Online BOD Measurements
BOD-2000 Instrument
Pilot Test Results

DRAFT REPORT

JUNE 1995

Wastewater Research Group

LIQUID WASTE MANAGEMENT DIVISION

BUREAU OF SANITATION

DEPARTMENT OF PUBLIC WORKS
CITY OF LOS ANGELES

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CITY OF LOS ANGELES

INTER-DEPARTMENTAL CORRESPONDENCE

DATE: July 3, 1995

TO: Distribution

FROM: Kenneth L. Ludwig, Division Manager
Liquid Waste Management Division

SUBJECT: ONLINE BOD MEASUREMENTS
BOD-2000 INSTRUMENT PILOT TEST RESULTS, DRAFT REPORT

This report describes a study conducted by the LWMD's Research Group on an instrument for fast measurement of BOD in wastewater. This is a detailed written version of information that was summarized in a presentation to management at the Plant Manager's Meeting in early October 1994, describing research on the Nissin Electric BOD-2000, manufactured in Japan by Central Kagaku Corporation (CKC).

The instrument was tested in the field from April to July, 1994 and in the Laboratory during August and September 1994. The results are promising, and the technology of this instrument needs further work for this application.

Other instruments such as the Cosa Instruments BIOX-1010, LANGE ARAS Sensor BOD, and the Anatel BioMonitor are also available. They perform comparable measurements using respirometry techniques that have various similarities to the BOD-2000. The BIOX-1010 has recently been under study by the Research Group and will be discussed in a forthcoming report.

As there is widespread agreement in the wastewater treatment industry that better BOD monitoring is essential for improved process control, we are pleased to present to the Bureau of Sanitation management this report on the most thorough study done to date on applying fast BOD instruments to wastewater process control.

I will be working with the group to investigate ways in which studies such as this can be incorporated into the group's overall Research Work Plan so that identified, ongoing research needs and efforts will not be deferred or disrupted. This effort will also involve discussions with the plant managers regarding process related research. Any comments or suggestions pertaining to prioritization of special projects such as this study or wastewater research in general, should be directed to Tito Jugo at (310) 548-7766. Any comments on this report should be forwarded to Reza Iranpour at (310) 548-7770 or Kris Flaig at (310) 548-7767 by the end of July 1995.

Attachment

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EXECUTIVE SUMMARY

INTRODUCTION

Biochemical Oxygen Demand (BOD) is the best available measure of the organic strength of influent/effluent wastewaters. The usual method of BOD determination is performed in a laboratory and requires five days to obtain a result. Although the standard five day BOD (BOD_5) analysis is suitable for regulatory compliance and retrospective influent/effluent and treatment process monitoring, it does not provide a timely measure of the efficiency of wastewater process operations. The standard BOD_5 determination cannot be used as an early-warning safeguard against plant upsets due to shock loadings of organic wastes or toxic chemical discharges by upstream industry. Other available measures of organic strength (e.g., chemical oxygen demand, total organic carbon, etc.) can not substitute for BOD measurements.

This report documents the investigations of the Liquid Waste Management Division's Research Group of a rapid, on-line monitoring system for the determination of biochemical oxygen demand. The results of the studies to date are very encouraging and indicate that a reliable method for nearly instantaneous BOD monitoring for plant process applications may soon be a reality. Data obtained by Research Group staff under laboratory conditions indicate that the technology is already capable of providing quantitative measures of BOD_5 in as little as 30 minutes. Although the equipment tested (Nissin BOD-2000) is proprietary, Division staff have identified important improvements in the technology that make its practical utilization at Bureau wastewater treatment facilities very promising.

Included in the report is a description of BOD biosensor technology, the tests that were conducted under both laboratory and field conditions, and the conclusions of Division research staff following extensive evaluation of the data. Although recommendations for additional research are included, it is recognized that the considerable efforts demanded by this and similar investigations need to be recognized in light of Liquid Waste Management's overall activities as a support division, particularly in terms of their benefit to the plants.

FIELD RESULTS

The BOD-2000 equipment was initially set up in April, 1994 at the Terminal Island Treatment Plant (TITP) in a rain-proofed metal cabinet. This was an attempt to test the instrument for field use in monitoring primary effluent. However, there were frequent problems with sewage solids clogging small tubes, and in hot weather the equipment went offline or gave clearly erroneous values. Some plausible results were obtained during a few days in June, but even these were unreliable. Statistical analysis showed no stable relationship between the instrument readings and BOD_5 values for the same samples measured by the standard laboratory method (Figures 4.1 and 4.2, Chapter 4). Consequently, in August the instrument was moved to the laboratory trailer at TITP.

LAB RESULTS

Results were much more satisfactory under controlled laboratory conditions. Measurements were taken on samples from both primary influent and primary effluent. One series of measurements was taken with unfiltered primary effluent, but since the clogging problems in the field were so severe, other runs were made with either influent or effluent samples that had been filtered. Each used one of three pore sizes: No. 4, No. 1, or No. .45. Portions of each sample were tested three or more times in the BOD-2000 to study the stability of the instrument readings and another portion was given the standard BOD_5 test which thus provided estimates of soluble BOD_5 (BOD_{S5}) of the filtered samples. Tests were also made of laboratory solutions of known concentrations in the same way, using both repeated tests with the BOD-2000 and the standard BOD_5 procedure.

The BOD-2000 readings showed excellent stability, with the individual readings differing little from the averages. Plots of successive readings (Figure 4.9, Chapter 4) for the samples showed that there were only slight random fluctuations, and readings for some samples showed modest upward or downward trends, probably as a result of fermentation during the periods of at least an hour required to make at least three repetitions of the measurements. Thus, little if any repetition of measurements is needed in future uses of the BOD-2000 in wastewater applications.

For all the combinations of filtering and sample source that were used, excellent correlations were obtained between the average of the instrument readings (BOD_{CKC}) for each sample and the corresponding soluble BOD_5 (BOD_{s5}). For the tests on laboratory solutions of known concentrations, the correlations are nearly perfect. Data were plotted both as time series, showing corresponding variations of BOD-2000 readings and BOD_5 values, and as scatter plots, where each point's horizontal and vertical coordinates are, respectively, the BOD-2000 reading and the corresponding BOD_5 value. The scatter plots also show the regression lines that best fit the points (Figures 4.3 to 4.8, Chapter 4). Table 4.1 (Chapter 4) summarizes the correlations obtained from the various series of experiments.

The plots also show systematic differences between the BOD-2000 and the BOD_5 results, and the finer the filter, the greater the difference. The probable explanation is that many microorganisms are filtered out, affecting the standard procedure which relies on the metabolic activity of the microorganisms in the wastewater sample. By contrast, the BOD-2000 relies on the yeast cells in its own biosensor, and so the instrument can be used even on sterilized solutions of nutrients.

Operation of the instrument requires bottles of rinse, buffer and standard solutions which were all monitored (Figure 4.10, Chapter 4).

Some total BOD_5 (BOD_{t5}) measurements were made in addition to soluble BOD_5 (BOD_{s5}) measurements, but limitation in laboratory staff time prevented obtaining comprehensive sets of measurements of BOD_5 during the experiments reported here. As total BOD_5 is the parameter that is important for plant operation and regulatory compliance, establishing the relationship between instrument readings and total BOD_5 should be done by additional laboratory work.

TECHNICAL CONSIDERATIONS FOR FUTURE USE

As the thirty minutes needed for a measurement are negligible compared with the time scale of hours over which influent BOD changes, the instrument could be used now to guide plant operation if it were kept in the laboratory and used to test grab samples of influent composite over the periods between equally spaced measurements made a few times a day. Probably four or five times a day would be adequate.

More automated operation would clearly be desirable, to eliminate the need for plant operators to collect samples frequently. As the operation of the biosensor makes it impossible in the foreseeable future to extend the operating temperature range of the instrument, it will have to be located where it is protected from excessive temperatures; collecting samples in wastewater treatment plants would therefore require piping or tubing from the influent stream to the instrument location. Hence, there must be provisions for preventing clogging, such as by filtering, washing with NaOCl or other disinfectants, ultrasonic cleaning, or other suitable technology.

Toxins in wastewater are also a concern. Toxicity sufficient to cause a sudden change in biosensor response could be detected during the calibration phase of each measurement cycle. A modest change in the programming of the microprocessor would allow the instrument to detect and report such events.

Presently available alternatives to the BOD-2000 are the BIOX-1010 respirometer, the LANGE ARAS biosensor and the Anatel BioMonitor. The BIOX-1010 is currently under study at TITP. The LANGE and Anatel instruments may also be tested in the future (Chapters 2 and 3).

FACTORS FOR DECISIONS

Economic analysis of using such instruments is not trivial because a half hour measurement is 240 times faster than a five-day test. The costs associated with using the current BOD_5 procedure include not only the direct costs of performing the tests, but also substantial costs resulting from process upsets. These include notification by telephone and mail of regulatory agencies, greatly increased laboratory activity, overtime for technical experts, changes in plant operation often lasting several weeks, and perhaps fines. Moreover, releases of improperly treated water represent failures of our commitment to protect the environment. Thus, a simple dollar for dollar comparison of direct measurement expenses, using the information in Chapter 5 does not capture these larger considerations. The comparisons in Chapter 5 show similar costs, and the other considerations argue strongly that fast BOD measuring instruments should be integrated into the Bureau of Sanitation's treatment plant operation in the near future.

RECOMMENDATIONS

On the basis of findings made to date, we recommend several types of work to accomplish this integration.

1. Additional laboratory studies with the BOD-2000:

   a. Further measurements to clarify observations made during the present study, such as the difference between BOD_{CKC} and BOD_{s5} for filtered samples;

   b. Testing modifications for more automated use, such as automatic detection of toxicity, and provisions against clogging.

2. Adaptation of the "field model" BOD-2200 to suit it for wastewater field use:

   a. Modification of the present sample handling hydraulics;

   b. Installation of a cooling device in the cabinet;

   c. Incorporation and perhaps further development of the modifications for toxicity detection, clogging prevention, etc. developed in recommendation 1b.

3. Evaluation of other instruments for this application, including the BIOX-1010, the Lange ARAS, Anatel BioMonitor and any similar units available.

ACKNOWLEDGMENT

The LWMD Wastewater Research Group would like to acknowledge the invaluable contributions made by the following throughout the project:

TITP Plant Manager, Clarence Mansell, Jr., Assistant Plant Manger, Y. J. Shao, and the operations and maintenance staff; EMD Assistant Division Manager, Lucy Jao, Lab Manager, Soun Chanjamsri and his staff; LWMD Sanitary Engineering Assistant, Alfredo Magallanes; the Bureau of Sanitation management for supporting this project; and Central Kagaku Corporation (CKC) of Japan, who provided the BOD-2000.

NOTATIONS AND KEYWORDS

BOD:	Biochemical oxygen demand
BOD_5:	BOD value obtained from the standard 5-day BOD test
BOD_{s5}:	Soluble BOD_5 (filtered samples)
BOD_{t5}:	Total BOD_5 (unfiltered samples)
BOD-2000:	Desktop instrument for BOD measurement, provided by CKC
BOD_{CKC}:	BOD data obtained from the BOD-2000
BOD_{SCKC}:	BOD data value obtained from the BOD-2000 (filtered samples)
CKC:	Central Kagaku Corporation of Tokyo, Japan, sole licensee to Nissin Electric Corporation for manufacture and marketing worldwide
COD:	Chemical oxygen demand
TOC:	Total organic carbon
EMD:	Environmental Monitoring Division
LWMD:	Liquid Waste Management Division

Regression:	a statistical procedure used to model one set of data with respect to another
Correlation:	statistical degree of correspondence between two sets of data
Yeast:	*Trichosporon cutaneum*, a single celled fungus
Electrode:	a terminal that, when exposed to specific environmental changes, produces a measureable change in current

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CHAPTER 1
INTRODUCTION

1.1 BACKGROUND

Timely Biochemical Oxygen Demand (BOD) monitoring of wastewater treatment plant influent and primary effluent is essential to process control. As an example of this need, the Terminal Island Treatment Plant (TITP) experiences diurnal variation of influent flow rate combined with unpredictable discharges from industries, which comprise 60% of the influent flow. Although less common now than five years ago, BOD shock loadings still occur on some occasions and cause process upsets. Hence, it would be very useful to determine the influent BOD in a timely manner, ideally by an automated monitoring system that would operate on a continuous basis. This would allow plant operators to institute appropriate process control measures in case of BOD shock loadings.

Until recently, the Chemical Oxygen Demand (COD) test was used to supplement the five day BOD (BOD_5) test. This test requires only a few hours as compared to the five day BOD analysis and can be correlated to BOD_5. However, mercuric sulfate ($HgSO_4$), a hazardous chemical, is used as a complexing agent in the COD test, and so Sanitation management required the treatment plants to end all COD testing. Environmental Monitoring Division (EMD) is now evaluating the use of Total Organic Carbon (TOC) analysis as a substitute for the COD test. However, TOC analysis does not measure other organic and inorganic bound elements (such as nitrogen and hydrogen) that can contribute to BOD_5 or COD. Hence, it cannot be considered a suitable replacement for BOD_5 or COD measurements.

Methods to monitor influent BOD spikes and plant-wide performance were reviewed in late 1993 by plant management and process/research engineers. Three promising BOD sensor devices were evaluated, two from Germany and one from Japan.

The Cosa Instrument BIOX1010 respirometer, a German made instrument, equalizes sample and dilution flows in a respirometry reaction chamber and measures the rate of oxygen uptake by the microbial populations. This instrument has been tested at TITP and a report is currently being prepared by Research staff.

Another is the LANGE ARAS BOD laboratory instrument, also from Germany, which uses biosensor caps impregnated with two specific types of microbes, *Rhodococcus erythropolis* and *Issatchenkia orientalis*. Although this model has been demonstrated on the West Coast (including one day at TITP), it requires operators to insert each sample separately, a labor intensive task for process control. An on-line version could be available sometime in late 1995.

The third instrument is the Nissin Electric BOD-2000, which is widely used in Japan in the food processing, pharmaceutical and wood pulp industries. This instrument uses a microbial membrane biosensor to analyze for soluble, carbonaceous BOD in benchtop applications. Another model, the BOD-2200, a field instrument, utilizes the same mechanism, but with three sample ports (rather than the single port on the BOD-2000), and has alarm capability along with space for larger solution containers housed in a metal enclosure. Except for a few test results supplied by the manufacturer, Central Kagaku Corporation(CKC), data on its performance in wastewater applications are limited. Because of its potential utility and the willingness of the manufacturer's representative to provide the City free use of the equipment for testing, Research staff decided to pursue evaluation of the BOD-2000.

This report describes the results of extensive testing of this equipment under field and laboratory conditions at TITP. On the basis of literature review and related academic discussions, we believe this test is the first attempt to fully assess the capability of this technology in a wastewater application in the United States.

1.2 GOALS AND OBJECTIVES

The overall goal was to understand how the BOD-2000 might be used in a treatment plant like TITP. The first objective was to test it under field conditions, estimating:

a. Quality of the results;

b. Maintenance requirement;

c. Costs of operational use.

The second objective was to test it in a more benign laboratory environment, to determine the same three types of information, using the greater flexibility of sample preparation available in the laboratory.

The third objective was to formulate recommendations for future work and to select one or more of the following options:

a. A plan for operational use;

b. Additional testing;

c. Modification of the instrument;

d. Selecting a different instrument.

CHAPTER 2

LITERATURE SURVEY

Research continues to expand in the development of biosensor technology in many areas (Amersham, 1988; Hale, et al., 1989; Halazy, et al., 1989; Schultz, 1991; Shamel and Brown, 1992; Walt, 1992; Matsumoto, et al., 1993), including pharmaceuticals, food processing, health and hospitals, and manufacturing. Considerable research indicates that microbial membrane technology could be a reliable method in wastewater applications to determine soluble carbonaceous BOD in a relatively short time with good correlation with the traditional BOD_5 test.

The technology involves measuring the electrical current from a dissolved oxygen probe placed on one side of a microbe impregnated membrane. According to Hikuma, et al. (1979), in an early form of the sensor in the BOD-2000, BOD's (mostly organics) of 20, 40 and 60 mg/l reduced the 0.9 microampere (μA) seen for tap water to about 0.72, 0.55 and 0.4 μA, respectively, Fig 2.1a. This biosensor technology is now established as a standard in several types of Japanese industry.

The usual configuration of the sensor draws from a number of studies on microbes, electrodes and cell configurations. Yeasts are the microbes of choice (Karube and Mitsuda, et al., 1977; Karube and Matsunaga, et al., 1977). Various electrode configurations have been replaced by dissolved oxygen meters (Hikuma, et al., 1979; Karube and Matsunaga, et al., 1977; Strand and Carlson, 1984), which take into account interferences caused by such factors as pH, temperature, salt concentration and simple organics (Hikuma, et al., 1977; Karube and Matsunaga, et al., 1977; MacKoul, et al., 1984; Kitagawa, et al., 1991).

These interferences result in current reductions that could strongly affect the accuracy of the BOD measurements. Temperature and pH variations reduce the microcurrent as shown in Figures 2.1b and 2.1c, respectively. The pH produces electrical current differences of about 0.15 to 0.25 (μA) over the pH range of 5 to 9, with the least interference occurring at a pH of around 7.0. Temperature produces electrical current differences of about 0.21 to 0.25 uA within a temperature range of 25°C

Figure 2.1a. Relationship between Current and BOD (Calibration Curve)

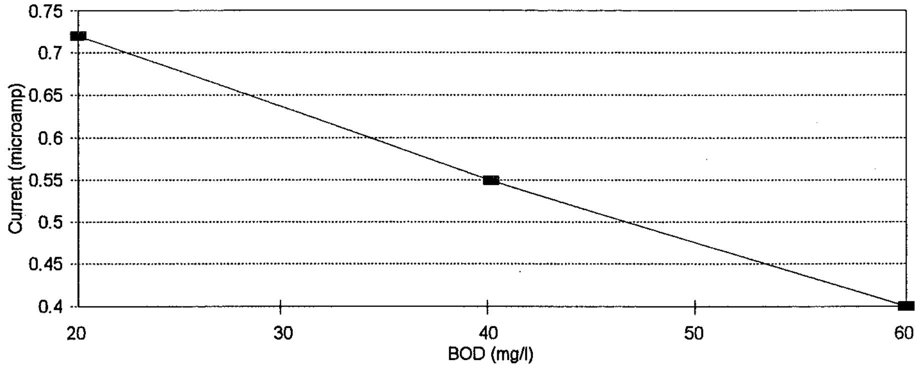


Figure 2.1b. Relationship between Current and pH of Buffer

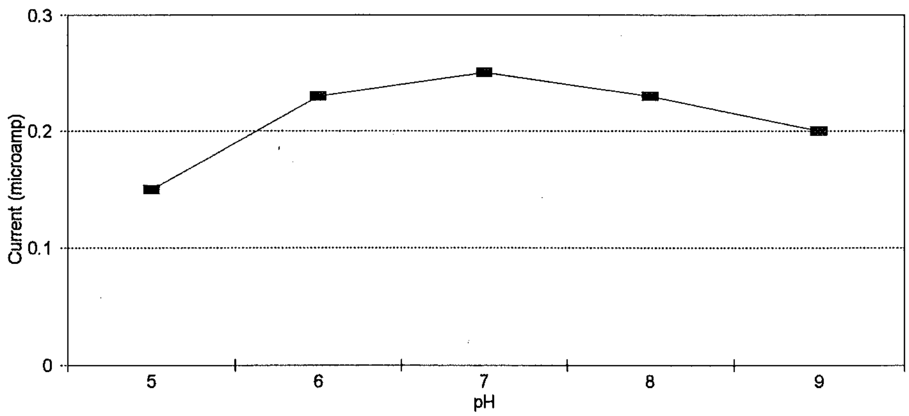
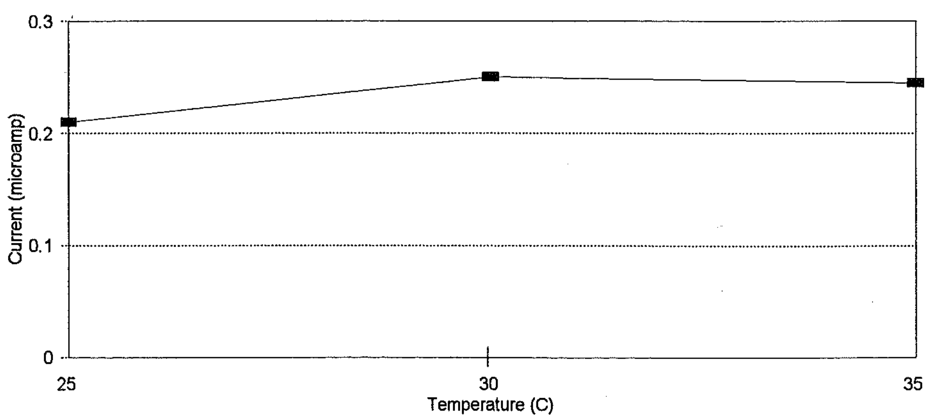


Figure 2.1c. Relationship between Current and Temperature



Source: CKC Manual

to 30° C, with minimum interference occurring at 30° C. Evidently these changes are the same order of magnitude as the changes produced by variations in BOD, so it is important to compensate for the interfering factors. In the BOD-2000 these interferences are minimized by using a constant temperature bath and a chemical buffer solution that provides a pH of about 7.

Other aspects of the instrument and its operation are also well documented. These include the use of glucose-glutamic acid solutions for standardized BOD calibration (Bond and Straub, 1973; Hikuma, et al., 1979; Karube and Matsunaga, et al., 1977), phosphate buffer (Bond and Straub, 1973; Hikuma, et al., 1979; Karube and Mitsuda, et al., 1977) and the specific procedures (Hikuma, et al., 1979; Karube and Mitsuda, et al., 1977; Karube, et al., 1977) for determining BOD values. MacKoul, et al. (1984), demonstrated the possibility of low level precision with the use of a peristaltic pump.

The BOD-2000 is one of a class of instruments collectively known as respirometers. A number of respirometers are currently available. These instruments are being offered to meet the anticipated demand for fast BOD measurements for process control (Roger Loomis, 1991). The LANGE ARAS instrument is very similar to BOD-2000, but uses *Issatchenkia orientalis* and *Rhodococcus erythropolis* in its biosensor. These microbes are claimed to be less of a health hazard to humans than the yeast in the Nissin instrument, so disposing of used membrane needs fewer safeguards. By contrast, the Cosa instrument BIOX1010 measures the respiration of biologically-active substances by detecting the pressure reduction in a tightly sealed chamber and relies on the respiration of organisms from the wastewater that grow on the inner surfaces of small plastic carriers of known surface area. Sewage samples are highly diluted for this instrument, so that nearly all the biomass is in the plastic carriers. All of these technologies are relatively new. By contrast, an older method of relatively rapid BOD measurement for sewage treatment plants relies on activated sludge from the plant, and measures the difference between the respiration of the sludge alone and the respiration of a mixture of sludge in the sample; this approach is used in the Anatel BioMonitor system. Columbus Instrument offers still another detection method, based on simultaneous measurements of oxygen uptake, using a special fuel cell as a detector, and carbon dioxide production, using an infrared spectrometer. An extensive effort would be needed to compare these instruments for the reliability of their results and their performance according to other criteria such as durability, cost of operation, etc.

CHAPTER 3
METHODOLOGY

3.1 THE BOD-2000 ANALYZER

The BOD-2000 is a laboratory instrument, approximately 18" wide, 16" deep and 13" high in size. It consists of a microcomputer with display to control all operational functions, a series of solenoid valves to regulate incoming flows, a roller pump to control flow rates, an air pump, an electronic temperature bath, the biosensor and an electrostatic printer. A photo of the instrument is shown in Figure 3.1.

The biosensor uses a yeast, *Trichosporon cutaneum.* This "microbial" electrode consists of a microbial membrane tightly mounted to a dissolved oxygen electrode as shown in Figure 3.2a. The electrode produces a current proportional to the amount of dissolved oxygen that reaches it after passage through the microbial membrane. When fluid without organic matter is fed into the flow cell (tap water is normally used), as shown in Figure 3.2b, the yeast has low metabolic activity, resulting in almost no reduction in the concentration of oxygen passing through the microbial membrane and a relatively high current from the electrode. When a solution containing organic matter is fed into the flow cell, as shown in Figure 3.2c, microbial metabolism becomes more active, resulting in higher consumption of oxygen and a corresponding decrease in electrode output. As a result the current output varies oppositely to the density of organic matter, as shown in Figure 3.3.

BOD-2000 measurements are taken at 30, 60 or 120 minute intervals, depending on the measurement pattern selected. Each corresponds to a cycle of washing, feeding of the standard solution and the test sample, with Pattern 1 requiring 30 minutes, Pattern 2 requiring 60 minutes, and Pattern 3 requiring 120 minutes. Three dilutions of a standard glucose and glutamic acid solution are used to calibrate the instrument. A phosphate buffer (0.01M, pH 7) is used to buffer and dilute the standard solutions and sample.

Figure 3.1 Automatic Desktop Microbe Electrode Type BOD-2000 Analyzer

Source: CKC Manual

Figure 3.2a Microbe Electrode

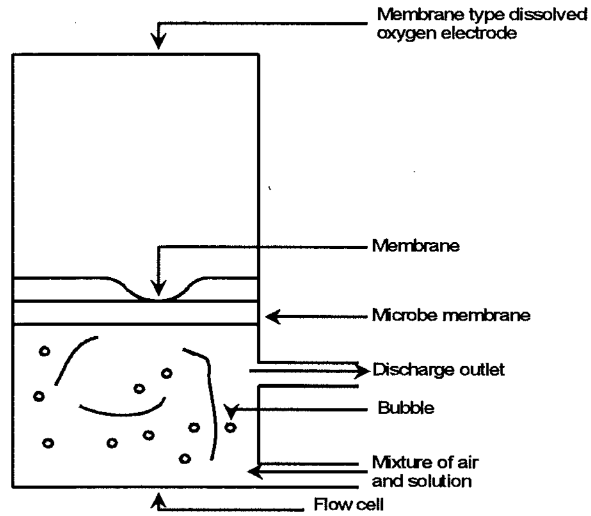


Figure 3.2b Microbe Membrane when solution has no organic matter

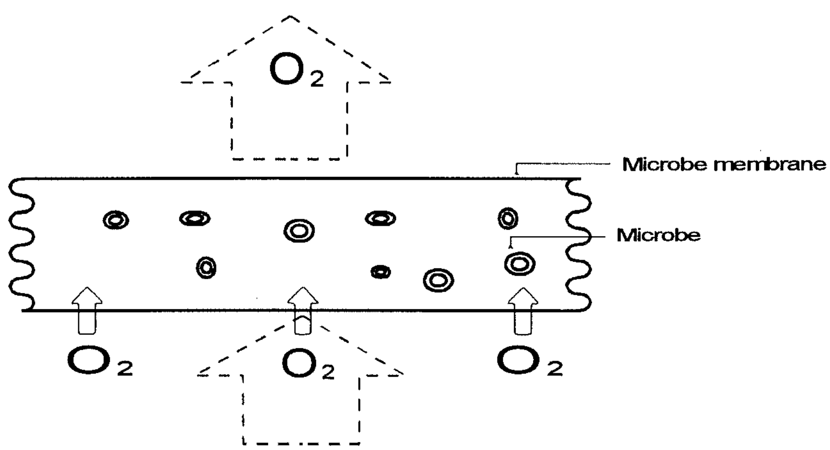
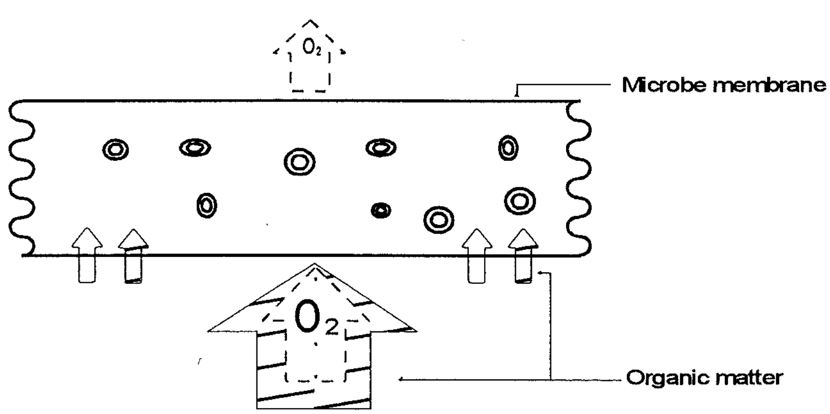
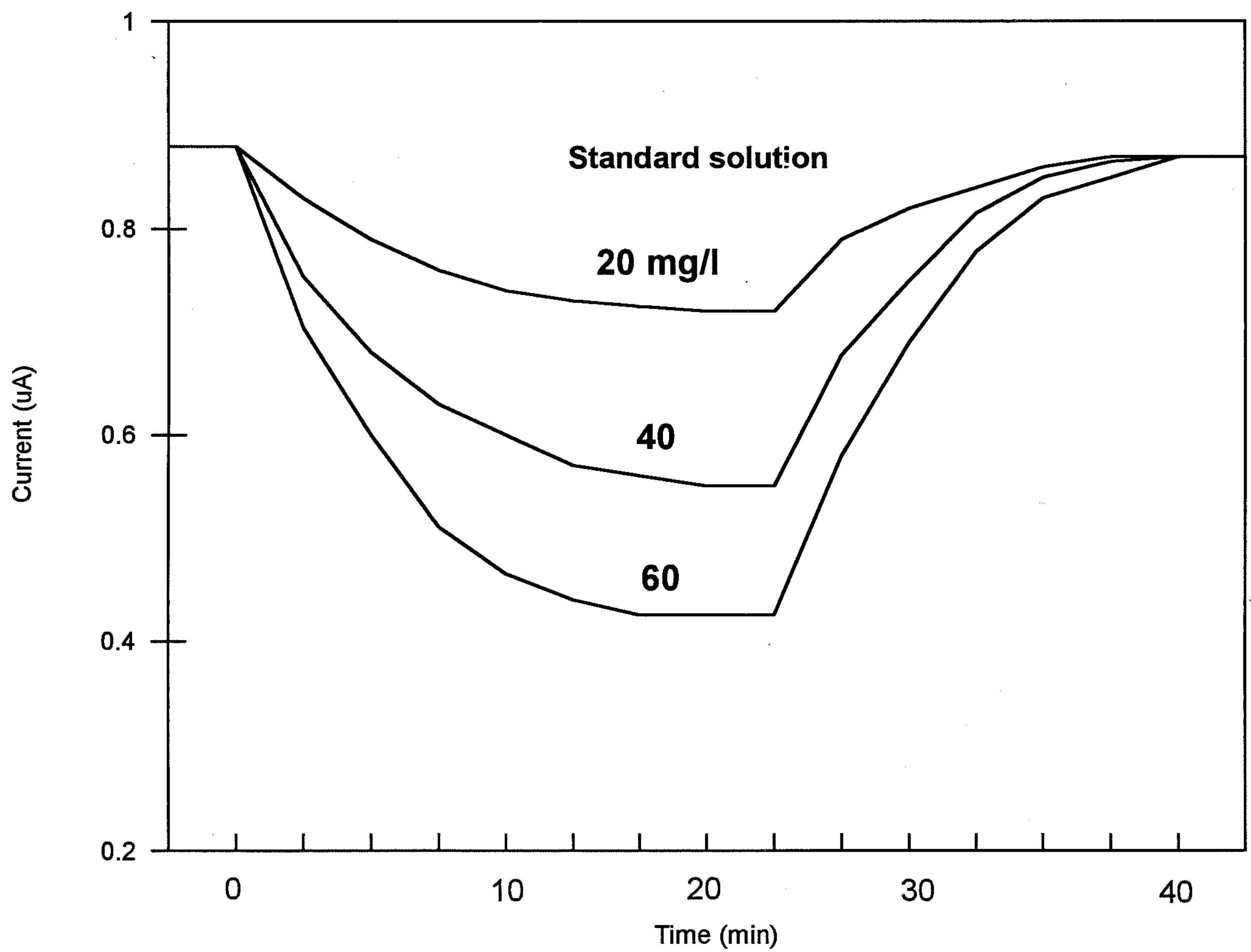


Figure 3.2c Microbe Membrane when solution has organic matter



Source: CKC Manual

Figure 3.3 Response curve of the microbial electrode sensor



Source: CKC Manual

3.2 TEST PROCEDURES

3.2.1 FIELD TESTING

The equipment was first installed on-site at TITP close to the primary distribution channel in mid-April 1994. It was set up with the assistance of the plant's operations and maintenance personnel, with the plant providing most of the required piping and electrical materials, including the pumps.

Generally, most solids fall out in the primary settling tanks where 30% to 35% of BOD_5 is removed. In the case of TITP, primary effluent soluble BOD is characteristically 85-90% of the total BOD. Hence, test runs were performed primarily with the primary effluent, with occasional tests done with the primary influent. The test started on the second week of April and continued until mid-August. Pattern 2, which takes one hour, was used most of the time, with a few runs using Pattern 1 and Pattern 3 taken. Shift operators took grab samples at 7:00, 9:00, 11:00 a.m. and at 1:00 p.m. for the BOD_5 analyses. EMD TITP laboratory staff performed the BOD_5 analyses.

Consumption of standard and rinsing solutions, replacement of plastic tubing and microbial membrane, as well as the time spent for maintenance activities, were carefully monitored and recorded.

The success of this instrument in the field depends to a large extent on how well it is maintained to prevent clogging of the small diameter sample plastic tubing. Since the test sample contains microbes and nutrients, slime tends to build up quickly in the tubing. It was found that the clogging problem was not confined to the sample tubing directly feeding the machine, but also to the 3/8-inch diameter plastic tubing connected to the 2-inch PVC intake pipe and feeding the sample container. In spite of a fine strainer installed at the intake end of the 2-inch PVC tubing, it was frequently coated with fine solids, requiring at least 5 to 10 minutes twice daily to clear the passage. Attempts to correct these problems proved to be time-consuming and difficult. Consequently, results of the field testing were inconclusive and unsatisfactory. Decision was then made to test the instrument in the EMD lab.

3.2.2 Laboratory Testing

The instrument was transferred to the EMD lab trailer at TITP in mid-August where testing was continued under a more controlled condition. One series of measurements was made on unfiltered samples. In an effort to minimize or prevent clogging, filtered samples were also used in four series of measurements.

Different filter sizes, namely, No. 0.45 (0.45 micron), No. 1 (1 micron), and No. 4 (3 microns) were used on the filtered samples. Similarly, the BOD_5 samples were filtered, using the same filter sizes. To maintain homogeneity in the unfiltered samples as they were being fed into the machine, a low speed magnetic stirrer was used continuously to stir the sample.

BOD-2000 measurements and corresponding BOD_5 lab analyses were conducted every four hours during the first three weeks, using filter No. 4 and No. 1 for grab samples from the primary influent and effluent. The sampling frequency was reduced to eight hours interval during the remaining three weeks, this time using filter No. 0.45 for the primary influent and unfiltered samples from the primary effluent. As a control, tests were also ran on the BOD standard solutions, using different concentrations.

Consumption of buffer, rinse and standard solutions, replacement of plastic tubing and microbial membrane, and time spent for keeping the instrument running were, likewise, monitored and recorded.

CHAPTER 4

RESULTS

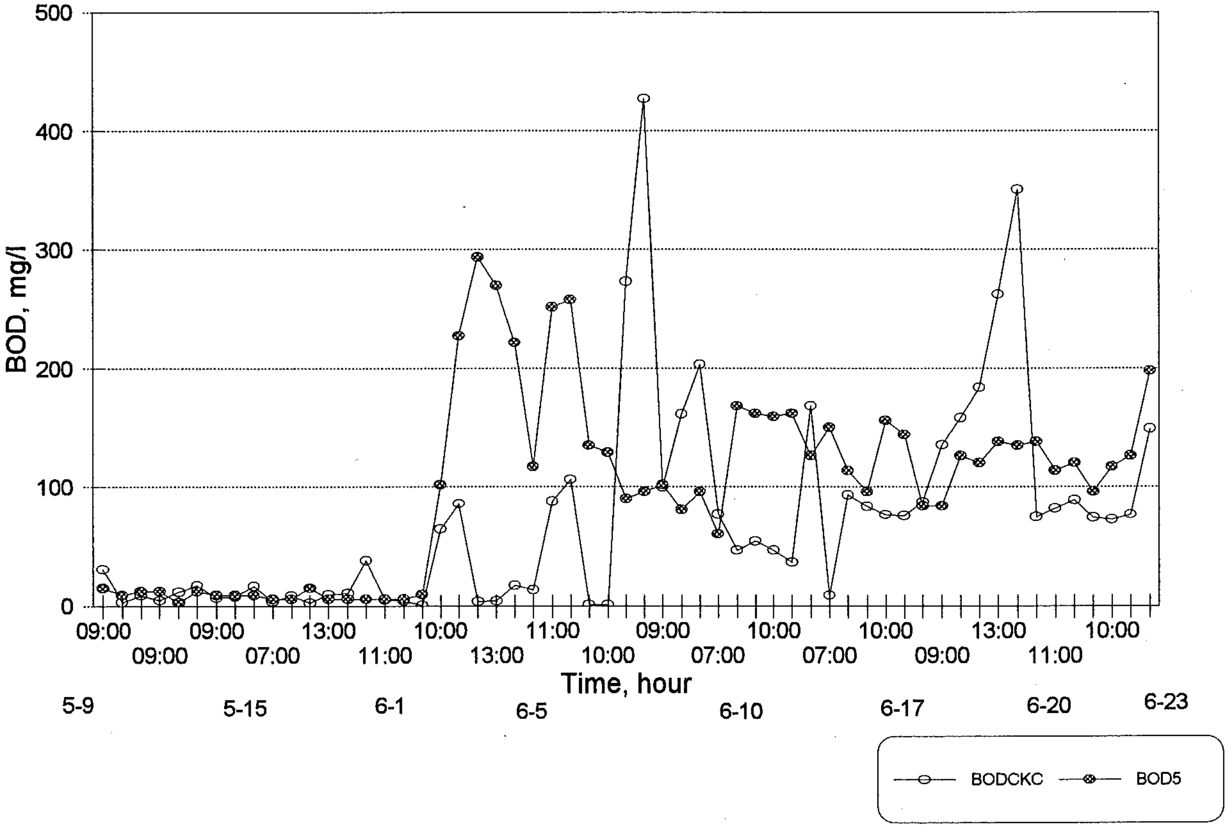
4.1 FIELD RESULTS

As indicated in Chapter 3, initial field experience with the BOD-2000 was unsatisfactory. There were very frequent problems with sewage solids clogging various small tubes in the unit and in hot weather the equipment went offline or gave clearly erroneous values such as below 10 mg/l or above 500 mg/l. Figure 4.1a is a time series plot of instrument readings that correspond most closely in time to the times when samples were collected for the standard five day BOD test. Thus no more than a few of the many instrument samples is plotted from each day. The corresponding BOD_5 values are also plotted in the figure. As might be expected, the correlation coefficient and regression line between the BOD5 values from the standard laboratory method and the corresponding readings recorded by the instrument under these conditions showed no significant relationship. Figure 4.1 is the corresponding best line regression fit. In this Figure the horizontal coordinate of each point is a BOD-2000 reading, and the vertical coordinate is the corresponding BOD5 value.

The few plausible results were obtained while the equipment received enhanced surveillance, but even these results were unreliable. Figure 4.2a and Figure 4.2b show the results for the best thirteen values from four months of data, recorded on June 11, 17, 22, and 27. One hardly needs to compute a correlation coefficient to see that there is no stable relationship between the laboratory and the instrument values.

By August it was clear that no further useful information would be obtained from expenditure of lab supplies and experiment labor on this setup.

Figure 4.1a. Time Series for CKC Field Data with Corresponding BOD5 Data.



NOTES:

1. CKC instrument in the field.

2. Three points have been omitted from the graph for adjustment of the 'Y' scale. They are:

Date	Time	BODCKC	BOD5
06/15/94	07:00	1282.2	84
06/15/94	09:00	1360	84
06/18/94	10:00	800	99

Figure 4.1b Relationship between CKC Field and BOD5 Data.

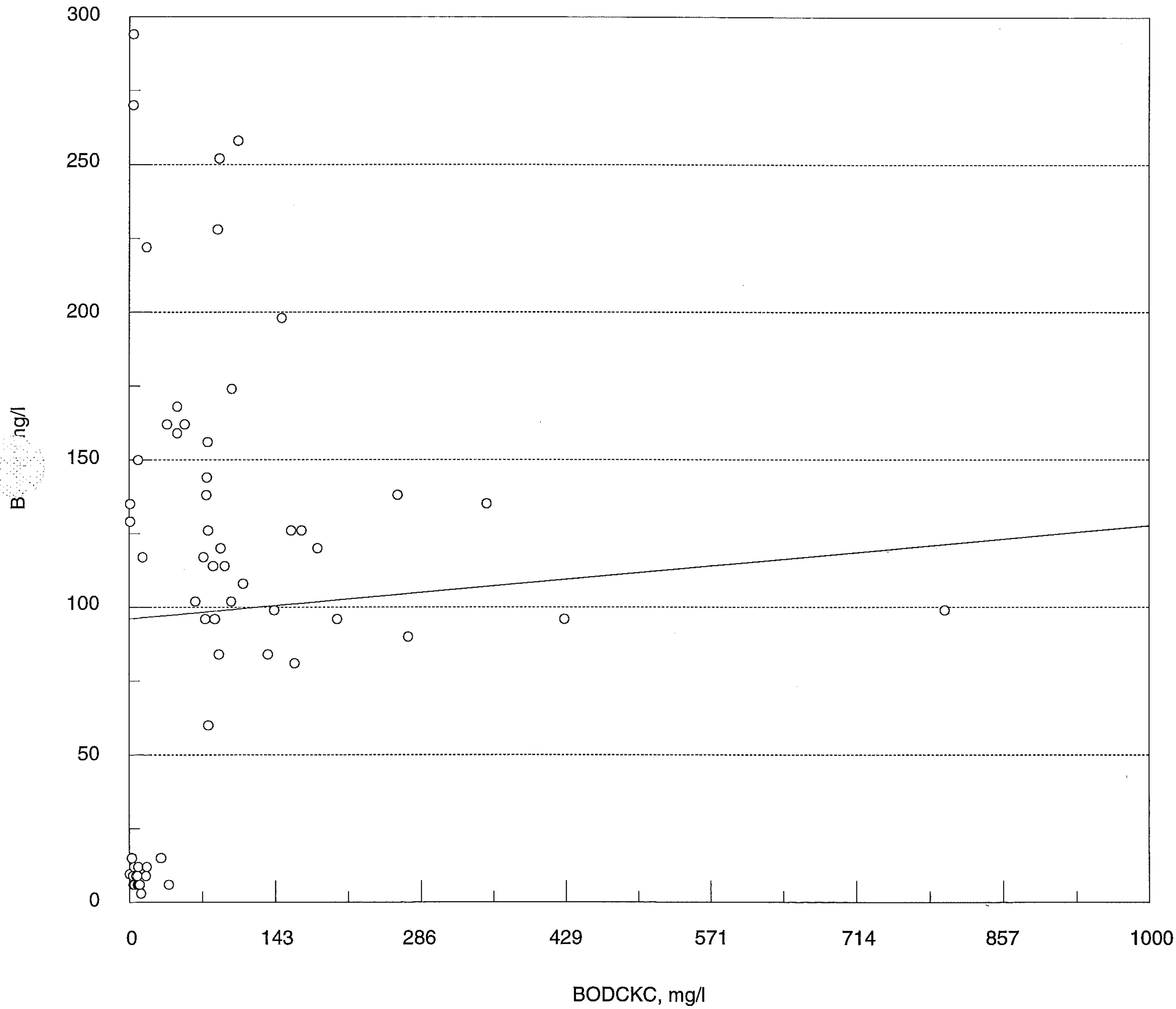
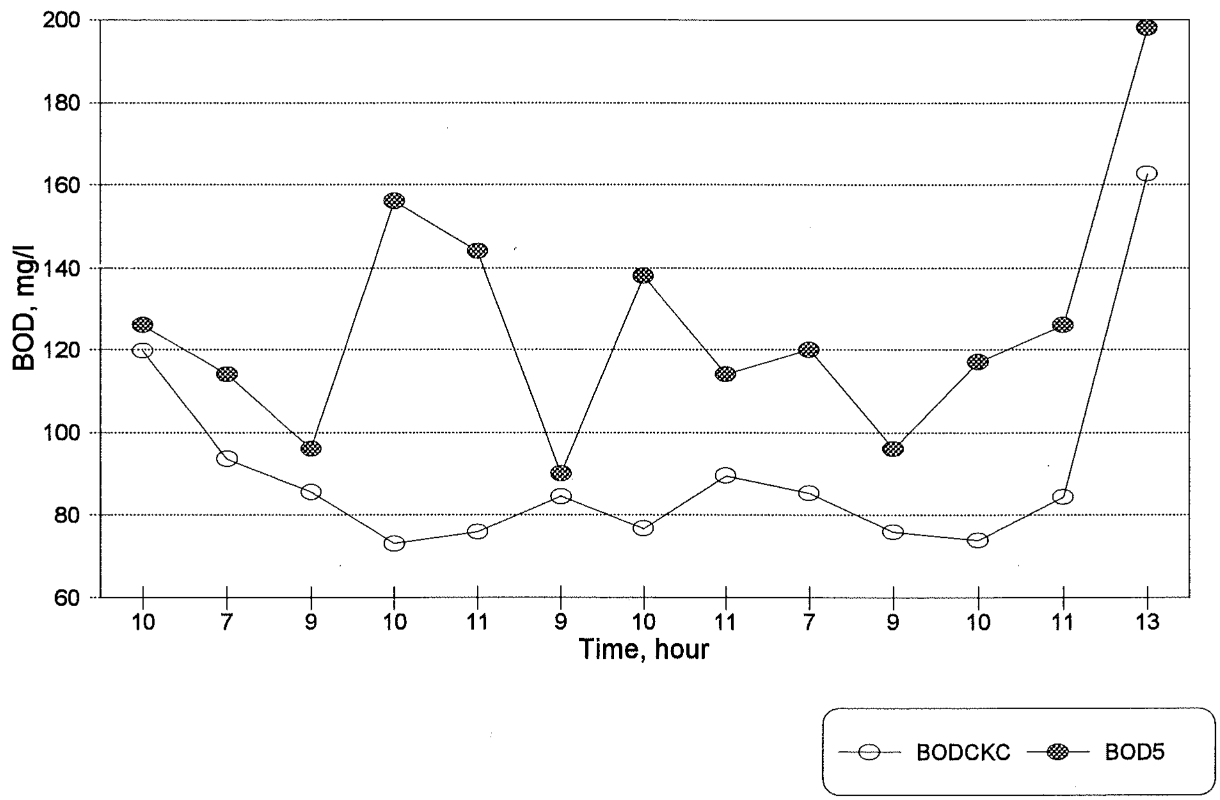


Figure 4.2a. Time Series of Selected CKC Field Data and Corresponding BOD5 Data.

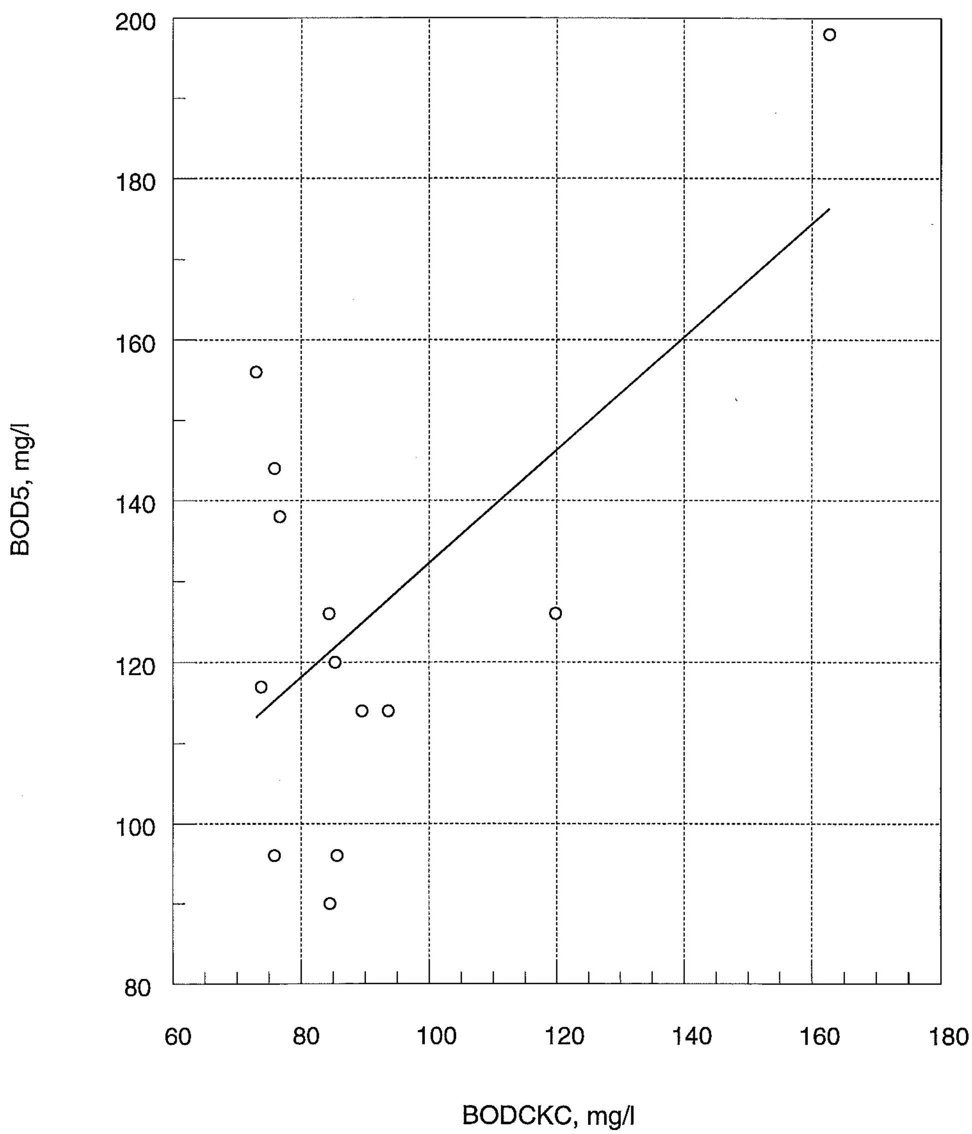


NOTES:

1. CKC instrument in the field.

2. Graph presents only few data in June.

Figure 4.2b Relationship between Selected CKC Field and BOD5 Data.



4.2 LAB RESULTS

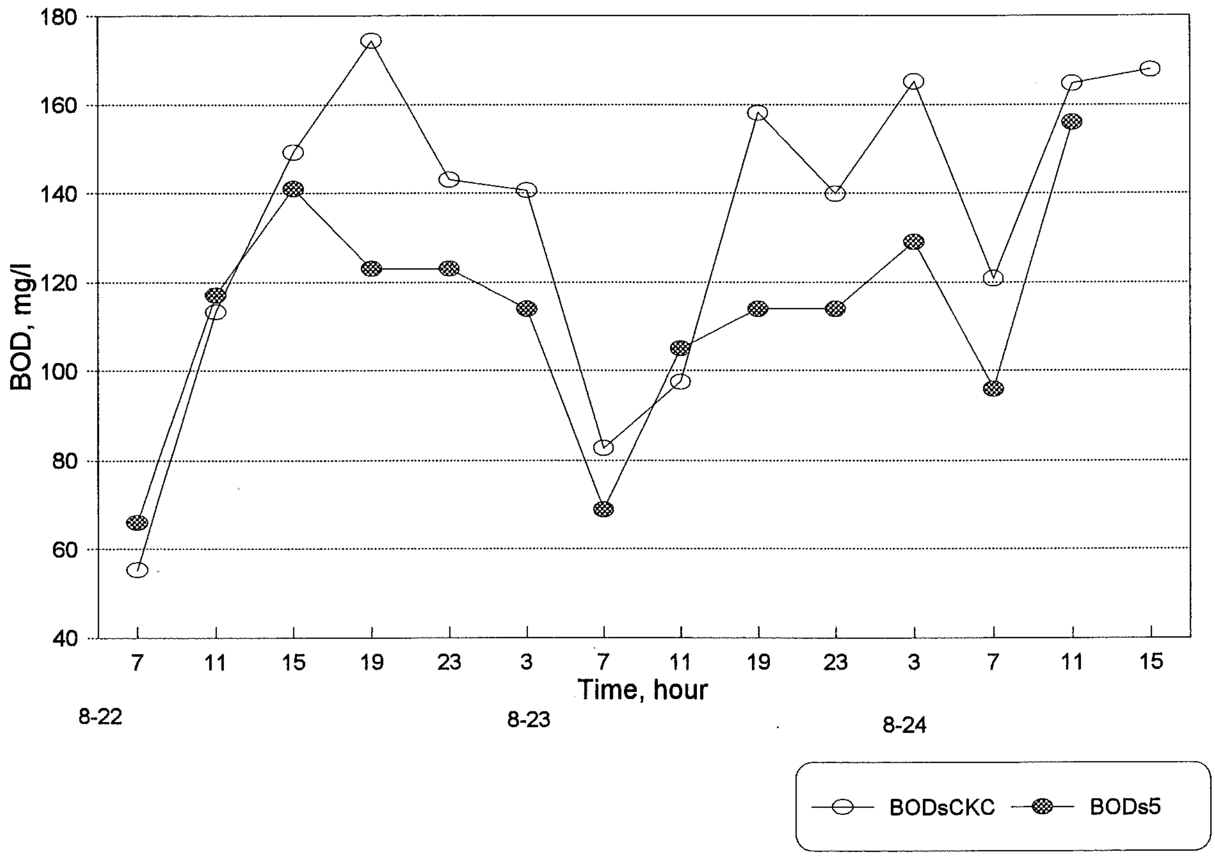
Results were much more satisfactory under controlled laboratory conditions. In order to asses the reliability of the BOD-2000, each sample of wastewater was tested repeatedly in the machine. Thus, the instrument readings in the following Figures are the averages for each sample. Figures 4.3a through 4.8a show time series plots for the six series of measurements and Figures 4.3b through 4.8b show the BOD-2000 versus BOD_5 pairs, and their best fit regression line. Figure 4.5c through 4.7c show the results of deleting from these data sets a few suspect points that laboratory records also implied may be incorrect. Table 4.1 lists the correlation coefficients for these experiment series, using either all the data, or the data sets with a few doubtful points discarded.

It is evident from these results that under controlled laboratory conditions, for all the combinations of filtering and wastewater source that were used testing each sample both with the instrument and standard laboratory method gave excellent correlations. For the tests on laboratory solutions of known concentrations, the correlations are nearly perfect.

It is also apparent that there are systematic differences between the BOD-2000 and the BOD_5 results, and the finer the filter the greater the divergence. This difference probably results because many microorganisms are filtered out, affecting the standard procedure that relies on the metabolic activity of the microorganisms in the water. By contrast, since the BOD-2000 biosensor has its own yeast cells, the instrument can be used even on sterilized solutions of nutrients. However, an anomaly was observed in the data for filter No. .45, because total BOD_5 as well as soluble BOD_5 was sometimes measured for this filter, and also for using filters No. 4 and No. 1 on primary influent. Total BOD_5 was greater and BOD_{CKC} for filter No. 1 and No. 4 as expected. However, Total BOD_5 was smaller than BOD_{CKC} for filter No. .45. This casts some doubt on the validity of the other results for filter No. .45, even though in all other respects the results for this filter appear plausible. Further measurements to resolve this anomaly would be desirable. Limitations in experimenter time prevented obtaining comprehensive sets of measurments of total BOD_5 during the experiments reported here, although this is the parameter that ultimately is to be estimated from the instrument measurements. Thus the few total BOD_5 data corresponding to the data in Figure series 4,5, and 6 are not plotted here.

It should also be noted that the presently available data leave open the possibility that some of the differences result from using primary influent in some measurement series and primary effluent in others. The Figure heading show that only the No. 4 filter was used on both primary influent and primary effluent. The rest were done with only one source or the other.

Figure 4.3a. Time Series for CKC Lab and BOD5 Data Using Filtered Primary Effluent Samples (Filter No. 4).



NOTE:

1. CKC instrument in the Lab.

Figure 4.3b. Relationship between CKC Lab and BOD5 Data for Filtered Primary Eff. Samples (Filter No. 4)

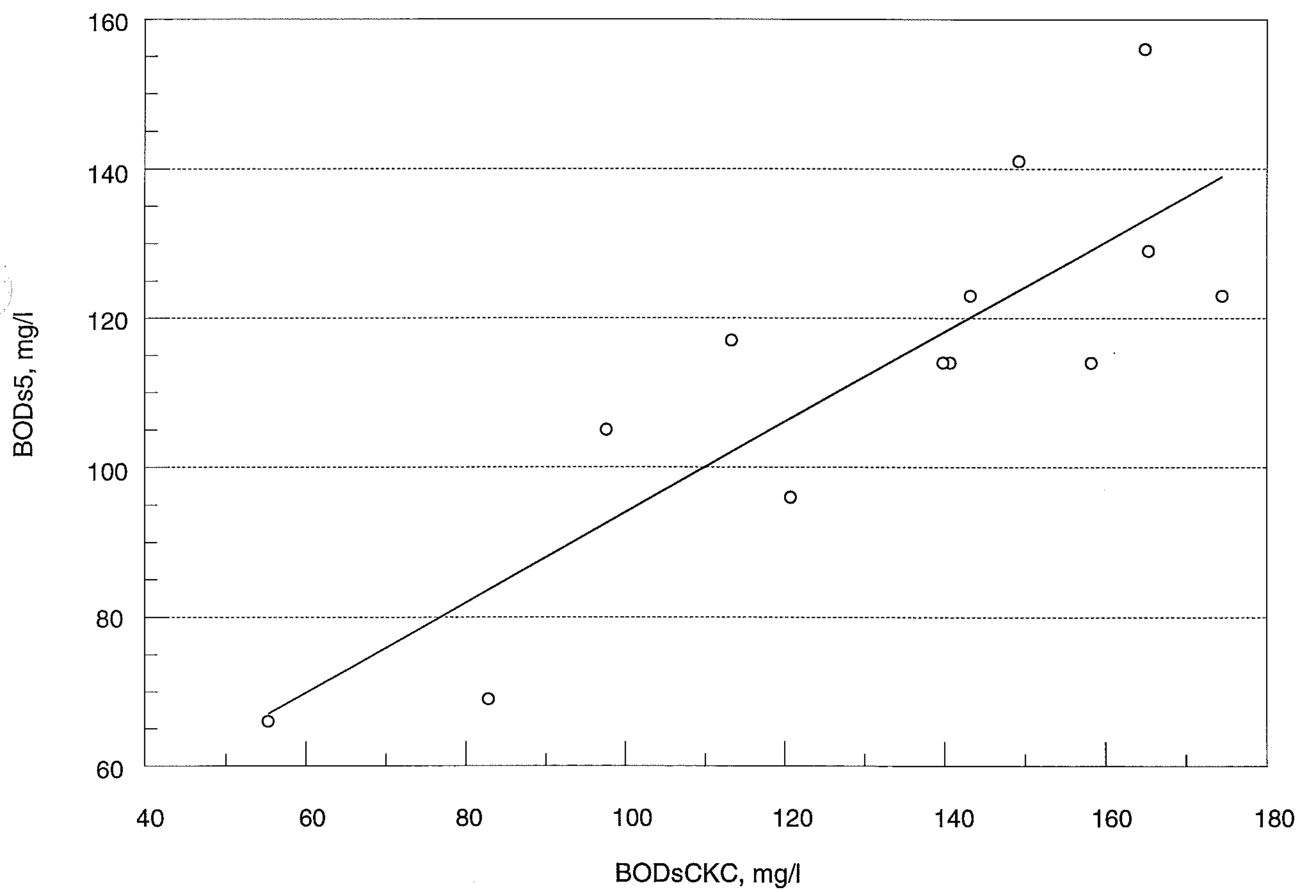
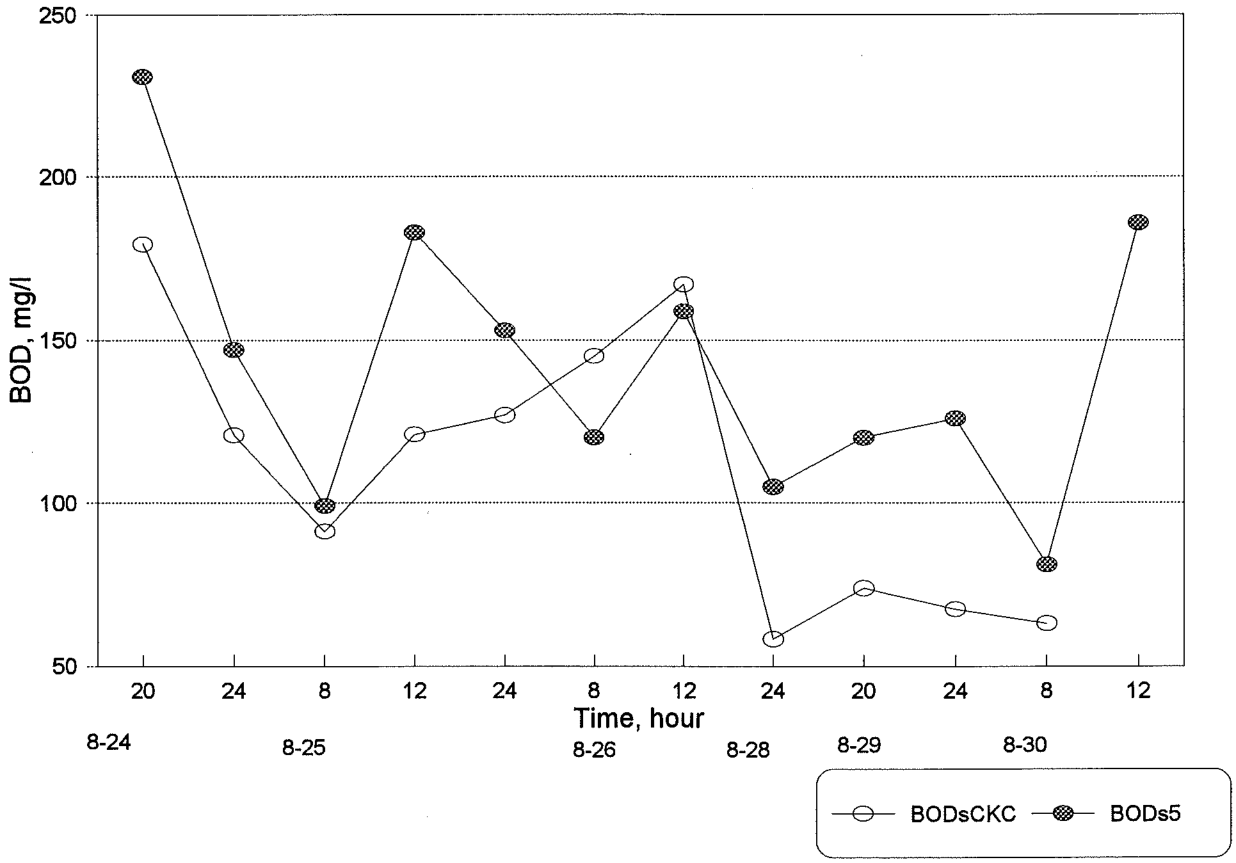


Figure 4.4a. Time Series for CKC Lab and BOD5 Data Using Filtered Primary Influent Samples (Filter No. 4).



NOTE:

1. CKC instrument in the Lab.

Figure 4.4b. Relationship between CKC Lab and BOD5 Data for Filtered Primary Inf. Samples (Filter No. 4).

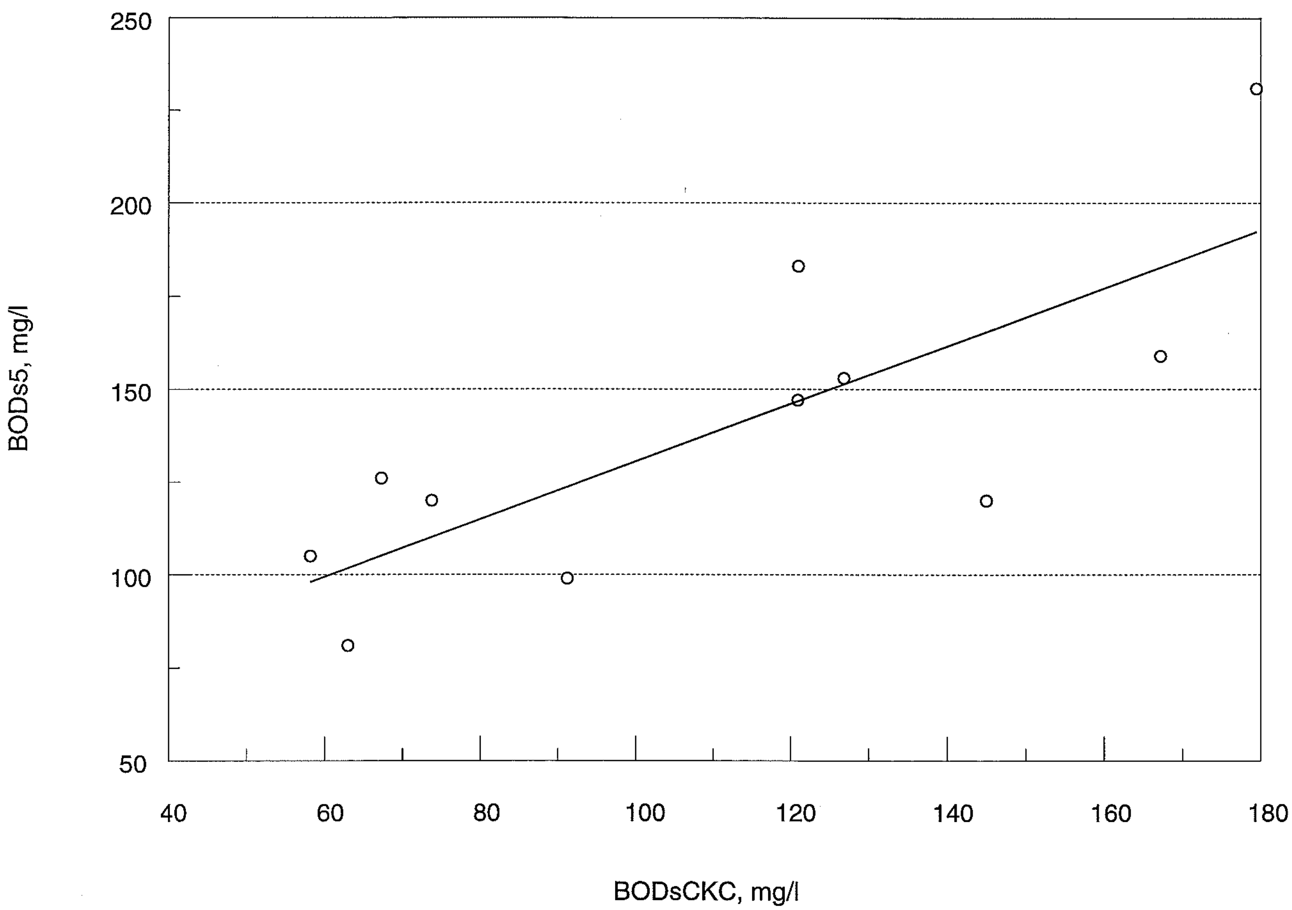
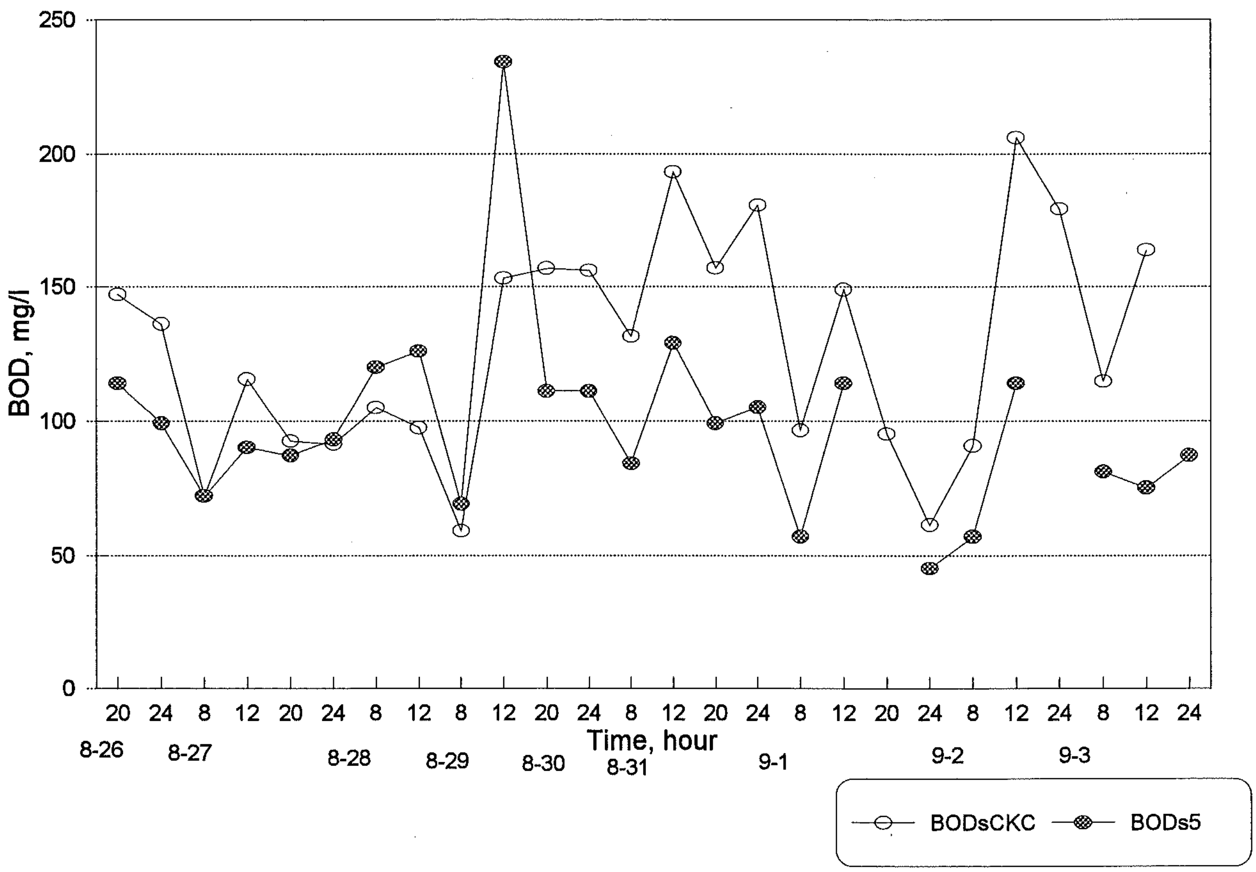


Figure 4.5a. Time Series for CKC Lab and BOD5 Data Using Filtered Primary Influent Samples (Filter No. 1).



NOTE:

1. CKC instrument in in the Lab.

Figure 4.5b. Relationship between CKC Lab and BOD5 Data for Filtered Primary Inf. Samples (Filter No. 1).

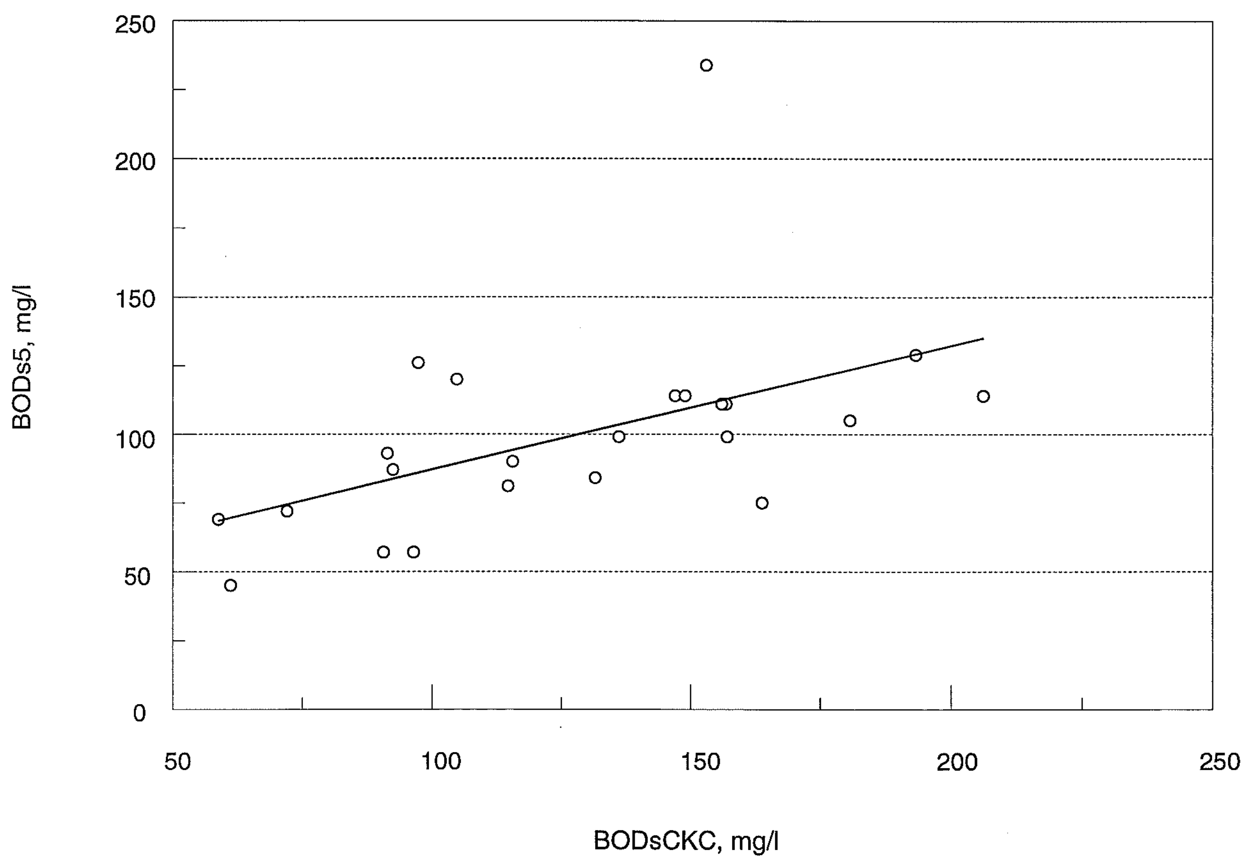
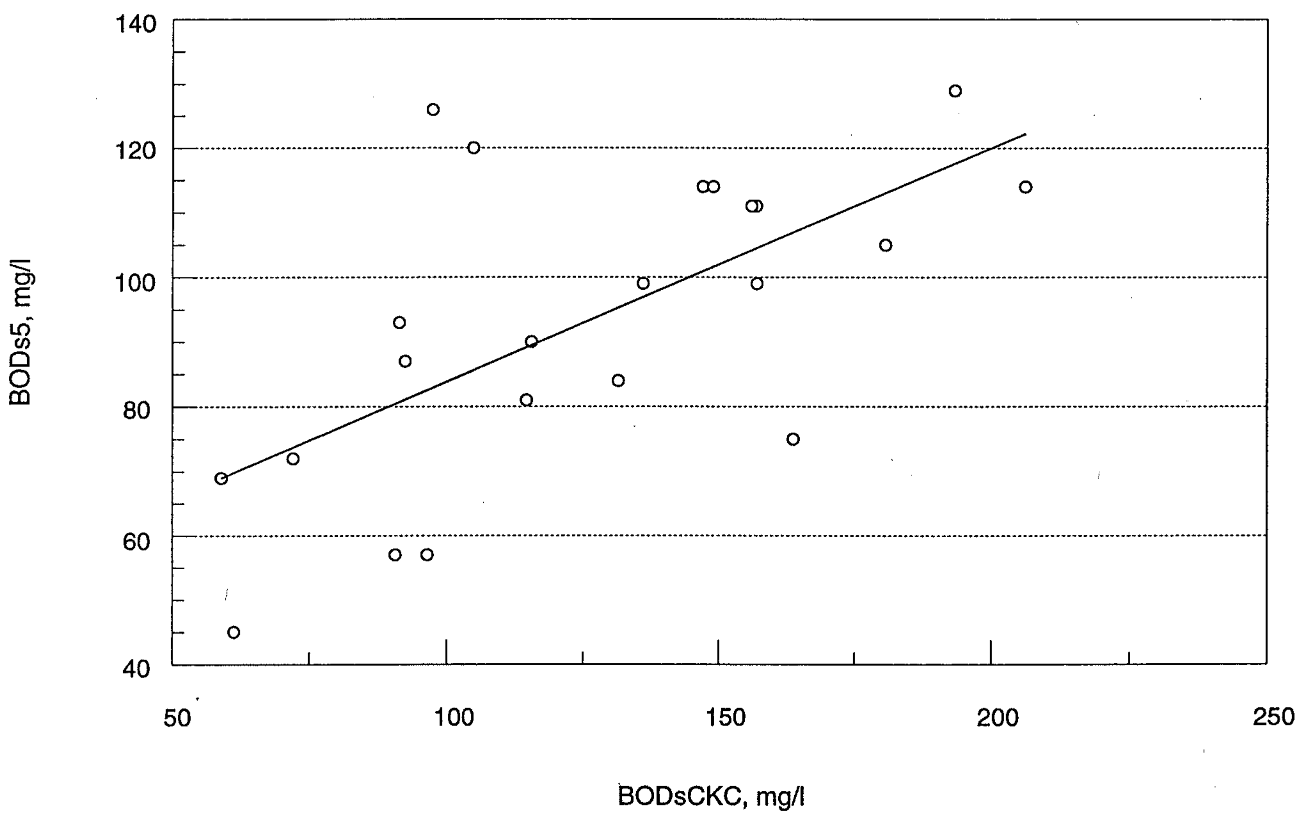


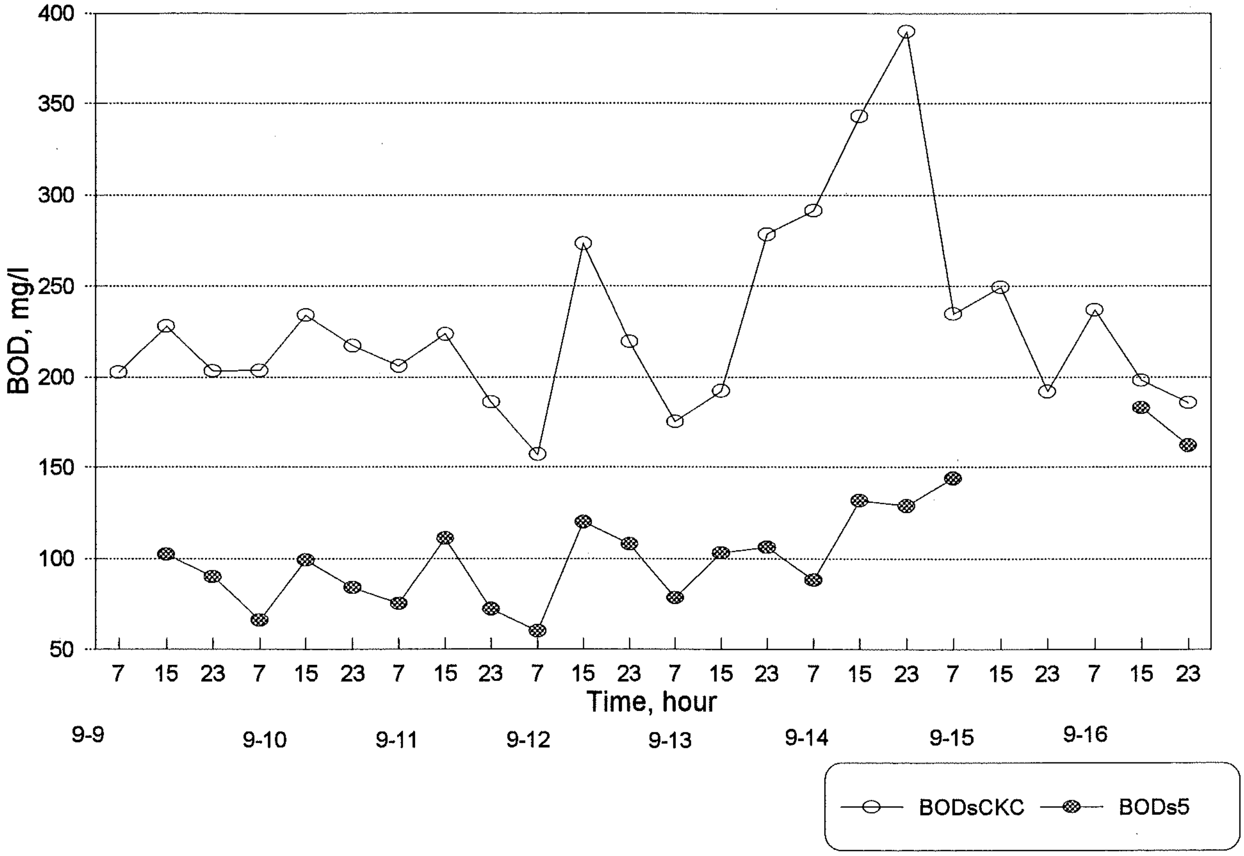
Figure 4.5c. Relationship between CKC Lab and BOD5 Data for Filtered Primary Inf. Samples (Filter No. 1).



NOTE:

1. **This graph is similar to that of Figure 4.5b, but without suspicious data points (See Table 4.1).**

Figure 4.6a. Time Series for CKC Lab and BOD5 Data Using Filtered Primary Effluent Samples (Filter No. .45).



NOTE:

1. CKC instrument in the Lab.

Figure 4.6b. Relationship between CKC Lab and BOD5 Data for Filtered Primary Eff. Samples (Filter No. .45).

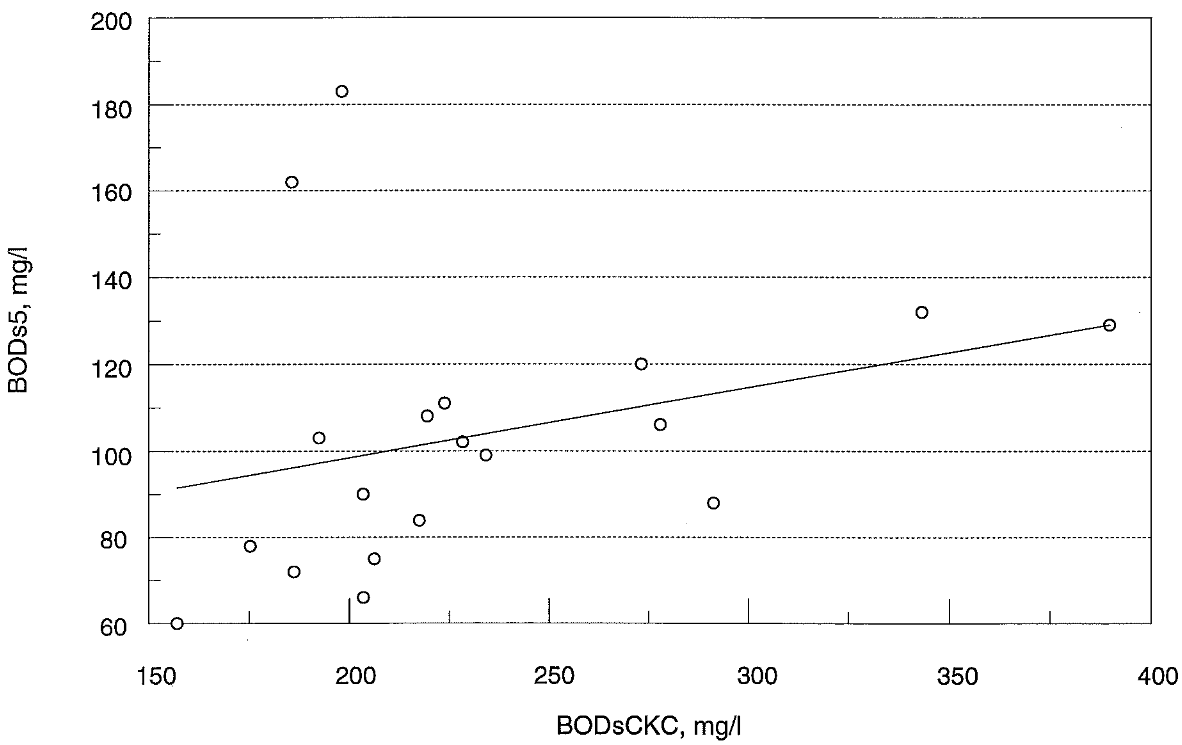
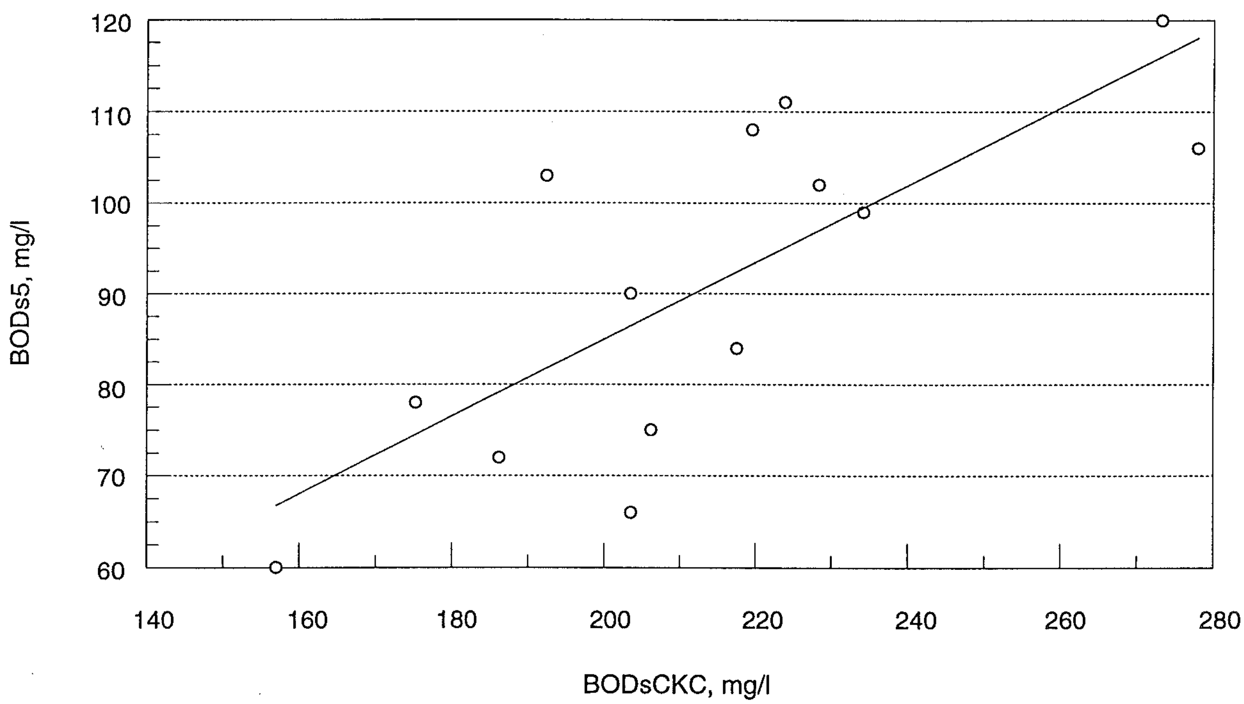


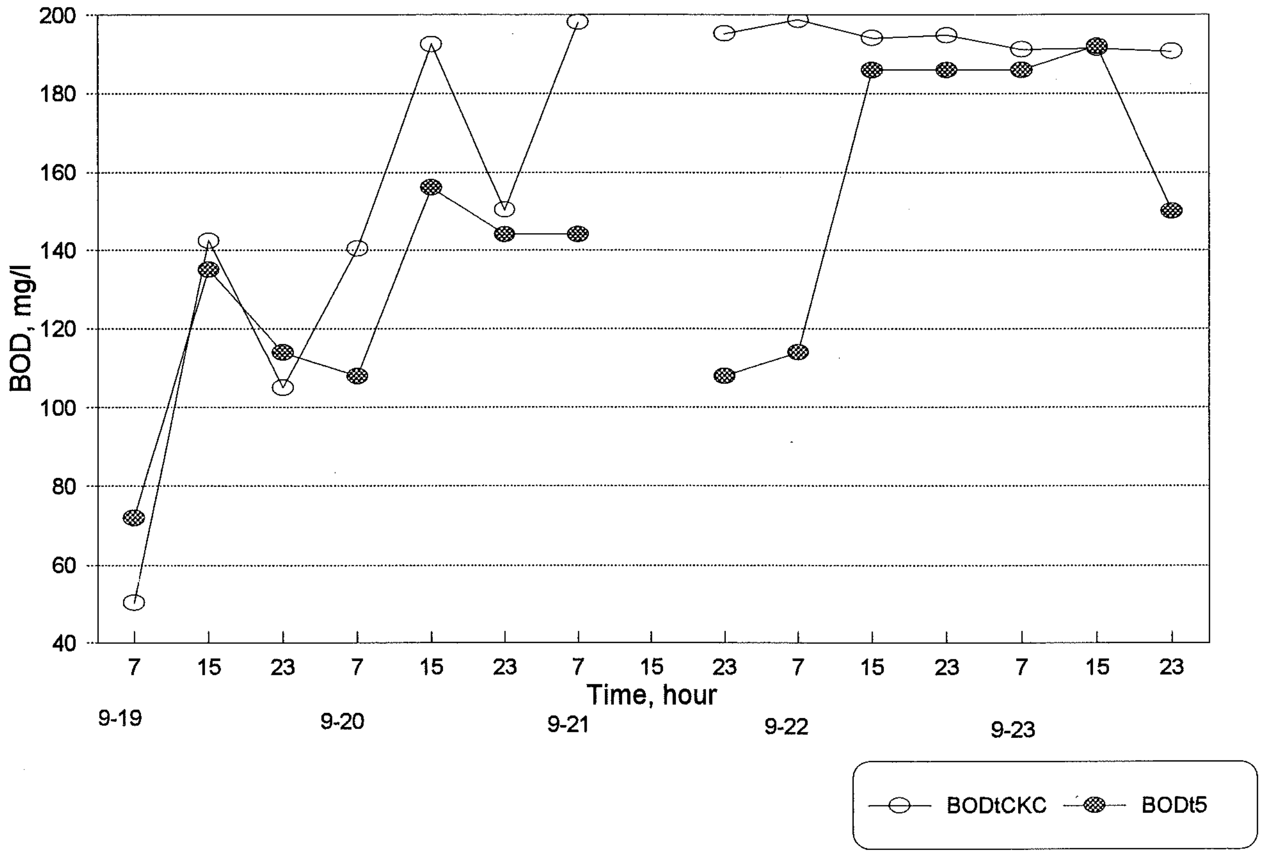
Figure 4.6c. Relationship between CKC Lab and BOD5 Data for Filtered Primary Eff. Samples (Filter No. .45).



NOTE:

1. This graph is similar to that of Figure 4.6b, but without suspicious data points (See Table 4.1).

Figure 4.7a. Time Series for CKC Lab and BOD5 Data Using Filtered Primary Effluent Samples (No Filter)



NOTE:

1. CKC instrument in the Lab.

Figure 4.7b. Relationship between CKC Lab and BOD5 Data for Primary Eff. Samples (No Filter).

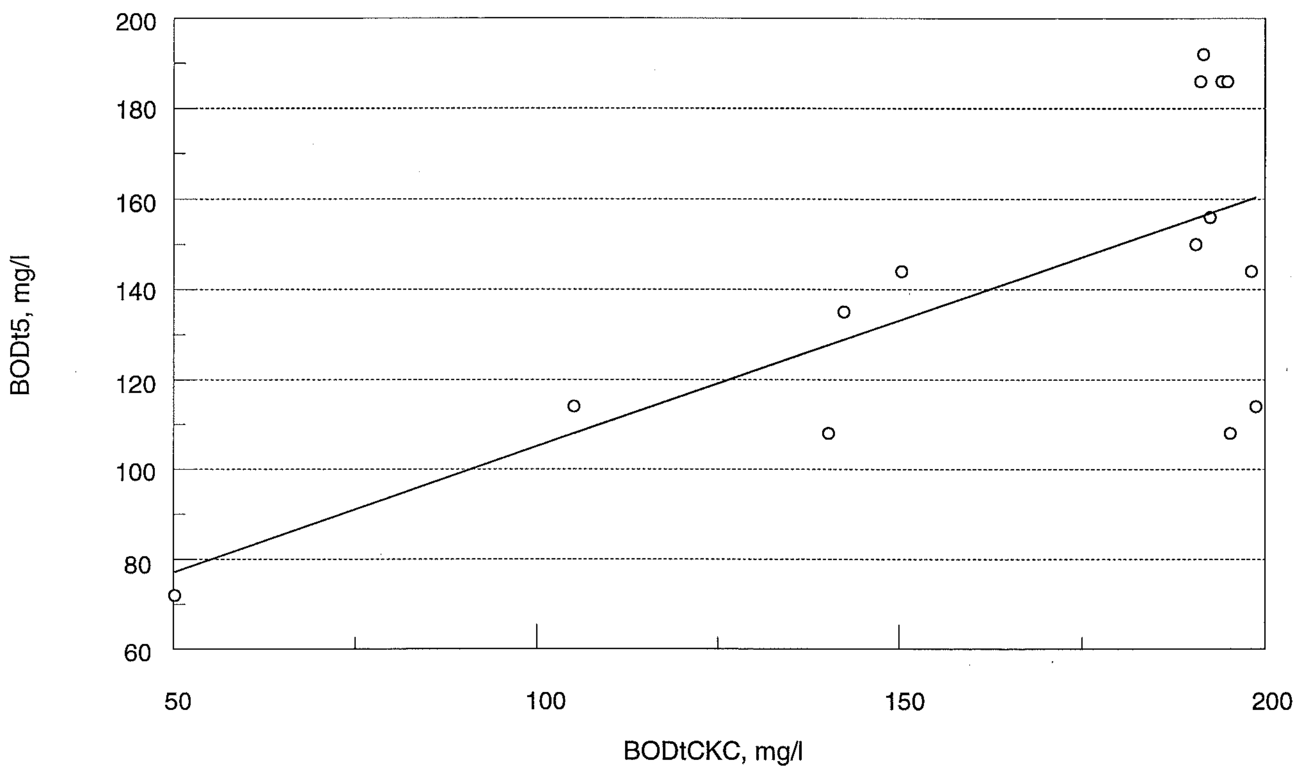
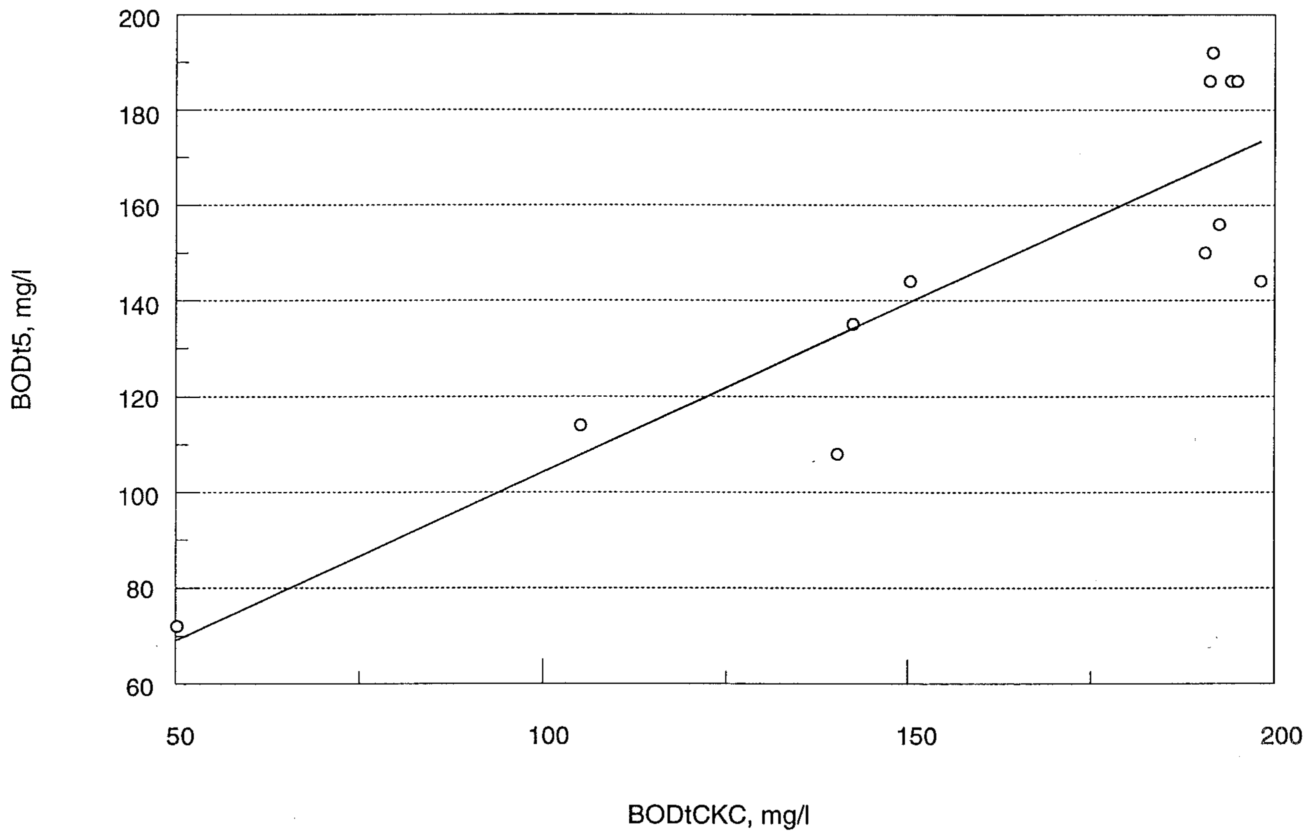


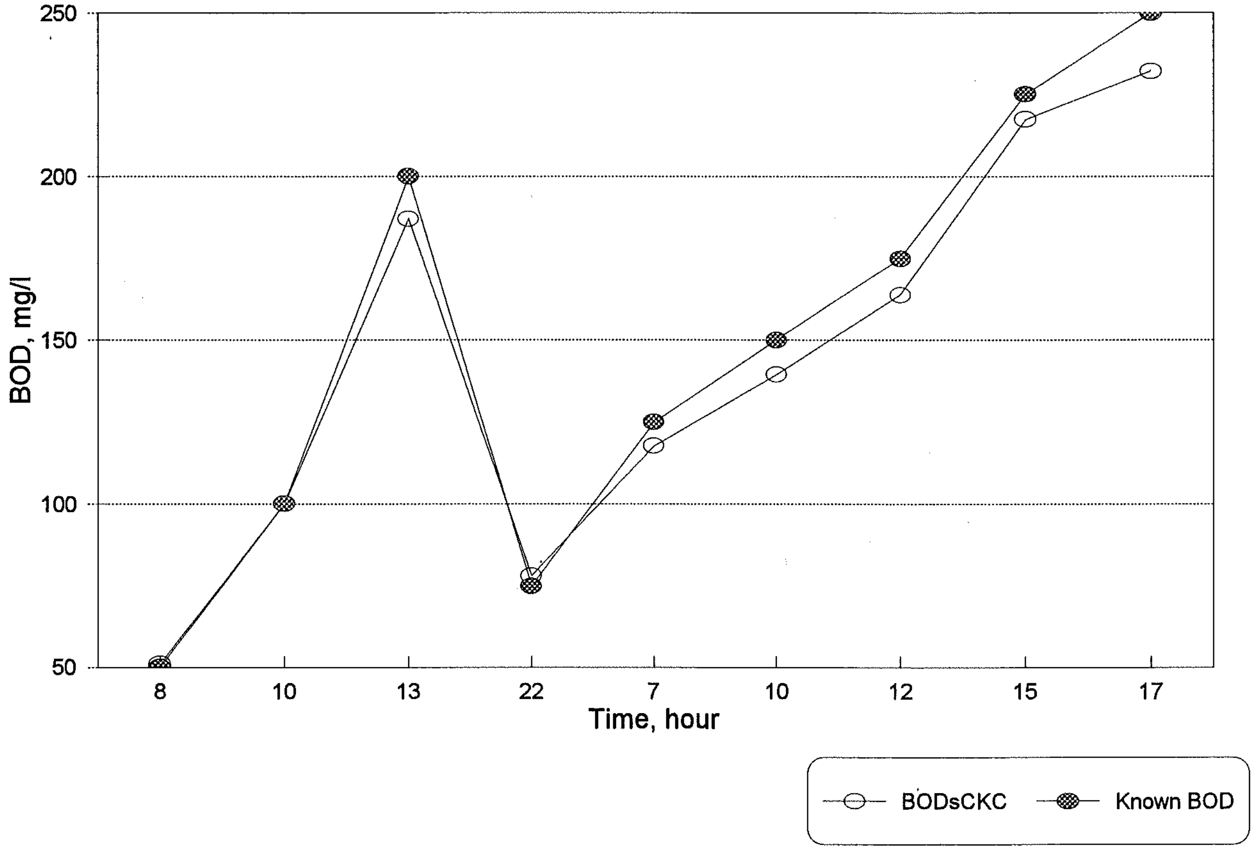
Figure 4.7c. Relationship between CKC Lab and BOD5 Data for Primary Eff. Samples (No Filter).



NOTE:

1. This graph is similar to that of Figure 4.7b, but without suspicious data points (See Table 4.1).

Figure 4.8a. Time Series for CKC Lab and BOD5 Data Using Solutions with Known BOD Concentrations.



NOTE:

1. CKC instrument in the Lab.

Figure 4.8b. Relationship between CKC Lab and Solution with Known Concentration Data.

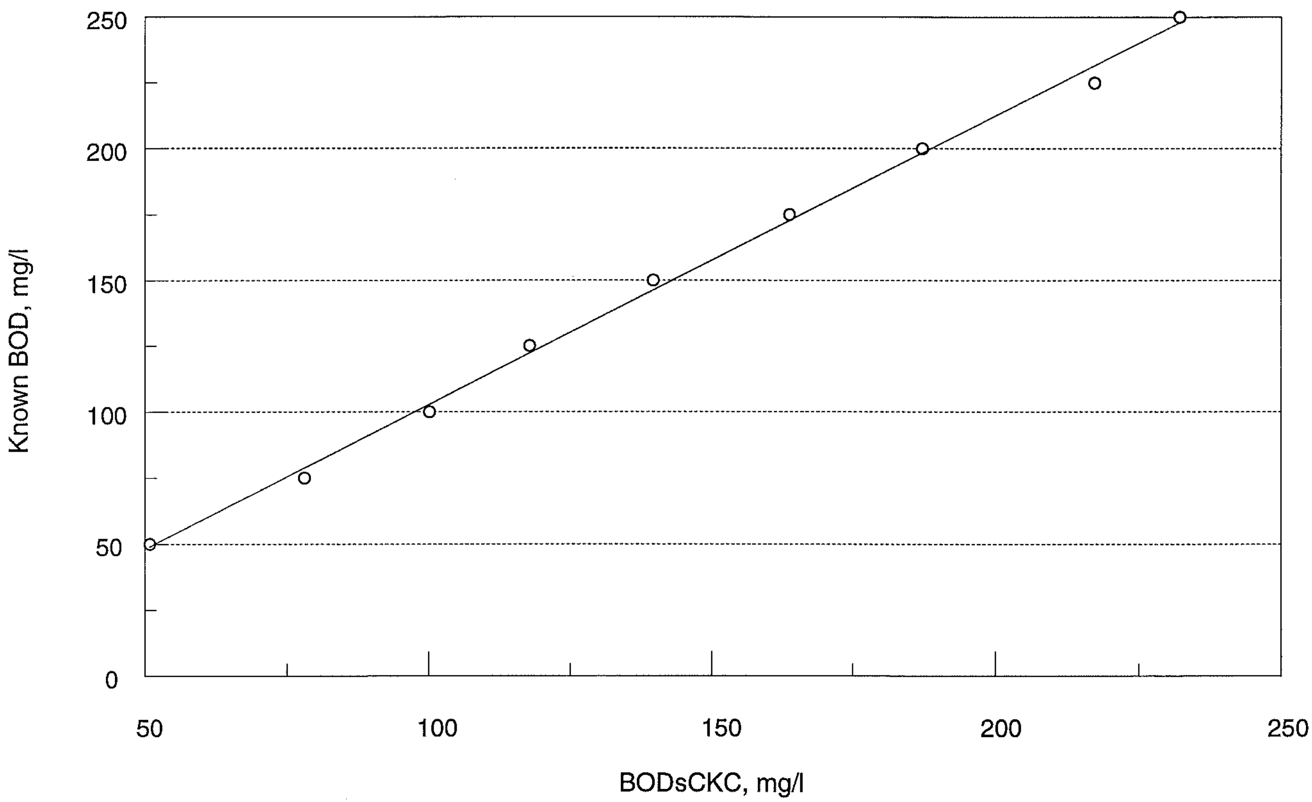


Table 4.1 Summary of Correlation Analysis Between BODCKC and BOD5 for All Cases in the Laboratory.

SAMPLE		PERIOD	FILTER	ALL DATA		GOOD DATA	
Source	Type	days	No.	No.	CORR	No.	CORR
Pri. Eff	grab	5	na	14	0.681	12	0.882
Pri Eff	grab	3	4	13	0.853	13	0.853
Pri Inf	grab	6	4	11	0.780	11	0.780
Pri Inf	grab	9	1	23	0.450	22	0.639
Pri Eff	grab	8	.45	19	0.300	14	0.764
Known Conc	na	na	na	9	0.999	9	0.999

NOTATIONS:

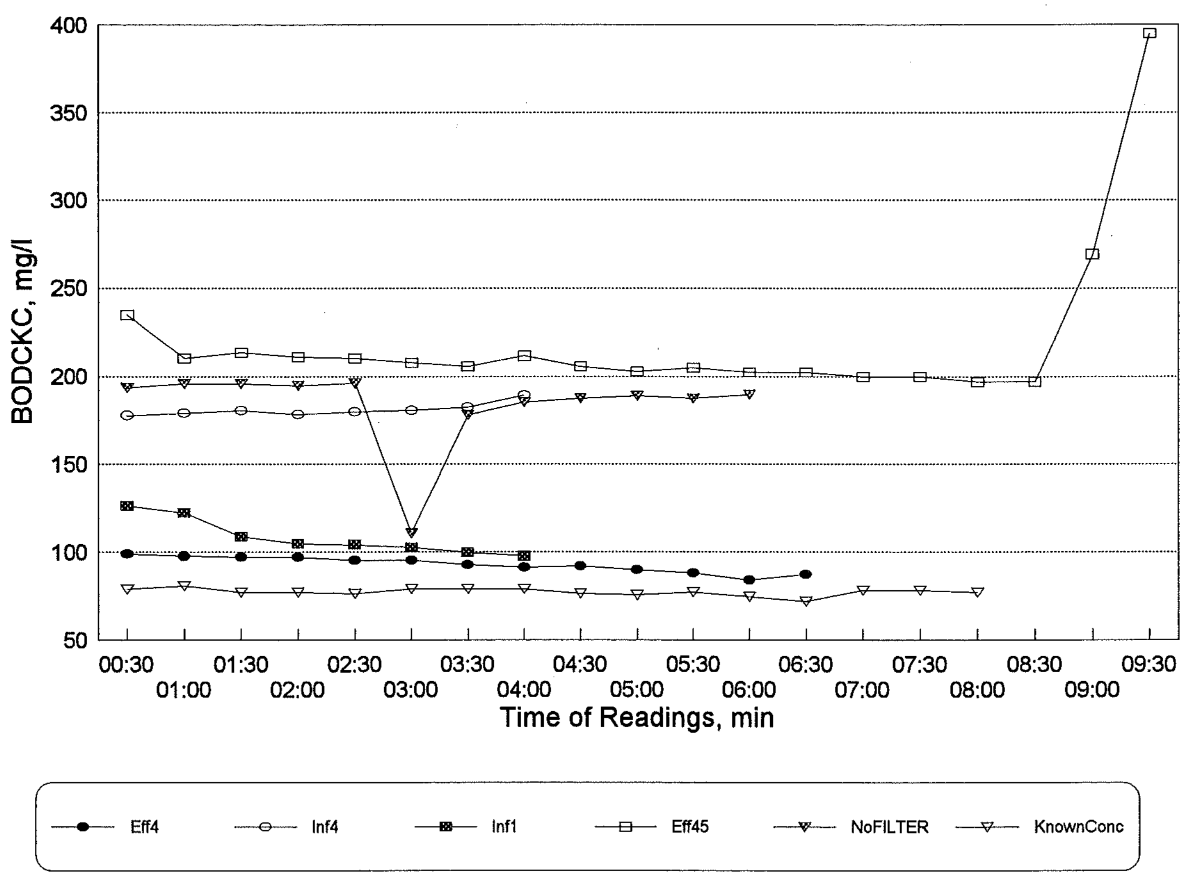
CORR: Correlation Coefficient
Conc: BOD Concentration
na: not applicable

NOTE:

1. CKC instrument in the Lab.

Since each sample of wastewater was tested repeatedly, Figure 4.9 presents representative plots of actual sample series. This time series plot provides more information than would be obtained by calculating standard deviations for the averages, since it shows whether systematic trends or random noise are causing the deviations. Evidently, the results are generally stable, with small random fluctuations and only a slight tendency to drift, perhaps because there was some settling of fine particles or fermentation occurring during test repetitions lasting several hours. The few gross deviations are attributed to mistakes.

Figure 4.9 Stability of CKC Lab Data Readings.

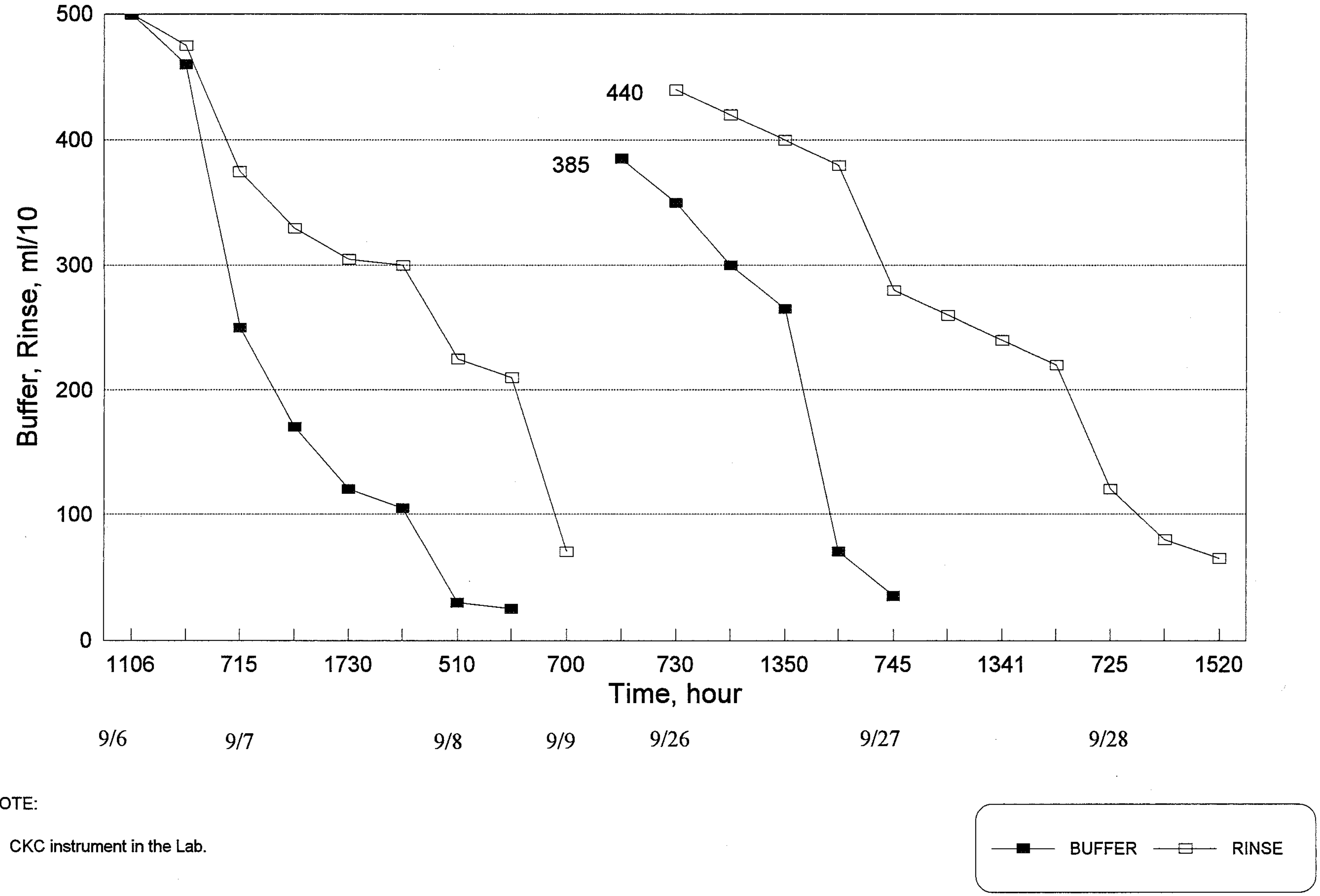


NOTE:

1. CKC instrument in the Lab.

Consumption of rinse, buffer, and standard solutions is depicted in Figures 10a and 10b. The reader is cautioned that in these plots the horizontal axis is not uniform, but has a tick mark for each data point, and the data points were taken at irregularly spaced times. Note also that the scale for the rinse and buffer solutions in Figure 10a is ten times the scale for the plot of the consumption of standard solutions in Figure 10b. This is as would be expected, since the standards are used only briefly during each measurement cycle. Evidently, supply bottles holding a few liters of buffer and rinse, and less than a liter of each of the standard, are adequate for several days of operation.

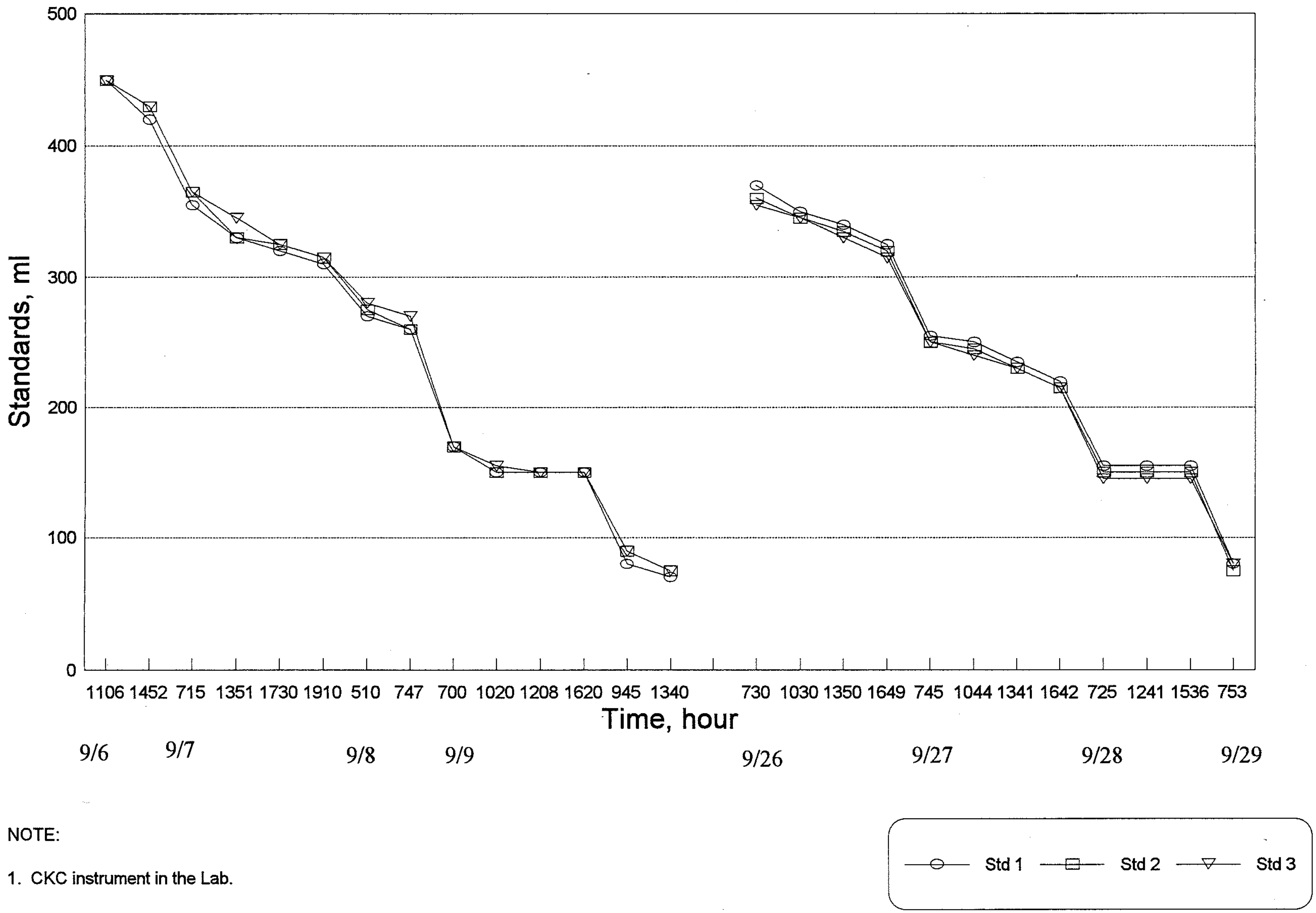
Figure 10a. Consumption of Buffer and Rinse by CKC Instrument.



NOTE:

1. CKC instrument in the Lab.

Figure 10b. Consumption of Standard Solutions by CKC Instrument.



NOTE:

1. CKC instrument in the Lab.

4.3 FURTHER INVESTIGATION

Much additional work would be needed to use this technology for monitoring BOD in wastewater applications. The excellent correlations between the instrument readings and conventional five day BOD measurements provide a basis for continuing with this work if such efforts are preferable, for technical or economic reasons, to using one of the other methods of measuring BOD that is incorporated into instruments from other manufacturers. Thus, the following suggestions for additional work assume that this justification is present. Several points, mentioned in Section 4.2, should be cleared up:

a. The anomalous total BOD_5 values recorded for filter No. .45;

b. Filter 1 and filter No. .45 should be used on both primary influent and primary effluent, as was done with filter No. 4 to get fully comparable sets of measurements.

Since the eventual goal is to develop technology for monitoring BOD of primary influent, to allow plant response to changing BOD loadings and to have a system that minimizes operator maintenance and surveillance, several further questions and issues must be resolved:

a. What is the mean time to clog for primary influent flowing through different sizes of filters?

b. What is the relationship between instrument readings on filtered primary influent and BODs of unfiltered primary influent?

c. For filters of different sizes, can regular cleaning of the intake tube with NaOCl prevent cloggings?

d. If so, what is the minimum cleaning frequency?

e. Can ultrasonic cleaning prevent clogging?

f. If so, is it preferable to using NaOCl?

g. If, the plastic intake tube were replaced by copper, would this be more resistant to clogging?

h. What is the biosensor's sensitivity to toxins, commonly found in the wastewater stream, such as cyanide and various heavy metals?

4.4 DEVELOPMENT FOR FIELD USE

The questions to be investigated in the previous section are to provide information to guide modifying CKC BOD instruments for field use. Since the company offers the model BOD-2200 for field use in other industries, it is likely that this model will be adapted for wastewater application. The chief obstacles to field use identified in this study are:

a. Intake tube clogging by wastewater solids;
b. Malfunction of the instrument at temperatures encountered during the summer;
c. Biosensor vulnerability to toxins.

Several ways to prevent clogging are to be evaluated during the work discussed in Section 4.3. This would allow selection among filtering, chemical disinfection, ultrasonic cleaning, and fouling resistant pipe as ways to prevent clogging. Additional modifications for field use should include:

a. Modification of microprocessor programming to detect a failure of sensor response resulting from toxicity;
b. Improvement of hydraulics such as pumps, pipes and valves, etc.;
c. Incorporation of provisions for cooling the cabinet of the instrument.

If the plastic intake tubes were replaced with copper, this might simultaneously provide stronger hydraulics and resistance to fouling. These modifications are likely to raise the costs of the instrument, but they should be useful considering the advantages of quick BOD measurements.

CHAPTER 5

MANAGEMENT ISSUES

5.1 IMPORTANT FACTORS

When a technology is not merely well established but mandated in governmental regulations, compelling reasons must exist if it is to be replaced with a newer one. That is the case for replacing the five day BOD test with an instrument that provides results in a few minutes. Now that it is known that the BOD-2000 provides good enough results that using it can be technically justified in narrow terms, it is necessary to consider comprehensively the costs and advantages of integrating such instruments into plant operations.

Since a half hour measurement cycle is 240 times faster than a five day laboratory BOD test procedure, using the BOD-2000 or a comurable instrument provides capabilities that are not possible with the standard BOD_5 method, and therefore additional information is needed beyond a simple comparison of costs of particular ways of using one or the other.

In particular, using an instrument for process control needs to be assessed by estimating money saved because process upsets from BOD shock loadings are prevented. These costs are of two types: extra plant operation costs resulting from measures taken to recover from a process upset, and fines assessed by regulatory agencies for violation of effluent standards.

The analysis is further complicated because some BOD_5 testing will have to be continued in the near future, even if an instrument is installed. Current governmental regulations mandate this testing.

The NPDES Permit compliance for BOD_5 discharge requires monitoring of the plant final effluent based on the five day BOD_5 test of 24-hour composite samples. Results of these analyses are submitted to the RWQCB on a monthly basis. Thus, from a legal standpoint in the near future, results from a BOD analyzer will not be admissible for the NPDES Permit compliance. Since the correlation between instrument readings and BOD_5 is so good, it is reasonable to hope that the regulatory agencies will reconsider their policies to accept instrument monitoring of final effluent, but for now it is necessary to assume continued BOD_5 testing at the required rate.

The following sections first give estimates of the direct costs of current BOD_5 testing, and on-line BOD analyzer, and then discuss indirect costs of different ways of dealing with potentially upsetting fluctuations in influent quality.

5.2 COSTS OF CURRENT BOD_5 TESTING

As part of the NPDES Permit requirements, the LAGWRP, TWRP and TITP plants collect and analyze daily samples for BOD_5 determination. LAGWRP conducts two daily sampling and lab analyses (one from the raw influent and the other from the final effluent), TWRP a total of five daily samples (one from the raw influent, one from the primary effluent, two from the secondary effluent and one from the tertiary effluent), and TITP three daily samples (one each from the primary influent and effluent, and one from the secondary effluent). Except for the raw influent sample from TWRP, the rest are 24-hour composite samples obtained from automatic samplers at the sampling sites that collect samples at 2-hour intervals. Raw influent samples from the TWRP are grab samples collected by the shift operator every two hours and composite in the lab.

No additional BOD_5 analyses are performed for process requirements, except on occasions when process upset occurs that could be traced to BOD shock loading. Such cases are infrequent. Several occurred in the TITP plant during 1992 and 1993, but the plant has not experienced similar problems since 1994. The potential for BOD shock loading remains because of industrial waste discharges.

Laboratory analyses are performed by the EMD laboratory staff, with each plant maintaining its own satellite analytical laboratory. The average cost of performing a BOD_5 analysis is estimated at $20 per sample. This includes both the lab supplies used and the labor expended from sample preparation to final result. A typical BOD_5 analysis requires 0.1 man-hour of chemist time and 0.05 man-hours of supervision by a Senior Chemist. The annual cost of BOD_5 analyses for LAGWRP is $14,600, for TWRP $36,500 and for TITP $21,900.

5.3 COSTS OF AN ONLINE BOD ANALYZER

The cost associated with using an on-line BOD analyzer would include equipment acquisition, installation, operation and maintenance. A typical BOD on-line analyzer, such as the Nissin BOD-2000, could cost as much as $30,000. Installation would involve plumbing and electrical connections at each site. The availability of these utilities at the site would considerably reduce the corresponding cost. Operation and maintenance of the equipment would involve regular visit to the monitoring station to ensure that the equipment is functioning properly. Other activities that require man-hours are replenishing the rinsing water, buffer and standard solutions, which are all parts of the machine operational requirements. Some small tubes also need to either be periodically purged or replaced because of clogging from solids accumulation, a problem that affects the accuracy of BOD measurements. Parts replacement also involves replacing the microbial membrane every month. Table 5.1 presents a list of maintenance requirements that need to be attended to. These items are recommended by the equipment manufacturer for the equipment to function accurately. Time needed to perform the maintenance activities ranges from a mere 5 minutes to as long as 45 minutes, with an average frequency of two times a week, except for replacing the microbial membrane and flow cell cleaning, which may be done on a monthly basis.

The following summarizes the cost associated with the installation and operation of an on-line BOD analyzer:

• Equipment acquisition (includes shipping & handling and sales tax)	$30,000
• Installation (includes labor and materials)	2,000
TOTAL	$32,000

Annual operation and maintenance cost consisting of:

• Chemicals	$ 350
• Parts replacement	1,200
• Labor	1,650
TOTAL	$ 3,200

Assuming a 10-year life cycle for the instrument with zero salvage value, and an annual inflation rate of 4%, the above expenditures translate to an annualized cost of $7,200 per monitoring station.

5.4 COSTS OF A PROCESS UPSET

When a process upset occurs, a large amount of extra work must be done to deal with the situation, incurring extra costs.

a. Regulatory agencies must be notified, usually by telephone, with confirming letters, subsequently written and mailed. This imposes a small increase in office expenses.

b. Analytical work at the plant laboratory must be stepped up to monitor the process condition in much finer detail than is done under normal circumstances. This increases costs both for laboratory personnel and supplies.

c. Experts must review the laboratory results to determine modifications of plant operations to reverse the upset.

d. The changes in plant operation usually impose increased energy costs for additional aeration or pumping of activated sludge or wastewater, and may also require costs for additional chemicals or inoculation of tanks with new cultures.

e. Other costs might also be incurred.

A typical process upset takes three to four weeks to correct. Thus the actual costs to the City of continuing the established BOD_5 tests is the cost of the testing plus the costs of the expected number of process upsets. This must be compared with the costs of using BOD instrument, continuing the legally required minimum of BOD_5 testing and the costs of adapting plant operation at the first warning of conditions that could lead to a process upset. Further costs may occur that are not directly charged to the Bureau: harm to wildlife, contamination of beaches, delayed harm to humans or animals from toxins that accumulate in the food chain, etc. These costs are the motivation for fines for failure to comply with NPDES regulations. Computing probable fine for pollution releases during a process upset further tips the scales toward using BOD monitoring instruments.

CHAPTER 6

CONCLUSIONS AND RECOMMENDATIONS

6.1 CONCLUSIONS

The overall conclusion is that the BOD-2000 can produce good results for wastewater BOD hundreds of times faster than the standard BOD_5 test, and therefore shows promise for use in treatment plant process control, to prevent process upsets. The instrument might be used now in this way if it were kept in a temperature controlled laboratory and used to test filtered samples of primary influent every few hours. This could be done if establishing such process control were sufficiently urgent. Alternatively, a number of possible modifications have been identified that could be applied to field model BOD-2200 to obtain a system with better durability, and less requirement for labor. Specific conclusions are:

a. Field testing confirms the manufacturer's recommendation that the instrument not be used at high temperatures (above 35-40 degrees C);

b. Clogging prevents reliable operation with unfiltered wastewater samples;

c. Under controlled laboratory conditions, correlation between BOD-2000 reading and standard BOD5 tests is excellent;

d. Repetition of BOD-2000 measurements on the same sample yields stable results, so that little repletion is likely to be necessary in future use;

e. Field application experienced much more operational and maintenance problems than lab;

f. Additional modifications need to be done on BOD-2000 before it can be used reliably and with greater accuracy in the field.

6.2 RECOMMENDATIONS

The recommendations are specific responses to the conclusions from the present study:

a. Additional testing to determine the best way to prevent clogging in laboratory use;

b. Testing to determine the possibility of using the instrument to detect toxic events, such as industrial discharges of cyanide or heavy metals;

c. Investigations of possible modifications to allow more automated use;

d. A more comprehensive economic analysis to assess the value of using the present instrument in the laboratory to analyze influent samples collected a few times a day for early detection of toxic events and shock loadings.

APPENDIX I. DATABASE

A. FIELD DATA

Appendix Table 1a presents the data chronologically that was obtained by the instrument during operation at TITP from from April to July 1994. A subset of this data, that has corresponding BOD_5 data, is shown in Appendix Table 1b.

APPENDIX TABLE 1a. CKC FIELD DATA: BODCKC WITH SOME CORRESPONDING BOD5 DATA.

			BODCKC (mg/l)				BOD5 (mg/l)	
Date		Time	Time Series	Daily Ave	Date	Time	5ml	10ml
4/19/94	PM							
		638	4					
		708	1.8					
		738	1.8					
		808	1.9					
		838	1.8					
		908	1.6					
		938	1.7					
		1008	2.4					
		1038	2.6					
		1108	2.5					
		1138	1.8					
				2.17				
4/20/94	AM							
		1208	2					
		1238	1.9					
		108	2.4					
		138	1.8					
		208	2.2					
		238	2.9					
		308	2					
		338	2.8					
		408	2.3					
		838	3.1					
		938	2.5					
		1008	2.6					
		1038	2.3					
		1108	2.3					
		1138	2.7					
	PM							
		1208	3					
		1238	2.7					
		108	2.9					
		138	3					
		637	1.7					
		707	1.4					
		737	1.6					
		807	1.3					
		837	1.6					
		907	1.6					
		937	1.4					
		1007	1.9					
		1037	2.3					
		1107	1.4					
		1137	1.6					
				2.25				

4/21/94				
		1207	2	
		1237	1.5	
		107	1.6	
		137	1.6	
		207	1.9	
		237	1.5	
		307	1.7	
		337	1.7	
		407	2.3	
				1.76
4/22/94	AM			
		737	5.4	
		900	4.7	
		1037	1.2	
		1144	1.3	
	PM			
		1251	5.1	
		1118	1	
				3.12
4/23/94	AM			
		1218	0.8	
		118	1.5	
		218	1.2	
		318	1.3	
		418	1	
		518	1.3	
		618	1.2	
		718	1.6	
		818	1.6	
		918	1.5	
		1018	1.6	
		1118	2	
	PM			
		1218	2	
		118	2.1	
		218	2.5	
		318	2.5	
		418	2.5	
		518	2.7	
		618	2.9	
		718	2.7	
		818	3.2	
		918	3.2	
		1018	3.2	
		1118	3.3	
				2.06
4/24/94	AM			
		1218	3.6	
		118	4	
		218	5	
		318	7.7	
		418	3.9	

		518	3.9	
		618	3.9	
		718	3.9	
		818	4.1	
		918	4.1	
		1018	3.8	
		1118	4.4	
	PM			
		1218	4.1	
		118	4.1	
		218	4.2	
		318	4	
		418	3.9	
		518	3.9	
		618	4	
		718	4.1	
		818	3.7	
		918	3.8	
		1018	4.5	
		1118	4.2	
				4.20
4/25/94	AM			
		1218	4.1	
		118	4.1	
		218	4.1	
		318	3.9	
		418	3.9	
		518	4.7	
		618	4.2	
		718	2.7	
	PM			
		1248	2.8	
		148	1.3	
		248	1.1	
		448	1.2	
		618	1.4	
		718	1.2	
		818	1.6	
		918	1.8	
		1018	2	
		1118	1.6	
				2.65
4/26/94	AM			
		1218	1.8	
		118	1.4	
		218	1.9	
		318	1.6	
		418	1.7	
		648	1.8	
		748	2	
		848	2.1	
		1018	2	
		1118	1.8	
	PM			
		553	93.8	

		653	75.1	
		753	97.5	
		853	96.1	
		953	86.2	
		1053	115.9	
		1153	117.8	
				41.21
4/27/94	AM			
		1153	117.8	
		1253	121.8	
		153	98.9	
		253	106.8	
		353	103.2	
		453	11.5	
		553	118.3	
		653	118.2	
		923	99.6	
		1023	97.7	
	PM	1123		
			104.4	
		1223	105.3	
		123	102	
		223	107.6	
		323	107.6	
		423	102.4	
		523	104.2	
		623	103.9	
		723	115.4	
		823	116.3	
		923	114	
		1023	127.1	
		1123	130	
				105.83
4/28/94	AM			
		1223	128.2	
		123	136.3	
		223	137.6	
		323	135.4	
		423	8.2	
		523	5.2	
		623	5.1	
		723	4.8	
		823	4.7	
		923	156.3	
		1023	118.1	
	PM	1123	123.1	
		1223	110.1	
		123	71.8	
		223	59	
		323	45.5	
		423	41.9	
		523	387	
		623	29.3	

		723	24.4	
		823	25.3	
		923	24.3	
		1023	24.1	
		1123	24	
				76.24
4/29/94	AM			
		1223	25.2	
		123	27.6	
		223	32.2	
		323	8.1	
		423	9	
		523	8.3	
		623	7.8	
		723	6.7	
		823	131.6	
		923	140.8	
		1023	122	
	PM	1123	127.5	
		1223	138.7	
		123	128.5	
		253	117.7	
		353	153.6	
		453	155.3	
		553	112.7	
		653	87.1	
		753	82.4	
		853	75.4	
		953	83.7	
		1053	80.7	
		1153	79.9	
				80.94
4/30/94	AM			
		1253	80.3	
		153	76.5	
		253	75.1	
		353	74.9	
		453	71.1	
		553	65.7	
		653	63.8	
		753	61.1	
		853	60.7	
		953	63.7	
		1053	64.3	
		1153	57.2	
	PM			
		1253	52.1	
		153	46.8	
		253	41	
		353	41	
		453	36.2	
		553	21.9	
		653	20.2	

		753	20.6	
		853	18.9	
		953	18.1	
		1053	18.2	
		1153	17.6	
				48.63
5/1/94	AM			
		1253	17.3	
		153	17	
		253	16.7	
		353	16.4	
		453	16	
		553	15.3	
		653	15.4	
		753	15.8	
		853	15.8	
		953	17.5	
		1053	15.4	
		1153	15.1	
	PM			
		1253	15.6	
		153	13.1	
		253	12.9	
		353	13.1	
		453	13.4	
		553	9.7	
		653	8.6	
		753	9.4	
		853	8.3	
		953	8.5	
		1053	8.5	
		1153	8	
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5/2/94	AM			
		1253	7.3	
		153	8.2	
		253	8.3	
		353	7.2	
		453	8	
		553	6	
		653	6	
		753	7	
		853	6.2	
		953	8.6	
	PM			
		3	71.6	
		4	100.5	
		5	121.6	
		6	112.4	
		7	110	
		8	104.2	
		9	115.3	
		10	108.6	
		11	96.8	

				53.36
5/3/94	AM	1200	80.3	
		1	46.5	
		2	35.5	
		3	34.7	
		4	29.5	
		5	23.5	
		6	19.5	
		7	7.5	
		8	6.3	
		9	5.8	
		1120	65.9	
	PM			
		1253	68.1	
		153	5.2	
		253	2.5	
		353	2	
		453	2	
		553	2.2	
		653	4.1	
		753	3	
		853	2.8	
		953	3.4	
		1053	2.2	
		1153	2.8	
				19.80
5/4/94	AM			
		1253	4.4	
		153	3.3	
		253	3.4	
		353	3.3	
		453	2.5	
		553	2.3	
		653	2.5	
		753	2.2	
		853	2.7	
		953	2.8	
		1053	3.6	
		1153	2.8	
	PM			
		1253	2.9	
		153	3.1	
		253	2.1	
		353	2.4	
		453	3.1	
		553	2.8	
		653	2.7	
		753	3	
		853	2.8	
		953	3.3	
		1053	3.5	
		1153	4.9	
				3.02

5/5/94	AM			
		1253	4.1	
		153	3.6	
		253	3	
		353	3.4	
		453	2.7	
		553	3.1	
		653	2.9	
		753	3.4	
		853	3.4	
		953	3.3	
		1053	4.3	
		1153	4.2	
	PM	1253	19.5	
		153	42	
		414	42.4	
		444	28.9	
		514	31.4	
				12.09
5/6/94	AM			
		938	31	
		1152	31	
	PM			
		223	85.7	
		330	30.6	
				44.58
5/9/94	AM			
		938	31	
	PM			
		223	85.7	
		330	30.6	
				49.10
5/10/94				
	PM			
		457	25	
		527	40.3	
		557	36.1	
		627	20.7	
		657	8.7	
		727	27.8	
		757	13	
		827	22.8	
		857	18.5	
		927	27.8	
		957	21.7	
		1027	36.1	

5/9/94	AM	7	21	108
		9	15	114
		11	15	162
	PM	1	21	222
5/10/94	AM			
		7		18
		9		42
		11		18
	PM			
		1		48

		1057	26.4	
		1127	30.6	
		1157	34.7	
				26.01
5/11/94				
	PM			
		1227	43.1	
		1257	26.4	
*		127	29.2	
		157	29.2	
		227	41.7	
		457	25	
		527	40.3	
		557	36.1	
		627	20.7	
		657	8.7	
		727	27.8	
		757	13	
		827	22.8	
		857	18.5	
		927	27.8	
		957	21.7	
		1027	36.1	
		1057	26.4	
		1127	30.6	
		1157	34.7	
				27.99
5/12/94	AM			
		1214	4.3	
		1244	3.9	
		114	3.5	
		144	3.8	
		214	4.2	
		244	3.6	
		314	3.8	
		344	3.5	
		414	3.6	
		444	3.5	
		514	4	
		544	3	
		614	2.8	
		644	2.8	
		714	3.4	
		744	3.2	
		814	3.1	
		844	3.2	
		914	8.1	
	PM			
		240	178.3	
		310	7.3	

5/11/94	AM			
		7		234
		9		138
		11		162
	PM			
		1		170
5/12/94	AM	7	9	132
		9	6	132
		11	12	186
	PM	1	9	258

		340	7.1						
		410	7.3						
		440	22						
		510	12.6						
		540	10.8						
		610	13.8						
		640	12.1						
		710	12.9						
		740	15.2						
		810	17.6						
		840	17.7						
		910	15.3						
		940	14						
		1010	12.2						
		1040	12.5						
		1110	10.3						
		1140	11.7						
				12.68					
5/13/94	AM	1210	10.8		5/13/94	AM			
		1240	11.6						
		110	11.7						
		140	11.2						
		210	9.7						
		240	9.1						
		310	8.6						
		340	7.7						
		410	7.3						
		440	6.3						
		510	5.9						
		540	5.8						
		610	5.6						
		640	6.2						
		710	8.6				7	12	138
		735	8						
		805	3.2						
		835	9.1						
		905	4.5				9	12	132
		935	2.4						
							11	3	204
	PM	1205	2.8						
		1235	2.7						
		105	11.6			PM	1	3	288
		135	6.7						
		205	7.3						
		235	7.7						
		305	8.1						
		335	8.1						
		405	9						
		435	8.5						
		505	9						
		535	8.2						
		605	8.1						
		635	7.6						
		705	7.7						

		735	8.2						
		805	7.6						
		835	8						
		905	7.6						
		935	7.7						
		1005	7.7						
		1035	7.3						
		1105	7.7						
		1135	7.7						
				7.63					
5/14/94	AM								
		1205	13.1		5/14/94	AM			
		1235	9.5						
		105	10.8						
		135	11.9						
		205	13.8						
		235	13.8						
		305	15.6						
		335	12.6						
		405	7.6						
		435	8						
		505	6.8						
		535	12.8						
		605	9.1						
		635	18.7						
		705	17.3				7	12	150
		735	19.1						
		805	7.1						
		835	8						
		905	6.6				9	9	132
		935	6.4						
		1005	8.4						
		1035	9.1						
		1105	7.9				11	9	216
		1135	14.3						
	PM	1205	9.3						
		1235	11.3						
		105	16.5				1	9	270
		135	3.7						
		205	0.6						
		235	3.9						
		305	3.5						
		335	2.7						
		405	0.9						
		435	879.2						
		505	7						
		535	22						
		605	38.8						
		635	22.3						
		705	11.7						
		735	14						
		805	13.1						
		835	3.9						
		905	2.8						
		935	2.6						

		1005	14.4						
		1035	3.4						
		1105	3						
		1135	3						
				28.37					
5/15/94	AM				5/15/94	AM			
		1205	9						
		1235	1.7						
		105	9.4						
		135	10.4						
		205	3.4						
		235	2.6						
		305	1.8						
		335	1.5						
		405	1.2						
		435	1.9						
		505	1.2						
		535	6.2						
		605	1.4						
		635	1.7						
		705	3.9				7	6	126
		735	1.4						
		805	3.2						
		835	2.6						
		905	8.9				9	6	114
		935	2.8						
		1005	4						
		1035	4.3						
		1105	2.4				11	15	186
		1135	16.8						
		1205	9.9						
		1235	4						
		105	9.5				1	6	306
		135	14.7						
		205	15.9						
		235	1770.8						
		305	35.6						
		335	22						
		405	11.1						
		435	13.9						
		505	566.7						
		535	8.8						
		605	12.5						
		635	14.4						
		705	13.4						
		735	2270.8						
		805	3.9						
		835	5.8						
		905	5						
		935	3.6						
		1005	4.9						
		1035	2.8						
		1105	4.4						
		1135	5.8						
				102.79					

5/16/94	AM				5/16/94	AM			
		1205	6.1						
		1235	4						
		105	3.7						
		135	2.1						
		205	4.9						
		235	9.9						
		305	10.4						
		335	6.1						
		405	2.4						
		435	3.6						
		505	4.3						
		535	2.8						
		605	4.1						
		635	3						
		705	10.3				7	6	120
		735	8.1						
		805	8.1						
		835	9						
		905	38.3				9	6	144
		935	11.3						
		1005	9.8						
		1035	4						
		1105	4.9				11	6	156
		1135	3.7						
	PM	1205	4.1						
		1235	10.7						
		105	4				1	6	216
		135	4.3						
		205	3.5						
		235	4.6						
		305	3.2						
		335	6.6						
		405	5.5						
		435	4.4						
		505	7.5						
		535	4						
		605	4						
		635	4.5						
		705	4004.2						
		735	6.1						
		805	4						
		835	4.4						
		905	5.9						
		935	3						
		1005	1						
		1035	1.5						
		1105	0.5						
		1135	0.4						
				89.10					
5/17/94	AM	1205	1		5/17/94	AM			
		1235	0.8						
		105	1.3						
		135	0.3						

		205	0.5						
		235	0.4						
		305	0.8						
		335	0.9						
		405	0.5						
		435	0.3						
		505	0.9						
		535	0.9						
		605	0.3						
		635	0.6						
		705	0.5				7	9.6	96
		813	108.3						
		1020	10.4						
							11		114
	PM	127	10.7						
				7.74					
5/18/94					5/18/94	AM	7	3.6	9.6
							9	2.4	120
							11	2.4	204
	PM	134	10						
				10.00					
5/19/94					5/19/94	AM	7	4.8	96
							9	1.2	96
							11	2.4	180
						PM	1	3.6	204
5/20/94	AM				5/20/94	AM	7	2.4	90
		911	30						
	PM	1218	6.8						
				18.40					
5/23/94	PM	225	57.5						
		325	16.7						
		425	25						
				33.07					
5/24/94	AM	832	16.7						
		1009	62.5						
				39.60					
5/25/94	AM	846	25						
		1053	62.5						
				43.75					
5/31/94	AM	915	109.3		5/31/94	AM			
		945	119.5						
		1015	141.5				10	99	unknown source
	PM	1247	89.6						
		117	61.1						
		147	62.8						
		217	21.3						
		247	14.1						
		317	22.3						
		347	54.4						

		417	61.4					
		447	67.8					
		517	32					
		547	89.3					
		617	78.5					
		647	24.6					
		717	11.9					
		747	11.7					
		817	13.5					
		847	11.5					
		917	30.5					
		947	14.1					
		1017	9.6					
		1047	7.6					
		1117	7.6					
		1147	5.5					
				45.12				
6/1/94	AM	1217	6.4		6/1/94			
		1247	6.1					
		117	5.9					
		147	5.7					
		217	6.1					
		247	5.9					
		317	5.9					
		347	5.7					
		417	5.7					
		447	5.9					
		517	5.9					
		547	6.1					
		617	6.1					
		647	6.1					
	PM	337	129.4					
		407	44.6					
		437	45.7					
		507	42.4					
		537	45.7					
		607	47.8					
		637	64.7					
		707	58.8					
		737	61.8					
		807	58.8					
		837	58.8					
		907	67.6					
		937	64.7					
		1007	64.7			AM	10	102
		1037	58.8					
		1107	61.8					
		1137	67.6					
				26.23				
6/2/94	AM	1207	64.7		6/2/94	AM		
		1237	64.7					
		107	67.6					
		137	67.6					
		207	61.8					

		237	67.6						
		307	67.6						
		337	64.7						
		407	67.6						
		437	61.8						
		507	161.8						
							7	138	168
		916	85.9				9	228	222
							10	117	
		1116	3.9				11	294	270
	PM	116	4				1	270	282
		407	55.7						
		437	23.8						
		507	6.5						
		537	6.5						
		607	6.7						
		637	6.2						
		707	6.3						
		737	5.6						
		807	6.3						
		837	19.8						
		907	6.7						
		937	6.5						
		1007	7.5						
		1037	7.1						
		1107	7.1						
		1137	15.1						
				36.82					
6/3/94	AM	1207	15.5		6/3/94	AM			
		1237	17.1						
		107	29.3						
		137	13.9						
		207	12.5						
		237	15.1						
		307	12.7						
		337	13.7						
		407	15.5						
		437	15.7						
		507	13.5						
		537	13.3						
		607	12.3						
							7	138	
		839	19.4						
		909	17.1				9	222	
		939	10.3						
		1009	13.2				10	117	
		1039	85.4						
		1109	87.5				11	252	
		1139	97.9						
	PM	1209	102.1						
		1239	168.8						
		109	106.3				1	258	
		139	110.4						
		209	150						
		239	160.4						

		309	172.9				
		339	195.8				
		409	216.7				
		439	237.5				
		509	262.5				
		539	262.5				
		609	252.1				
		639	247.9				
		709	243.8				
		739	235.4				
		809	227.1				
		839	222.9				
		909	202.1				
		939	204.2				
		1009	208.3				
		1039	10.3				
		1109	1.2				
		1139	0.6				
				107.56			
6/4/94	AM	1209	0.6				
		1239	0.9				
		109	2.4				
		139	0.6				
		209	0.3				
		239	0.6				
		309	0.6				
		339	0.9				
		409	0.9				
		439	1.2				
		509	0.6				
		539	0.6				
		609	0.9				
		639	0.6				
		709	2.1				
		739	1.2				
		809	0.6				
		839	0.9				
		909	1.2				
		939	1.2				
		1009	0.9		10	135	unknown source
		1039	1.2				
		1109	0.6				
		1139	0.9				
	PM	1209	1.8				
		1239	0.9				
		109	1.2				
		139	1.8				
		209	1.2				
		239	1.2				
		309	1.8				
		339	2.9				
		409	1.5				
		439	1.2				
		509	2.1				
		539	3.2				

		609	5.9					
		639	3.2					
		709	1.8					
		739	2.1					
		809	1.2					
		839	0.9					
		909	0.9					
		939	1.2					
		1009	1.8					
		1039	0.6					
		1109	1.8					
		1139	1.2					
				1.37				
6/5/94	AM	1209	0.9		6/5/94	AM		
		1239	0.3					
		109	1.5					
		139	0.6					
		209	0.9					
		239	0.6					
		309	0.9					
		339	1.2					
		409	0.6					
		439	0.9					
		509	1.2					
		539	0.9					
		609	0.9					
		639	1.2					
		709	0.9					
		739	1.8					
		809	0.6					
		839	1.2					
		909	0.9					
		939	0.9					
		1009	0.9				10	129
		1039	2.4					
		1109	0.6					
		1139	1.8					
	PM	1209	20					
		1239	23.8					
		109	13.5					
		139	8.5					
		209	6.2					
		239	1106.3					
		309	1.8					
		339	1.8					
		409	1.5					
		439	2.4					
		509	3.8					
		539	0.9					
		609	1.8					
		639	2.6					
		709	2.1					
		739	1.5					
		809	3.2					
		839	2.6					

		909	1.8					
		939	1.8					
		1009	1.2					
		1039	1.2					
		1109	0.6					
		1139	1.5					
				25.77				
6/6/94	AM	1209	1.2		6/6/94	AM		
		1239	0.6					
		109	0.9					
		139	0.9					
		209	0.9					
		239	1.2					
		309	0.6					
		339	0.9					
		409	0.6					
		439	0.6					
		509	1.2					
		539	0.6					
		609	0.6					
		639	0.9					
							7	162
							9	180
							10	111
							11	492
	PM	1253	100					
		123	76.9				1	174
		153	88.5					
		223	111.5					
		253	2069.2					
		323	150					
		353	188.5					
		423	196.2					
		453	300					
		523	203.8					
		553	203.8					
		623	226.9					
		653	238.5					
		723	250					
		753	253.8					
		823	242.3					
		853	246.2					
		923	242.3					
		953	242.3					
		1023	246.2					
		1053	246.2					
		1123	250					
		1153	261.5					
				179.63				
6/7/94	AM	1223	265.4					
		1253	261.5					
		123	269.2					
		153	276.9					
		223	253.8					

		253	269.2					
		323	242.3					
		353	257.7					
		423	261.5					
		453	257.7					
		523	265.4					
		553	261.5					
		623	265.4					
		653	273.1					
		723	273.1				7	90
		753	280.8					
		823	338.5					
		853	426.9				9	96
				277.77			10	138
6/8/94					6/8/94	AM	7	120
		853	99.6				9	102
		923	131.7					
		953	161.7				10	81
		1023	191.7					
		1053	203.3				11	96
		1123	245					
		1153	250					
	PM					PM	1	120
		225	54.7					
		255	45.8					
		325	57					
		355	57.4					
		425	58.9					
		636	230.9					
		706	232.1					
		736	255.6					
		806	264.2					
		836	264.2					
		906	266.7					
		936	255.6					
		1006	253.1					
		1036	255.6					
		1106	260.5					
		1136	249.4					
				188.90				
6/9/94	AM	1206	249.4		6/9/94			
		1236	243.2					
		106	228.4					
		136	217.3					
		206	188.9					
		236	207.4					
		306	155.6					
		336	149.4					
		406	119.8					
		436	116					
		506	97.2					
		536	95.5					
		606	85					
		636	82.1					

		706	77.2			AM	7	60
		736	163					
		806	196.3					
							9	84
							10	111
							11	96
	PM					PM	1	144
		525	280					
		555	316.7					
		625	503.3					
		655	620					
		725	716.7					
		755	740					
		825	793.3					
		855	843.3					
		925	850					
		955	883					
		1025	910					
		1055	920					
		1125	953.3					
		1155	963.3					
				418.21				
6/10/94	AM	1225	963.3		6/10/94			
		1255	990					
		125	1010					
		155	1040					
		225	1070					
		255	1103.3					
		325	1146.7					
		355	1190					
		425	1213.3					
		455	186.7					
		525	166.7					
		555	57.7					
		625	33.3					
		655	46.7				7	168
		725	57.7					
		755	46.7					
		825	36.7					
		855	54.1				9	162
		925	50.9					
		955	46.7				10	159
		1025	36.7					
		1055	36.7				11	162
		1125	16.7					
		1155	20					
		1225	20					
		1255	20				1	234
		125	1463.3					
		155	1703.3					
		403	112.7					
		433	97.8					
		503	93.1					
		533	147.6					
		603	103.2					

		633	99.7					
		703	93.1					
		733	50.3					
		803	50.5					
		918	163.1					
				390.48				
6/11/94	AM	955	168.3		6/11/94	AM	10	126
		1055	71.4					
				119.85				
6/12/94					6/12/94	AM	10	99
6/13/94	AM				6/13/94	AM	7	66
							9	72
							10	138
							11	114
	PM					PM	1	156
		340	67.6					
		517	66.7					
				67.15				
6/14/94					6/14/94	AM		
							7	108
							9	108
							10	117
							11	120
	PM					PM	1	204
		310	226.7					
		340	311.1					
		410	395.6					
		440	471.1					
		510	564.4					
		540	613.3					
		610	682.2					
		640	768.9					
		710	795.6					
		740	822.2					
		810	817.8					
		840	848.9					
		910	855.6					
		940	846.7					
		1010	822.2					
		1040	811.1					
		1110	824.4					
		1140	811.1					
				682.72				
6/15/94	AM	1210	842.2		6/15/94			
		1240	824.4					
		110	782.2					
		140	755.6					
		210	697.8					
		240	828.9					
		310	862.2					
		340	904.4					

		410	993.3					
		440	1071.1					
		510	1148.9					
		540	1213.3					
		610	1237.8					
		640	1251.1					
		710	1282.2			AM	7	84
		740	1293.3					
		810	1333.3					
		840	1360				9	84
							10	159
	PM	213	227					
		243	233.3					
		313	237.3					
		343	239.7					
		413	242.2					
		443	242.2					
		513	244.1					
		543	242.2					
		613	243.1					
		643	242.2					
		713	241.7					
		743	239.7					
		813	240.2					
		843	240.2					
		913	235.3					
		943	237.3					
		1013	235.8					
		1043	232.4					
		1113	234.8					
		1143	232.4					
				616.98				
6/16/94	AM	1213	233.8		6/16/94			
		1243	226					
		113	227.5					
		143	229.9					
		213	230.9					
		243	228.4					
		313	230.4					
		343	230.4					
		413	177.5					
		443	3.5					
		513	3.6					
		543	8.1					
		613	8.4					
		643	8.7			AM	7	150
		855	111.3				9	108
							10	159
							11	150
	PM	108	2812.5			PM	1	222
		138	2000					
		208	2000					
		416	350					
		446	98.1					
		516	600					

		546	350					
		616	750					
		646	700					
		716	500					
		746	550					
		816	400					
		846	450					
		916	450					
		946	99.6					
		1016	450					
		1046	200					
		1116	450					
		1146	750					
				537.29				
6/17/94	AM	1216	650		6/17/94			
		1246	750					
		116	600					
		146	1250					
		216	800					
		246	600					
		316	600					
		346	650					
		416	350					
		446	700					
		516	600					
		546	700					
		616	850					
		646	1250					
		716	92.9			AM	7	114
		746	91.4					
		816	96.6					
		846	83.5				9	96
		916	87.6					
		946	76.7				10	156
		1016	69.2					
		1046	75.9				11	144
		1116	1450					
		1146	4400					
	PM	1216	3800			PM		
		1246	3400				1	192
		116	3000					
		146	2750					
		216	2300					
		246	2000					
		316	2150					
		346	1650					
		416	1650					
		446	1400					
		516	1550					
		546	2100					
		616	2400					
		646	2450					
		716	2100					
		746	2200					
		816	1750					

		846	1650					
		916	1300					
		946	1200					
		1016	1500					
		1046	1450					
		1116	1600					
		1146	1650					
				1372.37				
6/18/94	AM	1216	1800		6/18/94			
		1246	1750					
		116	1750					
		146	1650					
		216	1550					
		246	1600					
		316	1400					
		346	1600					
		416	1600					
		446	1700					
		516	1400					
		546	1300					
		616	1300					
		646	1250					
		716	1100					
		746	1100					
		816	900					
		846	950					
		916	850					
		946	800			AM	10	99
		1016	750					
		1046	97.7					
		1116	850					
		1146	74.8					
	PM	1216	97.4					
		1246	94					
		116	1000					
		146	800					
		216	38.6					
				1074.22				
6/19/94					6/19/94	AM		
							10	93
	PM	902	123.6					
		932	131.3					
		1002	113.2					
		1032	121.5					
		1102	117.4					
		1132	125.7					
				223.50				
6/20/94	AM	1202	118.8		6/20/94			
		1232	116					
		102	106.9					
		132	105.6					
		202	96.5					

		232	98.5				
		302	95.2				
		332	92.4				
		402	88.9				
		432	87.6				
		502	92.8				
		532	87.4				
		602	90.6				
		632	88.7				
		702	87.4		AM	7	84
		732	76.5				
		802	94.6				
		832	152.8				
		902	135.4			9	84
		932	154.2				
		1002	158.3			10	126
		1032	156.9				
		1102	184			11	120
		1132	243.1				
	PM						
		1202	261.1				
		1232	263.2				
		102	262.5			1	138
		132	263.2				
		202	266.7				
		232	263.2				
		302	264.6				
		332	260.4				
		402	254.9				

156.63

6/21/94	AM			6/21/94	AM		
						7	90
						9	90
		941	350			10	135
						11	114
		1151	204.3				
	PM						
		1221	292.4				
		1251	356.5				
		121	390.2				
		151	417.4				
		221	440.2				
		251	457.6				
		321	473.9				
		351	490.2				
		421	501.1				
		451	518.5				
		521	548.9				
		551	571.7				
		621	585.9				
		651	598.9				
		721	608.7				
		751	622.8				
		821	625				

		851	630.4					
		921	626.1					
		951	571.7					
		1021	570.7					
		1051	587					
		1121	514					
		1151	512					
				502.54				
6/22/94	AM				6/22/94	AM		
		21	501.1					
		51	487					
		121	471.7					
		151	463					
		221	444.6					
		251	431.5					
		321	522.8					
		351	410.9					
		421	398.9					
		451	433.7					
		521	428.3					
		551	402.2					
		621	373.9					
		651	240.2					
		721	262					
		933	84.5			AM	9	90
		1003	75.2				10	138
		1033	78.2					
		1103	81.9				11	114
		1133	88.9					
	PM	1203	97.6					
		1233	99.2					
		103	104.9					
		133	127.9					
		203	146.3					
		233	155.8					
		303	181.6					
		333	174.2					
		403	155.1					
		433	147					
		503	170.3					
		533	166.1					
		603	166.8					
		633	146.6					
		703	120.5					
		733	110.6					
		803	98.5					
		833	96.9					
		903	97.7					
		933	97.4					
		1003	99.8					
		1033	94.3					
		1103	90.6					
		1133	94.6					
				220.93				

6/23/94	AM				6/23/94				
		3	94.8						
		33	85.3						
		103	96.9						
		133	94						
		203	90.7						
		233	91.7						
		303	92.3						
		333	91.9						
		403	87.8						
		433	85.5						
		503	87.8						
		533	86.3						
		603	83.7						
		633	97.2						
		703	88.9			AM	7	120	
		733	83.4						
		803	83.6						
		833	77.4						
		903	74.4				9	96	
		933	72.3						
		1003	72.5				10	117	
		1033	76.7						
		1103	77				11	126	
		1133	79.2						
	PM					PM			
		1203	86.8						
		1233	94.6						
		103	148.8				1	198	
		133	163.6						
		203	175.6						
				93.82					
6/24/94	AM					AM	7	96	130
							9	102	90
							11	180	
							1	234	
	PM	126	193.2						
		156	193.6						
		226	195.3						
				194.03					
6/25/94	AM	827	167.9						
		927	151.9						
		1027	109.5						
		1127	139.4						
	PM	1227	138.3						
		127	148.7						
		227	164.3						
		327	163.7						
		427	164.7						
		527	177.7						

		627	134.1				
		727	69.1				
		827	80.5				
		927	86.5				
		1027	87.5				
		1127	121.7				
				131.59			
6/26/94	AM	27	133.3				
		127	133.5				
		227	136				
		327	134.4				
		427	126.3				
		527	108.9				
		627	114.6				
		727	117.8				
		827	123				
		927	98.6				
		1027	104.6				
		1127	110.5				
		1227	147.6				
		127	98.2				
		227	200				
		327	114				
		427	84.9				
				122.72			
6/27/94	AM	734	217.3		7		156
		834	206.8		9		132
		934	189.1				
		1034	194.7		11		174
		1134	202.5				
		1234	219.1		1	234	
		134	220.6				
		234	217.2				
		334	350.4				
		434	338.3				
		534	348				
		634	393.7				
		734	388.2				
		834	360.9				
		934	376.7				
		1034	357.7				
		1134	361.8				
				290.76			
6/28/94	AM	34	374.2				
		134	372.9				
		234	368.7				
		334	377.8				
		434	371.7				
		534	360.2				
		634	338		7	150	

		909	167.3		9	126
		939	156.7			
		1009	136.9			
		1039	172.4			
		1109	209.2		11	156
		1139	212			
	PM	1209	206.9			
		1239	211.1			
		109	208.8		1	210
		139	213.4			
		209	213.8			
		239	213.8			
		309	209.2			
		339	204.6			
		409	202.8			
		439	196.3			
		639	214			
		709	190.5			
		739	173.5			
		809	162.5			
		839	144.5			
		909	134			
		939	131.5			
		1009	118			
		1039	118.5			
		1109	116			
		1139	117.5			
				215.27		
6/29/94	AM					
		9	104.5			
		39	98.8			
		109	111			
		139	100			
		209	103			
		239	99.3			
		309	97.6			
		339	98.6			
		409	96.7			
		439	97.2			
		509	97.6			
		539	99.5			
		609	99.8			
		639	105			
		709	109		7	99
		739	144			
		959	142.6		9	99
		1029	143.4			
		1059	159.4		11	114
		1129	168.9			
	PM	1159	181.6			
		1229	188.5			
		1259	200		1	162
		129	203.3			
		159	214.8			

		229	220.1						
		259	222.5						
		329	223						
		359	220.9						
		429	220.1						
		459	224.2						
		621	161.4						
		858	208.2						
		958	198.9						
		1059	199.2						
		1158	191.5						
				154.28					
6/30/94									
	AM	58	185.7						
		158	192.4						
		258	191.2						
		358	188.8						
		458	194.5						
		558	187.7						
		658	184.6				7	126	
		758	161						
		858	155				9	108	
		1058	116.9				11	60	
		1158	145.3						
		1258	213.4				1	210	
		158	239.5						
		258	255.6						
		358	251						
		458	255.2						
		558	243.2						
		658	180.5						
		758	95.9						
				191.44					
7/5/94					7/5/94	AM	700		114
							900		114
							1100		162
						PM	100	216	
7/6/94					7/6/94	AM	7	138	
							9	132	
							11	138	
						PM	1	174	
7/7/94					7/7/94	AM	7	138	
							9	120	
							11	144	
	PM					PM	1	186	
		243	100.7						
		343	177.6						
		443	212						
		543	164.8						
		643	98.4						
		743	88.5						
		843	96.5						

		943	99.4			
		1043	108.4			
		1143	128.1			
				127.44		
7/8/94	AM	43	134.7			
		143	107.9			
		243	113.3			
		343	103.2			
		443	89.7			
		543	79.9			
		643	76.4		7	90
		743	60.4			
		843	75.2		9	90
		943	85.3			
		1043	97.6		11	144
		1143	156.4			
		1243	199		1	186
		143	192.3			
		243	203.9			
		343	220.8			
		443	230.2			
		543	198.1			
		643	209.1			
		743	200			
		843	157.6			
		943	141.8			
		1043	150.2			
		1143	129.9			
				142.20		
7/9/94	AM	43	157.5			
		143	161.7			
		243	158			
		343	145			
		443	140			
		543	142.9			
		643	97.6			
		743	89.1			
		843	88			
		943	88.4			
		1043	93.1			
		1143	97.1			
	PM	1243	138.6			
		143	138.1			
		643	99.8			
		743	141.3			
		843	111.4			
		943	98.3			
		1043	103.4			
		1143	97.8			
				119.36		

7/10/94	AM	43	99.4						
		143	99.7						
		243	99.2						
		343	94.5						
		443	97.9						
		543	93.8						
		643	94.3						
		743	97.2						
		843	102.4						
		943	109.4						
		1043	98.7						
		1143	125.3						
	PM	1243	150.9						
		143	166.2						
		243	191.1						
		343	184.4						
		443	181.7						
		543	135.2						
				123.41					
7/11/94						AM	7	144	
							9	144	
							11	118	
						PM	1	210	
7/12/94	AM				7/12/94	AM	7	144	
							9	126	
							11	138	
		1134	116.8						
		1234	197.4						
	PM	134	210						
		234	197.6						
		334	206.5						
		434	6.2						
		534	3.8						
		634	4.2						
		734	4.2						
		834	4.2						
		934	4.8						
		1034	4.7						
		1134	4.3						
				74.21					
7/13/94	AM	34	4.8						
		134	5.1						
		234	4.8						
		334	5						
		434	5.1						
		534	5						
		634	5.4				7		168
		734	70						
		834	72.7						
		934	78.1						
		1034	106.6				11		252
		1134	124.2						
	PM	1234	180.9				1	216	

		134	180.4				
		234	193.5				
		334	199.5				
		434	184.1				
		534	180.6				
		634	169.4				
		734	158.4				
		834	157.1				
		934	195.8				
		1034	194.7				
		1134	202.5				
				111.82			
7/14/94	AM	34	208.7				
		134	206.9				
		234	208.7				
		334	166.6				
		434	144.2				
		534	166.7				
		634	176.5			7	186
		734	159.4				
		834	127.2			9	138
		934	126.1				
		1108	9.5			11	162
	PM	1208	2.6				
		108	3.8			1	216
		208	185.5				
		308	191.1				
		408	216.4				
		508	204				
		608	195				
		708	179.1				
		808	175.7				
		908	150.6				
		1008	152.8				
		1108	150.7				
				152.51			
7/15/94	AM	8	156.3				
		108	168.6				
		208	167.4				
		308	174.4				
		408	181				
		508	173.8				
		608	169.6				
		708	172.3			7	162
		808	0				
						9	150
						11	186
	PM				PM	1	234
		145	186.3				
		252	203.6				
		459	215.2				
		559	236.1				
		659	230.5				
		759	211.9				

		859	202.5					
		959	201.1					
		1059	213.6					
		1159	210.3					
				182.87				
7/16/94	AM	59	221.2					
		159	230.7					
		259	237.7					
		359	238.3					
		459	241.3					
		559	233.7					
		659	116.8					
		759	177.3					
		859	177.8					
		959	165.7					
		1059	146.8					
		1159	155					
		1259	173.8					
	PM	159	194.7					
		259	224					
		359	26.3					
		459	195.3					
		559	205.1					
		659	185.9					
		759	210.3					
		859	196.8					
		959	167.4					
		1059	169.7					
		1159	178.3					
				186.25				
7/17/94	AM	59	174.7					
		159	183.9					
		259	189.3					
		359	190.1					
		459	19.1					
		559	6.3					
		659	6.7					
		759	6					
		859	6.8					
				86.99				
7/18/94	AM	718	84.8		AM	7		282
		818	554.5					
		918	91.4			9		246
		1025	104.4					
						11		258
	PM	11	258		PM	1	246	
		1						
				218.62				
7/19/94	AM	709	95.5		AM	7		342
		809	92.7					
		909	94.4			9		264
		1009	105.1					

		1109	99.6				11		210
	PM	1209	115.1						
		109	131.2				1		246
		209	190.4						
		309	200.9						
		409	193.4						
		509	205.1						
		609	207.8						
		709	200.3						
		809	184.4						
		909	198.4						
		1009	134						
		1109	131.3						
				151.74					
7/20/94	AM	9	126.8						
		109	133.9						
		209	121.7						
		309	154.6						
		409	132.7						
		509	136.1						
		609	132						
		709	141.1				7	360	
		809	101.9						
		909	86.2				9	270	
		1009	85						
		1109	87.1				11	294	
	PM	1209	108.5						
		109	123.8				1	252	
		209	122.5						
		309	149.9						
		409	145.1						
		509	141.9						
		609	164.8						
		709	165						
		809	153						
		909	158.2						
		1009	133.5						
		1109	122.5						
				130.33					
7/21/94					7/21/94	AM	7		318
							9		162
							11		210
							1		210
7/21/94	AM	9	112.6						
		109	125.5						
		209	236.2						
		309	116.8						
		746	0.4						
		1023	7.4						
	PM	6	140.5						
				105.63					
7/22/94	PM	1036	162.2						
		1136	228.1						

195.15

APPENDIX TABLE 1b. CKC FIELD DATA: BOD5 AND CORRESPONDING BODCKC DATA.

Date	Time	BOD5	BODCKC
05/09/94	09:00	15	31
05/12/94	07:00	9	3.4
05/13/94	07:00	12	8.6
05/13/94	09:00	12	4.5
05/13/94	13:00	3	11.6
05/14/94	07:00	12	17.3
05/14/94	09:00	9	6.6
05/14/94	11:00	9	7.9
05/14/94	13:00	9	16.5
05/15/94	07:00	6	3.9
05/15/94	09:00	6	8.9
05/15/94	11:00	15	2.4
05/15/94	13:00	6	9.5
05/16/94	07:00	6	10.3
05/16/94	09:00	6	38.3
05/16/94	11:00	6	4.9
05/16/94	13:00	6	4
05/17/94	07:00	9.6	0.5
06/01/94	10:00	102	64.7
06/02/94	09:00	228	85.9
06/02/94	11:00	294	3.9
06/02/94	13:00	270	4
06/03/94	09:00	222	17.1
06/03/94	10:00	117	13.2
06/03/94	11:00	252	87.5
06/03/94	13:00	258	106.3
06/04/94	10:00	135	0.9
06/05/94	10:00	129	0.9
06/07/94	07:00	90	273.1
06/07/94	09:00	96	426.9
06/08/94	09:00	102	99.6
06/08/94	10:00	81	161.7
06/08/94	11:00	96	203.3
06/09/94	07:00	60	77.2
06/10/94	07:00	168	46.7
06/10/94	09:00	162	54.1
06/10/94	10:00	159	46.7
06/10/94	11:00	162	36.7
06/11/94	10:00	126	168.3
06/15/94	07:00	84	1282.2
06/15/94	09:00	84	1360
06/16/94	07:00	150	8.7
06/17/94	07:00	114	92.9
06/17/94	09:00	96	83.5
06/17/94	10:00	156	76.7
06/17/94	11:00	144	75.9
06/18/94	10:00	99	800
06/20/94	07:00	84	87.4
06/20/94	09:00	84	135.4
06/20/94	10:00	126	158.3
06/20/94	11:00	120	184
06/20/94	13:00	138	262.5
06/21/94	10:00	135	350
06/22/94	10:00	138	75.2
06/22/94	11:00	114	81.9
06/23/94	07:00	120	88.9
06/23/94	09:00	96	74.4
06/23/94	10:00	117	72.5
06/23/94	11:00	126	77
06/23/94	13:00	198	148.8
		6	8.1
		174	100
		108	111.3
		99	141.5

NOTE:

1. Data is from Appendix Table 1a.
2. Data used in Figure 4.1a and 4.1b.
3. Shaded data are eliminated to adjust 'Y' scale in Figures 4.1.
4. Dates and times are missing from the data given at the bottom of this Appendix Table.

B. LABORATORY DATA

The following pages present the data that was obtained from the instrument while operating under controlled conditions at the laboratory at TITP from August to September 1994. Appendix Table 2a shows in chronological order all the data, BOD_{CKC}, and their corresponding BOD_5 values. Appendix Table 2b displays these data grouped according to different sampling conditions.

APPENDIX TABLE 2a. CKC LABORATORY DATA: BODCKC AND CORRESPONDING BOD5 DATA, ORDERED CHRONOLOGICALLY.

DATE	TIME	BODsCKC		BODs5	BODt5	BODt5dup	Comments
Primary Eff		**Filter No. 4**					
8-22-94	3						
	7	55.3	55.3	66			
		55.1					
		54.4					
		56.3					
		55.3					
		54.9					
	11	108.8	113.3	117			
		114.9					
		114.9					
		114.5					
		113.6					
		107					
		110.5					
	15	146.5	149.2	141			
		149.3					
		150.4					
		150.7					
		155.4					
		151.2					
		151.8					
		152.9					
		149.9					
	19	174.5	174.5	123			
		173.4					
		175.9					
		174					
	23	147.6	143.2	123			
		143.5					
		143.2					
		138.5					
8-23-94	3	141.6	140.7	114			
		143.2					
		139.6					
		138.5					
		139.1					
	7	83	82.8	69			
		83					
		82.8					
		82.4					
		81.8					
		80.5					
		80.5					
	11	98.7	97.6	105			
		97.6					
		97					

		97			
		95.5			
		95.5			
		92.7			
		91.4			
		92.1			
		89.9			
		88			
		83.9			
		87.3			
	15	NS		NS	
	19	159.8	158.2	114	
		159.8			
		157.1			
		156			
		153.7			
		151.8			
		153.2			
	23	141.6	139.8	114	
		142.7			
		138.2			
		136.8			
		134.6			
8-24-94	3	165.7	165.3	129	
		167			
		163.2			
	7	122.2	120.7	96	
		124.1			
		115.8			
	11	163.4	164.9	156	
		165.9			
		165.9			
		164.3			
		163.2			
		164.3			
	15	175.7	168.0	NOT AVAILABLE	
		167.5			
		164.5			
		164.2			
		180.8			
Primary Inf		**Filter No. 4**			
	20	177.5	143.5	231	276
		178.8			
		180.6			
		178.3			
		179.5			
		180.6			
		182.1			
		189			
	24	127.4	120.9	147	198
		123			
		119.9			
		113.3			
		115.6			

8-25-94	8	95.4	91.2	99	126
		92.2			
		89.8			
		87.4			
	12	126.6	121.0	183	276
		120.2			
		119.4			
		117.6			
		113.6			
	20	NS		NS	
	24	133.3	126.8	153	228
		127			
		125.2			
		121.8			
		119.9			
8-26-94	8	149.3	145.0	120	126
		144.4			
		144.1			
		142			
		139.9			
	12	171.9	167.2	159	198
		165.4			
		166.7			
		164.6			

Primary Inf **Filter No. 1**

	20	151.9	147.0	114	96
		144.8			
		144.3			
	24	143.3	136.1	99	174
		136.5			
		134			
		130.5			
8-27-94	8	76.1	72.0	72	114
		72.2			
		70.7			
		69			
		67.2			
	12	126.2	115.5	90	174
		122.2			
		108.9			
		104.8			
		104.3			
		102.5			
		99.8			
		97.8			
	20	95.8	92.4	87	186
		92.9			
		91.1			
		89.7			
		88.9			
		86.9			
		86			
		83.3			
	24	95.8	91.3	93	180

		91.4			
		89.9			
		88.2			
8-28-94	8	108.1	104.8	120	300
		105.1			
		103.8			
		102			
		100.5			
	12	105.2	103.9	126	150
		104.1			
		102.3			

Primary Inf **Filter No. 4**

	24	61.5	58.2	105	167
		57.2			
		55.9			

Primary Inf **Filter No. 1**

8-29-94	8	64.1	58.9	69	144
		60.3			
		56.9			
		54.1			
	12	151.2	153.0	234	330
		154.1			
		152.6			
		154.1			
		152			

Primary Inf **Filter No. 4**

	20	79.8	73.8	120	
		73.9			
		73.3			
		68			
	24	73.9	67.3	126	
		67.7			
		64.9			
		62.6			
		64.3			
8-30-94	8	68.8	63.0	81	
		64			
		61.2			
		57.9			
		57			
		54.8			
	12			186	

Primary Inf **Filter No. 1**

	20	159.2	156.9	111	264
		155.9			
		155.6			
	24	163.7	156.0	111	174
		152.9			

		151.4			
		148.3			
8-31-94	8	132.4	131.5	84	180
		130.6			
		131.5			
	12	194.9	193.3	129	300
		195.5			
		191.6			
		191			
		188.6			
	20	158.9	157.0	99	198
		158.9			
		153.3			
	24	181.3	180.7	105	234
		183.8			
		179.1			
		178.5			
9-1-94	8	98.2	96.4	57	180
		95.2			
		95.8			
	12	150.2	148.9	114	252
		151.4			
		148.6			
		145.5			
	20	96.4	95.0		
		97.5			
		93.1			
		92.8			
	24	61.2	61.2	45	102
		63.8			
		60.5			
		59.1			
		59.1			
9-2-94	8	92.8	90.6	57	144
		91.3			
		90.2			
		88			
	12	205.4	206.1	114	270
		205.8			
		206.8			
		206.5			
		204.7			
	24	180.1	179.3		
		179.3			
		178.9			
		178.9			
		180.1			
		179.3			
		178.9			
		178.9			
9-3-94	8	118.4	114.7	81	120
		113.8			
		113			
		113.4			
	12	167.8	163.8	75	228
		165.5			

		160.9				
		160.9				
	24			87		

Primary Eff		**Filter No. .45**				
9-9-94	7	214.7	202.7			
		201.7				
		198.7				
		195.7				
		199.6				
		201.3				
		197				
		197				
		197.8				
		197.8				
	3	241.9	228.3	102	132	138
		230.9				
		231.4				
	11	208.9	203.4	90		
		204.7				
		204.7				
9-10-94	7	195.3	203.5	66		
		190.6				
		193.2				
	3	234.9	234.2	99		
		230.1				
		237				
	11	234.9	217.5	84	120	108
		210.3				
		213.7				
		211				
		210.3				
		207.5				
		205.5				
		211.6				
		205.5				
		202.7				
		204.8				
		202.1				
		202.1				
		200				
		200				
		196.6				
		196.6				
		269.2				
		395.2				
9-11-94	7	204.1	206.2	75		
		210.3				
		204.1				
	3	230	223.8	111		
		224.3				
		221.4				
		219.3				
	11	190	186.2	72		
		185.7				

		182.9				
9-12-94	7	161.4	157.0	60	114	96
		158.6				
		155.7				
		152.1				
		151.4				
	3	277.8	273.2	120		
		268.5				
	11	226.9	219.5	108	180	180
		219.4				
		216.7				
		214.8				
		210.2				
		213.9				
9-13-94	7	175.9	175.2	78		
		175.9				
		176.9				
		172.2				
		173.1				
		175.9				
	3	178.9	192.4	103		
		189.9				
		208.3				
	11	270.6	278.0	106	168	168
		285.3				
9-14-94	7	280.7	291.3	88		
		301.8				
	3	322.9	343.1	132		
		333				
		348.6				
		367.9				
	11	379.8	389.7	129	192	216
		386.2				
		391.7				
		400.9				
		416.5				
		420.2				
9-15-94	7	224	234.8	144		
		233.9				
		241				
		240.4				
		243.7				
		245.4				
	3	249.2	249.4		180	180
		247.5				
		251.4				
	11	192.3	192.1			
		190.2				
		194				
		191.8				
		194				
9-16-94	7	235.5	236.9			
		235				
		237.7				
		239.3				
		241				

	3	193.8	198.0	183	
		196.4			
		200			
		201.8			
	11	186.7	185.7	162	
		185.3			
		184.9			
		185.8			
Primary Eff		**No Filter**			
		BODt		BODt	
9-19-94	7	54.1	50.2	72	
		51.3			
		45.3			
	15	148.3	142.4	135	
		137.3			
		142.8			
		141.3			
		140.3			
		135.3			
		126.4			1.9
	23	115.4	105.1	114	0.6, 0.5, 14.1 (1st 3 data)
		100.5			
		99.3			
9-20-94	7	139.8	140.3	108	
		144.8			
		138.8			
		137.8			
		124.9			
		116.9			
		112.4			
		103			
		96.4			
		93.4			
	15	189.8	192.4	156	
		185.2			7.5
		198.9			
		195.5			
	23	160.2	150.3	144	
		151.7			
		147.7			
		141.5			
		127.8			
9-21-94	7	192.6	198.1	144	
		198.9			
		202.8			
	15				
	23	202.8	195.2	108	6.6, 3.9 (1st 2 data)
		196.4			
		192.7			
		188.7			
9-22-94	7	199.6	198.7	114	
		199.6			
		199.6			
		196			

		196			
	15	194.6	194.0	186	
		193.7			
		194.1			
		193.7			
	23	193.7	194.8	186	
		195.5			
		195.5			
		194.6			
		195.9			
		110.4			
		177.9			
		185.1			
		187.4			
		188.7			
		187.4			
		189.6			
9-23-94	7	189.6	191.1	186	
		190.5			
		191			
		193.2			
	15	192.8	191.5	192	
		190.5			
		191.4			
		191.4			
	23	190.4	190.5	150	
		190.4			
		190.7			
		190.4			
		185.2			
		178.1			
		168.9			
		160.7			
		153.7			

Solutions with Known BOD Concentrations

9-28-94	8	50.9	50.9	50	
		49.6			
		50.9			
		52.6			
		50.4			
	10	99.1	100.1	100	from 1030
		100.4			
		100.8			
		100.4			
		99.6			
	13	188.7	187.2	200	
		188.3			
		187.1			
		186.7			
		185.2			
9-30-94	22:18	78.9	78.1	75	
		80.7			
		77.2			

		77.2		
		76.3		
		78.9		
		78.9		
		78.9		
		76.3		
		75.4		
		77.2		
		74.6		
		71.9		
		78.1		
		78.1		
		77.2		
10-1-94	7:30	116.1	117.8	125
		114.3		
		119.6		
		119.6		
		119.6		
	10:18	139.3	139.6	150
		140.2		
		139.3		
	11:18	166.1	163.8	175
		165.2		
		163.4		
		161.6		
		162.5		
		166.1		
	14:48	212.5	217.3	225
		217.9		
		212.5		
		208.9		
	16:48	234.8	232.2	250
		236.6		
		229.5		
		227.7		

APPENDIX TABLE 2b. CKC LABORATORY DATA: BODCKC AND CORRESPONDING BOD5 DATA GROUPED ACCORDING TO SAMPLING CONDITIONS.

DATE	TIME	BODsCKC	BODs5	BODt5	COMMENT
Primary Eff		**Filter No. 4**			
8-22-94	7	55.3	66		
	11	113.3	117		
	15	149.2	141		
	19	174.5	123		
	23	143.2	123		
8-23-94	3	140.7	114		
	7	82.8	69		
	11	97.6	105		
	19	158.2	114		
	23	139.8	114		
8-24-94	3	165.3	129		
	7	120.7	96		
	11	164.9	156		
	15	168.0			
Primary Inf		**Filter No. 4**			
8-24-94	20	179.4	231	276	
	24	120.9	147	198	
8-25-94	8	91.2	99	126	
	12	121.0	183	276	
	24	126.8	153	228	
8-26-94	8	145.0	120	126	
	12	167.2	159	198	
8-28-94	24	58.2	105	167	
8-29-94	20	73.8	120		
	24	67.3	126		
8-30-94	8	63.0	81		
	12		186		
Primary Inf		**Filter No. 1**			
8-26-94	20	147.0	114	96	
	24	136.1	99	174	
8-27-94	8	72.0	72	114	
	12	115.5	90	174	
	20	92.4	87	186	
	24	91.3	93	180	
8-28-94	8	104.8	120	300	
	12	97.3	126	150	
8-29-94	8	58.9	69	144	
	12	153.0	234	330	

8-30-94	20	156.9	111	264	from here to 12 hr 31
	24	156.0	111	174	guess filter
8-31-94	8	131.5	84	180	
	12	193.3	129	300	
	20	157.0	99	198	
	24	180.7	105	234	
9-1-94	8	96.4	57	180	
	12	148.9	114	252	
	20	95.0			
	24	61.2	45	102	
9-2-94	8	90.6	57	144	
	12	206.1	114	270	
	24	179.3			
9-3-94	8	114.7	81	120	from here to 24 hr
	12	163.8	75	228	guess filter
	24		87		

Primary Eff		**Filter No. .45**		avg of two BODt's
9-9-94	7	202.7		
	15	228.3	102	135
	23	203.4	90	
9-10-94	7	203.5	66	
	15	234.2	99	
	23	217.5	84	114
9-11-94	7	206.2	75	
	15	223.8	111	
	23	186.2	72	
9-12-94	7	157.0	60	105
	15	273.2	120	
	23	219.5	108	180
913-94	7	175.2	78	
	15	192.4	103	
	23	278.0	106	168
9-14-94	7	291.3	88	
	15	343.1	132	
	23	389.7	129	204
9-15-94	7	234.8	144	
	15	249.4		180
	23	192.1		
9-16-94	7	236.9		
	15	198.0	183	
	23	185.6	162	

Primary Eff		**No filter**	
9-19-94	7	50.2	72
	15	142.4	135
	23	105.1	114
9-20-94	7	140.3	108
	15	192.4	156
	23	150.3	144
9-21-94	7	198.1	144

	15			
	23	195.2	108	
9-22-94	7	198.7	114	
	15	194.0	186	
	23	194.8	186	
9-23-94	7	191.1	186	
	15	191.5	192	
	23	190.5	150	

Solutions with Known BOD Concentrations

9-28-94	8	50.9	50	
	10	100.1	100	start 10:30
	13	187.2	200	
9-30-94	22	78.1	75	start 22:18
10-1-94	7	117.8	125	start 7:48
	10	139.6	150	start 9:55
	12	163.8	175	start 11:48
	15	217.3	225	start 14:48
	17	232.2	250	start 16:48

C. DATA ON SOLUTION CONSUMPTION

Appendix Table 3, presents data on the various solutions (buffer, rinse, etc.) consumed by the instrument while under operation in the laboratory.

APPENDIX TABLE 3. DATA ON CONSUMPTION OF BUFFER, RINSE AND STANDARDS.

DATE	TIME	BUFFER	RINSE	ABSOLUTE			RELATIVE			COMMENTS
				Std 1	Std 2	Std 3	Std 1	Std 2	Std 3	
9/6	1106	500	500	450	450	450	0.8	0.7	1.6	standby
	1452	460	475	420	430	430	5	10.4	19.7	
9/7	715	250	375	355	365	365	5	10.6	20.1	standby
	1351	170	330	330	330	345	4.9	10.9	21.4	
	1730	120	305	320	325	325	4.8	11	21.2	
	1910	105	300	310	315	315	5.2	10.6	21.4	
9/8	510	30	225	270	275	280	12	15.2	15.4	standby
	747	25	210	260	260	270	11.1	13.6	14.1	
	758	500								
9/9	700	220	70	170	170	170	4.1	8.8	18.3	standby
	712		510							
	1020	180	490	150	150	155	4.4	9.1	18.2	measure
	1208	500		150	150	150	4.4	8.7	18	
	1620	460	460	150	150	150	4.4	8.7	18	standby
9/10	945	245	345	80	90	90	4	7.9	15.4	measure
	1340	190	320	70	75	75	4	8	15.6	
	1510	500								standby, buffer at 160
9/11	1056	260	185	315	110	305	0.9	0.8	4.3	little of standard 2 available
	1936	155	130	280	75	275	3.3	6.2	12.4	measure
	2157			280	80	270	3.3	6.2	12.1	
9/12	722	500	500							buffer at 25, rinse at 50
	840									standby
	1010	475	480	275	70	270	3.3	6.2	12.1	measure
	1653	390	430	275	70	270	3.3	6.2	11.8	standby
9/13	800	200	340	215	210	205	3.2	5.9	10.3	standard 2 almost 0
	945	180	330	210	205	200	3.2	5.6	10	measure
	1230	150	310	200	200	200	3.3	5.9	10.2	
	1535	500	290	200	200	200	3.3	5.9	10.2	buffer at 100
	1830			200	200	200	3.3	5.9	10.2	
	2213			200	200	195	0	0	0	replaced membrane
9/14	726		200	150	150	145	0.5	0.3	0.5	
	940			140	150	140	1.6	0.2	0.7	
	1242	250	170	130	140	135	5.3	6.8	9.1	
	1429			120	125	120	6.6	11.2	11.7	standby
9/15	545	510	510	400	400	400				bottles empty
	700						8	5.4	17.8	measure
	1030									standby
	1510						10.9	17.7	21.7	measure
	1830	315	400	380	370	360	10.8	17.5	21.9	
9/16	1100	50	270	330	330	320	12.4	22.8	29.8	
	1130	500								
	1805	400	220							
9/17	1640	510	520	230	220	215	13.4	25.4	34.4	buffer and rinse at 15
	2110									standby
	2140	440	480	200	220	230	13.4	25.4	34.4	
	2200	430	480	200	220	230	13.4	25.4	34.4	
BODt										
9/18	1544	160	330	140	125	105	13.5	26.2	34.6	
	1602	500		400	400	385	12	26.2	34.6	
9/19	940	230	190	330	360	300	11.6	22.8	33.8	
	1411	160	150	300	310	270	11.8	23	33.8	
9/20	1400	500	400				12.5	24.3	32.3	
	1710	480	380	180	200	200	12.5	24.3	32.3	
9/21	732	260	270	150	150	135	13.2	25.2	31.9	
	925	235	255	145	145	120	12.8	24.7	31.6	measure, tube out at 12:09
	1258	180	230	140	135	110	12.8	24.4	31.4	cleaned out sampling T, last
	1540	130	205							
	1557	500		410	415	420	12.8	24.4	31.4	replenished standards

	1706									standby
9/22	940	230	60	330	325	340	11.9	23.1	33.2	measure
	954		505							
	1040									tube adjustment, samples m
	1530	500								standby
9/23	758	260	330	240	245	255	12.5	24.4	33.4	measure
	1032	220	305							
	1333	185	290	240	245	250	12.5	24.4	33.3	
	1502	150	270							cleaned out flow cell
	1700	120	250							buffer and rinse to 500
9/24	757	270	375	190	190	195	10.8	21.8	32.6	measure
	1410	175	325	180	180	185	12.2	21.9	32.7	standby, buffer to 500
										blink error, reset equipment
9/25	1030			405	400	395	9.4	19.4	31.4	
9/26	730	385	440	370	360	355	9	18.3	31.6	standby (MR)
	1030	350	420	350	345	345	9	18.5	31.1	same
	1350	300	400	340	335	330	9	18.3	30.8	same
	1649	265	380	325	320	315	8.5	18	30.3	same
9/27	745	70	280	255	250	250	7	14.8	27.5	same
	1044	35	260	250	245	240	6.6	13.6	26.4	same, buffer to 455
	1341	425	240	235	230	230	6.1	13.1	25.5	standby, measure ready
	1642	380	220	220	215	215	6.3	12.6	25.4	same
9/28	725	190	120	155	150	145	4.8	9.4	19.8	measure (50 mg/l st)
	1011									measure (100 mg/l std)
	1241	115	80	155	150	145	4.8	9.4	19.6	measure (200 mg/l std)
	1520	85	65							
	1531	305	505							
	1536			155	150	145	4.8	9.4	19.6	standby (MR)
9/29	753	175	390	80	75	80	3.2	6	12.9	same

APPENDIX II. REFERENCES

Standard Methods for the Examination of Water and Wastewater, 18th ed. (1992), American Public Health Association, Washington D.C.

"Amersham Boosts Biosensor R&D," Chemistry & Industry, (October 17, 1988), 635.

"Biosensors Boost for Biotechnologists," Chemistry & Industry, (June 17, 1985), p. 386.

BOD Quick Measuring Instrument: Model BOD-22000 Instruction Manual (1994), Central Kagaku Corporation.

Bond, R.G. and Straub, C.P. (eds.), Handbook of Environmental Control (1973), 664-687.

Borman, Stu, "Biosensors: Potentiometric and Amperometric," Analytical Chemistry, **59/18** (September 15, 1987), 1091A-1098A.

Ehntholt, D.J., et al., "Emerging Chemical Sensor Technologies for Use in On-Line Applications," ISA Transactions, **31/4** (1992), pp. 67-73.

Hale, P. D., et al., "A New Class of Amperometric Biosensor Incorporating a Polymeric Electron-Transfer Mediator," Journal of the American Chemical Society, **111/9** (1989), 3482-3484.

Hikuma, M., et al., "Amperometric Estimation of BOD by Using Living Immobilized Yeasts," European Journal of Applied Microbiology and Biotechnology, **8** (1979), 289-297.

Johnstone, B., "Japanese Industry Turns to Biosensors," New Scientist, **21** (November 1985), 36.

Karube, I., et al., "Microbial Electrode BOD Sensors," Biotechnology and Bioengineering, **19** (1977), 1535-1547.

Karube, I., et al., "A New Microbial Electrode for BOD Estimation," Journal of Solid-Phase Biochemistry, **2/2** (1977), 97-105.

Karube, I., et al., "A Rapid Method for Estimation of BOD by Using Immobilized Microbial Cells," Journal of Fermentation Technology, **55/3** (1977), 243-248.

Kitagawa, Y., et al., "Amperometric Detection of Alcohol in Beer Using Flow Cell and Immobilized Alcohol Dehydrogenase," Analytical Chemistry, **63/20** (October 15, 1991), 2391-2393.

LeBlanc, P.J., "Review of Rapid BOD Test Methods," Journal of the Water Pollution Control Federation, **46** (September, 1974), 2202-2207.

MacKoul, D., et al., "Effect of Variation in Flow Rate on Amperometric Detection in Flow Injection Analysis," Analytical Chemistry, **56** (March 1984), 436-439.

Matsumoto, K., et al., "Continuous-Flow Sensor Strategy Comprising a Rotating Bioreactor and a Stationary Ring Amperometric Detector," Analytical Chemistry, **65/5** (March 1, 1993), 636-639.

Nissin BOD Rapid Measuring Instrument: BOD-2000 (Microbe Electrode Automatic Desktop Type) Instruction Manual (1993), Central Kagaku Corporation (CKC).

Riegler, Gunther, Ph.D., "3-Minute BOD Assessments," InTech, (May 1987), 45-50.

Schultz, Jerome, S. (1991) "Biosensors," Scientific American, (August 1991), 64-69.

Shamel, R.E. and Brown, S.A., "Biosensors: Boon to Bioprocessing," Chemical Engineering Progress, (January 1992), 63-64.

Strand, S.E. and Carlson, D.A., "Rapid BOD Measurement for Municipal Wastewater Samples Using a Biofilm Electrode," Journal of the Water Pollution Control Federation, **56/5** (May 1984), 464-467.

Suzuki, H., et al., "Correspondence: Fabrication of an Oxygen Electrode Using Semiconductor Technology," Analytical Chemistry, **60/10** (May 15, 1988), 1078-1080.

Turner, A.P.F., et al. (eds.), Biosensors - Fundamentals and Applications, Oxford: University Press, (1987), 357-359.

Walt, D.R., "Recent Advances in Chemical Sensors," Chemistry & Industry, (January 20, 1992), 58-61.

APPENDIX III. PUBLICATIONS

A. **REAL TIME BOD MONITORING FOR WASTEWATER FIELD APPLICATION** *(UNDER REVIEW BY LWMD)*

B. **IMPORTANT ISSUES ON BIOSENSOR BASED BOD INSTRUMENTS FOR ONLINE APPLICATIONS** *(UNDER REVIEW BY LWMD)*

C. **RESPIROMETRY AND MICROECOLOGY OF WASTEWATER TREATMENT PLANTS** *(UNDER PREPARATION)*