SIDESTREAM ELEVATED POOL AERATION (SEPA) STATIONS: EFFECTS ON IN-STREAM DISSOLVED OXYGEN

by

Thomas A. Butts,
Dana B. Shackleford,
and
Thomas R. Bergerhouse

Illinois Department of Natural Resources
Illinois State Water Survey
2204 Griffith Drive
Champaign, Illinois 61820-7495

CONTENTS

SIDESTREAM ELEVATED POOL AERATION (SEPA) STATIONS: EFFECTS ON IN-STREAM DISSOLVED OXYGEN

by
Thomas A. Butts,
Dana B. Shackleford,
and
Thomas R. Bergerhouse

INTRODUCTION

As a result of increased pollutant loading and low in-stream velocities, dissolved oxygen (DO) levels in the Chicago waterway historically have been low. During the 1970s, water quality modeling was performed by the Metropolitan Water Reclamation District of Greater Chicago (District) to evaluate the effectiveness of tertiary treatment on reducing the occurrence of low DO levels. The results were not encouraging. The construction of advanced waste treatment facilities at each of the three major District plants would result in the expenditure of hundreds of millions of dollars while producing questionable results. Consequently, the District began investigating in-stream aeration as an alternative for increasing waterway DO concentrations.

Background

During the late 1960s the District considered four in-stream aeration approaches: barge-mounted aeration devices, in-stream mounted mechanical aerators, U-tubes at head-loss structures, and diffused air systems using ambient air blowers or molecular oxygen. The in-stream mechanical system, although the most cost-effective, could not be used because of navigational considerations. The District evaluated the barge-mounted system in Chicago area waterways, but it did not prove to be practical. The U-tubes are not applicable at most locations at which chronic low DO concentrations occur in the Chicago area waterways because such installations require large instantaneous head losses to operate. By default, diffused aeration was selected by the District for supplementing waterway DO at ten locations, and two diffused aeration stations were built. In 1979, the Devon Avenue station was completed on the North Shore Channel. A second aeration station was constructed at Webster Street on the North Branch of the Chicago River and became operational in 1980.

These diffused aeration stations experienced operational and maintenance problems. Prior to building eight additional aeration stations, the United States Environmental Protection Agency (USEPA) deferred on its demands for the District to build advanced wastewater treatment plants while, in turn, endorsing the use of in-stream aeration. This reversal in opinion prompted an immediate search for an improved

1984) issued a feasibility report on a new concept of artificial aeration referred to as sidestream elevated pool aeration (SEPA). The SEPA station concept involves pumping a portion of the water from the stream into an elevated pool. The water is then aerated by flowing over a cascade or waterfall that returns the aerated water to the stream.

Over the next several years, modifications were made to the SEPA station design originally proposed by Macaitis et al. (1984). In particular, Tom Butts, with the Illinois State Water Survey (ISWS), suggested using a stepped-weir system in place of a continuous cascade or one large waterfall. As a result, research scientists from the ISWS and the District's Research and Development Department cooperated in conducting full-scale testing of a sharp-crested weir system during 1987 and 1988. A prototype SEPA station was built along the Chicago Sanitary and Ship Canal at the District's Stickney Water Reclamation Plant. This experimental work led to the development of SEPA station design criteria by Butts (1988). Information and recommendations in this report (Butts, 1988) were used by District consultants to design five SEPA stations along the Calumet waterway system (figure 1). Figures 2-6 are photographs of all five SEPA stations. Table 1 presents waterway mile locations and basic design features of all five SEPA stations.

Study Objectives

Additional artificial aeration stations are being planned for future locations along

Acknowledgments

This study was funded by the Research and Development (R & D) and Engineering Departments of the District. Irwin Polls R & D project leader and liaison to the ISWS provided scheduling and sampling input. David Tang of the District's Maintenance and Operations Department provided SEPA station operational data used in this report. Thanks are extended to ISWS personnel Bob Larson and Bill Meyer for their

METHODS AND PROCEDURES

The approach used for determining the effects that SEPA stations have on in-stream water quality was to install continuous water quality monitors at critical points along portions of the Calumet and Little Calumet Rivers, the entire Cal-Sag Channel, and the Chicago Sanitary and Ship Canal below its junction with the Cal-Sag Channel. All continuous monitoring data were recorded hourly. Monitors were installed in early spring 1996 and were left in place until late fall 1996. Also, cross-sectional DO readings were made periodically at each monitoring station to generate data for relating mean cross-sectional DO values to the point values generated bylnd

be vulnerable to entanglement by passing barge tows. This concern, here and at two similar sites, proved to be justified and expensive.

All monitoring installations were placed into operation between March 13 and 15, 1996. The shallow, type IA installation at monitoring station 13 had remained in place,

even to a limited degree. Periodic drawdowns in anticipation of heavy rainfall, heavy runoff from actual storms, and other operational considerations precluded adherence to the proposed diversion schedule. On three occasions, as noted in table 4, mechanical

exchanged shrouds were scrubbed with water and a stiff-bristled brush immediately upon removal from the water. Care was taken not to disturb the probes when washing and cleaning the units.

The monitors were protected from jarring and shock inside the PVC shrouds by two thick rubber bushings shown on the YSI 6000 monitor in figure 21 and schematically illustrated on figure 7. The units were secured in the shrouds with ½-inch bolt-pins inserted through the monitor hangers as shown schematically by figure 7 and in reality by figure 12. The pins were restrained with washers and hitch-pin clips (figure 7).

The standard operation procedures (SOPs) and QA/QC methods used relative to the use of the monitors will be outlined and described later.

Cross-sectional DO/Temperature Measurements

Cross-sectional measurements were made at 19 of the 21 stations listed in table 2. Measurements were made on single verticals at 2-foot depth intervals at station 3, the lakeside entrance to the O'Brien Lock and Dam, and monitoring station 21, the entrance to the Lockport Powerhouse forebay,. The cross-sectional measurements were made at 13 of the monitoring sites and on the vertical at Lockport Lock and Dam to generate data for developing statistical relationships between the DO levels at the fixed monitoring points and cross-sectional (and the Lockport vertical) means. The intent was to determine if these point measurements represent cross-sectional means and, if not, to develop statistical regression equations that could be used to estimate cross-sectional means. Measurements at sites intermediate to the monitoring locations were selected to generate data to better define the DO sag curves in reaches of the waterway influenced by SEPA station operation. Also, DO/temperature readings were taken in the outfalls of each SEPA station during their operation. The outfall locations are indicated by "Out" in table 2.

A minimum of ten cross-sectional runs was originally planned. However, 15 runs working at the lower stations would complete the sampling. Except on a few occasions, all cross-sectional data were collected on the same day.

At stations along the Cal-Sag Channel, cross-sectional point-measurements were recorded on a minimum of five verticals. Only points on three verticals were sampled along the Chicago Sanitary and Ship Canal because of its relatively narrow width and rectangular cross-sectional shape. At all transects, except those at the SEPA station intakes and those located immediately below the SEPA station outfalls, initial temperature in degrees Centigrade (ºC), DO in milligrams/liter (mg/L), and percent saturation were recorded. The meter was then adjusted to 100 percent saturation, and the cycle was repeated. The end readings were used to make incremental temporal adjustments in DO readings due to meter drift over the time period required to complete a transect and the start of the next. Proportionate, linear extrapolation was used to make the temporal adjustments in DO.

Nitrogen Sampling

Water samples were collected at the depth of the monitors at all 14 sites for laboratory analyses of ammonia-nitrogen (N), nitrite-N, nitrate-N, and Kjeldahl-N using a 1 L Kemmerer sampler. From this, 250 mL of unfiltered water was retained for Kjeldahl-N analysis and another 250 mL was filtered for ammonia-N, nitrite-N, and nitrate-N analyses. Filtering was done with a Katadyn Model 2050 field pressure filter equipped with a 0.2 μm diatomaceous earth filter element. All samples were iced. Upon completion of a run, samples were immediately transferred to the District's Stickney laboratory for chemical analyses. Collections were made on ten dates.

Laboratory Operations and QA/QC Procedures

Monitors were prepared in the laboratory for field use, data were downloaded, QA/QC measures were applied, and data were reduced and computer filed. Regimented procedures were developed for performing each of these work tasks and were adhered to throughout the study. Many of the SOP and QA/QC methodologies used in this study were developed over the past 15 years and applied to numerous studies. These procedures are more stringent and more detailed than the manufacturer's recommended SOP and QA/QC methodologies.

Monitor Preparation and Use

Principally, two types of continuous monitors were used during the study: HydroLab DataSonde I units and YSI 6000 units. Also, on a few occasions a DataSonde 3 unit and a YSI 6920 unit were used. Between March 15 and May 21, 1996, only DataSonde I units were used. The reasons were twofold: the chance of losing a new YSI unit was too great until the "bugs" were eliminated from the installation rigging designs

The YSI 6000 monitors were calibrated for DO, pH, and specific conductance in the laboratory. All calibrations and downloading were performed using the PC6000 software provided with the monitors. Data files were downloaded in the proprietary PC6000 format and converted within PC6000 to comma-delimited values for importing into Microsoft Excel Version 7.0. Hydrolab DataSonde I units were calibrated using the standard Windows 95 terminal program. Data files for the DataSondes were downloaded as ASCII capture files and imported into Excel. After formatting in Excel, the data were moved into a Microsoft Access 97 database in which all calculations and statistical reductions were performed.

Calibration of pH was performed using Fisher Scientific buffers of pH 7.0 and 10.0. Before calibration, the probes were cleaned and rinsed with de-ionized water and pH 7.0 buffer to remove any contamination. Probes then were placed in 500 mL of the pH 7.0 calibration buffer and allowed to stabilize for ten minutes, or until the electrode readings were stable. The probes then were removed from the solution and rinsed in a beaker of de-ionized water. Prior to placement in the pH 10.0 calibration buffer, the probe assembly was rinsed with pH 10.0 calibration buffer to remove any residual pH 7.0 buffer or de-ionized water droplets that might contaminate the pH 10.0 calibration buffer. The probes then were immersed in a beaker containing 500 mL of pH 10.0 calibration buffer

For the YSI units, calibration cups containing moist sponges were installed. The instruments were laid longitudinally with the DO probes on top to reduce the chance of water dripping onto the DO membranes. The monitors were run for at least ten minutes in the discrete sampling mode to warm the electrodes and confirm the environmental stability within the calibration cups. Calibration for DO began with compensation for measurements were made. These include beginning and ending Winkler DO values in the laboratory water tank and beginning and ending YSI Model 59 meter DO values in the field. During Phase II, a number of intermediary measurements also were included.

The cross-sectional DO readings were corrected for meter drift using linear extrapolation. However, these adjustments were proportioned in terms of percent saturation because the meters were calibrated to 100 percent of saturation (using either water or air) at the initiation of cross-sectional measurements. Mathematically this can be expressed as:

$$cm_{ti} = \left\{ \frac{p_1 + \left[(t_i - t_{p1})/(t_2 - t_{p1})\right](p_2 - p_1)}{100} \right\} m_{ti} \qquad (2)$$

where:

cm_{ti}

Stream Dissolved Oxygen (DO) Water Quality Standards for Study Area

Reach			*DO (mg/L)*	
Name	*Inclusive RM*	*Type of standard*	*16-hr average*	*minimum*
Calumet River	333.2–326.6	General use	6.0	5.0
Little Calumet River	326.6–319.7	Secondary contact		4.0
Cal-Sag Channel	319.7–303.3	Secondary contact		3.0
Chicago Sanitary and Ship Canal	303.3–291.2	Secondary contact		4.0

An overall analysis of the data was made for the 249-day study period. However, because of the extreme variations in flow, weather, and SEPA operation, six additional analyses were made to account for these variables as presented in table 6. Descriptions of the scenarios in table 6 are:

Study Period Scenarios, March 16-November 19, 1996

Period	*Dates*	*Description*
1	03/16-04/18	No diversion without SEPA operation during cool weather
2	04/19-05/30	Low diversion with SEPA operation during cool weather
3	05/31-07/03	Low diversion with SEPA operation during mild weather
4	07/04-09/25	High diversion with SEPA operation during hot weather
5	09/26-10/31	High diversion with SEPA operation during cool weather
6	11/01-11/19	No diversion without SEPA operation during cold weather
1- 6	03/16-11/19	Total study period

Probability statistics were used to estimate the frequency at which the DO standards were not met during the study periods. Frequency distribution curves (FDCs) were used to estimate when DO standards were not met for hourly and mean daily values. The ordinates (percent exceedance values) on the probability graphs were computed by the formula:

$$P = \frac{100(n - 0.5)}{N} \qquad (3)$$

where:

P = ordinal percentage
n = ordinal number
N = sample size

This formula was used to negate the computation of a 100 percent plotting ordinate. All future text, table, and graphic reference to the results derived by equation 3 will be referred to as FDC results.

A second, more limited approach was taken for ascertaining the probability of DO standards not being met. The hourly DO concentrations at each monitoring station were assumed to be normally distributed. This assumption permitted probabilities to be determined by computing the standard deviations and comparing them to the normal cumulative distribution curve or a statistical-reference *z*-table. The FDC development is independent of the normality assumption.

The mean and standard deviation of the daily mean monitor outputs were computed for each station, and the percentage of times in which DO concentrations were less than the DO standard were calculated. The procedure is as follows:

- Compute the standard deviation of the sample,

$$s = \sqrt{\frac{\Sigma (x - \overline{x})^2}{N - 1}} \tag{4}$$

where:

s = standard deviation of the sample
x = discrete sample value
$\overline{x}$ = mean (arithmetic average) of sample
N = sample size

- Compute the *z*-statistic,

$$z = \frac{x_i - \overline{x}}{s} \tag{5}$$

where:

x_i = any discrete or specified value

- Look up percentage value in a statistical reference *z*-table.

Computed percentages should be very accurate, even if the sampling distribution is only approximately normal because extremely large sample sizes are involved in the calculations. Large sampling theory applies to sample sizes of 30 or greater. Generally in this study, samples sizes were much greater than 30. For hourly analyses, N is in the hundreds; for daily means, N exceeds 30 except for period 6 (table 6). All future text, The basic statistical parameter computations, the FDC developments, and the *z*-T data generation were done using Microsoft Excel.

Comparative Analyses

Statistical analyses were performed to determine if significant differences existed between data groupings generated during this study. Statistical analyses were performed using standard computer programs capable of handling the large number of data generated. Tests were performed using various analyses of variance (ANOVA) procedures, *t*-tests, and multiple range analyses. Either “normal” or rank-order techniques were applied, depending on the condition of the data. Data were first tested for normality. If the data appeared to fit a normal distribution curve with a 95 percent degree of confidence, statistical tests applicable to “normal” data were used. When the data were not normally distributed, nonparametric, rank-order testing was performed. These tests provided a robust means of testing for differences in data sets that do not fit normality testing criteria.

The nonparametric Mann-Whitney Rank Sum Test was used to determine if differences existed between average cross-sectional DO concentrations and point values measured at the monitor locations in the cross sections. The cross-sectional averages were computed either by straight averaging or by weighted averaging. All cross-sectional data were thoroughly examined and evaluated, and only those sections that exhibited significant variability in DO throughout were weight-averaged. Only 10 of the 195 cross-sectional DO profiles generated required weighted averaging. Of interest is the fact that seven of the ten situations occurred either at the SEPA station 2 intake transect or at transects located immediately below the SEPA station outfalls.

Weighted averages were computed using isoplethic diagrams. Isopleths are lines on a cross section connecting points at which a given variable has a specified constant value. The DO isopleths were drawn on the cross sections at either 0.25 or 0.50 mg/L intervals. A computer program was developed for placing the lines between two DO

A parametric one-way ANOVA test was used to determine if statistically significant differences existed between the mean near surface, “mid-depth”, and bottom DO values at the Lockport Lock and Dam vertical (monitoring station 21) for dates during which measurements were made at 2-foot depth intervals. Additionally, the nonparametric Kruskall-Wallis one-way ANOVA test for ranks was used to determine if statistically significant differences existed at the 95 percent confidence level for the medians of the hourly DO values recorded at the three depths over the course of the study. The rank-order ANOVA test was used for the hourly values to accommodate the variability of the sample sizes between the three depths. Also, the Mann-Whitney Rank Sum Test was used to determine if any of the three point values at monitoring station 21 are representative of the vertically averaged DO concentration.

The statistical testing calculations were performed using SigmaStat Version 2.0 for Windows 95, NT, and 3.1. Details of the testing procedures and the output formats are presented in detail in the report of the Phase II portion of this study (Butts et al., 1999).

RESULTS

All the DO data were subjected to QA/QC adjustments. The adjusted DO data for all the monitor outputs is available on disk in a Microsoft Access 97 database format. The

the projected total. Eliminating the advertent removal of the units for use in the Phase II study and the inadvertent destruction to units by barges, this percentage would have increased to 82 percent. In other words, the reliability of the monitors used throughout Phase I applications appears to be about 82 percent. This reliability percentage includes the exclusive use of the older DataSonde I units during the initial stages of this Phase I study and during the Phase II study. The exclusive use of the YSI 6000s probably would less than the standard along the entire study reach of the Chicago Sanitary and Ship Canal (figures 24-27). As shown on figures 25 and 26, the mean DO profile was less than the 4.0 mg/L DO standard along the extreme lower end of the Chicago Sanitary and Ship Canal. This means that, in a short reach along the lower segment of the canal, hourly DO levels were less than the standard at least 50 percent of the time.

Other Parameters

The continuous monitors were equipped with probes to measure specific conductance and pH in concert with DO and temperature. Although the measurements of these two parameters were not mandated as part of this study, they were included. Only a moderate amount of additional effort was expended to include specific conductance and pH, and potentially useful information was produced. The raw data are available on computer disks and are summarized in appendix C in a reduced form using descriptive statistics. The raw nitrogen data also are available on computer disk and are summarized in appendix C using descriptive statistics.

The most significant aspect of this data is the wide variation shown in specific conductance. Lake Michigan water and discretionary diversion have a major affect on specific conductance levels over a year. Note from appendix C that, during period 1, monitoring stations 1 and 2 had low specific conductance values compared to all the stations below the O'Brien Lock and Dam. Apparently, the specific conductance of Lake Michigan water normally ranges between 0.30 and 0.50 mS/cm; whereas, the specific conductance of Cal-Sag Channel water runs as high as 1.50 mS/cm. During periods 4 and 5, when discretionary diversion was highest, Cal-Sag Channel and Chicago Sanitary and Ship Canal water specific conductance levels are reduced to values ranging from 0.23 to 1.10 mS/cm.

Lake Michigan water, used for discretionary diversion, appears to have a less pronounced affect on pH downstream of the O’Brien Lock and Dam than it does on specific conductance. However, this affect is discernible. Before diversion, pH values ranged between 7.64 and 7.86 at monitoring station 1 (RM 328.10) above the dam and between 6.92 and 7.62 at the intake of SEPA station 5 (RM 303.63). During peak diversion, from July 4-October 31, 1996, the pH range for monitoring stations 1 and 15

At monitoring station 10 (RM 317.62), two complete cross-sectional measurements were made on July 24–one during the morning and the other during mid-afternoon. The objective was to determine if primary productivity changes the cross-sectional DO profile significantly from morning to afternoon during warm sunny conditions. During this particular situation, the effect appeared minimal because the morning mean DO value was 3.90 mg/L, compared to an afternoon mean of 4.25 mg/L (table 12), a difference of only 0.35 mg/L.

Table 12 presents the cross-sectional data summarized by station. The mean DO and temperature values in table 12 were rearranged in terms of longitudinal profiling by date and are presented in table 13. Table 13 shows how the mean cross-sectional DO sag curves varied in magnitude on various dates throughout the study period. The lowest DO sag curve extending from RM 328.10 to RM 291.20 occurred on June 19, 1996. On this date, the DO levels dropped below 3.0 mg/L for all stations downstream of station 11 (RM 316.00) except at monitoring station 16 (RM 304.69), at which the transect average was 3.53 mg/L. No other daily cross-sectional average DO profile came close to the June 19, 1996, low DO conditions. The next lowest overall DO profile occurred on July 24, 1996, when the cross-sectional average DO values below station 11 (RM 316.00) ranged from 3.12 to 3.97 mg/L.

The major purpose for taking cross-sectional measurements was to provide information for statistically relating monitor point values to cross-sectional means. The monitor point values are listed in table 12 for the continuous monitoring sites. Overall, 317 cross-sectional measurements were made. The correlations between cross-sectional means and the continuous monitor point values could be more expeditiously derived for such a large number of data sets if the simple means could be used in lieu of weighted means in the statistical computations. Consequently, the possibility of using simple means was explored by selecting ten transects, displaying the most DO variability, for constructing isopleths for use in computing weighted means. Appendix D presents these cross sections, with resultant DO isoplethic construction. Table 14 presents the locations, dates, and unweighted and areal-weighted means. Note, that monitoring stations 6, at the intake of SEPA station 2 (RM 321.32), and 10, immediately below the SEPA station 3 outfall (RM 317.62), accounted for half of the values–two at monitoring station 6 and three at monitoring station 10.

Table 14b presents the results of a paired *t*-test used to determine if the mean differences between the paired DO values are statistically significant. The test indicated they are equal at a 95 percent confidence level because the computed *t*-value is significantly less than the theoretical value. Consequently, the unweighted mean cross-sectional profiles were used to determine the relationships between the monitor readings recorded during the time interval of the transect measurements.

The paired *t*-test was used to determine if the assumption can be made that the monitor readings represent cross-sectional means for each station. Table 15 summarizes the results. At the 95 percent confidence interval, the monitor point readings appear to represent the cross-sectional means at 12 of the 14 sites. The two sites at which this assumption appears invalid are at monitoring stations 10 and 13. This is not surprising in that both stations are located immediately below SEPA station discharges. Monitoring station 10 is approximately 2,000 feet below the SEPA station 3 outfall (table 2), and monitoring station 13 is approximately 4,000 feet below the SEPA station 4 outfall (table 2). More than 4,000 feet of channel length appears to be needed to effect complete mixing of SEPA stations 3 and 4 discharges. Monitoring station 10 is on the opposite side of SEPA station 3 (figure 16f), and monitoring station 13 and SEPA station 4 are on the same side (figure 16h).

A special explanation is needed for the comparison between the monitor "point" value and the "cross-sectional" value presented for the Lockport Lock and Dam (monitoring station 21) in table 12. The monitor value is not a "point" value, and the cross-sectional value is not a cross-sectional value. The Lockport monitor value in table 15 (monitoring station 21) is the mean of the near surface, "mid-depth", and bottom monitor values, and the cross-sectional value is the mean of readings taken at 2-foot intervals on the vertical.

A Kruskal-Wallis one-way ANOVA test was performed on the data generated by the three monitors at Lockport (monitoring station 21) to determine if the assumption could be made that the mean DO values produced by all three monitors over common time intervals are equal. The results of this test are presented in table 16. The nonparametric ANOVA test was performed because the data failed the normality test. The results of the test indicate that the three monitor locations produced different results during the study period (table 16). Consequently, a single location may not be representative of the vertical mean, although the mean of the three monitor locations proved to be representative. Correlation and linear regression statistics were used to ascertain which singular location best represents the vertical mean. Fourteen sets of data common to all three continuous monitoring points were available. The vertical means are given for monitoring station 21 in table 12. The results of the statistical testing are as follows:

Statistical Analysis of Vertically Placed Monitors at Lockport, Monitoring Station 21

Location	*Correlation coefficient (r)*	r^2	*Standard error of estimate*	*Y-axis intercept*	*Independent variable coefficient*
near surface	0.966	0.933	0.370	0.198	0.950
mid-depth	0.947	0.897	0.463	0.600	0.818
bottom	0.938	0.880	0.500	0.692	0.834

All three locations in the vertical would suffice for estimating the vertical mean as evidenced by the high coefficient of variance (r^2) values. The r^2 values represent the percentage of variability in the dependent variable, which can be explained by the

whether or not DO values are less than a given standard is not relevant to these results. It merely shows that SEPA stations 3, 4, and 5 are significantly improving DO conditions

DISCUSSION

To facilitate the following discussion, the IEPA stream-segment DO standards in the Probability Analyses section of this report and those standards specific to each SEPA station intake are:

Stream Dissolved Oxygen (DO) Water Quality Standards for Study Area

Location	*River mile*	*Minimum DO standard (mg/L)*
SEPA station 1	328.1	5.0
Calumet River	333.2-326.6	5.0
SEPA station 2	321.3	4.0
Little Calumet River	326.6-319.7	4.0
SEPA station 3	318.1	3.0
Cal-Sag Channel	319.7-303.3	3.0
SEPA station 4	311.6	3.0
SEPA station 5	303.6	3.0
Chicago Sanitary and Ship Canal	303.3-291.2	4.0

Table 20 summarizes the results of this study in terms of DO concentration, and table 21 summarizes the results in terms of the percent of time the DO concentration was less than the standard at each SEPA station intake. Only SEPA station intake monitoring station data is presented because these values best reflect the in-stream effects of SEPA station operation. The results for monitoring stations immediately downstream of each SEPA station are not presented for reasons outlined in the Results section of this report (i.e., incomplete mixing at these stations). The significance of this factor will be further expanded upon in this discussion. The percentages in table 21 are averages of the FDC values in table 17 and the *z*-T values in table 18.

Table 20 shows that on an actual basis the SEPA station 1 intake DO values were never observed to be less than the minimum standard of 5.0 mg/L. Statistically, however, table 21 indicates that a slight probability exists in which the DO at SEPA station 1 could fall below the standard approximately 0.47 percent of the time (28 hours) for conditions similar to those experienced during the entire study period (03/16-11/19/1996).

Conditions at the intake of SEPA station 2 appeared to be less favorable than those at the other SEPA stations. This should not be interpreted as a failure of SEPA station 1 to function properly. It is not, and the details concerning these results will be discussed later.

The intake DO values at SEPA station 3 essentially remained above the DO standard during the entire study period, except for a brief time during period 3 (05/31-

07/03/1996). During this time a minimum DO of 2.48 mg/L occurred (table 20), and the DO values were less than the standard only 1.53 percent of the time (12 hours). These good results, however, should not be attributed in any way to any upstream DO input from SEPA station 2. Reasons for this will be presented and discussed later.

Essentially intake DO at SEPA station 4 was less than the standard of 3.0 mg/L during periods 2 (04/19-05/30/1996), 3 (05/31-07/03/1996), and 4 (07/04-09/25/1996). During period 3, an extremely low DO of 0.92 mg/L was recorded (table 20). However, such low values at this location rarely occurred. The probability of such low values occurring during conditions exemplified by period 3 at SEPA station 4 is less than 0.07 percent (tables 17 and 18), or less than one hour. The possibility of the DO falling below 3.0 mg/L at this location during period 3 is only 4.14 percent (table 21), or approximately 34 hours. During the entire study period, the probability of the DO falling below 3.0 mg/L is only 1.45 percent (table 21), or approximately 87 hours. These good results can be directly attributed to the operation of SEPA station 3, as will be shown and discussed later.

At the intake of SEPA station 5, the DO values were essentially less than the standard of 3.0 mg/L only during periods 3 and 4 (table 21). For periods 3 and 4 the DO values were less than the standard 4.59 and 3.21 percent of the time, respectively. The combined number of hours during which such conditions persisted was 102. These are respectable figures, and the success at this location can be attributed to the upstream DO inputs from SEPA stations 3 and 4. This will be documented and discussed later.

The in-stream DO study produced two important results. One is that the SEPA stations, particularly stations 3, 4, and 5, are fulfilling the intended function of maintaining stream DO standards in the Calumet and Little Calumet Rivers and in the Cal-Sag Channel. The second is that DO levels less than the DO standard frequently are observed in the Chicago Sanitary and Ship Canal in a reach beginning above its juncture with the Cal-Sag Channel to the Lockport Lock and Dam. Continuous hourly monitoring was conducted at four sites within this reach. A summary of the percent of times and number of hours during which the DO concentrations were less than 4.0 mg/L, the DO standard, is as follows:

Period of Time that Dissolved Oxygen (DO) Concentrations Were Below the Standard at Monitoring Stations on the Chicago Sanitary and Ship Canal during the Entire Study

Monitoring station	*River mile*	*Concentrations less than DO standard*	
		Percent of time	*Number of hours*
16	304.69	23.32	1394
17	302.56	12.52	748
18	299.55	13.27	793
21 near surface	231.20	32.76	1958
21 mid-depth		32.52	1943
21 bottom		28.50	1703

Note: These results were derived using the FDC statistical method.

The results in this tabulation indicate that SEPA station 5 does a good job of reducing the frequency at which the DO values in the Chicago Sanitary and Ship Canal are less than the DO standard for at least 4 miles downstream of SEPA station 5 (RM 303.57). This observation is clearly supported by data generated during study periods 3 and 4, as illustrated by figures 25 and 26. These two figures represent critical warm-weather, low-flow conditions. Note from figure 25 that the mean DO concentration at monitoring station 17 (RM 302.56) is significantly higher than the mean DO at monitoring station 16 (RM 304.69). During period 4, the difference in mean DO values between monitoring stations 16 and 17 is less than that for period 3, but the DO at monitoring station 17 is increased to values above the DO values at monitoring station 16 on the average, and the supplement of DO from SEPA station 5 appears to prevent a rapid deterioration in DO below the junction of the two waterways.

The SEPA stations 1 and 2 appear to have minimal effects on improving in-stream DO levels. The SEPA station 1 is poorly located longitudinally along the waterway. Its intake is in an area of high ambient in-stream DO concentrations (table 20). At monitoring station 1, during critical periods 3 and 4, a 6.0 mg/L DO level was exceeded 100 percent of the time during period 3 and 95 percent of the time during period 4 (table 18). The 5.0 mg/L DO level was exceeded virtually 100 percent of the time for both periods 3 and 4 (table 18). The mean water temperature during period 4 was approximately 23°C (table 10). The DO saturation at 23°C is approximately 8.2 mg/L at the elevation of SEPA station 1. Consequently, a 6.0 mg/L DO represents a saturation of 73 percent, and 5.0 mg/L DO represents 69 percent saturation. These are relatively high values for that time of year.

A slight chance exists (2.5 percent, figu al3 Tw[(monitoring)9.7d.00lp expm eof the[abmdyeof effectiveness of a one-pump operation is not fully known and could be questioned. The question could be asked, “Would completely shutting down the station increase the frequency at which the in-stream DO would fall below the DO standard?” In contrast, another question could be asked, “Would using more than one pump at certain times prevent the DO from falling to values less than the standard some or all the time?” These questions cannot be answered by this study. The DO levels were less than the 5.0 mg/L DO standard approximately 7.48 percent of the time in reference to the FDC data (table 17) or 2.62 percent of the time in reference to the *z*-T data (table 18) for the 2016 hours of period 4.

The SEPA station 2 appears to be no more effective than SEPA station 1 in increasing waterway DO levels. The DO profiles presented in figures 25 and 26 demonstrate this. Note that the DO profiles between SEPA station 1 and continuous monitoring station 7, immediately below SEPA station 2, show a continuous drop or sag without any evidence of immediate increases in DO levels at the stations or significant reductions in the slope of the DO profiles below the stations. This can be attributed to natural processes in DO consumption during warm weather associated with long travel times in this reach of 7.39 river miles. Possible contributions could come from periodic and/or fluctuating flows from Lake Calumet and the Grand Calumet River and operations

Similarly, a good estimate of what the DO concentration would have been near the mouth of the Cal-Sag Channel, in the absence of SEPA stations 3 and 4 on July 24, 1996, can be made by subtracting the combined DO drops between SEPA stations 3 and 4 and SEPA stations 4 and 5 from the 3.35 mg/L mean cross-sectional DO recorded at the SEPA station 3 intake. On July 24, 1996, the SEPA station 4 outfall DO was 8.42 mg/L with two pumps operating (240 cfs). The mean cross-sectional values at the intakes of SEPA stations 4 and 5 were 3.46 and 3.78 mg/L (table 12), respectively. The computed, mass balance, completely mixed DO value of the SEPA station 4 transect is 4.54 mg/L. Consequently, the DO drop between SEPA stations 4 and 5 is 4.54 - 3.78 or 0.76 mg/L. The total drop in DO between SEPA stations 3 and 5 would be 1.01 + 0.76 or 1.77 mg/L. Therefore, in the absence of SEPA stations 3 and 4, the DO at the mouth of the Cal-Sag Channel would have been approximately 3.35 - 1.77 or 1.58 mg/L. The actual value would be somewhat, but not significantly, greater than 1.58 mg/L due to DO input from natural in-stream aeration.

The operation of SEPA stations 3 and 4 appear to be doing a good job of preventing the DO levels from becoming less than the DO standard during critical warm-weather, low-flow conditions as the following shows:

Percent of Time Mean Cross-sectional DO Exceeds DO Standard of 3.0 mg/L

SEPA station	*Period 3*		*Period 4*	
intake	*FDC*	*z-T*	*FDC*	*z-T*
4	96	96	92	99
5	95	96	96	98

These results are very positive and show SEPA stations 3 and 4 successfully prevent DO levels from becoming less than the DO standard for the Cal-Sag Channel. This is a testament to: (1) excellent SEPA station designs that produce 90 to 100 percent DO saturation output, (2) proper engineering design relative to longitudinal placement of each SEPA station along the waterway, and (3) excellent operation and management of each SEPA station.

The DO values below SEPA station 3 were less than the DO standard of 3.0 mg/L on one date (6/19/1996), during which manual cross-sectional DO/temperature measurements were made (table 13). These low DO values, plus the fact that only two pumps were in operation at the time at SEPA stations 3 and 4, permitted making evaluations relative to increasing DO concentrations above the stream standard by increasing pumping rates at SEPA stations 3 and 4. The results of these evaluations are summarized as:

Evaluation of Mean Cross-sectional DO Values at SEPA Station Intakes under Various Pump Operations and Scenarios

	Number of pumps operating at SEPA station		*Mean cross-sectional DO (mg/L) at intake of SEPA station*		
Scenario	*3*	*4*	*3*	*4*	*5*
1	2	2	3.83	2.47	1.97
2	3	2	3.83	3.18	2.48
3	3	3	3.83	3.18	3.28

Scenario 1 represents observed ambient conditions; the experimental design for this period specified that only two pumps were to be operated at SEPA stations 3 and 4. A three-pump operation at SEPA station 3 probably would have increased the mean cross-sectional DO significantly above 3.18 mg/L at SEPA station 4, but to maintain such a level at SEPA station 5, three pumps would have had to be used at SEPA station 4. The tabular FDC and *z*-T percentages presented here may have been greater if pumping rates had not been controlled as per experimental design specifications (table 4). The pumping rate flexibility of the SEPA stations appear to be more than adequate to prevent DO levels from being less than the standard within the Cal-Sag Channel under a wide range of conditions. However, consideration should be given to operating SEPA stations 3 and 4 at pumping rates in excess of those needed to solely maintain the DO standards of the Cal-Sag Channel. Pumping rates beyond this minimal requirement appear to significantly improve in-stream DO values as far downstream as Lockport. Information in support of this will be presented and discussed in detail later.

Analyzing the effects of SEPA station 5 on in-stream DO is more complicated, and the results are less determinant, than those just presented for SEPA stations 3 and 4. Complicating factors involve having to: (1) split SEPA station 5 outfall flows, (2) combine two waterway flows, and (3) analyze downstream conditions without the reach terminating at a SEPA station. Illustrative analyses will be presented for various scenarios for the two dates, July 24 and June 19, 1996, used to examine the influences of SEPA stations 3 and 4 on in-stream DO along the lower reaches of the Cal-Sag Channel.

The computed, completely mixed DO in the Chicago Sanitary and Ship Canal immediately below SEPA station 5 was 3.98 mg/L for the July 24, 1996, conditions. It was derived using the following criteria: ambient DO values at monitoring stations 15 and 16 are 3.78 and 3.82 mg/L, respectively; ambient outfall DO values are 8.30 mg/L; and outfall, Chicago Sanitary and Ship Canal, and Cal-Sag Channel flows are 116, 1890, and 1102 cfs, respectively. The Chicago Sanitary and Ship Canal DO is raised 0.16 mg/L (3.98 – 3.82) with only one pump operating as was specified by the experimental design criteria (table 4). Completely mixed DO concentrations in the Chicago Sanitary and Ship Canal immediately downstream of SEPA station 5 for July 24, 1996, conditions are presented below for various pumping rates:

Chicago Sanitary and Ship Canal below SEPA station 5 and at Lockport for ambient conditions, as well as other pumping rates, are presented:

Completely Mixed DO Concentrations on Chicago Sanitary and Ship Canal Immediately below SEPA Station 5 and at Lockport, June 19, 1996

	Operating pumps at SEPA station			*Mean cross-sectional DO (mg/L)*	
Scenario	***3***	***4***	***5***	*Immediately below SEPA station 5*	*Lockport*
1	2	2	1	3.34	0.53
2 (ambient)	2	2	2	3.59	0.77
3	2	2	3	3.81	1.00
4	2	2	4	4.04	1.23
5	3	3	1	3.64	0.83
6	3	3	2	3.83	1.02
7	3	3	3	4.02	1.21
8	3	3	4	4.20	1.39

Note that, under the June 19 extreme conditions, three-pump operations at SEPA stations 3 and 4 and a four-pump operation at SEPA station 5 produced a mean DO at Lockport that is considerably less than the 4.0 mg/L DO standard. The June 19, 1996, conditions may appear to be extreme, but similar "extremes" often were recorded via continuous monitoring as illustrated by the DO plots for monitoring stations 21t (near surface), 21m (mid-depth), and 21b (bottom) at Lockport (appendix B).

The DO values at Lockport for the warm-weather, low-flow conditions, similar to those encountered during periods 3 and 4 of this study, can be expected to be less than 4.0 mg/L at the frequencies presented:

Expected Frequency of Hours when DO Would be Less than 4.0 mg/L Standard DO at Lockport, 1996

Location on	*Period 3 (5/31-7/03)*		*Period 4 (7/04-9/25)*	
Lockport vertical	*FDC*	*z-T*	*FDC*	*z-T*
Near surface	50.1	57.5	71.7	74.2
Mid-depth	55.7	61.4	69.0	68.1
Bottom	51.0	51.2	51.7	54.4

Note: Percentage values from tables 17 and 18.

The following tabulation presents the mean cross-sectional DO concentrations that would have been needed for various pumping rates at SEPA station 5, with three-pump operations at SEPA stations 3 and 4, to maintain DO values of 4.0 mg/L at Lockport on June 19 and July 24, 1996. These dates are the only two for which the mean DO at Lockport was less than the DO standard of 4.0 mg/L for the dates when cross-sectional DO measurements were taken.

DO Required in Chicago Sanitary and Ship Canal above SEPA Station 5 to Maintain 4.0 mg/L Standard DO at Lockport, 1996

Operating pumps	*DO (mg/L) required*

intake value of 6.08 mg/L, whereas the “mixed value” of 6.22 mg/L was significantly greater.

The positive impacts of SEPA stations 3, 4, and 5 are much more evident than those for SEPA stations 1 and 2, in reference to both the immediate downstream monitoring station results and the computed, completely mixed results. For example, for SEPA station 3, the means for the monitoring station below SEPA station 3 (monitoring station 10) and the computed, “mixed value” are, in order, 0.56 mg/L and 0.86 mg/L greater than the 4.84 mg/L mean intake value.

The drop in the DO values between the SEPA stations and the immediate downstream monitoring stations (2, 7, 10, 13, and 17), as depicted on figures 24-27, are an artifact of location. These drops are not caused by a lack of DO input from the SEPA stations. Of the 20 SEPA station area subprofiles (shown on figures 24-27), 12 exhibit oxygen depletion immediately downstream. This is illusionary and would not appear as such if “completely mixed” values could have been computed and plotted for each period. The fact that an immediate DO sag did not occur during the four scenarios for SEPA station 4 (shown on figures 24-27) should not be interpreted as SEPA station 4 doing a better job or being a more efficient aerator than the other four SEPA stations. It only appears that SEPA station 4 is more efficient because monitoring station 13, located immediately downstream, more closely approximates completely mixed conditions than the other downstream monitoring stations 2, 7, 10, and 17.

Data presented in table 22 reveal many daily situations for which the recorded mean cross-sectional DO values immediately below the SEPA stations are actually lower than the intake values when, in reality, they are not as evidenced by the computed “mixed” values. This is best exemplified by conditions for the intake at SEPA station 2 (monitoring station 6) and downstream monitoring station 7. Of the 11 dates for which all three values are available in table 22, for SEPA station 2, only one exhibited a cross-sectional mean DO at monitoring station 7 which was equal to or greater than that at monitoring station 6. However, the computed, completely mixed values were greater for all 11 dates (table 22) in spite of the fact that the DO load discharged by SEPA station 2 was relatively small.

Although the cross-sectional means below SEPA stations 3 and 4 (monitoring stations 10 and 13, respectively) are generally higher than the intake values, the computed “mixed” values are all greater than those recorded for each date. On a number of dates, the “mixed” values were much greater than the recorded values. For example, below SEPA station 4 on June 19, 1996, the recorded mean cross-sectional DO value was only 2.66 mg/L versus a computed, completely mixed value of 4.27 mg/L. And on September 18, 1996, the mean cross-sectional value recorded at monitoring station 13, below SEPA station 4, was 0.10 mg/L less than the cross-sectional mean recorded at monitoring station 12 (SEPA station 4 intake).

The absolute effects of each station and the relative effects between stations on in-stream DO is demonstrated by the data in table 23. For SEPA stations 2-5, intake DO values were computed for situations in which the upstream SEPA stations were assumed not operating and compared to ambient conditions. Note that the mean daily intake DO value at SEPA station 3 would have been reduced by only 0.13 mg/L if SEPA station 2 had not been operating; but without SEPA station 3 operating, the mean daily intake DO at SEPA station 4 would have been reduced by 0.86 mg/L. With SEPA stations 1-3 operating, but not SEPA station 4, the mean daily intake DO at SEPA station 5 would have been reduced by 1.08 mg/L. A summary of what the approximate mean DO values of table 23 would have been and their deviations from ambient for conditions without any SEPA station operation is as follows:

Summary of Projected Mean DO Values at SEPA Station Intakes with and without SEPA Operation

	Dissolved oxygen (mg/L)		
Intake at SEPA station	*With (ambient)*	*Without*	*Difference*
2	6.12	5.63	0.49
3	4.86	4.24	0.62
4	4.42	2.94	1.48
5	4.70	2.14	2.56

Although these results are based on only nine dates when manual cross-sectional measurements were taken, they are good indicators of the importance of each station. This summary and the daily results in tables 22 and 23 indicate that, if SEPA stations 1 and 2 were not operated, DO values at the intakes of SEPA stations 2 and 3 probably would not be less than the DO standard of 4.0 mg/L at SEPA station 2 and 3.0 mg/L at SEPA station 3. However, SEPA stations 3 and 4 are needed so that the DO values at the intake of SEPA station 5 are never less than the DO standard of 3.0 mg/L.

CONCLUSIONS

A field study was conducted between March 16 and November 19, 1996, to means. At 12 of 14 continuous monitoring stations, the hypothesis that the continuous monitoring point values and the cross-sectional means are equal proved to be true (95 percent confidence level). The two stations for which this hypothesis was rejected are below SEPA stations 3 (RM 317.62) and 4 (RM 310.70) on transects that are not completely mixed with SEPA station aerated water. These results indicate that continuous monitoring point data can be used to approximate cross-sectional means in the study area. For objective 2, the supplemental data generated between continuous monitoring stations indicated that the DO drops in long reaches are gradual and relatively smooth. This, in

Effectiveness of SEPA Station Operations, July 2, 1996

Condition	*DO (mg/L) at SEPA station* 2	3	4	5
With upstream SEPA operation	6.37	4.28	3.98	5.14
Without upstream SEPA operation	6.36	4.13	2.83	2.16
DO standard	4.00	3.00	3.00	3.00

On July 2, 1996, SEPA station 1 contributed only 0.1 mg/L of DO to the mean cross-sectional DO at the intake of SEPA station 2, and SEPA stations 1 and 2 combined contributed only 0.15 mg/L of DO to the mean cross-sectional DO at the intake of SEPA station 3. Furthermore, in both instances the DO values at these locations would have remained well above the standard if one or both stations had not been operating. The situation below SEPA station 3 is entirely different. Both SEPA stations 3 and 4 generated DO loads that were needed to maintain DO standards. Without SEPA stations 3 and 4 operating, the mean cross-sectional DO at the intake of SEPA station 5 would have been almost 1.0 mg/L less than the standard. This example is typical of daily events as they occurred during this study period. The DO data generated by the continuous monitors support this contention. During the overall study period, the DO standard at the intake of SEPA station 3 was exceeded 99.33 percent of the time. The supplemental oxygen injected at SEPA stations 1 and 2 played an insignificant role in producing this high percentage.

During the study period, SEPA stations 3 and 4 were well managed relative to maintaining at least a 3.0 mg/L DO concentration in the Cal-Sag Channel. During warm-weather, low-flow periods 3 and 4, the DO standard was exceeded approximately 98.1 percent of the time at the intake of SEPA station 4 and 96.5 percent of the time at the intake of SEPA station 5. For the entire study period, the DO standard was exceeded 98.6 percent of the time at the intake of SEPA station 4 and 97.5 percent of the time at the intake of SEPA station 5. These high percentages were achieved without having to routinely operate either SEPA station at full capacity. Three pumps were operated only 1.6 percent of the time at SEPA station 3 and 2.4 percent of the time at SEPA station 4 during the study.

The results of the Phase II part of this study (Butts et al., 1999) showed that SEPA station 5 was a highly efficient aerator. This finding is supported by data derived from this in-stream (Phase I) study. Although SEPA station 5 was operated at less than 50 percent of its maximum pumping capacity of 461.6 cfs 50 percent of the time for critical warm-weather, low-flow conditions from May 31 through September 25, 1996, significant improvements in DO were achieved at least 4 miles downstream on the Chicago Sanitary and Ship Canal, This is illustrated by the following tabulation showing the percent of the time the DO was less than the standard of 4.0 mg/L at three locations below SEPA station 5 compared to the percentage in the Chicago Sanitary and Ship Canal above SEPA station 5.

Percent of Time DO Value Was Less than the 4.0 mg/L Standard DO

Continuous monitoring station description	*Chicago Sanitary and Ship Canal (RM)*	*Miles above/below SEPA station 5*	*Percent*
Highway 83	304.69	1.10 above	59.4
SEPA station 5	303.59	-	-
Power lines	302.56	1.03 below	22.5
Slip No. 2	299.55	4.04 below	25.1
Lockport	291.20	12.39 below	63.0

The combined DO inputs from SEPA stations 3, 4, and 5 did not prevent the DO from being less than 4.0 mg/L in the Chicago Sanitary and Ship Canal. But it significantly reduced the frequency of occurrence at sites at least 4 miles downstream of SEPA station 5 relative to what occurred at the Highway 83 continuous monitoring station 16, above SEPA station 5.

The theoretical effects of operating SEPA stations 3, 4, and 5 at maximum pumping capacities during warm-weather, low-flow conditions was investigated. The results indicated that significant increases in DO levels in the Chicago Sanitary and Ship Canal below SEPA station 5 could be achieved by operating all three SEPA stations at maximum practical pumping rates. This was exemplified by conditions during June 19, 1996. Two pumps were operating at SEPA stations 3 and 4 and three pumps were operating at SEPA station 5. The completely mixed DO at a cross section immediately below SEPA station 5 was computed as 3.81 mg/L, and the observed DO at Lockport was 1.0 mg/L. For three-pump operations at SEPA stations 3 and 4 and a four-pump operation at SEPA station 5, the computed, completely mixed and Lockport DO values were 4.20 mg/L and 1.39 mg/L, respectively. This suggests that, when DO values at Lockport are less than 4.0 mg/L during periods of less than maximum SEPA station pumping rates, significant improvements in DO levels can be achieved below SEPA station 5 by increasing pumping rates at all three SEPA stations. For DO values at Lockport, which are marginally lower than the DO standard (e.g., 3.70 mg/L for two-pump operations at all three stations), maximum pumping rates probably would raise DO levels above 4.0 mg/L. However, for extremely low DO levels at Lockport (as was exemplified for June 19, 1996, conditions) maximum pumping rates alone will not prevent DO levels from falling below 4.0 mg/L and supplemental oxygen would be needed. For example, the in-stream DO in the Chicago Sanitary and Ship Canal above SEPA station 5 would have had to be increased from 3.53 mg/L to 6.78 mg/L to achieve 4.0 mg/L of DO at Lockport if maximum SEPA station pumping had been in effect on June 19, 1996. Similarly, but for

The use of continuous monitors can be a highly effective and efficient method of generating data for short-term, intensive studies or for conducting long-term monitoring when used judiciously with a fine-tuned QA/QC program. Approximately an 88 percent data recovery rate was experienced during this study, which is good to excellent considering the magnitude of the study and the obstacles that had to be overcome to make the study successful.

REFERENCES

Butts, T.A. 1988. *Development of Design Criteria for Sidestream Elevated Pool Aeration Stations*. Illinois State Water Survey Contract Report 452.

Butts, T.A., D.B. Shackleford, and T.R. Bergerhouse. 1999. *Evaluation of Reaeration Efficiencies of Sidestream Elevated Pool Aeration (SEPA) Stations*. Illinois State Water Survey Contract Report 653.

Illinois Environmental Protection Agency. 1993. *Title 35: Environmental Protection; Subtitle C: Water Pollution, Chapter I: Pollution Control Board*. State of Illinois Rules and Regulations, Springfield, IL.

Macaitis, B., J. Variakojis, and B. Kuhl. 1984. *A Planning Feasibility Report on Elevated Pool Aeration Stations*. The Metropolitan Sanitary District of Greater Chicago, Chicago, IL.

Table 1. Engineering Design Features of SEPA Stations

Station			*Pumps*			*Weirs*			*Design maximum flow (cfs)*
							Height (ft)		
No.	*Location*	*River mile*	*Type*	*No.*	*Size*	*No.*	*Per weir*	*Total*	

Table 3. Transect Horizontal-Vertical Location of Monitor Sensors at Monitoring Stations

	Horizontal location (ft) referenced to bank looking downstream			*Total water*	*Probe distance (in) from*	
Station	*Distance (ft)*	*Left*	*Right*	*depth (ft)*	*Surface*	*Bottom*
1	15		X	14		3
2	200		X	30		3
6	50		X	3	20	
7	0	X		7	60	
9	0		X	3	30	
10	0	X		8		3

Table 6. Data Analysis Periods, 1996

Period	*Inclusive dates*	*No. days*	*SEPA stations operating*	*Discretionary diversion (cfs)**		*No. DO cross section profiles*
				Planned	*Actual*	
1	03/16 - 04/18	34	0	0	0	1
2	04/19 - 05/30	42	5	0	199	2
3	05/31 - 07/03	34	5	192	162	3
4	07/04 - 09/25	84	5	384	380	6
5	09/26 - 10/31	36	5	192	336	2
6	11/01 - 11/19	19	0	0	0	1
1-6	03/16 - 11/19	249	0-5	0-384	0-380	15

Note: * Daily mean diversion

Table 7. Chronological Review of Monitor Installation and Exchange Schedule, 1996

	Station																				
Date	*1*	*2*	*6*	*7*	*9*	*10*	*12*	*13*	*14*	*15*	*16*	*17*	*1*	*1*	*4*	*e*	*o*	*T*	*c*	*1*	*T*

Table 8. Continuous Monitoring Data Available at Monitoring Stations, March 13-November 20, 1996

	Period	*Periodic data*	*Period*	*Periodic data*

5

Table 9. Number of Usable Hourly DO Values for Recorded Continuous Monitoring Stations, March 16-November 19, 1996

	Monitoring periods						
Station	*1*	*2*	*3*	*4*	*5*	*6*	*1-6*
1	815	996	512	1275	260	322	4180
2	780	684	816	940	331	349	3900
6	814	736	514	2015	508	456	5043
7	36	1005	814	2015	508	456	4834
9	815	1007	815	2012	864	456	5969

Table 10. Summary by Period of DO and Temperature Measurements, March 16-November 19, 1996

DO	*Temperature (°C)*	*DO (mg/L)*	*Temperature (°*

Table 10. Concluded

Station	DO std.	*Temperature (℃)*			*DO (mg/L)*			*Temperature (℃)*			*DO (mg/L)*		
		Min	*Mean*	*Max*	*Min*	*Mean*	*Max*	*Min*	*Mean*	*Max*	*Min*	*Mean*	*Max*
		Period 5 (09/26 - 10/31)						Period 7 (03/16 - 11/19)					
1	5.0	13.10	15.82	20.36	7.05	8.01	8.47	4.52	15.71	25.69	5.10	8.33	12.66
2	"	13.28	15.62	20.44	7.33	9.38	10.64	3.29	15.73	25.15	3.42	8.72	13.45
6	4.0	12.57	16.50	20.15	5.64	7.25	8.76	6.67	17.99	27.88	0.88	6.67	10.38
7	"	13.27	16.74	20.44	5.26	6.86	8.04	11.62	19.02	26.02	0.28	5.98	9.83
9	3.0	12.22	16.83	20.15	4.68	6.48	8.13	6.21	17.54	26.74	2.48	6.10	10.78
10	"	11.99	16.82	19.98	4.72	6.43	8.12	6.25	17.13	25.26	2.57	5.91	10.41
12	"	11.88	16.50	20.23	4.31	6.37	8.40	6.42	17.51	26.44	0.92	3340.3(11.99	8.c340

Table 11. Concluded

Table 12. Summary of Cross-Sectional DO and Temperature Data by Station, Including Monitor Readings at Continuous Monitoring Stations, 1996

	Monitor reading		*Cross-sectional data*							
			Begin		*DO (mg/L)*			*Temperature (°C)*		
Date	*DO (mg/L)*	*Temp (°C)*	*time*	*N*	*Min*	*Mean*	*Max*	*Min*	*Mean*	*Max*
Station 1, RM 328.10, DO std = 5.0 mg/L										
03/28	11.53	5.30	1525	12	11.30	11.40	11.63	5.1	5.3	5.4
04/23	8.71	11.01	1505	19	9.05	10.84	12.27	11.3	11.5	11.8
05/22	7.72	18.76	1820	15	8.74	9.58	10.20	18.2	19.2	19.9
06/05	-	-	1528	32	7.44	8.04	9.09	17.8	18.6	19.8
06/19	7.42	20.06	0946	46	7.41	7.48	7.54	19.5	19.9	20.1
07/02	7.80	22.22	1004	46	7.34	7.48	7.61	22.1	22.4	22.8
07/10	7.45	21.84	1118	43	7.13	7.32	7.73	21.6	21.9	22.3
07/17	7.23	22.90	0932	35	7.07	7.24	7.46	21.6	22.8	23.0
07/24	5.65	23.15	1009	30	6.13	6.31	6.61	23.4	23.5	23.9
07/31	-	-	1005	32	6.77	7.05	7.31	22.4	22.6	22.8
09/04	7.08	24.23	0945	29	6.92	7.23	7.63	24.0	24.2	24.7
09/18	6.96	22.05	0829	35	5.77	6.70	7.72	21.8	21.9	22.0

Table 12. Continued

	Monitor reading		Cross-sectional data		
Date	DO (mg/L)	Temp (°	Begin	DO (mg/L)	Temperature (°C)

Table 12. Continued

Date	Monitor reading DO (mg/L	Cross-sectional data Begin	DO (mg/L)	Temperature (℃)

Table 12. Continued

Date	Monitor reading DO (mg/L)	Monitor reading Temp (℃)	Begin time	N	DO (mg/L) Min	DO (mg/L) Mean	DO (mg/L) Max	Temperature (℃) Min	Temperature (℃) Mean	Temperature (℃) Max
Station 10, RM 317.62, DO std = 3.0 mg/L										
03/28	8.55	7.35	0956	11	8.49	8.59	8.66	7.5	7.5	7.6
04/23	-	-	0951	42	6.24	7.16	8.38	11.7	12.1	12.6
05/22	4.34	17.85	1057	39	4.77	6.95	9.54	17.9	18.2	19.5
06/05	5.11	16.75	1052	26	4.90	5.44	6.74	16.4	16.8	17.8
06/19	4.16	20.91	1454	20	3.54	4.21	4.82	20.7	20.7	20.9
07/02	4.58	23.95	0956	24	4.87	5.37	5.75	23.6	23.8	24.3
07/10	-	-	0943	31	5.87	6.17	6.62	22.2	22.3	22.6
07/17	6.15	23.74	1015	33	5.59	5.82	6.07	23.6	23.7	23.8
07/24	3.50	21.88	0946	33	3.21	3.90	5.07	21.6	21.7	21.9
07/24	3.85	22.77	1550	24	3.56	4.25	5.12	22.5	22.6	22.8
07/31	-	-	1022	25	3.93	4.67	5.93	21.0	21.2	21.5
09/04	5.85	24.26	1330	25	5.50	5.79	6.13	24.1	24.2	24.6
09/18	5.62	21.00	1312	25	5.62	6.10	6.52	20.7	21.1	21.8
10/22	6.23	16.18	1132	10	7.78	7.96	8.06	16.0	16.1	16.1
10/30	6.23	14.35	1250	18	6.28	6.72	7.20	14.1	14.3	14.4
11/13	6.99	10.05	1323	11	6.80	7.12	7.32	9.9	10.0	10.0
Station 11, RM 316.00, DO std = 3.0 mg/L										
03/28			0930	14	7.98	8.07	8.21	7.2	7.2	7.2
04/23			0858	41	6.24	8.12	9.26	11.7	12.1	12.3
05/22			0953	39	4.93	7.70	8.91	17.4	17.7	18.2
06/05			1148	24	5.12	5.25	5.57	16.5	16.9	17.9
06/19			1329	23	3.77	4.20	4.63	21.1	21.2	21.3
07/02			0905	26	4.35	4.89	5.19	24.1	24.2	24.3
07/10			1036	29	5.91	6.30	7.00	22.5	22.8	23.6
07/17			1048	33	4.99	5.33	5.54	23.6	23.7	23.7
07/24			1025	33	3.62	3.85	4.27	21.7	21.9	22.4
07/31			1112	26	4.00	4.37	4.75	20.9	21.1	21.7
09/04			1545	27	5.68	5.87	6.16	24.2	24.4	24.5
09/18			1238	27	5.25	5.60	5.85	20.7	21.0	21.4
10/22			1112	9	7.15	7.21	7.38	15.6	15.7	15.7
10/30			1314	20	6.07	6.29	6.48	14.3	14.4	14.4
11/13			1342	5	6.93	6.99	7.12	9.3	9.4	9.4
Station 12, RM 311.55, DO std = 3.0 mg/L										
03/28	8.23	7.05	1646	8	8.78	8.88	9.10	6.8	6.9	7.1
04/23	6.47	12.21	0929	21	6.18	6.29	6.43	11.9	12.0	12.0
05/22	4.22	18.27	1003	23	3.56	3.62	3.70	17.8	17.9	18.1
06/05	4.80	17.55	1300	24	4.85	5.00	5.18	17.1	17.4	18.1
06/19	2.40	21.61	1241	20	2.04	2.47	2.67	21.1	21.2	21.5
07/02	3.88	24.79	0844	17	3.78	3.94	4.17	24.5	24.6	24.9
07/10	5.60	23.57	1133	37	5.36	6.13	7.06	22.8	23.3	24.0
07/17	4.48	24.06	1207	29	4.34	4.78	5.09	23.6	23.8	23.8
07/24	3.47	22.77	1102	23	3.41	3.46	3.51	22.2	22.3	22.4
07/31	3.57	22.13	1201	23	3.57	3.76	3.96	21.4	21.5	21.8
09/04	5.74	24.29	1120	23	5.29	5.36	5.55	24.0	24.2	24.5
09/18	6.79	21.31	1152	23	5.68	5.90	6.66	20.4	20.6	21.3
10/22	6.47	15.53	1038	17	7.06	7.38	7.56	15.4	15.4	15.4
10/30	8.32	14.22	1358	14	7.21	7.31	7.53	14.0	14.1	14.2
11/13	6.90	8.29	1303	13	6.41	6.60	6.78	8.1	8.2	8.2

Table 12. Continued

Monitor reading	Begin	Cross-sectional data DO (mg/L)	Temperatu

Table 12. Continued

	Monitor readina	Beain	Cross-sectional data DO

Table 13. Summary of Mean Cross-sectional DO and Temperature Values by Date

Station	River mile	Mean DO (mg/L)	Mean Temp (°C)	Mean DO (mg/L)	Mean Temp (°C)	Mean DO (mg/L)	Mean Temp (°C)	Mean DO (mg/L)	Mean Temp (°C)
		03/28/96		05/22/96		06/19/96		07/10/96	
1	328.10	11.40	5.3	9.58	19.2	7.48	19.9	7.32	21.9
2	327.69	12.69	4.4	9.54	18.8	7.17	19.9	7.72	21.9
3	326.62	13.89	4.0	10.64	18.7	6.69	20.5	7.00	22.2
4	325.31	12.61	4.8	4.80	19.5	0.52	21.1	6.88	22.7
5	322.66	15.33	4.5	6.80	20.6	6.03	22.0	7.58	23.2
6	321.32	7.81	10.1	6.74	19.4	5.32	19.4	6.85	22.7
7	320.71	7.49	9.9	5.09	18.6	4.70	19.6	6.85	22.9
8	318.51	8.54	8.1	4.79	18.8	3.89	20.6	6.76	22.9
9	318.08	9.00	7.7	5.55	18.7	3.83	20.6	5.82	22.2
10	317.62	8.59	7.5	6.95	18.2	4.21	20.7	6.17	22.3
11	316.00	8.07	7.2	7.70	17.7	4.20	21.2	6.30	22.8
12	311.55	8.88	6.9	3.62	17.9	2.47	21.2	6.13	23.3
13	310.70	8.86	6.9	4.19	18.2	2.66	21.2	7.25	23.6
14	307.13	9.47	7.2	3.97	19.2	2.03	21.3	7.04	23.8
15	303.63	8.42	7.0	4.25	18.9	1.97	21.1	7.65	24.0
16	304.69	7.70	10.0	4.80	18.8	3.53	20.7	4.35	23.6
17	302.56	8.19	8.6	4.64	18.9	2.88	21.0	5.07	23.7
18	299.55	8.40	8.5	4.49	18.9	2.22	21.3	4.84	23.8
19	296.19	8.09	8.2	4.36	19.1	1.50	21.4	4.58	24.0
20	295.34	8.03	8.3	4.28	20.3	1.36	23.2	4.55	27.2
21	291.20	6.93	12.5	4.06	20.6	1.00	21.2	4.04	27.1
		04/23/96		06/05/96		07/02/96		07/17/96	
1	328.10	10.84	11.5	8.04	18.6	7.48	22.4	7.24	22.8
2	327.69	13.04	11.1	8.39	18.4	7.15	22.9	7.12	22.9
3	326.62	10.70	11.3	8.20	18.2	6.27	23.4	6.60	22.9
4	325.31	4.32	12.5	6.12	18.2	5.89	24.1	6.02	23.5
5	322.66	8.27	13.2	6.30	18.4	6.07	25.5	7.03	23.9
6	321.32	6.58	13.4	5.76	16.7	6.32	23.4	6.11	22.9

Table 13. Concluded

Station	River mile	Mean DO (mg/L)	Mean Temp (℃)	Mean DO (mg/L)	Mean Temp (℃)	Mean DO (mg/L)	Mean Temp (℃)	Mean DO (mg/L)	Mean Temp (℃)
		07/24/96		09/04-05/96		10/22-23/96		11/13/96	
1	328.10	6.31	23.5	7.23	24.2	9.27	14.9	8.91	9.2
2	327.69	6.13	23.5	7.59	24.2	9.26	14.9	9.27	8.6
3	326.62	5.20	23.2	7.14	24.0	8.99	14.7	9.60	7.3
4	325.31	5.28	23.6	6.88	24.2	8.22	15.0	8.44	6.6
5	322.66	4.61	23.8	7.41	24.4	8.24	14.6	9.31	5.4
6	321.32	4.84	22.6	6.41	24.0	8.25	16.8	6.92	12.2
7	320.71	4.35	23.1	5.60	24.4	7.87	16.8	6.59	12.9
8	318.51	-	-	5.60	24.1	7.47	16.1	6.92	10.8
9	318.08	3.35	21.6	5.80	24.1	7.45	16.1	7.05	10.7
10	317.62	3.90	21.7	5.79	24.2	7.96	16.1	7.12	10.0
11	316.00	3.85	21.9	5.87	24.4	7.21	15.7	6.99	9.4
12	311.55	3.46	22.3	5.36	24.2	7.38	15.4	6.60	8.2
13	310.70	3.96	22.3	5.98	24.5	7.69	15.4	6.48	8.1
14	307.13	3.97	22.3	5.37	24.1	7.55	15.3	6.24	7.6
15	303.63	3.78	22.1	5.59	24.3	7.17	14.9	6.02	8.5
16	304.69	3.82	23.8	-	-	5.64	19.9	6.03	14.0
17	302.56	3.96	22.6	5.96	25.5	6.33	18.4	6.42	12.0
18	299.55	3.77	22.5	4.84	25.8	5.93	18.4	6.30	11.6
19	296.19	3.58	22.4	4.81	26.2	5.95	18.2	5.98	12.3
20	295.34	3.57	23.7	4.59	29.6	-	-	5.60	15.5
21	291.20	3.12	23.3	4.49	28.0	4.47	28.1	5.47	15.0
		07/31/96		09/18-19/96		10/30/96			
1	328.10	7.05	22.6	6.70	21.9	8.96	14.5		
2	327.69	7.70	22.8	7.69	21.9	9.37	14.2		
3	326.62	7.06	23.0	7.59	21.7	9.21	13.8		
4	325.31	4.53	22.9	7.54	21.3	8.65	13.4		
5	322.66	4.78	23.4	7.70	21.2	8.93	13.1		
6	321.32	5.77	22.3	6.74	21.6	7.47	15.2		
7	320.71	5.35	22.4	6.68	21.8	6.91	15.3		
8	318.51	4.64	21.6	6.00	21.3	6.55	14.2		
9	318.08	4.22	21.0	5.70	21.1	6.22	14.2		
10	317.62	4.67	21.2	6.10	21.1	6.72	14.3		
11	316.00	4.37	21.1	5.60	21.0	6.29	14.4		
12	311.55	3.76	21.5	5.90	20.6	7.31	14.1		
13	310.70	3.91	21.6	5.80	20.2	7.51	14.0		
14	307.13	3.15	21.6	5.20	20.0	7.36	13.8		
15	303.63	3.85	21.8	5.62	21.5	7.10	14.5		
16	304.69	4.04	23.7	5.17	21.9	6.17	19.0		
17	302.56	4.39	22.5	5.11	21.2	6.38	16.7		
18	299.55	4.49	22.5	4.94	21.4	5.87	17.6		
19	296.19	4.65	22.6	4.97	22.0	5.98	17.3		

Table 14. Unweighted and Weighted DO Means for Cross-sectional Measurements with Worst-Case Conditions, 1996

a. Data

		Mean DO (mg/L)	
Station	*Date*	*Unweighted*	*Weighted*

Table 15. Statistical Summary Comparing 1996 Continuous Monitoring DO

Notes: t = near the surface, m = mid-depth, and b = bottom.

Table 17. Percentage of Time DO Values Are Less than a Specified Value by Period Based on Hourly Data Using Frequency Distribution Curves

		Percentage of time less than
River	*D*	

Table 17. Concluded.

				Percentage of time less than													
				DO concentration (mg/L)							*DO concentration (mg/L)*						
Station	*Waterway*	*River mile*	*DO std. (mg/L)*	*1.0*	*2.0*	*3.0*	*4.0*	*5.0*	*6.0*	*7.0*	*1.0*	*2.0*	*3.0*	*4.0*	*5.0*	*6.0*	*7.0*
				Period 5 (864 hr. 09/26-10/31/96)							Period 6 (456 hr. 11/01-11/19/96)						
1	CR	328.10	5.0														
2	"	237.69	5.0														
6	LCR	321.32	4.0						2.00	29.03							22.48
7	"	320.71	4.0						4.94	64.37					0.14	2.36	53.73
9	CSC	318.08	3.0					1.80	18.85	79.98					0.41	12.53	68.86
10	"	317.62	3.0					1.65	22.04	83.06						12.06	77.19
12	"	311.55	3.0					5.35	26.45	80.40						12.26	50.44
13	"	310.70	3.0					2.19	18.77	63.03					7.85	25.00	73.19
14	"	307.15	3.0						18.51	86.60					2.32	45.82	89.96
15	"	303.63	3.0				0.25	6.88	48.43	92.87						5.70	50.00
16	CSSC	304.69	4.0	0.99	1.42	1.82	5.31	28.04	75.66	99.50							
17	"	302.56	4.0		0.29	1.59	3.83	7.64	63.14	99.86					1.23	32.58	91.81
18	"	299.55	4.0		0.34	1.30	5.33	29.93	89.79	99.94				0.13	6.14	41.94	96.93
21t	"	291.20	4.0		1.16	2.32	15.49	67.55	99.44	99.94					19.30	67.98	99.89
21m	"	"	4.0				3.13	17.19	84.79	99.81						44.65	92.84
21b	"	"	4.0				2.28	18.77	90.11	99.81					8.13	56.04	98.46
				Period 1-6 (5976 hr, 03/16-11/19/96)								"					
1	CR	328.10	5.0						9.80	45.57							

Table 18. Percentage of Time DO Values Are Less than a Specified Value by Period Based on Hourly Data Using *z*-table Statistics

				Percentage of time less than													
		River	*DO std.*	*DO concentration (mg/L)*							*DO concentration (mg/L)*						
Station	*Waterway*	*mile*	*(mg/L)*	*1.0*	*2.0*	*3.0*	*4.0*	*5.0*	*6.0*	*7.0*	*1.0*	*2.0*	*3.0*	*4.0*	*5.0*	*6.0*	*7.0*
				Period 1 (816 hr, 03/16-04/18/96)							Period 2 (1008 hr, 04/19-05/30/96)						
1	CR	328.10	5.0							<0.02						<0.	

Table 18. Concluded

				Percentage of time less than													
				DO concentration (mg/L)							*DO concentration (mg/L)*						
Station	*Waterway*	*River mile*	*DO std. (mg/L)*	*1.0*	*2.0*	*3.0*	*4.0*	*5.0*	*6.0*	*7.0*	*1.0*	*2.0*	*3.0*	*4.0*	*5.0*	*6.0*	*7.0*
				Period 5 (864 hr, 09/26-10/31)							Period 6 (456 hr, 11/01-11/19/96)						
1	CR	328.10	5.0							<0.02							<0.02
2	"	237.69	5.0						<0.02	0.19							<0.02
6	LCR	321.32	4.0					<0.02	1.29	32.64						<0.02	21.19
7	"	320.71	4.0					<0.02	4.55	60.64					<0.02	1.70	54.38
9	CSC	318.08	3.0				<0.02	1.13	22.96	78.81				<0.02	0.26	12.30	68.08
10	"	317.62	3.0				<0.02	1.43	25.46	80.78				<0.02	0.13	13.57	78.81
12	"	311.55	3.0			<0.02	0.10	3.67	31.56	79.39				<0.02	0.11	8.23	60.26
13	"	310.70	3.0				<0.02	1.22	17.88	65.91			<0.02	0.17	4.46	31.56	77.34
14	"	307.15	3.0				<0.02	0.29	19.22	84.61			<0.02	0.09	5.16	44.04	90.82
15	"	303.63	3.0			<0.02	0.31	8.38	48.80	90.82				<0.02	0.19	7.78	52.39
16	CSSC	304.69	4.0		<0.02	0.60	7.21	33.72	73.57	95.25							
17	"	302.56	4.0			<0.02	0.64	14.92	65.54	96.78				<0.02	0.75	34.09	94.74
18	"	299.55	4.0		<0.02	0.08	4.09	36.69	85.77	99.34			<0.02	0.07	5.94	53.19	95.73
21t	"	291.20	4.0		<0.02	1.19	18.14	67.36	96.41	99.92			<0.02	0.27	14.46	74.22	99.11
21m	"	"	4.0			<0.02	1.02	23.27	80.51	99.29				<0.02	1.70	48.97	94.06
21b	"	"	4.0			<0.02	0.51	27.76	91.62	99.96			<0.02	0.31	10.03	57.53	95.15

Station	*Waterway*	*River mile*	*DO std. (mg/L)*	*1.0*	*2.0*	*3.0*	*4.0*	*5.0*	*6.0*	*7.0*
				Period 1-6 (5976 hr, 03/16-11/19/96)						
1	CR	328.10	5.0			<0.02	0.11	0.94	5.05	17.36
2	"	237.69	5.0	<0.02	0.06	0.28	1.13	3.59	9.34	20.33
6	LCR	321.32	4.0	<0.02	0.02	0.31	2.33	10.56	30.85	59.87
7	"	320.71	4.0	<0.02	0.03	0.47	4.18	19.77	50.80	81.33
9	CSC	318.08	3.0	<0.02	0.13	1.16	6.18	21.19	47.21	74.54
10	"	317.62	3.0	<0.02	0.14	1.29	7.21	24.20	52.79	79.67
12	"	311.55	3.0	<0.02	0.23	1.83	9.18	28.10	56.75	82.38
13	"	310.70	3.0	<0.02	0.05	0.62	4.46	18.67	46.41	76.42
14	"	307.15	3.0	<0.02	0.23	1.66	7.93	24.51	51.20	77.34
15	"	303.63	3.0	0.05	0.48	3.07	12.30	32.64	60.26	83.65
16	CSSC	304.69	4.0	0.05	2.87	10.38	26.76	50.40	74.22	90.15
17	"	302.56	4.0	<0.02	0.16	1.92	11.70	37.45	71.23	92.51
18	"	299.55	4.0	0.03	0.47	3.51	15.39	40.90	71.23	91.15
21t	"	291.20	4.0	0.57	3.07	11.51	29.46	55.17	78.52	92.79
21m	"	"	4.0	0.57	2.94	10.38	26.43	50.00	73.57	89.62
21b	"	"	4.0	0.29	1.97	8.85	25.78	52.39	77.64	92.92

Notes: CR = Calumet River, LCR = Little Calumet River, CSC = Cal-Sag Channel, and CSC = Chicago Sanitary and Ship Canal, t = near surface, m = mid-depth, and b = bottom.

Table 19. Percentage of Occurrence When DO Values Were Less than 3.0 mg/L at Selected Stations, 1996

		Percent of time DO values are less than 3.0 mg/L on an hourly basis for period						
Station	*River mile*	*1*	*2*	*3*	*4*	*5*	*6*	*1-6*
15	303.63	0.00	0.00	4.90	4.02	0.00	0.00	2.00
16	304.69	0.00	4.11	13.30	12.23	1.82	0.00	7.86
5								
17	302.56	0.00	0.00	0.66	5.27	1.59	0.00	2.05
12	311.55	0.00	0.53	4.26	1.10	0.00	0.00	1.07
4								
13	310.70	0.00	0.00	1.36	1.66	0.00	0.00	0.78
9	318.08	0.00	0.00	1.26	0.00	0.00	0.00	0.18
3								
10	317.62	0.00	0.00	0.37	2.06	0.00	0.00	0.66

Note: Stations 3-5 are SEPA stations.

Table 20. Seasonal DO Summaries at SEPA Station Intakes for Hourly Readings, 1996

Location			*Hourly DO (mg/L) for seasonal periods*						
			1	*2*	*3*	*4*	*5*	*6*	*1-6*
SEPA station intake	*River mile*	*Hourly DO statistic*	*03/16-04/18*	*04/19-05/30*	*05/31-07/03*	*07/04-09/25*	*09/26-10/31*	*11/01-11/19*	*03/16-11/19*
1	328.10	minimum	7.71	7.47	6.55	5.10	7.05	8.79	5.10
		mean	10.46	8.46	7.54	6.96	8.01	9.45	8.33
		maximum	12.66	9.95	8.29	8.39	8.47	10.30	12.66
2	321.32	minimum	5.76	1.15	1.56	0.88	5.64	6.25	0.88
		mean	8.29	5.87	5.80	6.23	7.25	7.35	6.67
		maximum	10.38	8.62	9.32	8.93	8.76	8.21	10.38
3	318.08	minimum	5.94	3.59	2.48	3.15	4.68	4.79	2.48
		mean	8.28	6.34	4.91	5.28	6.48	6.71	6.10
		maximum	10.78	9.18	6.59	7.62	8.13	8.08	10.78
4	311.55	minimum	4.65	2.87	0.92	2.36	4.31	5.39	0.92
		mean	7.62	5.53	4.81	5.05	6.37	6.84	5.77
		maximum	9.46	8.47	8.73	7.65	8.40	8.15	9.46
5	303.63	minimum	5.97	3.04	1.39	2.30	3.93	5.60	1.39
		mean	7.74	5.61	4.81	4.60	6.02	6.96	5.63
		maximum	10.03	8.11	7.01	7.61	8.27	8.48	10.03

Table 21. Percent of Time DO Concentrations Are Less than Stream Standard at SEPA Station Intakes on Hourly Readings, 1996

Location			*Percent of time hourly DO Values are less than the DO standard for seasonal periods*						
			1	*2*	*3*	*4*	*5*	*6*	*1-6*
SEPA station intake	*River mile*	*DO std. (mg/L)*	*03/16-04/18*	*04/19-05/30*	*05/31-07/03*	*07/04-09/25*	*09/26-10/31*	*11/01-11/19*	*03/16-11/19*
1	328.10	5.00	0.00	0.00	0.00	0.00	0.04	0.00	0.47
2	321.32	4.00	0.00	11.18	5.92	3.08	0.00	0.00	3.21
3	318.08	3.00	0.00	0.00	1.53	0.00	0.00	0.00	0.67
4	311.50	3.00	0.00	0.79	4.14	1.02	0.01	0.00	1.45
5	303.63	3.00	0.00	0.00	4.59	3.21	0.01	0.00	2.54

Table 22. In-Stream DO Concentrations, at Intake and Below SEPA Stations, Including Computed Completely Mixed Values for Cross-sectional DO Measurements Made, 1996

		DO concentration (mg/L) at SEPA station														
		1			*2*			*3*			*4*			*5*		
		In	*Below*		*In*	*Below*		*In*	*Below*		*In*	*Below*		*In*	*Below*	
Period	*Date*	*(1)*	*(2)*	*Mixed*	*(6)*	*(7)*	*Mixed*	*(9)*	*(10)*	*Mixed*	*(12)*	*(13)*	*Mixed*	*(15)*	*(17)*	*Mixed*
2	04/23	10.84	13.04	-	6.58	5.51	6.82	6.14	7.16	6.89	6.29	6.62	7.09	5.86	6.29	6.67
	05/22	9.58	9.54	9.30	6.74	5.09	6.96	5.55	6.95	6.46	3.62	4.19	5.08	4.25	4.64	5.12
3	06/05	8.04	8.39	8.57	5.76	5.51	5.92	5.05	5.44	5.57	5.00	5.46	6.05	4.84	5.23	5.11
	06/19	7.48	7.17	8.79	5.32	4.70	5.51	3.83	4.21	5.26	2.47	2.66	4.27	1.97	2.88	3.59
	07/02	7.48	7.15	7.44	6.32	5.41	6.47	4.27	5.37	5.74	3.94	4.97	5.31	5.09	5.45	5.92
4	07/10	7.32	7.72	7.57	6.85	6.85	6.92	5.82	6.17	6.60	6.13	7.25	7.06	7.65	5.07	5.52
	07/17	7.24	7.12	7.75	6.11	-	-	4.94	5.82	5.83	4.78	5.83	6.65	-	-	-
	07/24	6.31	6.13	6.77	4.84	4.35	4.98	3.35	3.90	4.47	3.46	3.96	4.54	3.78	3.96	3.98
	07/31	7.05	7.70	7.27	5.77	5.35	5.85	4.22	4.67	5.01	3.76	3.91	4.60	3.85	4.39	4.49
	09/04	7.23	7.59	7.46	6.41	5.60	6.50	5.80	5.79	6.13	5.36	5.98	6.19	5.59	5.96	5.17
	09/05	-	-	-	-	-	-	-	-	-	-	-	-	5.30	5.11	5.14
	09/18	6.70	7.69	7.15	6.74	6.68	6.83	5.70	6.10	6.10	5.90	5.80	6.27	5.12	5.11	4.92
	09/19	-	-	-	-	-	-	-	-	-	-	-	-	5.62	5.11	5.44
5	10/22	9.26	9.24	9.62	8.23	7.87	8.26	7.45	7.96	-	7.38	7.69	8.23	6.71	6.46	6.49
	10/23	-	-	-	-	-	-	-	-	-	-	-	-	7.17	6.33	6.21
	10/30	8.96	9.37	-	7.47	6.91	-	6.22	6.72	6.66	7.31	7.51	7.73	7.10	6.38	-
Mean *		7.47	7.68	7.81	6.08	5.50	6.22	4.84	5.40	5.70	4.40	4.91	5.49	4.68	4.74	4.87

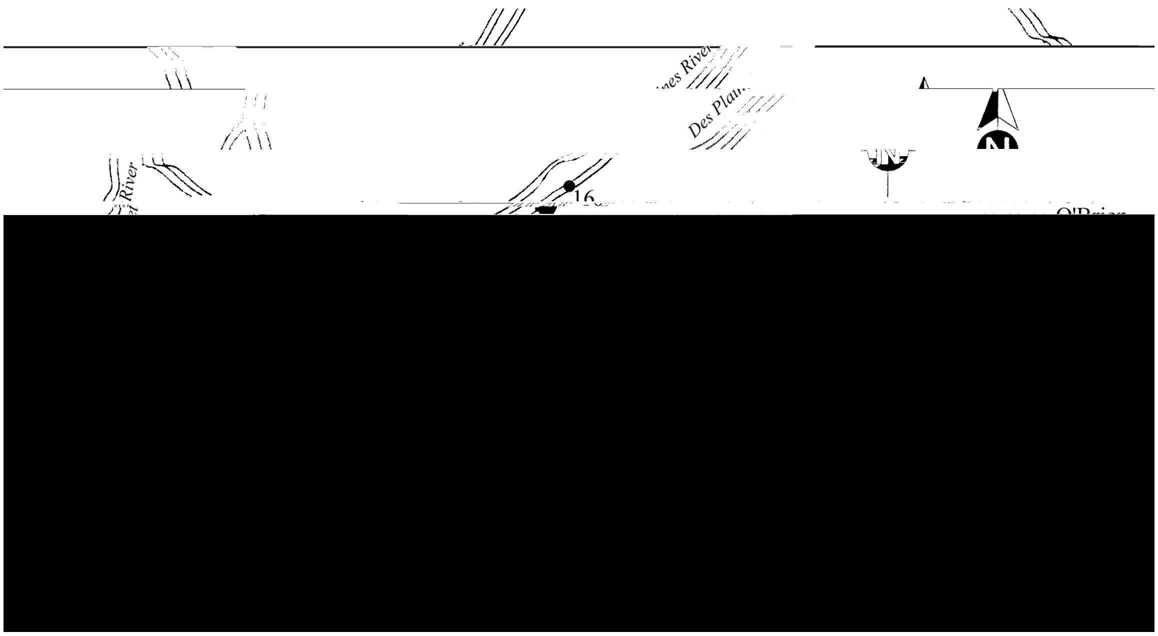
Notes: Numbers in parentheses indicate monitoring stations; In = intake; Mixed = computed completely mixed.

Table 23. Comparison of DO Concentrations at SEPA Station Intakes with and without Upstream SEPA Station Operations for Cross-sectional DO Measurements Made, 1996

		Mean cross-sectional DO concentrations (mg/L) at intakes of SEPA stations							
		SEPA station 2		*SEPA station 3*		*SEPA station 4*		*SEPA station 5*	
Period	*Date*	*w-1*	*w/o-1*	*w-1,2*	*w/o-2*	*w-1,2,3*	*w/o-3*	*w-1,2,3,4*	*w/o-4*
2	04/23	6.63	-	6.14	5.90	6.29	5.53	5.86	5.05
	05/22	6.78	5.80	5.63	5.42	3.63	2.74	4.25	2.80
3	06/05	5.80	5.28	5.06	4.90	5.01	4.49	4.84	3.79
	06/19	5.35	4.04	3.83	3.64	2.48	1.06	1.99	0.19
	07/02	6.37	6.36	4.28	4.14	3.94	2.48	5.14	3.77
4	07/10	6.89	6.64	5.83	5.77	6.18	5.40	7.73	6.82
	07/17	6.12	5.61	4.94	-	4.78	3.89	-	-
	07/24	4.93	4.47	3.35	3.21	3.46	2.34	3.78	2.70
	07/31	5.78	5.56	4.22	4.14	3.76	2.97	3.86	3.02
	09/04	6.46	6.24	5.80	5.71	5.37	5.04	5.59	4.76
	09/05	-	-	-	-	-	-	5.30	-
	09/18	6.76	6.32	5.70	5.61	5.91	5.51	5.12	4.76
	09/19	-	-	-	-	-	-	5.62	-
5	10/22	8.25	7.89	7.45	7.42	7.38	-	6.72	5.83
	10/23	-	-	-	-	-	-	7.17	-
	10/30	7.47	-	6.23	-	7.31	6.88	7.11	6.69
Mean *		6.12	5.63	4.86	4.73	4.42	3.56	4.70	3.62

Notes: All numbers in column headings indicate SEPA stations; w - with, w/o - without
* For the nine dates having two values common for all locations

FIGURES



Continuous Monitoring Stations

01	SEPA Station 1 intake, RM 328.10	13	Southwest Hwy, RM 310.70
02	Norfolk/Western RR, RM 327.69	14	104th Avenue, RM 307.15
06	SEPA Station 2 intake, RM 321.32	15	SEPA 5 intake, RM 303.63
07	Penn Central RR, RM 320.71	16	Hwy 83, RM 304.69
09	SEPA Station 3 intake, RM 318.08	17	Power Lines, RM 302.36
10	Baltimore/Ohio RR, RM 317.62	18	Slip No. 2, RM 299.55
12	SEPA Station 4 intake, RM 311.55	21	Lockport Lock and Dam, 291.20

Figure 1. SEPA station and continuous monitoring locations in the Chicago, Illinois area along the Calumet River, Little Calumet River, Cal-Sag Channel, and the lower Chicago Sanitary and Ship Canal

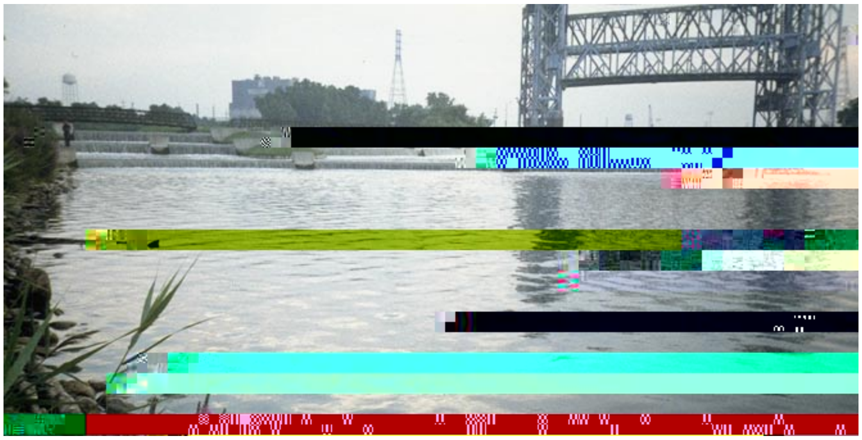


Figure 2. SEPA Station 1 outfall

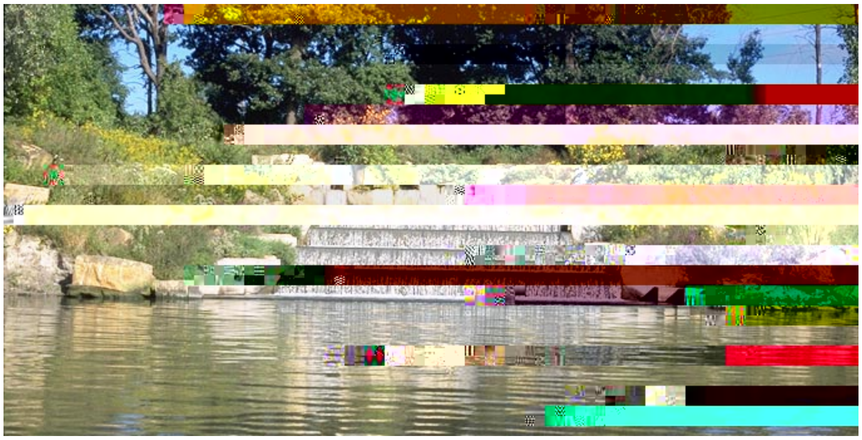


Figure 3. SEPA Station 2 outfall

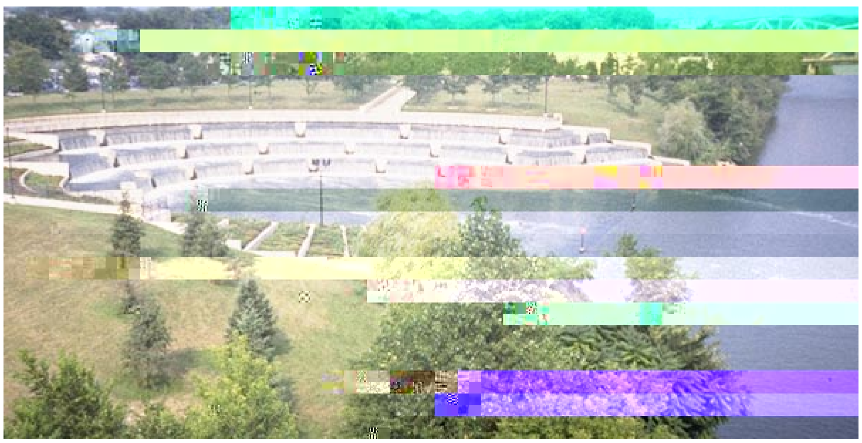


Figure 4. SEPA Station 3 outfall

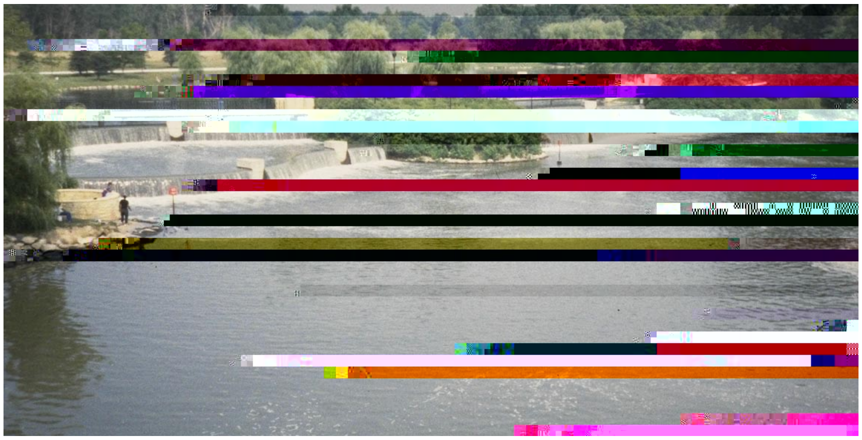


Figure 5. SEPA Station 4 outfall

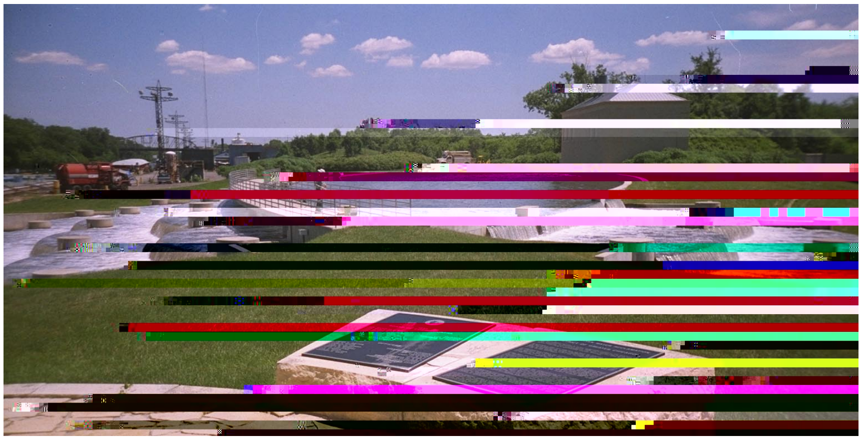
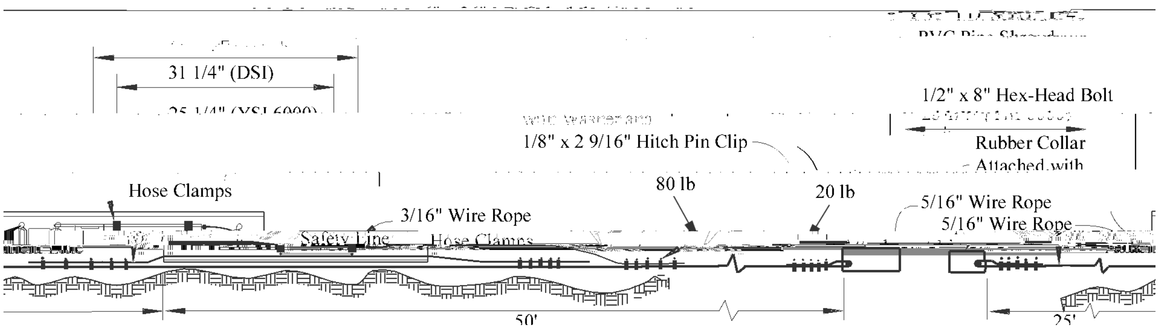
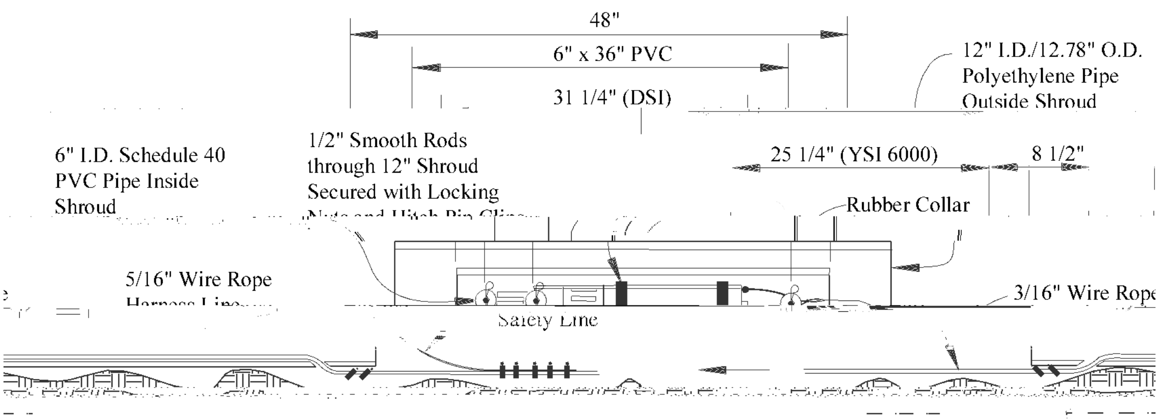


Figure 6. SEPA Station 5 outfalls: Chicago Sanitary and Ship Canal (left) and Cal-Sag Channel (right)



7a. Type I



7b. Type IA

Figure 7. Schematics of type I and IA monitor riggings

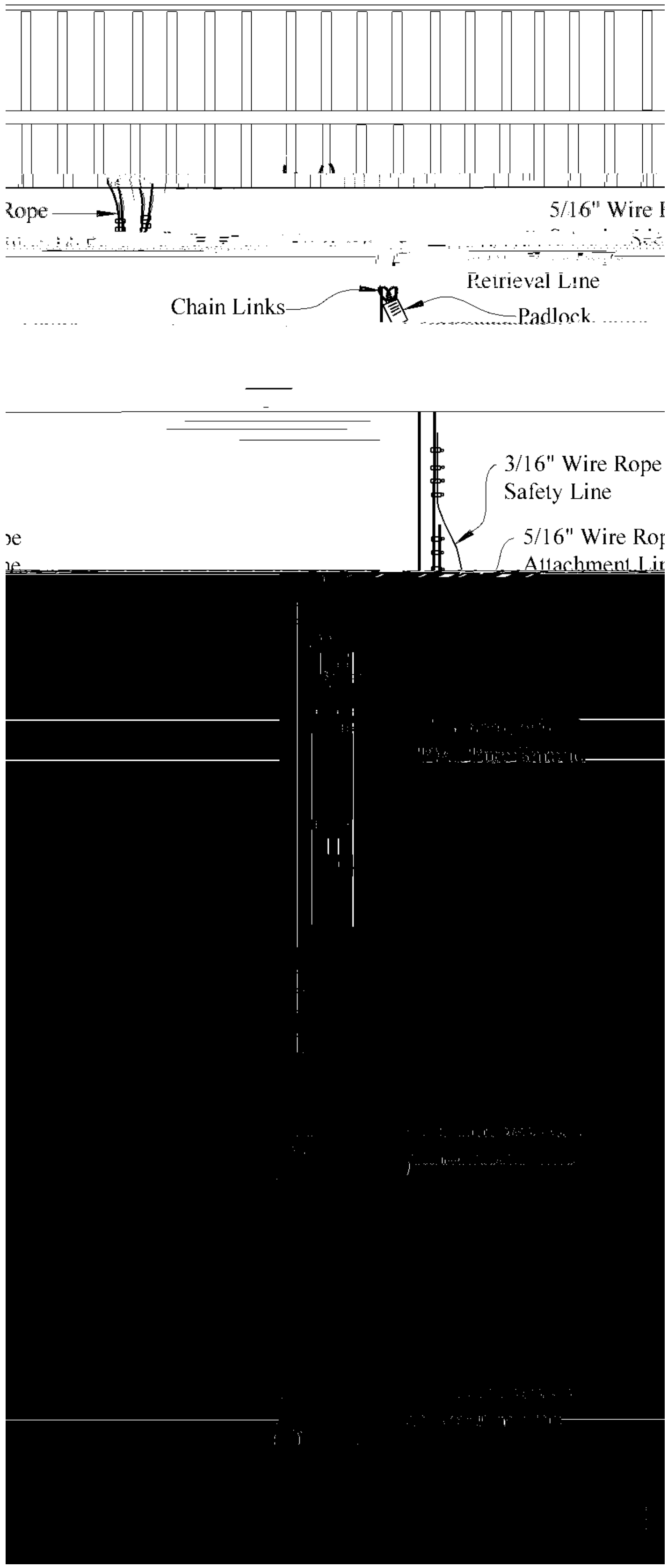


Figure 8. Schematic of type II monitor rigging

Figure 9. Schematics of type IIA (left) and IIB (right) riggings used at Lockport

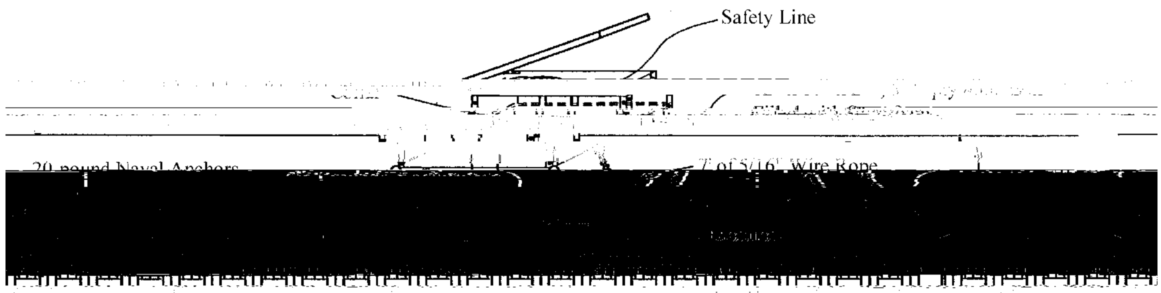


Figure 10. Schematic of type III rigging

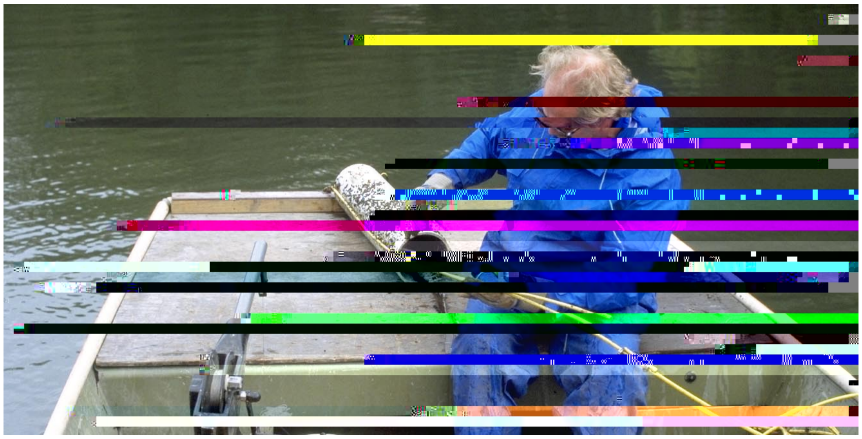


Figure 11. Type I rigging

Figure 12. Type IA rigging

Figure 13. Type II rigging

Figure 14. Type III rigging

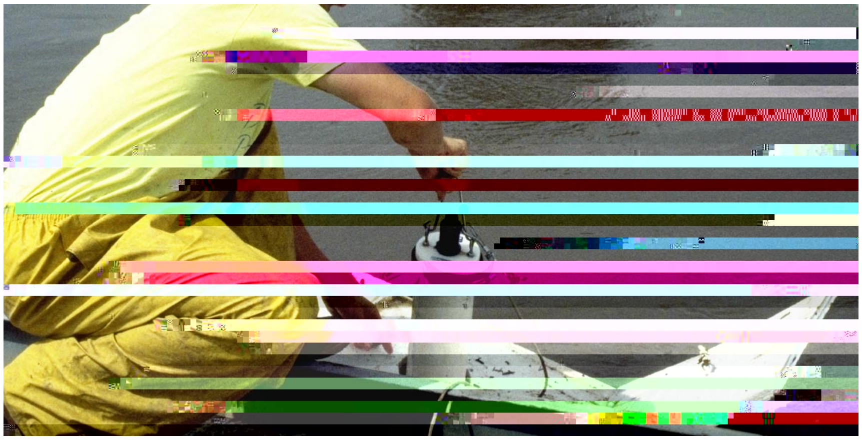
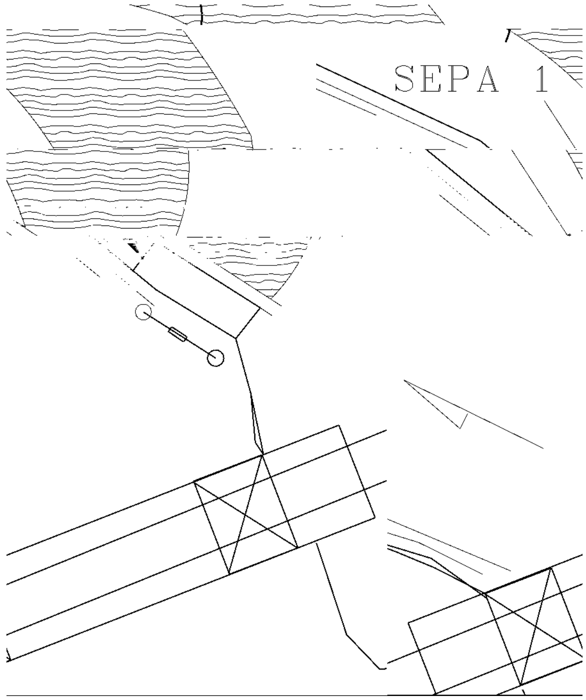
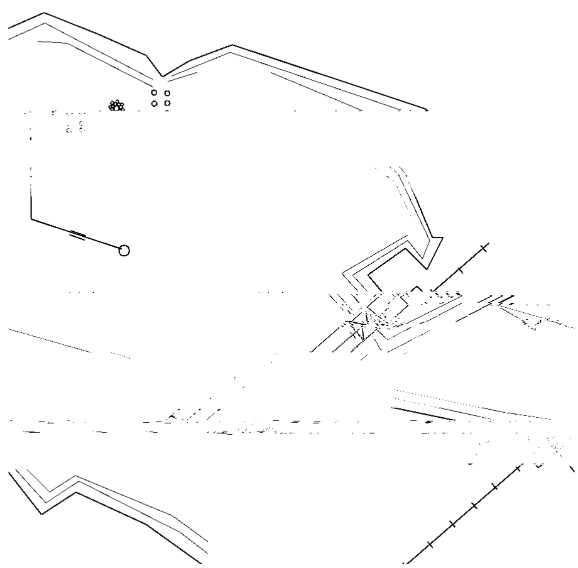


Figure 15. Inserting Data Sonde I into type III rigging

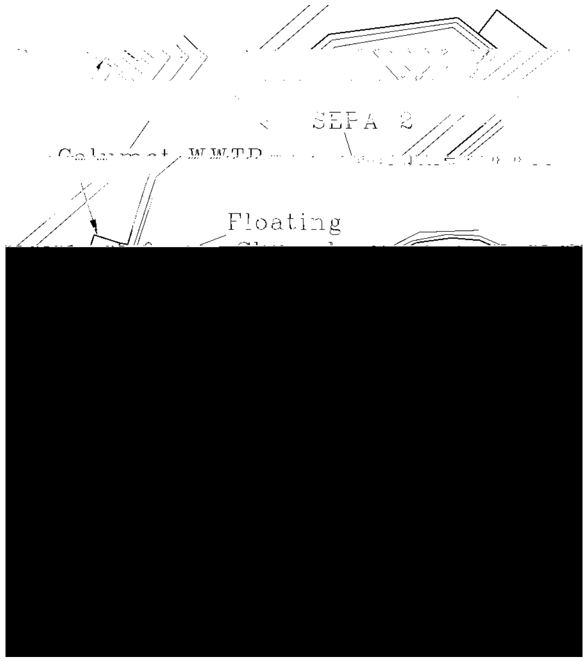


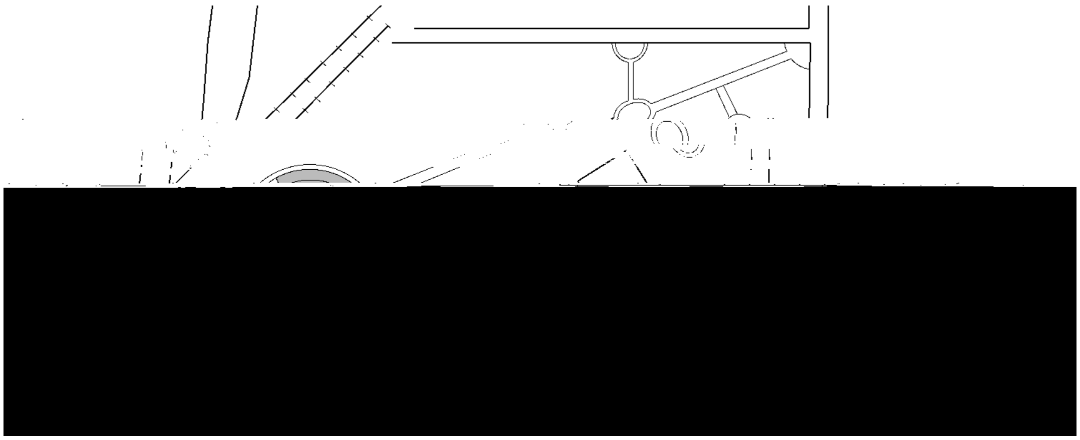
a. Station 01: SEPA Station 1 intake, Calumet River at RM 328.10



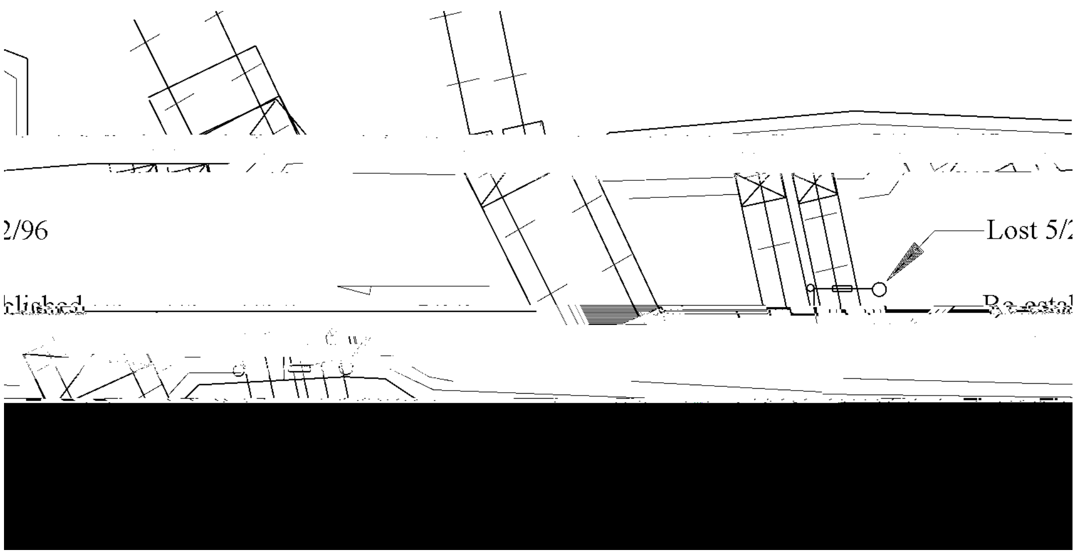
b. Station 02: Norfolk/Western RR, Calumet River at RM 327.69

Figure 16. Plan view schematics of riggings at each continuous monitoring station


SEFA 2
Floating

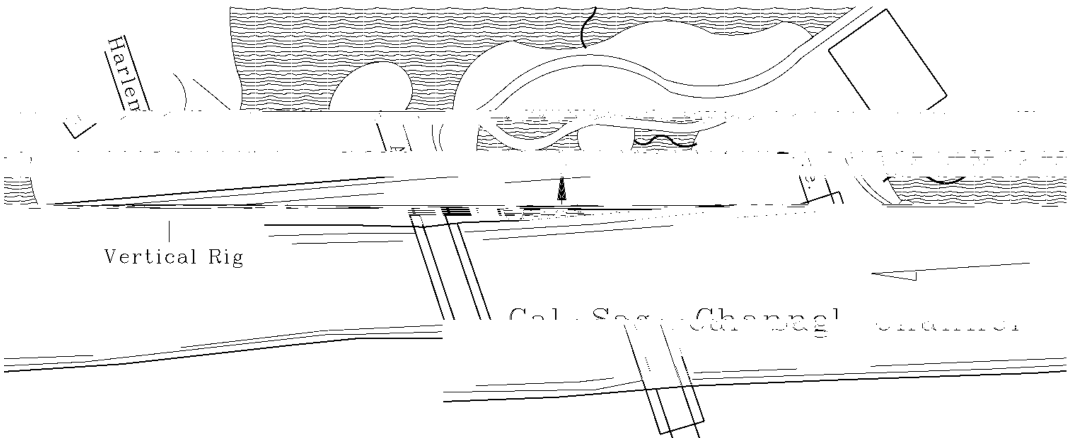


e. Station 09: SEPA Station 3 intake, Cal-Sag Channel at RM 318.08

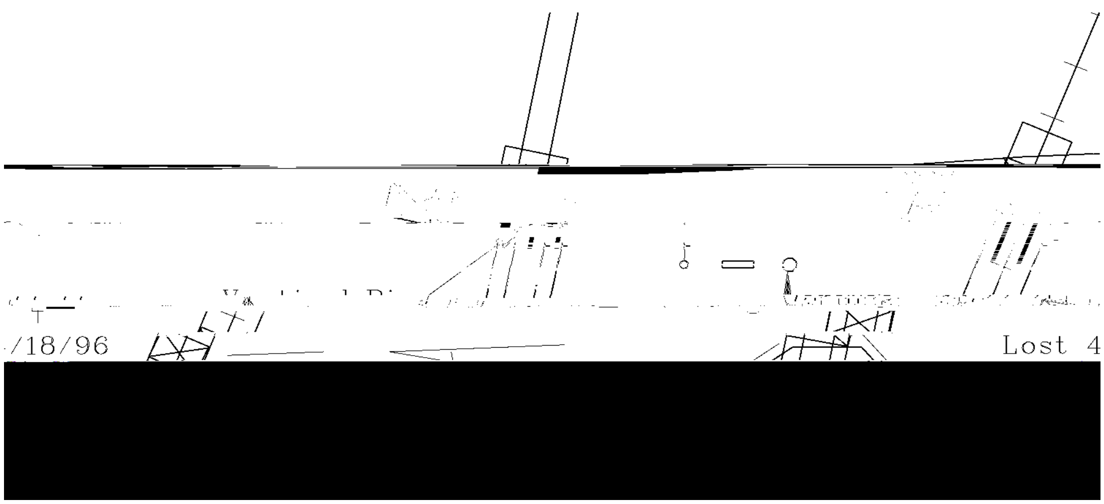


f. Station 10: Baltimore/Ohio RR, Cal-Sag Channel at RM 317.62

Figure 16. (continued)

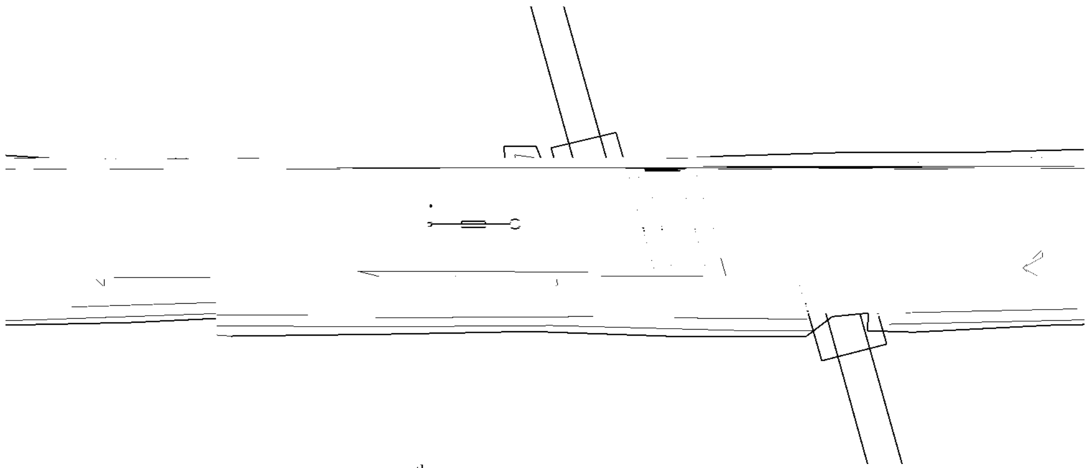


g. Station 12: SEPA Station 4 intake, Cal-Sag Channel at RM 317.62



h. Station 13: Southwest Hwy, Cal-Sag Channel at RM 310.70

Figure 16. (continued)

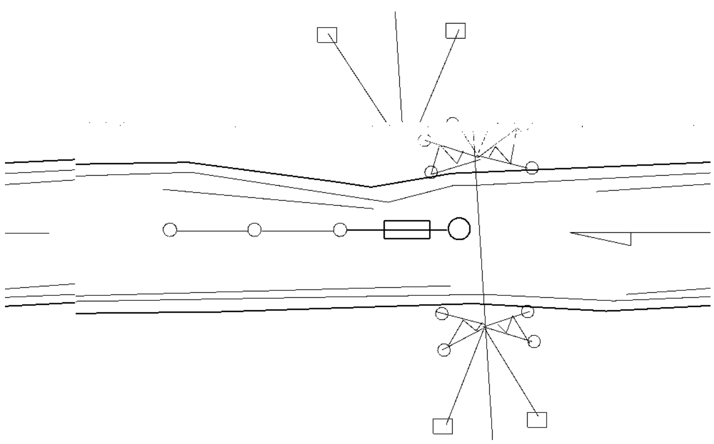


i. Station 14: 104th Avenue, Cal-Sag Channel at RM 307.15

j. Station 15: SEPA Station 5 intake, Cal-Sag Channel at RM 307.15

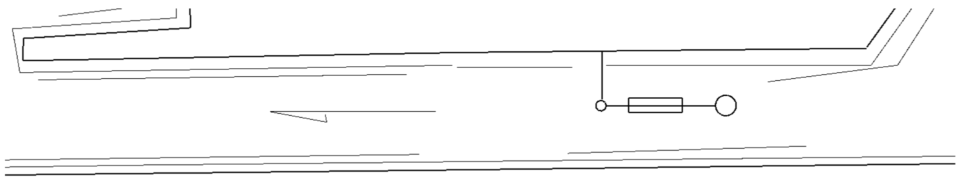
Figure 16. (continued)

k. Station 16: Hwy83, Chicago Sanitary and Ship Canal at RM 303.63

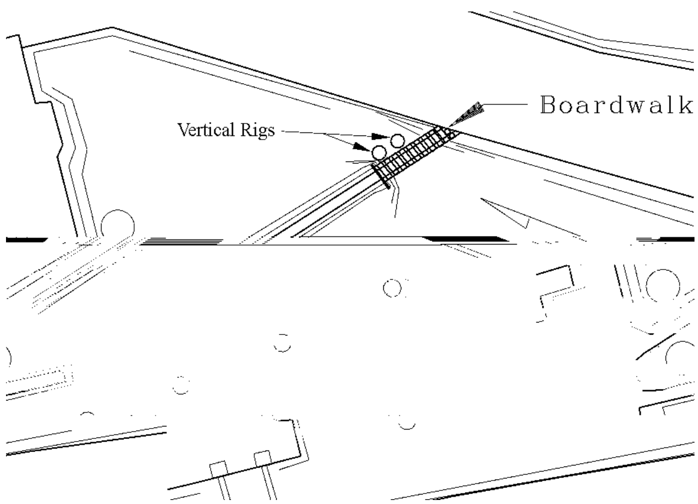


l. Station 17: Power Lines, Chicago Sanitary and Ship Canal at RM 302.36

Figure 16. (continued)

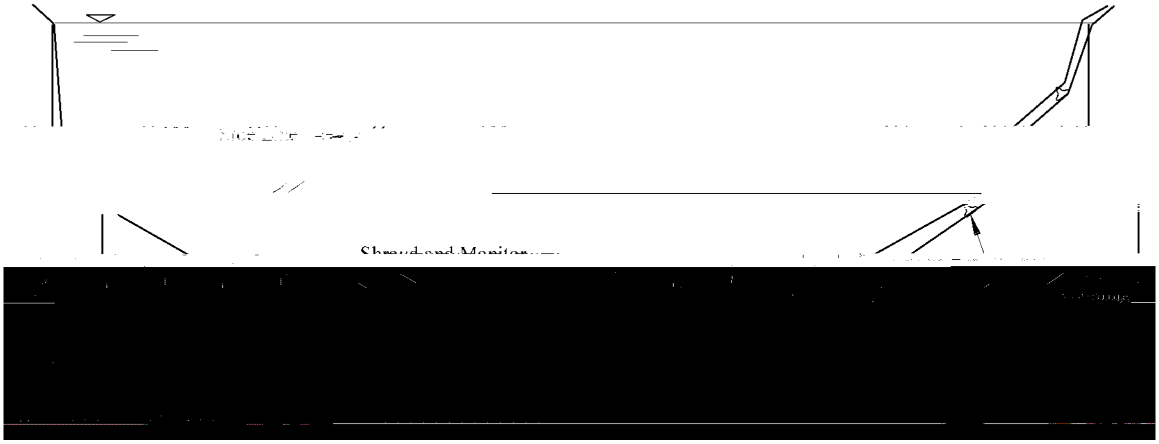


m. Station 18: Slip No. 2, Chicago Sanitary and Ship Canal at RM 299.55

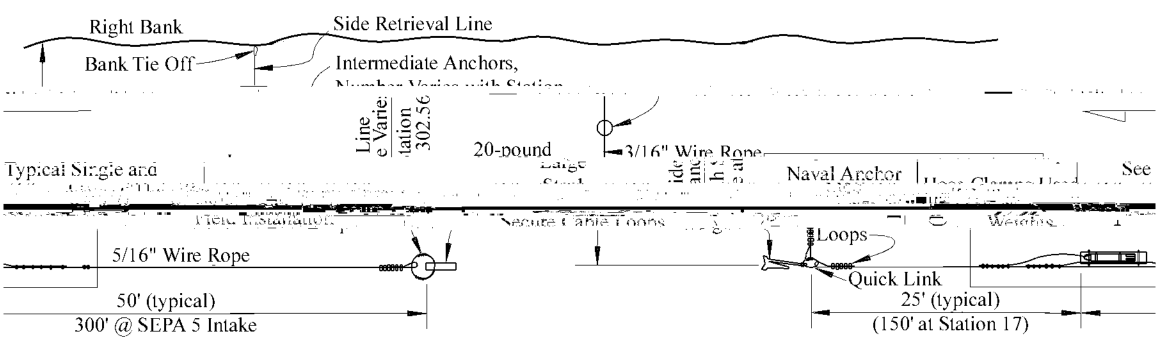


n. Station 21 (t, m, b): Lockport Lock and Dam,
Chicago Sanitary and Ship Canal at RM 291.20

Figure 16. (concluded)



a. Transverse view looking downstream



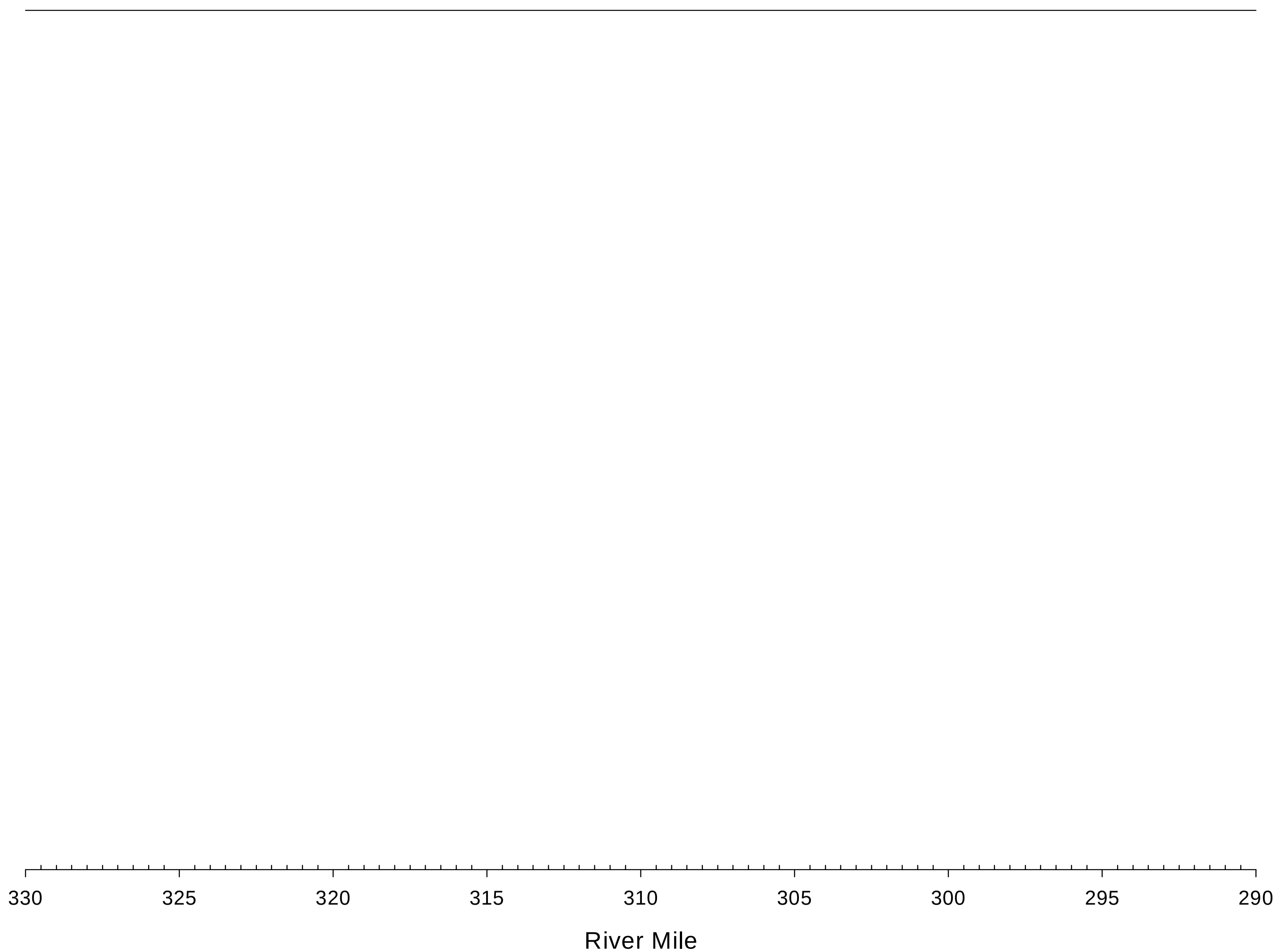
b. Longitudinal view

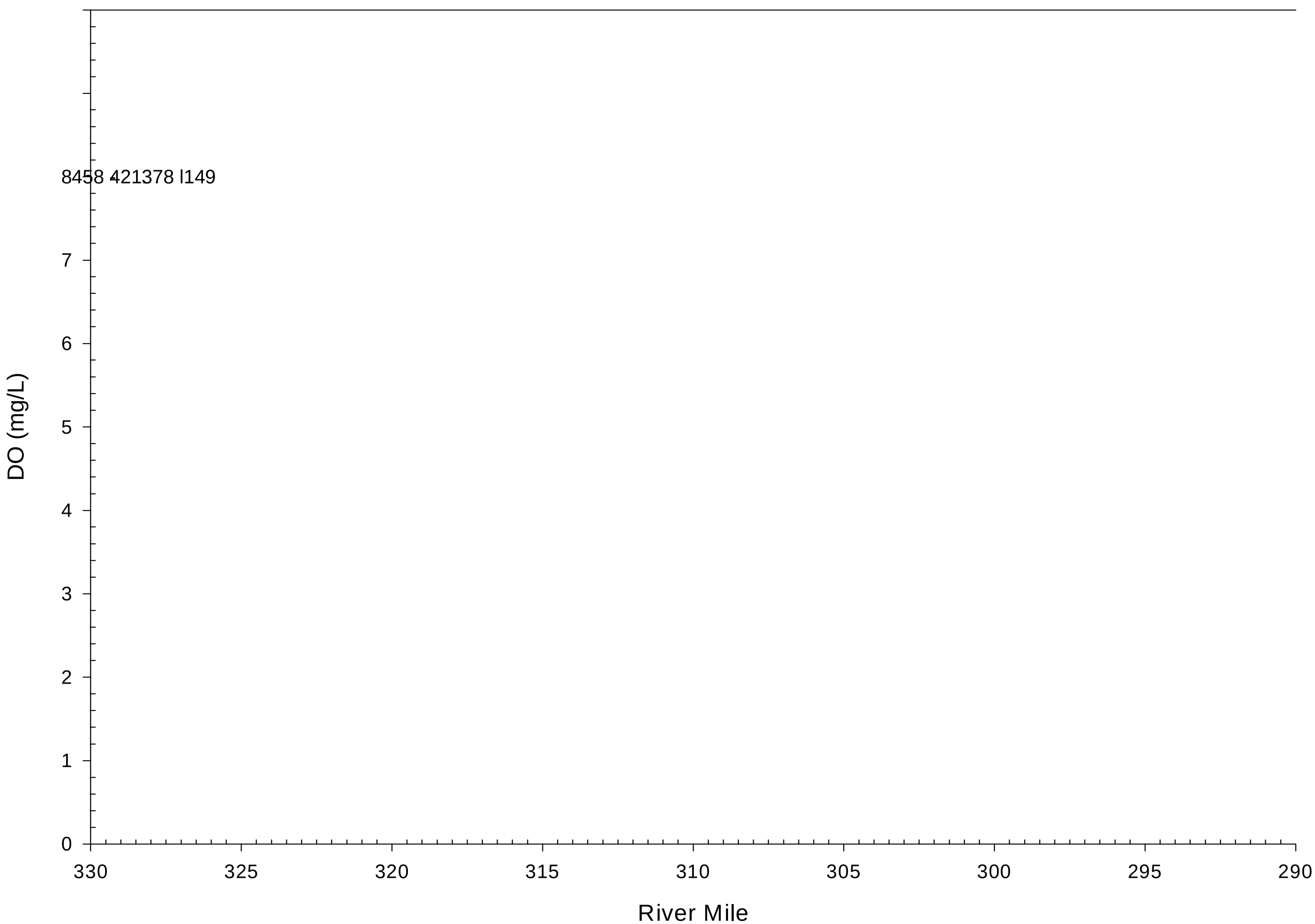
Figure 20. Exchanging a DataSonde I monitor at a type IA site

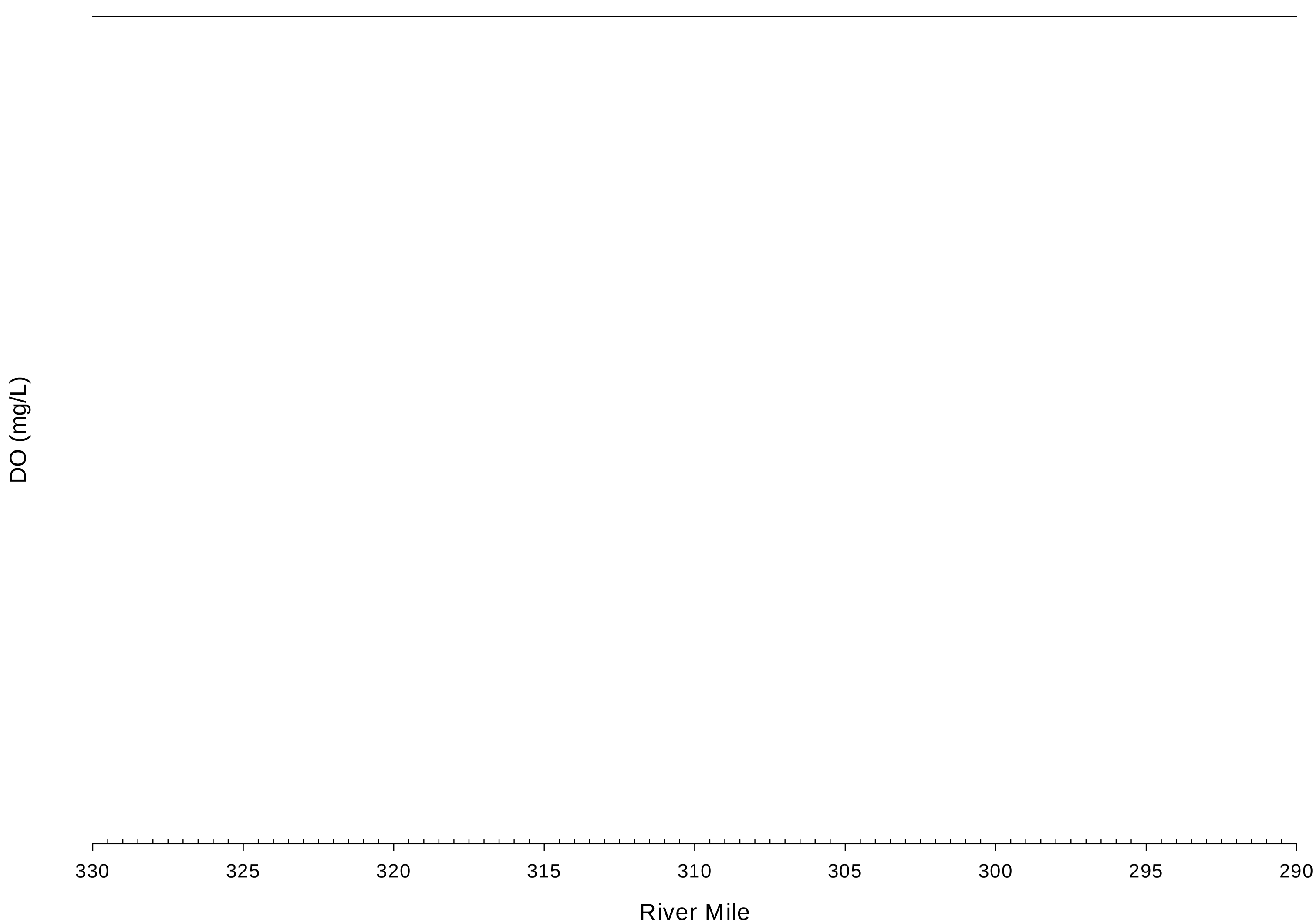
Figure 21. Exchanging a YSI 6000 monitor at a type IA site

Figure 22. Downrigger fitted with YSI DO/temperature meter, stirrer, and probes


River Mile


330
325
320
315
310
305
300
295
290
River Mile


8458 421378 l149
7
6
5
4
3
2
1
0
DO (mg/L)
330
325
320
315
310
305
300
295
290
River Mile


DO (mg/L)
330
325
320
315
310
305
300
295
290
River Mile

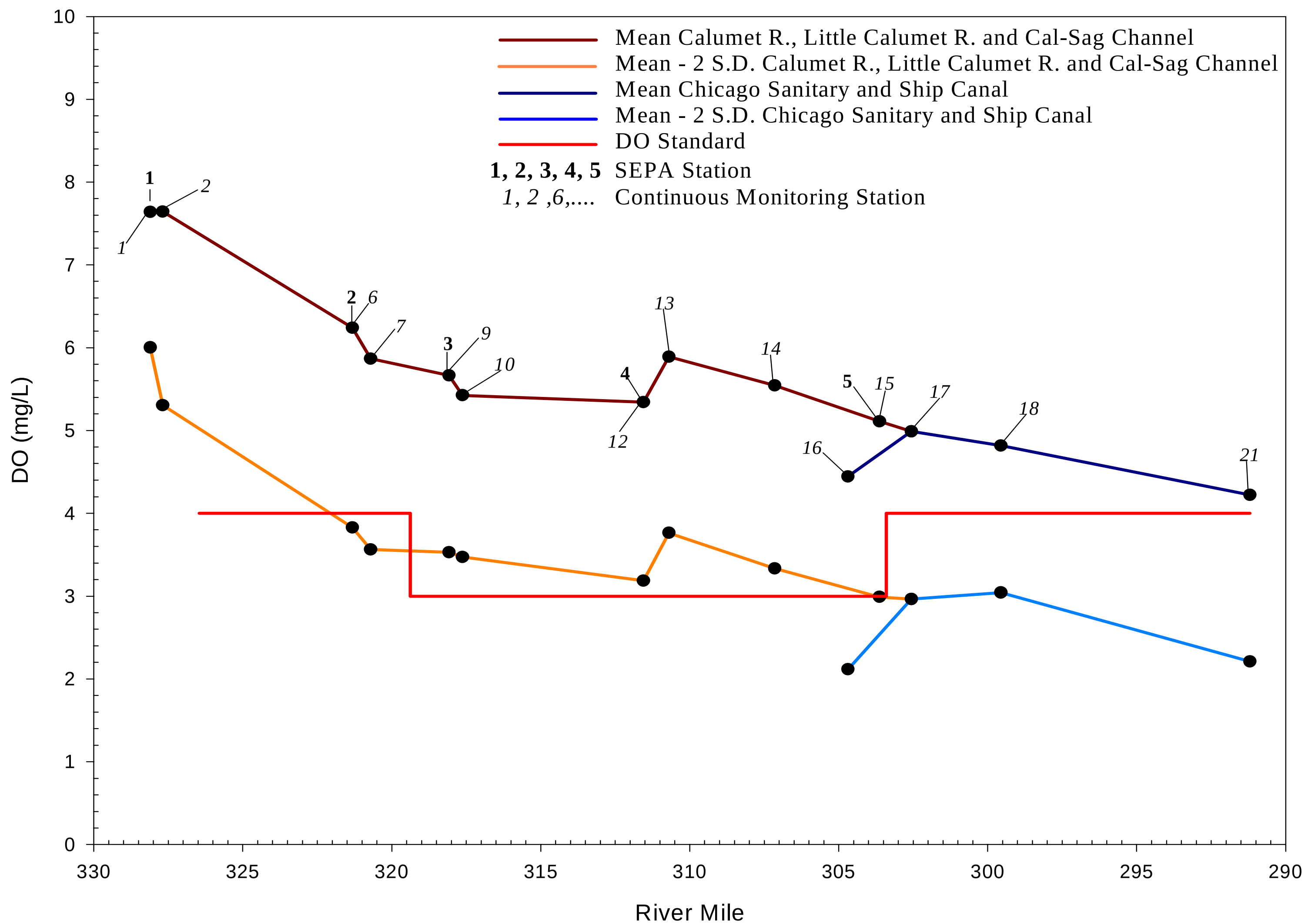


Figure 30. DO profile for 04/19–10/31/1996, the period during which the SEPA stations operated