TVA
EPA

Tennessee Valley Authority
Energy Demonstrations and Technology
Chattanooga TN 37401

U.S. Environmental Protection Agency
Office of Research and Development
Industrial Environmental Research Laboratory
Research Triangle Park NC 27711

EPA-600/7-79-198
August 1979

Chlorine Minimization/ Optimization for Condenser Biofouling Control

(Phases I and II)

Interagency Energy/Environment R&D Program Report

RESEARCH REPORTING SERIES

Research reports of the Office of Research and Development, U.S. Environmental Protection Agency, have been grouped into nine series. These nine broad categories were established to facilitate further development and application of environmental technology. Elimination of traditional grouping was consciously planned to foster technology transfer and a maximum interface in related fields. The nine series are:

1. Environmental Health Effects Research
2. Environmental Protection Technology
3. Ecological Research
4. Environmental Monitoring
5. Socioeconomic Environmental Studies
6. Scientific and Technical Assessment Reports (STAR)
7. Interagency Energy-Environment Research and Development
8. "Special" Reports
9. Miscellaneous Reports

This report has been assigned to the INTERAGENCY ENERGY-ENVIRONMENT RESEARCH AND DEVELOPMENT series. Reports in this series result from the effort funded under the 17-agency Federal Energy/Environment Research and Development Program. These studies relate to EPA's mission to protect the public health and welfare from adverse effects of pollutants associated with energy systems. The goal of the Program is to assure the rapid development of domestic energy supplies in an environmentally-compatible manner by providing the necessary environmental data and control technology. Investigations include analyses of the transport of energy-related pollutants and their health and ecological effects; assessments of, and development of, control technologies for energy systems; and integrated assessments of a wide range of energy-related environmental issues.

EPA REVIEW NOTICE

This document is available to the public through the National Technical Information Service, Springfield, Virginia 22161.

EPA-600/7-79-198

August 1979

Chlorine Minimization/Optimization for Condenser Biofouling Control (Phases I and II)

by

R. D. Moss, H. B. Flora II, R. A. Hiltunen,
S. H. Magliente, and N. D. Moore

Tennessee Valley Authority
470 Commerce Union Bank Building
Chattanooga, Tennessee 37401

EPA Interagency Agreement D5-E-721
Program Element No. INE624A

EPA Project Officer: Michael C. Osborne

Industrial Environmental Research Laboratory
Office of Energy, Minerals, and Industry
Research Triangle Park, NC 27711

Prepared for

U.S. ENVIRONMENTAL PROTECTION AGENCY
Office of Research and Development
Washington, DC 20460

DISCLAIMER

ABSTRACT

This interim report summarizes the results obtained from the chlorine minimization/optimization study conducted by TVA at the John Sevier Steam Plant from December 1975 till September 1977. Many facts about chlorination have become apparent through the data obtained. The following synopsis depicts the salient points gleaned from this study.

It was found that chlorine feed rate is a function of inlet water temperature and chlorine demand. The statistical analysis of the data did not indicate a significant impact of water quality parameters (pH, total suspended solids, ammonia, total organic carbon, nitrates plus nitrites, organic nitrogen, alkalinity, and conductivity) on the feed rate. It was determined that the inlet water temperature may be used as an indicator for raising or lowering the chlorine feed rate.

It was determined that natural water and system chlorine consumption vary directly with the chlorine feed rate and the inlet water temperature, i.e., when the feed rate is increased and/or the inlet water temperature is increased, the amount of chlorine consumed is also increased. Also, as the frequency of chlorine application is increased and the length of chlorine application is decreased, the chlorine consumption by the system is decreased. The data analysis indicates that one should be able to determine the system demand and set the feed rate so that the demand is satisfied such that only a trace amount of free residual chlorine may be found at the outlet of the condenser.

It is proposed that the relationships between the chlorine demand and corresponding feed rate as determined at John Sevier may be used to transpose these findings to other plants by relating their chlorine demand to a ballpark feed rate for initiating their minimization studies.

Results have indicated a direct relationship between the change in inlet water temperature and the change in turbine back pressure and condenser performance. Different chlorine feed regimes have shown statistically to have an effect on condenser performance, i.e., the condenser performance has not decreased due to more frequent and shorter chlorination periods.

There is a statistically significant difference in free residual chlorine across the condensers, i.e., there is a "condenser demand." It was noted that the average free residual chlorine consumed in the condenser declines significantly as the feed rate is lowered.

An important point emphasized by this study is that chlorination is site-specific. Every plant must conduct its own minimization studies if warranted, and this report has portrayed a format which will assist in conducting such studies.

The final report, which will contain Phase III, will furnish data to elucidate the complexities of water chlorination for biofouling control and answers the many questions prompted by this interim report.

This report was submitted in partial fulfillment of contract number EPA-IAG-D5-E-721 by the Tennessee Valley Authority under the sponsorship of the U.S. Environmental Protection Agency. This report covers a period from December 1975 to September 1977.

TABLE OF CONTENTS

FIGURES

TABLES

ACKNOWLEDGMENT

We would like to express our appreciation to the following TVA organizations for their support during this study.

Division of Power Production

Plant Engineering Branch - C. Cain, Jr., E. S. Lisle, C. B. Moultrie, V. C. Shattuck, and J. F. Shiau

Steam-Electric Generation Branch - W. H. Thompson

Division of Environmental Planning

Laboratory Branch - C. W. Holley, D. G. Carpenter, and J. W. Bobo

A special appreciation is extended to J. T. Thompson, John Sevier Steam Plant Superintendent, his staff, and the Results Section for their continued cooperation and support throughout this study.

SECTION 1

PROJECT INITIATION

In December of 1975, TVA obtained EPA energy pass-through funds for the task entitled "Study of Chlorinated Water Effluent Quality from a Once-Through Cooling System" under the project "Characterization of Effluents from Coal-Fired Utility Boilers." Such a research effort was needed to develop a methodology for performing chlorine minimization/optimization programs needed to comply with EPA effluent guidelines and National Pollutant Discharge Elimination System (NPDES) permits.

NPDES permits for TVA fossil-fueled power plants require that free chlorine residual shall not exceed an average concentration of 0.2 mg/l and a maximum instantaneous concentration of 0.5 mg/l at the outlet corresponding to an individual unit during a maximum of one 2-hour period per day. They further require that no discharge of chlorine is allowed from one unit while another unit at the same station is being chlorinated. Other utilities around the United States have received permits containing similarly worded discharge limitations.

EPA has contended that a lower feed concentration of chlorine coupled with an increase in the frequency of the treatment would result in adequate condenser performance and satisfactory levels of chlorine residuals in the cooling water effluent. Therefore, the purposes of this study were as follows: (1) To fully characterize the chlorinated effluent from a once through condenser cooling system, (2) to identify the main factors that control chlorine used, (3) to evaluate the interrelationship of these factors with chlorine usage, (4) to evaluate the efficiency of different chlorination practices, (5) to determine the levels of chlorine that are necessary to maintain unit efficiency with optimization and/or minimization of the use of chlorine, and (6) to develop a methodology so that TVA and other power plants may also quantify and evaluate their current chlorination practices.

Originally, this research effort was to take place at TVA's Kingston Steam Plant. Since a significant seasonal change in the raw water source for this plant results in a corresponding variation of raw water pH, affecting chlorination efficiency, the study was changed to the John Sevier Steam Plant on the Holston River. Although there is some variation in this raw water source, the drastic seasonal change in pH does not occur. This study change was made on January 16, 1976.

The research effort consists of three phases. Phase I in the summer of 1976 was used to characterize the chlorinated cooling water system at the plant. Phase II in the summer of 1977 consisted of a more detailed study for further understanding the characteristics of the system affecting chlorine use. Phase III in 1978 will test the most optimum procedure for operating the cooling system with minimum chlorine usage.

SECTION 2

INTRODUCTION

The John Sevier Steam Plant was chosen for this study due to the nature of its cooling water source, i.e., the Holston River has a high chlorine demand, high nitrogen content, and high biochemical oxygen demand as compared to the cooling water source at other TVA plants. The Environmental Protection Agency conducted a water quality study on the upper Holston River in 1972 (TS-03-71-208-07)[1]. They determined that the South Fork of the Holston River downstream of Fort Patrick Henry Dam, and the Holston River downstream of the confluence of the North and South Fork, were grossly polluted by five major waste dischargers. Although effluent limitations have been established for these sources and much progress in pollution abatement has been achieved, these rivers are still significantly polluted by a wide variety of waste dischargers. They are:

Tennessee Eastman Corporation

Holston Army Ammunition Plant

Mead Paper Company

City of Kingsport Sewage Treatment Plant

Holliston Mills

Due to this problem and the need for more definitive data on chemical species that might affect the use of chlorine, the experimental design included the analyses of water samples for the following parameters: ammonia, pH, temperature, alkalinity, total organic carbon, total nitrogen, conductivity, total suspended solids, and chlorine demand. Phase I sampling of the intake water was conducted approximately twice per month on the days the chlorinated cooling water system was tested for free and total residual chlorine. During Phase II of the study, sampling and testing were conducted weekly.

The chlorinated water samples were analyzed for free and total chlorine residuals. Amperometric and diethyl-p-phenylenediamine (DPD) methods of chemical analysis were used although the majority of the data was collected with the amperometric direct titration method. Three sampling stations were used during Phase I (see Figure 1). They were (1) the unit intake pump discharge tunnel approximately ten feet from the chlorine injection point, (2) the condenser inlet, and (3) the condenser outlet. Sampling of chlorinated water at locations a, a^1, b, and c (Figure 1) was initially scheduled to occur several times during Phase I and once per week per unit at locations b and c during Phase II of the research effort. In an effort to identify the efficiency of the present chlorination practice and alternate practices, condenser performance tests were initially performed once per month per condenser during Phase I and increased to once every two weeks per condenser during Phase II.

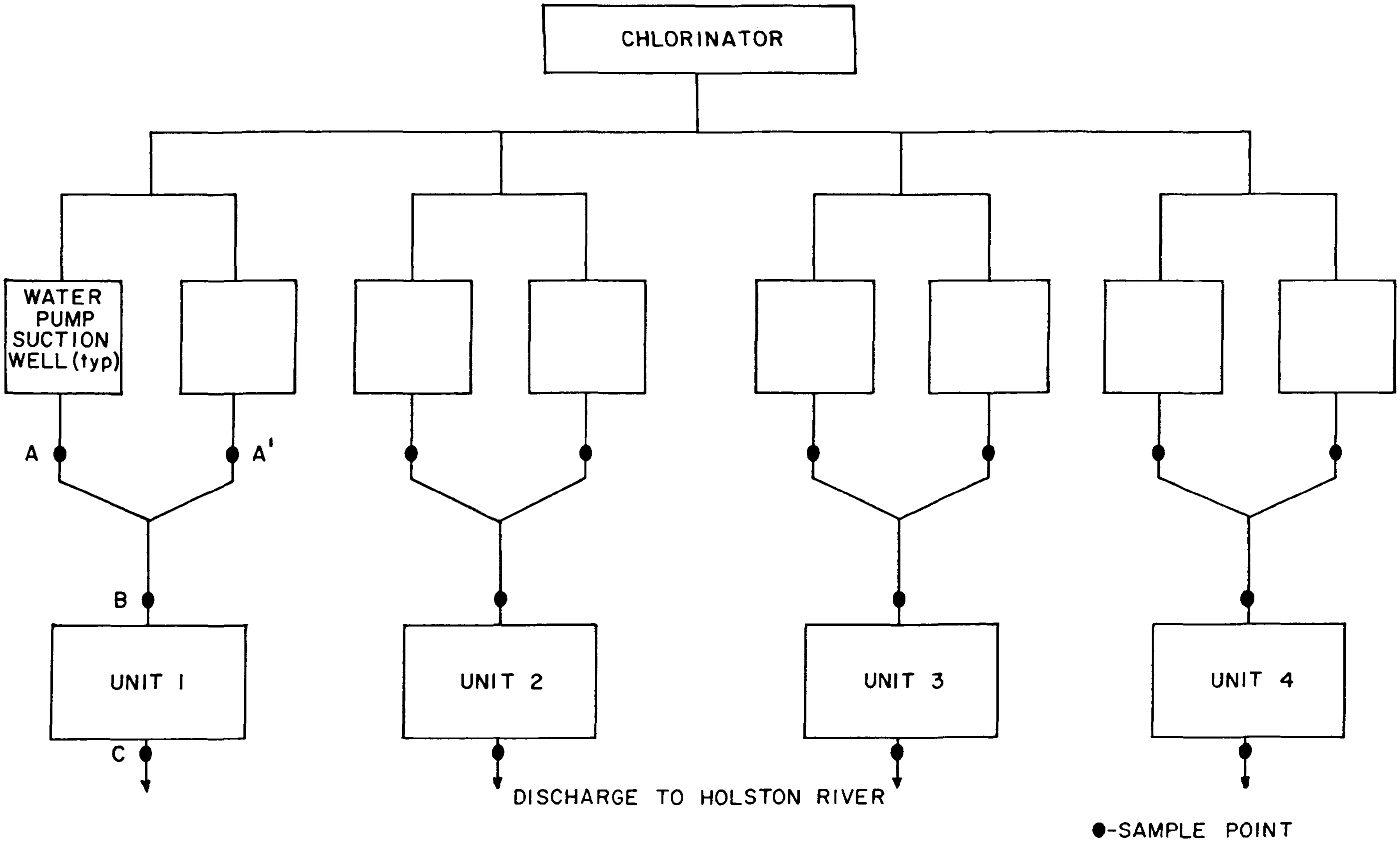

Figure 1. Chlorination system at John Sevier Steam Plant.

SECTION 3

CONCLUSIONS

The following conclusions are based upon data of Phases I and II and should not be construed as final until Phase III has been completed and the data analysis from all three phases combined. The following conclusions summarize the results obtained from Phases I and II.

1. Chlorine feed is a function of inlet water temperature and chlorine demand.

2. Chlorine feed has a direct effect on chlorine consumption through the system.

3. There is a direct relationship between the chlorine feed rate and the consumption of free chlorine across the condenser.

4. No significant relationship was noted between inlet water temperature and general water quality at John Sevier; however, trends were observed.

5. Chlorine feed rate may be lowered at John Sevier with no loss in condenser performance as long as a free residual concentration between 0.1 and 0.2 mg/l is maintained at the condenser outlet.

6. Optimum chlorine feed regime for John Sevier is three times per day for 20 minutes or six times per day for 10 minutes for each condenser.

7. Proposed new feed rates for John Sevier based on inlet water temperature are:

Temperature Range (°F)	Feed Rate (lb/day)
68° and up	2,500-3,500
60-68°	2,000-2,500
Less than 60°	Less than 2,000

8. Relationship between chlorine demand and corresponding feed rate at John Sevier may be applied to other TVA power plants by taking the following data obtained at the other plants: water quality, condenser performance history, present chlorination regimes, performance of the chlorinator, and (comparing with John Sevier data) water flow. Field studies would subsequently be initiated.

9. The decrease in chlorine usage at John Sevier would reduce the amount of chlorine used and therefore reduce the amount of money spent on chlorine.

SECTION 4

THE APPROACH

The initial chlorine feed rate and duration of feed at the John Sevier Steam Plant under past and present operating practices was 6000 lb/24 hrs. per unit at 20 minutes twice per day. After obtaining preliminary test data in March of 1976, the following feed rates and duration of feed were incorporated into a test plan for Phase I:

Unit 1	6000 lb/day for 2 hrs. once/day
Unit 2	7500 lb/day for 20 min. twice/day
Unit 3	4500 lb/day for 20 min. twice/day
Unit 4	6000 lb/day for 20 min. twice/day

The feed rate used on Unit 1 represented an attempt to measure the effect of increased chlorine duration on condenser cleanliness. The feed rate presented for Unit 2 represented an attempt to measure the effect of increased chlorine concentration on condenser cleanliness. The feed rate used for Unit 3 represented an attempt to measure the effect of decreased chlorine concentration on condenser cleanliness. Unit 4 was the control condenser with the feed rate, duration, and frequency the same as current plant practice.

SECTION 5

PRELIMINARY DATA

The results of preliminary tests are shown in Tables 1 and 2. With the condition that the only data considered in the analysis to determine future experiment changes would be data taken during steady state conditions, the following conclusions were obtained from the preliminary testing:

1. Total chlorine measurements taken at the point of chlorination (A,A´) agreed (±10%) with the calculated chlorine based upon the feed rate and flow at the point of chlorination.

2. Total residual chlorine at the inlet to the condenser was approximately 65 percent of the chlorine feed.

3. Total residual chlorine at the outlet of the condenser was approximately 50 percent of the chlorine feed.

4. Chlorine was being consumed within the system and not being measured by the analytical techniques employed.

5. Free residual chlorine measured at the inlet to the condenser varied from test to test with a range of approximately 1 to 2 mg/l. However, the within-test range was approximately 0.3 mg/l.

6. Free residual chlorine at the outlet of the condenser was highly variable from test to test spanning a range of 0.1 to 1.65 mg/l. The within-test variation was small compared to the test-to-test variation.

As part of the data necessary to evaluate the present chlorination practice, the condenser performance data for 1974 and 1975 at John Sevier for Units 1-4 was plotted and found to display a seasonal trend (see Figure 2). The condenser apparent cleanliness factor begins to decline in late March from a value of 80-85 percent [85 percent is the maximum assumed in the HEI calculation[2] for a clean condenser (see Appendix A for explanation)] to approximately 70 percent in late August and then increases to 80-85 percent by November. Typically, the condensers are brush cleaned in the November to March period.

The historical performance (record) of the John Sevier condensers in conjunction with a control condenser performance record during the chlorination study would allow a comparison for the effect of different chlorination rates on condenser performance as measured by the apparent cleanliness factor. However, we must note that several other factors also affect the apparent cleanliness factor in addition to biofouling, i.e., inlet water temperature, air leakage, turbine back pressure, etc.

TABLE 1. JOHN SEVIER MAXIMUM MEASURED CHLORINE RESIDUALS AT CONDENSER INLET

Unit	Calculated Chlorine Feed (mg/l)	Free Chlorine (mg/l)	Total Chlorine (mg/l)
		March 2, 1976 1818-2031	
1	5.26	1.5	3.71
2	5.26	1.74	3.92
3	5.26	1.68	2.46
		March 3 0845-1017	
1	5.26	1.52	3.80
2	5.26	2.21	3.68
3	5.26	1.86	3.92
	MAXIMUM MEASURED CHLORINE RESIDUALS AT CONDENSER OUTLET		
		March 2 0915-0935	
1	5.26	1.56	4.53
2	5.26	0.70	4.00
3	5.26	0.35	2.87
		1230-1344	
1	4.38	0.91	2.98
1	3.51	1.20	3.45
		1818-2031	
1	5.26	0.99	2.67
2	5.26	1.20	3.40
3	5.26	0.6	1.42
		March 3 0845-1017	
1	5.26	1.65	2.69
2	5.26	0.41	2.10
3	5.26	0.33	2.19

Continued

TABLE 1 (continued)

March 11, 1976

Unit	Calculated Chlorine Feed (mg/l)	Free Chlorine (mg/l)	Total Chlorine (mg/l)
1	5.26	1.82	3.76
1	4.38	1.58	3.32
1	3.50	1.02	2.72
2	5.26	1.34	3.51
2	4.38	0.92	2.70
3	5.26	1.4	3.61
3	4.38	0.94	2.91
MAXIMUM MEASURED CHLORINE RESIDUALS AT CONDENSER OUTLET			
1	5.26	0.42	2.61
1	4.38	0.27	1.10
1	3.50	0.09	0.87
2	5.26	0.21	1.07
2	4.38	0.17	1.05
3	5.26	0.30	1.30
3	4.38	0.10	1.12

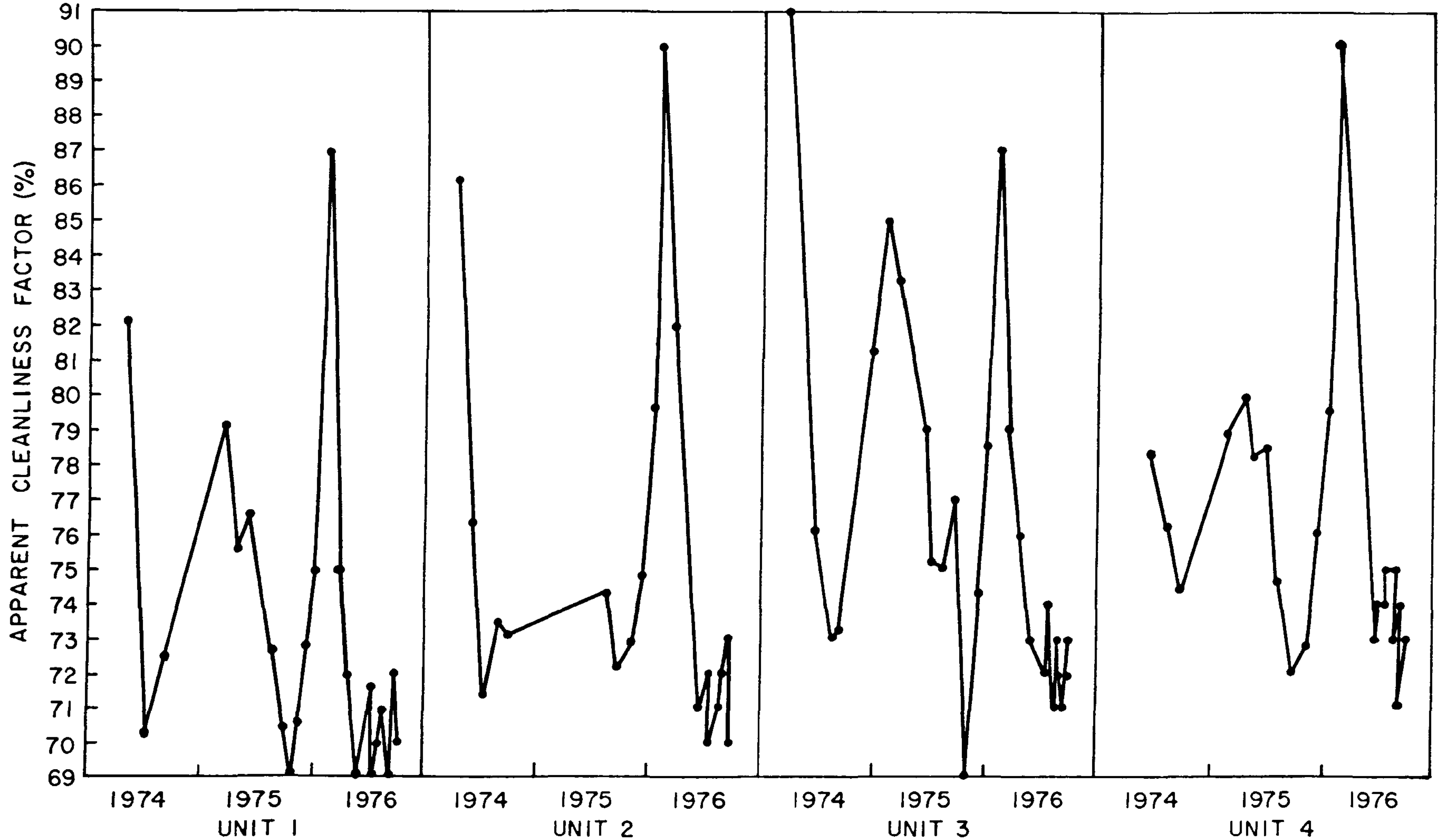

Figure 2. Units 1-4 condenser performance - John Sevier Steam Plant.

TABLE 2. CHLORINE CONCENTRATIONS

Date	Unit	Cl_2 Feed Rate lb/24 hrs.	Flow Rate Gal/min	Total Cl_2 Conc. (mg/l)	Intake Measurements FRC (mg/l)
6/9/76	2	6000	113,967	4.38	3.47
	3	4500	99,799	3.75	2.43
	4	6000	124,694	4.00	3.68
6/15/76	1	6000	128,581	3.88	2.14
6/16/76	1	4500	128,581	2.91	2.56
	2	4500	133,390	2.77	2.61
	3	4500	121,317	3.09	2.80
	4	4500	122,466	3.06	2.41
7/7/76	2	7500	138,798	4.50	3.50
	3	4500	139,631	2.68	2.33
	4	6000	129,241	3.86	2.90
7/8/76	1	6000	139,924	3.57	1.76
	2	7500	138,798	4.49	-
	3	4500	139,631	2.68	1.75
	4	6000	129,241	3.86	3.00
7/16/76	1	6000	124,128	4.02	1.92
	2	7500	137,866	4.52	2.60
	3	4500	119,689	3.13	0.91
8/13/76	1	6000	130,245	3.83	1.23
	3	4500	103,227	3.63	1.53
	4	6000	115,352	4.33	2.56
8/19/76	1	6000	139,655	3.58	-
	2	7500	128,108	4.87	-
	3	4500	132,630	2.82	-
	4	6000	130,766	3.82	-

$$\frac{\text{Feed Rate lb/24 hrs.}}{\text{Flow Rate gal/min.}} \times 83.22 = \text{mg/l } Cl_2$$

Based on this preliminary data, it was recommended that:

1. The free and total residual chlorine measurements be taken at the point of chlorination, the inlet to the condenser, and the outlet of the condenser.

2. Condenser performance tests and chlorine measurements should be taken weekly and together.

3. If the test condensers fall below 70 percent apparent cleanliness factor on five successive measurements or 5 percent below the control condensers' apparent cleanliness factor, then the chlorination rate and/or duration of feed should be increased.

4. The free chlorine concentration at the outlet of the condenser must be carefully measured by the most skilled laboratory analyst.

SECTION 6

PHASE I

TESTING AT JOHN SEVIER STEAM PLANT, MAY-AUGUST 1976

TVA initiated more intensive sampling of the condenser cooling water on May 11, 1976. The initial sampling attempted on the night of May 11 had to be terminated due to problems with the chlorinator. Because of these problems, testing was not started until May 26. On May 26, water samples were taken at the intake to determine the chlorine demand and its affect on chlorine dosage rates. Samples of chlorinated water were also taken at the inlet and outlet of the condensers for free and total residual chlorine determinations.

It was apparent from the preliminary data that a large variable existed since there was no reasonable correlation of measured total residual chlorine at the injection point and the feed rate of the chlorinator. This phenomenon occurred even when the same feed rate was tested on a different unit. Although other possibilities exist, it was hypothesized that this phenomenon was mainly a result of the feed rate of the chlorinator, i.e., the instrument setting on the chlorinator may not always correlate with what was actually fed since the chlorinators were twenty years old and in poor physical condition. On May 26, the prescribed feed rate of 7500 lbs/24 hrs could not be attained. The maximum feed rate experienced was 7000 lbs/24 hrs. On June 16, only 4500 lbs/24 hrs maximum could be fed to the condensers. This problem existed throughout Phase I testing.

Problems were also experienced with the amperometric titrators. Electrode malfunctions and electronic drift were the main problems.

A sample of the results of field tests from June 9, 1976 through August 19, 1976, may be found in the following pages. It was noted that the concentration of total residual chlorine obtained at the intake was far below the calculated feed concentration (see Table 2).

During the course of Phase I, we identified several factors that should be taken into account when comparing the data. The factors consist of water quality, the condition of the chlorinator, the condition of the cooling system, the feed rate, and accuracy and precision of the chlorine analysis. The following data is representative of that obtained during the Phase I study:

1. Water quality data (Figure 3).

2. Chlorine demand data (Table 3).

3. Condenser performance data (Figures 4-7).

TABLE 3. CHLORINE DEMAND

1976 Unit 3

Date	Feed Rate ($mg/l\ Cl_2$)	10 Min. ($mg/l\ Cl_2$)	30 Min. ($mg/l\ Cl_2$)
6/9/76	3.75	2.0	2.75
6/16/76	3.09	1.10	1.60
7/7/76	2.68	.98	1.68
7/8/76	2.68	.88	1.48
7/16/76	3.13	1.33	1.93

Date	Feed Rate ($mg/l\ Cl_2$)	1 Min. ($mg/l\ Cl_2$)	5 Min. ($mg/l\ Cl_2$)	10 Min. ($mg/l\ Cl_2$)
8/13/76	3.63	.43	.73	1.03
8/19/76	2.82	.30	.65	1.35

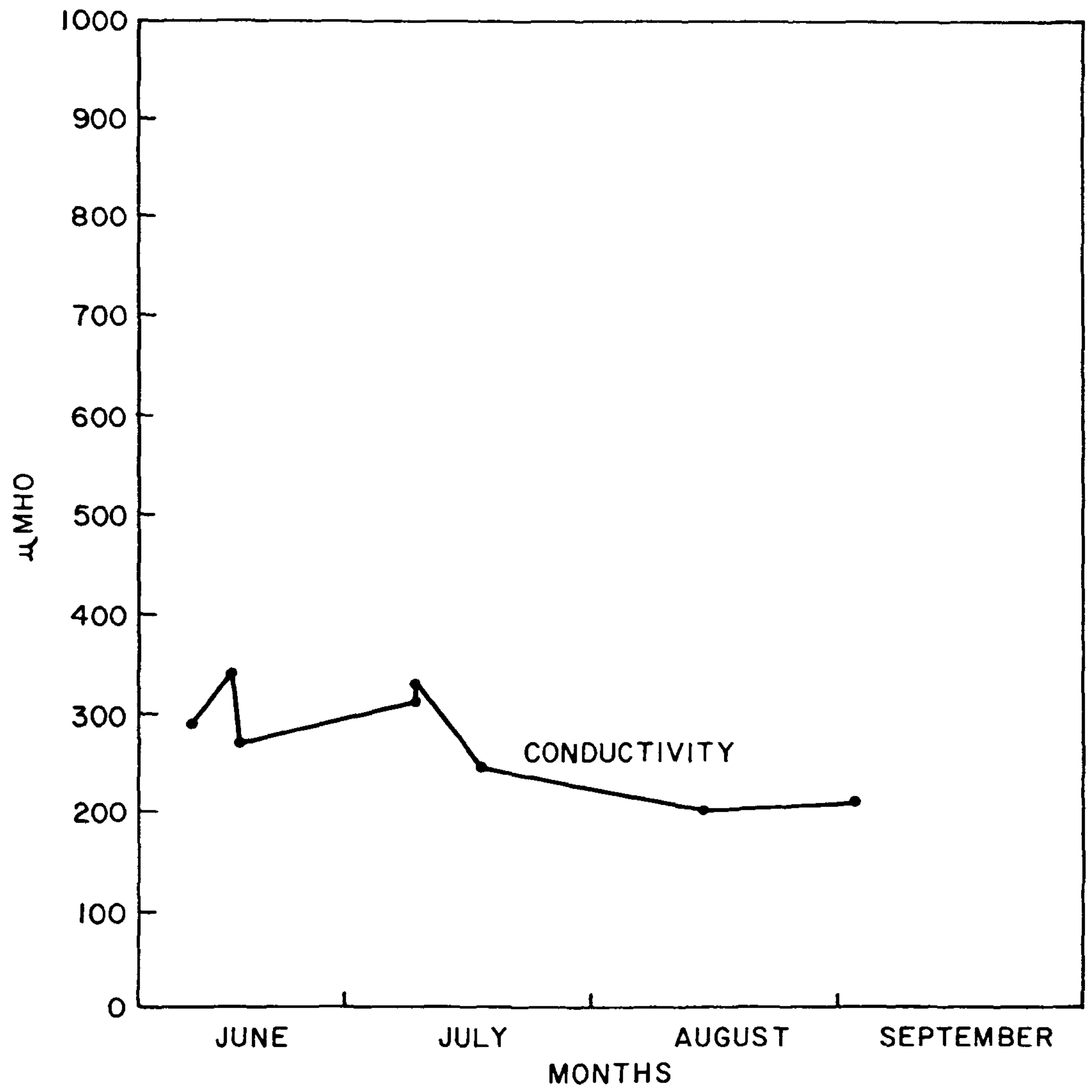

Figure 3. 1976 water quality data.

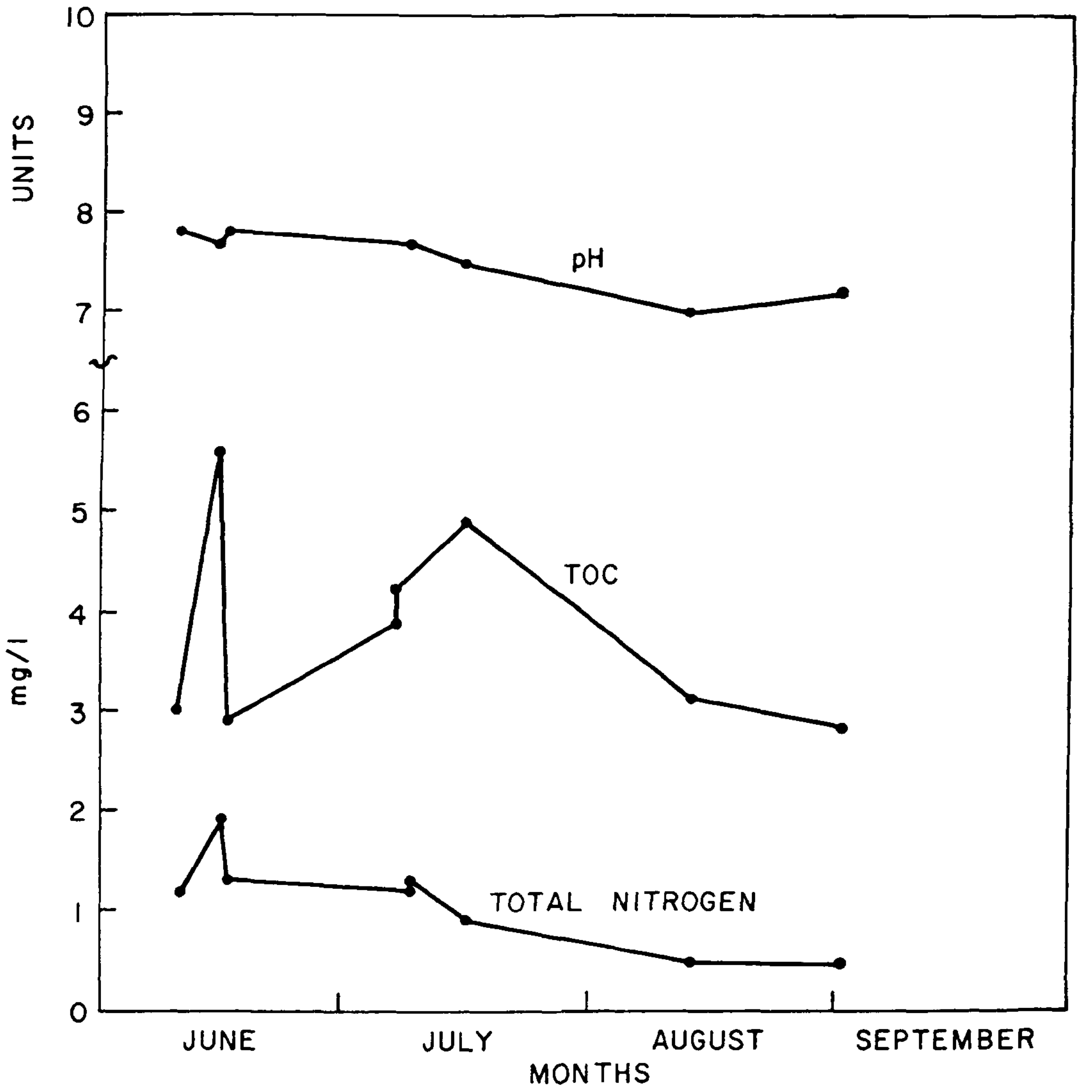

Figure 3 (continued)

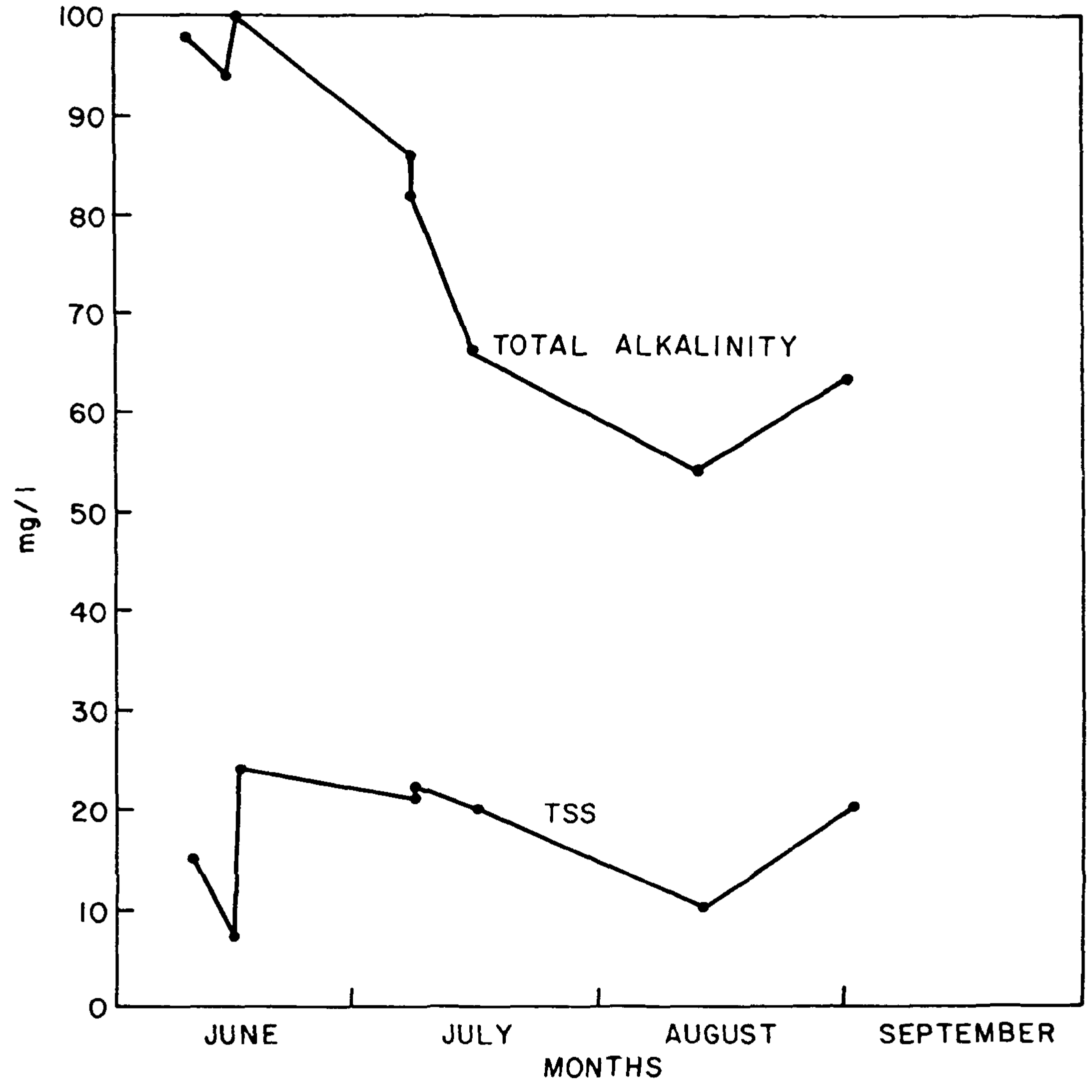

Figure 3 (continued)

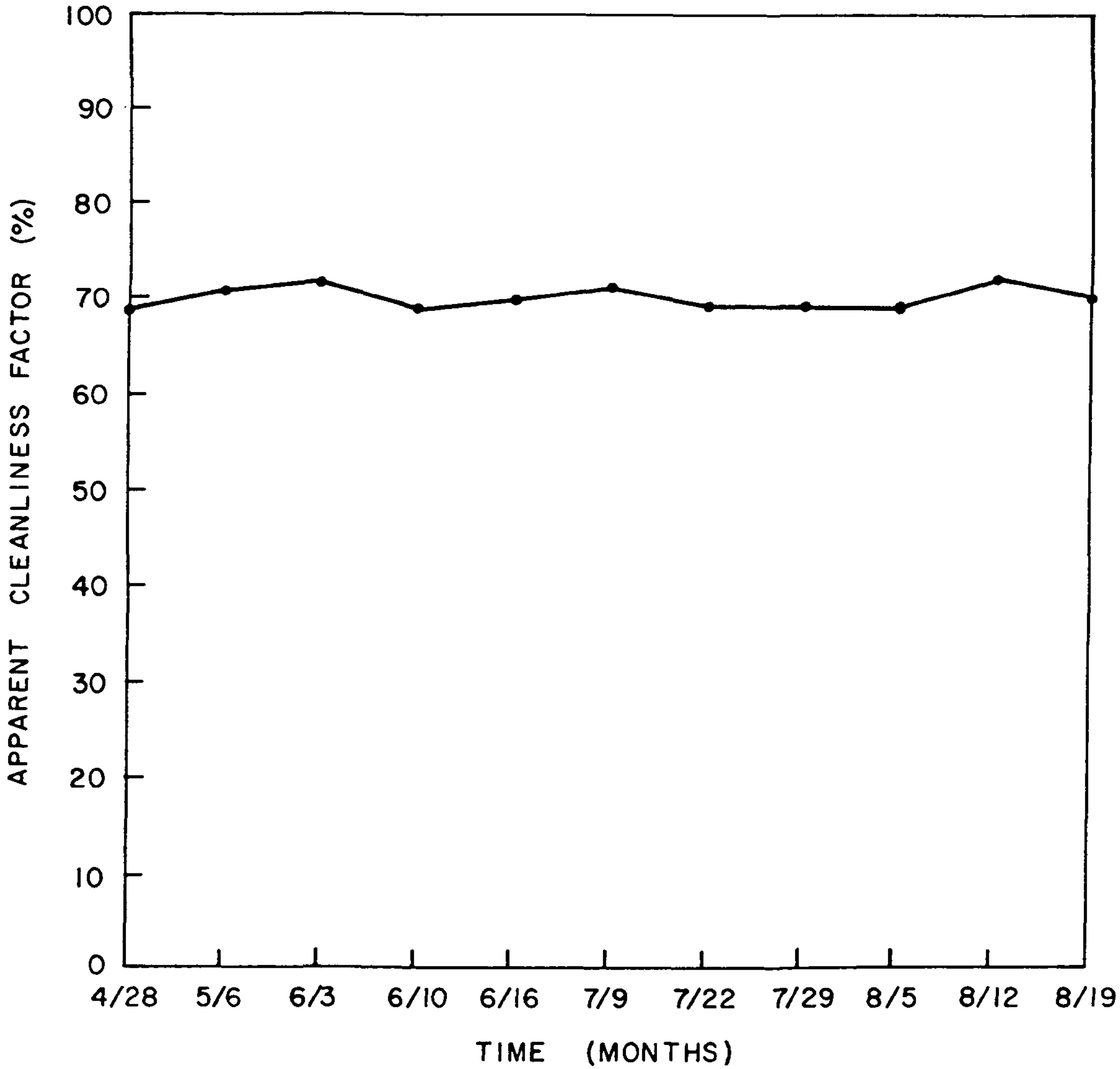

Figure 4. Unit I 1976 record of apparent cleanliness factor.

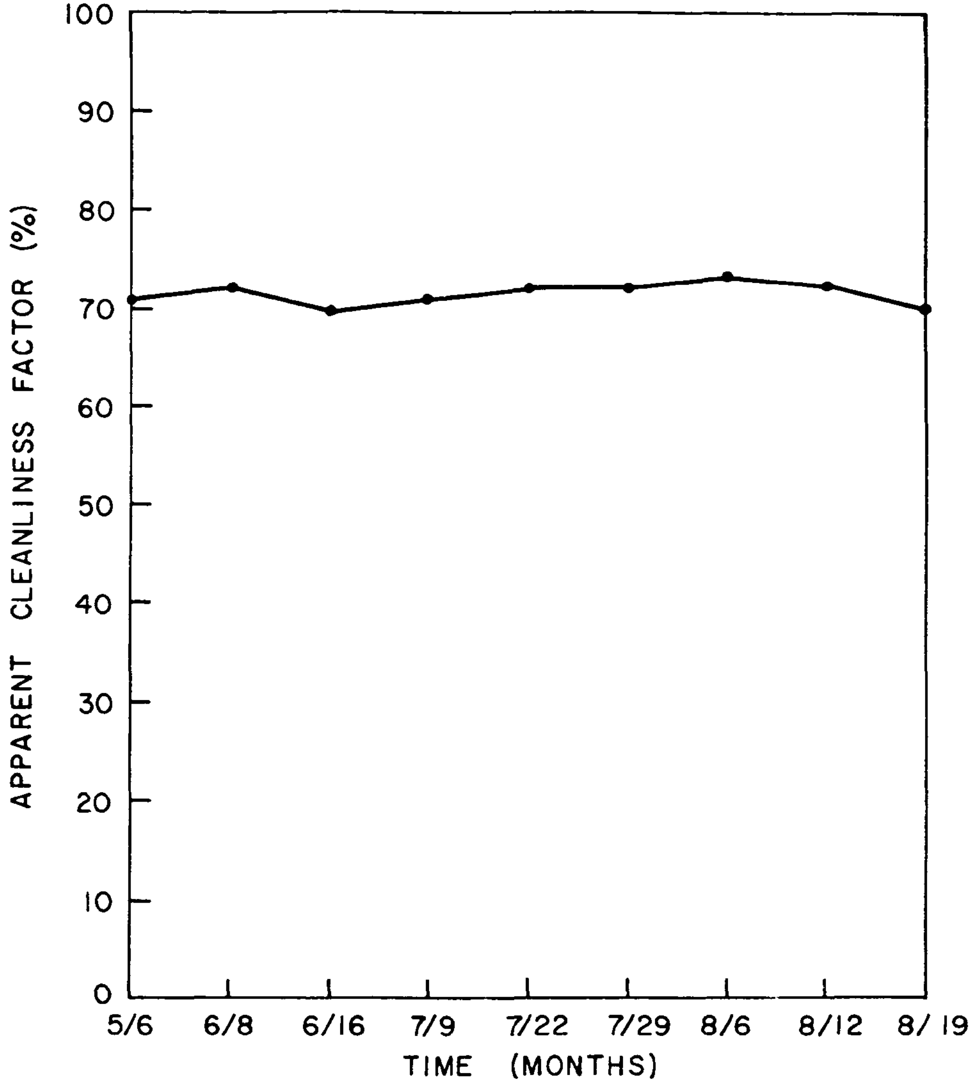

Figure 5. Unit 2 1976 record of apparent cleanliness factor.

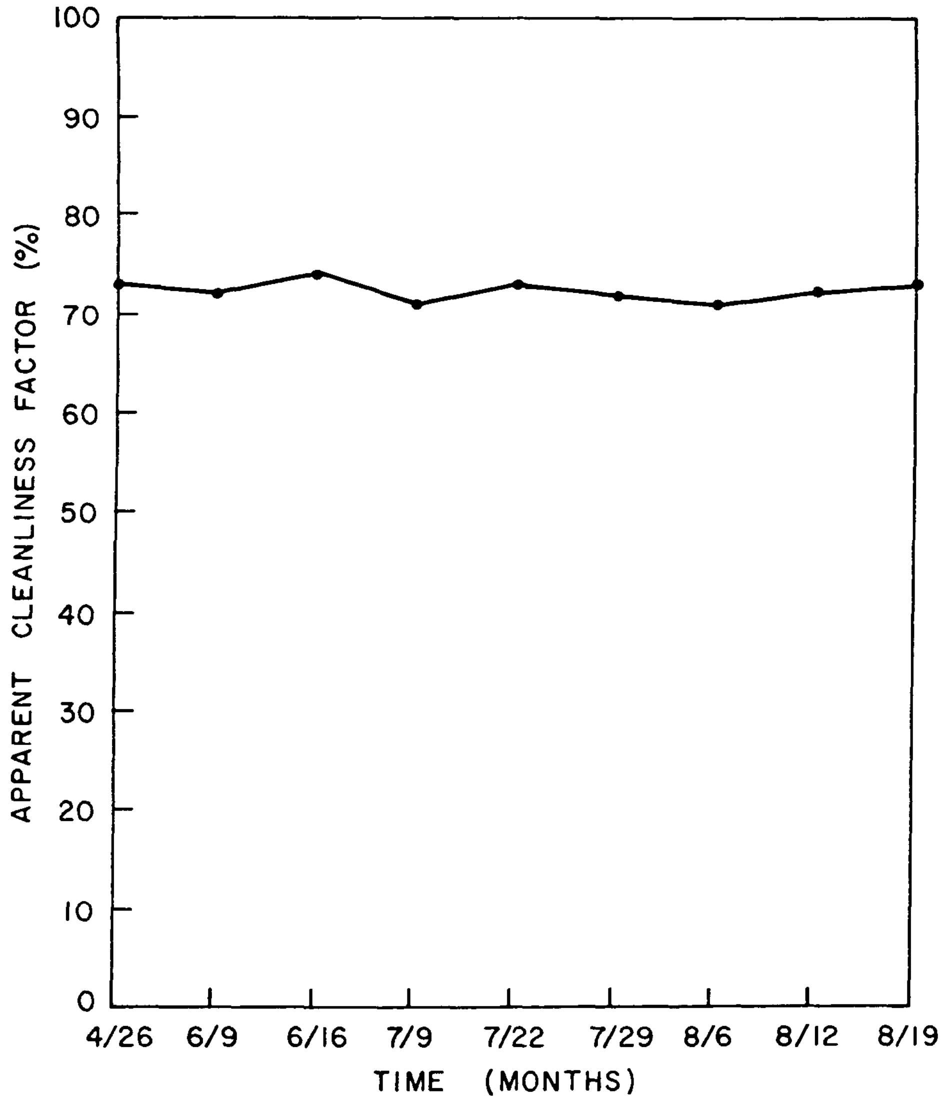

Figure 6. Unit 3 1976 record of apparent cleanliness factor.

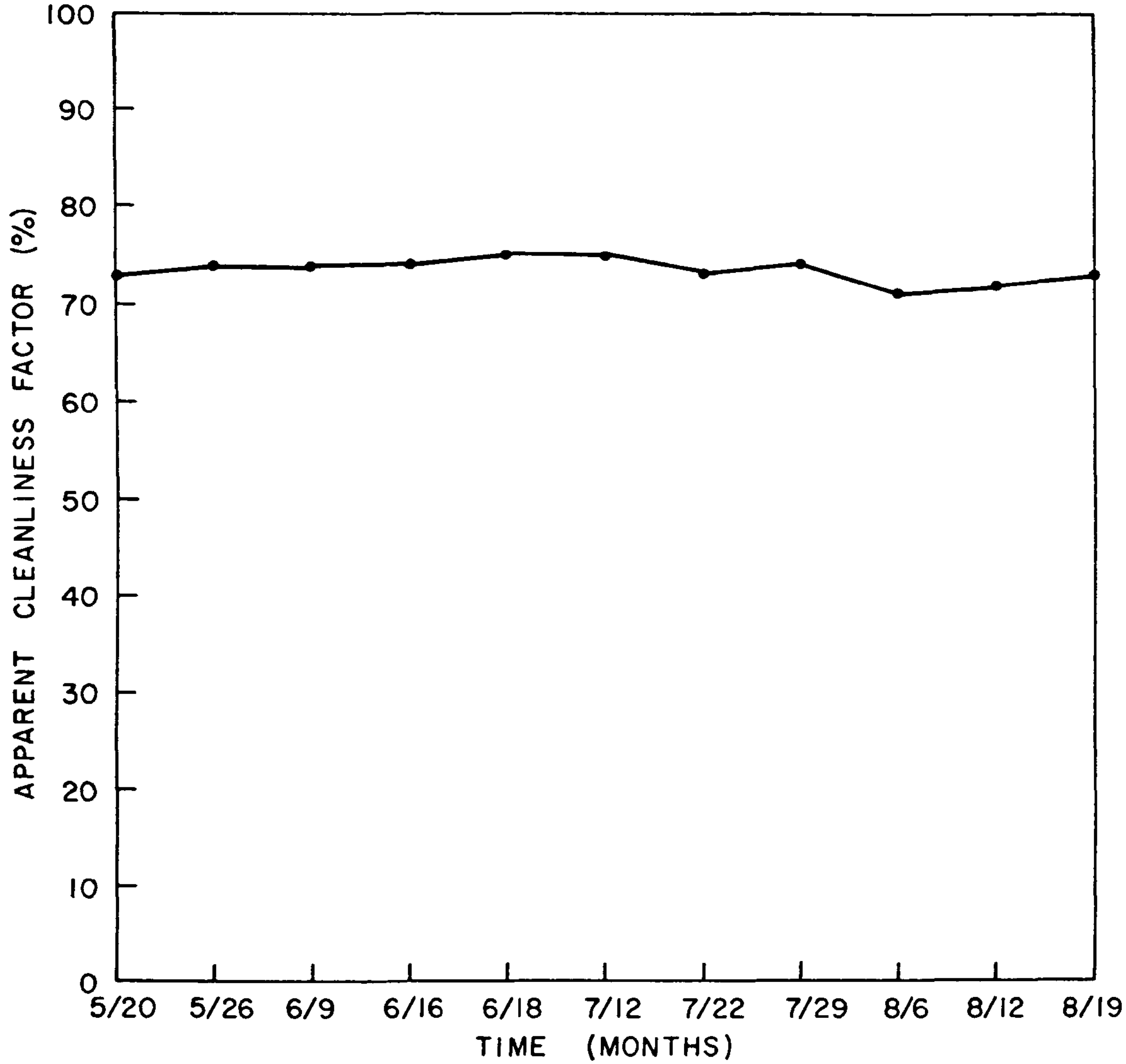

Figure 7. Unit 4 1976 record of apparent cleanliness factor.

4. Data for free and total residual chlorine concentrations at the intake, inlet, and outlet of the condenser for Units 1-4 (Table 4 and Figures 8-11).

An analysis of Phase I data was performed in order to address the following questions:

1. Do we sample the system often enough to get statistically meaningful data?

2. Do we get enough data points during a 20 minute chlorination period to allow reasonable statistical analysis of results?

3. Is there any correlation between feed rate and free and/or total residual chlorine at the outlet of the condenser?

4. Is there any trend in the amount of chlorine consumed through the system for different feed rates and water quality?

5. Is there any correlation between the chlorine demand of the intake water and the free or total residual chlorine at the outlet of the condenser for a given rate?

The data analysis indicated that there are several factors which influence the use of chlorine in the system. Some of these factors are:

1. Chlorine demand of the river water used for condenser cooling water.

2. Chlorine demands of the mixing tank at the chlorinator and the tunnel.

3. Chlorine demand of the condenser.

4. Flow rate of the condenser circulating cooling water.

Chlorine demand data was collected on the river water at the intake to the condenser cooling water system from May 27, 1976 to August 19, 1976. Ten and thirty minute chlorine demand curves were obtained for all test dates except for August 13 and 19. Samples taken on these respective dates had chlorine demand curves for 1, 5, and 10 minute intervals. Chlorine demands are shown in Table 3.

During this period the flow rates through the system varied from approximately 100,000 gal/min to 131,000 gal/min. Based upon the length of the tunnels (685 feet), the diameter of each tunnel (8 ft.), the number of tunnels (1), and an average flow rate of 120,000 gal/min, it takes approximately 2.2 minutes for water to arrive at the inlet to the condenser after exiting the chlorine injection point.

The chlorine demand data for the river water indicates a significant demand at 5 and 10 minutes. The difference between the respective measured value for total residual measured at the inlet to the condenser and at the intake has indicated that a chlorine demand exists within the

TABLE 4

CHLORINE STUDIES DATA SHEET

UNIT 2 FEED RATE 6,000 lbs/day LENGTH OF FEED 2x20 min DATE June 9, 1976

INLET			OUTLET			INTAKE			DISCHARGE		
TIME	FREE	TOTAL	TIME	FREE	TOTAL	TIME	FREE	TOTAL	TIME	FREE	TOTAL
10:05	.5	2.0	10:02	-	0.7	10:01	1.05	2.41			
10:10	.53	1.7	10:05	1.3	1.7	10:04	2.91	3.72			
10:14	.65	1.6	10:09	.92	1.56	10:08	2.57	3.07			
10:16	.65	1.8	10:12	.67	1.68	10:11	2.53	3.31			
10:22	.7	2.4	10:17	1.12	1.25	10:14	2.23	3.45			
10:26	.1	.2	10:20	?	1.07	10:17	2.69	3.47			
			10:24	.65	1.00						
			10:27	.5	0.0						

DEMAND DATA

- PH 7.5
- TEMP 21 °C
- 1 MIN. CLORINE DEMAND ____
- 5 MIN. CLORINE DEMAND ____
- 10 MIN. CLORINE DEMAND ____

FLOW RATE

APPARENT CLEANLINESS FACTOR 113,967 gpm

WATER QUALITY

- NH_3 .26
- NO_2, NO_3 .78
- ORG. N .13
- COND. 290
- TSS 15
- TOC 3.0
- TOT. ALK. 98

TABLE 4 (continued)

CHLORINE STUDIES DATA SHEET

UNIT 3 FEED RATE 4,500 lbs/day LENGTH OF FEED 2x20 min DATE June 9, 1976

INLET			OUTLET			INTAKE			DISCHARGE		
TIME	FREE	TOTAL	TIME	FREE	TOTAL	TIME	FREE	TOTAL	TIME	FREE	TOTAL
11:04	1.0	2.0	11:00	-	1.58	11:01	1.34	2.43			
11:08	.7	1.5	11:04	1.1	1.56	11:04	1.14	2.27			
11:13	.6	1.85	11:10	.85	1.16	11:07	2.36	2.85			
11:16	.8	1.9	11:15	.61	.95	11:11	1.54	2.28			
11:22	.15	.15	11:19	.62	1.08	11:14	1.51	2.57			
11:24	0.0	0.0	11:23	.42	0.0	11:17	1.97	2.39			

DEMAND DATA

PH 7.5

TEMP 21 °C

1 MIN. CLORINE DEMAND

5 MIN. CLORINE DEMAND

10 MIN. CLORINE DEMAND

FLOW RATE

APPARENT CLEANLINESS FACTOR 99,799 gpm

WATER QUALITY

NH_3 .26

NO_2, NO_3 .78

ORG. N .13

COND. 290

TSS 15

TOC 3.0

TOT. ALK. 98

TABLE 4 (continued)

CHLORINE STUDIES DATA SHEET

UNIT 4 FEED RATE 6,000 lbs/day LENGTH OF FEED 2x20 min DATE June 9, 1976

INLET			OUTLET			INTAKE			DISCHARGE		
TIME	FREE	TOTAL	TIME	FREE	TOTAL	TIME	FREE	TOTAL	TIME	FREE	TOTAL
12:05	.55	1.6	12:04	-	1.51	12:05	1.97	4.02			
12:08	.8	1.45	12:07	1.19	1.51	12:07	2.30	3.87			
12:12	.65	1.75	12:11	.73	1.23	12:12	2.24	3.52			
12:17	.65	2.0	12:15	.75	1.24	12:16	2.47	3.68			
12:22	.85	2.0	12:19	.78	1.15						
12:24	1.3	0.0	12:23	.7	1.07						
			12:26	.8	1.12						

DEMAND DATA

PH 7.5
TEMP 21^oC
1 MIN. CLORINE DEMAND ____
5 MIN. CLORINE DEMAND ____
10 MIN. CLORINE DEMAND ____

FLOW RATE

APPARENT CLEANLINESS FACTOR 124,694 gpm

WATER QUALITY

NH_3 .26
NO_2, NO_3 .78
ORG. N .13
COND. 290
TSS 15
TOC 3.0
TOT. ALK. 98

TABLE 4 (continued)

CHLORINE STUDIES DATA SHEET

UNIT 1 FEED RATE 6,000 lbs/day LENGTH OF FEED 1x2 hrs DATE June 15, 1976

INLET TIME	INLET FREE	INLET TOTAL	OUTLET TIME	OUTLET FREE	OUTLET TOTAL	INTAKE TIME	INTAKE FREE	INTAKE TOTAL	DISCHARGE TIME	DISCHARGE FREE	DISCHARGE TOTAL
9:09	1.07	1.54	8:55	-	.94	8:53	0.0	0.0			
9:14	1.24	1.72	8:59	.09	-	8:54	0.0	.85			
9:18	1.54	1.73	9:02	0.0	1.32	8:57	.43	1.34			
9:21	1.46	1.71	9:07	.09	1.39	9:01	.48	.76			
9:25	1.72	1.72	9:12	.1	1.52	9:06	.79	2.34			
9:30	1.32	2.03	9:17	.21	1.46	9:10	.32	.72			
9:35	1.32	2.6	9:21	.1	.9	9:13	.97	2.14			
9:40	1.1	1.1	9:25	.12	1.43	9:17	.27	.87			
9:44	1.21	2.61	9:30	.15	1.80	9:28	1.42	3.05			
9:49	1.4	2.59	9:37	.38	1.27	9:32	.43	1.35			
9:54	1.73	2.5	9:42	.21	1.00	9:44	2.23	5.52			
			9:45	.32	2.37	9:48	1.43	2.98			
			9:50	.30	2.38	9:51	2.32	4.94			
			9:55	~.5	2.39						
			10:00	.13	0.0						

DEMAND DATA

PH 7.5
TEMP 27.2°C
1 MIN. CLORINE DEMAND ____
5 MIN. CLORINE DEMAND ____
10 MIN. CLORINE DEMAND ____

FLOW RATE

APPARENT CLEANLINESS FACTOR 128,581 gpm

WATER QUALITY

NH_3 .5
NO_2, NO_3 .97
ORG. N .43
COND. 340
TSS 7
TOC 2.9
TOT. ALK. 94

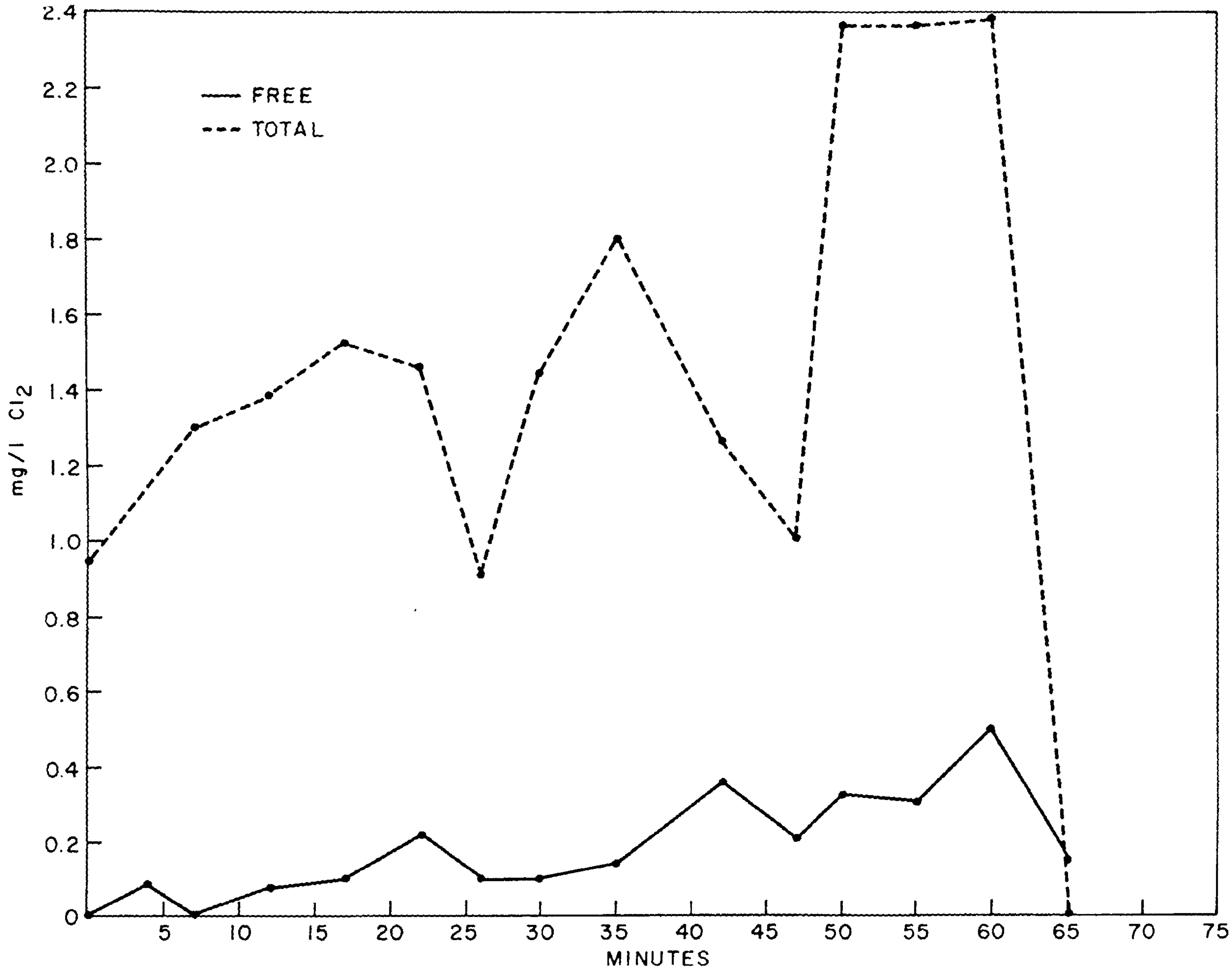

Figure 8. Unit I free vs. total residual measurements (outlet).

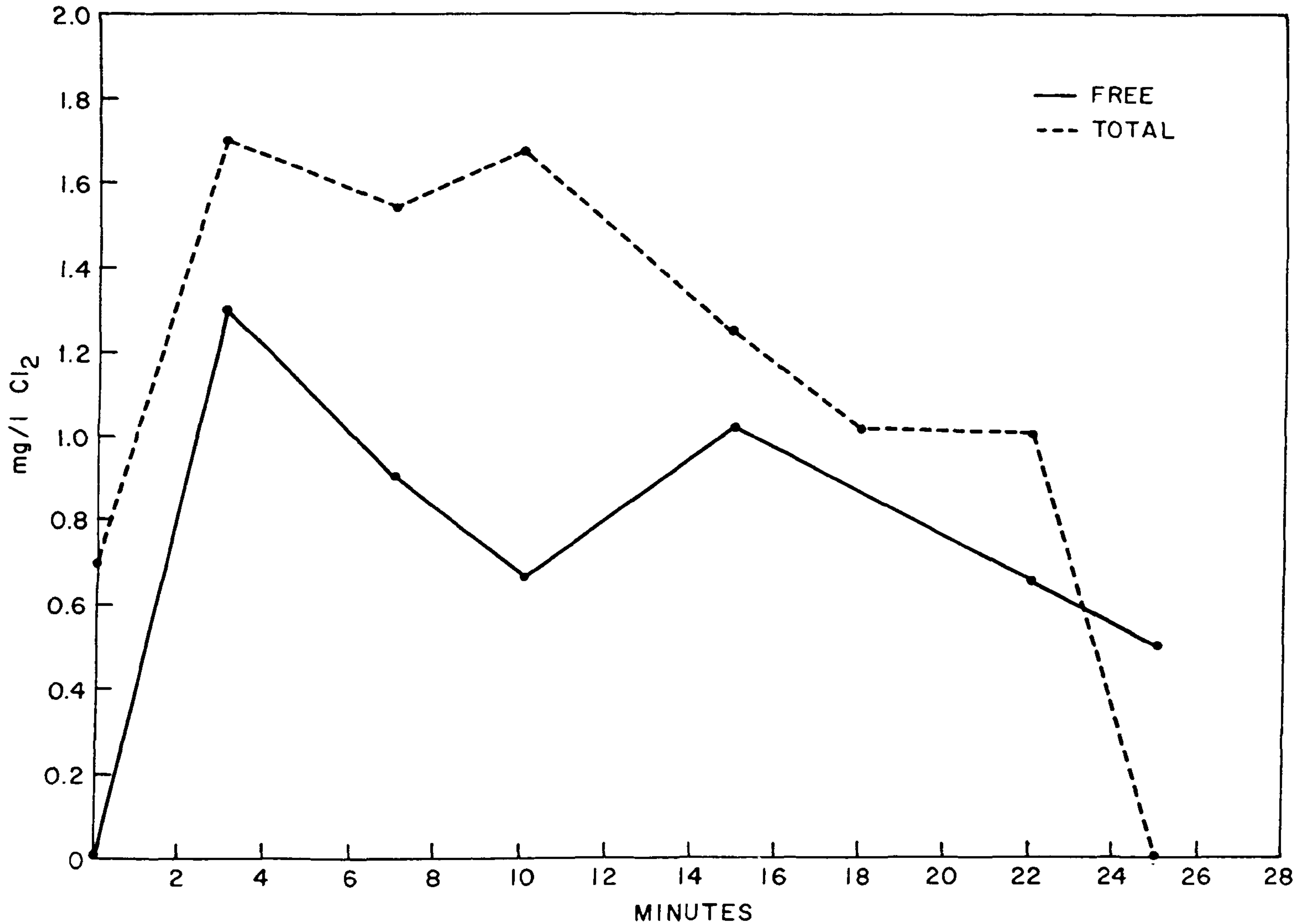

Figure 9. Unit 2 free vs. total residual measurements (outlet).

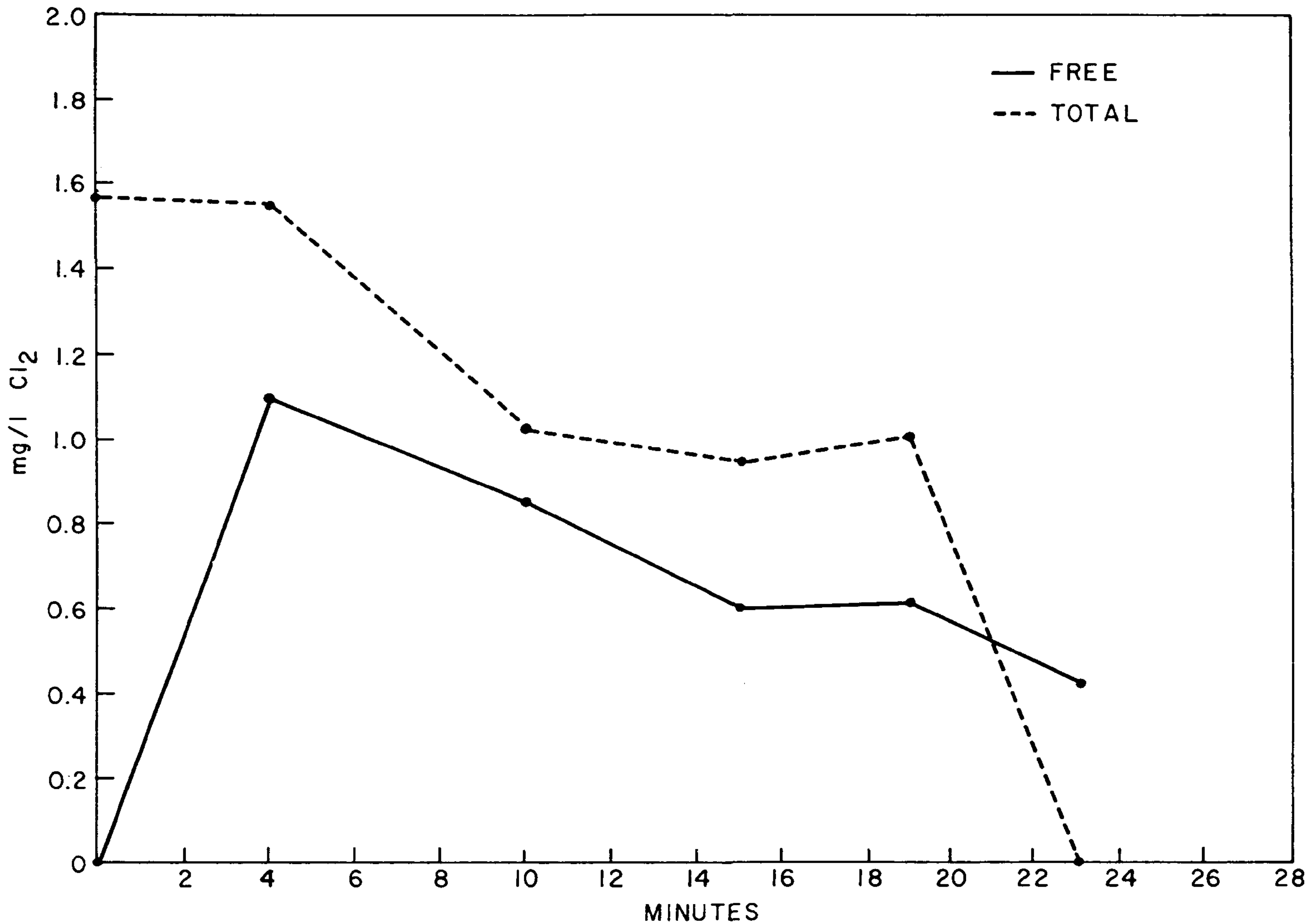

Figure 10. Unit 3 free vs. total residual measurements (outlet).

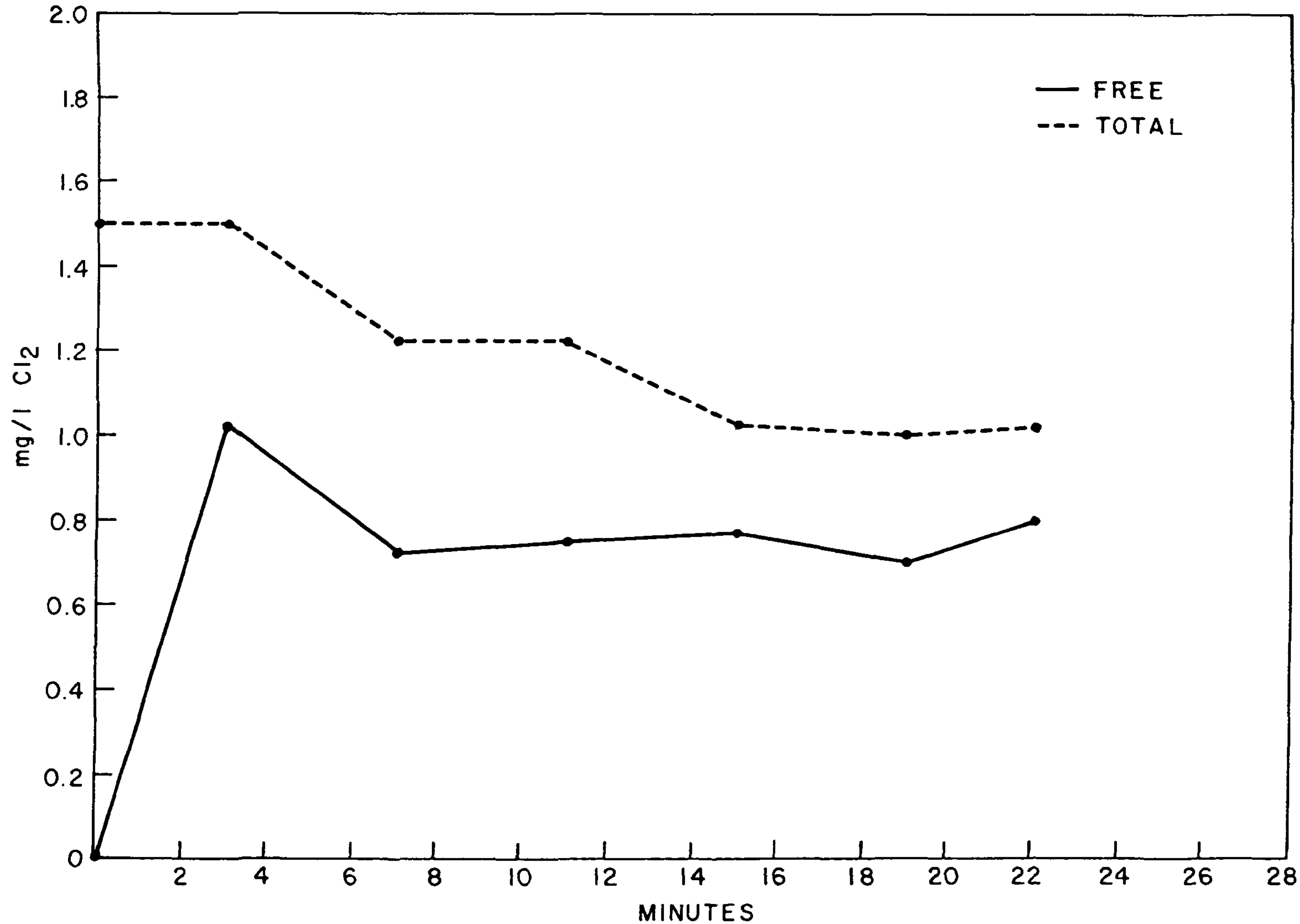

Figure 11. Unit 4 free vs. total residual measurements (outlet).

system and may be caused by any one or all of the following: demand of the water as a function of time and the chlorine demand of the tunnels and/or the mixing tank at the chlorinator injection point.

An accurate comparison of the chlorine demand of the water for samples HB2-7 with the difference in the feed concentration and the field measurement at the inlet of the condenser was not possible due to the time of reaction (2.2 minutes) from the chlorine injection to the inlet of the condenser. The chlorine demand for the water during this narrow period of time was not examined in the laboratory during Phase I except during the last two test days of August 13 and 19, 1976. Although the values could be calculated by extrapolating a plot of chlorine demand versus time, we believe that to assume the demand to be linear from 10 minutes to zero would be an error.

Chlorine concentration measurements at the outlet of the intake pump suction well were consistently less than the calculated chlorine feed rate. This difference has been attributed to the mixing tank, to the reaction of chlorine with water, and to the inability of the old chlorinator to maintain a set feed rate. The difference due to the mixing tank varied greatly from March of 1976, when the demand associated with the mixing tank was approximately 10 percent of the calculated input, to August of 1976, when the demand increased to approximately 40 percent of the calculated input (see Table 2).

During the test period of May through August, the total residual chlorine at the inlet of the condenser was generally 50 percent of the total residual chlorine measured at the intake. The free residual chlorine at the inlet to the condenser was approximately 70 percent of the total chlorine measured at the inlet. Furthermore, the outlet free residual chlorine was approximately 0.5 mg/l less than the inlet free residual chlorine and was to some extent independent of chlorination time and feed rate. Therefore, the change of free residual chlorine was attributed to a condenser demand.

The limiting factor for maintaining a high apparent cleanliness factor during the summer months appears to be the short time (5 seconds) for the reaction of free chlorine in the condenser. Therefore, on July 8, 1976, Unit 1 was chlorinated for one hour instead of the usual 20 minutes in order to determine if the free residual chlorine at the outlet of the condenser would change with a longer period of reaction. The outlet free chlorine measurements showed a consistent 0.5 mg/l difference for the total hour. This was similar to the inlet to outlet free chlorine measurement experienced previously for 20 minute chlorination periods. Thus, at a feed rate of 6000 lb/day, periods of chlorination longer than 20 minutes would probably not be advantageous.

Based on this information and an analysis of the data, recommendations for Phase II studies at John Sevier Steam Plan were established. They are as follows:

1. Chlorine demand tests on the river water should be performed at 1, 3, and 5 minute intervals.

2. Subsequent chlorination rates should be at 6000 lb/day at two 20 minute periods for a control basis and rates of 4500 and 3000 lbs/day on two other units.

3. Longer chlorination periods (2 hours) at 1500 lb/day should be tested on the fourth unit.

4. Most skilled laboratory analysts should be used to take measurements.

An analysis was also made of the chlorine demand test data for the river water at John Sevier Steam Plant. The formula used for this analysis was:

$$D = kt^n \tag{1}$$

where:

D = demand of the water (feed - residual)
k = chlorine demand after 30 minutes, ppm
t = contact time in % of 30 minutes
n = slope of curve (tan Θ)

$$D = kt^n$$

$$\frac{D}{k} = tn$$

$$\log \frac{D}{k} = n \log t$$

$$\frac{\log \frac{D}{k}}{\log t} = n$$

The above formula was developed and extensively researched and tested by Douglas Feben and Michael J. Taras using Detroit's water supply as the major source of samples.

The usefulness of this basic equation derived from measuring chlorine demands is the variation in the exponent n, i.e., the slope of the demand curve. The value of the exponent n reveals the speed of the reaction and is theoretically related to the nature of the organic material involved in the reactions with chlorine. Inorganic ions such as NH_3, Fe^{++}, and S^{-2} react instantaneously, causing rapid initial chlorine demand. This causes the exponent n to approach zero. Other results obtained from well waters in the greater Detroit metropolitan area, and Long Beach, California, show remarkably similar exponential values, varying between 0.01 for the Long Beach wells to 0.03-0.07 for the Detroit area wells. A chemical analysis of the well samples indicated the presence of the three most rapid chlorine-consuming substances-ammonia nitrogen, sulfide and ferrous ions. Also some simple unsubstituted amino acids were present; all of these substances resulted in the low exponential value.

As the value of the exponent increases, the more complicated the organic material. Of the organic materials, Feben and Taras found that the simple amino acids were generally found to react most readily with chlorine, whereas complex molecules like peptides and proteins were found to react more slowly.[4] The surface waters tested contained sizable amounts of complex organic material and traces of ferric ions as opposed to ferrous ions. This analysis substantiated the high exponential values calculated with the formula $D = kt^n$.[3,4,5]

In one series of tests conducted by Taras, several simple and complex organic and inorganic substances were tested for their individual chlorine demands; the simple and the inorganic materials resulted in low exponential values (0.02-0.19), and the complex organic materials resulted in high exponential values (0.19-0.30).[5]

The exponential reaction constant as a function of time is dependent upon the individual structure of the amino acid. An increase in the structural complexity results in higher values of the reaction constant n, and will, therefore, exhibit prolonged chlorine demand. A significant rise in the value of n would indicate a rise in the organic nitrogen present and, further, a deterioration in the raw water quality.[6]

The resulting application of this equation to data from the water samples taken during Phase I testing at John Sevier is found in Table 5 and Figure 12. As evidenced by the data in Table 5, approximately 20-25 percent of the total nitrogen consisted of organic nitrogen throughout Phase I even though the total nitrogen varied from 0.89 to 1.9 mg/l.

TABLE 5

1976 CHLORINE DEMAND UNIT 3

Test	Date	Hypothetical Feed Rate (mg/l)	Chlorine Demand (mg/l)		Slope (n)	Total N	% Organic N
			10 Min.	30 Min.			
HB-2	6/9/76	5.0	2.4	2.7	0.106	1.17	11%
		4.0	2.1	2.7	0.227	1.17	11%
HB-3	6/15/76	5.0	2.85	4.2	0.366	1.90	23%
HB-4	6/16/76	4.0	2.7	2.65	-0.017	1.33	23%
HB-5	7/7/76	6.5	2.1	1.6	-0.245	1.20	19%
		4.0	2.3	2.1	-0.082	1.20	19%
		5.0	2.3	2.0	-0.126	1.20	19%
HB-6	7/8/76	5.0	1.4	2.1	0.366	1.32	29%
		6.5	0.7	1.6	0.746	1.32	29%
		4.0	1.4	2.1	0.366	1.32	29%
		5.0	1.4	2.1	0.366	1.32	29%
HB-7	7/16/76	5.0	1.7	2.2	0.233	0.89	23%
		6.5	1.3	1.8	0.293	0.89	23%
		4.0	1.7	2.3	0.273	0.89	23%
			5 Min.	10 Min.			
HB-8	8/13/76	5.0	0.8	1.2	0.585	0.98	24%
		4.0	0.7	1.1	0.652	0.98	24%
HB-9	8/19/76	5.0	1.1	1.9	0.788	1.01	22%
		6.5	1.3	2.3	0.823	1.01	22%
		4.0	0.9	1.9	1.078	1.01	22%
		5.0	1.1	1.9	0.788	1.01	22%

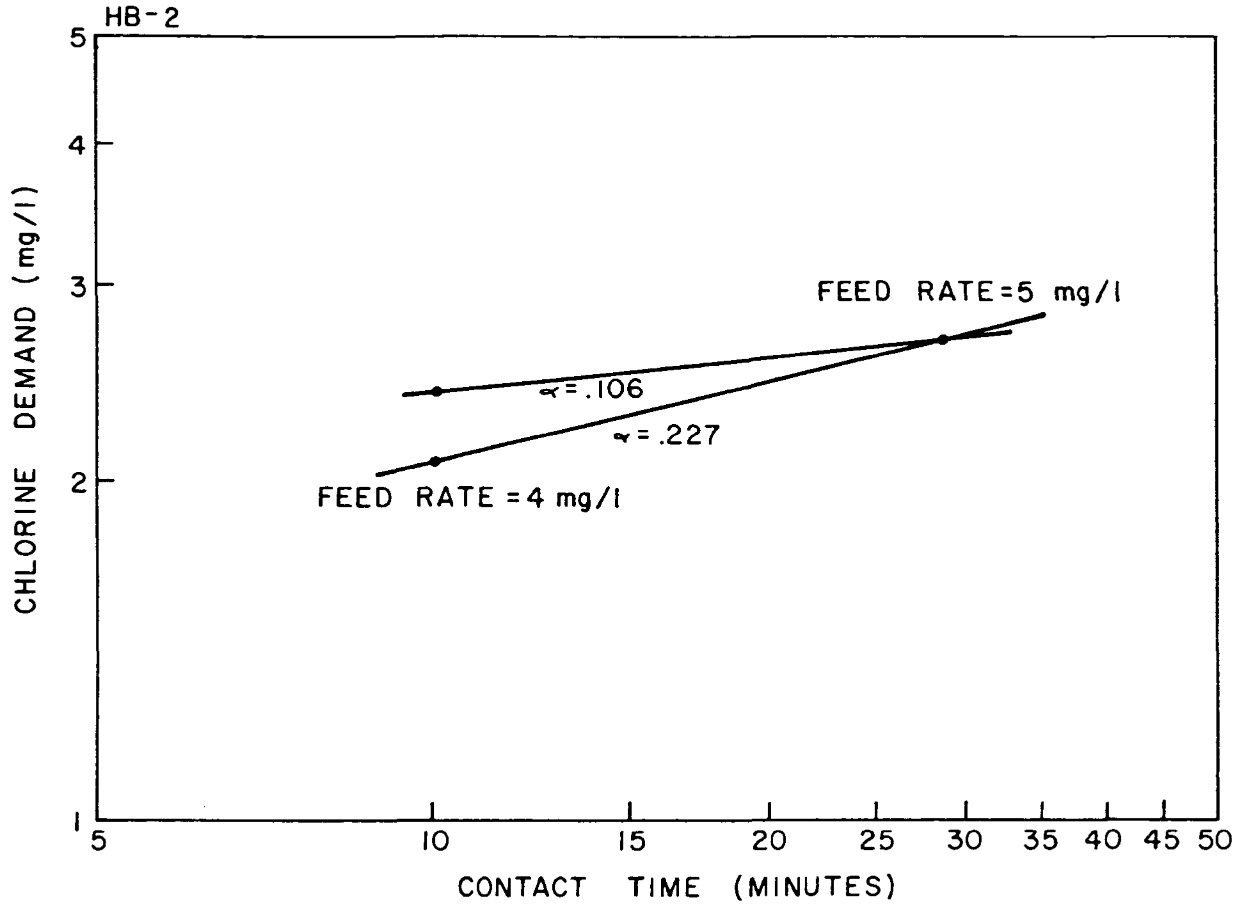

Figure 12. Relationship between chlorine consumed and contact time.

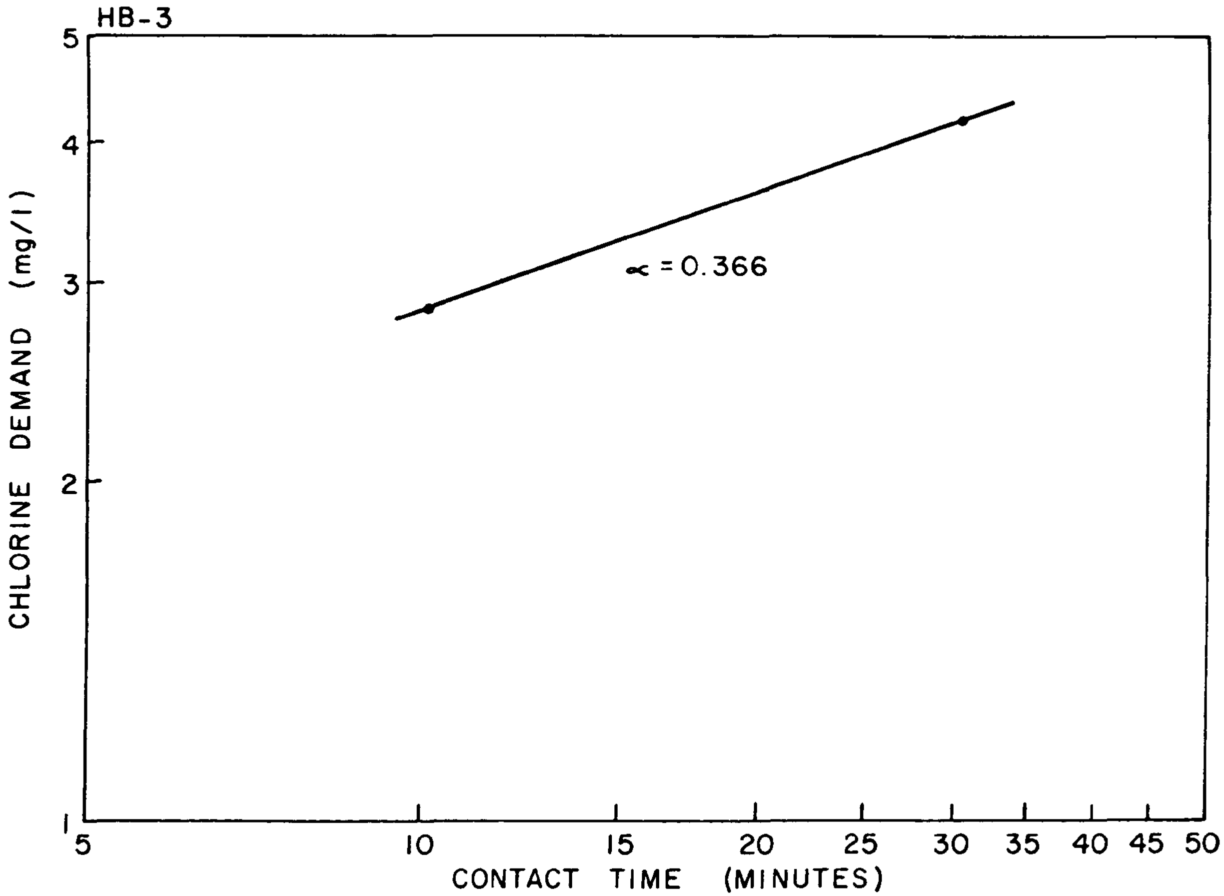

Figure 12 (continued)

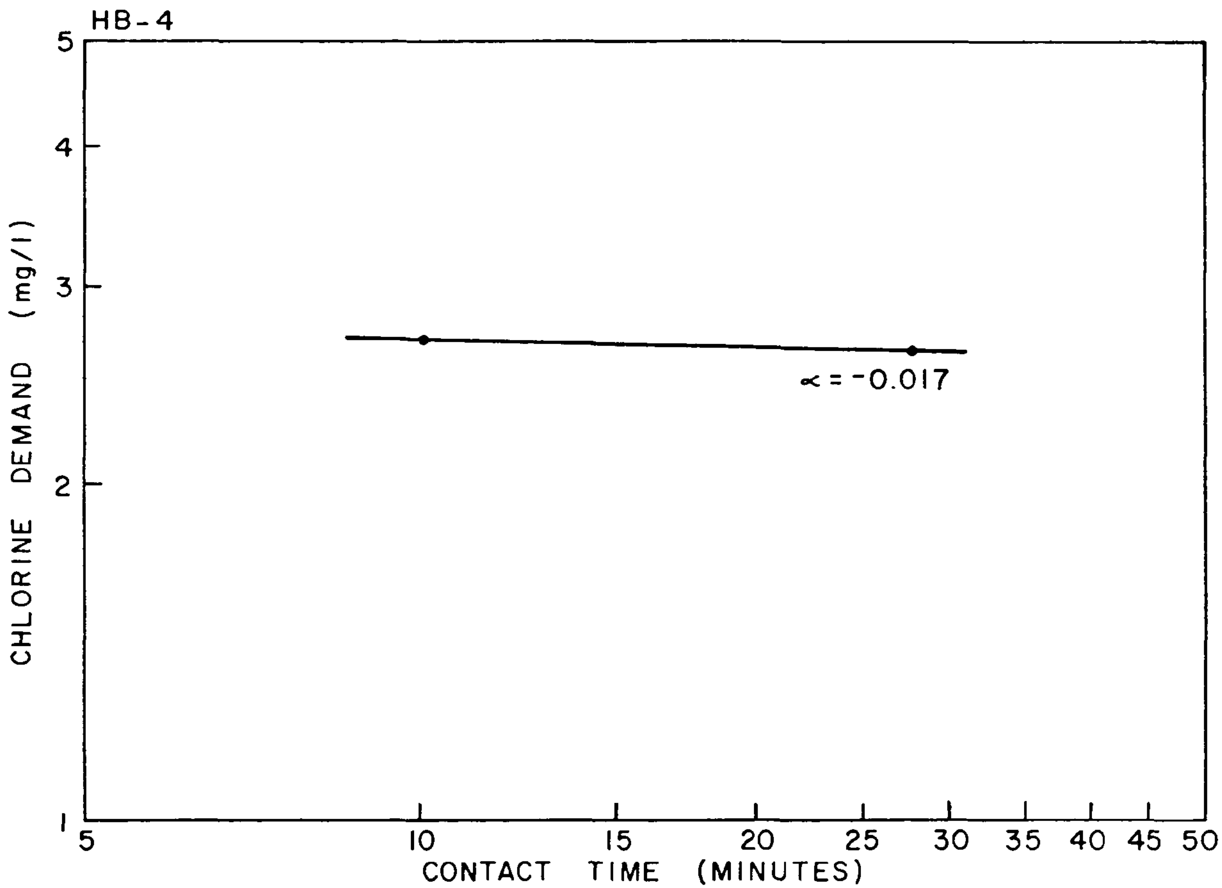

Figure 12 (continued)

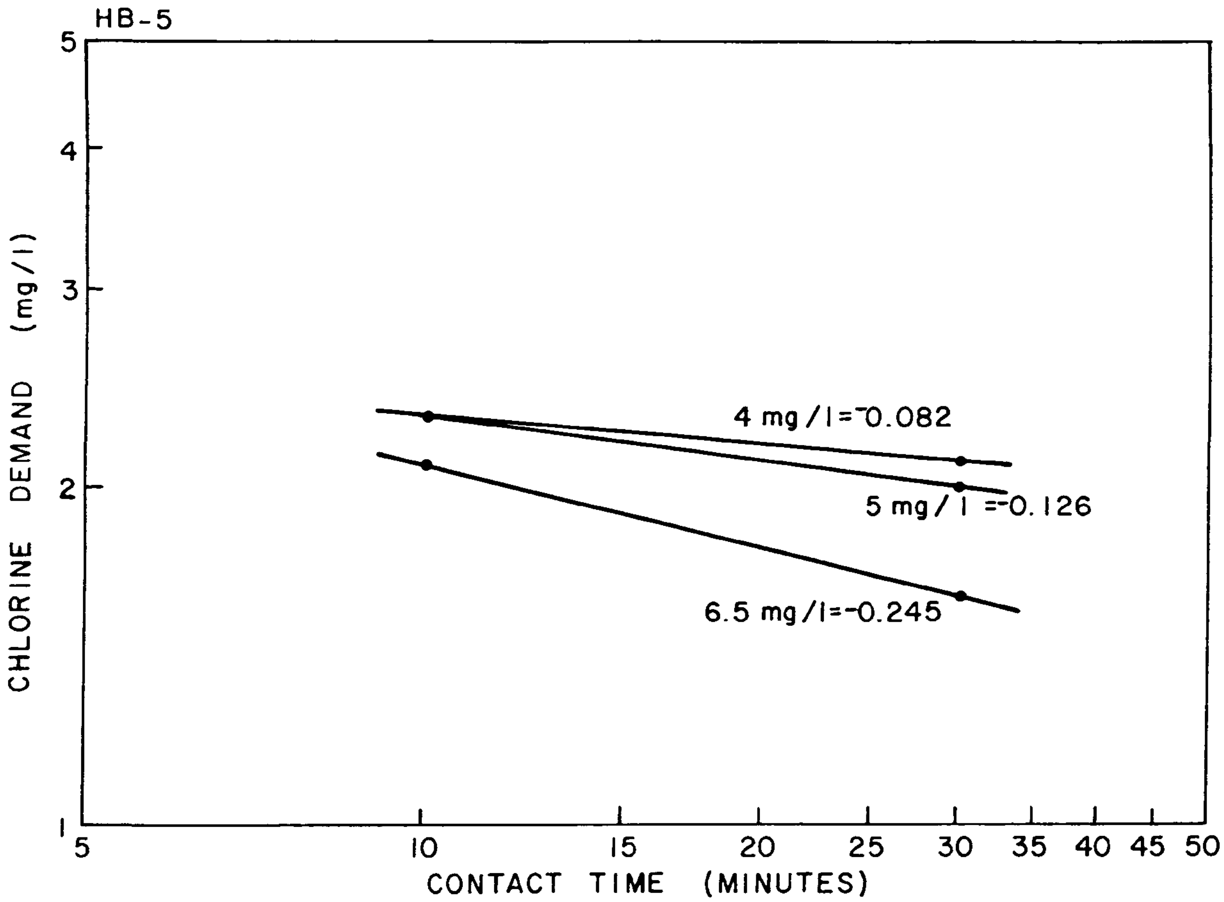

Figure 12 (continued)

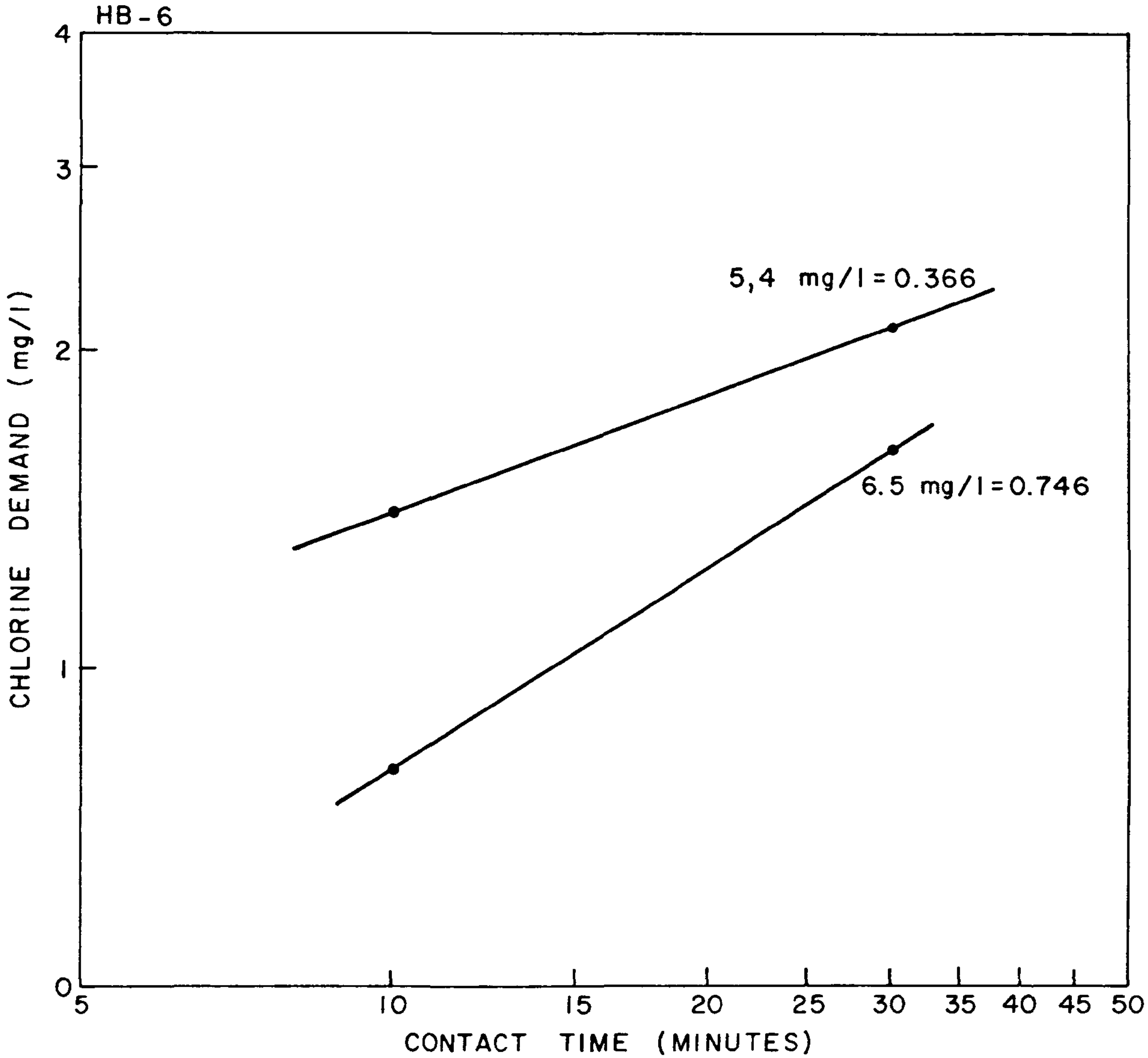

Figure 12 (continued)

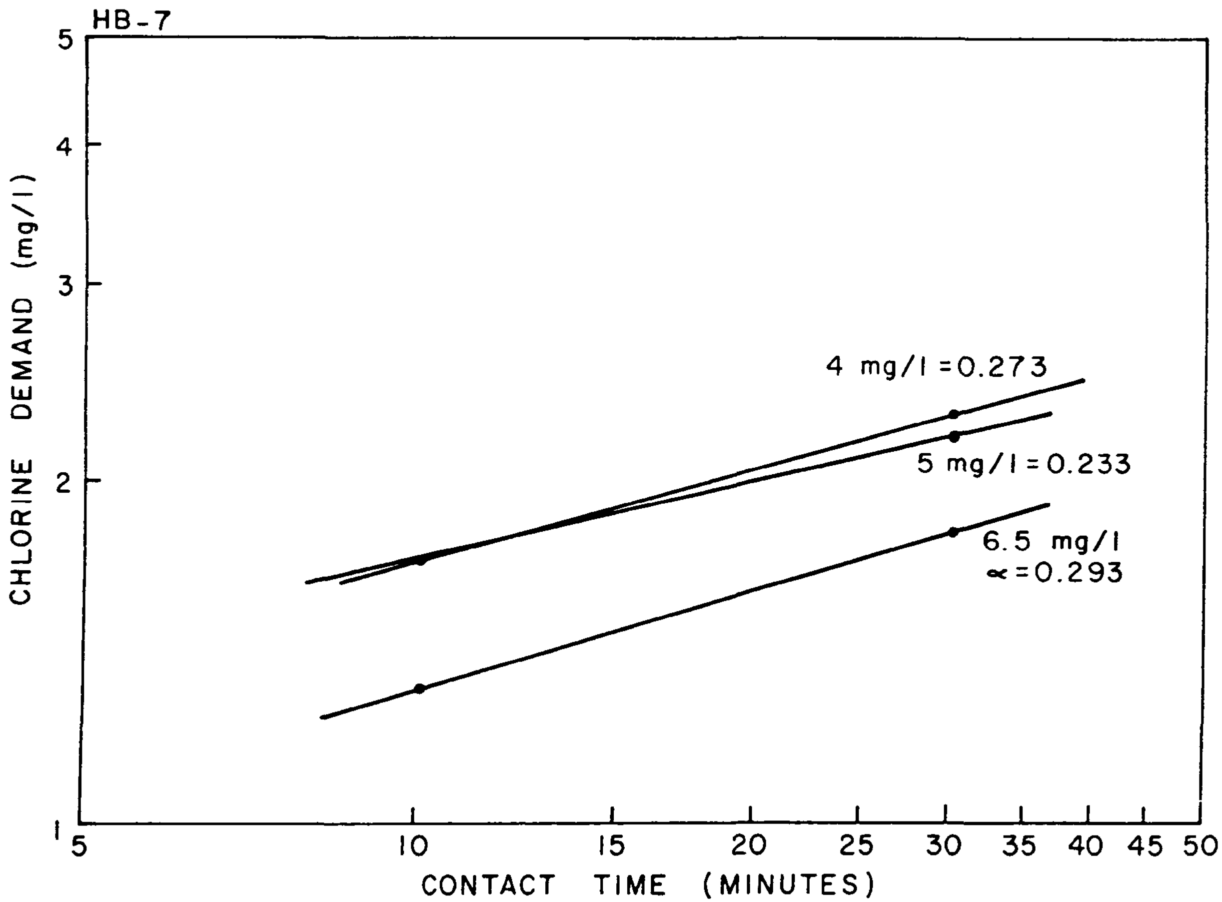

Figure 12 (continued)

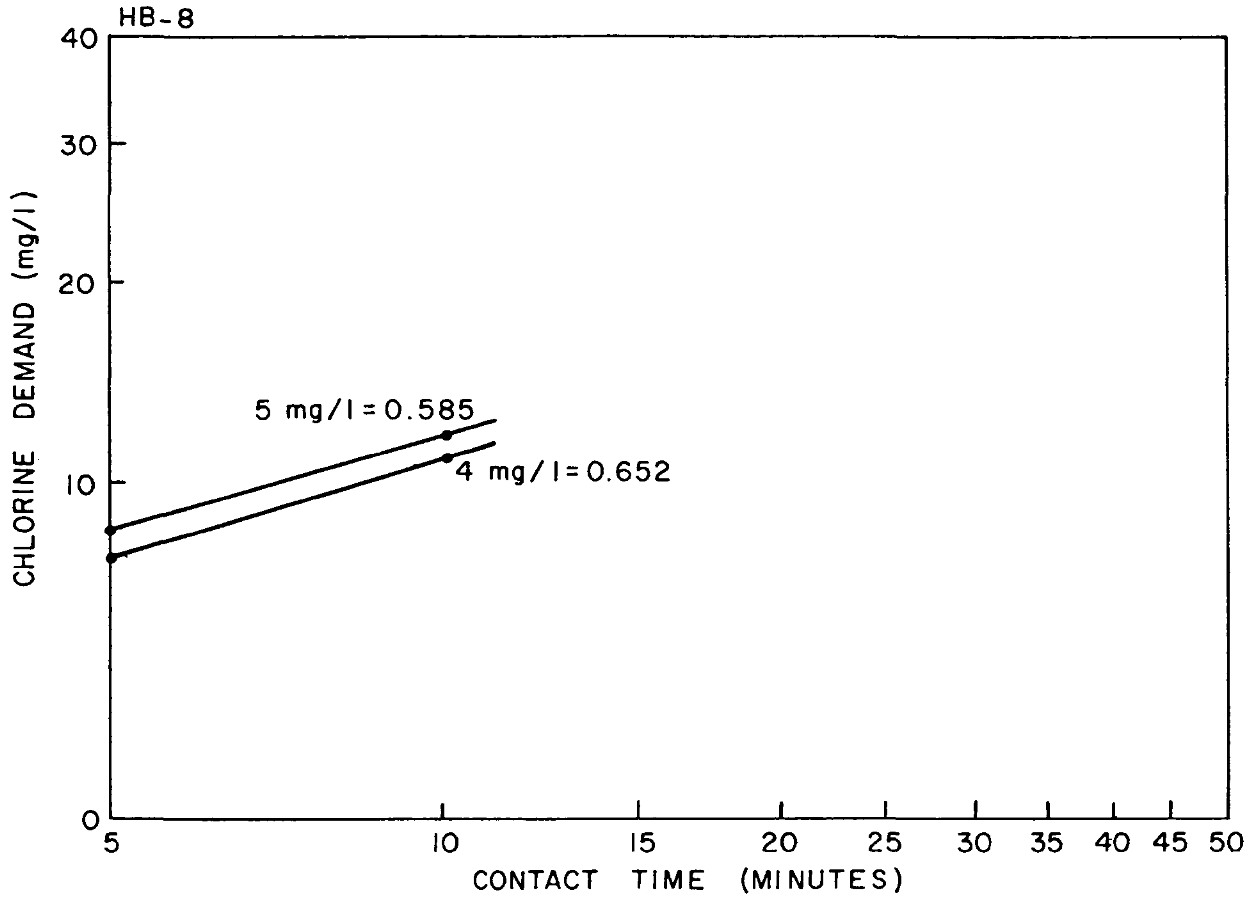

Figure 12 (continued)

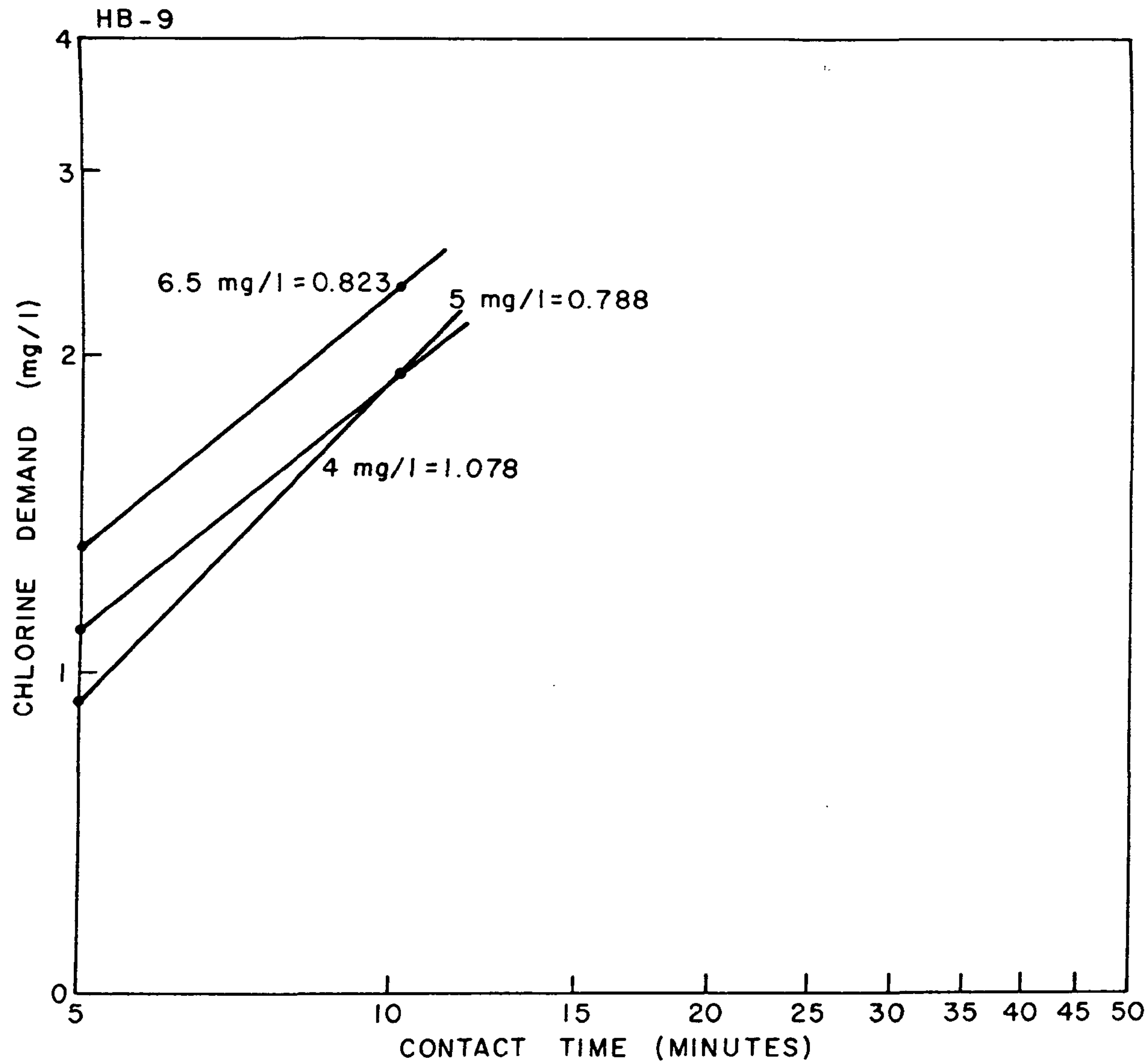

Figure 12 (continued)

SECTION 7

THE NEW CHLORINATOR

Based on the analysis of Phase I data, it was concluded that the fluctuating operation of the chlorinator was one major variable in qualifying and quantifying the chlorine feed rates at John Sevier. Thus, a search was initiated for a chlorination system that could accurately monitor the flow of chlorine gas. After study and several non-TVA site visits to inspect operating systems similar to those defined as necessary for the study, it was recommended that a Capital Control Series 800 Chlorinator and Series 910 flow meter and transmitter would be the best system for gathering feed rate data in the chlorination study. A comparative analysis of chlorine gas monitoring systems indicated that the Capital Control chlorine gas flow meter-transmitter measured flow by means of a variable orifice, and that the mechanism for monitoring gas flow was less susceptible to corrosion and possibly more reliable and more accurate than other available equipment. A diagram of the system is presented in Figure 13. This system, i.e., chlorine and gas metering device, was installed at the plant in April 1977 for use during Phase II studies.

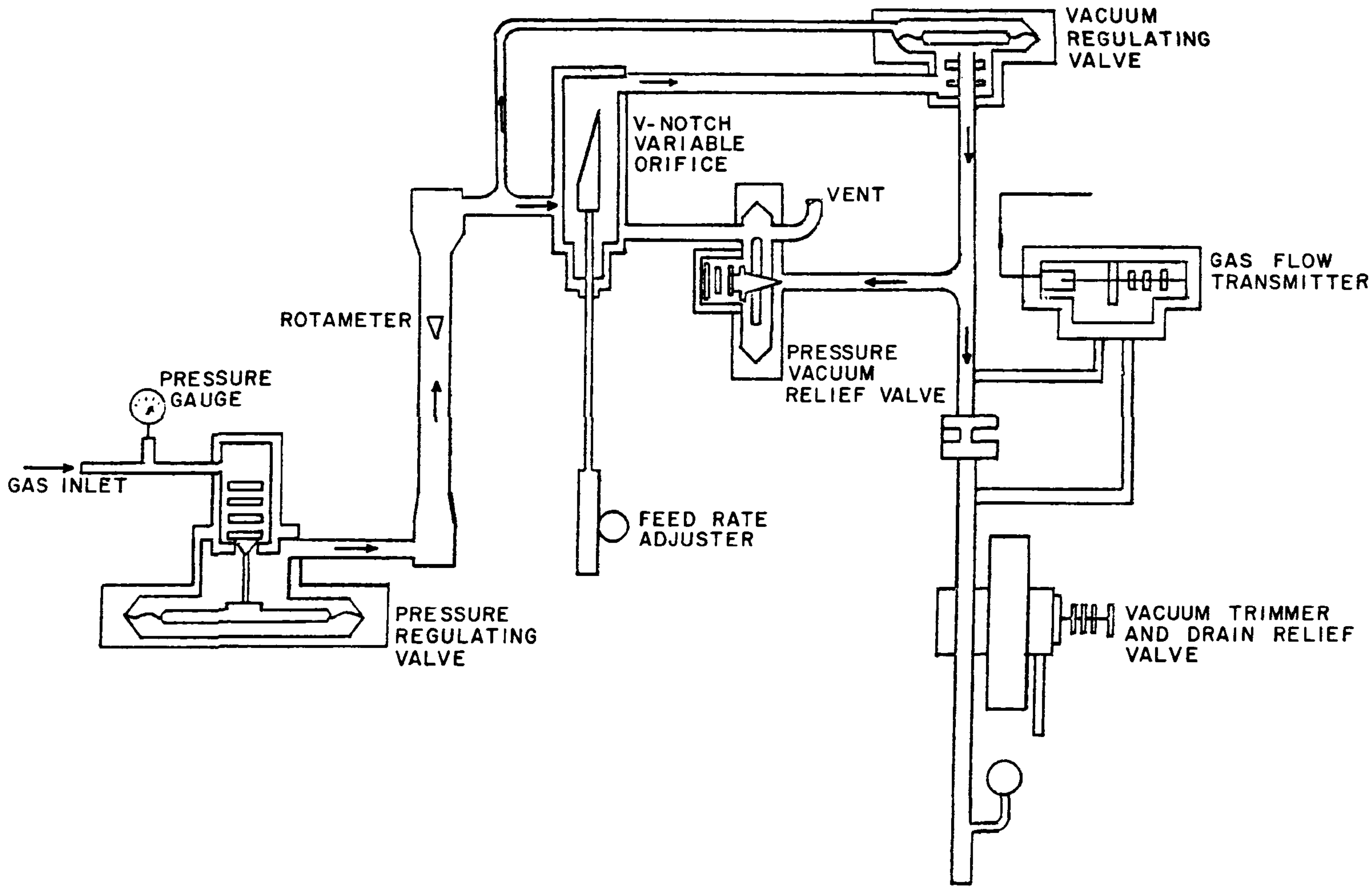

Figure 13. Schematic diagram of capital control chlorinator.

SECTION 8

PHASE II

TESTING AT JOHN SEVIER APRIL-SEPTEMBER 1977

The Approach

On April 19, 1977, a meeting was held at the John Sevier Steam Plant to discuss the past chlorination tests (Phase I) and the Phase II chlorination tests at the plant.

The new chlorinator, purchased by the plant, was in service at this time. However, due to high back pressure in the vacuum water line, water leaked into the gas flow metering system. Thus, the chlorinator went out of service the second week in May 1977. As a result, Phase II tests were conducted mostly with the old chlorinator.

Since data from Phase I indicated that the "condenser demand" (i.e., inlet to outlet change in free residual chlorine) was about 0.5 mg/l free chlorine, the approach for Phase II was to maintain a free chlorine residual of 0.5 mg/l at the inlet to the condenser. During Phase I it was found that a chlorine feed rate of 4500 lb/day would maintain approximately 0.5 mg/l free chlorine residual at the inlet to the condenser assuming similar water quality. Thus, a feed rate of 4500 lbs/day was fed to all units with only the frequency and length of feed changed. The following test conditions were established for Phase II.

Unit	Feed Rate lbs/day	Frequency/24 hours	Chlorine Feed time in Minutes
Unit 1	4500	2	60
Unit 2	4500	2	30
Unit 3	4500	3	20
Unit 4	4500	6	10

The long chlorination period on Unit 1 was to determine if the chlorine could satisfy the "condenser demand." This would result in the free residual chlorine at the inlet and outlet being equal within experimental error.

Test procedures consisted of performing condenser performance tests every two weeks and measuring flow rates weekly. Tests would begin May 6, 1977, and continued each week throughout the summer. If there was no appreciable change in the condenser performance of each unit and the free and total chlorine residuals were higher than 0.1 to 0.2 mg/l FRC,[7,8] then the feed rate was lowered accordingly after at least an initial two months at a feed rate of 4500 lbs/day.

The Program

Tests at John Sevier during Phase II began as scheduled on May 6, 1977. Weekly tests continued during May, June, July, August, and September 1977. Each week, samples of the chlorinated condenser cooling water were taken at the inlet and outlet of each condenser. During each weekly test period, water samples were taken at the intake and analyses were performed by TVA's Laboratory Branch to determine the following parameters: (1) pH, (2) temperature, (3) alkalinity, (4) chlorine demand - 1, 5, and 10 minutes, (5) total organic carbon, (6) conductivity, (7) ammonia as N, (8) total suspended solids, (9) nitrates plus nitrites as N, and (10) organic nitrogen as N. A plot of some of the above parameters as a function of time may be found in Figure 14. Chlorine demand data for 1977 is presented in Table 10.

Amperometric titration[9] was the method used on all test days. On nine of the test dates, the DPD method was used on Unit 1 in addition to the amperometric method. Since both methods are identified in the Federal Register by EPA as standard analytical methods for collecting residual chlorine data, the use of both methods would allow a field comparison of the reliability, consistency, and accuracy of the two methods. Problems of drift and inconsistent results were experienced in the measurement of free and total residual chlorine using the amperometric titrators. The problems were improved by cleaning the electrodes with distilled water between samples and with a nonchlorinated detergent every two weeks, 24 hour acclimation of the electrodes to chlorine, and titrating excess phenylarsine oxide into solutions after each sample was analyzed.

The electrodes are susceptable to a thin film forming on the surface of the platinum plates when left in or out of water. This film will cause drift and unusual readings. In addition, after running one sample for free and total residual chlorine, the iodide reagent tends to form a film on the electrode surfaces. This contributes to the drift and unusual measurements on subsequent readings. Frequent electrode cleaning reduces the film formation of the water constituents on the platinum plates. It was also recommended by the Fischer and Porter Central Laboratories in Warminster, Pennsylvania, that by titrating excess phenylarsine oxide into the solution, excess iodine is prohibited from forming a film on the electrodes. The 24-hour acclimation of the electrodes is normal procedure when using sensitive potentiometric equipment.

The feed rate of the chlorinator remained at 4500 lb/24 hrs through three months. A complete chart of feed rates and initial chlorine concentrations may be found in Table 7. Condenser performance tests were performed biweekly in order to monitor the changes in the apparent cleanliness factor. The apparent cleanliness factor (ACF) data and the free and total residual chlorine levels were used as a basis for formulating any changes in the feed rate. When the ACF data indicated a sudden decrease, the chlorine feed rate was increased and when the free residual chlorine suddenly increased, the feed rate was reduced.

In these tests the condenser performances were evaluated on the basis of the apparent cleanliness factor (ACF). It is not possible to directly compare the apparent cleanliness factor of one year to the next without

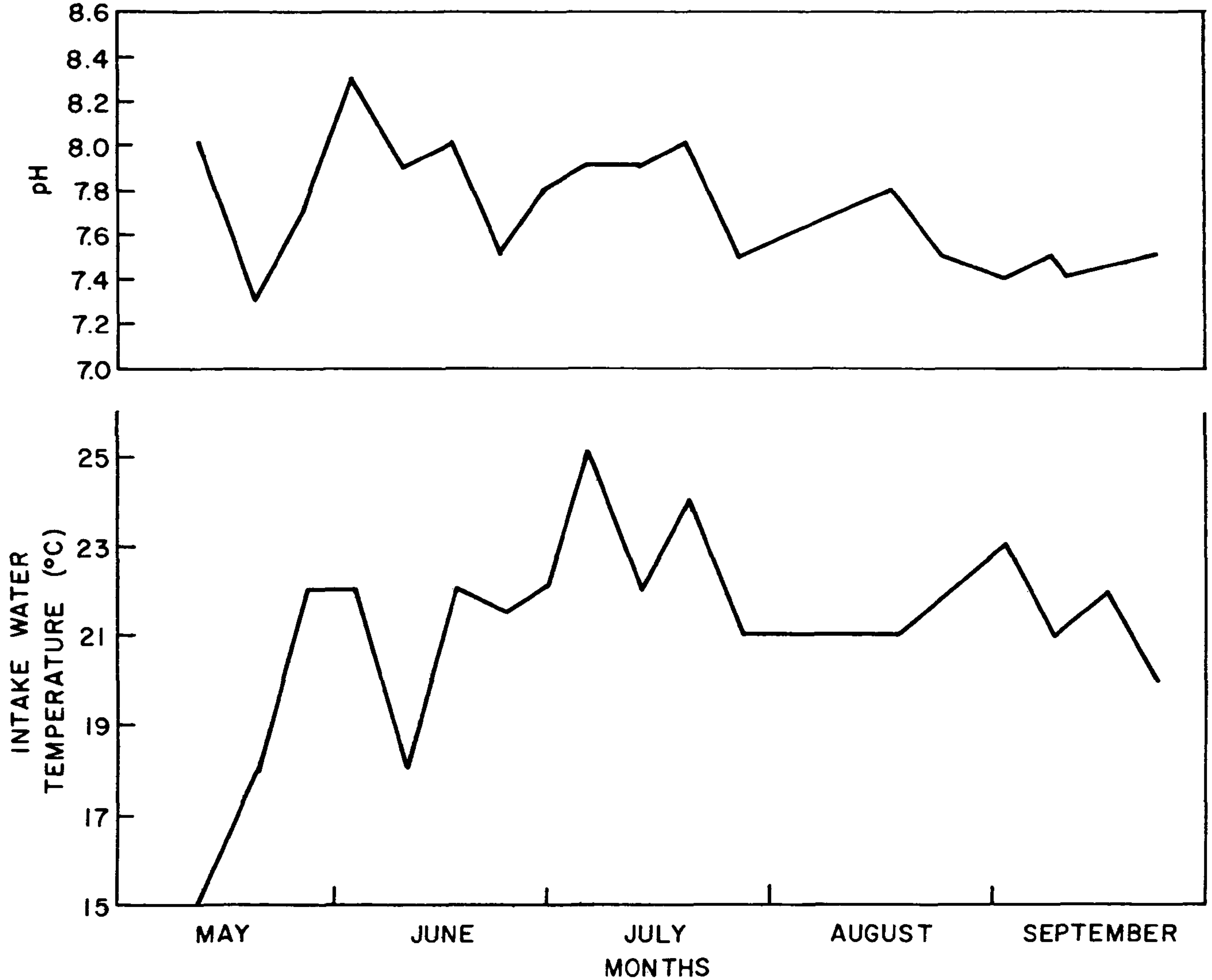

Figure 14. Water quality data for 1977.

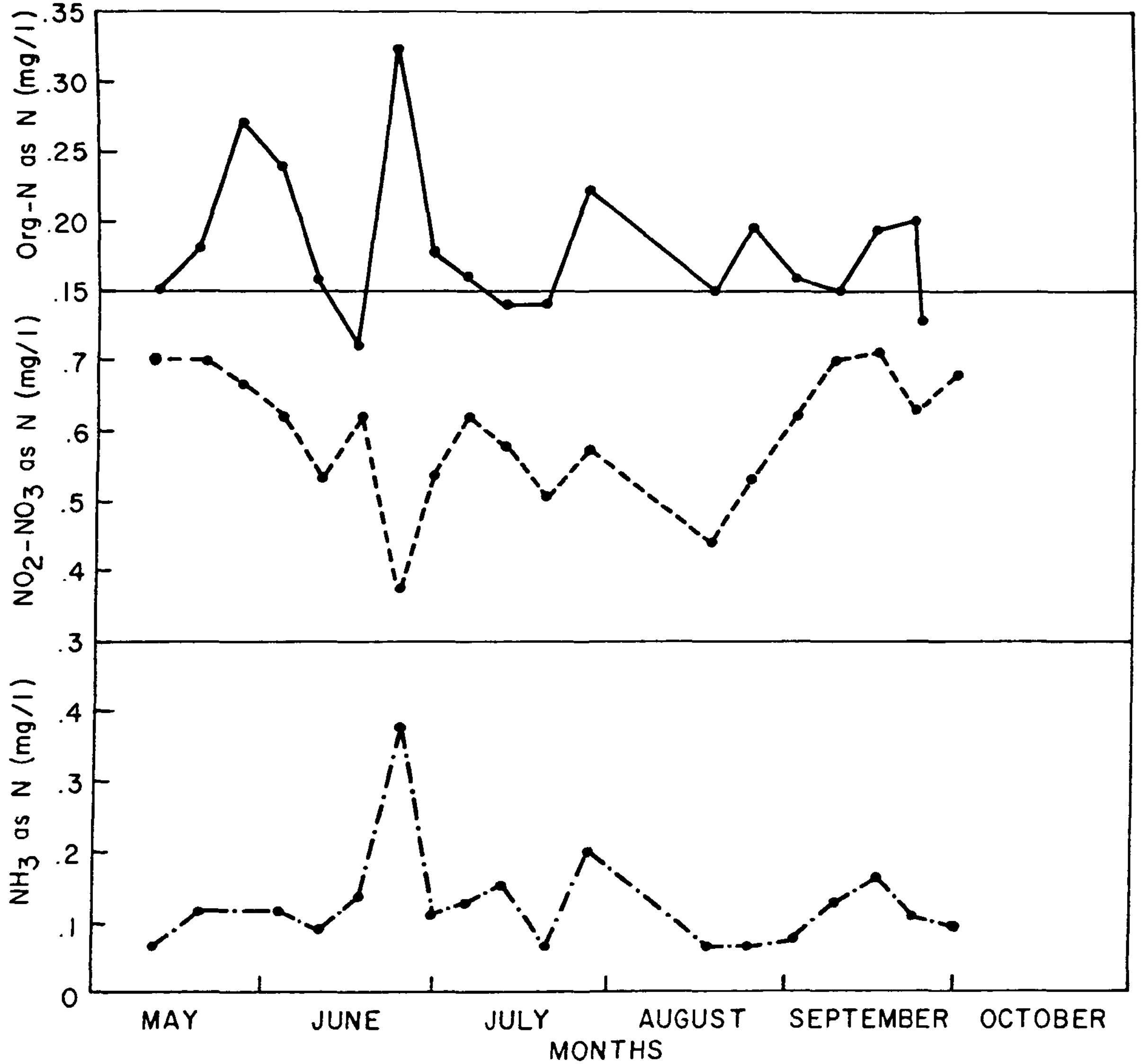

Figure 14 (continued)

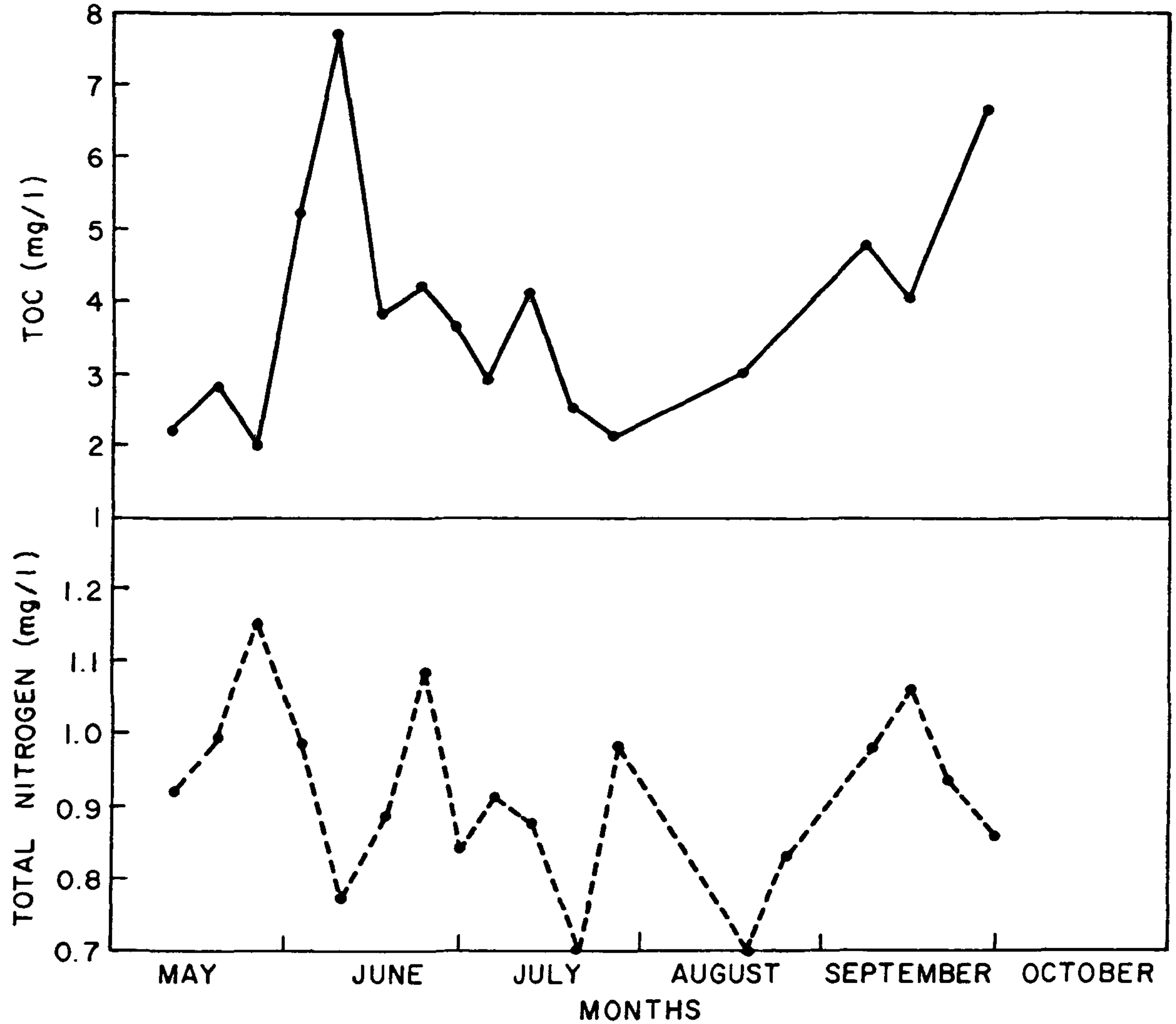

Figure 14 (continued)

TABLE 6. CHLORINE DEMAND 1977

UNIT 4

Date	*Feed Rate in mg/l	1 Min.	5 Min.	10 Min.
5/6/77	2.48	0.18	0.78	-
5/12/77	2.75	0.64	0.50	0.79
5/20/77	2.96	0.19	0.58	0.79
5/27/77	2.92	0.44	0.97	1.40
6/3/77	2.86	0.41	0.91	1.31
6/10/77	2.88	0.18	0.58	0.78
6/17/77	2.89	0.30	0.59	1.14
6/24/77	2.93	0.38	0.97	1.07
6/30/77	3.03	0.51	0.82	1.21
7/6/77	2.97	0.59	0.79	1.67
7/13/77	3.07	0.51	0.85	1.22
7/20/77	3.01	0.29	0.69	1.00
7/27/77	3.20	0.70	1.25	1.46
8/18/77	2.95	0.68	1.07	1.39
9/2/77	1.63	0.30	0.41	0.54
9/9/77	1.67	0.20	0.37	0.60
9/16/77	1.65	0.29	0.47	0.56
9/23/77	1.68	0.27	0.38	0.61

*See Table 7

TABLE 7. CHLORINE CONCENTRATION

Date	Unit	Cl_2 Feed Rate lb/24 hrs.	Flow Rate Gal/Min.	Cl_2 Concentration (mg/l)
5/6/77	1	4500	154,000	2.43
	3	4500	141,000	2.66
	4	4500	151,000	2.48
5/12/77	1	4500	135,872	2.76
	3	4500	114,000	3.28
	4	4500	136,425	2.75
5/20/77	1	4500	140,007	2.67
	2	4500	122,911	3.05
	3	4500	131,289	2.85
	4	4500	126,583	2.96
5/27/77	1	4500	137,765	2.72
	2	4500	128,856	2.91
	3	4500	132,873	2.82
	4	4500	128,117	2.92
6/3/77	1	4500	137,591	2.72
	2	4500	125,638	2.98
	3	4500	134,127	2.79
	4	4500	130,984	2.86
6/10/77	1	4500	137,609	2.72
	2	4500	110,547	3.39
	3	4500	133,895	2.80
	4	4500	129,926	2.88
6/17/77	1	4500	138,196	2.71
	2	4500	138,243	2.71
	3	4500	133,404	2.81
	4	4500	129,732	2.89
6/24/77	2	4500	136,154	2.75
	3	4500	137,242	2.73
	4	4500	127,881	2.93
6/30/77	1	4500	140,402	2.68
	2	4500	137,322	2.73
	3	4500	133,030	2.82
	4	4500	123,675	3.03
7/6/77	1	4500	139,381	2.69
	2	4500	140,354	2.67
	4	4500	125,952	2.97
7/13/77	1	4500	135,885	2.76
	2	4500	135,287	2.77
	3	4500	132,145	2.83
	4	4500	122,053	3.07

Continued

TABLE 7 (Continued)

Date	Unit	Cl_2 Feed Rate lb/24 hrs.	Flow Rate Gal/Min.	Cl_2 Concentration (mg/l)
7/20/77	1	4500	137,828	2.72
	2	4500	133,534	2.80
	3	4500	131,285	2.85
	4	4500	122,505	3.01
7/27/77	1	3000	136,518	1.83
	2	4500	136,904	2.74
	4	4500	117,125	3.20
8/18/77	1	4500	135,131	2.77
	3	4500	132,390	2.83
	4	4500	126,904	2.95
8/25/77	1	2500	132,934	1.56
	2	3000	130,492	1.91
9/2/77	1	2500	130,785	1.59
	2	2500	134,564	1.55
	3	2500	125,908	1.65
	4	2500	127,631	1.63
9/9/77	1	2500	125,812	1.65
	2	2500	135,583	1.53
	3	2500	122,450	1.70
	4	2500	124,760	1.67
9/16/77	1	1500	124,049	1.01
	2	2500	134,233	1.55
	3	2500	121,183	1.72
	4	2500	126,038	1.65
9/23/77	1	1500	124,200	1.01
	2	2500	131,287	1.58
	3	2500	117,328	1.77
	4	2500	123,407	1.68

considering when each condenser was manually brush cleaned, and other operational data. After each brush cleaning, the cleanliness factor ranges from 80-85 percent. After cleaning, there is a sharp ACF decline in the spring and then a further gradual decline through the summer. In order to determine if the lower feed rates of 1977 resulted in any significant change in ACF as compared with 1976, the time interval between each manual cleaning of the tubes was considered in the analysis. For a comparison of the ACF for 1976 with the ACF for 1977, see Figures 15-18 and Table 8.

After examination of the data collected in May, June, and most of July, the feed rate was reduced to 3000 lbs/day on July 22, 1977. The justification for such reduction was that higher than necessary levels of free and total residual chlorine were measured at the inlet and outlet of the condensers and the condenser apparent cleanliness factor was the same or better than it was during the Phase I tests in the summer of 1976, and during 1974 and 1975. It was also noted that the condenser demand was not 0.5 mg/l as found in Phase I, but rather 0.3 mg/l. This discovery was primarily due to an increase in samples and better measuring techniques. However, the chlorine feed rate was not reduced until the end of July to ensure that we had found an operable level which would keep the condensers relatively clean during periods when the inlet water temperature reached extreme conditions (80°-82°F). At these temperatures there is stronger propensity for biological fouling. It was noted from Phase I tests (1976) that as the inlet water temperature increased, there was a noted corresponding increase in total residual chlorine consumed. A comparison of the inlet water temperatures of 1976 and 1977 may be found in Figures 19-22.

On August 25, 1977, test results for free residual chlorine at the outlet of the condensers and the condenser performance records of each unit indicated further reductions in the chlorine feed rate were justified (see Table 9). On September 2, 1977, the feed rate was lowered to 2500 lbs/24 hrs. This feed rate resulted in a lower measurement of free and total residual chlorine at the outlet of each condenser (see Table 10). This feed rate was maintained through September. As the inlet water temperatures decreased, the free and total residual chlorine measurements increased with no apparent deterioration in condenser performance as measured by the ACF.

The ACF for 1977 was higher on all condensers than the ACF of 1976 except for Unit 4 (see Figures 15-18). However, the ACFs measured at equal lengths of time after cleaning showed a slight increase in ACF for 1977 compared to 1976. Discussions with Power Production experts in condenser performance and operations indicated that this difference is primarily due to a decrease in the air leakage for 1977 compared to 1976. Considering this data and a visual condenser inspection of Unit 4, we conclude that there has been no apparent decrease in condenser performance that could be attributed to lower feed rates of chlorine.

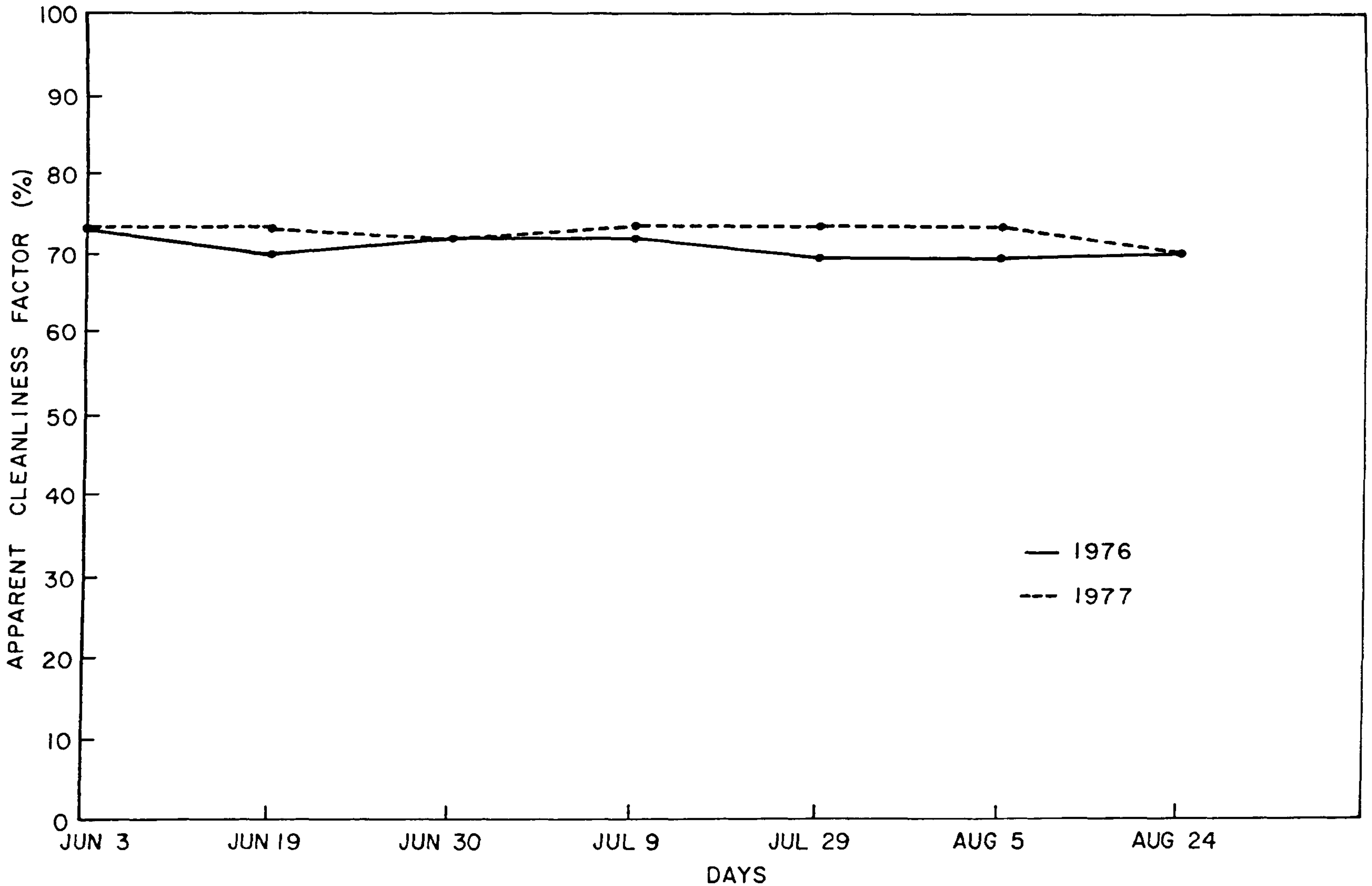

Figure 15. Unit I 1976 vs. 1977 apparent cleanliness factor.

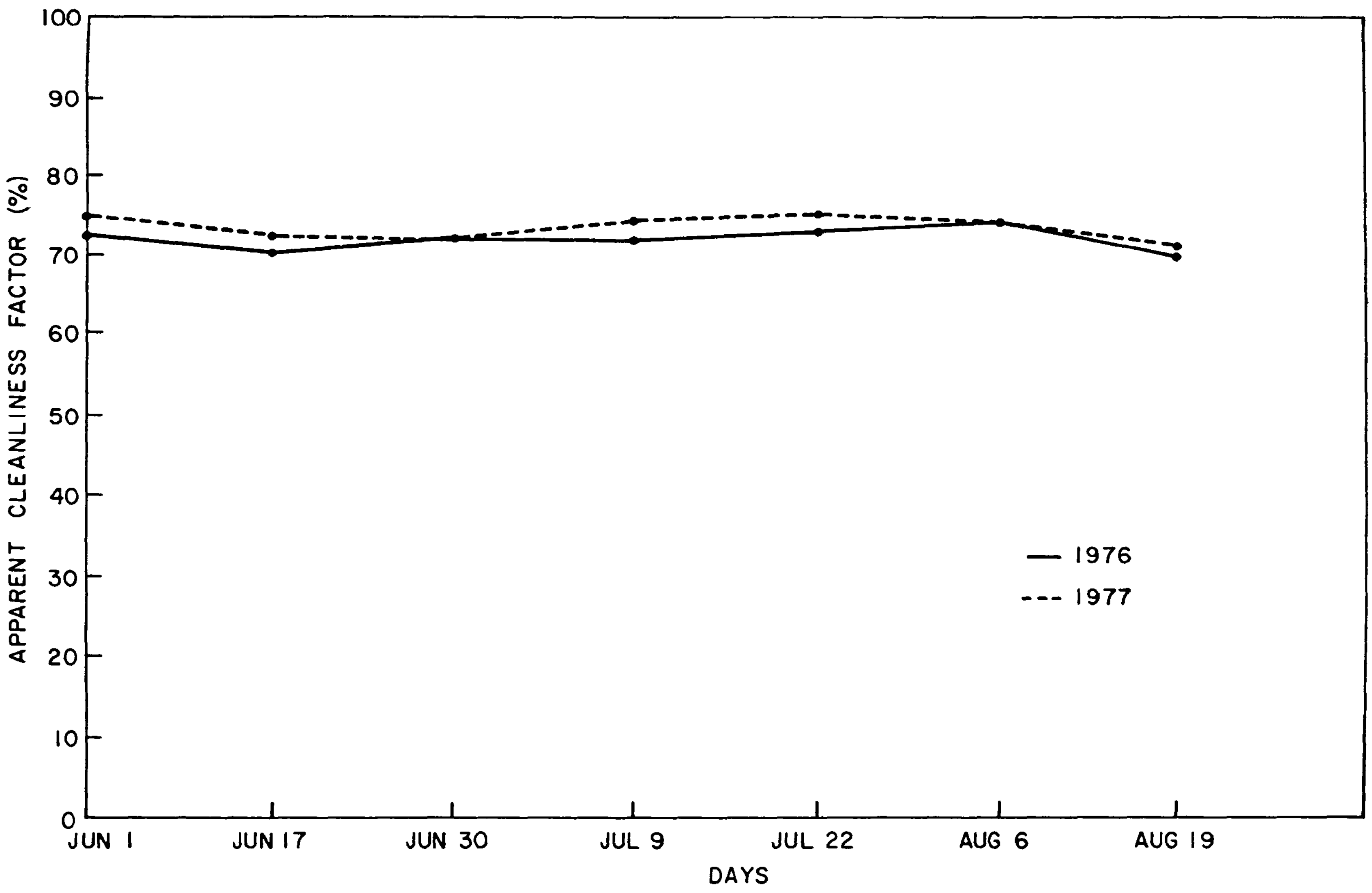

Figure 16. Unit 2 1976 vs. 1977 apparent cleanliness factor.

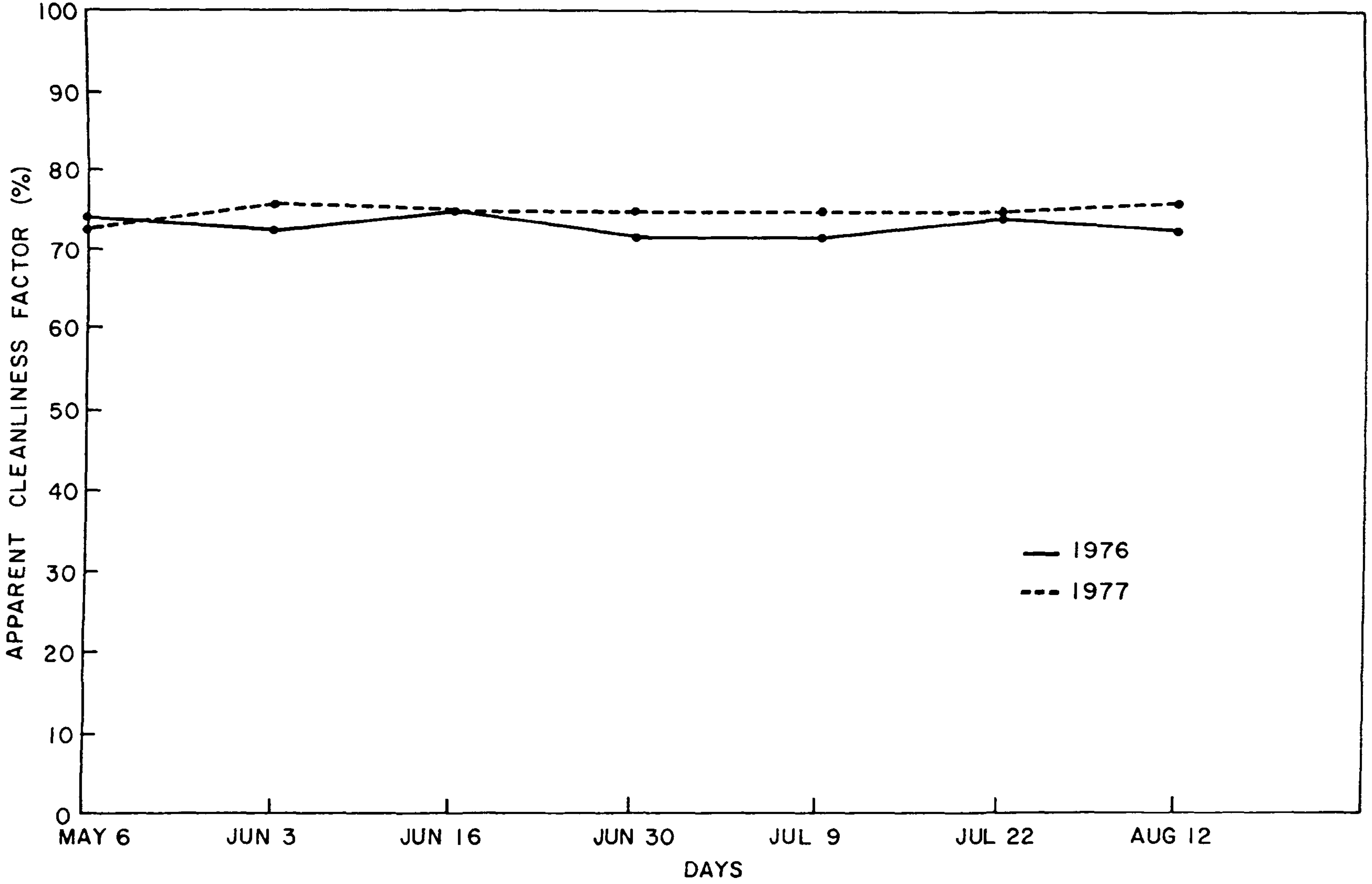

Figure 17. Unit 3 1976 vs. 1977 apparent cleanliness factor.

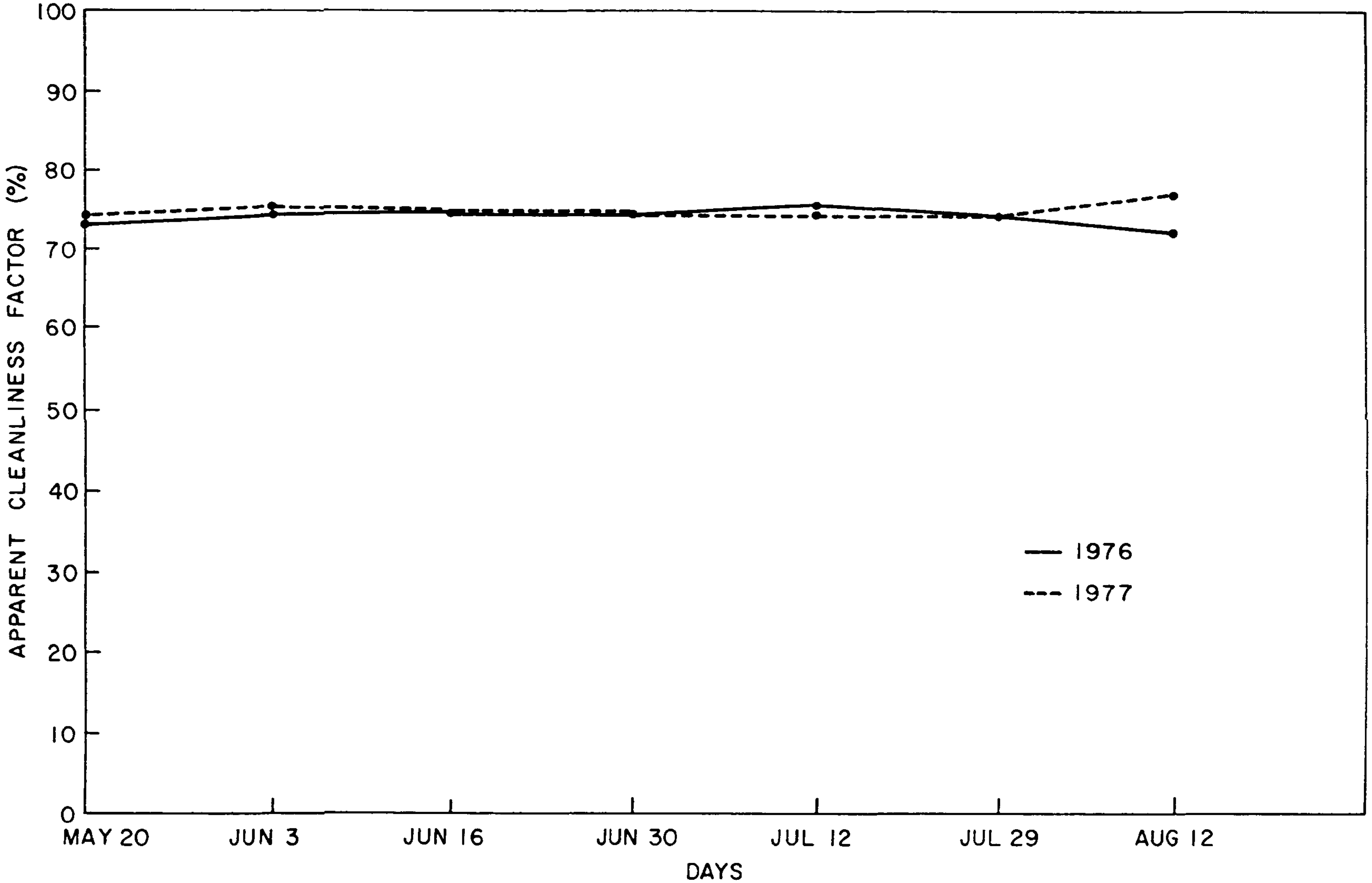

Figure 18. Unit 4 1976 vs. 1977 apparent cleanliness factor.

TABLE 8. DATES OF CONDENSER CLEANING

UNIT 1

Date (1976)	Nature of Cleaning	Date (1977)	Nature of Cleaning
June 10	Tubes	June 23	Tube Sheet
June 20	Tubes		
June 26	Tubes		
June 27	Tubes		
July 3	Tube Sheet		
August 1	Tube Sheet		
August 15	Tubes		

UNIT 2

Date (1976)	Nature of Cleaning	Date (1977)	Nature of Cleaning
June 17	Tubes	May 5-6	Tube Sheet
June 23	Tubes		
June 28	Tubes		
July 1	Tubes		
July 2	Tubes		

UNIT 3

Date (1976)	Nature of Cleaning	Date (1977)	Nature of Cleaning
June 15	Tubes	June 8	Tube Sheet
July 3	Tubes	July 24	Tube Sheet
July 4	Tubes	August 15	Tube Sheet
July 17	Tube Sheet		
August 13	Tubes		

UNIT 4

Date (1976)	Nature of Cleaning	Date (1977)	Nature of Cleaning
May 25	Tube Sheet	May 21	Tube Sheet
June 19	Tubes	June 6	Tube Sheet
June 21	Tubes		
July 3	Tube Sheet	December 21	Tubes
August 1	Tube Sheet		
August 14	Tubes		

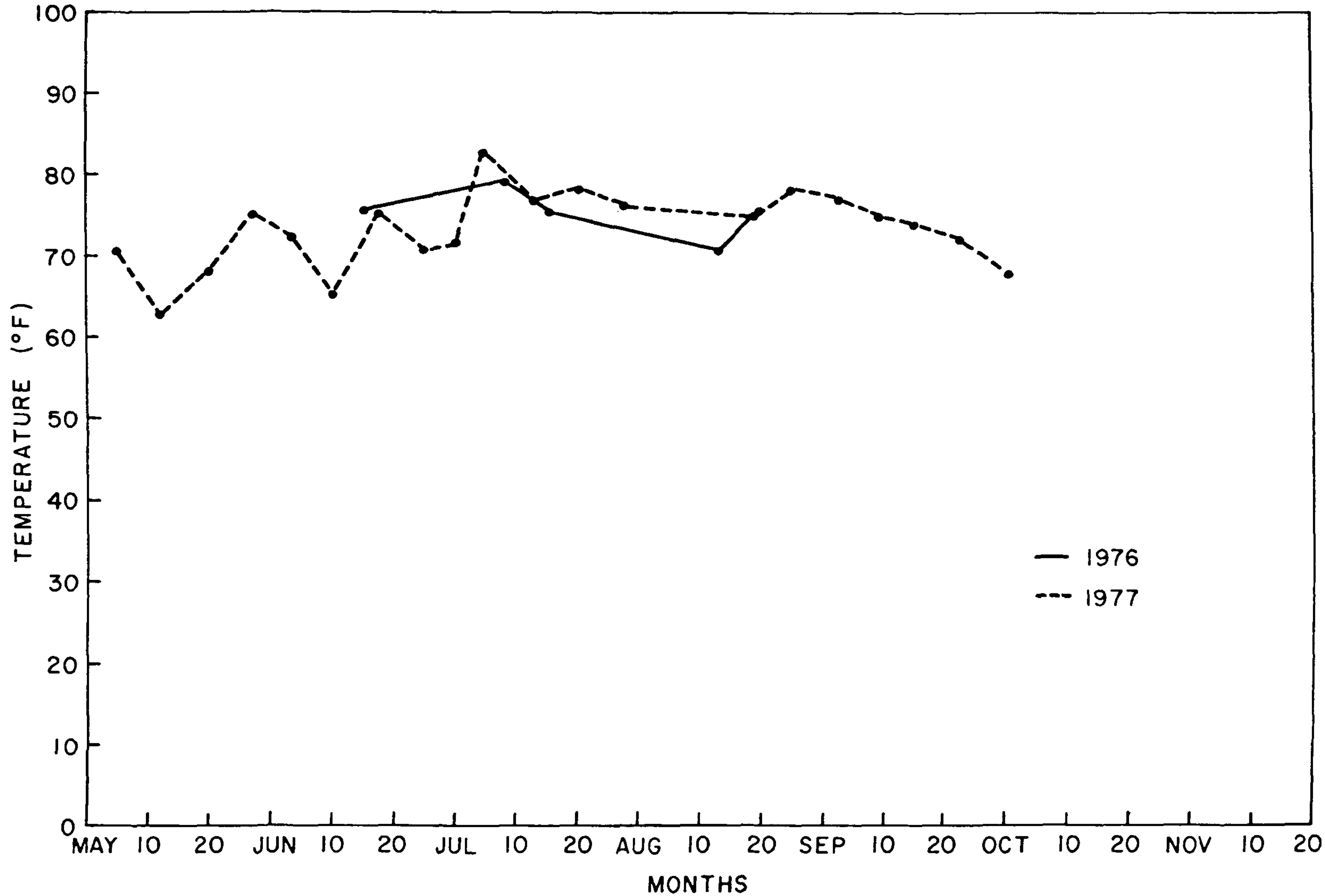

Figure 19. Unit 1 1976 vs. 1977 inlet water temperature.

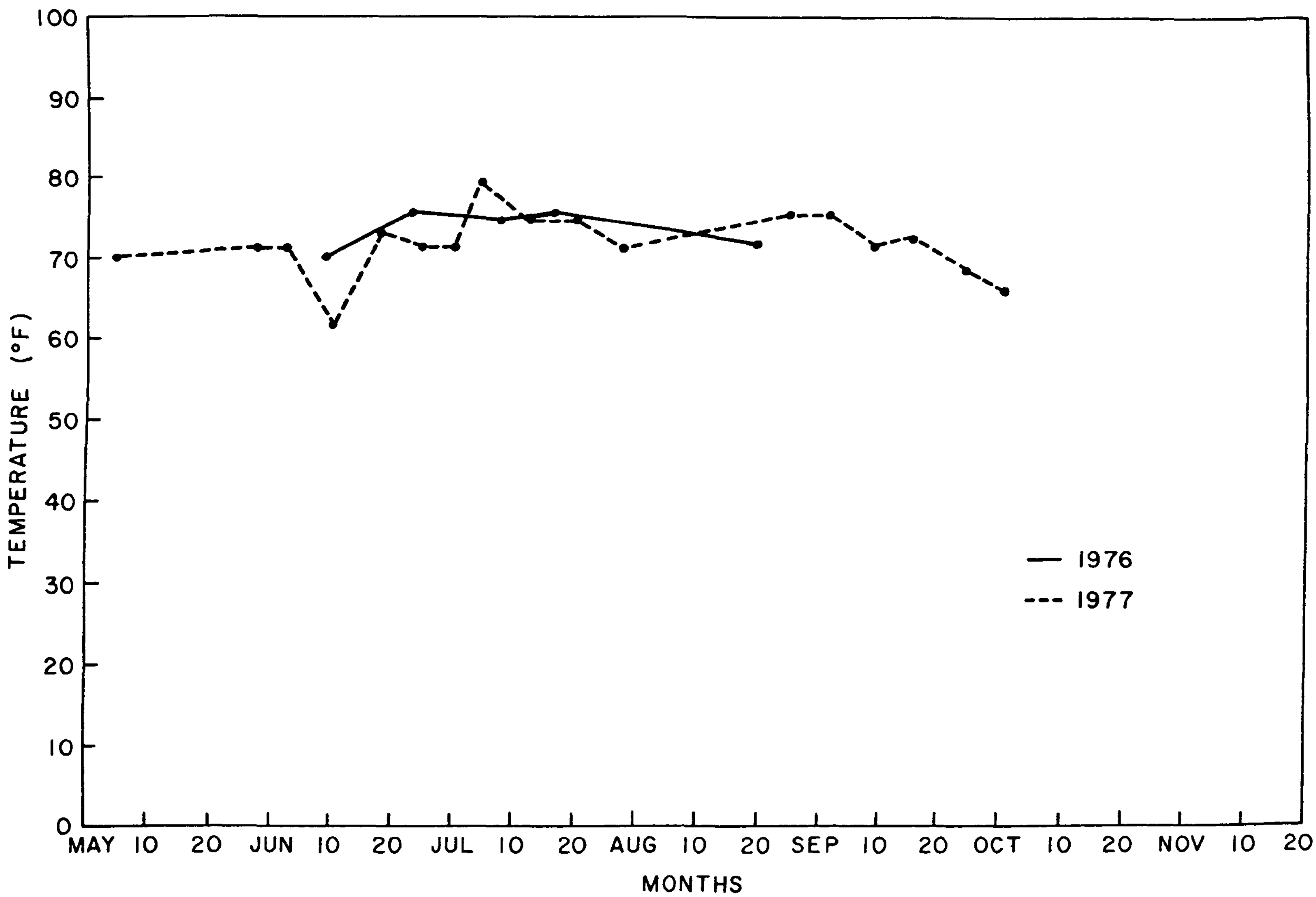

Figure 20. Unit 2 1976 vs. 1977 inlet water temperature.

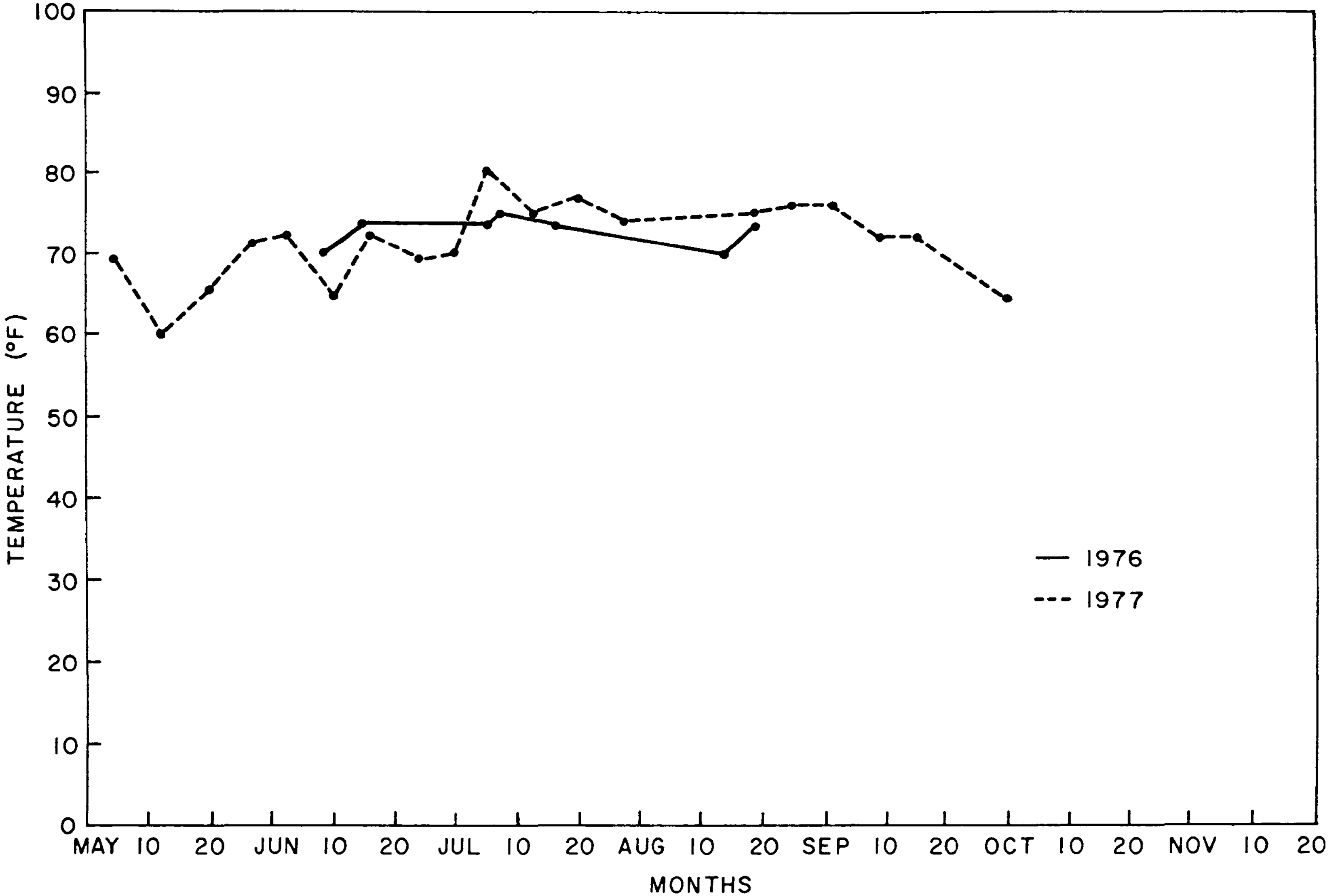

Figure 21. Unit 3 1976 vs. 1977 inlet water temperature.

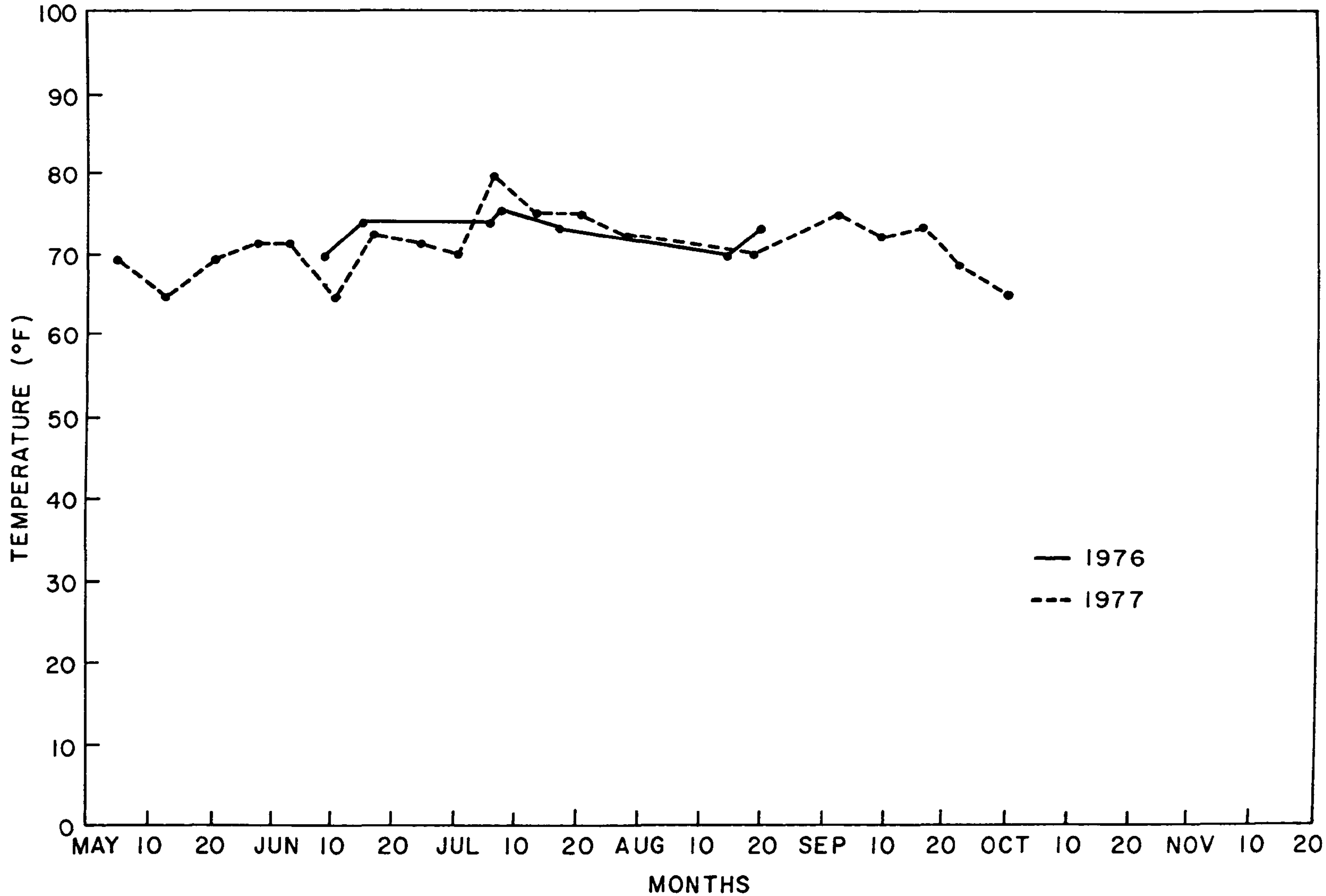

Figure 22. Unit 4 1976 vs. 1977 inlet water temperature.

TABLE 9. SAMPLES TAKEN AT OUTLET ON AUGUST 25, 1977

Unit	Feed Rate (lb/24 hrs)	FRC* Outlet (mg/l)
1	2500	.08
2	3000	.25
3	3000	.25
4	unit off line	

TABLE 10. SAMPLES TAKEN AT OUTLET ON SEPTEMBER 2, 1977

1	2500	.23
2	2500	.16
3	2500	.22
4	2500	.14

*Average of steady-state outlet-free residuals.

The frequency and length of chlorine feed to each condenser was different throughout Phase II in order to determine if infrequent long chlorination periods, or frequent short chlorination periods, are more conducive to maintaining adequate condenser performance. The frequencies and lengths of chlorine feed to each condenser are listed below.

Condenser	Length of Chlorine Feed	Frequency of Feed/24 hrs
Unit 1	60 minutes	2
Unit 2	30 minutes	2
Unit 3	20 minutes	3
Unit 4	10 minutes	6

It was noted throughout this test period that Units 2, 3, and 4 showed generally the same outlet free and total residual chlorine measurements on each test day. However, Unit 1 frequently exhibited higher measurements compared to the other three units. This condenser was the only condenser chlorinated for two hours each day. The other condensers were chlorinated for only one hour total each day.

An analysis similar to the analysis of the Phase I demand data using the equation $D = kt^n$ was made for the chlorine demand test data of Phase II. The calculations may be found in Table 11 and a representative graphic relationship may be found in Figure 23.

TABLE 11. CHLORINE DEMAND 1977

UNIT 3

Date	Feed Rate mg/l	Chlorine Demand 1 min.	5 min.	10 min.	Slope (N)	Total N mg/l	% Organic N
5/12	3.28	0.80	0.56	0.68	0.097	0.92	16.3
5/20	2.85	0.17	0.55	0.75	0.660	1.0	18
5/27	2.82	0.43	0.92	1.31	0.482	1.15	23.5
6/3	2.79	0.41	0.90	1.29	0.496	0.98	24.5
6/10	2.80	0.17	0.55	0.75	0.660	0.77	19.5
6/17	2.81	0.31	0.59	1.10	0.524	0.87	12.6
6/24	2.73	0.34	0.89	0.99	0.488	1.09	30.3
6/30	2.82	0.47	0.77	1.12	0.365	0.83	21.7
7/13	2.83	0.47	0.75	1.12	0.362	0.87	16.1
7/20	2.85	0.29	0.66	0.92	0.503	0.70	20
8/18	2.83	0.70	1.03	1.32	0.269	0.65	23.1
9/2	1.65	0.30	0.40	0.55	0.248	0.90	17.8
9/9	1.70	0.20	0.39	0.62	0.288	0.98	15.3
9/16	1.72	0.29	0.50	0.61	0.326	1.06	17.9
9/23	1.77	0.28	0.39	0.67	0.348	0.93	21.5
10/28	1.11	0.26	0.35	0.35	0.139	0.85	15.3
11/18	1.24	0.29	0.30	0.39	0.110	1.06	30.2
12/22	1.49	0.09	0.29	0.40	0.662	1.02	21.6

$$n = \frac{\log \frac{D}{K}}{\log t}$$

D = 1 min. demand; K = 10 min. demand;
t = Contact time in % 10 min.; n = slope
Slope is finally determined by linear regression through the three demand points.

$$\text{Chlorine Feed Rate} = \frac{\text{Feed Rate lb/day}}{\text{Flow Rate gal/min}} \times 83.22 = \text{mg/l } Cl_2$$

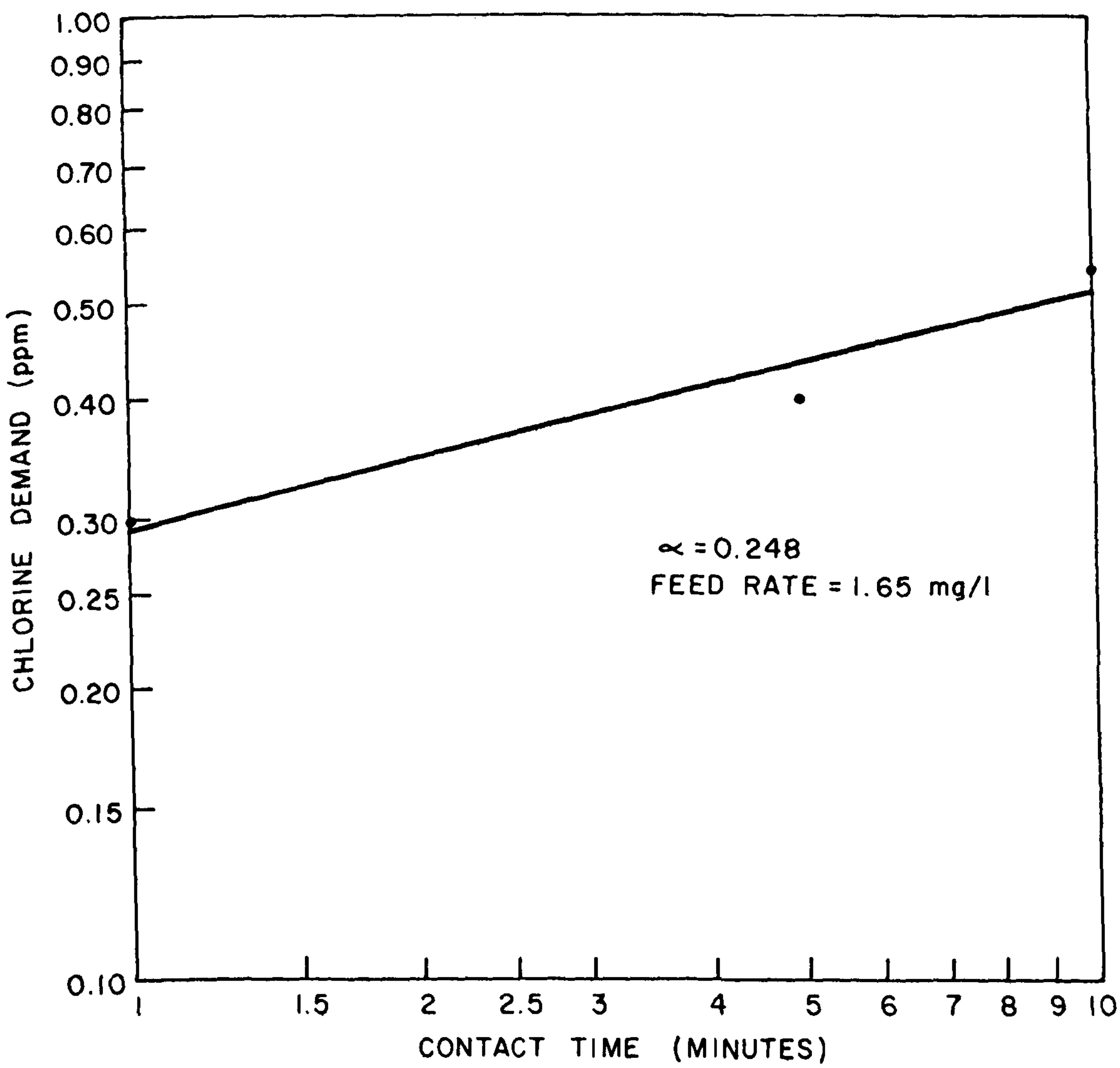

Figure 23. Relationship between chlorine consumed and contact time.

SECTION 9

STATUS - OCTOBER 1, 1977

In late September, the feed rate on all units was lowered to a feed rate of 1,500 lbs/24 hrs. Measurements at the outlet of the condenser indicated that the chlorinated water effluent was within the effluent limitation guideline requirements (<0.2 mg/l free residual chlorine) set by EPA (see Table 12). Weekly tests during January will be conducted to determine if the chlorine feed can be completely terminated with no significant decrease in condenser performance.

TABLE 12. SAMPLES TAKEN AT OUTLET ON SEPTEMBER 30, 1977

Unit	Feed rate, lbs/24 hr.	Free residual chlorine, mg/l
1	1500	.18
2	1500	.04
3	unit off line	
4	1500	.05

SECTION 10

STATISTICAL ANALYSIS OF PHASE II DATA*

A statistical analysis was performed on the data obtained from the Phase II study at John Sevier. The analysis focused on the factors affecting condenser performance, free and/or total residual chlorine consumed in the system, the relationship between inlet water temperature and variables associated with chlorine use, and the correlation of chlorine demand versus feed rate, inlet water temperature, and total organic carbon. In cases where the outlet FRC and/or TRC is greater than the inlet, all values above .05 mg/l difference have been omitted for statistical analysis. The following summarizes the analysis. The complete analysis may be found in Appendices A, B, C, D, and E.

CONDENSER PERFORMANCE

1. Effects of Inlet Water Temperature
   Inlet water temperature significantly affects condenser performance. Based on the 1977 data, over the range of inlet water temperature of 53°F to 77°F, on the average an increase of 3°F in inlet water temperature results in a 1 percent reduction in ACF. The remainder of the analysis of condenser performance data took this relationship into account.

2. 1977 Condenser Performance vs. 1976 Condenser Performance
   Condenser performance as estimated by ACF averaged about .74. This may be an increase in performance over 1976, but many factors influence the ACF and the change of chlorine feed rate cannot be specifically identified as being solely responsible. However, no decrease in ACF was noted in 1977 when compared to 1976.

3. Frequency, Duration of Feed, and Feed Rate
   Increasing the frequency of feed and lowering the duration of feed resulted in no decrease in condenser performance. It appears that adequate condenser performance may be maintained with either of two methods: (1) feeding three times per day for 20 minutes each, or (2) feeding six times per day for 10 minutes each. Preliminary results, subject to verification in Phase III, indicate that to have low concentrations of chlorine in the effluent and adequate condenser performance the approximate feed rate for different levels of inlet water temperatures could be:

   a. 2,500 - 3,000 lb/24 hours for inlet water temperatures of 68°F or more;

   b. 2,000 - 2,500 lb/24 hours for inlet water temperatures between 60°F and 68°F, and

---

*All statistical results and conclusions pertain to the experimental region of this study.

c. less than 2,000 lb/24 hours for inlet water temperatures less than 60°F.

FREE AND/OR TOTAL RESIDUAL CHLORINE CONSUMED THROUGH THE SYSTEM

Both free and total residual chlorine consumed in the system were estimated by subtracting the equivalents of chlorine at the outlet of the condenser from the equivalents of the chlorine at the intake where the chlorine is fed.

1. Fixed Feed Rate
   The amount of free and/or total chlorine consumed in the system for the same feed rate on different dates is not statistically significantly different. There is a tendency for both free and total residual chlorine consumption in the system to increase with increased inlet water temperature. By reducing the duration of feed and increasing the frequency of feed, chlorine consumption increased for the fixed feed rate.

2. Fixed Duration of Feed
   For the fixed duration of feed, there is a general trend for the chlorine system consumption (absolute) to decline as the feed rate is lowered. As inlet water temperature increases, an increase in chlorine consumption tends to occur.

3. Varying Feed Rate, Frequency and Duration of Feed
   Chlorine consumed in the system is most affected by the feed rate. In general, as the feed rate is lowered, consumption is lowered. The effects of varying frequency and duration of feed are small when compared to varying the feed rate. Significant chlorine consumption takes place at the lower feed rates (2,500 lb/24 hours and 1,500 lb/24 hours) and the higher frequency and lower duration of feed (3 times per day for 20 minutes each and 6 times per day for 10 minutes each). Based on the free and total residual chlorine consumed in the system, the amount of chlorine in the effluent may be minimized to a degree by lowering the feed rate and increasing the frequency of feed while shortening the duration of the feed. The decrease in the feed rate must be correlated to the inlet water quality, i.e., a decrease in feed is only valid if the chlorine demand and nitrogen content of the water do not warrant a higher feed rate. The feed rate must be observed as a function of the water quality.

AVERAGE DIFFERENCES ACROSS THE CONDENSER FOR FREE AND TOTAL RESIDUAL CHLORINE (ASSUMING STEADY STATE)

1. Free Residual Chlorine
   Free residual chlorine averaged about .46 mg/l at the inlet to the condenser in the 1977 data; .38 mg/l at the outlet; and .08 mg/l across the condenser. Significantly lower levels of free residual chlorine occurred at the condenser outlet for units 2, 3, and 4 as compared to unit 1. Lower levels of free residual chlorine also

appeared at the lower feed rates. Average free residual chlorine consumed in the condenser was not significantly different between units, but declined significantly as the feed rate was lowered. A feed rate of 4,500 lbs/24 hrs. averaged 0.13 mg/l free residual chlorine consumed, 2,500 averaged 0.07 mg/l, and 1,500 averaged 0.03 mg/l (see Appendix B).

2. Total Residual Chlorine
   Total residual chlorine averaged about 1.08 mg/l at the inlet, 1.04 mg/l at the outlet, and .04 mg/l across the condenser.

It must be stated at this point that in laboratory tests conducted using very pure water, the percentage difference of the method means from the overall target mean (method accuracy) at .25 mg/l concentration showed the amperometric method to vary 10.8 percent and the DPD method 11.9 percent. In river water, many interferences are added which would increase this variance. Therefore, the previously mentioned differences in free and total residual chlorine across the condenser are the same within experimental error.

COMPARISON OF THE DPD AND AMPEROMETRIC TITRATOR

Analysis of the data showed a significant difference between the two methods. The DPD method was significantly higher in its readings than the amperometric titrator, except at low levels of concentration (less than 0.5 mg/l). This phenomenon was also found in the previously mentioned laboratory studies. At residuals of 0.5 mg/l the DPD method measured much higher than the amperometric method and other methods tested, however, at lower residuals (below .1 mg/l) the DPD method was consistently lower than all the methods tested.

RELATIONSHIP BETWEEN INLET WATER TEMPERATURE AND (1) TURBINE BACK PRESSURE, (2) TOTAL NITROGEN, AND (3) TOTAL ORGANIC CARBON

1. Turbine Back Pressure
   A positive linear relationship appears to exist between turbine back pressure and inlet water temperature. The simple correlation coefficient is 0.8.

2. Total Nitrogen*
   A positive trend appears to exist between total nitrogen and inlet water temperature. The simple correlation coefficient is 0.4.

3. Total Organic Carbon
   Total organic carbon seems to have no directly discernable relationship to inlet water temperature. A plot of total organic carbon versus time indicates some sort of cyclical behavior which may be masking any relationship. At this time, the cyclic behavior has not been explained.

---

*Total Nitrogen is the sum of the following nitrogen concentrations: ammonia, organic, nitrates plus nitrites.

ANALYSIS OF RIVER WATER CHLORINE DEMAND

Analysis of the chlorine demand of river water from unit 4 at contact times of one, five, and ten minutes examined possible relationships between chlorine demand and inlet water temperature, total organic carbon, total nitrogen, dosage, and time. A comparison of chlorine demand at the inlet of the condenser with the chlorine demand of one, two and a half, and five minute contact times was made.

When the difference between the inlet water temperature and the temperature of the water at the time of its analysis exceeded one degree Celsius, the chlorine demand at all contact times was significantly lower than those samples whose inlet water temperature and laboratory analysis temperature differed by less than one degree Celsius. The data indicates consistently that lowering the temperature of the water lowered chlorine demand while raising the temperature increased chlorine demand.

No apparent relationships were found in the data between chlorine demand and total nitrogen.

Total organic carbon data showed a cyclical behavior over time, but no relationship with chlorine demand or any of the other independent variables could be identified.

A weak relationship between inlet water temperature and the chlorine demand at contact times of five and ten minutes appeared to exist.

Comparisons of chlorine demand at contact times of one and five minutes, plus an estimated (by interpolation) two and a half minutes were made with chlorine demand at the inlet of the condenser. Free residual chlorine was used as the measure of chlorine demand at the condenser inlet. Previous work indicated a mixing time of approximately 2.2 minutes from the intake to the inlet of the condenser. Results indicate that the one minute chlorine demand was significantly less than that at the condenser inlet, while there was no significant difference between the two and a half and five minute demands and the demand at the condenser inlet.

The average chlorine demands and the associated standard errors for the various contact times for the test period from May 12 through July 20, 1977, are summarized in the following table.

AVERAGE CHLORINE DEMANDS (mg/l) AND
STANDARD ERROR FOR VARIOUS CONTACT TIMES

Contact Time	Mean (N = 11)	Std. Error of Mean
1.0 min.	0.40	0.046
*2.5 min.	0.53	0.039
5.0 min.	0.75	0.051
10.0 min.	1.07	0.065

*To arrive at the 2.5 minute chlorine demand figure, linearity of the demand curve was assumed.

OTHER FACTORS

Other factors were present in the analysis which should be identified as they influenced the results of the analysis:

1. The Chlorination Variability
   The variability of the chlorinator was evident in the data. This made it difficult to accurately estimate what the feed rate should be for different levels of inlet water temperature. The new chlorinator to be used in Phase III should reduce the variability and allow more accurate determination of optimal feed rates for varying conditions.

2. Seasonal Changes
   Inlet water temperatures follow a seasonal pattern. The changes in feed rate during 1977 coincided with seasonal changes in inlet water temperature. The fixed feed rate did not allow identification of the magnitude of the temperature change with respect to chlorine feed rate.

RECOMMENDATIONS

In order to maintain adequate condenser performance with low concentrations of chlorine in the effluent, the chlorine should be fed into the system three times per day for twenty minutes each time with the feed rates recommended earlier. In addition to sustained condenser efficiency, this feed rate is desirable for the following reasons:

1. The condenser is chlorinated once per shift.

2. The length of feed allows sufficient time for periodic grab sample analyses.

3. The timing cogs for the automatic chlorine feed system are already available.

SUMMARY

The objective of the Phase II data analysis was to broaden the understanding of the characteristics for the system affecting chlorine use while identifying more precisely the operating conditions to maintain adequate condenser performance with low concentrations of chlorine in the effluent. This section focuses on factors affecting the interpretation of the statistical results and examines the results of the condenser performance, chlorine consumption, and chlorine in effluent analyses in terms of the overall objective.

1. Significant Sources of Variation

   During the analysis of the data, it became evident that significant sources of variation existed which affected the data interpretation and conclusions drawn from the data. The variability of the chlorinator performance, the inherent error in the measurement technique for chlorine, and the variations induced by changes in inlet water temperature were adjusted for, if possible, or recognized and considered when interpreting the results.

   An unpublished report by the TVA Division of Environmental Planning indicated that a diurnal pH variation exists within the limits of this study on the Holston River. The 24-hour tests were conducted in July 1969. This information was not considered in the statistical analysis.

2. Some Statistical Considerations

   Wherever possible considerable cross-checking of estimates such as means, variances, and standard errors was done. In order to have balance in some of the analyses, some data points were not used, but were included in the cross-checking. Some of the raw data was obviously in error, such as extremely negative chlorine consumption in the system, and not used at all.

   For most of the analyses, the error mean square was fairly consistent (after adjusting for unequal sample sizes), usually about 0.02. Stability of the error mean square is a desirable statistical property.

3. Condenser Performance Considered in the Presence of Chlorine Consumption and Chlorine in the Effluent

   As the analysis has indicated, adequate condenser performance is achieved at a low feed rate with a short duration of feed, applied fairly frequently. The chlorine could be fed to each condenser either 3 times per day for 20 minutes or 6 times per day for 10 minutes. Chlorine consumption was affected by inlet water temperature.

   In order to assure adequate condenser performance the chlorine consumed through the system must take into account the chlorine demand of the condenser. As long as the condenser demand is met, the greater the percentage of chlorine consumed in the system, the less chlorine present in the effluent. As the analysis of chlorine consumption showed, better results were obtained on units 3 and 4.

Finally, the average for free and total residual chlorine at the outlet of the condenser is lower for the lower feed rates and units 3 and 4 in general. The general conclusion was that a feed rate lower than 4,500 lbs/24 hours should be fed three times a day for 20 minutes each, or six times a day for 10 minutes each to minimize chlorine in the effluent while maintaining adequate condenser performance. The three times per day and twenty minutes duration of feed is more desirable, from an operations viewpoint and therefore, is the recommended scheme.

4. Proposed New Feed Rates for John Sevier Based on Inlet Water Temperature

Condenser performance, as estimated by ACF, was examined as a function of feed rate and inlet water temperature. Various models were hypothesized and fitted to the data. A nonlinear model of the form ACF = Exp (β*IWT), where IWT is the inlet water temperature and β is a cofficient dependent on the feed rate, was used. The resulting contours of feed rate, for a given level of ACF, allowed determination of feed rates for various temperature levels. Estimates were cross-checked against a quadratic model for inlet water temperature. Final recommendations were based on feed rate contours empirically adjusted due to the variability of the data and the need to maintain adequate condenser performance. Phase III data will allow further examination and determination of the above relationships and models.

REFERENCES

1. Environmental Protection Agency. Water Quality and Waste Treatment Requirements on the Upper Holston River. EPA-TS-03-71-208-07, U.S. Environmental Protection Agency, Athens, Georgia, 1972.

2. Heat Exchange Institute. Standards for Steam Surface Condensers. Sixth edition, New York. 1970.

3. Feben, Douglas, Taras, Michael J., "Chlorine Demand Constants of Detroit's Water Supply," Journal AWWA. [42(5): 453-461, May 1950].

4. Feben, Douglas, Taras, Michael J., "Studies on Chlorine Demand Constants," Journal AWWA. [43(11): 922-932, November 1951].

5. Taras, Michael J., "Preliminary Studies on the Chlorine Demand of Specific Chemical Compounds," Journal AWWA. [42(5): 462-474, May 1950].

6. White, George Clifford. Handbook of Chlorination, Van Nostrand Reinhold Company, New York, NY, 1972. pp. 204-207.

7. Since Free Residual Chlorine (FRC) is the active specie, we used the FRC for controlling the chlorination regime. The rationale for limiting FRC to a range of 0.1-0.2 mg/l is as follows:

   a. 0.2 mg/l is the NPDES permit limit at a point approximately 2 min. downstream of the outlet of the condenser.

   b. Due to the daily fluctuations of chlorine demand (many times severe) at John Sevier, 0.1 mg/l FRC is the lowest level we can attain in order to preserve the operation of the condenser.

8. Additional information which will corroborate our approach may be found on page 3 of the paper "Collaborative Test Results for Chlorine Analysis by Amperometric Titration" by UWAG, EEI, and NRECA." This paper was submitted to EPA in March 1979.

9. American Public Health Association. Standard Methods for the Examination of Water and Wastewater. Fourteenth edition, Washington, D.C., 1971. p. 1193.

APPENDIX A

ANALYSIS OF PHASE II CHLORINATION STUDY DATA

APPENDIX A

ANALYSIS OF PHASE II CHLORINATION STUDY DATA

ABSTRACT

This report summarizes the results of the data analysis of Phase II of the chlorination study at John Sevier Steam Plant. The analysis focused on the factors affecting condenser performance, free and/or total residual chlorine consumed in the system, the relationship between inlet water temperature and variables associated with chlorine use, and the correlation of chlorine demand versus feed rate, inlet water temperature, and total organic carbon.

Results indicate that adequate condenser performance can be maintained with low concentrations of chlorine in the effluent if the chlorine feed is three times per day for 20 minutes each with approximately the following feed rates for different levels of inlet water temperature and assuming that there is no drastic change in seasonal chlorine demand as demonstrated by 1977 data:

(1) 2,500 - 3,000 lb/24 hours for inlet water temperatures of 68°F or more;

(2) 2,000 - 2,500 lb/24 hours for inlet water temperatures between 60°F and 68°F; and

(3) less than 2,000 lb/24 hours for inlet water temperatures less than 60°F.

I. INTRODUCTION

This report documents the data and its analysis from the second phase of a three phase program underway at the John Sevier Steam Plant studying chlorine minimization/optimization needed to comply with EPA effluent guidelines and National Pollutant Discharge Elimination System (NPDES) permits. Phase II, conducted during the summer of 1977, focused on the factors affecting condenser performance, free and/or total residual chlorine consumption in the system, and the relationship between inlet water temperature and variables associated with chlorine use such as turbine back pressure, total nitrogen, total organic carbon, and chlorine demand.

The scheduled test program was for twenty test dates. For May through July the feed rate was 4,500 lbs/24 hours, 3,000 lbs/24 hours for August, and 2,500 lbs/24 hours for September. As the raw data in the Appendices A-C indicate, some minor departures from the schedule took place. The frequency and rate of chlorine feed to each condenser were as follows:

Unit 1: Twice per day for 1 hour each (control)
Unit 2: Twice per day for 30 minutes each
Unit 3: Three times per day for 20 minutes each
Unit 4: Six times per day for 10 minutes each.

In addition, on nine test dates outlet free and total residual chlorine were measured by the DPD and amperometric methods. This data was gathered to allow a comparison of the two methods.

This test schedule was designed so that the fixed feed rate for May through July would allow estimation of time effects, frequency and duration of chlorine feed rates. The frequency and duration of feeds at the various condensers allows a comparison of the effects of frequency and duration of feed rates. The August and September data were to allow estimation of the differences in feed rates as compared with varying the other factors.

II. CONDENSER PERFORMANCE

A. Discussion

Condenser performance is measured by the apparent cleanliness factor (ACF) as calculated by the Heat Exchange Institute.[1] The main concern was the effect of different chlorination rates and frequency and duration of feed on the apparent cleanliness factor. Compounding the analysis problem was inlet water temperature variation which is related to the apparent cleanliness factor. An analysis of covariance with inlet water temperature as the covariate was calculated.

The analysis of condenser performance, adjusting for the effects of inlet water temperature, assumed that the apparent cleanliness factor was a linear function of feedrate and "unit factor" with an interaction. Although there are many other factors which influence ACF, we are limiting these factors for statistical purposes.

"Unit factor" is the effect of frequency and duration of feed. Since the effects of frequency and duration of feed were mixed or confounded with the units, special comparisons or contrasts of the unit means were made to estimate the effects of varying frequency and the duration of feed.

Table A-1 summarizes the analysis. Note that feed rate, "unit factor," and their interaction were significant. Table A-2 presents the adjusted ACF means.

---

[1]This method of calculating the ACF is widely used throughout the utility industry. It must be carefully noted, however, that the ACF only approximates the true condenser performance. Thirty-seven variables are used in this calculation so it must not be construed as absolute. Such variables as inlet water temperature, turbine back pressure, gross generation, condenser duty, and air leakage will greatly affect the results of this calculation.

TABLE A-1

ANALYSIS OF APPARENT CLEANLINESS FACTOR
(AFTER ADJUSTING FOR INLET WATER TEMPERATURE)

Source	DF	Sum of Squares	Mean Square	F Value
Feed Rate	1	0.0091	0.0091	73.88*
Unit	3	0.0076	0.0025	20.53*
Interaction	3	0.0039	0.0013	10.55*
Inlet Water Temperature	1	0.0004	0.0004	3.49*
Error	15	0.0018	0.0001	
Corrected Total	23	0.0228		

*Significant

TABLE A-2

MEAN VALUES OF APPARENT CLEANLINESS FACTOR
AFTER ADJUSTING FOR INLET WATER TEMPERATURE

Feed Rate (lb/24 hrs.)*	Unit			
	1	2	3	4
4,500	.7351	.7364	.7549	.7549
1,500	.6861	.7516	.7641	.7756

*This is only a relative feed rate. The absolute FRC concentration is not constant from day to day at the inlet to the condenser due to changing levels of chlorine demand and cooling water flow.

Testing for interaction effects yielded a significant interaction effect. While it was smaller than the main effects, it did indicate that the proper model was not additive in its effects. Interpretation of the interaction effect was difficult due to the effect of duration of feed being completely confounded with the unit effects. Examination of the adjusted mean apparent cleanliness factors indicates that at the lower feed rate, as the frequency of feed increases while the duration is lowered, the response of condenser performance increases more rapidly than the pure addition of feed rate and "unit factor."

A comparison of the mean apparent cleanliness factors for each feed rate was made to examine the means and the differences between them for units 3 and 4 combined. Two considerations were made in choosing the appropriate error mean square. First, because an analysis of covariance was carried out, an allowance for the sampling error of the regression coefficient was made. Secondly, the unequal sample sizes for the two feed rates were factored in. The comparison showed the lower feed rate had a significantly higher apparent cleanliness factor.

A comparison of the average apparent cleanliness factors for each unit was made to determine the differences between units. Comparisons were made to determine the direction of change necessary in frequency and duration of feed to increase condenser performance. Estimating the appropriate error mean square for the comparisons was simpler because the sample size (six good data points) was equal for each unit. To evaluate the effects of varying frequency, the average of units 1 and 2 (which had the same frequency) were contrasted with the means of unit 3 and unit 4, respectively. The comparisons showed that unit 3 and unit 4 had significantly higher condenser performance than the average of units 1 and 2. The higher condenser performance of units 3 and 4 was not solely attributed to the change in frequency alone as there may have been unit differences and duration of feed differences. Since units 1 and 2 had the same frequency but different durations of feed, the response of condenser performance was indicated by comparing units 1 and 2. The difference between units 1 and 2 condenser performance was significant, with the lower interval of duration having significantly higher condenser performance. Units 3 and 4 were not significantly different from each other, but were significantly higher than units 1 or 2.

Significantly better condenser performance was achieved by using a lower feed rate, more frequently, with a shorter duration of feed than a higher feed rate, less frequently for longer durations of feed. Units 3 and 4 were not significantly different from each other indicating that either the combination of feeding three times a day for 20 minutes or 6 times a day for 10 minutes will result in adequate condenser performance.

B. Statistical Analysis

1. Comparing feed rates, adjusting for inlet water temperature, similar units.

Mean ACF for a feed rate of 4500 lbs/24 hours (adjusted for inlet water temperature) based on 8 data points = .7549. Mean ACF for a feed rate of 1500 lbs/24 hours (adjusted for inlet water temperature) based on 4 data points = .7699.

Comparison = .7699 - .7549 = .0150
Error Mean Square of the Comparison = .0067
T = .0150/.0067 = 2.24

This comparison is significant at the 0.10 level.

2. Comparing changes in frequency and duration of feed.

	Adjusted for Inlet Water Temperature
Unit 1 mean ACF =	.7189
Unit 2 mean ACF =	.7414
Unit 3 mean ACF =	.7579
Unit 4 mean ACF =	.7618

(a) Unit 3 versus the average of units 1 and 2:

Comparison = .7579 - ((.7189 + .7414)/2) = .0278
Error Mean Square of the Comparison = .0049
T = .0278/.0049 = 5.67

This comparison is significant at the 0.10 level.

(b) Unit 4 versus the average of units 1 and 2:

Comparison = .7618 - ((.7189 + .7414)/2) = .0317
Error Mean Square of the Comparison = .0049
T = .0317/.0049 = 6.46

This comparison is significant at the 0.10 level.

(c) Unit 2 versus unit 1:

Comparison = .7414 - .7189 = .0225
Error Mean Square = .0057
T = .0225/.0057 = 3.95

This comparison is significant at the 0.10 level.

(d) Unit 4 versus unit 3:

Comparison = .7618 - .7579 = .0039
Error Mean Square = .0057
T = .0039/.0057 = 0.68

This comparison is not significant.

(e) Unit 4 versus Unit 2*

Comparison = .7618 - .7414 = .0204
Error Mean Square = .0057
T = .0204/.0057 = 3.58

This comparison is significant at the 0.10 level.

III. CHLORINE CONSUMPTION

A. Discussion

This section discusses the behavior of the system consumption of free and total residual chlorine. The system consumption was estimated by subtracting the amount of chlorine at the outlet of the condenser from one-half of the chlorine concentration at the intake for reasons mentioned earlier in Section I.

1. Fixed Feed Rate

Data gathered for May, June, and July with the units operating at a feed rate of 4500 lbs/24 hours allowed evaluation of the time and operating conditions for a fixed feed rate. For both free and total residual chlorine, there was no significant difference in consumption over the time period of the data. There was a tendency for chlorine consumption to rise as inlet water temperature rose with the trend stronger for free residual chlorine than total residual chlorine.

While the difference between units was not significant for free residual chlorine consumed in the system, it was for total residual chlorine. Unit 4 shows the highest consumption in both cases, but it is only statistically significant in the total residual chlorine consumption case. As Table A-3 indicates, reducing the duration of feed and increasing the frequency of feed tends to increase chlorine consumption for the fixed feed rate.

TABLE A-3

MEANS OF FREE AND TOTAL RESIDUAL CHLORINE CONSUMPTION (mg/l) BY UNIT. (FEED RATE = 4,500 LBS/24 HOURS)

	Unit 1	Unit 2	Unit 3	Unit 4
Average Free Residual Chlorine Consumed	.84	.93	.87	.97
Average Total Residual Chlorine Consumed	.12	.14	.20	.27

*No comparison of units 3 and 2 is necessary since there is no significant difference between units 4 and 3.

2. Fixed Duration of Feed

Effects within units were used to make inferences about the response of chlorine consumption to varying the feed rate and different inlet water temperatures. Each unit had a different duration of feed, so the sources of variation affecting chlorine consumption for a given unit were feed rate, time, inlet water temperature, and chlorine demand. Chlorine demand can be assumed equal for all units. The mean free residual chlorine consumed in the system for each feed rate, time interval, and unit is presented in Table A-4.

TABLE A-4

MEANS OF FREE RESIDUAL CHLORINE CONSUMED IN SYSTEM IN mg/l (SAMPLE SIZE)

Feed Rate (lbs/24 hours)	Date	Unit 1	Unit 2	Unit 3	Unit 4
4500	May	0.82(3)	1.22(1)	0.93(4)	1.01(4)
	June	0.82(4)	0.87(5)	0.90(5)	0.95(5)
	July	0.93(2)	0.92(2)	0.52(1)	0.95(2)
2500	Sept.	0.45(2)	0.41(2)	0.50(2)	0.55(2)
1500	Oct/Nov	0.46(2)	0.47(2)	0.40(2)	0.49(2)

For free residual chlorine consumption for fixed duration of feed, there was a consistent trend for consumption to decline as the feed rate and inlet water temperature declined. Free residual chlorine consumption tends to increase as inlet water temperature increases and decreases as inlet water temperature decreases, stabilizing around 0.45 mg/l for inlet water temperatures of 60°F or less.

Reliable data for total residual chlorine consumed in the system was available for May, June, and July at a feed rate of 4,500 lbs/24 hours. Table A-5 displays the mean total residual chlorine consumed by data for the different units.

TABLE A-5

MEANS OF TOTAL RESIDUAL CHLORINE CONSUMED IN SYSTEM
IN mg/l (SAMPLE SIZE) FEED RATE = 4,500 LSB/24 HOURS

Date	Unit 1	Unit 2	Unit 3	Unit 4
May	0.07(2)	0.02(1)	0.42(2)	0.25(3)
June	0.08(4)	0.15(5)	0.14(5)	0.26(5)
July	0.27(2)	0.19(2)	0.09(1)	0.31(2)

As in the free residual chlorine case, consumption tracks the behavior of inlet water temperature.

3. Varying Feed Rate, Frequency, and Duration of Feed

Free residual chlorine consumed in the system is, as expected, most responsive to feed rate. As the feed rate is lowered, consumption is lowered. Table A-6 presents the analysis of variance table (ANOVA) for the free residual chlorine consumption over all feed rates.

Table A-6

FREE RESIDUAL CHLORINE CONSUMED IN SUSTEM
ALL FEED RATES

Factor	df	Sum Sq	MSQ	F Calc.	Calculated Sig. Level
Feed Rate	2	2.1716	1.0858	43.17	Very High
Units	3	0.0975	0.0325	1.29	0.30 approx.
Interaction	6	0.0195	0.0033	0.13	Not sig.
Error	41	2.7863	0.0680 0.0252*		
Total	52	5.0749			

*Adjusted for unequal sample sizes

An adjustment to the error mean square was necessary to adjust for unequal sample sizes. The effect of frequency and duration of feed as identified by the "unit factor" was marginally significant. A test for interaction effects yielded no significant interaction indicating that an additive model was essentially correct for free residual chlorine consumption.

Total residual chlorine consumption in the system had an effect due to "unit factor." Table A-7 shows the analysis of variance table for the analysis. Available data did not allow quantitative analysis of varying feed rates.

Table A-7

TOTAL RESIDUAL CHLORINE CONSUMED IN SYSTEM
FEED RATE = 4,500 LBS/24 HOURS

ANOVA

Factor	df	Sum Sq	MSQ	F Calc.	Calculated Sig. Level
Time	2	0.0365	0.0183	1.33	>0.25
Units	3	0.1105	0.0368	2.67	0.07 approx.
Error	28	0.814	0.0291 0.0138*		
Total	33	0.9610			

*Adjusted for unequal sample sizes.

"Unit factor" did show up as being significant. Comparisons of the unit means indicated that units 3 and 4 were significantly different from units 1 and 2 and also significantly different from each other. Significantly higher consumption occurred on units 3 and 4.

B. Statistical Analysis

1. ANOVA table for free residual chlorine consumed in system with a feed rate of 4500 lbs/24 hours.

Factor	df	Sum Sq	MSQ	F Calc.	Calculated Sig. Level
Time	2	0.0324	0.0162	0.51	>.25
Units	3	0.0882	0.0294	0.92	>.25
Error	31	2.2694	0.0732 0.0321*		
Total	36	2.3900			

*Adjusted for unequal sample sizes.

Conclude time and units are not significant at the 0.10 level.

2. Contrasts of means of total residual chlorine (TRC) consumption among units.

	Mean TRC
Unit 1	0.1256
Unit 2	0.1438
Unit 3	0.2056
Unit 4	0.2663

(a) Unit 4 versus Unit 3

Comparison = 0.2663 - 0.2056 = 0.0607
Error mean square of the comparison = 0.0234
T = 0.0607/0.0234 = 2.59

This comparison is significant at the 0.10 level.

(b) Unit 3 versus Unit 2:

Comparison = 0.2056 - 0.1438 = 0.0618
Error mean square of the comparison = 0.0246
T = 0.0618/0.0246 = 2.51

This comparison is significant at the 0.10 level.

IV. INLET WATER TEMPERATURE VERSUS OTHER VARIABLES

Inlet water temperature was examined and adjusted for as a covariate in the condenser performance analysis. It was also examined briefly regarding its effects on chlorine consumption. This section examines, briefly, inlet water temperature and possible relationships with (1) turbine back pressure, (2) total nitrogen, and (3) total organic carbon.

1. Turbine Back Pressure

Based on an analysis of 34 data points, turbine back pressure exhibits a general linear trend over the range of inlet water temperatures of 54°F to 76°F. The simple correlation coefficient is 0.8. The average rate of change of turbine back pressure per unit change in inlet water temperature is 0.033. Variation in turbine back pressure appears to be fairly constant over the range of inlet water temperatures.

2. Total Nitrogen

Based on an analysis of 59 points, total nitrogen shows a positive linear trend with inlet water temperature. The simple correlation coefficient is 0.4. An average rate of change was not calculated as the variation in total nitrogen increases as inlet water temperature increases. A transformation of the data would result in a stabilization of the variance with the logarithm being the most likely transformation.

3. Total Organic Carbon (TOC)

Total organic carbon seems to have no directly discernible relationship to inlet water temperature based on an analysis of 55 data points. A plot of TOC versus time indicates a cyclical behavior which may be masking any relationship to inlet water temperature. At this time, the cyclic behavior remains unexplained.

V. DPD VERSUS AMPEROMETRIC TITRATOR

A. On nine test dates in 1977 outlet free and total residual chlorine were measured by both the amperometric and DPD methods on Unit 1. The use of both methods allowed a statistical comparison on the equality of the two methods. Appendix D contains the raw data gathered on the nine test dates. Table A-8 summarizes a paired samples analysis carried out on the data. At a significance level of 0.10, there is a significant difference between the two methods for both free and total residual chlorine. Based on the differences calculated, DPD is consistently higher than the amperometric method.

A further examination of the calculated differences shows that negative differences occur at low levels of concentration, approximately 0.5 mg/l and less. This indicates the measurements by the two methods may depend on the level of the concentration, and possibly bias the comparison between the two methods. Section B summarizes a paired samples analysis of free and total residual chlorine where the effect of the level of concentration has been removed.

B. Removing the Effect of Level of Concentration from DPD and Amperometric Data

The true concentration was estimated as the mean of the observed DPD and amperometric readings for both free and residual chlorine. The estimated true concentration was then fitted by regression analysis as a linear function of the observed data for each method. This allowed adjusting of the DPD and amperometric data to remove the effects of concentration level.

Table A-8

SUMMARY OF PAIRED SAMPLES ANALYSIS COMPARING DPD AND AMPEROMETRIC METHODS

Differences = DPD - Amperometric (In Mg/l)

Date	*Free Residual Chlorine*	*Total Residual Chlorine*
6-10	0.46	0.17
6-17	0.63	0.13
6-30	0.15	0.00
7-13	0.11	0.03
7-20	0.07	0.30
7-27	-0.04	0.10
9-2	-0.03	0.03
9-8	0.11	0.07
9-16	0.05	0.08
	Mean = 0.1678	Mean = 0.1011
	Variance = 0.0515	Variance = 0.0084
	Calculated t value = 2.22	Calculated t value = 3.31
	df = 8	df = 8
	Alpha = 0.10	Alpha = 0.10

At a significance level of 0.10, there is a significant difference between the two methods for both free and total residual chlorine. The DPD method is significantly higher than the amperometric method in its readings on the chlorine level. Table A-9 summarizes the paired samples analysis on the adjusted data.

Table A-9

SUMMARY OF PAIRED SAMPLES ANALYSIS COMPARING DPD AND AMPEROMETRIC METHODS AFTER ADJUSTMENT FOR EFFECT OF CONCENTRATION LEVEL

Free Residual Chlorine			Total Residual Chlorine		
DPD	AMP	DIF	DPD	AMP	DIF
0.89	0.79	0.10	0.93	0.81	0.12
0.90	0.80	0.10	0.94	0.81	0.13
0.92	0.80	0.12	0.95	0.82	0.13
0.93	0.80	0.13	0.96	0.82	0.14
0.94	0.79	0.15	0.97	0.83	0.14
0.95	0.81	0.14	0.98	0.83	0.15
0.96	0.82	0.14	0.98	0.83	0.15
0.96	0.80	0.16	0.98	0.83	0.15
0.96	0.83	0.13	0.98	0.83	0.15
Mean = 0.13			Mean = 0.14		
Variance = 0.000424			Variance = 0.000125		
Calculated t value = 18.94			Calculated t value = 37.50		
df = 8			df = 8		
Alpha = 0.10			Alpha = 0.10		

VI. DESCRIPTIVE STATISTICS

Descriptive statistics not presented in this report elsewhere, but still of interest, are summarized here.

A. Chlorine Consumption

1. Mean Free Residual Chlorine at Inlet of Condenser (sample size)

   (a) By unit Unit 1 = 0.52(14) Unit 3 = 0.46(13)
   Unit 2 = 0.43(14) Unit 4 = 0.43(13)

   (b) By feed rate 4500: 0.61(26)
   2500: 0.42(14)
   1500: 0.23(14)

   (c) Overall mean = 0.46(54)

2. Mean Free Residual Chlorine at Outlet of Condenser (sample size)

   (a) By unit Unit 1 = 0.43(14) Unit 3 = 0.38(14)
   Unit 2 = 0.36(14) Unit 4 = 0.33(14)

   (b) By feed rate 4500: 0.48(28)
   2500: 0.34(14)
   1500: 0.20(14)

   (c) Overall mean = 0.38(56)

3. Mean Free Residual Chlorine Consumed in Condenser (sample size)

   (a) By unit Unit 1 = 0.09(14) Unit 3 = 0.08(13)
   Unit 2 = 0.08(14) Unit 4 = 0.10(13)

   (b) By feed rate 4500: 0.13(26)
   2500: 0.07(14)
   1500: 0.03(14)

   (c) Overall mean = 0.09(54)

4. Mean Total Residual Chlorine at Inlet of Condenser (sample size)

   (a) By unit Unit 1 = 1.09(12) Unit 3 = 1.08(12)
   Unit 2 = 1.07(11) Unit 4 = 1.06(12)

   (b) By feed rate 4500: 1.22(24)
   2500: 0.96(13)
   1500: 0.70(10)

   (c) Overall mean = 1.08(47)

5. Mean Total Residual Chlorine at Outlet of Condenser (sample size)

(a) By unit

Unit 1 = 1.05(12)	Unit 3 = 1.05(12)
Unit 2 = 1.05(11)	Unit 4 = 1.01(12)

(b) By feed rate

4500:	1.22(24)
2500:	0.91(13)
1500:	0.67(10)

(c) Overall mean = 1.04(47)

6. Mean Total Residual Chlorine Consumed in Condenser (sample size)

(a) By unit

Unit 1 = 0.05(12)	Unit 3 = 0.03(12)
Unit 2 = 0.01(11)	Unit 4 = 0.06(12)

(b) By feed rate

4500:	0.04(24)
2500:	0.05(13)
1500:	0.03(10)

(c) Overall mean = 0.04(47)

VII. SUMMARY

The objective of the analysis of the Phase II data was to broaden the understanding of the characteristics for the system affecting chlorine use while identifying more precisely the operating conditions to maintain adequate condenser performance with low concentrations of chlorine in the effluent. This section focuses on factors affecting the interpretation of the statistical results and examines the results of the condenser performance, chlorine consumption, and chlorine in effluent analyses in terms of the overall objective.

1. Significant Sources of Variation

During the analysis of the data, it became evident that significant sources of variation existed which affected the interpretation and conclusion drawn from the data. The variability of the chlorinator, the inherent error in the measurement technique of chlorine, and the variation induced by inlet water temperature were adjusted for, if possible, or recognized and considered when interpreting the results.

2. Some Statistical Considerations

Wherever possible considerable cross-checking of estimates such as means, variances, and standard errors was done. In order to have balance in some of the analyses, some data points were not used, but were included in the cross-checking. Some of the raw data was obviously in error, such as extremely negative chlorine consumption in the system, and not used at all.

For most of the analyses, the error mean square was fairly consistent (after adjusting for unequal sample sizes), usually about 0.02.

3. <u>Condenser Performance Considered in the Presence of Chlorine Consumption and Chlorine in the Effluent</u>

As the analysis has indicated, adequate condenser performance is achieved at a low feed rate with a short duration of feed, applied fairly frequently. Either the chlorine could be fed 3 times per day for 20 minutes or 6 times per day for 10 minutes to each condenser. Chlorine consumption was affected by inlet water temperature. In order to assure adequate condenser performance, the chlorine consumed through the system must take into account the chlorine demand of the condenser. As long as the condenser demand is met, the greater the percentage of chlorine consumed in the system, the less chlorine present in the effluent. As the analysis of chlorine consumption showed, better results were obtained on units 3 and 4. Finally, the average for free and total residual chlorine at the outlet of the condenser was lower for the lower feed rates and units 3 and 4 in general. The overall pattern was that a feed rate lower than 4,500 lbs/24 hours could be fed 3 times a day for 20 minutes each, or 6 times a day for 10 minutes each to maintain adequate condenser performance and minimize chlorine in the effluent. From an operations viewpoint, the 3 times per day and 20-minute duration of feed is more desirable and, therefore, the recommended scheme.

CONDENSER PERFORMANCE DATA

Table A-10

ALL AVAILABLE ACF AND INLET WATER TEMPERATURE (IWT) DATA

Date	Unit 1		Unit 2		Unit 3		Unit 4	
	ACF	IWT	ACF	IWT	ACF	IWT	ACF	IWT
05-06-77					.72			
05-20-77					.75	66	.74	
06-01-77	.72		.74					
06-03-77		72		71	.75	71	.75	71
06-16-77					.74	72	.74	
06-17-77	.72	74	.71	73				72
06-30-77	.71	72	.71	71	.74	70	.74	70
07-13-77	.72	76	.73	74	.74	74	.74	74
07-27-77	.71	75	.74	71			.74	72
08-09-77	.72		.73					
08-10-77					.75	71	.77	72
08-24-77	.70	77	.71	75				
09-08-77	.70		.71		.73	72		
09-09-77		71		71			.74	71
09-21-77					.73	69	.73	68
09-22-77	.69	71	.72	68				
10-05-77	.72		.73					
10-06-77					.77		.77	
10-18-77			.76					
10-19-77	.74				.78		.79	
11-02-77	.70	61	.77	59				
11-03-77					.79	65	.78	65
11-17-77					.79	53	.82	54
11-18-77	.73	55	.80	54				
12-01-77					.85	53	.82	
12-02-77	.81		.80					
12-14-77	.81		.84		.85			

Table A-11

CONDENSER PERFORMANCE DATA USED TO ESTIMATE THE CHANGE IN AFC RELATIVE TO A CHANGE IN INLET WATER TEMPERATURE (IWT)

Date	Unit 1		Unit 2		Unit 3		Unit 4	
	ACF	IWT	ACF	IWT	ACF	IWT	ACF	IWT
05-20-77					.75	66		
06-03-77					.75	71	.75	71
06-16-77					.74	72		
06-17-77	.72	74	.71	73				
06-30-77	.71	72	.71	71	.74	70	.74	70
07-13-77	.72	76	.73	74	.74	74	.74	74
07-27-77	.71	75	.74	71			.74	72
08-10-77					.75	71	.77	72
08-24-77	.70	77	.71	75				
09-08-77					.73	72		
09-09-77							.74	71
09-21-77					.73	69	.73	68
09-22-77	.69	71	.72	68				
11-02-77	.70	61	.77	59				
11-03-77					.79	65	.78	65
11-17-77					.79	53	.82	54
11-18-77	.73	55	.80	54				
12-01-77					.85	53		

Table A-12

DATA USED TO ANALYZE CONDENSER PERFORMANCE WITH INLET WATER TEMPERATURE (IWT) AS A COVARIATE

Date	Feed Rate	Unit 1		Unit 2		Unit 3		Unit 4	
		ACF	IWT	ACF	IWT	ACF	IWT	ACF	IWT
06-03	4500	.72	72	.74	71	.75	71	.75	71
06-17	4500	.72	74	.71	73	.74	72	.74	72
06-30	4500	.71	72	.71	71	.74	70	.74	70
07-13	4500	.72	76	.73	74	.74	74	.74	74
11-03	1500	.70	61	.77	59	.79	65	.78	65
11-18	1500	.73	55	.80	54	.79	53	.82	54

APPENDIX B

DATA USED AND SUMMARY STATISTICS FOR THE PHASE II CHLORINATION STUDY

Date	Unit	Inlet Free: Avg. of All No's	Inlet Free: Avg. of Steady State	Inlet Free: No's Not Used	Outlet Free: Avg. of All No's	Outlet Free: Avg. of Steady State	Outlet Free: No's Not Used	Difference* Steady State Free Inlet-Outlet	Inlet Total: Avg. of All No's	Inlet Total: Avg. of Steady State	Inlet Total: No's Not Used	Outlet Total: Avg. of All No's	Outlet Total: Avg. of Steady State	Outlet Total: No's Not Used	Difference Steady Stat Total Inlet-Outle
5/06/77	1	.417	.410	.1;.8	.356	.351	.25;.49	.059	1.33	1.52	.2;.6	1.24	1.31	.55;1.4	.21
5/06/77	2	.797	.734	.15;1.88		No Data		-	1.53	1.62	.29;2.2		No Data		-
5/06/77	3	.56	.483	.35;1.0	.482	.523	.15;.69	-.041	1.46	1.48	1.3;1.6	1.41	1.40	1.37;1.45	.08
5/12/77	1	1.15	1.26	.1;.3		No Data		-	1.43	1.49	.1;.4;.9; 9;.92		No Data		-
5/12/77	3	1.40	1.60	.3;.66;1.68	.242	.233	.12;.44	1.37	1.42	1.60	.3;.66;1.8	.79	.77	.29;.3;1.87	.83
5/12/77	4	.797	.936	.1	.375	.355	.17;.66	.58	.797	.936	.1	.91	.917	.17;1.62	.019
5/20/77	1	1.13	1.135	.4;1.3	.868	.864	.78;.91	.271	1.53	1.57	.5;1.75	1.15	1.19	.39;1.36	.38
5/20/77	3	.98	1.2	.1;.3	.877	1.0	.61;1.02	.20	1.21	1.44	.1;1.8	1.54	1.54	-	-.10
5/20/77	4	.7	1.15	.1	.577	.7	.33	.45	1.07	1.4	.2;.3	1.1	1.22	.88	.18
5/27/77	1	.512	.496	.1;.8	.223	.234	.08;.32	.262	1.26	1.3	.3;1.45	1.28	1.38	.08;1.46	-.08
5/27/77	2	.478	.414	.22;1.5	.234	.236	.2;.26	.178	1.28	1.41	.4	1.43	1.43	.52;1.48	-.12
5/27/77	3	.345	.375	.1;.5	.206	.208	.14;.26	.167	1.10	1.15	.2;1.55	1.32	1.43	.52;1.48	-.28
5/27/77	4	.367	.467	.1;.6	.22	.22	-	.247	.87	1.51	.1;.2;.3; 1.6	1.05	1.44	.40;.51	.07
6/03/77	1	.364	.382	.16;.48	.25	.241	.05;.54	.141	.99	1.29	.16;.31; 1.32	1.08	1.15	.14;1.31	.14
6/03/77	2	.367	.389	.06;.50	.358	.366	.21;.45	.023	.975	1.25	.12;.33;.56	1.184	1.285	.11;1.45	-.035
6/03/77	3	.24	.27	.05;.31	1.57	.147	.1;.2	.123	1.15	1.295	.41;1.33	1.20	1.21	1.06;1.30	.085
6/03/77	4	.24	.33	.06	1.73	.21	.1	.12	.878	1.255	.22;.78	1.13	1.13	-	.125
6/10/77	1	.581	.663	.07;.05;.8	.659	.676	.2;.98	-.013	1.14	1.245	.43;.51; 1.45	1.21	1.29	.51	-.045
6/10/77	2	.93	.93	-	.834	.937	.01	-.007	1.49	1.59	.3;1.7	1.57	1.53	1.69;1.7	.06
6/10/77	3	.764	.778	.65	.56	.62	.15;.73	.158	1.44	1.45	1.325	1.25	1.29	.65;1.63	.16
6/10/77	4	.975	.975	-	.58	.745	.25	.230	1.55	1.58	1.46	1.10	1.26	.79	.32
6/17/77	1	.526	.569	.15;.8	.248	.268	.15;.17	.301	1.11	1.24	.21;.56	1.23	1.25	1.01;1.28	-.01
6/17/77	2	.537	.544	.45	.458	.46	.37;.53	.084	1.21	1.28	.35	1.19	1.28	.44;1.35	0
6/17/77	3	.297	.311	.15;.35	.25	.245	.17;.34	.066	1.19	1.22	.95	.99	1.20	.48;.37;1.28	.02
6/17/77	4	.495	.50	.45;.525	.365	.365	-	.135	1.06	1.19	.53	1.21	1.21	-	-.02
6/24/77	1	1.49	1.49	1.4;1.61	1.5	1.54	1.15	-.05	1.88	1.93	1.45	2.05	.264	1.75;2.15	-.71
6/24/77	2	.779	.773	.57;1.03	.60	.608	.375;.675	.165	1.36	1.35	1.17;1.45	1.27	1.28	1.05;1.35	.07
6/24/77	3	.97	1.00	.7	.83	.878	.4	.122	1.27	1.45	.2;.9;1.65	1.33	1.375	.9;1.4	.075
6/24/77	4	1.05	1.1	.9	.58	.688	.15	.412	1.21	1.38	.5	1.065	1.28	.2	.10
6/30/77	1	.939	.931	.78;1.05	.961	.957	.74;1.22	-.026	1.42	1.41	.28;1.69	1.35	1.38	1.02;1.43	.03
6/30/77	2	.767	.758	.32;1.32	.535	.539	.45;.60	.219	1.17	1.17	.32;1.98; 1.32	1.13	1.17	.5;1.95	0
6/30/77	3	.862	.875	.16;1.42	.519	.603	.1;.3;.65	.272	1.31	1.44	.31;.32; 2.08	1.15	1.20	.6;1.31	.24
6/30/77	4	.577	.64	.1;.8	.485	.519	.35	.121	1.297	1.51	.28;1.45	1.0	1.11	.55	.40

*We have noted free and total residual chlorine concentrations at the condenser outlet higher than at the condenser inlet. Since this phenomenon (inlet minus outlet ≤ - 0.1 mg/l) has only occurred 28 times out of 354 data points (7.9%), we have attributed the phenomenon to field experimental error until hypotheses can be tested.

Date	Unit	Inlet Free: Avg. of All No's	Inlet Free: Avg. of Steady State	Inlet Free: No's Not Used	Outlet Free: Avg. of All No's	Outlet Free: Avg. of Steady State	Outlet Free: No's Not Used	Difference Steady State Free Inlet-Outlet	Inlet Total: Avg. of All No's	Inlet Total: Avg. of Steady State	Inlet Total: No's Not Used	Outlet Total: Avg. of All No's	Outlet Total: Avg. of Steady State	Outlet Total: No's Not Used	Differen[ce] Steady St[ate] Total Inlet-Out[let]
7/06/77	1	.804	.814	.36;1.15	.324	.339	.18;.2; .55	.475	1.09	1.09	.79;1.43	.973	.988	.6;1.15	.102
7/06/77	2	.407	.42	.08;.6	.378	.386	.125;.475	.34	.681	.706	.08;1.03	1.05	1.16	1.075;.2	-.454
7/06/77	3	1.00	1.02	.62;1.3	.345	.411	.05;.075; .45	.609	1.27	1.33	.66;1.53	1.0	1.19	.1;.4	.14
7/06/77	4	1.1	1.1	-	.392	.394	.3;.475	.706	1.37	1.55	1.0	1.02	1.14	.45	.41
7/13/77	1	.991	.991	-	.813	.859	.2;1.06	.132	1.29	1.29	-	1.19	1.20	1.1;1.28	.09
7/13/77	2	.580	.678	.05;.75	.485	.485	.35;.62	.193	1.12	1.32	.1;1.35	1.15	1.17	.96;1.27	.15
7/13/77	3	.748	.864	.05;.4;.975	.893	.89	.813;.98	-.026	1.24	1.30	.55;1.45	1.31	1.32	1.37;1.18	-.02
7/13/77	4	.484	.542	.05;.1;.95	.76	.76	-	-.218	.706	.879	.1	1.26	1.26	-	-.381
7/20/77	1	.989	1.04	.36;1.13	1.05	1.07	.9	-.03	1.41	1.47	.45;1.65	1.45	1.46	1.35	.01
7/20/77	2	1.06	1.12	.19;1.26	.891	.977	.025	.143	1.35	1.42	.28;1.58	1.28	1.37	.325;1.45	.05
7/20/77	3	.622	.62	.2;1.05	.963	1.0	.55;1.15	-.38	.846	.83	.5;1.24	1.32	1.42	.60	-.59
7/20/77	4	.70	.55	.4;1.15	1.04	1.13	.45	-.58	1.06	1.3	.48;1.4	1.45	1.54	.85;1.625	-.24
7/27/77	1	.638	.575	.35;1.30	.154	.193	.01;.05; .42	.382	.956	.942	1.4;.6	.772	.826	.05;.96	.116
7/27/77	2	.46	.479	.1;.7	.337	.306	.25;.375	.173	1.27	1.33	.55;1.45	1.26	1.27	1.2;1.3	.06
7/27/77	3	2.01	2.4	.25;3.0	2.63	3.45	.225;.55; 3.8	-1.05	2.75	3.13	1.05;3.7	3.34	4.34	.6;1.1	-1.21
7/27/77	4	.567	.8	.1	.388	.436	.05	.364	1.0	1.28	.45	1.21	1.28	.45;1.50	0
8/18/77	1	.462	.481	.03;.66	.724	.722	.68;.78	-.241	.964	1.02	.52;.54; 1.18	1.22	1.36	1.08;1.3	-.34
8/18/77	2	.747	.792	.04;.08; 1.01		No Data		-	1.31	1.38	.42;1.54		No Data		
8/18/77	3	.64	.64	-	.761	.772	.68;.79	-.132	1.25	1.2	1.4	1.25	1.26	1.17;1.3	-.06
8/18/77	4	.514	.52	.05;.74	.75	.75	.61;.89	-.23	1.12	1.07	.25;1.6	1.07	1.24	.28;1.36	-.17
8/25/77	1	.247	.249	.1;.38	.078	.072	.06;.10	.177	.667	.668	.58;.75	.622	.622	-	.046
8/25/77	2	.291	.283	.225;.38	.252	.248	.225;.275	.035	.889	.892	.85;.92	.758	.821	.2;.875	.071
8/25/77	3	.249	.248	.2;.3	.245	.247	.225;.3	.001	.835	.883	.54;.94	.821	.825	.80	.058
9/02/77	1	.26	.276	.1	.229	.228	.18;.26	.048	.738	.768	.44	.72	.724	.7;.75	.044
9/02/77	2	.154	.185	.13;.23	.158	.157	.13;.225	.028	.854	.874	.66;.91	.807	.842	.35;.875	.032
9/02/77	3	.255	.246	.1;.48	.217	.221	.15;.26	.025	.728	.854	.1;.32;.88	.729	.729	-	.125
9/02/77	4	.205	.20	.17;.25	.142	.142	-	.058	.77	.77	-	.742	.742	-	.028
9/08/77	1	.469	.475	.28;.58	.462	.488	.08;.58	-.013	.829	.931	.01;1.02	.873	.926	.1;.98	.005
9/08/77	2	.409	.412	.15;.65	.544	.563	.15;.76	-.151	.830	.92	.4;1.28	.843	.887	.25;1.0	.033
9/08/77	3	.447	.463	.08;.58	.475	.46	.425;.65	.003	.905	.994	.085;1.1	.958	.931	.9;1.15	.058
9/08/77	4	.376	.367	.2;.58	.422	.422	-	-.055	.914	.923	.5;1.30	.955	.967	.825;1.05	-.044
9/16/77	1	.515	.509	.4;.6	.596	.596	.54;.63	-.087	1.05	1.06	.9;1.1	1.06	1.07	1;1.1	.001
9/16/77	2	.492	.518	.12;.63	.166	.171	.1	.347	.943	.957	.8	.814	.905	.15;.3	.052
9/16/77	3	.373	.39	.2;.44	.375	.375	-	.015	.94	1.03	.22;1.1	.906	.992	.22	.038
9/16/77	4	.646	.606	.4;1.09	.159	.153	.05;.2	.453	.99	1.07	.5;1.09	.818	.938	.1	.132
9/23/77	1	.522	.531	.26;.7	.450	.473	.05;.64	.058	.916	.872	.52;1.15	.809	.83	.1;1.05	.042
9/23/77	2	.444	.433	.2;.6	.345	.369	.05;.45	.064	.894	.91	.8;1.0	.845	.906	.2;.95	.004

Date	Unit	Inlet Free			Outlet Free			Difference	Inlet Total			Outlet Total			Difference
		Avg. of All No's	Avg. of Steady State	No's Not Used	Avg. of All No's	Avg. of Steady State	No's Not Used	Steady State Free Inlet-Outlet	Avg. of All No's	Avg. of Steady State	No's Not Used	Avg. of All No's	Avg. of Steady State	No's Not Used	Steady State Total Inlet-Outlet
9/23/77	3	.75	.75	.6;.9	.628	.64	.575;.675	.11	1.1	1.1	1.05;1.12	1.05	1.05	1.025;1.07	.05
9/23/77	4	.4	.475	.1;.55	.35	.388	.05;.425	.012	.75	.933	.2	.721	.80	.1;.95	.133
9/30/77	1	.264	.28	.02;.4	.164	.181	.05;.26	.099	.506	.54	.04;.67	.488	.476	.1;.65	.064
9/30/77	2	.102	.105	.03;.16	.039	.039	.02;.06	.101	.388	.403	.21;.43	.341	.367	.03	.036
9/30/77	3	.418	.42	.37;.44	.241	.244	.2;.275	.174	.664	.663	.65;.68	.618	.619	.6;.63	.044
9/30/77	4	.20	.20	-	.051	.05	.03;1.0	.15	.49	.51	.43;.53	.373	.376	.03;.7	.134
10/05/77	2		No Data		.406	.414	.2;.55	-		No Data		.807	.833	.5;.88	-
10/0[illegible]/77	3		No Data		.205	.21	.14;.25	-		No Data		.682	.7	.55;.74	-
10/05/77	4		No Data		.367	.367	-	-		No Data		.85	.85	.8;.9	-
10/12/77	2		No Data		.367	.41	.1;.46	-		No Data		.907	.988	.5	-
[illegible]77	3		No Data		.30	.42	.1;.46			No Data		.74	.767	.44;.96	-
[illegible]/77	4		No Data		.353	.383	.26	-		No Data		.958	.96	.87;1.0	-
10/19/77	1		No Data		.429	.423	.3;.6	-		No Data		1.13	1.14	1.1;1.5	-
10/19/77	2		No Data		.290	.315	.12;.35	-		No Data		1.01	1.05	.88	-
10/19/77	3		No Data		.235	.250	.04;.34	-		No Data		.868	.932	.2;1.04	-
10/19/77	4		No Data		.34	.4	.1	-		No Data		1.02	1.1	.6;1.2	-
10/28/77	1	.212	.211	.09;.34	.289	.297	.22;.375	-.086	1.06	1.02	.69;1.75	.726	.709	.65;.92	.311
10/23/77	2	.159	.162	.09;.28	.126	.127	.1;.15	.035	.594	.608	.49;.73	.58	.58	.52;.60	.028
10/23/77	3	.167	.187	.09;.26	.11	.113	.06;.13	.074	.577	.578	.49;.66	.541	.58	.25;.60	-.002
10/23/77	4	.194	.167	.07;.40	.124	.123	.1;.15	.071	.582	.60	.39;.72	.588	.593	.53;.63	.007
11/02/77	1		No Data		.407	.4	.44	-		No Data		.713	.7	.74	-
11/02/77	2		No Data		.406	.423	.3;.46	-		No Data		.740	.72	.66;.8	-
11/02/77	3		No Data		.31	.3	.34	-		No Data		.615	.6	.58;.64	-
11/02/77	4		No Data		.28	.26	.14;.44	-		No Data		.547	.56	.34;.74	-
11/13/77	1	.193	.188	.1;.33	.172	.165	.13;.20	.023	.745	.737	.65;.91	.642	.657	.45;.7	.08
12/15/77	2	.131	.124	.01;.29	.147	.148	.13;.16	-.024	.448	.451	.19;.68	.493	.504	.13;.55	-.053
12/15/77	3	.073	.068	.01;.16	.145	.150	.13;.16	-.082	.53	.55	.07;.69	.559	.617	.05;.66	-.067
12/15/77	4	.086	.087	.05;.12	.128	.145	.06	.058	.51	.548	.22;.65	.583	.613	.45;.625	-.065
12/22/77	2	.324	.356	.04	.163	.162	.13;.2	.194	.527	.533	.4;.6	.443	.443	.4;.48	.09
12/22/77	3	.305	.308	.1;.4	.141	.136	.18	.172	.475	.493	.3;.54	.466	.462	.43;.53	.031

FREE RESIDUAL CHLORINE
CONSUMED IN SYSTEM

Feed Rate	Date	Unit 1	Unit 2	Unit 3	Unit 4
4500	05-06-77	.86	-	.67	-
4500	05-12-77	-	-	1.41	1.02
4500	05-20-77	.47	-	.42	.78
4500	05-27-77	1.13	1.22	1.20	1.24
4500	06-03-77	1.12	1.12	1.25	1.22
4500	06-10-77	.68	.76	.78	.69
4500	06-17-77	1.09	.89	1.16	1.08
4500	06-24-77	-	.77	.48	.78
4500	06-30-77	.38	.83	.81	1.00
4500	07-06-77	1.01	.95	-	1.09
4500	07-13-77	.86	.90	.52	.77
4500	07-20-77	.30	.42	.42	.37
U1=3000 U2-4=4500	07-27-77	.72	1.06	-	1.16
4500	08-18-77	.66	-	.64	.72
U1=2500 U2-4=3000	08-25-77	.71	.71	-	-
2500	09-02-77	.57	.62	.60	.67
2500	09-09-77	.34	.20	.39	.41
U1=1500 U2-4=2500	09-16-77	-.09	.60	.48	.67
U1=1500 U2-4=2500	09-23-77	.03	.42	.24	.45
1500	10-30-77	.43	.53	.31	.50
1500	11-18-77	.48	.40	.47	.47
1500	12-22-77	-	.38	.42	-

TOTAL RESIDUAL CHLORINE
CONSUMED IN SYSTEM

Feed Rate	Date	Unit 1	Unit 2	Unit 3	Unit 4
4500	05-06-77	-.09	-	-.07	-
4500	05-12-77	-	-	.87	.46
4500	05-20-77	.14	-	-.11	.26
4500	05-27-77	-.02	.02	-.02	.02
4500	06-03-77	.21	.20	.18	.3
4500	06-10-77	.07	.16	.11	.18
4500	06-17-77	.10	.07	.20	.23
4500	06-24-77	-	.09	-.01	.18
4500	06-30-77	-.04	.19	.21	.40
4500	07-06-77	.36	.17	-	.34
4500	07-13-77	.18	.21	.09	.27
4500	07-20-77	-.10	.03	.01	-.03
U1=3000 U2-4=4500	07-27-77	.09	.1	-	.32
4500	08-18-77	.02	-	.15	.23
U1=2500 U2-4=3000	08-25-77	.16	.13	-	-
2500	09-02-77	.07	-.07	.10	.07
2500	09-09-77	-.10	-.12	-.08	-.13
U1=1500 U2-4=2500	09-16-77	-.56	-.13	-.13	-.11
U1=1500 U2-4=2500	09-23-77	-.32	-.12	-.16	.04
1500	10-30-77	-.09	-.01	-.02	-.04
1500	11-18-77	-.01	0	0	-.01
1500	12-22-77	-	.09	.10	-

FREE RESIDUAL CHLORINE CONSUMED IN SYSTEM
USED IN ANALYSIS
TOTALS (SAMPLE SIZE)

Feed Rate	Date	Unit 1	Unit 2	Unit 3	Unit 4
4500	May	2.46(3)	1.22(1)	3.71(4)	3.04(3)
	June	3.27(4)	4.37(5)	4.48(5)	4.77(5)
	July	1.86(2)	1.85(2)	0.52(1)	1.89(2)
2500	Sept	0.90(2)	0.82(2)	0.99(2)	1.09(2)
1500	Oct/Nov	0.91(2)	0.93(2)	0.79(2)	0.97(2)

TOTAL RESIDUAL CHLORINE CONSUMED IN SYSTEM
USED IN ANALYSIS
TOTALS (SAMPLE SIZE)

Feed Rate	Date	Unit 1	Unit 2	Unit 3	Unit 4
4500	May	0.14(2)	0.02(1)	0.85(2)	0.74(3)
	June	0.32(4)	0.73(5)	0.70(5)	1.30(5)
	July	0.54(2)	0.39(2)	0.09(1)	0.62(2)

FREE RESIDUAL CHLORINE
AT INLET

Feed Rate	Date	Unit 1	Unit 2	Unit 3	Unit 4
4500	05-27-77	.50	.41	.38	.47
4500	06-3-77	.38	.39	.27	.33
4500	06-10-77	.66	.93	.78	.98
4500	06-17-77	.57	.54	.31	.50
4500	06-30-77	.93	.76	.88	.64
4500	07-06-77	.81	.42	1.02	1.10
4500	07-13-77	.99	.68	.86	.54
2500	09-02-77	.28	.19	.25	.20
2500	09-08-77	.48	.41	.46	.37
U1=1500 U2-4=2500	09-16-77	.51	.52	.39	.61
U1=1500 U2-4=2500	09-23-77	.53	.42	.75	.48
1500	09-30-77	.28	.11	.42	.20
1500	10-28-77	.21	.16	.19	.17
1500	11-18-77	.19	.12	.07	.09

TOTAL RESIDUAL CHLORINE
AT INLET

Feed Rate	Date	Unit 1	Unit 2	Unit 3	Unit 4
4500	05-27-77	1.30	1.41	1.15	1.51
4500	06-03-77	1.29	1.25	1.30	1.26
4500	06-10-77	1.25	1.59	1.45	1.58
4500	06-17-77	1.24	1.28	1.22	1.19
4500	06-30-77	1.41	1.17	1.44	1.51
4500	07-13-77	1.29	1.32	1.30	.88
2500	09-02-77	.77	.87	.85	.77
2500	09-08-77	.93	.92	.99	.92
U1=1500 U2-4=2500	09-16-77	1.06	.96	1.03	1.07
U1=1500 U2-4=2500	09-23-77	.87	.91	1.1	.93
1500	10-28-77	1.02	.61	.58	.60
1500	11-18-77	.74	.45	.55	.55

FREE RESIDUAL CHLORINE AT OUTLET

Feed Rate	Date	Unit 1	Unit 2	Unit 3	Unit 4
4500	05-27-77	.23	.24	.21	.22
4500	06-03-77	.24	.37	.15	.21
4500	06-10-77	.68	.94	.62	.75
4500	06-17-77	.27	.46	.25	.37
4500	06-30-77	.96	.54	.60	.52
4500	07-06-77	.34	.39	.41	.39
4500	07-13-77	.86	.49	.89	.76
2500	09-02-77	.23	.16	.22	.14
2500	09-08-77	.49	.56	.46	.42
U1=1500 U2-4=2500	09-16-77	.60	.17	.38	.15
U1=1500 U2-4=2500	09-23-77	.47	.37	.64	.39
1500	09-30-77	.18	.04	.24	.05
1500	10-28-77	.30	.13	.11	.12
1500	11-18-77	.17	.15	.15	.15

TOTAL RESIDUAL CHLORINE AT OUTLET

Feed Rate	Date	Unit 1	Unit 2	Unit 3	Unit 4
4500	05-27-77	1.38	1.43	1.43	1.44
4500	06-03-77	1.15	1.29	1.21	1.13
4500	06-10-77	1.29	1.53	1.29	1.26
4500	06-17-77	1.25	1.29	1.20	1.21
4500	06-30-77	1.38	1.17	1.20	1.11
4500	07-13-77	1.20	1.17	1.32	1.26
2500	09-02-77	.72	.84	.73	.74
2500	09-08-77	.93	.89	.93	.97
U1=1500 U2-4=2500	09-16-77	1.07	.91	.99	.94
U1=1500 U2-4=2500	09-23-77	.83	.91	1.05	.80
1500	10-28-77	.71	.58	.58	.59
1500	11-18-77	.66	.50	.62	.61

FREE RESIDUAL CHLORINE
DIFFERENCE BETWEEN INLET AND OUTLET

Feed Rate	Date	Unit 1	Unit 2	Unit 3	Unit 4
4500	05-27-77	.27	.17	.17	.25
4500	06-03-77	.14	.02	.12	.12
4500	06-10-77	-.02	-.01	.16	.23
4500	06-17-77	.30	.08	.06	.13
4500	06-30-77	-.03	.22	.28	.12
4500	07-06-77	.47	.03	.61	.71
4500	07-13-77	.13	.19	-.03	-.22
2500	09-02-77	.05	.03	.03	.06
2500	09-08-77	-.01	-.15	0	-.05
U1=1500 U2-4=2500	09-16-77	-.09	.35	.01	.46
U1=1500 U2-4=2500	09-23-77	.06	.06	.11	.09
1500	09-30-77	.10	.07	.18	.15
1500	10-28-77	-.09	.03	.08	.05
1500	11-18-77	.02	-.03	-.08	-.06

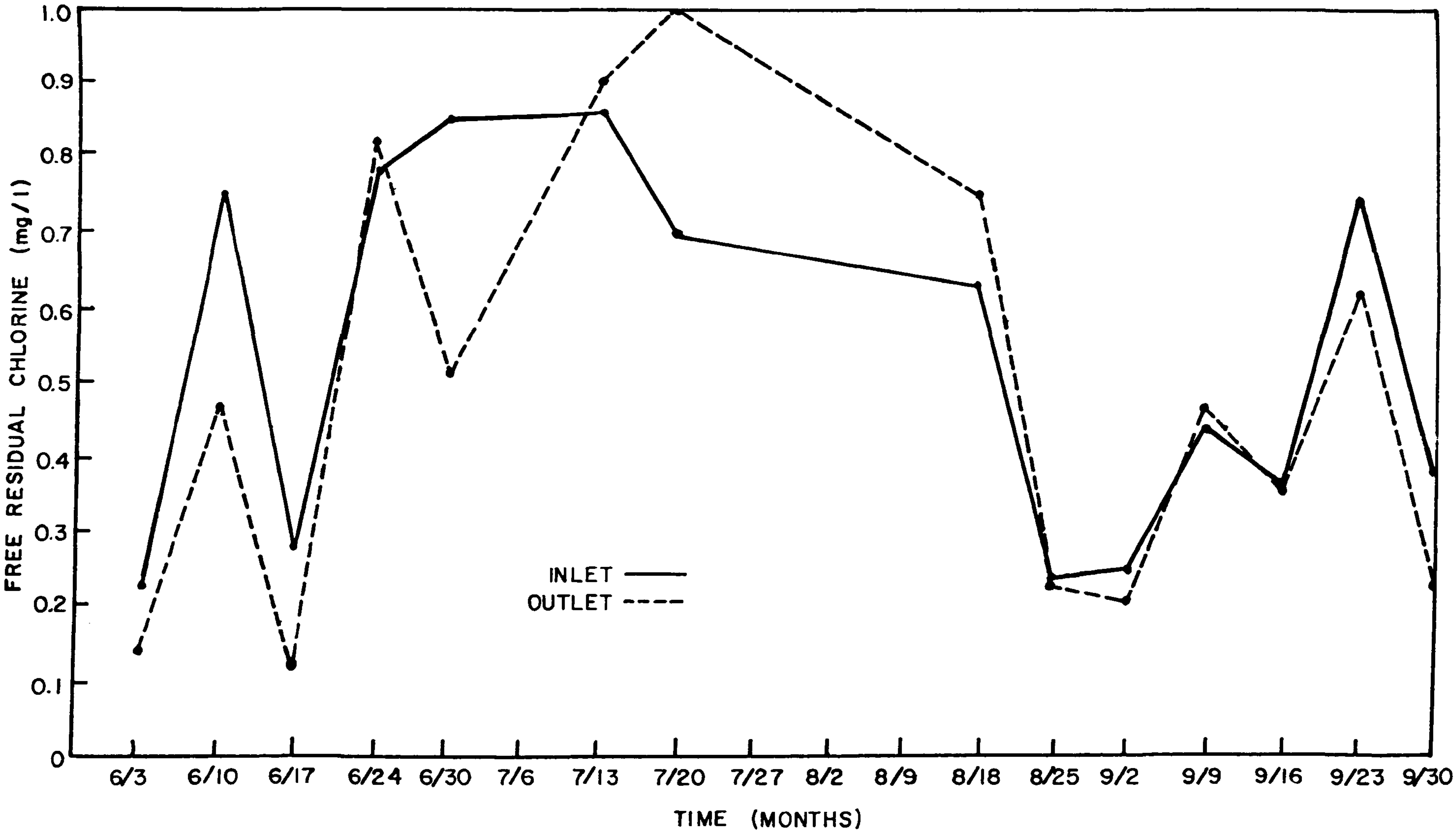

Figure B-1. Unit 3 inlet vs. outlet free residual chlorine 1977.

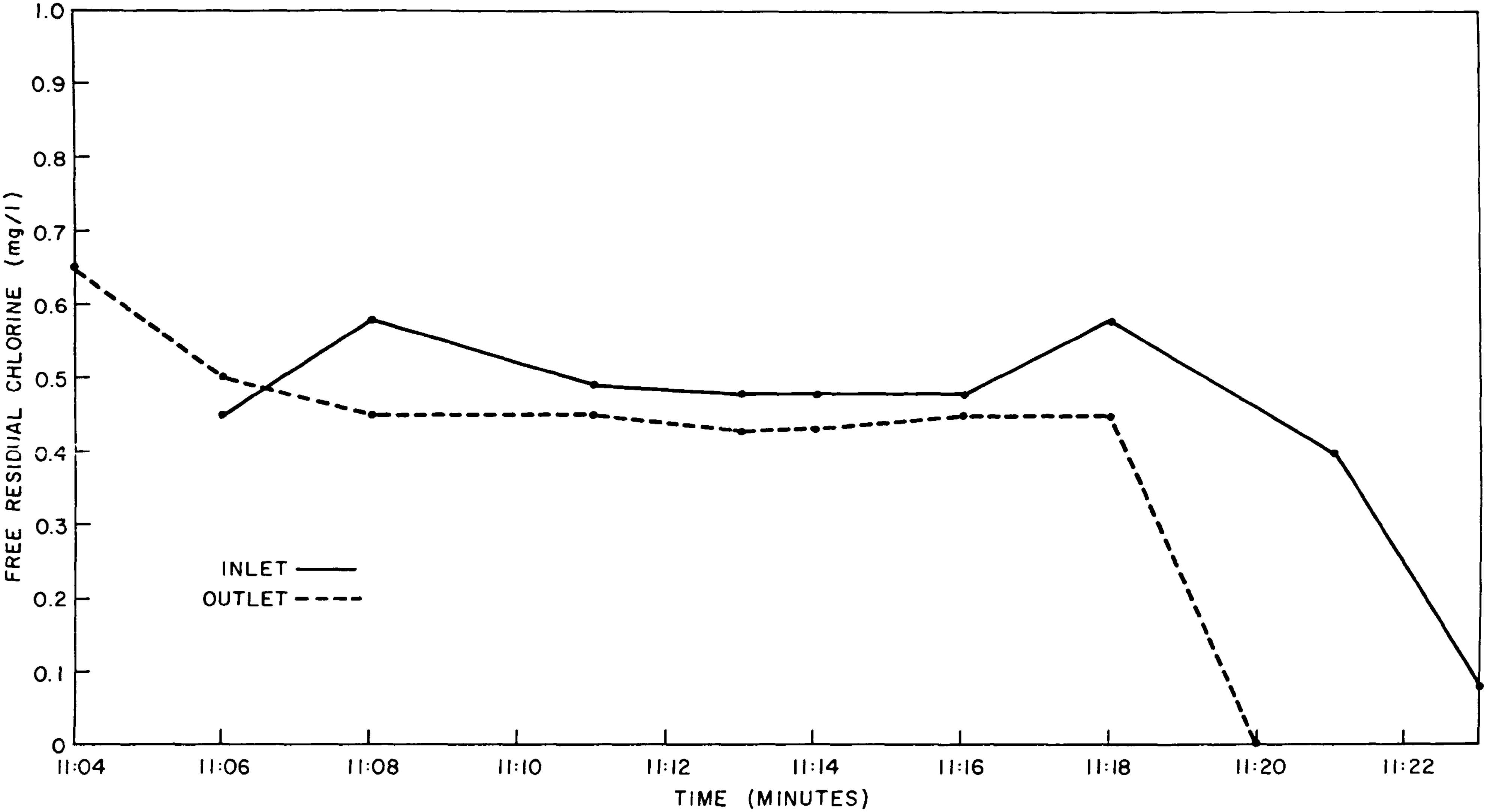

Figure B-2. Unit 3 inlet vs. outlet free residual chlorine 9-9-77.

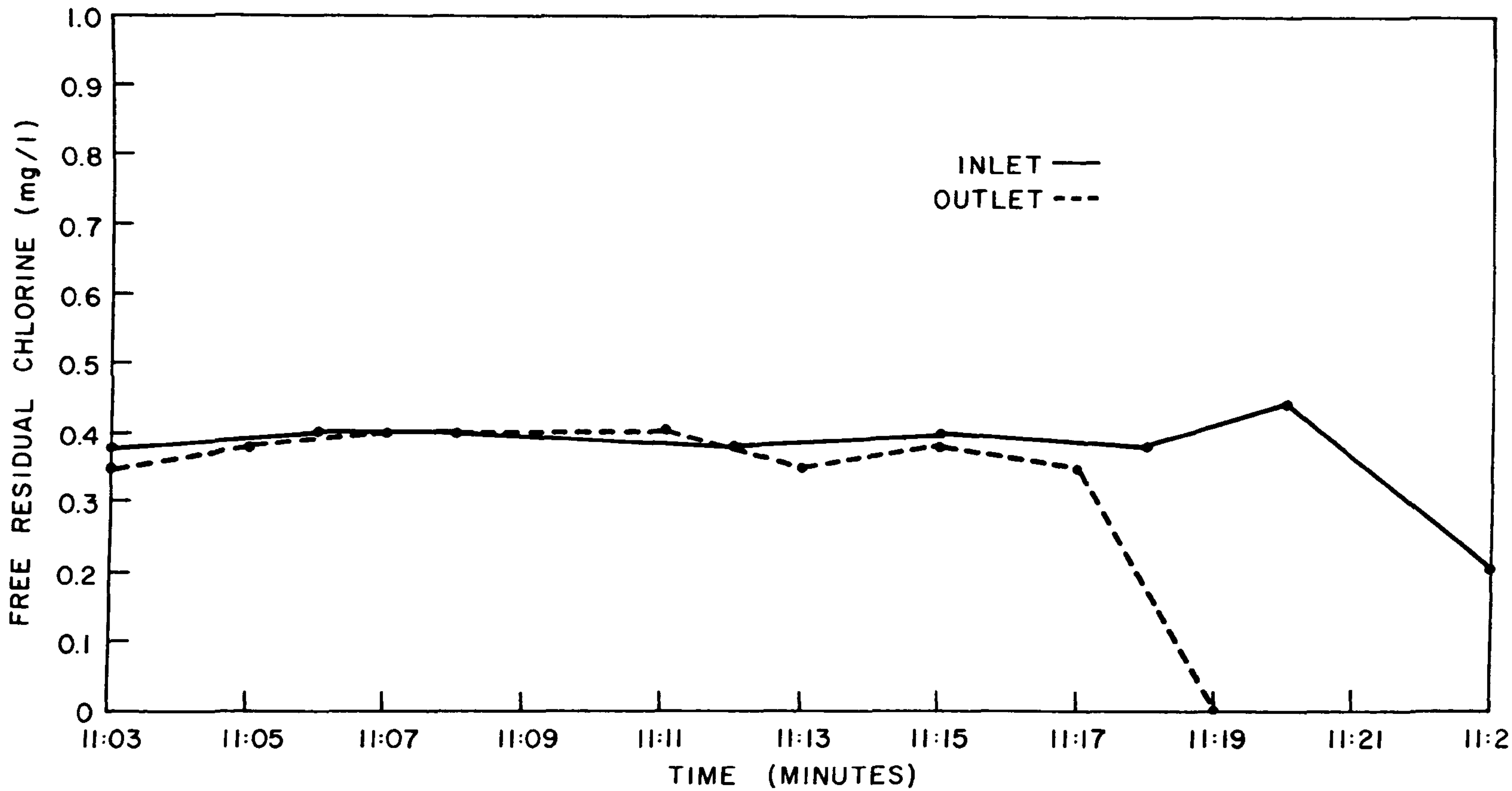

Figure B-3. Unit 3 inlet vs. outlet free residual chlorine 9-16-77.

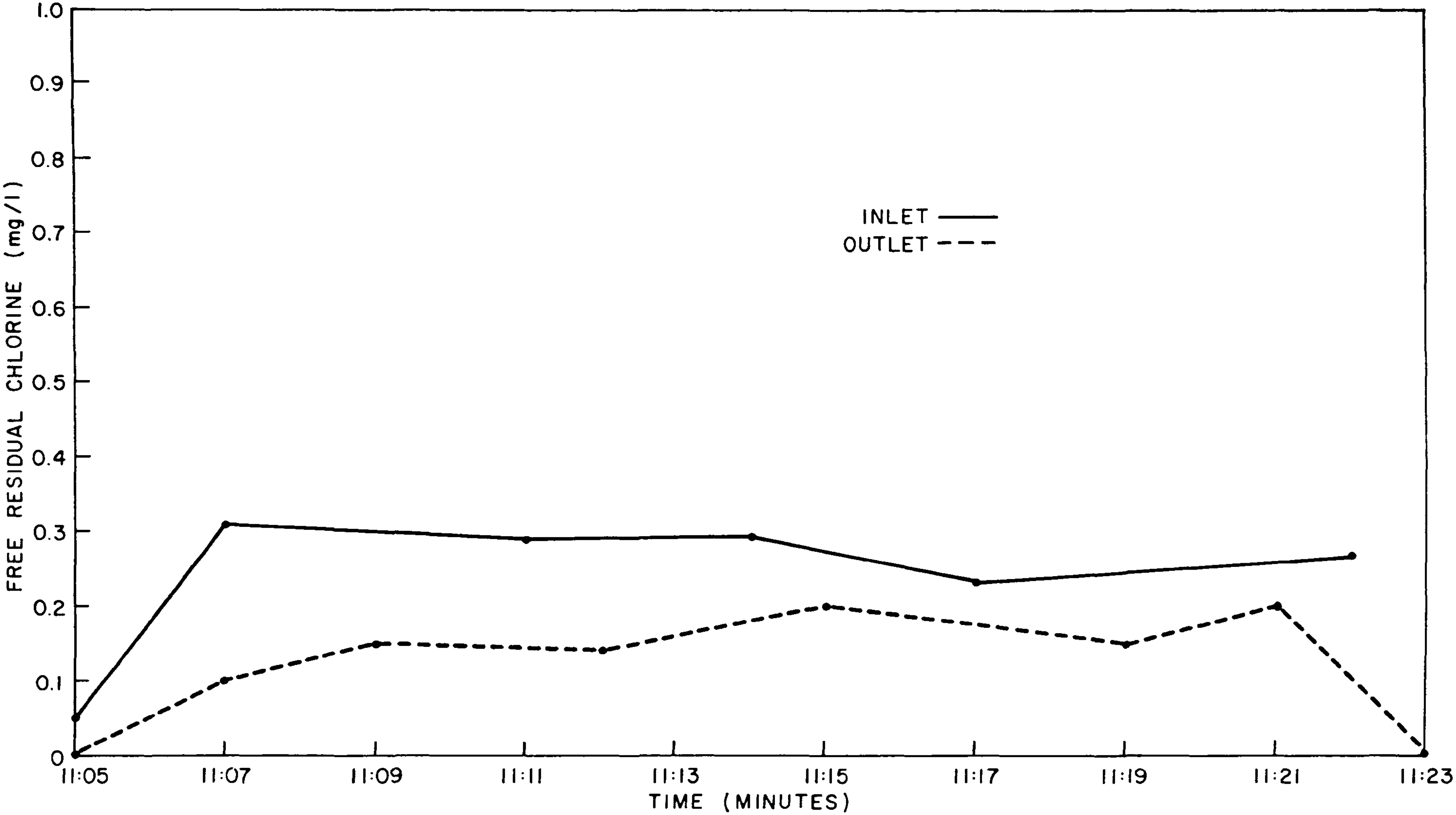

Figure B-4. Unit 3 inlet vs. outlet free residual chlorine 6-3-77.

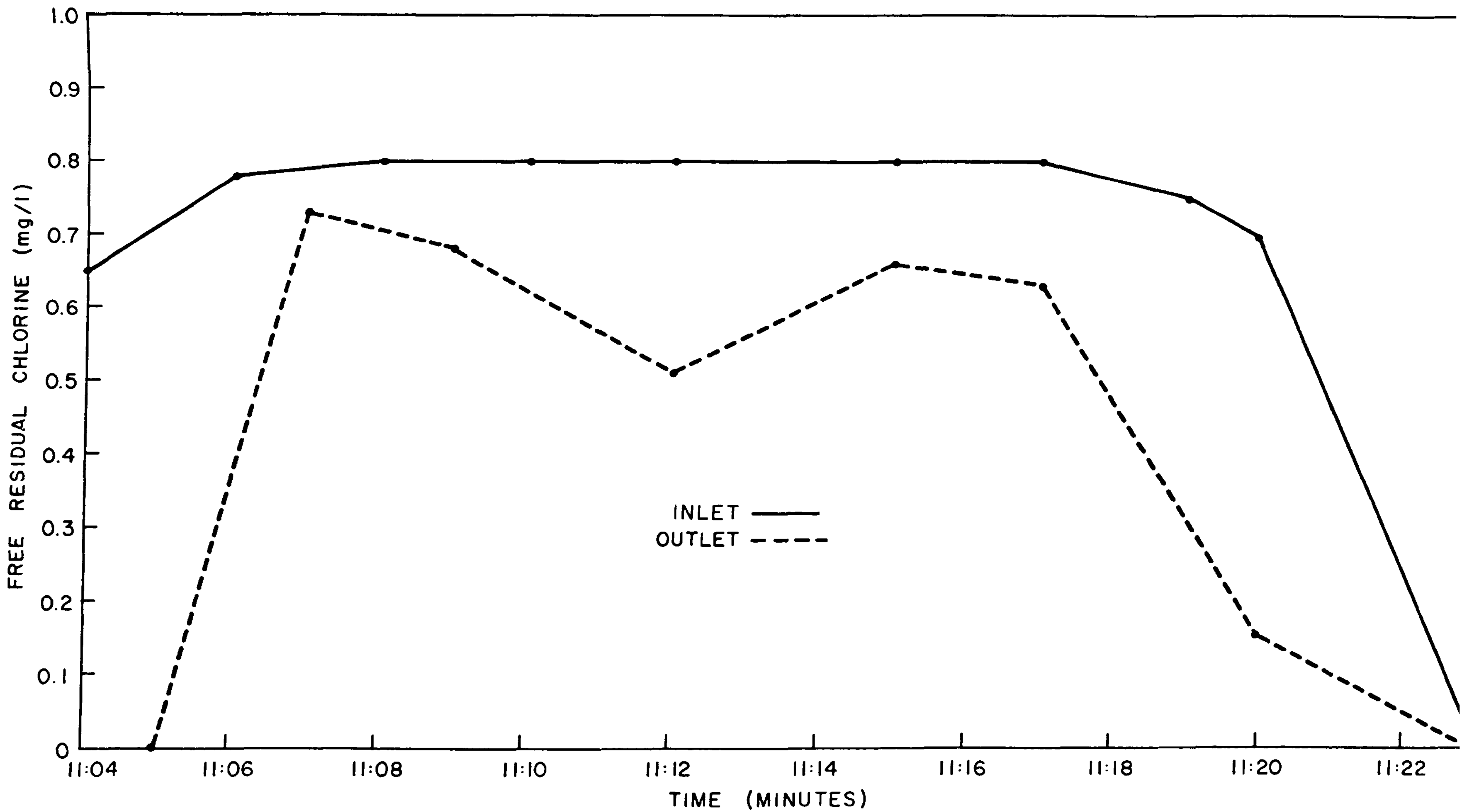

Figure B-5. Unit 3 inlet vs. outlet free residual chlorine 6-10-77.

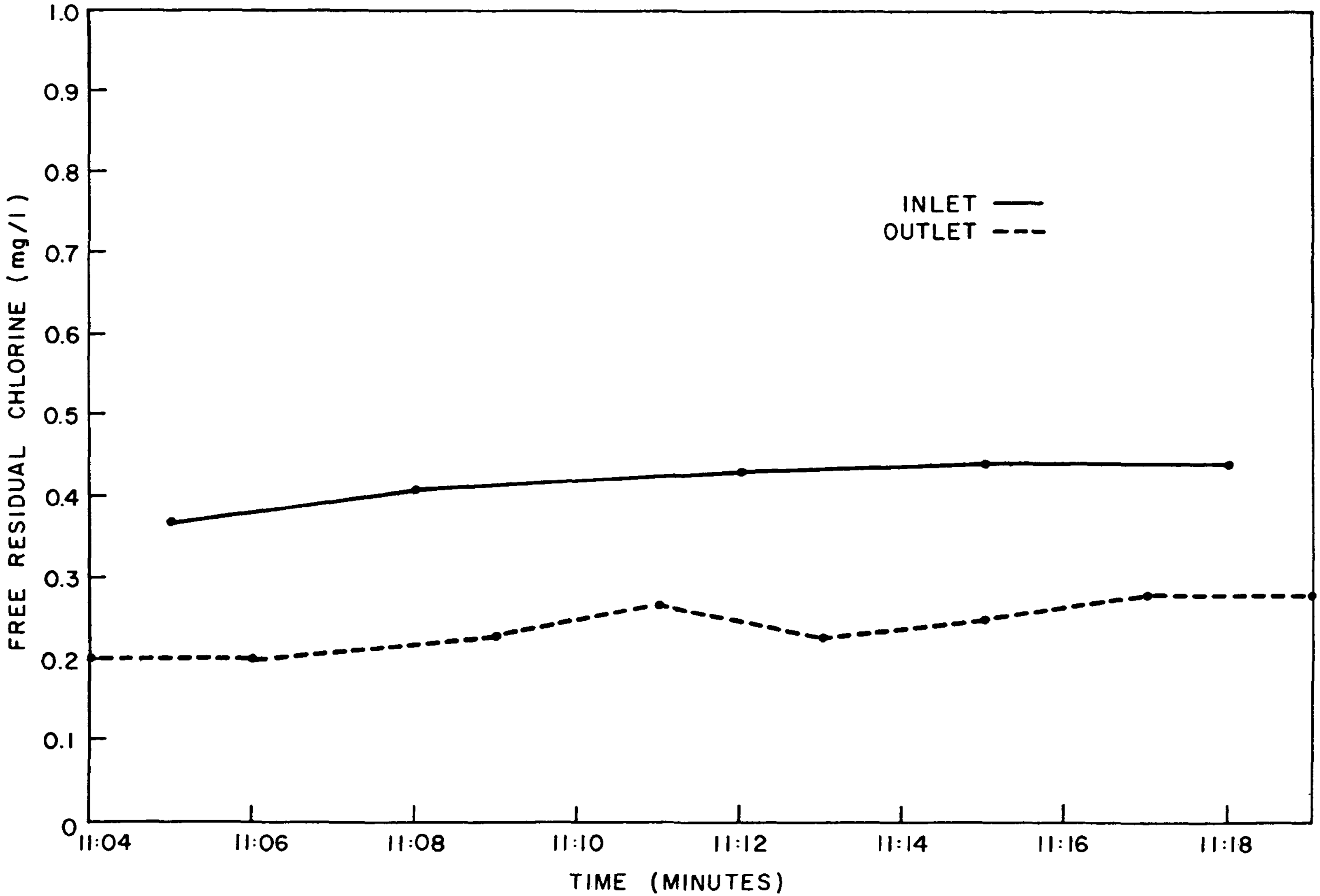

Figure B-6. Unit 3 inlet vs. outlet free residual chlorine 9-30-77.

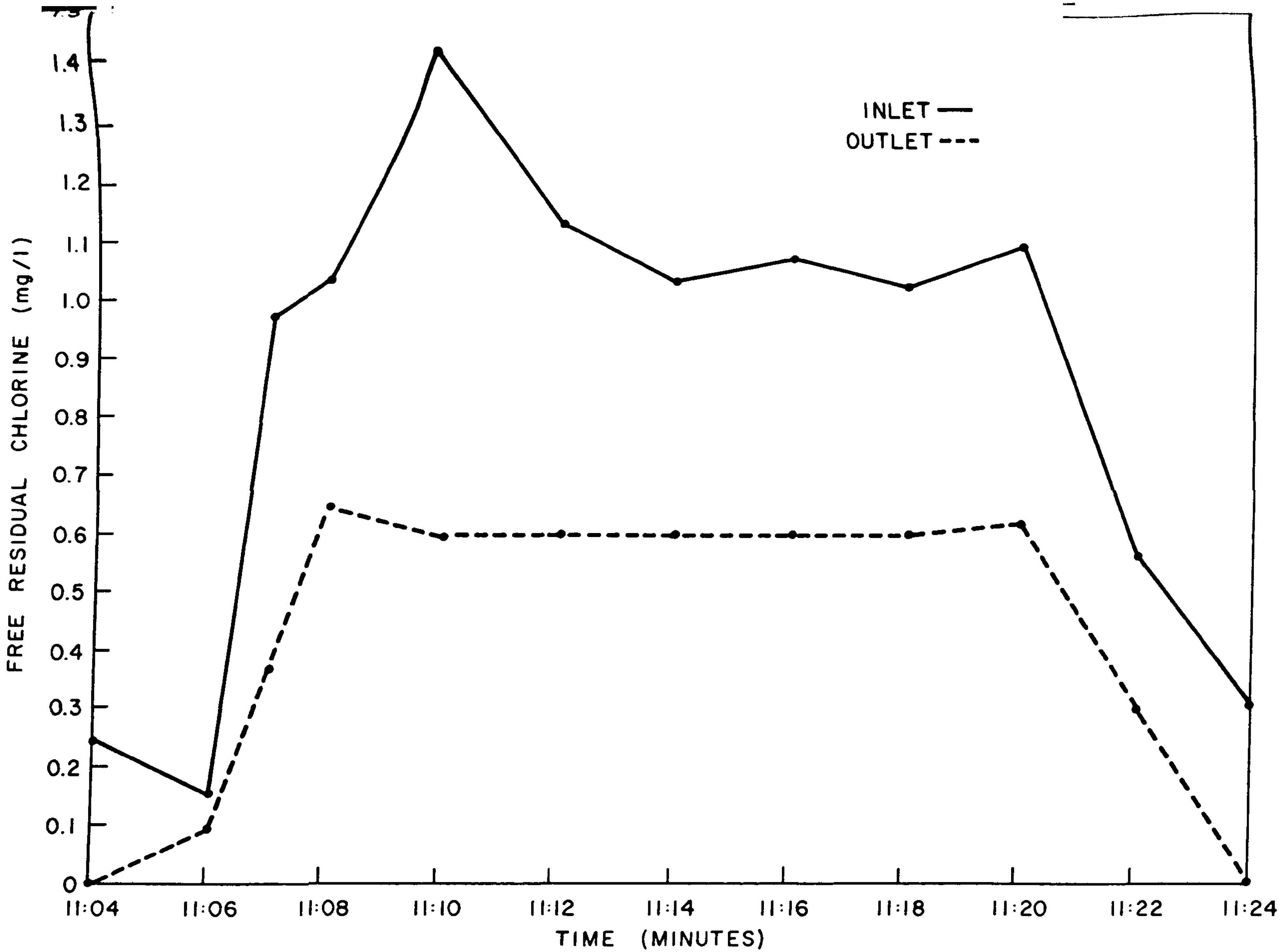

Figure B-7. Unit 3 inlet vs. outlet free residual chlorine 6-30-77.

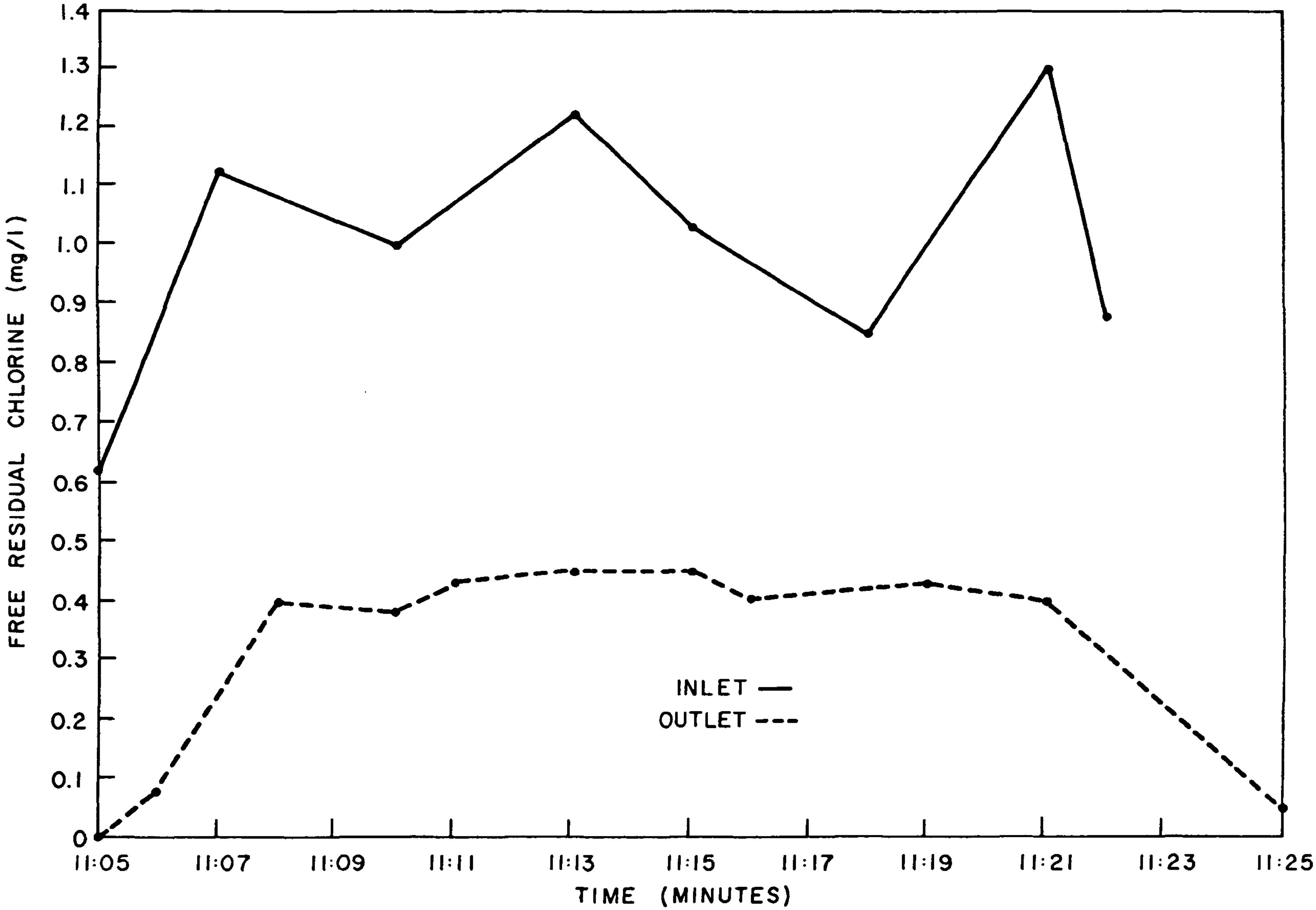

Figure B-8. Unit 3 inlet vs. outlet free residual chlorine 7-6-77.

FREE RESIDUAL CHLORINE
CONSUMED IN SYSTEM
AND INLET WATER TEMPERATURE

Date	Unit 1		Unit 2		Unit 3		Unit 4	
	Chlor.	Temp.	Chlor.	Temp.	Chlor.	Temp.	Chlor.	Temp.
05-06-77	.86	71	-	-	.67	69	-	69
05-12-77	-	62	-	-	1.41	60	1.02	64
05-20-77	.47	68	-	-	1.20	66	.78	69
05-27-77	1.13	74	1.22	71	1.20	71	1.24	72
06-03-77	1.12	72	1.12	71	1.25	71	1.22	71
06-10-77	.68	66	.76	62	.78	64	.69	64
06-17-77	1.09	74	.89	73	1.16	72	1.08	72
06-24-77	-	71	.77	71	.49	69	.78	71
06-30-77	.38	72	.83	71	.81	70	1.00	70
07-06-77	1.01	82	.95	79.5	-	80	1.09	79
07-13-77	.86	76	.9	74	.52	74	.77	74
07-20-77	.29	77.5	.42	74	.42	76	.37	74
07-27-77	.72	75	1.06	71	-	72	1.16	72
08-18-77	.66	73	-	-	.64	71	.72	70
08-25-77	.71	77	.71	75	-	75	-	-
09-02-77	.57	76	.62	75	.60	75	.67	74
09-09-77	.34	71	.20	71	.39	72	.41	71
09-16-77	-.09	73	.60	72	.48	72	.67	72
09-23-77	.03	71	.42	68	.24	69	.45	68
10-30-77	.43	61	.53	59	.31	65	.5	-
11-18-77	.48	55	.40	54	.47	53	.47	54
12-22-77	-	-	.38	44	.42	43	-	-

TOTAL RESIDUAL CHLORINE
CONSUMED IN SYSTEM
AND INLET WATER TEMPERATURE

Date	Unit 1		Unit 2		Unit 3		Unit 4	
	Chlor.	Temp.	Chlor.	Temp.	Chlor.	Temp.	Chlor.	Temp.
05-06-77	-.09	71	-	-	-.07	69	-	69
05-12-77	-	62	-	-	.87	60	.46	64
05-20-77	.14	68	-	-	-.11	66	.26	69
05-27-77	-.02	74	.02	71	-.02	71	.02	72
06-03-77	.21	72	.05	71	.18	71	.3	71
06-10-77	.07	66	.16	62	.11	64	.18	64
06-17-77	.10	74	.07	73	.20	72	.23	72
06-24-77	-	71	.09	71	-.01	69	.18	71
06-30-77	-.04	72	.19	71	.21	70	.40	70
07-06-77	.36	82	.17	79	-	80	.34	79
07-13-77	.18	76	.21	74	.09	74	.27	74
07-20-77	-.1	77	.03	74	.01	76	-.03	74
07-27-77	.09	75	.1	71	-	72	.32	72
08-18-77	.02	73	-	-	.15	71	.23	70
08-25-77	.16	77	.13	75	-	75	-	-
09-02-77	.07	76	-.07	75	.10	75	.07	74
09-09-77	-.10	71	-.12	71	-.08	72	-.13	71
09-16-77	-.56	73	-.13	72	-.13	72	-.11	72
09-23-77	-.32	71	-.12	68	-.16	69	.04	68
10-30-77	-.09	61	-.01	59	-.02	65	-.04	-
11-18-77	-.01	55	.0	54	.00	53	-.01	54
12-22-77	-	-	.09	44	.10	43	-	-

TOTAL RESIDUAL CHLORINE
DIFFERENCE BETWEEN INLET AND OUTLET

Feed Rate	Date	Unit 1	Unit 2	Unit 3	Unit 4
4500	05-27-77	-.08	-.02	-.28	.07
4500	06-03-77	.14	-.04	.09	.13
4500	06-10-77	-.04	.06	.16	.32
4500	06-17-77	-.01	0	.02	-.02
4500	06-30-77	.03	0	.24	.40
4500	07-13-77	.09	.15	-.02	-.38
2500	09-02-77	.05	.03	.12	.03
2500	09-09-77	0	.03	.06	-.05
U1=1500 U2-4=2500	09-16-77	-.01	.05	.04	.13
U1=1500 U2-4=2500	09-23-77	.04	0	.05	.13
1500	10-30-77	.31	.03	0	.01
1500	11-18-77	.08	-.05	-.07	-.06

APPENDIX C

WATER TEMPERATURE VERSUS OTHER VARIABLES

APPENDIX C
WATER TEMPERATURE VS. OTHER VARIABLES

Date	Inlet Water Temperature	Turbine Back Pressure	Total Nitrogen	Total Organic Carbon	Unit
05-06-77	71.0	1.53	1.62	2.9	1
05-06-77	.	1.67	1.62	2.9	2
05-06-77	69.0	1.66	1.62	2.9	3
05-06-77	69.0	1.53	1.62	2.9	4
05-12-77	62.0	.	0.92	2.2	1
05-12-77	.	.	.	.	2
05-12-77	60.0	.	0.92	2.2	3
05-12-77	64.0	.	0.92	2.2	4
05-20-77	68.0	1.97	1.00	2.8	1
05-20-77	.	.	.	.	2
05-20-77	66.0	1.63	1.00	2.8	3
05-20-77	69.0	1.73	1.00	2.8	4
05-27-77	74.0	.	1.15	1.9	1
05-27-77	71.0	.	1.15	1.9	2
05-27-77	71.0	.	1.15	1.9	3
05-27-77	72.0	.	1.15	1.9	4
06-03-77	72.0	2.03	0.98	5.2	1
06-03-77	71.0	2.17	0.98	5.2	2
06-03-77	71.0	1.91	0.98	5.2	3
06-03-77	71.0	1.92	0.98	5.2	4
06-10-77	66.0	.	0.77	7.8	1
06-10-77	62.0	.	0.77	7.8	2
06-10-77	64.0	.	0.77	7.8	3
06-10-77	64.0	.	0.77	7.8	4
06-17-77	74.0	1.91	0.98	5.2	1
06-17-77	73.0	1.95	0.98	5.2	2
06-17-77	72.0	1.74	0.98	5.2	3
06-17-77	72.0	1.75	0.98	5.2	4
06-24-77	71.0	.	1.09	4.2	1
06-24-77	71.0	.	1.09	4.2	2
06-24-77	69.0	.	1.09	4.2	3
06-24-77	71.0	.	1.09	4.2	4
06-30-77	72.0	1.77	0.83	3.7	1
06-30-77	71.0	1.83	0.83	3.7	2
06-30-77	70.0	1.83	0.83	3.7	3
06-30-77	70.0	1.92	0.83	3.7	4
07-06-77	82.0	1.79	0.91	2.9	1
07-06-77	79.5	1.83	0.91	2.9	2
07-06-77	80.0	1.84	0.91	2.9	3
07-06-77	79.0	1.92	0.91	2.9	4
07-13-77	76.0	.	0.87	4.1	1
07-13-77	74.0	.	0.87	4.1	2
07-13-77	74.0	2.03	0.87	4.1	3
07-13-77	74.0	2.12	.	.	4

(continued)

APPENDIX C

WATER TEMPERATURE VS. OTHER VARIABLES
(continued)

Date	Inlet Water Temperature	Turbine Back Pressure	Total Nitrogen	Total Organic Carbon	Unit
07-27-77	75.0	2.26	0.99	2.1	1
07-27-77	71.0	2.21	0.99	2.1	2
07-27-77	72.0	.	0.99	2.1	3
07-27-77	72.0	2.38	0.99	2.1	4
07-27-77	75.0	2.26	0.99	2.1	1
07-27-77	71.0	2.21	0.99	2.1	2
07-27-77	72.0	.	0.99	2.1	3
07-27-77	72.0	2.38	0.99	2.1	4
09-02-77	76.0	.	0.90	.	1
09-02-77	75.0	.	0.90	.	2
09-02-77	75.0	.	0.90	.	3
09-02-77	74.0	.	0.90	.	4
09-09-77	71.0	1.84	0.98	4.8	1
09-09-77	71.0	1.77	0.98	4.8	2
09-09-77	72.0	1.82	0.98	4.8	3
09-09-77	71.0	1.95	0.98	4.8	4
09-16-77	73.0	.	1.06	4.0	1
09-16-77	72.0	.	1.06	4.0	2
09-16-77	72.0	.	1.06	4.0	3
09-16-77	72.0	.	1.06	4.0	4
09-23-77	71.0	1.85	0.93	5.2	1
09-23-77	68.0	1.76	0.93	5.2	2
09-23-77	69.0	2.01	0.93	5.2	3
09-23-77	68.0	1.89	0.93	5.2	4
09-30-77	67.0	.	0.86	6.6	1
09-30-77	66.0	.	0.86	6.6	2
09-30-77	65.0	.	0.86	6.6	3
09-30-77	65.0	.	0.86	6.6	4
10-28-77	61.0	1.73	0.85	4.1	1
10-28-77	59.0	1.52	0.85	4.1	2
10-28-77	.	1.48	0.85	4.1	3
10-28-77	.	1.56	0.85	4.1	4
11-19-77	54.0	1.52	.	.	1
11-19-77	55.0	1.22	.	.	2
11-19-77	55.0	1.41	.	.	3
11-19-77	55.0	1.35	.	.	4

APPENDIX D

DPD VERSUS AMPEROMETRIC TITRATOR DATA

APPENDIX D

DPD VERSUS AMPEROMETRIC TITRATOR DATA

Table D-1

FREE RESIDUAL CHLORINE

Date	DPD	Amperometric	Difference
06-10-77	1.12	0.66	0.46
06-17-77	0.86	0.23	0.63
06-30-77	1.11	0.96	0.15
07-13-77	0.92	0.81	0.11
07-20-77	1.12	1.05	0.07
07-27-77	0.11	0.15	-0.04
09-02-77	0.23	0.26	-0.03
09-08-77	0.57	0.46	0.11
09-16-77	0.65	0.60	0.05

Table D-2

TOTAL RESIDUAL CHLORINE

Date	DPD	Amperometric	Difference
06-10-77	1.38	1.21	0.17
06-17-77	1.36	1.23	0.13
06-30-77	1.35	1.35	0.00
07-13-77	1.22	1.19	0.03
07-20-77	1.42	1.12	0.30
07-27-77	0.87	0.77	0.10
09-02-77	0.72	0.69	0.03
09-08-77	0.93	0.86	0.07
09-16-77	1.14	1.06	0.08

Table D-3

FREE RESIDUAL CHLORINE - ADJUSTED FOR CONCENTRATION LEVEL

Date	Adjusted DPD	Adjusted Amperometric
07-27-77	0.89	0.79
09-02-77	0.90	0.80
09-08-77	0.92	0.80
09-16-77	0.93	0.80
06-17-77	0.94	0.79
07-13-77	0.95	0.81
06-30-77	0.96	0.82
06-10-77	0.96	0.80
07-20-77	0.96	0.83

Table D-4

TOTAL RESIDUAL CHLORINE - ADJUSTED FOR CONCENTRATION LEVELS

Date	Adjusted DPD	Adjusted Amperometric
09-22-77	0.93	0.81
07-27-77	0.94	0.81
09-08-77	0.95	0.82
09-16-77	0.96	0.82
07-13-77	0.97	0.83
06-30-77	0.98	0.83
06-17-77	0.98	0.83
06-10-77	0.98	0.83
07-20-77	0.98	0.83

APPENDIX E

CHLORINE DEMAND VERSUS FEED RATE AND TOTAL ORGANIC CARBON

APPENDIX E

CHLORINE DEMAND VERSUS FEED RATE AND TOTAL ORGANIC CARBON

CHLORINE DEMAND

Analysis of the chlorine demand of river water from unit 4 with contact times of 1, 5, and 10 minutes was examined for possible relationships with inlet water temperature, total organic carbon, total nitrogen, dosage, and time. A comparison of the chlorine demand at the inlet of the condenser, as estimated by the difference in total residual chlorine measured at the condenser inlet and the amount calculated at the chlorine injection point, with the interpolated 2-1/2 minute chlorine demand from the laboratory results was made. This was done since previous work indicated a mixing time of approximately 2.2 minutes from the intake to the inlet of the condenser.

1. Temperature Effects on Chlorine Demand

Inlet water temperature was examined for possible effects on chlorine demand. The one-minute chlorine demand consistently did not have any discernible relationship with inlet water temperature. The five- and ten-minute chlorine demands did have a stronger correlation with inlet water temperature. Examination of the data indicated the formation of three groups depending on the inlet water temperature as indicated by Figure 1. Group 2 had a significantly higher chlorine demand than either group 1 or group 3. The factor that groups 1 and 3 had in common which was different from group 2 was the difference between inlet water temperature and the temperature of the sample at the time of analysis. Groups 1 and 3 are samples where the difference exceeded one degree Celsius while group 2 had a difference or one degree of less. This indicates there is an effect from temperature, but the differential between the inlet water temperature and the analysis temperature for groups 1 and 3 does not allow estimation of the effect.

2. Total Organic Carbon and Chlorine Demand

Total organic carbon exhibited no apparent relationship with chlorine demand at the five- and ten-minute contact times. At the one-minute contact time, a weak negative inverse relationship is "suggested" by the data; but, since the relationship is not strong at the one-minute level and is not discernible at the five- and ten-minute intervals, it was concluded that no apparent relationship is evident. A cyclical behavior over time was exhibited, but there is no explanation for it at this time.

3. Total Nitrogen and Chlorine Demand

Total nitrogen was examined for its possible effects on chlorine demand and interaction with inlet water temperature, total organic carbon, dosage, and time. No relationships were found.

4. Dosage and Chlorine Demand

Dosage was examined for a relationship with chlorine demand. The existence of a relationship would indicate the chlorine was reacting with something in the water that altered chlorine demand. No such relationship was found.

5. Time and Chlorine Demand

Time in this analysis refers to the length of the test period. The one-, five-, and ten-minute demands were examined for possible patterns of behavior over time in conjunction with the other variables' behavior over time. The ten-minute chlorine demand followed the same movement over time for the first eight test dates as inlet water temperature, but after that the behavior of the two diverged. The other contact times did not display any significant "tracking" of inlet water temperature.

6. Comparison of Chlorine Demand at the Condenser Inlet and "Interpolated" 2.5-Minute Demand

Total residual chlorine from previous work at the inlet of the condenser has a mixing time from the intake of approximately 2.2 minutes. As a check on chlorinator variability, temperature variability, and other sources of variation, the estimated chlorine demand at 2.5 minutes was compared with the apparent chlorine demand as measured at the condenser inlet. The chlorine demand at the condenser inlet was significantly higher than the estimated value. The demand was more comparable to the ten-minute demand. This difference is probably due to the cumulative chlorine demand of the mixing tank and tunnels more than any other factor. Table 1 summarizes the average chlorine demands and the associated standard errors for the different contact times for the test period of May 12 through July 20, 1977.

Table E-1

AVERAGE CHLORINE DEMANDS (mg/l) AND STANDARD ERROR FOR VARIOUS CONTACT TIMES

Contact Time	Mean (N = 11)	Std. Error of Mean
1.0 min.	0.40	0.046
2.5 min.[1]	0.53	0.039
5.0 min.	0.75	0.051
10.0 min.	1.07	0.065

[1]Estimated by linear interpolation

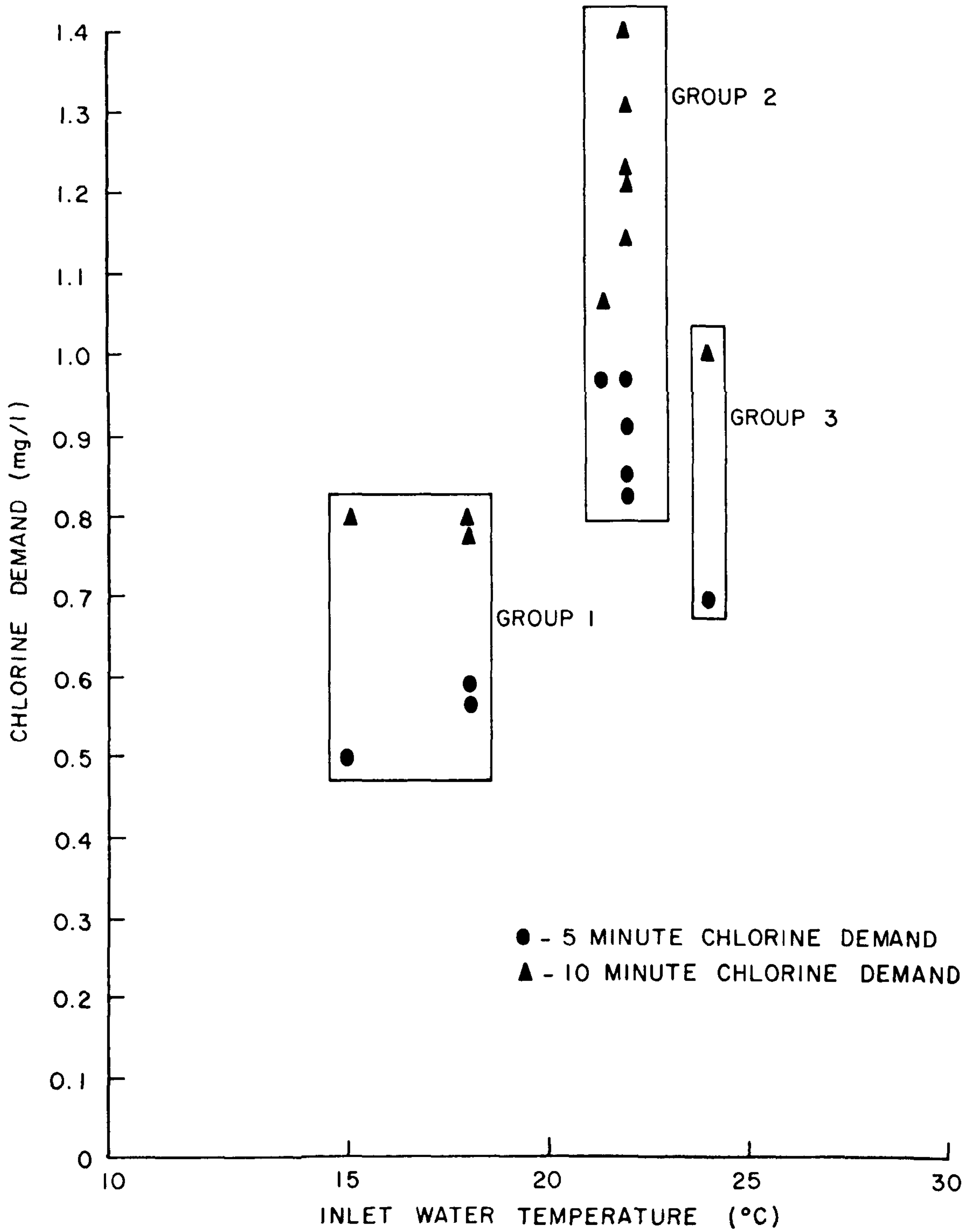

Figure E-1. Temperature effects on chlorine demand.

TECHNICAL REPORT DATA
(Please read Instructions on the reverse before completing)

1. REPORT NO. EPA-600/7-79-198	2.	3. RECIPIENT'S ACCESSION NO.
4. TITLE AND SUBTITLE Chlorine Minimization/Optimization for Condenser Biofouling Control (Phases I and II)		5. REPORT DATE August 1979
		6. PERFORMING ORGANIZATION CODE
7. AUTHOR(S) R. D. Moss, S. H. Magliente, H. B. Flora II, N. D. Moore, and R.A. Hiltunen		8. PERFORMING ORGANIZATION REPORT NO.
9. PERFORMING ORGANIZATION NAME AND ADDRESS Tennessee Valley Authority 470 Commerce Union Bank Building Chattanooga, Tennessee 37401		10. PROGRAM ELEMENT NO. INE624A
		11. CONTRACT/GRANT NO. EPA Interagency Agreement D5-E-721
12. SPONSORING AGENCY NAME AND ADDRESS EPA, Office of Research and Development Industrial Environmental Research Laboratory Research Triangle Park, NC 27711		13. TYPE OF REPORT AND PERIOD COVERED Phase; 5/75 - 9/77
		14. SPONSORING AGENCY CODE EPA/600/13

15. SUPPLEMENTARY NOTES IERL-RTP project officer is Michael C. Osborne, Mail Drop 61, 919/541-2915.

16. ABSTRACT The report summarizes results of a chlorine minimization/optimization study for the control of biofouling on the surface of condenser tubes at TVA's John Sevier Plant from December 1975 to September 1977. The required chlorine feed rate was found to be a function of inlet water temperature and chlorine demand. Statistical analysis of the data did not indicate a significant impact of water quality parameters (pH, total suspended solids, ammonia, total organic carbon, nitrates plus nitrites, organic nitrogen, alkalinity, and conductivity) on the required feed rate. It was determined that inlet water temperature may be used as an indicator for raising or lowering the chlorine feed rate. Natural water and system chlorine consumption was found to vary directly with the chlorine feed rate and the inlet water temperature; e.g., increasing feed rate and/or inlet water temperature also increases chlorine consumption. Also, as the frequency of chlorine application is increased and the length of chlorine application is decreased, the less chlorine is consumed by the system. Data analysis indicates that system demand can be determined and feed rate can be set to satisfy demand with only a trace of free residual chlorine at the condenser outlet. The final report, containing the final phase of the study, will provide data from tests of the optimum procedure for cooling system operation with minimum chlorine usage.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
Pollution	Pollution Control	13B
Steam Electric Power Generation	Stationary Sources	10A
Chlorine	Biofouling	07B
Feedwater		13A
Biodeterioration		06A
Condenser Tubes		07A

18. DISTRIBUTION STATEMENT Release to Public	19. SECURITY CLASS *(This Report)* Unclassified	21. NO. OF PAGES 129
	20. SECURITY CLASS *(This page)* Unclassified	22. PRICE

EPA Form 2220-1 (9-73)