [illegible]

MERRIMACK [illegible]

WASTEWATER TREATMENT PLANT

A C [illegible]

TIME	0400		1200		2000		24 HR AVG (TOTALIZER)	
FLOWS (MGD)	AFI	24	AFI	[illegible]	AFI	[illegible]	AFI	
	RSF	.4	RSF	[illegible]	RSF	.3	RSF	
	XSF	0.0144	XSF	0.0458?	XSF	0.0403?	XSF	
SST	SSV	SSC	SSV	SSC	SSV	SSC	SSV	SSC
SETTLOMETER 0	1000	[illegible]	1000	[illegible]	1000	[illegible]	1000	
5	820	[illegible]	900	[illegible]	[illegible]	[illegible]		
10	720	[illegible]	800	[illegible]	[illegible]	[illegible]		
15	620	742?	[illegible]	575	750	[illegible]		
20	580	793	[illegible]	[illegible]	[illegible]	[illegible]		
25	520	985	600	[illegible]				
30	450	1022	[illegible]	[illegible]				
40	400	[illegible]	450	[illegible]				
50	350	[illegible]	430	[illegible]				
60	320	[illegible]	395	[illegible]				
RISE TIME	[illegible]	HRS	[illegible]	HRS		HRS		
CENTRIFUGE (%)	ATC	[illegible]	ATC	[illegible]	ATC		ATC	
	RSC	[illegible]	RSC	[illegible]	RSC		RSC	
	XSC	[illegible]	XSC	[illegible]	XSC		XSC	
SLUDGE BLANKET DEPTH	DOB	[illegible]	DOB	[illegible]	DOB		DOB	
TURBIDIMETER (JTU)	INIT	[illegible]	INIT	[illegible]	INIT		INIT	
	1-HR	[illegible]	1-HR	[illegible]	1 HR		1-HR	
AERATION TANK DO	IN	-	IN	-	IN		IN	
	OUT	-	OUT	-	OUT		OUT	
pH	RAW	-	RAW	-	RAW		RAW	
	AT	7.3	AT	7.0	AT		AT	

MIDNIGHT TOTALIZER READING AFI [illegible] RSF 473456? XSF [illegible]

COMMENTS and SPECIAL DATA

1000 - 1100 HRS - "BLANK" WASTED @ 500 GPM FOR 1 HOUR

CONTROL TEST DATA

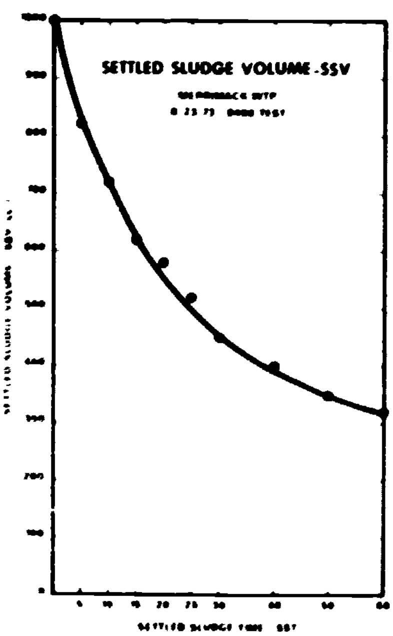
Data from the control tests described in Part II Control Tests should be recorded in an organized manner at each test period. A generalized data sheet suitable for this purpose is shown on the facing page.

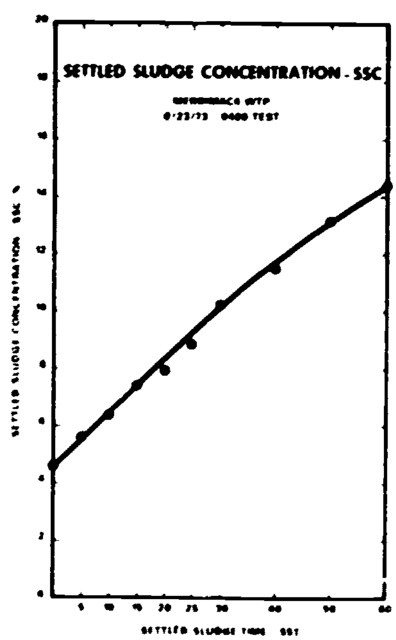
The test times shown near the top of the sheet will not be standard for each plant but will normally be determined by personnel shift changes and diurnal flow or load variation. At times additional centrifuge and depth of blanket tests may be desireable. These data may be recorded at the bottom of the sheet under comments and special data.

Except for the Settled Sludge Concentration (SSC) values, all numbers recorded on the data sheet are observed values. The SSC's are calculated as described in Part IIIA - Calculation Procedures.

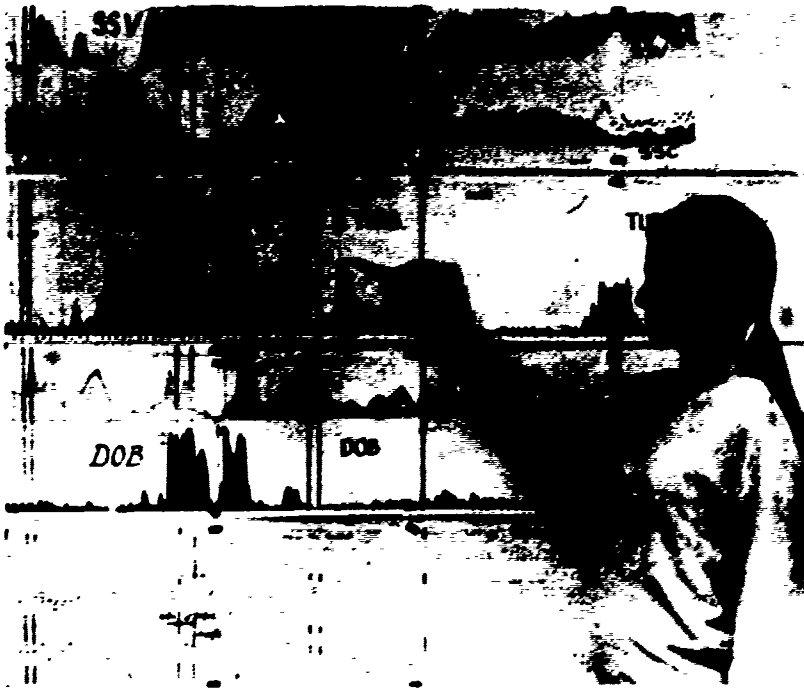
The two sketches below illustrate how the 0400 centrifuge and settlometer test data were used to develop Settled Sludge Volume (SSV) and Settled Sludge Concentration (SSC) curves to help analyze sludge quality.

A seperate column is provided on the data sheet for averaging the days' data. Flows recorded in this column should be totalizer values. These daily average values will be further used to calculate moving averages and additional process parameters.





TREND CHARTS



Data from individual daily tests and calculations should be graphically displayed on "Trend Charts" so that operators coming on duty can tell process status at a glance. At least once each day, and preferably during each shift, the data from the settlometer and centrifuge tests, the final effluent turbidity, the depth of blanket, and other selected parameters should be posted on the Trend Charts. These charts, usually kept on a wall in the laboratory area where the tests are performed, contain much of the data essential to the operation of an activated sludge plant. They provide graphic illustrations of process responses to selected operational controls.

Figures 1, 2 and 3 are copies of actual trend charts maintained by Waste Treatment Branch personnel at a recent technical assistance project. Final effluent turbidity and other selected process parameters are also tabulated on Figure 3. The heavy line through August 20 on these charts delineates a change in operating mode from two aerators and one clarifier to two aerators and two clarifiers.

The symbols, control tests and calculation procedures for determining the parameters illustrated on Figures 1, 2 and 3 have been explained in previous Parts of this series. For convenient referencing, all symbols used in this pamphlet series and their definitions are restated in alphabetical order on pages 23 through 27.

It should be kept in mind that trend charts such as these are really work sheets and are appropriate places for posting notes or data that might otherwise be recorded in a log book and then forgotten. For example, unusual occurrences that might affect plant performance, such as slugs of strong industrial wastes or toxic chemicals entering the plant, heavy rains, power failures, etc. can be noted directly on the trend charts. If this is done, reasons for sudden upsets or process imbalance can be easily identified.

When time permits, trend charts may be expanded to provide plant personnel with greater insights into the operation of their treatment plant. Certain information should be drawn on semi-log paper to help determine relationships between various process parameters, and the moving averages developed to damp out any large day-to-day variations that occur.

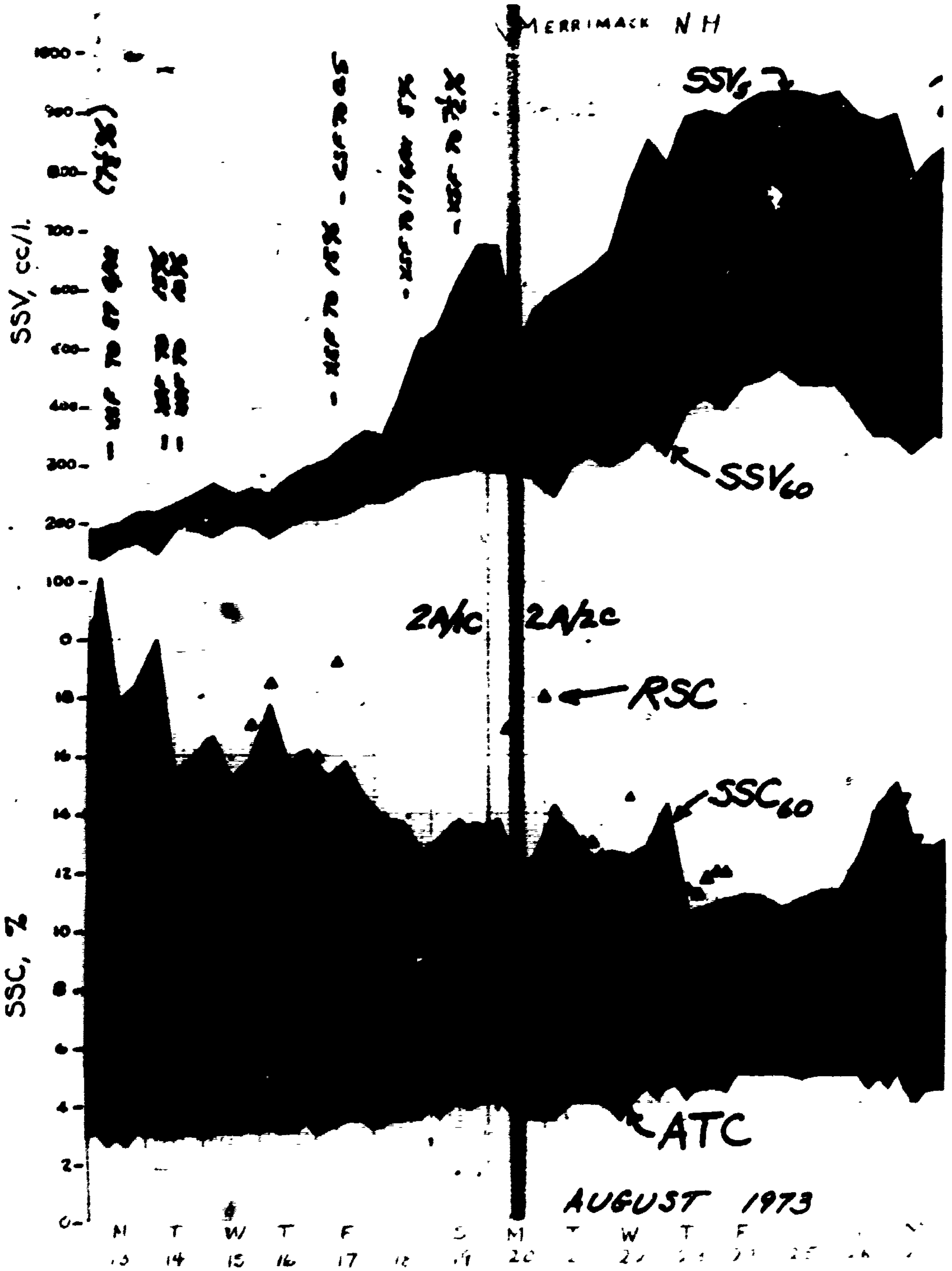


Figure 1

TYPICAL TREND CHART SHOWING SSV & SSC CURVES

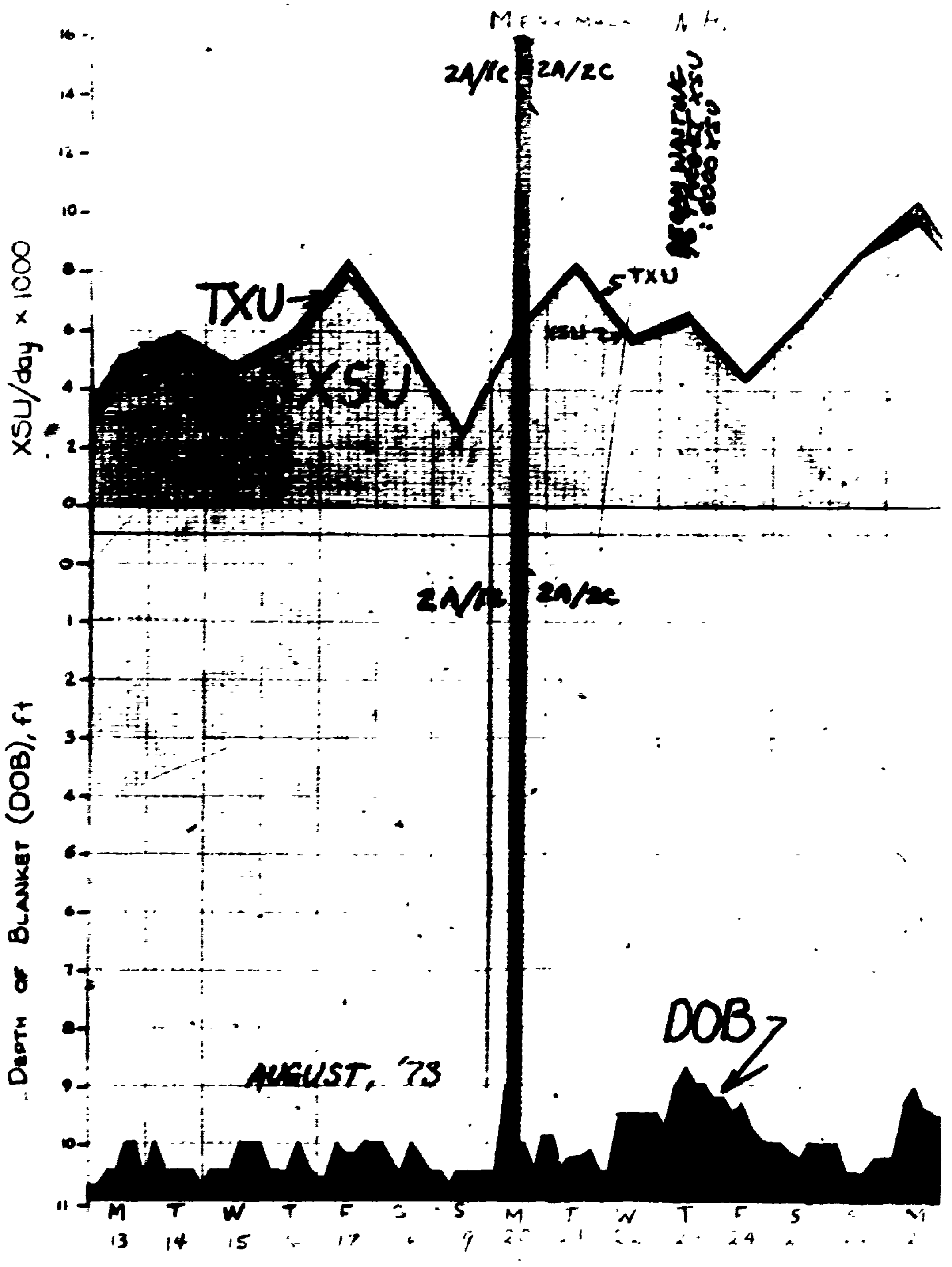


Figure 2

TYPICAL TREND CHART SHOWING XSU/day & DOB CURVES

Merrimack NH WTF

FLOWS (mgd)															
AFI	2.48	2.65	2.34	2.65	2.38	1.795	1.595	2.26	2.75	2.638	2.641	2.206	1.575	1.455	2.600
RSF	.254	.264	.268	.265	.403	.496	.519	.545	.826	1.058	1.110	1.26	1.063	.750	.969
XSF	.029	.036	.033	.035	.065	.050	.026	.051	.058	.047	.055	.044	.072	.100	.081
[illegible]RATION TANK CHARACTERISTICS															
ADT@TFL	15.9	14.9	16.7	14.9	15	19.0	20.6	15.5	12.2	11.8	11.6	12.6	16.5	14.7	12.2
BOD/1000ft³	19.2	36.5	19.1	23.7	35.5	24.0	11.0	20.2	43.6	33.4	45.5	22.8	19.9	30.1	58.8
F/M	.15	.24	.15	.17	.24	.18	.07	.13	.26	.22	.25	.105	.088	.146	.189
D.O. #1/#2	3.6/2.9	3.9/3.9	4.4/3.9	3.6/3.2	3.1/2.6	3.0/2.4	3.6/3.2	3.6/3.2	3.3/3.2	3.6/3.3	3.4/3.0	3.0/2.9	3.0/3.0	3.8/3.7	3.2/3.[illegible]
FINAL CLARIFIER CHARACTERISTICS															
OFR	561	600	530	600	539	406	361	341	311	298	299	250	178	165	294
CSDT	.97	.85	.99	1.07	.78	.76	.47	1.20	.96	1.07	1.73	1.22	1.03	.97	1.57
CFP	11.4	11.3	12.8	11.5	19.2	30.4	34.2	26.4	32.1	41.1	44.1	59.2	72.1	58.4	40.4
FINAL EFFLUENT QUALITY															
BOD₅	17	11	10	7	12	5	6	4	12	5+	5+	2	2	2	5
COD	83	58	54	45	66	50	55	59	38	46	42	39	39	34	51
SS	30	16	9	12	19	10	7	6	6	6	11	7	3	3	20

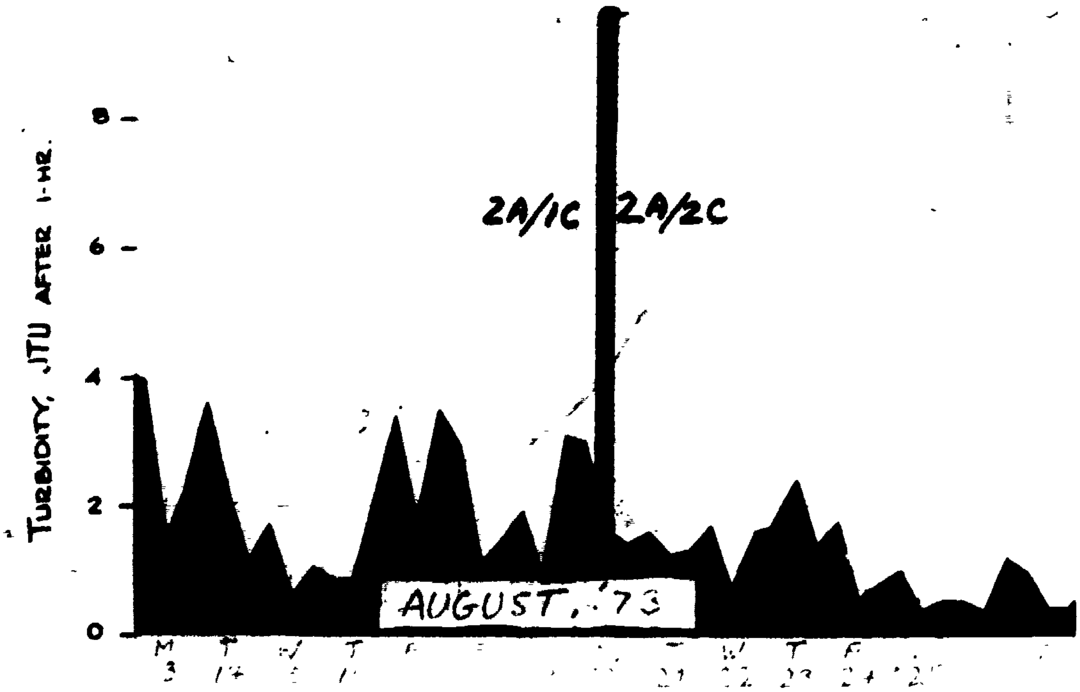


Figure 3

TYPICAL TREND CHART SHOWING FINAL EFFLUENT TURBIDITY AND A TABULATION OF SELECTED PROCESS PARAMETERS

MOVING AVERAGES

Moving averages, especially those for 7- and 28-day intervals, are useful for evaluating process responses to operational control adjustments. The effects of a major change in operating procedures are usually confirmed about a week after the start of the new control procedures. The development of a stable sludge, fully acclimated to the change, usually takes about a month.

The 7-day moving average (7DMA), which reflects the effects of low load Saturdays and Sundays as well as high load Mondays and Tuesdays, permits a realistic review of medium term process response. The 28-day moving average (28DMA) permits evaluation of long-term stabilization performance.

Figure 4 is a graph of sludge wasting data, showing the daily data points, the 7-day moving average, and the 28-day moving average. The individual data points show considerable variation from day to day. By plotting a 7-day moving average, the large variations are smoothed out and the actual trends (increasing or decreasing wasting rates) become more apparent. The 28-day moving average shows the long term trends.

Table 1 includes the daily (24 hour) average, and the 7-day and 28-day moving average data that are plotted on Figure 4.

The 7-day moving average for any given day is the average of the data for that day and the six previous days. For example, from Table 1, the 7-day moving average for 1/4/73 is 1.932. This is obtained by averaging the data for 1/4/73 and the six previous days, starting with 12/29/72:

12/29/72	5.058
12/30/72	0.0
12/31/72	1.374
1/ 1/73	2.459
1/ 2/73	0.960
1/ 3/73	1.598
1/ 4/73	2.076
	7 /13.525
	1.932 = 7-day moving avg.

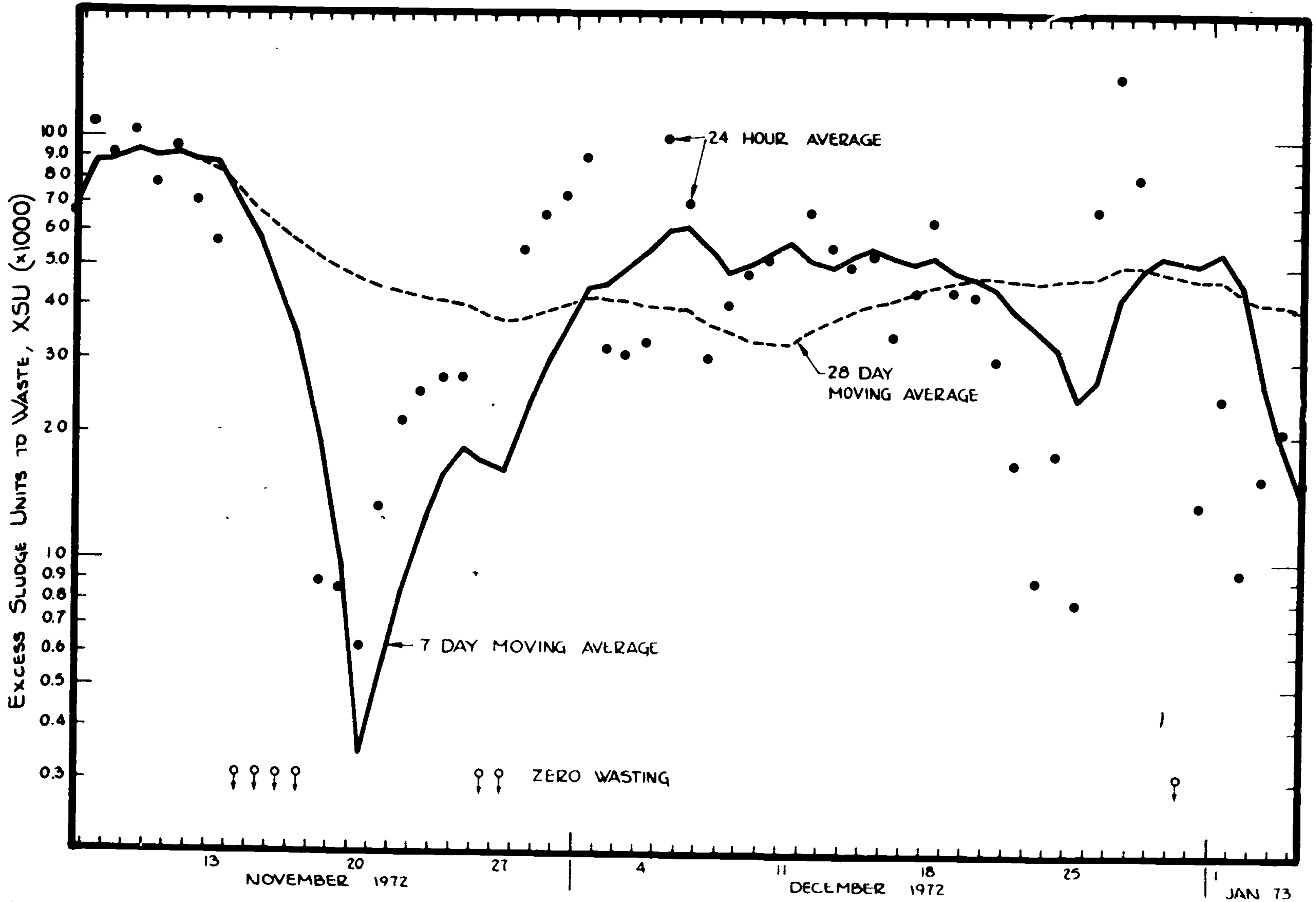


Figure 4

MOVING AVERAGE PLOTS OF XSU DATA

Table 1

24 HOUR AVERAGES, 7 DAY & 28 DAY MOVING AVERAGES OF XSU DATA

DATE	XSU 24HRA	XSU 7DMA	XSU 28DMA
11/ 6/72	BOUNDARY DATE	*	*
11/ 6/72	6.678	6.678= 1	6.678= 1
11/ 7/72	10.873	8.775= 2	8.775= 2
11/ 8/72	9.259	8.937= 3	8.937= 3
11/ 9/72	10.586	9.349= 4	9.349= 4
11/10/72	7.853	9.050= 5	9.050= 5
11/11/72	9.600	9.142= 6	9.142= 6
11/12/72	7.119	8.853	8.853= 7
11/13/72	5.750	8.720	8.465= 8
11/14/72	0.0	7.167	7.524= 9
11/15/72	0.0	5.844	6.772=10
11/16/72	0.0	4.332	6.156=11
11/17/72	0.0	3.710	5.643=12
11/18/72	0.900	1.967	5.278=13
11/19/72	0.870	1.074	4.963=14
11/20/72	0.630	0.343	4.675=15
11/21/72	1.350	0.536	4.467=16
11/22/72	2.160	0.844	4.331=17
11/23/72	2.520	1.204	4.230=18
11/24/72	2.736	1.595	4.152=19
11/25/72	2.772	1.863	4.083=20
11/26/72	0.0	1.738	3.888=21
11/27/72	0.0	1.648	3.712=22
11/28/72	5.508	2.242	3.790=23
11/29/72	6.624	2.880	3.908=24
11/30/72	7.421	3.580	4.048=25
12/ 1/72	9.120	4.492	4.243=26
12/ 2/72	3.230	4.558	4.206=27
12/ 3/72	3.120	5.003	4.167
12/ 4/72	3.326	5.479	4.047
12/ 5/72	10.091	6.133	4.020
12/ 6/72	7.182	6.213	3.945
12/ 7/72	3.084	5.593	3.677
12/ 8/72	4.098	4.876	3.543
12/ 9/72	4.831	5.105	3.373
12/10/72	5.242	5.408	3.306
12/11/72	5.741	5.753	3.306
12/12/72	6.750	5.275	3.547
12/13/72	5.580	5.047	3.746
12/14/72	5.058	5.329	3.927
12/15/72	5.364	5.509	4.118
12/16/72	3.468	5.315	4.210
12/17/72	4.368	5.190	4.335
12/18/72	6.444	5.290	4.542
12/19/72	4.399	4.954	4.651
12/20/72	4.327	4.775	4.729
12/21/72	3.037	4.487	4.747
12/22/72	1.732	3.968	4.711
12/23/72	0.907	3.602	4.645
12/24/72	1.818	3.238	4.710
12/25/72	0.801	2.432	4.738
12/26/72	6.854	2.783	4.786
12/27/72	14.019	4.167	5.051
12/28/72	8.188	4.903	5.078
12/29/72	5.058	5.378	4.933
12/30/72	0.0	5.248	4.817
12/31/72	1.374	5.185	4.755
1/ 1/73	2.459	5.422	4.724
1/ 2/73	0.960	4.580	4.398
1/ 3/73	1.598	2.805	4.199
1/ 4/73	2.076	1.932	4.163
1/ 5/73	1.577	1.435	4.073

LEGEND:

XSU = EXCESS SLUDGE UNITS WASTED (IN 1,000 SLUDGE UNITS)
24HRA = 24-HOUR (DAILY) AVERAGE
7DMA = 7-DAY MOVING AVERAGE
28DMA = 28-DAY MOVING AVERAGE

BOUNDARY DATE = THE FIRST DAY OF DATA INCLUDED IN THE CALCULATIONS

* = INDICATES THE NUMBER OF DAILY DATA POINTS INCLUDED IN THE CALCULATIONS, WHERE LESS THAN 7 (OR 28) ARE AVAILABLE.

Similarly, the 7-day moving average for the next day, 1/5/73, is the average of the data for that day and the six previous days, starting with 12/30/72:

12/30/72	0.0
12/31/72	1.374
1/ 1/73	2.459
1/ 2/73	0.960
1/ 3/73	1.598
1/ 4/73	2.076
1/ 5/73	1.577

7 /10.044

1.435 = 7-day moving avg.

The 7-day moving average for 1/5/73 could also be calculated easily from the previous day's calculations by subtracting the data for 12/29/72 (5.058) from the previous day's subtotal (13.525), adding the data for 1/5/73 (1.577) and dividing by 7:

13.525
- 5.058 (12/29/72)

8.467
+ 1.577 (1/5/73)

7 /10.044

1.435 = 7-day moving avg.

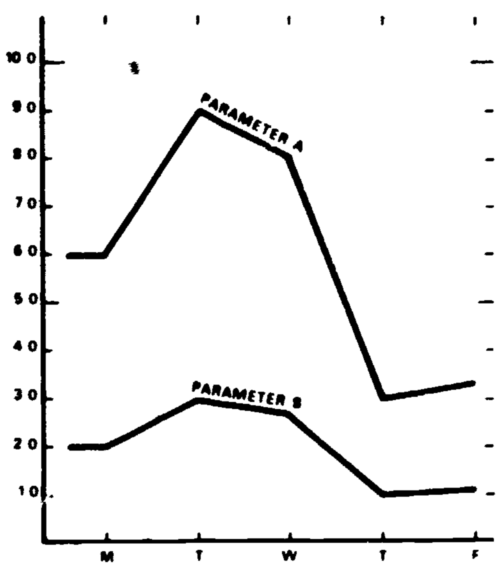
A 28-day moving average is derived by the same type of calculation.

When working with a new set of data, such as at the start of a new operational control phase, it is necessary to start with a progressive average (rather than a 7-day moving average) until seven days of data are included. Note that the 7 DMA column on Table 1 does not start with a true 7-day moving average, since the time period covered is less than seven days. The initial values for the first 6 days shown in the 7 DMA column are progressive averages until 11/12/72, at which point they become true 7-day moving averages. Similarly, the initial values for the first 27 days in the 28 DMA column are progressive averages until 12/3/72, when they become 28-day moving averages.

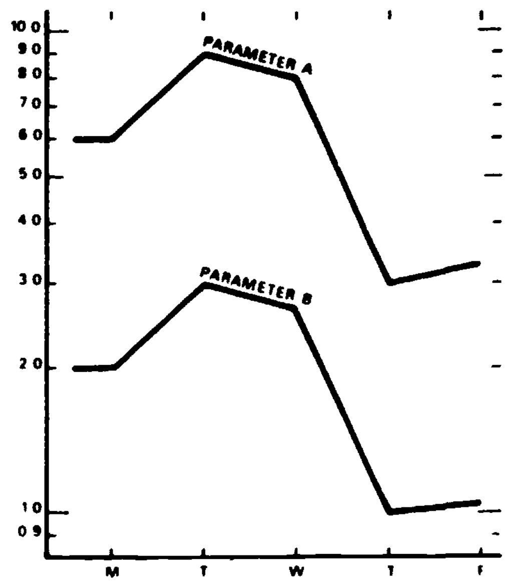
SEMI-LOGARITHMIC PLOTS

Process responses (SSV, ATC, SSC, turbidity, etc.) to control adjustments are normally plotted on a test-by-test basis to permit process evaluation. Semi-logarithmic plots are useful when one wishes to compare the rate of change of various parameters to a process adjustment because it permits direct observation of rate changes between the parameters regardless of their magnitudes.

Consider the following hypothetical example as displayed on the two graphs below. Two identical data sets (A and B) are plotted on each graph. The left graph is drawn on rectangular coordinate paper, the right on semi-logarithmic paper. Note how readily the trend similarity becomes apparent from a comparison of the semi-logarithmic curves. In this example, the plotted parameters have identical slopes and remain parallel to each other. The rectangular plot of the same parameters does not readily display that the rate changes, defined by their slopes, are identical. The probable relationship between parameters A and B might have been overlooked if only rectangular coordinate paper had been used.



RECTANGULAR PLOT



SEMI LOGARITHMIC PLOT

Now consider two plots drawn from the actual plant data shown below:

TABLE 2

Day/Date		Turb (JTU)	CSDT (hrs)
M	12/18/72	9.93	0.69
T	19	9.53	1.09
W	20	9.13	1.73
T	21	13.00	3.32
F	22	12.33	3.17
S	23	13.53	2.85
S	24	13.87	3.96
M	12/25/72	21.67	4.04
T	26	17.33	4.61
W	27	19.00	3.36
T	28	20.00	3.29
F	29	17.67	2.81
S	30	13.30	2.88
S	31	9.80	2.29
M	1/1/73	6.90	1.36
T	2	6.30	1.10
W	3	6.10	0.84
T	4	5.77	0.78
F	5	8.10	0.92
S	6	9.25	0.92
S	7	6.57	0.91
M	1/8/73	6.47	0.69
T	9	5.03	0.74
W	10	3.67	0.79
T	11	5.40	1.43
F	12	5.90	1.25
S	13	10.90	1.49
S	14	10.47	1.39

The upper illustration on Figure 5 shows a rectangular plot of final effluent turbidity and CSDT (Clarifier Sludge Detention Time) versus Time. The lower illustration is a plot of the same data on semi-logarithmic paper. When plotted on semi-log paper, the similarity between the two curves becomes evident. The possible cause and effect relationship between CSDT and turbidity might have been overlooked if only rectangular paper had been used.

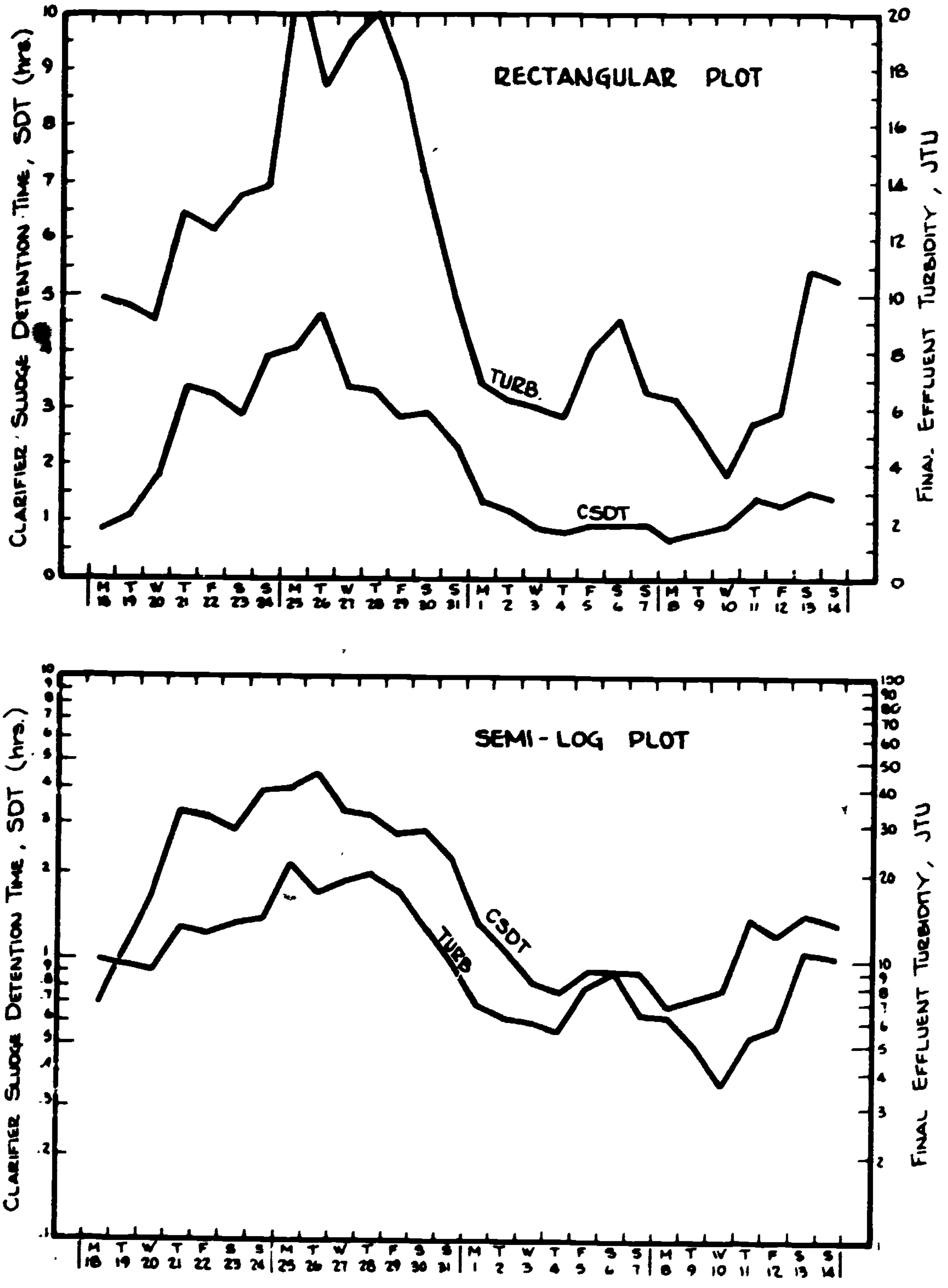


Figure 5

COMPARISON OF RECTANGULAR AND SEMI-LOGARITHMIC PLOTS

PROBABILITY PLOT EXAMPLES

When collected data are plotted on probability paper, they can be used to predict frequencies at which certain events may occur. For example, from a probability plot of past treatment plant data, one may estimate the percentage of time that the hydraulic capacity of the plant may be exceeded, and the percentage of time that the final effluent quality may be less than acceptable limits.

Two examples of probability plots are presented. Bacteriological data, conforming to logarithmic growth rates, are usually plotted on probability paper with a logarithmic vertical scale (Figure 6). Chemical data are usually plotted on probability paper with a uniformly divided vertical scale (Figure 7).

The first step in preparing a probability plot consists of reorganizing the raw data, regardless of collection date, into an orderly progression starting with the smallest number and finishing with the largest. Such a progression of 50,000 through 1,600,000+ for the 13 bits of data in the first example is shown in the second column of Table 3.

TABLE 3

COLIFORM PROBABILITY PLOT EXAMPLE

Coliform Density - MP /100 ml Tabulated Chronologically	Ranked in Ascending Order	"Exact" Plotting Position N = 13
330,000	50,000	4.8
50,000	78,000	12.2
820,000	110,000	19.2
220,000	130,000	27.3
1,600,000	220,000	34.9
350,000	230,000	42.5
110,000	330,000	50.0
700,000	350,000	57.5
130,000	700,000	65.1
820,000	820,000	72.7
1,600,000 +	820,000	80.2
230,000	1,600,000	87.8
78,000	1,600,000 +	95.2

NOTE: 541,000 = Arithmetic Mean
330,000 = Probability Mean (Fig. 7)

The plotting position, shown in the third column of Table 3 for each data item, can then be obtained directly from Table 4 if 50 or less data points are to be plotted. Plotting positions for sample sizes greater than 50 can be calculated according to the formula on Table 4, page 18. For this sample size of 13, the plotting positions ranged from "less than" 4.8% of the time for 50,000 to "less than" 95.2% of the time for 160,000+.

The coliform concentrations were then plotted according to their respective plotting positions. The completed probability plot of the coliform data is illustrated in Figure 6.

At first glance, the large and irregular day-to-day differences in coliform concentrations shown in column one of Table 3 appeared irreconcilable. But the probability plot of this same information displayed the data in an orderly fashion and permitted logical evaluation of the survey results. As shown on Figure 6, the mean density was 330,000 MPN/100 ml and it could be expected that the concentration would most probably equal or exceed 58,000 90% of the time, and equal or exceed 1,850,000 10% of the time.

Figure 7 is a probability plot of final effluent BOD5 concentrations and aeration tank BOD5 loadings at an activated sludge plant. The data were arranged as in the previous example, and the plotting positions were determined from the formula on Table 4. In this example normal (rectangular coordinate) probability paper was used.

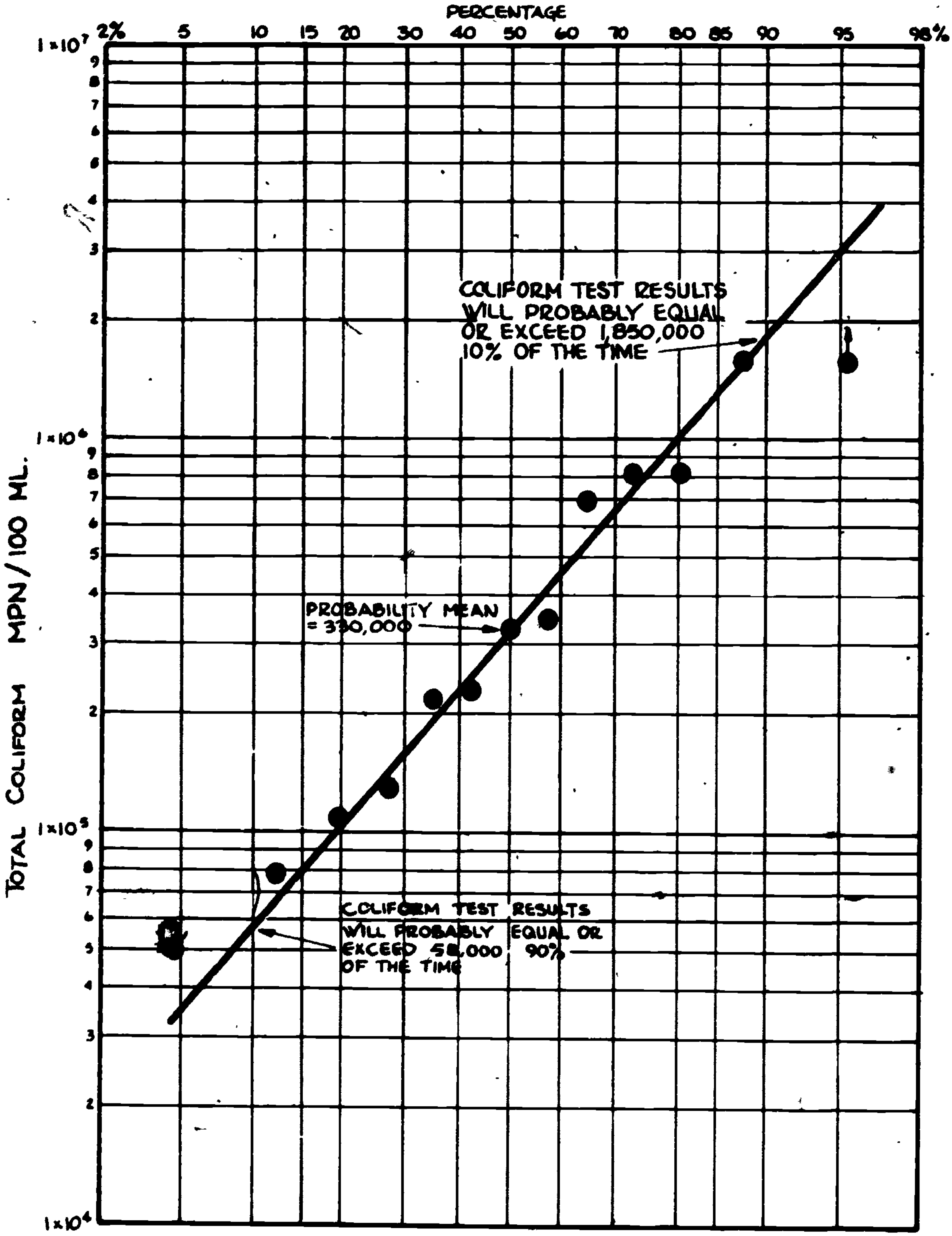


Figure 6

SEMI-LOGARITHMIC PROBABILITY PLOT OF COLIFORM DATA

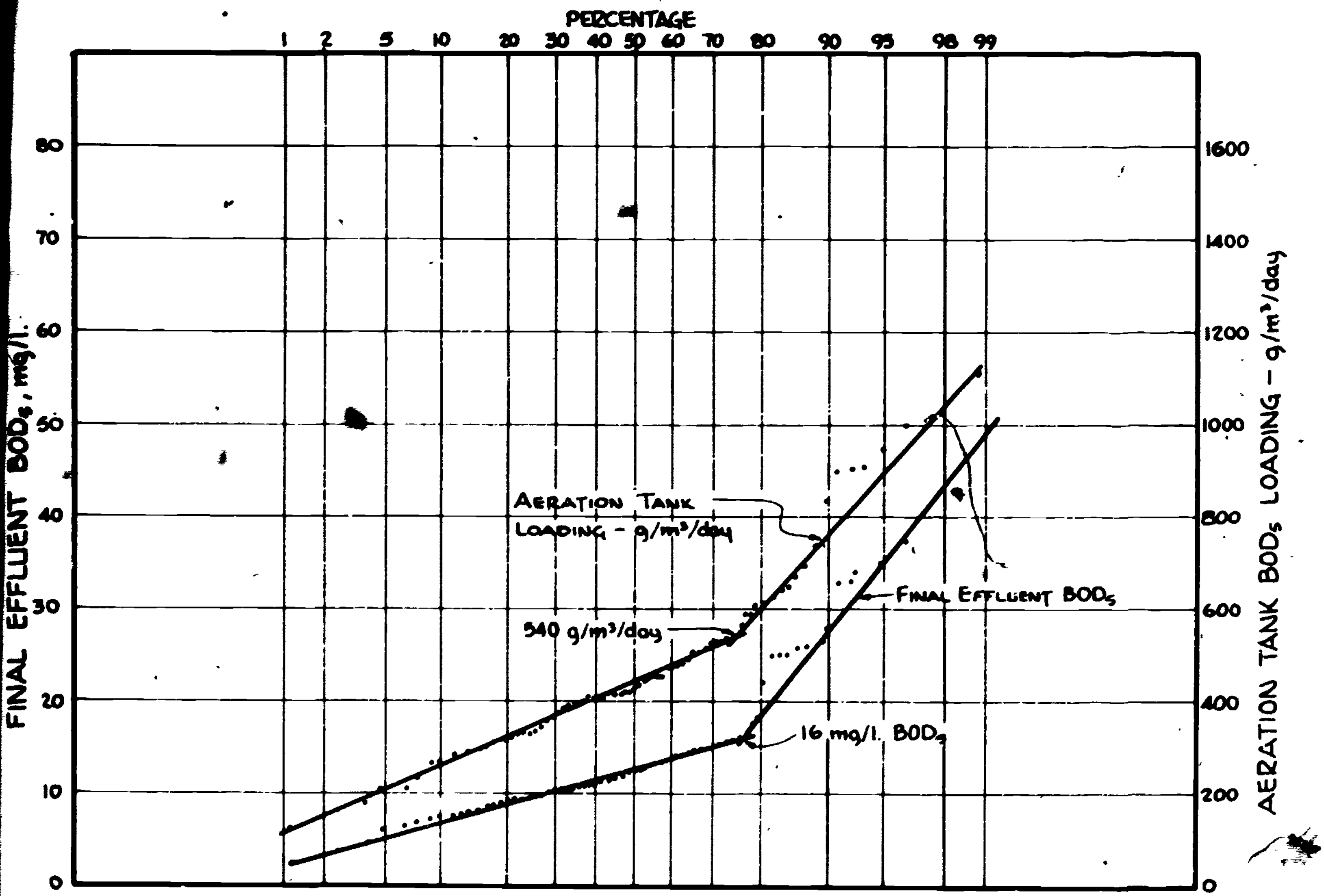


Figure 7

RECTANGULAR PROBABILITY PLOT OF LOADING AND BOD DATA

Table 4

PLOTTING POSITIONS FOR NORMAL PROBABILITY PAPER

Ordinal No.	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	Ordinal No.
1	28.6	19.9	15.2	12.2	10.3	8.8	7.7	6.9	6.2	5.6	5.2	4.8	4.4	4.1	3.9	3.6	3.4	3.3	3.1	2.9	2.8	2.7	2.6	2.4	2.4	2.3	2.2	2.1	2.1	2.0	1
2	71.4	50.0	38.3	31.0	26.0	22.5	19.7	17.6	15.8	14.4	13.2	12.2	11.4	10.6	9.9	9.4	8.9	8.4	8.0	7.7	7.2	6.8	6.7	6.4	6.2	5.9	5.7	5.5	5.3	5.2	2
3		80.1	61.7	50.0	42.0	36.2	31.8	28.4	25.6	23.3	21.4	19.8	18.4	17.2	16.1	15.2	14.3	13.6	12.9	12.3	11.7	11.3	10.7	10.4	9.9	9.5	9.2	8.9	8.7	8.4	3
4			84.8	69.0	58.0	50.0	43.9	39.2	35.3	32.2	29.6	27.3	25.4	23.7	22.3	21.0	19.8	18.8	17.9	17.1	16.4	15.6	14.9	14.2	13.8	13.3	12.7	12.3	11.9	11.5	4
5				87.8	74.0	63.8	56.1	50.0	45.1	41.1	37.8	34.9	32.4	30.3	28.4	26.8	25.3	24.0	22.8	21.8	20.6	19.8	18.9	18.1	17.6	16.9	16.4	15.9	15.2	14.7	5
6					89.7	77.5	68.2	60.8	54.9	50.0	45.9	42.5	39.5	36.5	34.6	32.6	30.8	29.2	27.8	26.4	25.1	24.2	23.3	22.4	21.5	20.4	19.8	19.2	18.7	17.9	6
7						91.2	80.3	71.6	64.7	58.9	54.1	50.0	46.5	43.4	40.7	38.4	36.3	34.4	32.7	31.2	29.8	28.4	27.4	26.1	25.1	24.2	23.3	22.7	21.8	21.2	7
8							92.3	82.4	74.6	67.8	62.2	57.5	53.5	50.0	46.9	44.2	41.8	39.6	37.6	35.9	34.1	32.6	31.6	30.2	29.1	28.1	27.1	26.1	25.1	24.6	8
9								93.1	84.2	76.7	70.4	65.1	60.5	56.6	53.1	50.0	47.2	44.8	42.6	40.5	38.6	37.1	35.6	34.1	33.0	31.6	30.5	29.5	28.4	27.4	9
10									93.8	85.6	78.6	72.7	67.6	63.1	59.3	55.8	52.8	50.0	47.5	45.2	43.3	41.3	39.7	38.2	36.7	35.2	34.1	33.0	31.9	30.9	10
11										94.4	86.8	80.2	74.6	69.7	65.4	61.6	58.2	55.2	52.5	50.0	47.6	45.6	43.6	42.1	40.5	39.0	37.4	36.3	35.2	34.1	11
12											94.8	87.8	81.6	76.3	71.6	67.4	63.7	60.4	57.4	54.8	52.4	50.0	48.0	46.0	44.4	42.5	41.3	39.7	38.6	37.1	12
13												95.2	88.6	82.8	77.7	73.2	69.2	65.6	62.4	59.5	56.7	54.4	52.0	50.0	48.0	46.4	44.8	43.3	41.7	40.5	13
14													95.6	89.4	83.9	79.0	74.7	70.8	67.3	64.1	61.4	58.7	56.4	54.0	52.0	50.0	48.4	46.4	45.2	43.6	14
15														95.9	90.1	84.8	80.2	76.0	72.2	68.8	65.9	62.9	60.3	57.9	55.6	53.6	51.6	50.0	48.4	46.8	15
16															96.1	90.6	85.7	81.2	77.2	73.6	70.2	67.4	64.4	61.8	59.5	57.5	55.2	53.6	51.6	50.0	16
17																96.4	91.1	86.4	82.1	78.2	74.9	71.6	68.4	65.9	63.3	61.0	58.7	56.7	54.8	53.2	17
18																	96.6	91.6	87.1	82.9	79.4	75.8	72.6	69.8	67.0	64.8	62.6	60.3	58.3	56.4	18
19																		96.7	92.0	87.7	83.6	80.2	76.7	73.9	70.9	68.4	65.9	63.7	61.4	59.5	19
20																			96.9	92.3	88.3	84.4	81.1	77.6	74.9	71.9	69.5	67.0	64.8	62.9	20
21																				97.1	92.8	88.7	85.1	81.9	78.5	75.8	72.9	70.5	68.1	65.9	21
22																					97.2	93.2	89.3	85.8	82.4	79.4	76.7	73.9	71.6	69.1	22
23																						97.3	93.3	89.6	86.2	83.1	80.2	77.3	74.9	72.6	23
24																							97.4	93.6	90.1	86.7	83.6	80.8	78.2	75.4	24
25																								97.6	93.8	90.5	87.3	84.1	81.3	78.8	25
26																									97.6	94.1	90.8	87.7	84.8	82.1	26
27																										97.7	94.3	91.1	88.1	85.3	27
28																											97.8	94.5	91.3	88.5	28
29																												97.9	94.7	91.6	29
30																													97.9	94.8	30
31																														98.0	31

References:
(1) Statistical Tables for Biological Agricultural and Medical Research, by Fisher and Yates, Hafner Pub. Co., '63, Table XX, 94-95
(2) Tables of Normal Probability Functions, U. S. Government Printing Office, '53, Table I, 2-338
(3) Pearson, E., and Hartley, H., Biometrika Tables for Statisticians Volume 1, Cambridge University Press, '54, Table 28, 175, Table 1, 104-110

Table 4 (Cont.)

PLOTTING POSITIONS FOR NORMAL PROBABILITY PAPER

Ordinal No.	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	Ordinal No.
1	1.92	1.88	1.83	1.76	1.70	1.66	1.62	1.58	1.54	1.50	1.46	1.43	1 39	1.36	1.32	1.32	1.29	1.25	1.22	1
2	4.9	4.8	4.6	4.6	4.5	4.3	4.2	4.1	4.0	3.9	3.8	3.7	3.6	3.5	3.4	3.4	3.3	3.2	3.2	2
3	8.1	7.8	7.6	7.4	7.2	6.9	6.8	6.7	6.4	6.3	6.2	6.1	5.8	5.7	5.6	5.5	5.4	5.3	5.2	3
4	11.1	10.9	10.6	10.2	10.0	9.7	9.4	9.2	9.0	8.7	8.5	8.4	8.1	7.9	7.8	7.6	7.5	7.4	7.2	4
5	14.2	13.8	13.3	13.1	12.7	12.3	12.1	11.7	11.5	11.1	10.9	10.6	10.4	10.2	10.0	9.7	9.5	9.3	9.2	5
6	17.4	16.9	16.4	15.9	15.4	15.2	14.7	14.2	14.0	13.6	13.3	12.9	12.7	12.3	12.1	11.9	11.7	11.3	11.1	6
7	20.4	19.8	19.2	18.7	18.1	17.9	17.4	16.9	16.4	16.1	15.6	15.4	14.9	14.7	14.2	14.0	13.8	13.3	13.1	7
8	23.6	23.0	[illegible]	21.5	20.9	20.3	19.8	19.5	18.9	18.4	18.1	17.6	17.1	16.9	16.4	16.1	15.9	15.4	15.2	8
9	26.8	25.8	[illegible]	24.5	23.6	23.3	22.7	22.1	21.5	20.9	20.3	20.0	19.5	18.9	18.7	18.1	17.9	17.4	17.1	9
10	29.8	28.8	28.1	27.4	26.4	25.8	25.1	24.5	23.9	23.3	22.7	22.4	21.8	21.2	20.9	20.3	20.0	19.5	19.2	10
11	33.0	31.9	30.9	30.2	29.5	28.4	27.8	27.1	26.4	25.8	25.1	24.5	23.9	23.6	23.0	22.4	22.1	21.5	21.2	11
12	35.9	34.8	34.1	33.0	31.9	31.2	30.5	29.5	28.8	28.1	27.4	26.8	26.1	25.8	25.1	24.5	24.2	23.6	23.0	12
13	39.0	37.8	36.7	35.9	34.8	33.7	33.0	32.3	31.2	30.5	29.8	29.1	28.4	27.8	27.4	26.7	26.1	25.5	25.1	13
14	42.1	40.9	39.7	38.6	37.4	36.7	35.6	34.8	33.7	33.0	32.3	31.6	30.9	30.2	29.5	28.8	28.1	27.8	27.1	14
15	45.2	44.0	42.9	41.3	40.5	39.4	38.2	37.1	36.3	35.6	34.5	33.7	33.0	32.3	31.6	30.9	30.2	29.8	29.1	15
16	48.6	46.8	45.6	44.4	43.3	42.1	40.9	39.7	39.0	37.8	37.1	35.9	35.2	34.5	33.7	33.0	32.3	31.6	31.2	16
17	51.6	50.0	48.6	47.2	46.0	44.6	43.6	42.5	41.3	40.1	39.4	38.6	37.4	36.7	35.9	35.2	34.5	33.7	33.0	17
18	54.8	53.2	51.6	50.0	48.8	47.2	46.0	44.8	43.6	42.9	41.7	40.9	39.7	39.0	38.2	37.4	36.7	35.9	35.2	18
19	57.9	56.0	54.4	52.8	51.2	50.0	48.8	47.6	46.4	45.2	44.0	43.3	42.1	41.3	40.1	39.4	38.6	37.8	37.1	19
20	61.0	59.1	57.1	55.6	54.0	52.8	51.2	50.0	48.8	47.6	46.4	45.2	44.4	43.3	42.5	41.7	40.5	39.7	39.0	20
21	64.1	62.2	60.3	58.7	56.7	55.6	54.0	52.4	51.2	50.0	48.8	47.6	46.4	45.6	44.4	43.6	42.9	41.7	40.9	21
22	67.0	65.2	63.3	61.4	59.5	57.9	56.4	55.2	53.6	52.4	51.2	50.0	48.8	47.6	46.8	45.6	44.8	44.0	42.9	22
23	70.2	68.1	65.9	64.1	62.6	60.6	59.1	57.5	56.4	54.8	53.6	52.4	51.2	50.0	48.8	48.0	46.8	46.0	44.8	23
24	73.2	71.2	69.1	67.0	65.2	63.[illegible]	61.8	60.3	58.7	57.1	56.0	54.8	53.6	52.4	51.2	50.0	48.8	48.0	46.8	24
25	76.4	74.2	71.9	69.8	68.1	66.3	64.4	62.9	61.0	59.9	58.3	56.7	55.6	54.4	53.2	52.0	51.2	50.0	48.8	25
26	79.4	77.0	74.9	72.6	70.5	68.8	67.0	65.2	63.7	62.2	[illegible]	59.1	57.9	56.7	55.6	54.4	53.2	52.0	51 2	26
27	82.6	80.2	77.6	75.5	73.6	71.6	69.5	67.7	66.3	64.4	62.9	61.4	60.3	58.7	57.5	56.4	55.2	54.0	53.2	27
28	85.8	83.1	80.8	78.5	76.4	74.2	72.2	70.5	68.8	67.0	65.5	64.1	62.6	61.0	59.9	58.3	57.1	56.0	55 2	28
29	88.9	86.2	83.6	81.3	79.1	76.7	74.9	72.9	71.2	69.5	67.7	66.3	64.8	63.3	61.8	60.6	59.5	58 3	57.1	29
30	91.9	89.1	86.7	84.1	81.9	79.7	77.3	75.5	73.6	71.9	70.2	68.4	67.0	65.5	64.1	62.6	61.4	60.3	59 1	30
31	95.1	92.2	89.4	[illegible]	84.6	82.1	80.2	77.9	76.1	74.2	72.6	70.9	69.1	67.7	66.3	64.8	63.3	62.2	61.0	31
32	98.08	95.2	92.4	[illegible]	87.3	84.8	82.6	80.5	78.5	76.7	74.9	73.2	71.6	69.8	68.4	67.0	65.5	64.1	62.9	32
33		98.12	95.4	92.6	90.0	87.7	85.3	83.1	81.1	79.1	77.3	75.5	73.9	72.2	70.5	69.1	67.7	66.3	64.8	33
34			98.17	95.4	92.8	90.3	87.9	85.8	83.6	81.6	79.7	77.6	76.1	74.2	72.6	71.2	69.8	68.4	67.0	34
35				98.26	95.5	93.1	90.6	88.3	86.0	83.9	81.9	80.0	78 2	76.4	74.[illegible]	73.2	71.9	70.2	68 8	35
36					98.30	95.7	93.2	90.8	88.5	86.4	84.4	82.4	80.5	78.8	77.0	75.5	73.9	72.2	70.9	36
37						98.34	95.8	93.3	91.0	88.9	86.7	84.6	82.9	81.1	79.1	77.6	75.8	74.5	72.9	37
38							98.38	95.9	93.6	91.3	89.1	87.1	85.1	83.1	81.3	79 7	77.9	76.4	74 9	38
39								98.42	[illegible]	[illegible]	91.5	89.4	87.3	85.3	83.6	81.9	80.0	78 5	77.0	39
40									98.46	[illegible]	93.8	91.6	89.6	87.7	85.8	83.9	82.1	80.5	78.8	40
41										98.50	96.2	93.9	91.9	89.8	87.9	86 0	84.1	82.6	80.8	41
42											98.54	96.3	94.2	92.1	90.0	88 1	86.2	84.6	82.9	42
43												98.57	96.4	94.3	92.2	90.3	88 3	86.7	84.8	43
44													98.61	96.5	94.6	92.6	90.5	88.7	86.9	44
45														98.64	96.6	94.5	92.5	90.7	88.9	45
46															98.68	96.6	94.6	92.6	90.8	46
47																98 68	96.7	94.7	92.8	47
48																	98.71	96.8	94.8	48
49																		98.75	96.8	49
50																			98.78	50

For sample sizes larger than 50 plotting position is estimated as:

$$\frac{100\ (\text{ordinal number} - 0.5)}{\text{sample si.}}$$

EXAMPLE:

Sample Size 51	Ordinal number
$0.98 = \frac{100(1-0.5)}{51}$	1
$2.94 = \frac{100(2-0.5)}{51}$	2
$99.02 = \frac{100(51-0.5)}{51}$	51

TESTING EQUIPMENT

Some special equipment for operational control testing are used in the NFIC-C Procedures. Basically a settlometer, centrifuge, turbidimeter, and optical sludge blanket finder are needed.

The construction of a typical sludge blanket finder is shown in Figure 8. Approximate prices (1973) and types of control test equipment that have been used by the Waste Treatment Branch are as follows:

Blanket Finder Parts

Site Glass - Part No. 4045 for 1 1/2" pipe $5.00

Gitz Mfg. Co.
1846 South Kilbourn Ave.
Chicago, Illinois 60623

Use Schedule 40 aluminum pipe. Tape the tube every 0.5 ft. starting at the site glass to facilitate reading the blanket depth. Faster readings may be obtained if distinctive markings are used at the 5 ft. and 10 ft. points.

Mallory Direct Reading Settlometer

5" dia. x 7" high, 2 liter graduated cyl. $24.00

Scientific Glass Apparatus Co.
735 Broad Street
Bloomfield, New Jersey 07003

Turbidimeter

Hach Model 2100-A Laboratory Turbidimeter $525.00

Hach Chemical Co.
Box 907
Ames, Iowa 50010

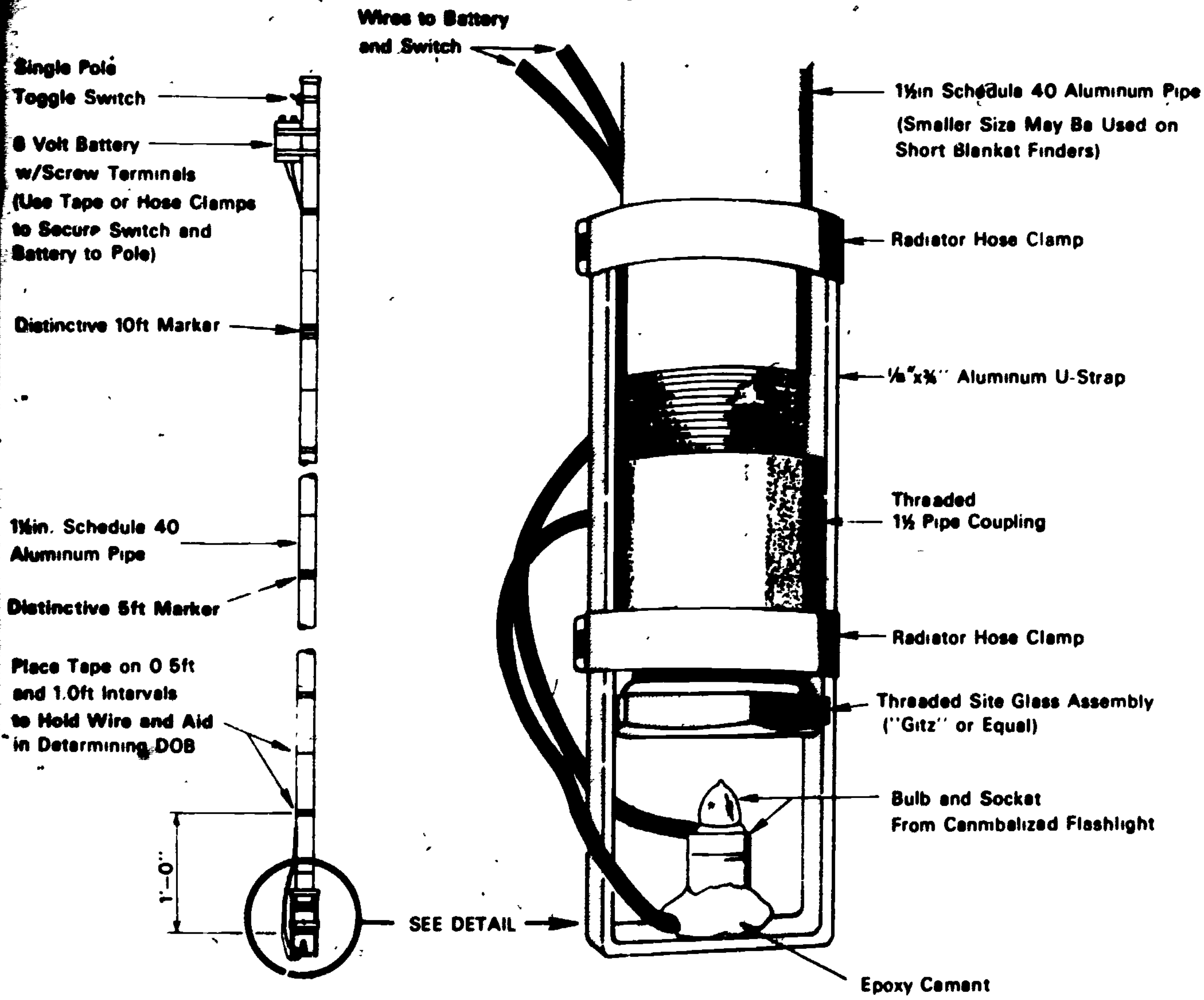


Figure 8

SLUDGE BLANKET FINDER

<u>Clinical Centrifuge, I.E.C. No. 428</u>	$208.00
1 - Head, Trunion, 6-place, 15 ml., I.E.C. No. 221	$59.00
6 - Shields, Cornell Style, 15 ml., I.E.C. No. 303	$31.50/6
1 Pk - Replacement Thrust Cushions, Rubber, I.E.C. No. 570	$2.40

International Equipment Co.
300 Second Ave.
Needham Heights, Mass. 02194

<u>Centrifuge Tubes - A.P.I.</u>	
1 Dz - Kimax No. 45170	$30.00/Dz

<u>Laboratory Timer</u>	
Interval, electric, 60-minute, with alarm, 2 switches and elapsed time circuit	$35.00

Matheson Scientific
12101 Centron Place
Cincinnati, Ohio 45246

<u>Note</u>: Some of this special testing equipment is not listed in generalized laboratory equipment catalogs. Manufacturers' catalog numbers are used only to identify <u>types</u> of equipment and this does not constitute an endorsement of any manufacturer or supplier.

SYMBOLS AND TERMINOLOGY USED IN ACTIVATED SLUDGE PROCESS CALCULATIONS

AAG - Aeration Age (Number of days sludge subjected to aeration)

ADT - Aeration Tank Detention Time (Hours)

AFI - Aeration Tank Wastewater Flow-In (mgd or cu m/day)

AGE - Sludge Age (Days)

ASDT - Aeration Tank Sludge Detention Time (Hours)

ASA - Aeration Tank Surface Area

ASF - Aeration Tank Surface Area (Square Feet)

ASM - Aeration Tank Surface Area (Square Meters)

ASU - Aeration Tank Sludge Units

ATC - Aeration Tank Concentration (% by Centrifuge)

ATCm - Mean Aeration Tank Concentration

ATCn - Aeration Tank Concentration (Final Bay)

AV - Aeration Tank Volume

AVF - Aeration Tank Volume (Cubic Feet)

AVG - Aeration Tank Volume (Gallons)

AVM - Aeration Tank Volume (Cubic Meters)

AWDT - Aeration Tank Waste Detention Time

BLT - Sludge Blanket Thickness

BLV - Sludge Blanket Volume

BOD - Biochemical Oxygen Demand (5-day unless stated otherwise)

BODd - Calculated Net Five-Day Biochemical Oxygen Demand of waste water and the "liquid portion" of the return sludge at the aeration tank entrance (diluted waste water)

BODi - Five-Day Biochemical Oxygen Demand of the waste water entering (in) the aeration tank

BODo - Five-Day Biochemical Oxygen Demand of the final clarifier effluent (out)

CDT - Final Clarifier Detention Time (Hours)

CFI - Final Clarifier Flow - In (mgd or cu m/day)

CFL - Final Clarifier Sludge Floor Loading

CFO - Final Clarifier Flow - Out (mgd or cu m/day)

CFP - Final Clarifier Sludge Flow Percentage

COD - Chemical Oxygen Demand

CSA - Final Clarifier Surface Area (Square Feet)

CSM - Final Clarifier Surface Area (Square Meters)

CSC - Final Clarifier Sludge Concentration

CSDT - Final Clarifier Sludge Detention Time (Hours)

CSF - Final Clarifier Sludge Flow (RSF + XSF)

CSFD - Final Clarifier Sludge Flow Demand

CSU - Final Clarifier Sludge Units

CSUI - Final Clarifier Sludge Units - In

CSUO - Final Clarifier Sludge Units - Out of Clarifier

CV - Final Clarifier Volume

CVF - Final Clarifier Volume (Cubic Feet)

CVG - Final Clarifier Volume (Gallons)

CVM - Final Clarifier Volume (Cubic Meters)

CWD - Final Clarifier Mean Water Depth

DOB - Depth Of Sludge Blanket

ESU - Final Effluent Sludge Units (Total Suspended Solids lost in Final Effluent expressed as SLU)

FEC - Final Effluent Concentration (Total Suspended Solids converted to % by Centrifuge - FETSS/WCR)

FET - Final Effluent Turbidity (JTU)

FETSS - Final Effluent Total Suspended Solids (mg/l)

j - Suffix Notation (Used to indicate a particular aeration tank bay)

j-1 - Suffix Notation (Used to indicate the bay preceding the bay of reference, j)

JTU - Jackson Turbidity Units

LOD - Load (lbs BOD/day to aeration tanks)

LODk - Load (kg BOD/day to aeration tanks)

MLTSS - Mixed Liquor Total Suspended Solids (mg/l)

MLVSS - Mixed Liquor Volatile Suspended Solids (mg/l)

OFR - Final Clarifier Surface Overflow Rate (Gal/day/sq ft or cu m/day/sq m)

PEC - Primary Effluent Concentration (PETSS / WCR)

PET - Primary Effluent Turbidity (JTU)

PETSS - Primary Effluent Total Suspended Solids (mg/l)

PFI - Primary Flow Into Primary Clarifiers

PFO - Primary Flow Out Of Primary Clarifiers

PSF - Primary Sludge Flow (mgd or cu m/day)

PSAF - Primary Clarifier Surface Area (Square Feet)

PSAM - Primary Clarifier Surface Area (Square Meters)

PVF - Primary Clarifier Volume (Cubic Feet)

PVG - Primary Clarifier Volume (Gallons)

PVM - Primary Clarifier Volume (Cubic Meters)

RFD - Return Sludge Flow Demand

RFP - Return Sludge Flow Percentage (RSF as a % of AFI by meter)

RSC - Return Sludge Concentration (% by Centrifuge)

RSF - Return Sludge Flow (mgd or cu m/day)

RSP - Return Sludge Percentage (Calculated from ATC, RSC, and PEC)

RSTSS - Return Sludge Total Suspended Solids (mg/l)

RSU - Return Sludge Units (To aeration tanks)

RSVSS - Return Sludge Volatile Suspended Solids (mg/l)

SAH - Sludge Aeration Hours (Hours/day in aeration tank)

SAP - Sludge Aeration Hours In Percent Of Day

SCR - Sludge Concentration Ratio (SSC60 / RSC)

SCY - Sludge Cycles (per day)

SDR - Sludge Distribution Ratio (ASU / CSU)

SLR - Sludge Ratio (RSC / ATC)

SLU - Sludge Units

SSC - Settled Sludge Concentration (% by Centrifuge)

SST - Settled Sludge Time

SSV - Settled Sludge Volume

TDT - Total Sludge Detention Time (ADT + SDT in Hours)

TFI - Sludge Thickener Flow-In (mgd or cu m/day)

TFL - Total Flow (mgd or cu m/day out of aeration tank)

TFO - Thickener Flow Out (mgd or cu m/day)

TKR - Tank Ratio (AVG / CVG)

TSF - Thickener Sludge Flow (mgd or cu m/day)

TSS - Total Suspended Solids (mg/l)

TSU - Total Sludge Units (ASU + CSU)

TXU - Total Excess Sludge Units To Waste (ESU + XSU)

WCR - Weight To Concentration Ratio (MLTSS / ATC)

WCRS - Weight To Concentration Ratio - Return Sludge (RSTSS / RSC)

V - Volume Of Aeration Tank (gal, cu ft, or cu m)

XFP - Excess Sludge Flow (as Percent of AFI)

XMF - Excess Mixed Liquor Sludge Flow To Waste (mgd or cu m/day)

XRF - Excess Return Sludge Flow To Waste (mgd or cu m/day)

XSC - Excess Sludge Concentration (% by Centrifuge)

XSF - Total Excess Sludge Flow To Waste (mgd or cu m/day)

XSU - Total Excess Sludge Units To Waste

NOTE: It is necessary, especially in Part IIIB, to use subscript notation to refer to particular bays within an aeration tank or to refer to flow values into a particular bay of an aeration tank. Several parameters, ADT, AFI, ATC, AV, AVG, TFL and V are combined with subscripts in Part IIIB. With these parameters, the reader need only remember that the number refers to the bay of the aeration tank. For example, ATC2 means the concentration of the mixed liquor, % by centrifuge, in the second bay of the aeration tank. AVG3 means the volume of the third bay expressed in gallons. TFLj means the total flow through the "j th" bay, and finally, TFLj-1 means the total flow through the bay preceding the "j th" bay.

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SLUDGE PUMP