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Evaluation of Reaeration Efficiencies of Sidestream Elevated Pool Aeration (SEPA) Stations

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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, four in-stream aeration approaches were considered by the District: 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 barge-mounted system was evaluated by the District in Chicago area waterways, but it was shown not to be practical. The U-tubes are not applicable at most locations at which chronic low DOs 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. Subsequently, 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 became beset with operational and maintenance problems. Prior to building the eight additional aeration stations, the United States Environmental Protection Agency (USEPA) deferred its regulatory requirement that the District build advanced wastewater treatment plants while, in turn, endorsing the use of in-stream aeration. This reversal prompted an immediate search for an improved technological approach to aerating the waterways. In 1984, the District (Macaitis et al., 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, and the aerated water is returned to the stream.

Over the next several years, modifications were made to the SEPA station design as 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, during 1987 and 1988, research scientists from the ISWS and the District's Research and Development (R&D) Department cooperated in conducting full-scale testing of a sharp-crested weir system. A prototype SEPA station was built along the Chicago Sanitary and Ship Canal at the District's Stickney Water Reclamation Plant. As a result of the experimental work, SEPA station design criteria were developed (Butts, 1988). Information and recommendations in this report were used by District consultants to design five SEPA stations located along the Calumet waterway system shown in figure 1. Vicinity area details of SEPA stations 3, 4, and 5 (the three SEPA stations evaluated) are presented in figure 2. Plan views of the principal geometric features of these three SEPA stations are shown in figures 3-5. Photographs of all five SEPA stations are shown in figures 6-12. Waterway mile locations and basic design features of all five SEPA stations are presented in table 1.

Study Objectives

Additional artificial aeration stations are being planned for future locations along the Chicago waterway system. Information is needed on the operating characteristics of the SEPA stations and their effects on DO concentrations in the waterways below their discharge. The District, in a November 25, 1994, letter to James Park of the Illinois Environmental Protection Agency (IEPA), proposed a two-year study to accomplish five objectives. Three of these objectives were addressed through a two-phase study conducted between 1995 and 1997.

The two-phase study was designed to:

1. Determine the actual oxygen transfer rate due to the waterfalls at the SEPA stations.

2. Determine the actual oxygen transfer rate due to the spiral-lift screw pumps at the SEPA stations.

3. Determine the effect of the operation of the SEPA stations on the DO levels in the Calumet waterway system.

This report will present the results and conclusions relative to objectives 1 and 2. Objective 3 is addressed by the separate report *Sidestream Elevated Pool Aeration (SEPA) Stations: Effects on In-stream Dissolved Oxygen* (Butts et al., in press). The work tasks to address objective 3 were deemed the highest priority and were performed first. Therefore, that part of the overall study was designated as Phase I. Consequently, the studies associated with objectives 1 and 2 were designated as Phase II work items.

Acknowledgments

This study was funded principally by a research contract granted to the ISWS from the R & D and Engineering Departments of the District. Irwin Polls (R&D) was project leader and coordinated scheduling and sampling. Mike Sopcak, Rich Schackart, and Irwin Polls performed specialized water quality sampling and measurements during the SEPA station monitoring events. David Tang of the District's Maintenance and Operations (M&O) Department coordinated SEPA station pumping operations with ISWS monitoring schedules and provided the operational data used in this report. Thanks are extended to ISWS personnel Bob Larson and Bill Meyer for their intensive efforts in the field and in the laboratory that helped make this study successful. Bill Meyer's role was especially significant in that he was responsible for preparing the monitors/dataloggers for field use, downloading and filing the data, and performing quality assurance/quality control (QA/QC) procedures.

This report was prepared under the general administration of Derek Winstanley, Chief of the ISWS. The original manuscript was typed by Linda Dexter and edited by Eva Kingston and Agnes Dillon.

DAM OR WEIR AERATION THEORY

The theory governing weir or dam aeration (or deaeration) will be succinctly reviewed and discussed. Both theoretical and stochastic relationships that are particularly relevant to and useful in analyzing the large amount of data generated in the present study will be presented. Appendices A-F give supplemental data.

Theoretical Considerations

A simple, theoretical mathematical relationship, referred to as the deficit ratio, is generally used to evaluate aeration efficiency of a head-loss structure in a stream or river. It is formulated as:

$$r = \frac{S_a - C_a}{S_b - C_b} \qquad (1)$$

where

r = deficit ratio

S_a, S_b = the DO saturation concentrations above and below a head-loss structure, milligrams per liter (mg/L), respectively

C_a, C_b = the observed DO concentrations above and below a head-loss structure, mg/L, respectively

This basic relationship was the primary tool Butts (1988) used to evaluate the aeration efficiencies of the full-scale prototype study used in developing SEP A design parameters.

Reaeration is proportional to the DO deficit, i.e., waters low in oxygen reaerate at a much faster rate than do those that have DO concentrations near saturation (S). The deficit ratio should remain constant for a given geometric configuration regardless of the value of C_a. The nature of equation 1 indicates that higher deficit ratios are commensurate with higher aeration efficiencies. The deficit ratio is unity when no aeration occurs. Values less than 1.0 or negative values indicate measurement errors or anomalous conditions. Frequently, anomalies do occur in field-generated, weir-aeration data resulting in unrealistic r-values from equation 1.

In some situations data reduction using equation 1 can result in r-values that cannot be effectively used to evaluate aeration (or deaeration) efficiencies. Various combinations of field-measured C_a, C_b, S_a, and S_b values that produce unusable information frequently are observed. Assuming $S = S_a = S_b$, the various scenarios that produce unusable r-values, as computed by equation 1, can be described mathematically as follows:

		Resultant r-value	
Case	*Specifications*	*Sign*	*Value*
I	$S > C_a > C_b$	+	r<1.0
II	$S < C_a < C_b$	+	r<1.0
III	$C_a < S < C_b$	-	1.0<r<1.0
IV	$C_a > S > C_b$	-	1.0<r<1.0
V	$S = C_a \neq C_b$	±	r = 0
VI	$S = C_b \neq C_a$	±	r = α

Two situations produce theoretically correct r-values, i.e., ones that are both positive and greater than unity; they are:

VII	$C_a<C_b<S$	+	r>1.0
VIII	$C_a>C_b>S$	+	r>1.0

Case VII represents reaeration when the up-stream DO concentration is below saturation, and Case VIII represents deaeration when the up-stream DO concentration ranges between 100 and 200 percent saturation. A special situation develops when DO levels equal or exceed 2S as expressed by Case LX.

IX	$C_a>2S>C_b$	+	r>1.0

When DO concentrations reach levels above 200 percent, the fraction above 200 percent is extremely unstable and will tend to be released immediately in bubble form at the top of the weir, dam, or spillway during physical disturbance. True dam deaeration will occur only at DO concentrations between 100 and 200 percent of saturation, and it will occur on the face or at the foot of the weir (Butts and Evans; 1978). Between 200 and 100 percent saturation, water will deaerate at the same rate as water will reaerate between 0 and 100 percent saturation. True weir aeration (deaeration) efficiencies cannot be determined for situations in which $C_a > 2S$.

Often Case VH and VIII values also are unusable in evaluating the reaeration capacity of a head-loss structure when $C_a \approx C_b \approx S$. Although positive values can result, they become exaggerated as C_a approaches the DO saturation level as exemplified by the wide range of situations presented in table 2. Note, measurement errors as small as ± 0.1 mg/L in C_a, C_b, or S result in very large or inflated deficit ratio values as shown by the eight-fold r/3-ratio derived for the 30° C, C_a = 7.40 mg/L example in table 2. Small errors in the DO measurements have little affect on r-values when C_a is low compared to S even at high temperatures when S is at its lowest level.

All the data generated during the original prototype weir study were reduced to useable r-values (Butts, 1988). This was achieved principally by operating the system only when input DO levels were significantly below saturation. Also, the results from the prototype weir study were not significantly influenced by unusual water quality conditions, such as those resulting from photosynthesis or increased sediment loads due to storm events. Due to storm events and photosynthesis, dramatic and, at times, almost instantaneous changes in water quality in the Cal-Sag Channel occurred during the SEPA station evaluation. For QA/QC purposes, the prototype r-values computed for various weir-step combinations were used as the criteria to accept or reject extreme positive r-values computed for the SEPA station experimental data. The criteria for rejection are presented in table 3. The criterion for SEPA station 5 differs from that for SEPA stations 3 and 4 because of the differences in the heights and number of weirs (table 1).

The r-values for the intake to pool 1 in the SEPA stations are governed by screw pump operation and aeration. Because prototype r-values were available for screw pump operation, acceptance criteria were estimated. The assumption was that the screw pumps are somewhat better aerators than a single 3- to 5-foot weir. Corollary to this, the overall intake to outfall r-values in table 3 also are estimated due to the inclusion of the screw pump operation. Only from pool 1 to the other pools and the outfall are the values taken directly from Butts' (1988) prototype study. For example, for either SEPA station 3 or 4, normal r-values would be expected to range from a low of 4.6 to a high of 10.0 between pool 1 and the outfall (Butts, 1988).

The DO saturation concentrations for various water temperatures were computed using the American Society of Civil Engineers (1960) DO saturation formula:

$$S_T = (14.652 - 0.41022T + 0.007991T^2 + 0.000077774T^3)\beta \tag{2}$$

where

S_T = DO saturation concentration, at sea level, mg/L
T = water temperature, °C
β = water quality factor (1.0 for distilled water)

This formula represents saturation levels at sea level. Water impurities can increase the saturation level ($\beta > 1.0$) or decrease the saturation level ($fi < 1.0$), depending upon the surfactant characteristics of the contaminant. The sea level concentrations produced by the formula must be corrected for differences in air pressure caused by air temperature changes and for elevations above sea level. The following formula was developed for use during this study:

$$f = \frac{2116.8 - [(0.08 - 0.000115s)(E)]}{2116.8} \tag{3}$$

where

f = correction factor above sea level
s = air temperature, °C
E = site elevation, feet above mean sea level (ft-msl)

The mean sea elevations used for this study are the following:

Mean Sea Level Elevations (ft-msl) at SEPA Stations 3, 4, and 5

	SEPA stations	
	3 and4	*5*
Inlet	578.6	578.6
Pool 1	593.6	590.6
Pool 2	588.6	587.6
Pool 3	583.6	584.6
Pool 4	-	581.6
Outlet	578.6	578.6

Ambient water temperatures were used to approximate "s" in equation 3.

Semiempirical Weir Aeration Formula

Gameson (1957) and Gameson et al. (1958) developed a semiempirical equation relating water temperature, water quality, geometric design, and head loss to the deficit ratio, as represented by equation 1. A modified form of this equation, as presented by the Water Research Centre (1973), is:

$$r = 1 + 0.38abh\,(1 - 0.11h)\,(1 + 0.046T) \tag{4}$$

where

a = water quality factor
b = geometric reaeration coefficient
h = head loss, meter (m)
T = water temperature, ˚C

This equation can be used to model the relative and absolute efficiencies of a weir spillway or flow-release structure by determining specific values of b. Every spillway or gate has a specific coefficient, but generalized categories can be developed in reference to a standard. The standard weir, in which b = 1.0, is, by definition, a sharp-crested weir with the flow free-falling into a receiving pool having a depth equal to or greater than O.1h + 6 centimeters (cm). An idealized step weir (a series of sharp-crested weirs) has a b-value of 1.9 (Water Research Centre, 1973). However, actual field-measured values usually are lower.

Equation 4 was developed by British researchers from data collected at many relatively low-head channel dams and weirs transecting small streams. Good reproducibility can be achieved when h does not exceed 3 to 4 m, the maximum height of the dams at which data collections were made during development of the formula. In addition, close examination of the equation reveals that the factor (h) (1 to O.11h) mathematically restrains the use of the equation to heights of 4.55 m or less.

The water quality factor (a) has to be evaluated experimentally in the field or estimated from published criteria. Refinements of Gameson's (1957) early categorization of a-values are: grossly polluted water, a = 0.65; moderately polluted water, a = 1.0; slightly polluted water, a = 1.6; and clean water, a = 1.8. These values are based on a minimal amount of field and laboratory data. Their direct applications are subjective; and, because considerable numerical latitude exists between values, significant errors can result.

For 44 in-stream head loss structures across rivers and streams in northeastern Illinois, Butts and Evans (1978) found b-values ranging from a low of 0.05 for an underflow sluice gate to a high of 2.55 for a flat, broad-crested, vertical-face weir. For the controlled, full-scale experimental pilot study, conducted at the Stickney Water Reclamation Plant (WRP) on the Chicago Sanitary and Ship Canal, Butts (1988) observed b-values from a low of 0.90 for a 5-foot simple weir to a high of 3.54 for a 15-foot high, 3-step, step-weir SEPA station pilot system.

Empirical Design Equation

Butts (1988) developed an empirical equation, using statistical stepwise regression techniques to predict weir-aeration efficiencies. The evaluation included statistically correlating 11 physical- and chemical-dependent variables to the output DO in percent of saturation based on equation 2, the weir aeration factor b derived from equation 4, or the deficit ratio r derived from equation 1. These analyses resulted in the following prediction or design equation:

$$P_o = 0.32P_i + 4.13N + 0.81H + 54.78 \tag{5}$$

where

P_o = output DO, percent saturation (% of *f.* S_T)
P_i = input DO, percent saturation
N = number of steps
H = total weir-system height, ft
54.78 = intercept constant

The range of values for each independent variable for which this equation was derived is as follows:

Range of Values

Independent variable	*Low*	*High*
P_I	2.0%	93.1%
N	1	3
H	5ft	15ft

Also, although temperature is not directly included in the equation, water temperatures ranged between 15 and 28° C during the experimental work; theoretically, the application of this equation is best limited to conditions within these temperature ranges. Overall, the three independent variables associated with equation 5 explained 87 percent of the variability observed in P_o.

METHODS AND PROCEDURES

The study was designed to determine weir and screw-pump aeration efficiencies under seasonal and controlled operating conditions at SEP A stations 3, 4, and 5. These three stations are the largest of the five SEP A stations on the Calumet waterway system in terms of maximum flow (table 1), represent divergent design configurations (figures 2-5 and 8-12), and are located in the most critical DO-deficit area in the Cal-Sag Channel. Data were generated using continuous water quality monitors/dataloggers. Two-way analysis of variance (ANOVA) statistical tests were performed to determine if seasons and pumping rates affect aeration efficiencies within the SEPA stations, and a one-way ANOVA test was used to determine whether aeration efficiencies differed among stations. The deficit ratio or r-value (equation 1), the weir aeration coefficient or b value (equation 4), and the output DO saturation value or P_o (equation 5) are the parameters that gage weir aeration efficiencies and are amenable to ANOVA testing.

Study Design

Temporal Considerations

Four seasonal monitoring/sampling events were scheduled.

Monitoring/Sampling Events

Event	*Season*	*Inclusive dates*
1	Summer	08/12-08/23/96
2	Fall	09/30-10/11/96
3	Spring	04/28-05/09/97
4	Early summer	06/16-06/27/97

During these four events, different pumping rates were sustained for the time periods shown in table 4. Tests were not conducted with the operation of four pumps at stations 3 and 4 or five pumps at SEPA station 5 because doing so would result in severe turbulence in the Cal-Sag Channel. Such turbulence interferes with commercial and recreational boat traffic and resuspends benthic sediments affecting water quality.

Perusal of the pumping periods presented in table 4 shows that the general plan for events 1, 2, and 4 consisted of operating one and two pumps at SEPA stations 3 and 4 and one, two, three, and four pumps at SEPA station 5 for a minimum of 72 hours. Three-pump operations at SEPA stations 3 and 4 were extended to a continuous 144 hours to match the time periods for the four pump settings at SEPA station 5. During event 1, two pumps at SEPA station 3 became inoperative. Consequently, two-pump operation was extended to cover the planned three-pump operation period as shown in table 4.

The seasonally staged events include the entire range of Lake Michigan diversion flow rates released into the Little Calumet River that flows into the Cal-Sag Channel at the

O'Brien Lock and Dam. Because Lake Michigan water quality is different in all aspects (chemical, physical, and biological) than waters in the Cal-Sag Channel, water quality in the Cal-Sag Channel will vary greatly, depending on the volume of diversion being maintained during a given period. Consequently, diversion rates, theoretically, could influence the reaeration efficiencies at the SEPA stations as witnessed by the incorporation of the water quality factor in equation 4. The timing of the events was selected, in part, to capture the possible effects due to lake water diversion and no diversion (spring), 180 to 200 cubic feet per second (cfs) (early summer), and 300 to 400 cfs (summer and fall).

Monitoring Schedule

Continuous Monitoring. Because the primary purpose of this phase of the study was to evaluate the oxygen transfer rates through the screw pumps and at the step weirs, accurate and frequent DO/temperature measurements were required. This was accomplished using 25 YSI model 6000 water quality monitors/dataloggers purchased for this study. In addition, at selected monitoring locations and under certain conditions, Hydrolab DataSonde I water quality monitors/dataloggers were used. The Model 6000 performance specifications (Yellow Springs Instruments, Yellow Springs, Ohio) and standard operating procedures (SOPs) developed and used by ISWS staff for deploying the monitors are presented in appendix A.

All monitors, including the DataSondes, were equipped with sensors to measure DO, conductivity, temperature, pH, and salinity. These parameters were recorded at hourly intervals for events 1 and 2, and at 30-minute intervals for events 3 and 4. Settings were staged so that a minimum of 48 hours of data was collected for any given pump setting. Each monitoring event required 12 to 14 days (including one or two weekends).

Times for the pump settings per event at each SEPA station, including the start and stop dates and times, are given in table 4. This schedule resulted in inequitable "sample sizes" (e.g., monitoring periods) for different pumping rates. As an example, during event 2, pumping periods were:

Pumping Periods (hours) at SEPA Stations 3, 4, and 5

Number of pumps	*Stations*		
	3	*4*	*5*
1	48	48	48
2	216	120	120
3	0	96	48
4	0	0	48

During this event, the inequitable times resulted from two pumps failing at SEPA station 3, inclusion of a weekend during two-pump operations, and the fact that four pumps were operated at SEP A station 5. As evident from table 4, four-pump operations were not evaluated at SEPA stations 3 and 4 (explained previously).

The normal one, two, and three pump time sequences at SEPA stations 3 and 4 were 48, 120, and 96 hours, respectively; for SEPA station 5, the one, two, three, and four normal sequences were 48, 120, 48, and 48 hours, respectively. The 120-hour period for two pumps was constant because it always included an extra weekend (72-hour period). Event 3 did not fit this criteria by design, in contrast to the inadvertent anomalous sequence that occurred during event 2. Event 3 operations were modified to fit Phase I, or in-stream experimental needs. Instead of continuing to operate three pumps at SEPA stations 3 and 4 during the four-pump operation at SEPA station 5, all pumps at SEPA stations 3 and 4 were shut down during this 48-hour period. The in-stream study objective was to determine what influence a four-pump, SEPA station 5 operation alone had on the DO profile of the Chicago Sanitary and Ship Canal without the influence of lake diversion.

Grab Sampling. The primary objective was to determine SEPA station reaeration efficiencies, but several additional studies were conducted to determine if other water quality improvements were occurring within the SEPA stations. The SEPA stations could possibly be functioning as "wastewater" treatment facilities, thereby effectively reducing oxygen-demanding substances in water passing through the stations. Consequently, a sampling program was designed to evaluate this possibility by periodically collecting inlet and outlet samples for analysis of nitrogen and biochemical oxygen demand (BOD) constituents.

Consideration also was given to the possibility that sediment oxygen demand (SOD) in the distribution pools could reduce the DO concentration of the SEPA stations. This appeared to be a distinct possibility as significant sediment deposition was occurring in SEPA stations 3, 4, and 5, as shown by figure 13. Contingency plans were developed to perform in situ SOD measurements using methods developed by Butts and Evans (1978) if early DO monitoring results indicated SODs may be affecting DO levels in the SEPA station pools. Preliminary results indicated that SOD testing was not necessary.

Weir-box Operation. An accurate evaluation of SEPA station aerating efficiencies requires precise knowledge of water quality conditions and DO saturation levels of water being routed through the SEPA stations at specific time intervals. When β-values are actually less than unity (1.0), use of a standard DO saturation computation formula, such as equation 2 without adjustment, will tend to underestimate reaeration efficiencies, whereas using such equations without adjustment when β-values exceed unity will overestimate reaeration efficiencies. Also, as equation 4 indicates, weir aeration efficiency varies with changes in water quality. Therefore, the effects of water quality require investigation when conducting weir aeration experiments under ambient conditions.

For the present study, a standard weir box as used by Butts (1988) during the full-scale SEPA station pilot study, was used to determine the variability in water quality and to assess its affect on SEPA station reaeration efficiencies. The weir-box setup used at SEP A station 5 is shown in figure 14. Identical setups were operated at SEPA stations 3 and 4. The basic operation consists of using compressed air to aerate water to saturation and to measure the above and below weir-box DO concentrations during the beginning and ending of each event and during the beginning of each change in pump settings. With the physical factors being set (including $\beta = 1.0$) and S_a and S_b being determined experimentally on site, the effects of variability in water quality on deficit ratio can be computed using equations 1 and 4.

This procedure was applied to events 1, *2,* and 3 but was discontinued when preliminary analyses of the data indicated that the use of experimentally derived DO saturation concentrations and water quality factors did little to enhance the data analyses and outputs. In fact, inclusion of these adjustments in the data reduction process tended to obscure the results even more by producing more rejected data sets on the basis of the criteria required for equation 1.

QA/QC Program

Many procedural safeguards were used to ensure that credible results were achieved. The SOP and QA/QC procedures detailed in appendix A and D, relative to the management and handling of the continuous monitors, were applied at all times under close supervision of the principal investigator. Normally, monitor deployment time is limited to six to eight days during warm weather in nutrient-rich waters such as the Cal-Sag Channel. However, because the SEPA events required 12 to 14 days of undisturbed deployment, extra effort was taken to collect significant amounts of independently measured DO/temperature data for use in making QA/QC corrections or adjustments in the recorded outputs.

A number of factors were expected to negatively impact datalogged DO readings with time. Principle among these are influences due to inherent instrument drift, biological growth on sensors, and sediment accumulations around sensors and in the protective shrouds. To determine the combined, cumulative effects of these factors, periodic DO/temperature measurements were manually made at each SEPA station using a YSI Model 59 DO/temperature meter equipped with a YSI Model 5739 stirrer/probe. The number of manual measurements made for each event were: four for event 1, three for event 2, and two for each of events 3 and 4.

When practical, surface DO/temperature measurements were manually recorded near the locations of the submerged monitors. The stirrer/probe was maneuvered into position using a flotation device consisting of an 8½ inch x 19½ inch piece of standard green-treated lumber (figure 15). The stirrer/probe was secured on the bottom side with rubber-covered ¼ inch U-bolts fastened with wing nuts on top. The rig was positioned using either a rope or a long-handled, rigid pole. A garage-door handle was provided for carrying the setup between measurement locations. The rope or pole was attached through an eyebolt so that the stirrer/probe would always face downstream. The upstream comers of the board were cut at 45-degree angles so that the flotation device would remain stable and in-line with the flow.

Measurements of DO and temperature were manually taken at a number of locations within each SEPA station as shown by the areal schematics presented in appendix B. The approximate locations of monitor placements are shown on figures 3, 4, and 5. Measurements were taken at or near the location of monitors within SEPA station 5; at all monitor locations, with the exception of the distribution pool placement, within SEPA station 4; and at the monitor location of the distribution pool within SEPA station 3.

The manual measurements provided data and information for deriving the "best estimate" or average DO and temperature values for monitor locations that could not be accessed with the YSI meter and probe setups (figure 15). Also, it provided data and information, albeit somewhat limited, for determining the variability of DO and temperature within the distribution and aeration pools. Furthermore, manual measurements were made outside the bounds of QA/QC requirements during the staging of the first two events. The measurements were actually started during the summer of 1995 and continued into 1996 in excess of the required QA/QC needs associated with events 1 and 2. During 1997, manual measurements were conducted only during events 3 and 4. No independent measurements were made.

The DO and temperature measurements also were manually made at SEPA stations 1 and 2, albeit less frequently than at SEPA stations 3, 4, and 5. This accounts for the inclusion of the SEPA station 1 and SEPA station 2 schematics in appendix B. These manual measurements were made in unison with the manual measurements at SEPA stations 3, 4, and 5 starting in late summer 1995 and continuing through the fall of 1996.

Regimented SOP and QA/QC procedures were developed specifically for the project study and applied to DO/temperature meter calibration procedures and measurement techniques used for taking manual measurements. The portable YSI meters were turned on and left to warm up for at least 15 minutes prior to calibration; potassium chloride (KG) solutions and cell membranes were changed in the laboratory 24 hours prior to field use. Calibration of the DO meters with air was performed in a 6-inch diameter by 8-inch deep (3.7 liter) chamber constructed with schedule 40 polyvinyl chloride (PVC) pipe. The chamber was designed to house the inclusive stirrer/probe in an airtight, constant-temperature environment. Temperature stability was maintained via a ½-inch thick water bath contained around the outside of the chamber. A moist sponge provided 100 percent humidity.

The portable YSI meter was readjusted to 100 percent DO saturation when drift occurred. When 100 percent stability was registered, the meter was switched to the oxygen/temperature (operating) mode, and the initial calibration time, temperature, DO concentration (mg/L), and percent saturation were recorded on the field forms in appendix B. After the manual measurements were completed, the sensor was patted dry with a paper towel and inserted into the air calibration chamber. Sufficient time was allowed for a stable reading. The time, temperature, DO concentration, and percent saturation were recorded on the field form. The beginning and ending readings were used to correct the manually collected data for instrument drift using linear interpolation.

The early 1995 manual DO/temperature measurements provided important planning information relative to choosing the best or more representative monitor placements, i.e., optimum areal locations in SEPA pools and outfalls and optimum vertical locations at intakes. Intake measurements were made at 2-foot depth intervals; outfall measurements were made at 1-foot depth intervals.

During each monitoring event, water quality monitors were placed in duplicate at the inlet and outlet locations at each SEPA station as shown on figures 3, 4, and 5 to minimize loss of data at the most critical measurement locations. A malfunction of one or both monitors at these locations would prevent making an assessment of the overall reaeration efficiency for a particular set of operating conditions. The ISWS experienced approximately 95 percent functional reliability during in-stream deployment, but the placement of two water quality monitors at these locations, significantly but not completely, reduced the risk of data loss. A complete loss of intake data alone also would preclude assessing the aeration efficiencies of the screw pumps, a major consideration to be addressed during the present study.

In spite of the safeguard of collecting data in duplicate at the intake and outfall, some loss of data occurred for the intake structure during event 3 at SEPA station 5. The primary cause appeared to be due to severe sedimentation inside the protective shrouds and around the sensors. This loss of data occurred in spite of using a double-shroud, duplicate in-line rigging at the SEPA station 5 intake (figure 16). The monitors were deployed along the bottom of the intake wall to prevent obliteration by barges and their towboats. Barges use the intake wall as a navigation guide wall when traveling both up- and downstream in the Cal-Sag Channel. Loose, thick sediments are pandemic in the extreme lower reaches of the Cal-Sag Channel. High flows and/or barge traffic tend to cause continual shifting and movement of these sediments.

During event 4, a third intake monitor was installed inside SEPA station 5 in a vertical position on the pump-1 trash rack. This unit was deployed for added insurance against a complete loss of intake data during the event and provided an opportunity to compare two totally independent monitoring locations at this station. The trash-rack installation was not used previously, nor was it even considered as a replacement for the outside rigging; the outside location was a permanent installation used in conjunction with the continuous in-stream monitoring program associated with the Phase I portion of the study. The outside location was quickly and conveniently accessible and serviceable by boat, as were the intake and outfall installations at SEPA stations 3 and 4. A disadvantage of the independent trash-rack setup was that data generated would be selectively dependent on pumping rates. Four-pump operations may have required a rigging at all five trash racks; and, when certain pumps were not operating, superfluous data would be generated. If only two monitors were used, conceivably one or both could have been recording stagnant water DO and temperature readings during times when less than five pumps were operating.

Deploying monitors in tandem also enhanced the QA/QC procedures. It permitted evaluating on a selective basis the reliability, consistency, and reproducibility of data generated by individual monitors at a given location. Tandem installations were restricted because of the limited number of monitors available and the preparation and deployment times necessary.

A total of 27 water quality monitors were required during events 1, 2, and 3. During event 4, 28 units were required due to the addition of the intake unit at SEPA station 5. At SEPA stations 3 and 4, seven units were used as shown in figures 3 and 4. At SEPA station 5, either 13 or 14 units were used as shown in figure 5. The monitor/datalogging units available for deployment for a given event were: 25 YSI 6000s, 1 YSI 6920, 1 DataSonde 3 (DS3), and 5 DS1s. Whenever possible, the 25 YSI models and the DS3 were used, and replacements, backups, or additions were selected from the pool of old DS1s when warranted.

Beginning with event 1, at least one of the YSI monitors became dysfunctional prior to deployment in the field. Consequently, during all the events, to some extent, DS1s were used to fill voids created by inoperable YSI units. Because these units were old, less reliable, and technologically less sophisticated, they were placed at locations in which failures would least influence or hinder analyses associated with determining overall SEPA station aeration efficiencies. An example of such placement was the addition of the third intake unit at SEPA station 5 during event 1. A contingency rank-order schedule was devised for DS1 deployment as outlined below:

DS1 Deployment

Rank	*Placement*
1	Third unit at any station intake
2	Second unit in outlets of SEPA stations 3 or 4
3	Second unit in either outlet of SEPA station 5
4	Both units in one of SEPA station 5's two outlets
5	Any interior aeration pool
6	Any distribution pool

The need to use DS1s never extended beyond a rank-3 situation.

The routine tandem installations at all the inlet and outlets, plus the triplicate inlet installations during event 4 at SEPA station 5, provided QA/QC data for use in evaluating the duplicity of outputs between separate monitors installed at the same location. By using the data in concert with the manually measured data, the accuracy, precision, and reliability of each instrument could be identified and characterized. These data were particularly valuable in assessing and identifying the best DS1 units as the study progressed and how well their outputs matched those of the YSI 6000s, YSI 6920, and the DS3.

Field Operations

Field tasks included monitor installation and removal, weir-box operation, periodic manual measurements, and BOD and nitrogen sample collections. The ISWS was responsible for the installation and removal of the monitors and for periodic manual DO and temperature measurements. Personnel from the District's R & D were responsible for conducting the weir-box and DO-saturation experiments and for collecting and analyzing the nitrogen samples. The ISWS personnel collected and analyzed the BOD samples. All these tasks were performed with the cooperation and aid of District personnel, who were responsible for the operation, management, and maintenance of the SEPA stations.

Monitor Installation/Removal

The in-line, single-shroud riggings (figure 17) were installed within each SEPA station a week before the start of event 1. The riggings were left in place until spring 1997, at which time they were replaced with double-shroud, V-riggings (figure 17). The in-place riggings were redesigned over the winter with the intent to reduce sediment deposition and fouling of the sensors. With the new design, the monitor has been raised off the bottom by securing the standard 6-inch PVC shroud to the top of a 12-inch polyethylene pipe section. This, in effect, raised the centerline of the monitor 9 inches above the bottom compared to 3 inches for the single-shroud system. The raising of the level of deployment was limited to approximately this elevation because siltation had reduced the water depths to approximately 1 to *VA* feet at many points upstream of the weirs.

The monitor installation process began on the first Monday of each event beginning at SEPA station 3 and ending at SEPA station 5. The pumps at SEPA station 3 were shut down by District personnel around 0800, and installation was completed by 0900. Similarly, pump shutdowns and installations were completed by 1000 at SEPA station 4 and by 1100 at SEPA station 5. Removal of the monitors would commence after the pumps were shut down at each SEPA station on the last Friday of each event. Time schedules adhered to during deployment would be duplicated during the removal process.

The deployment of the monitors at the intake and outlet structures of SEPA stations 3 and 4 was done using a boat. These units often were installed on the Friday prior to an event as part of the weekly or biweekly exchanges associated with the Phase I, in-stream monitoring operation. However, the units were always removed at the termination of an event in concert with the in-SEPA monitor removals.

Weir-Box Operation

Weir boxes were installed at each SEPA station and left in place throughout the duration of the study. The only difference between weir boxes was that the box at SEPA station 3 was constructed of ¾-inch plywood (figure 18), whereas the boxes at SEPA stations 4 and 5 were constructed of ½-inch Plexiglas. The setups, along with associated equipment and materials, were supplied, installed, and checked for proper operating performance by ISWS personnel. Operational experiments were conducted four times during each event by District R&D personnel.

Two work tasks were associated with the weir-box experiments. One was to pump water into the elevated box under a fixed set of conditions to periodically determine water quality conditions as represented by a in equation 4. The second task was to aerate contained channel water, in concert with running the weir box, to determine ambient DO saturation concentrations.

The weir boxes were set up in areas above trash racks in the intake channels of each SEPA station (figure 14). The experiments were started by priming the pumps to fill the boxes. As soon as the boxes were filled, pumping continued for a minimum of 20 minutes to ensure representative measurements. The pumps were 2-horsepower (hp), electric-driven, cast iron units with 2-inch suction and l½-inch discharge connections (figure 19). Standby pumps were available at SEPA station 4 in case of failures. One standby was a gasoline-driven unit; the other was a 1½ hp electric-driven unit.

Pumping rates of 0.95 liters per second (L/sec) were maintained via a gate valve on the discharge line. This produced water surface elevations of 1.79 and 0.51 m in the weir and receiving boxes, respectively, and a constant water fall height h in equation 4 of 1.28 m.

Special field sheets were used to record the weir box and DO-saturation data (appendix B). Two DO samples were collected near the V-notch weir in the upper box and two DO samples were collected near the rectangular outlet weir on the receiving box. All four samples were siphoned simultaneously into 300-milliliter (mL) DO bottles through Vi-inch flexible tubing. The DO concentrations were determined using the Winkler Method (APHA, 1992) using chemicals and titration apparatuses on site (figure 20). If the difference between the duplicate samples was 0.2 mg/L, a third sample was siphoned and fixed. Similarly, a third analysis was performed if the difference between the two DO-saturation samples exceeded 0.2 mg/L. The DO saturation was achieved by aerating 2 liters (L) of water with small, household-type, 120-volt, 1.0 cubic feet per minute or cfm (30 pounds per square inch or psi) air compressors fitted with fine-bubble air stones.

The pumps were shut off after completing each weir-box experimental sequence, and both boxes were siphoned dry with ¾-inch tubing. A stepladder was provided for accessing the top weir box for DO sampling and for draining.

Grab Sampling

Grab samples were collected periodically for BOD and nitrogen analyses. The ISWS collected two sets of BOD samples at each SEPA station in 1-gallon Nalgene bottles. One set was collected from the inlets and outlets during the monitor installations on Monday; the other set was collected at the same locations during the removal of the monitors on Friday. These samples were immediately transferred to the ISWS Peoria laboratory and prepared for 20-day BOD incubations. The maximum time lapse between collection and incubation was approximately eight hours. The samples were not iced because the relatively short time between collection and incubation made it unnecessary, and the method used for analyses (Elmore, 1955) precludes cooling below 20°C. Samples returned to the laboratory cooler than 20°C were allowed to warm to 20°C or greater to avoid production of "phantom" BODs during the initial incubation period.

Nitrogen grab samples were collected ten times at the inlet and outlet of each SEPA station by District R & D personnel during events 1, 2, and 3. No samples were collected during event 4. Nitrate and nitrite samples were filtered through a Katadyn Model 2050 field pressure filter fitted with a 0.2 micrometer (µm) diatomaceous earth filter element. Total Kjeldahl nitrogen samples were not filtered. Samples were cooled in the field and in the laboratory until analyses were completed. Sampling times were recorded on the weir-box field form as shown in appendix B.

Manual DO/Temperature Surveys

The DO and water temperature measurements were conducted by two ISWS personnel, one of which was always the principal investigator of this study. The principal investigator was present at all times and provided an element of consistency in performing the technical aspects of this task. The principal investigator also could make field observations relative to anomalies in the operation of a SEPA station.

The DO and temperature measurements were taken approximately 2 inches below the water surface at all distribution and aeration pool locations using the floatation device shown in figure 15. Measurements were made at 2-foot intervals beginning at the bottom from the relatively deep vertical seawalls containing the intakes at SEPA stations 3, 4, and 5. Only bottom and surface readings were taken at the shallow intake areas of SEPA stations 1 and 2. Effort was made to consistently record data at all the points shown on the schematics in appendix B.

Walkways provided access to a larger number of measurement locations in some pools of SEPA stations 1, 3, 4, and 5. This was particularly true at SEPA station 5. The walkway across aeration pool 1S at SEPA station 5 permitted four measurements to be made in this pool and five to be made in the distribution pool. Measurements in the distribution pool were made by attaching the stirrer/probe float, shown in figure 15, to a 16-foot rigid pole to counteract the high velocities at weir 1S. From 60 to 90 minutes were required to complete DO and water temperature measurements.

A backup YSI meter, complete with a separate stirrer/probe hookup, was available. If a meter/probe failure occurred at any point during the survey, the backup unit was calibrated and the entire survey was repeated.

Laboratory Operations

Continuous Monitors

In the laboratory, YSI 6000 monitors were calibrated for DO, pH, and specific conductivity. All calibrations and data downloading were performed using the PC6000 software provided with the instruments. Data files were downloaded in the proprietary PC6000 format and converted within PC6000 to comma-delimited value format for importing into Microsoft Excel (version 7.0). Hydrolab DataSonde I instruments 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, data were moved into Microsoft Access where all calculations and statistical analysis were performed.

The pH calibrations were performed using Fisher Scientific® buffers of pH 7.0 and 10.0. Before calibration, the sensor was cleaned and rinsed with deionized water and pH 7.0 buffer to remove any contamination. The sensor was placed in 500 mL of pH 7.0 buffer, and allowed to stabilize for ten minutes, or until the electrode readings were stable, at which time the calibration was entered. The sensor then was removed from the solution and rinsed in a beaker of deionized water. Prior to placement in the pH 10.0 buffer, the sensor was rinsed with pH 10.0 buffer to remove any residual pH 7.0 buffer or deionized water droplets, which may contaminate the pH 10.0 buffer. The sensor then was immersed in a beaker containing 500 mL of pH 10.0 buffer and allowed to stabilize for ten minutes, or until stable readings were obtained. After calibrating at pH 10.0, the sensor was rinsed again and returned to the pH 7.0 buffer to verify calibration. Calibration buffers were checked periodically with an Orion model 920A benchtop meter equipped with a model 91-56 pH electrode. Hydrolab instruments were calibrated in an identical manner, with the exception that the amount of buffer used was reduced to the amount necessary to cover the electrodes in the smaller calibration cups.

Specific conductance at 25° C was calibrated using a standard of 1.413 millisiemens/centimeter (mS/cm). The standard was made by diluting a stock solution of 12.880 mS/cm. The standard was checked using a Labcraft model 264-774 conductivity meter calibrated separately with ready-made standards. Sensors were cleaned and prerinsed with the conductivity standard before immersion in 500 mL of the calibration standard. Calibration was accepted after a ten-minute interval if all readings were stable. Cell constant values were confirmed to be within the correct operating range. Units with "out-of-range" cell constant values were cleaned and recalibrated. Cell constants could not be checked on the DataSondes because the internal software of the sonde does not provide a means for doing this.

The DO sensor was always calibrated after specific conductance because specific conductance is utilized by the internal software of the monitors to calculate DO. The DO sensor membranes were changed prior to each deployment. This was done at least 24 hours prior to calibration to allow for relaxation of the membrane. The sensor was rinsed with deionized water and dried with tissue before calibration. Care was taken to ensure that no water droplets were present on the membrane.

For the YSI monitors, calibration cups containing moist sponges were placed over the sensors. The monitors were placed on their sides with the DO sensors on top for calibration. This reduced the chance of water dripping onto the membranes from the top of the sensor. Monitors were run for at least ten minutes in the discrete sampling mode prior to calibration to warm the electrodes and confirm the stability of the environment within the calibration cup. Monitors then were calibrated for DO while compensating for barometric pressure. Barometric pressure was obtained from the National Weather Service and adjusted to the elevation of the laboratory.

Hydrolab instruments were calibrated in an inverted position in a specially designed open-bottom calibration cup. Calibration cups were filled with tap water to levels below an o-ring holding the DO membrane on the electrode. Care was taken to ensure that the membrane was free of water droplets. Rubber caps were lightly placed over the open cup bottom to isolate the probe from ambient air currents. These monitors do not need preliminary warming up. The monitors are run in a calibration mode until acceptable, stable calibrations are obtained. These instruments automatically compensate for atmospheric pressure.

The data generated by the continuous monitors are subject to a certain amount of drift. This drift is a combination of two factors: calibration drift inherent to the sensor design and operation, and drift caused by environmental conditions such as the buildup of foreign matter on the sensor. Therefore, corrections were applied to the DO measurements obtained by the monitors to compensate for such drift. Drift compensation was performed in Microsoft Access 97 through a Visual Basic program written by ISWS personnel. The program utilized a combination of pre- and post-deployment Winkler test values and field values obtained during manual measurements. The compensation equation adjusts for drift between two known points, but more than two points may be used by segmenting the data into sequential time periods. The compensation or correction equation can be expressed mathematically as:

$$co_{ti} = mo_{ti} - \left\{ (mo_1 - co_1) + \left[\frac{(mo_2 - co_2) - (mo_1 - co_1)}{t_2 - t_1} \right] (t_i - t_1) \right\} \qquad (6)$$

where:

co_{ti} = corrected DO, mg/L at time t_i, days
mo_{ti} = monitor DO, mg/L, to be corrected at time t_i
mo_1 = monitor DO, mg/L recorded at time t_i, days
co_1 = correct YSI 59/Winkler DO, mg/L at time t_i
mo_2 = monitor DO, mg/L, recorded at time t_2, days
CO_2 = correct YSI 59/Winkler DO, mg/L at time t_2

Biochemical Oxygen Demand

Twenty-day BOD tests were performed in the ISWS laboratory in Peoria. Total BOD (TBOD) and carbonaceous BOD (CBOD) were directly measured, whereas nitrogenous BOD (NBOD) was determined indirectly by calculation. The CBOD was determined using a nitrification inhibitor. Bottles and DO probes used for measuring CBOD were labeled and used only for samples containing inhibitor to prevent the inhibitor from contaminating the TBOD samples. The TBOD and CBOD tests were performed in triplicate. The YSI model 59 DO meters were calibrated to air saturation in a custom-made, six-probe capacity calibration chamber. Six YSI model 5730 BOD stirrer/temperature/DO probes and meters were used simultaneously. Three were reserved for each of the triplicate TBOD and CBOD (inhibited) readings.

Nitrogenous BOD data and curves, presented in this report, were derived by subtracting measured CBODs from measured TBODs. The CBODs were determined by inhibiting nitrification using Hach nitrification inhibitor formula 2533. During event 1, for a cursory comparison, the inhibitor method was run in concert with the progressive ammonia oxidation (nitrification) method. The latter involves measuring ammonia nitrogen (NH_3-N) concentrations in the BOD water at periodic daily intervals and calculating the oxygen usage stoichiometrically by multiplying each 1.0 mg/L decrease in NH_3-N by 4.57 as 4.57 mg of DO is required to oxidize 1.0 mg of ammonia-N to nitrate-N (Gaudy and Gaudy, 1980). The stoichiometric results appeared to be somewhat more accurate, but time and monetary constraints dictated the use of the inhibitor method. Extreme accuracy was not needed as the BOD experiments were a relatively minor part of this study.

The BOD samples were collected in 1-gallon bottles and analyzed within a few hours of collection. The initial 1-gallon samples were split into two half-gallon sample bottles with dispenser tubes on the bottom. The first bottle was used for TBOD, and the second was used for CBOD. A dose of 1.92 grams (g) of Hach nitrification inhibitor formula 2533 was added to the CBOD bottle. No inhibitor was added to the TBOD bottle. Both bottles were aerated with airstones for approximately 30 minutes to raise the DO to near saturation levels. Three 300-mL BOD bottles with glass stoppers and plastic caps were filled from each half-gallon bottle. Excess sample was retained in the half-gallon bottles for replacing sample losses occurring during periodic DO measurements.

The DO measurements were made in each of the six 300-mL bottles. Between readings all sensors were rinsed with deionized water. If significant disagreement was found between the readings, the meters were checked and recalibrated. When necessary, sample was added from the half-gallon bottles to replace volume displaced by the sensors. The bottles were capped with glass stoppers and checked for air bubbles. Plastic caps were placed over the mouths of the bottles to prevent evaporation of the water seal. The 300-mL and half-gallon bottles were then placed in a Hotpack model 352602 incubator set to 20° C. Using the same protocol, subsequent DO measurements of the 300-mL bottles were made every 1 to 2 days for 20 days. When DO levels in the 300-mL bottles became low (~3 mg/L) the samples were returned to their respective half-gallon bottles, aerated for 30 minutes, and again dispensed into the 300-mL bottles. The NH_3-N samples were taken from the half-gallon TBOD bottle every four to five days. The NH_3-N testing from BOD samples was performed by ISWS personnel at the Peoria laboratory; 100 mL samples were analyzed by method 4500-NH_3 D from *Standard Methods for the Examination of Water and Wastewater* (APHA, 1992) using an Orion 920A meter and a model 95-12 ammonia electrode.

The TBOD, CBOD, and NH_3-N data were entered into a Microsoft Excel spreadsheet. All calculations were performed within Excel.

Nitrogen

Nitrogen samples from the SEPA stations were analyzed by District personnel at the Stickney R & D laboratory facilities using method 4500-NH_3 D from *Standard Methods for the Examination of Water and Wastewater* (APHA, 1992).

Data Reduction and Analyses

Field DO measurements, continuously recorded at the SEPA stations, had to be reduced and organized so that meaningful mathematical and statistical analyses could be performed to achieve the two major objectives of the study. The first step in data reduction was to adjust and/or correct for differences between the continuous monitor DO measurements and manually recorded values and those derived from QA/QC laboratory procedures using the Winkler method by use of equation 6. After these corrections and/or adjustments were made, the DO data were subjected to statistical analyses in the form of the deficit ratio, as derived from equations 1 and 2, and in the form of the output DO saturation percentage, as predicted by equation 5.

Statistical analyses were performed using standard computer programs capable of handling the large number of data generated by the current study. The ANOVA procedures, *t*-tests, and multiple range analyses were used to evaluate the data. 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 be normally distributed with a 95 percent degree of confidence, statistical tests applicable to "normal" data were used. For data not normally distributed, nonparametric, rank-order testing usually was performed. These tests provide powerful means of testing for differences in data sets that are not normally distributed.

Monitor Output Adjustments

The continuously recorded DO values were first corrected by matching measured and recorded laboratory tank values. The initial and ending Winkler DOs (co_1 and CO_2, respectively, equation 6) were compared with corresponding monitor outputs (mo_1 and mo_2, equation 6) recorded close to the time at which the DOs were determined by the Winkler method. All monitor values were then corrected using equation 6. Further corrections following the same procedure were made using the DOs manually measured in the field with the YSI Model 59 DO/temperature meters.

Table 5 lists the manual DO/temperature measurement locations (as referenced to the appropriate figures in appendix B), which were used to adjust or correct monitor outputs. The intake water depths ranged between 10 and 12 feet at SEPA stations 3 and 4 and between 8 and 10 feet at SEPA station 5. At times, pronounced DO stratification occurred at these intakes. For example, on August 14, 1996, the DOs ranged from 3.54 mg/L on the bottom to 6.03 mg/L at the surface. Table 6 lists all 5-foot depth values at SEPA stations 3 and 4 and all bottom and near-bottom values at SEPA station 5 recorded manually, including those in 1995.

Statistical tests, using the *t*-test, were performed to determine if one could accept the hypothesis that the individual DO values measured at the intakes are equal to the vertical means listed in table 6 at a 95 percent confidence level. The results show that such a hypothesis could be accepted only for the SEPA station 4 data. Although the 5-foot depth and average means are relatively close for the SEPA stations 3 and 5 data, the individual data points display more variability (see variance statistic in table 6). Consequently, regression equations were developed and used to predict the average intake DOs based on the individual values. A prediction equation also was developed for SEPA station 4 to provide consistency in the data analyses.

The equations developed using linear statistical regression analyses are:

$$DO_{3avg} = 0.959 \quad DO_5 + 0.166 \tag{7}$$

$$DO_{4avg} = 1007\, DO_5 - 0.072 \tag{8}$$

$$DO_{5avg} = 0.875\, DO_{-1} + 0.841 \tag{9}$$

where

DO_{3avg} = average vertical DO, mg/L, at SEPA station 3
DO_{4avg} = average vertical DO, mg/L, at SEPA station 4
DO_{5avg} = average vertical DO, mg/L, at SEPA station 5
DO_5 = DO, mg/L, at 5-foot depth
DO_{-1} = DO, mg/L, 1-foot off bottom

The coefficient of determination (R^2) for equations 7, 8, and 9 are 0.9893, 0.9667, and 0.9407, respectively, and the standard error of estimate (SEE) for equations 7, 8, and 9 are 0.091, 0.215, and 0.334, respectively. The R^2 represents the fraction or percentage of the total variance in the mean DO that is explained by the point source DOs. In other words, 98.93 percent of the variability in the mean DO at SEPA station 3 is explained by the variability in the DO observed at the 5-foot depth. At SEPA station 5, the observations made 1 foot above the bottom account for 94.07 percent of the variability observed in the vertical average.

Equations 7, 8, and 9 were used to compute a mean DO concentration for every intake monitor reading recorded during both the Phase I and II studies. The equations produce good estimates of the mean vertical values and could be applied with confidence to future data generated using point monitoring at these three locations. The conversion of the point data to mean values was done using Microsoft Access 97.

Missing Data and Curve Reconstruction

Overall the YSI and Hydrolab monitors performed satisfactorily. However, at times, gaps in the data developed due to unit malfunctions caused by either defects inherent in the instruments or by technician error. Depending upon the severity of the data loss and the sampling location, some of the missing data could be reconstructed with a good degree of confidence.

Reconstruction of missing data was done using a combination of: residual data from the deployment of the defective monitor, fully generated DO curves from monitors up- and downstream of the defective unit, and manually recorded measurements. For example, if a monitor in aeration pool 2 produced an incomplete curve or a complete curve with obvious outliers, the shape and proportionality of curves generated by units in pools 1 and 3 would be compared and the possibility of reconstruction evaluated. If overall consistency between the two curves prevailed, including sinuosity, difference in magnitude, and proportionate manually recorded values, attempts would be made to fully reconstruct the pool-2 curve.

Attempts at reconstruction usually were successful to some degree. The overall results of this study would not have been significantly affected if they had not been. The end result was that essentially complete, finely tuned sets of data were produced.

Aeration Efficiency

Parameter Selection. The SEPA station components and overall aeration efficiencies can be evaluated using deficit ratios, as defined either by equations 1 and 4 or by relative DO outputs expressed as a function of the percentage of saturation (P_o in equation 5). However, in the final analyses, P_o was selected for use. Preliminary calculations indicated that deficit ratios (r-values) would not be suitable because use of equation 1 resulted in too many rejections due to acceptance criteria. This is shown by the low (<1.0) and negative values exemplified in table 7.

Table 7 lists deficit ratios calculated for both a day and a night situation at SEPA station 4 for all combinations of point changes in DO, including those between the intake and all the pools and between all pool combinations. Theoretically, the deficit ratio should remain relatively constant for a specific geometric design, irrespective of the ambient DO level of the above-weir water. Consequently, the r-values for all single and double weir combinations listed in table 7 should, theoretically, be roughly equivalent. In other words, the r-value for the three single weir passes (pools 1 to 2, 2 to 3, and 3 to out) should be reasonably equivalent. Similarly, the two double-weir combinations (pools 1 to 3 and 2 to out) should exhibit equivalency to some degree. Review of the data shows this is not true.

Note, from table 7, that during the April 25, 1997, day operation, the r-values generated between the intake and the first weir were realistic and consistent up to the 1200 hour. The average for this period was 2.57, and it represents the r-value equivalency of the screw pumps. However, after the first pool, r-values became extreme both in magnitude and variability with many negative values. The values ranged from a low of -833.2 (intake to out at 0930) to a high of+566.8 (intake to out at 1000). These untenable results were produced because ambient above-weir DO concentrations quickly approached saturation levels after pumping and were at or above saturation above weir 3. Consequently, conditions exemplified by the computations summarized in table 2 occurred between weir 1 and the outfall.

The June 13, 1997, night deficit ratio results also were ambiguous, but the nature of the ambiguity was slightly different from that of April 25, 1997. In this case, the intake-to-pool-1 r-values produced were somewhat less than realistic. Deficit ratios rose steadily from somewhat unacceptable negative values during the early morning hours of June 14, 1997. Overall, r-values ranged from a low of-684.9 (intake to out at 0300) to a high of +928.9 (intake to out at 0215). Interestingly, two nighttime situations produced consistent, reasonable data. The intake-to-pool-2 average was 5.2 and the pool-2-to-pool-3 average between 2100 to 0330 hours was also 5.2. However, after 0330 hours the values steadily rose to 18.9 at 0600 hours.

An effort was made to improve the r-value outputs by incorporating DO saturation and water quality factor corrections in their calculations. The DO saturation concentrations calculated using equations 2 and 3 were adjusted using a β-factor derived from the experimental DO saturation values generated during the weir-box experiments. Also, water quality factors, a in equation 4, were computed from the weir-box experimental data. The modified deficit ratio that resulted did not improve the overall output at any SEPA station location. In fact, the problem of negative and/or inordinately high values was often exacerbated, apparently because the β-values were often less than unity as shown by the results in table 8; 35 of the 54 β-values presented are less than one.

The r-values derived for selected April 25, 1997, monitor outputs at SEPA station 4 using a β-factor of 0.966 are presented in table 9. The "uncorrected" results are presented in table 7; table 9 lists 136 negative values compared to only 52 in table 7. This simple example illustrates the extreme sensitivity of r to small changes in DO concentrations, relative to either saturation or ambient DOs, when ambient DO values are near saturation levels.

Temperature/DO Saturation. To circumvent the pitfalls of using r as the evaluation parameter, P_o was selected as the comparative variate. Dissolved oxygen saturation values were computed using equations 2 and 3 in conjunction with temperature data generated by the continuous monitors. A β-factor was not applied to the DO saturation concentrations used to compute P_o.

Historically, ISWS researchers have found that monitor temperature outputs are accurate, relative to National Institute of Standards and Technology grade mercury thermometers, and are precise relative to other monitors. Elaborate QA/QC procedures have been developed to ensure adherence to accepted deviation tolerances (Butts et al., 1995). The QA/QC procedures employed when monitors were used to measure water temperature during thermal discharge studies are presented in appendix D. During the present study, these strict procedures were not followed precisely. Monitors that were not individually calibrated were routinely compared with those that historically had been (mostly YSI Model 59 DO/temperature meters). During this study, as is commonly the case, temperature sensor malfunctions did not occur.

Table 10 presents water temperature data, which shows good-to-excellent precision between duplicate monitors and monitors and temperatures manually measured with YSI Model 59 DO/temperature meters. No statistically significant differences could be shown to exist at a 95 percent confidence interval between the means for each location within each SEPA station.

Statistical Analyses

The results and subsequent conclusions of this study were largely derived through the use of statistical testing. The statistical testing calculations were performed using SigmaStat (Version 2.0). This statistical software package automatically subjects data to a normality check. If the data fail normality, appropriate nonparametric statistical tests are offered. Both parametric and nonparametric statistical testing were used and is done on either a two-group basis or a three- or greater group basis. Two groupings use the *t*-statistic as the basic test parameter; greater-than-two groupings use the *F*-statistic (or its nonparametric equivalent) as the basic test parameter. Most data sets failed the "normal test". Therefore, many of the analyses were performed using nonparametric methods. The nonparametric tests used in this report produced more reliable results than could be achieved using a transform to normalize data, then subjecting the normalized data to parametric testing.

Two-Group Tests. The Mann-Whitney Rank Sum Test (a nonparametric test) was used to ascertain if two samples come from the same population of values. One form uses the *t*-statistic as the test parameter. This test was used to determine if the medians of the meter-measured and sonde-measured temperatures could be assumed to be equal at a 5 percent level of significance.

The methodology used in rank-order testing will be presented using SEPA station 3 meter and sonde intake temperature data presented in table 10. The computations are outlined as follows:

Temperature order		*Rank*	
Meter (m)	*Sonde (s)*	*Meter (m)*	*Sonde (s)*
14.8		1	
	14.94		2
	15.25		3
15.3		4	
16.3		5	
	17.18		6
19.3		7	
	19.32		8
	19.37		9
19.4		10	
19.6		11	
	19.79		12
24.1		13	
	24.21		14
24.3		15	
	24.31		16
24.7		17	
24.8	24.80	18.5	18.5
	24.96		20
25.3		21	
	25.33		22

Rank sums, T	122.5	130.5	
No. of samples, N	11	11	
Mean rank, R	11.14	11.86	
Total Rank sums ($T_m + T_s$)			253

$$\text{Mann-Whitney normal variate} = \frac{T}{6}\left(\frac{1}{N_m}+\frac{1}{N_s}\right)$$

$$\text{Standard error} = \sqrt{\frac{T}{6}\left(\frac{1}{N_m}+\frac{1}{N_s}\right)}$$

$$SE = \sqrt{\frac{253}{6}\left(\frac{1}{11}+\frac{1}{11}\right)}$$

$$SE = 2.77$$

$$t\text{-statistic} = \frac{\overline{R}_s - \overline{R}_m}{SE}$$

$$= \frac{11.86 - 11.14}{2.77}$$

$$= 0.260$$

From a standard *t*-distribution table for a two-tail test at $a = 0.05$ and 21 degrees of freedom ($N_m + N_s - 1$), $t = 2.080$.

Because the computed /-value is smaller than the table value, the conclusion is that the median values are equal, signifying both groups probably came from a common population. In other words, a statistically significant difference does not exist between the two groups.

Three or More Group Testing. Data generated from scientific studies involving three or more levels of one or more variables can be analyzed statistically using ANOVA. This statistical approach separates the variances of the measured variable in the fraction caused by several factors (each of which can be viewed singly or in combinations) and the fraction caused by experimental error. Both parametric and nonparametric ANOVA tests are available. However, data that fail a normality check are best analyzed using rank-order procedures (nonparametric test).

Rank-order testing is limited to a one-way analysis. This study was designed to examine data using parametric two- and three-way testing. For example, a two-way design could include using, as comparable variates, seasons (events) and pumping rates (number of pumps) for SEPA station outlet P_o-values (P) given below:

	Number of pumps (N)				
Events (E)	*1*	*2*	*3*	*4*	*E-mean*
a	P_{a11}, $P_{a12},\ldots P_{a1i}$	P_{a21}, $P_{a22},\ldots P_{a2i}$	P_{a31}, $P_{a32},\ldots P_{a3i}$	P_{a41}, $P_{a42},\ldots P_{a4i}$	$\bar{E}_a$
b	P_{b11}, $P_{b12},\ldots P_{b1i}$	P_{b21}, $P_{b22},\ldots P_{b2i}$	P_{b31}, $P_{b32},\ldots P_{b3i}$	P_{b41}, $P_{b42},\ldots P_{b4i}$	$\bar{E}_b$
c	P_{c11}, $P_{c12},\ldots P_{c1i}$	P_{c21}, $P_{c22},\ldots P_{c2i}$	P_{c31}, $P_{c32},\ldots P_{c3i}$	P_{c41}, $P_{c42},\ldots P_{c4i}$	$\bar{E}_c$
d	P_{d11}, $P_{d12},\ldots P_{d1i}$	P_{d21}, $P_{d22},\ldots P_{d2i}$	P_{d31}, $P_{d32},\ldots P_{d3i}$	P_{d41}, $P_{d42},\ldots P_{d4i}$	$\bar{E}_d$
N-Mean	$\bar{N}_1$	$\bar{N}_2$	$\bar{N}_3$	$\bar{N}_4$	

The objective of this example is to determine if null hypotheses that $\bar{N}_1 = \bar{N}_2 = \bar{N}_3 = \bar{N}_4$ and $\bar{E}_a = \bar{E}_b = \bar{E}_c = \bar{E}_d$ can be accepted as being true at some confidence level such as 95 percent. This is accomplished by examining the variability between column and row groupings and the interactions between the two. Looking at only mean values without considering the overall variability of the individual data points often can be misleading and result in incorrect conclusions. A simple example can demonstrate this point. Two hypothetical sets of five numbers (1, 25, 50, 75, and 99) and (48, 49, 50, 51, and 52) both have a mean of 50, but the first set is much more variable than the second. A *t*-test or ANOVA testing procedure would reject the hypothesis that both sets of numbers are equal.

Unfortunately, most of the data failed the normality test. Consequently, one-way, rank-order ANOVAs were used to analyze the data for significant differences. The Kruskal-Wallis one-way ANOVA on ranks was used to determine if median values were equal by examining the variability of the rankings between groupings. A representation designed to test the variability between pumping rates for SEPA station outlet P_o-values (P) is given below:

	Number of pumps (N)			
	1	*2*	*3*	*4*
	$P_{11}, P_{12}, P_{13}, P_{14}, \ldots P_{1i}$	$P_{21}, P_{22}, P_{23}, P_{24}, \ldots P_{2i}$	$P_{31}, P3_2, P_{33}, P_{34}, \ldots P_{3i}$	$P_{41}, P_{42}, P_{43}, P4_4, \ldots P_{41}$
N-Median (Ñ)	$\tilde{N}_1$	$\tilde{N}_2$	$\tilde{N}_3$	$\tilde{N}_4$

The P_o values under each pump column include results from all four seasons. To determine if seasonal variability exists, the test is used with seasonal groupings as the following illustrates:

	Event (E)			
	a	*b*	*c*	*d*
	$P_{al}, P_{a2}, P_{a3}, P_{a4}, \ldots P_{ai}$	$P_{bl}, P_{b2}, P_{b3}, P_{b4}, \ldots P_{bi}$	$P_{el}, P_{c2}, P_{c3}, P_{c4}, \ldots P_{ci}$	$P_{dl}, P_{d2}, P_{d3}, P_{d4}, \ldots P_{di}$
E-Median (Ẽ)	$\tilde{E}_1$	$\tilde{E}_2$	$\tilde{E}_3$	$\tilde{E}_4$

In this case, the P_o values under each column are inclusive of all pumping rates (three for SEPA stations 3 and 4 and four for SEPA station 5).

The ANOVA testing results only provide information about whether two or more groups in a multiple comparison are different at some defined level of significance (usually at 5 percent, i.e., $P < 0.05$). A null hypothesis is stated that is either accepted or rejected on the basis of a computed test statistic. For normally distributed data, ANOVA is used and an F-statistic is computed from the data and compared to a tabulated F-value at the appropriate degree of freedom and confidence level. The F-statistic compares sample variances that permit conclusions to be drawn as to whether two or more means are different. For data that are not normally distributed, ANOVA is used by nonparametric methods and the H-statistic is computed. The H-statistic compares median values to determine if the data are consistent with the null hypothesis, and that the samples were all derived from the same population. In either case, if the computed F or H values are greater than the table value, the conclusion can be reached that significant differences occur within groupings.

When differences are found among groups, they can be separated using multiple comparison or multiple range tests. Pairwise comparisons are made of all possible combinations of group pairs. The tests compute the *Q-test* statistic and make comparisons with theoretical distributions of *Q*. The Dunn's test is applied to nonparametric rank ANOVA test results, and the Tukey test usually is applied to parametric ANOVA results. Large calculated (*Q*-values, exceeding theoretical *Q*-values at some level of significance, indicate that differences between groups being compared are statistically significant. Differences in rank means are used in the Dunn test whereas differences in arithmetic means are used in the Tukey test.

RESULTS

The results will be presented in three categories. First, temperature and DO-data generated by manual measurements, including the preliminary evaluations conducted at all five SEPA stations and the QA/QC data collected during the three-station SEPA operational studies. Second, the results of additional studies and sampling conducted to determine water quality conditions of water entering and exiting SEPA stations 3, 4, and 5. Third, the results of the continuous DO/temperature monitoring within SEPA stations 3, 4, and 5. The results are best reported in this order as the continuous monitoring results were adjusted and modified by the information developed during the walk-through runs and from the operation of the weir box.

Manual DO/Temperature Measurements

The water temperatures, DO concentration, and percent saturation values measured at the intake and outfall for each date manual measurements were made and for each SEPA station are presented in table 11. Statistical summaries of DO percent saturation values (minimum, average, maximum, and standard deviation) for all sampling locations within each SEPA station are shown in figures 21-25. Also, presented in table 11 are the predicted outlet DO percent saturation values (P_o) derived using equation 5. Similarly, predicted P_o values will be presented for the continuous-monitoring data.

The preliminary manual DO and temperature measurements produced valuable information. Foremost they provide good overviews of the basic characteristics of each SEPA station from which the best monitor placement strategies could be determined. Without the study, monitors could have been inadvertently placed in the distribution and/or aeration pools at locations that would have produced incorrect and/or misleading results. For example, without prior knowledge of the aeration characteristics and flow patterns at SEPA station 5, the selection of sampling location V (appendix B, figure 25) as the Cal-Sag Channel outfall monitoring site would have been disastrous. At this location, an eddy current or hydraulic "dead zone" exists. Low-DO, Cal-Sag Channel water is drawn into this eddy current, trapped, and obscures the weir-aeration effects. Figure 25 shows that average P_o value at location V was only 89.2 percent versus a value of 97.7 percent at location V1 on the opposite side of the outfall pool. Note that the minimum P_o value at location V was 64.4 percent versus a minimum of 91.1 percent at location V1. Such "dead zones" caused by unusual circulatory patterns persisted at many locations in all the SEPA stations. The "dead zones" detected while conducting manual measurements at SEPA stations 3, 4, and 5 are indicated by the shaded areas in figures 3-5. Other "dead zones" undoubtedly exist but cannot be ascertained by walking the periphery of the stations. The manual DO and temperature measurements provided good data for assessing deficiencies in flow patterns and hydraulic design.

Peripheral "dead zone" affects can be demonstrated by presenting DO observations made at specific locations in a SEPA station on a given date. As an example, the results of the manual observations made in the "dead zone" areas of SEPA station 4 on June 17, 1997 are presented below (see appendix B for alpha designations of measurement locations):

"Dead zone" location	*DO percent saturation*
C	111.7
D	107.6
E	128.0
G	147.4
J	107.8
L	100.4
M	100.6

The "dead zones" in SEPA station 4, as well as those in the other stations, usually produce supersaturated values in localized areas. "Dead zone" G, in SEPA station 4, was notorious in producing very high supersaturated DO levels as exemplified by the 147.4 percent value. Perusal of the minimum, average, and maximum percent saturation summaries for all five SEPA stations given in figures 21-25 can provide additional insight into the affects of the dead zones on overall SEPA station operations.

The manual DO and temperature data also afforded the opportunity to generate significant background data on the basic operational characteristics of SEPA stations 1 and 2, the two stations that were not included in the continuous monitoring studies. Of particular interest is the data collected from SEPA station 1. Table 11 shows that, on all but one occasion, observed P_o values at SEPA station 1 were > 100.1 percent. However, table 11 also shows that the inlet DO percent saturation (Pi) values were > 90 percent during nine of the ten runs. Because of the high saturation at the intake, only once, on July 23, 1996, was P_i sufficiently low (73.9 percent) to permit reaeration to be reasonably traced throughout the SEPA. The high DO saturation levels at the intake suggest that SEPA station 1, although effective in aerating water flowing through it, may have a minimal impact on in-stream DO saturation levels.

Observed P_o values in excess of 100 percent were continuously observed throughout this study, although these values violate the theoretical precepts as discussed in the section "Dam or Weir Aeration Theory". For the manual measurements, the ratio of the number of observed P_o values greater than 100 percent that violate theoretical precepts versus the total number of runs are: SEPA station 1 (9/10), SEPA station 2 (4/11), SEPA station 3 (5/19), SEPA station 4 (7/19), SEPA station 5C (5/18), and SEPA station 5S (7/18). Table 11 lists the applicable reaeration case scenarios for the preliminary, manual measurements. The italicized cases indicate situations in which theoretical conditions were violated.

Ninety-five total runs were made at all SEPA stations. Of course, 38 had outfall DO conditions that theoretically could not of been caused solely by physical reaeration processes. All but two of the situations were Case HI scenarios; the other two included a

Case I scenario (SEPA station 2, 8/10/95) and a Case II scenario (SEPA station 2, 8/22/96). These results, which defy theoretical physical reaeration laws, indicate that biological activity must be contributing significantly to the oxygen balance within the SEPA pools.

Photosynthesis, as would be expected, appears more pronounced in SEPA stations 1 and 4 in which the design includes long, wide distribution and aeration pools. Figure 21 shows that the average DO percent saturation values for all 10 SEPA station 1 runs at location H in aeration pool 1 was 103.4 percent with the maximum value being 114.8 percent. Similarly, the SEPA station 4, G-location average value (figure 24) is 100.6 percent, and the maximum is an amazingly high 146.7 percent. The covered distribution pool and the compact design at SEPA station 3 reduce, but do not eliminate, photosynthesis. Note that supersaturated DO levels were recorded in all three SEPA station 3 aeration pools. Figure 25 shows that the average DO value within the SEPA station 5 distribution pool increased by 0.5 to 1.8 percent from the top of the pool to the weir, and no supersaturation levels were observed. Therefore, SEPA station 5 shows little evidence of photosynthetic activity.

The manually measured DO data also provided an opportunity to evaluate the predictive accuracy of equation 5 using quality controlled data. Table 11 lists outfall P_o values predicted by equation 5. Statistical *t* tests were performed to determine if the mean values of the observed and calculated P_o values were equal. The results of the statistical analysis are summarized in table 12. They indicate that statistically significant differences exist between the observed and predicted P_o-values at SEPA stations 1, 2, and 3. However, for SEPA station 4 and for both SEPA station 5 outlets, no statistically significant differences were found between the two means.

Additional Studies

The results of the weir-box aeration experiments, DO saturation aeration determinations, and nitrogen and BOD sampling analyses will be presented.

Weir-Box Aeration Experiments

Weir-box aeration experiments were conducted to provide information on the relative condition of the quality of the water being routed through each SEPA station during each pumping scenario. The water quality was determined indirectly with standard weir setups as shown in figures 14 and 18-20. The methods and procedures are presented in the "Methods and Procedures" section of this report. Weir-box data were used in equation 4 to produce a dimensionless water quality coefficient a that was intended to be used to adjust all sample runs to a common water-quality base.

The results of the weir-box experiments are presented in appendix C. Only one run was conducted during event 4 at all SEPA stations. The experiments were reduced for this event because the manually measured data and results from the previous events indicated that the results probably would be of limited use in determining overall SEPA aeration efficiencies. Also, several weir-box experiments were not conducted due to equipment failures.

Statistical analyses were used to determine if significant differences existed between the mean a-values for events, SEPA stations, and varying pumping rates (table 13). No significant differences were found between the aerating capacity of the station intake waters. However, a seasonal difference was shown between the second and third events. No significant interaction occurred between events and stations ($F = 0.868$).

The average a values for SEPA stations 3, 4, and 5 were 0.56, 0.57, and 0.65, respectively, for all four events. Gameson et al. (1958) state that a-values range from a low of approximately 0.65 for water that only can be poorly aerated to a high of 1.8 for water that can be well aerated. Based on this scale, the aerateability of the Cal-Sag Channel water was persistently low throughout all four events. Experimental a-values (assuming b = 1.0) derived at other locations and situations are referenced as follows:

Experimental Values at Various Locations

Location	*a-value*	*Reference*
Peoria, Illinois River tap water	1.11	Butts and Evans (1980)
Chicago Sanitary and Ship Canal	1.20	Butts (1988)
Lockport Dam	1.28	Butts and Evans (1980)
Brandon Road Dam	1.22	Butts and Evans (1980)
Dresden Island Dam	0.95	Butts and Evans (1980)
Marseilles Dam	1.01	Butts and Evans (1980)
Starved Rock Dam	1.12	Butts and Evans (1980)
Peoria Dam	0.90	Butts and Evans (1980)
LaGrange Dam	1.08	Butts and Evans (1980)

Relative to these reported values, Cal-Sag Channel water appears to be the most difficult to aerate. Interestingly, the Chicago Sanitary and Ship Canal water, used during the SEPA station prototype study, exhibited the highest reaeration factor. Peoria tap water (from the Illinois River) exhibited only a slight improvement in aerating capability over that found in the river at the Peoria Dam. Although Chicago area waterways exhibit high a-values, the current SEPA stations are such highly efficient aerators that these high a-values appear to have little or no affect on the ability of the stations to operate at maximum efficiencies. Consequently, water quality represented by the a-value should not play a major role in future SEPA station design as long as the designs are patterned after those now operating.

DO Saturation Experiments

Results from the saturation experiments are presented in table 8. Although maximum DO saturation values (β) in table 8 indicate that day-to-day ambient saturation values may deviate somewhat from theoretical clean-water levels, statistical tests indicate that long-term ambient measured mean values cannot be distinguished from computed means at the 95 percent confidence level. The *t*-test was used to compare the average experimental and computed means for SEPA stations 3, 4, and 5. The results of the statistical analyses are summarized in table 14. The results indicate that the differences in either the median or mean values for each data set are not great enough to exclude the possibility that the differences are due to randomness or experimental error. Consequently, using DO saturation concentrations based on equations 2 and 3 to analyze SEPA aeration efficiencies are fully justified for this study.

Nitrogen Changes

The mean and median nitrogen values of the samples collected during the study are presented in table 15. In order to determine if the inlet and outlet mean or median values were equal, the nitrogen data were subjected to a rank sum or *t*-test (table 15). The statistical analyses showed that the mean or median values were equal. Apparently, neither significant biological oxidation nor biological assimilation of nitrogen is occurring within the SEPA stations. No tests were run to ascertain if statistical differences occurred between station means, but a subjective examination of the data listed in table 15 indicates that differences may have occurred for some parameters. However, the total nitrogen concentrations are remarkably close for intake and outfall locations and between stations. Note, particularly, that differences between the 5C and 5S (C = Cal-Sag Channel, S = Chicago Sanitary and Ship Canal) outfall values are extremely small for all the nitrogen species.

BOD Changes

The cumulative 20-day BOD values are presented in appendix E for all samples collected. Typical BOD curves, showing TBOD, CBOD, and NBOD, are shown on figures 26 and 27 for SEPA station 4 intake and outfall conditions during event 3.

Statistical tests were performed to determine if the SEPA stations removed significant amounts of BOD. The testing was done collectively by integrating the data for all the stations into one data set for each BOD component. Both *t*-test and rank sum tests were performed using the collective ± 20-day long-term values to determine if statistically significant reductions in BOD were being affected by the SEPA stations. The results, presented in table 16, show no significant difference between intake and outfall BOD, CBOD, or NBOD values. This indicates that the SEPA stations probably do not effectively remove BOD, although the outfall mean and median 20-day BODs are slightly less than the intake values for each fractional BOD.

Continuous DO Monitoring

The results presented in this section represent the most important facet of the study. Continuous monitoring of DO concentration and temperature at the SEPA station locations was conducted for different seasonal and hydraulic conditions. The enormous amount of data permitted finite conclusions to be reached concerning the aeration efficiencies associated with the design and operation of the SEPA stations. The summary data will be presented in tables. The manually measured DOs and companion monitor results are summarized in appendix F to show the DO values used in the QA/QC adjustments of the continuous monitors.

Typical QA/QC-adjusted DO-curves are shown for each station in figures 28-31 (the adjusted data are available on floppy disk in a Microsoft Access 97 Database format). The summarized, tabular data and those used for statistical analyses are presented in percent saturation. The matched monitor and manually measured DO values used for QA/QC adjustments to the overall DO curves generated in each SEPA station pool during the four events are presented in appendix F.

General Observations

Figures 28-31 show some interesting results that occurred during the monitoring. Most striking are the sharp "spikes", which are evident in figures 28, 30, and 31. Those shown in figure 29 are particularly deep. These spikes appear to be caused by temporary fouling of the DO sensors. In almost all cases, this fouling was very transient; but, in a few instances, significant periods of data were lost due to this phenomenon.

The probe fouling appears to be biologically induced and occurs because of the extended deployment time required to conduct this study in the nutrient-rich waters of the Cal-Sag Channel. Normally, the monitors are retrieved on a weekly basis in the waterway proper. However, during this study the monitors had to be left undisturbed for a minimum of two weeks. Probe fouling is minimal for weekly deployment periods, but two-week deployment encourages fouling.

Figures 28-31 also show the dramatic increase in DO that occurs in a stepwise manner through the SEPA stations. Particularly evident is the large increase effected by the screw pumps as shown by the differences between the intake and the distribution pool. The weir systems also temper the wide temporal fluctuations in intake DO levels. Beyond the distribution pool, almost no correlation exists between pool DO and intake DO concentrations.

At the initiation of this study, the reaeration capacity of the screw pumps was completely unknown; albeit, it was suspected to be significant. Because it turned out to be highly significant, as shown by figures 28-31, new design equations have been derived using data generated from this study and will be presented and discussed later. At this point, suffice to say that the basic stepwise design concept appears sound and adheres to predicted results; however, because of screw-pump considerations, at least one weir can probably be eliminated as will be demonstrated later.

During event 4 at both the SEPA station 3 inlet and outfall, data for one of the two duplicate monitors were lost due to instrument failure. This demonstrates the importance in the study design of providing two monitors at critical locations. These curves also serve to show the excellent precision in the outputs of the companion intake and outfall units. Note that the A and B DO curves for the intakes on figures 29, 30, and 31 are almost indistinguishable. The small spikes are about the only physical evidence that distinguishes unit B from A at the SEPA station 5 intake (figures 30 and 31).

Table 17 provides a summary of the continuous DO monitoring data for all conditions in terms of both percent saturation and concentration. Note the large number of individual data points listed in the last column of table 18 that were generated using the monitors. The totals of the data readings recorded or computed for each station are: SEPA station 3, 20,294; SEPA station 4, 20,124; and SEPA station 5, 47,204. The data points for all three stations totaled 87,622. The intake and outfall measurements are nearly double those for the internal pools because of the duplicate units placed at these locations.

The arrangement of the data presented in table 17 provides a convenient means for determining overall average conditions at any location within the three SEPA stations. For example, an extraordinary situation developed in SEPA station 4, pool 1, event 4 in that the mean DO saturation was 99.91 percent. Furthermore, conditions for SEPA station 4, pool 1 with two pumps operating reveals that the DO averaged well above saturation. Obviously, physical aeration could not account for these values. This suggests that photosynthesis within the distribution pool appears to influence the aeration characteristics of this station a great deal of the time.

Overall, all three SEPA stations are highly efficient aerators as shown by the DO concentration and percent of saturation summaries given in table 17 and the following tabulation of DO concentrations.

SEPA Station DO Summary from Table 17

	Mean DO (mg/L)		*Mean DO (% saturation)*		
SEPA	*In*	*Out*	*In*	*Out*	*% Change*
3	6.41	9.21	68.6	100.3	43.7
4	6.20	9.11	66.3	101.9	46.7
5C	5.32	8.78	59.8	98.5	65.0
5S	5.32	8.93	59.8	98.4	67.9

Both outfall values at SEPA station 5 are slightly lower than at SEPA stations 3 and 4. This is probably due to the fact that the mean intake DO (P_i, equation 5) at SEPA station 5 is significantly lower (59.75 percent) than those for the intakes at SEPA station 3 (68.59 percent) and SEPA station 4 (66.25 percent). Also, the P_o-values at SEPA station 4 appear to be "artificially" elevated due to photosynthesis. Note that the DO values for the distribution pools immediately above the outfalls (pool 3 for SEPA stations 3 and 4 and pools 4C and 4S for SEPA station 5) approach 100 percent saturation and differ little from the outfall values.

The fact that the mean percentage change in DO at SEPA station 5 is greater than those changes observed at SEPA stations 3 and 4 should not be construed to mean that SEPA 5 is a more efficient aerator. It may or may not be. Conversely, the fact that the mean outfall DO concentrations are lower at SEPA station 5 does not necessarily mean that SEPA station 5 is the least efficient aerator. The information presented in the proceeding paragraph helps explain this phenomenon. For further insight relative to this, the "Dam or Weir Aeration Theory" section of this report should be perused.

Although the differences between percent saturation for many of the scenarios in table 17, such as seasons for SEPA station 3 and events 2 and 3 for pool 3 of SEPA station 3, are small, these differences can be statistically significant. The large sample sizes associated with this study greatly contribute to these statistical outputs and conclusions. For example, the difference in the mean percentage saturation values between the summer and fall events for pool 3 of SEPA station 3 is only 0.30 (102.43-102.13). However, this value can be shown to be statistically significant because the number of data points total almost 800 for each event. If such a small difference were associated with sampling sets one-tenth this size, this difference would not be statistically significant.

Also, contributing to the frequent rejection of null hypotheses (the assumption that the means are equal) is that much of the data displayed great variability. Analysis of variance tests actually check to determine if sample sets come from the same population of values through sample-value variability as the ANOVA connotations implies. Two sample sets may have exactly equal numerical means; but they could, with a high degree of probability, not come from the same population of values. A simple example is used to illustrate this point. Assume the means of two, three-value sample sets are 50 resulting from set-values of 1, 50, and 99 and 49, 50, and 51. The variability of the former is very large and for the latter it is very small. One could only accept the fact they are equal with a high degree of probability of being wrong.

Specific Observations

Statistical analyses have been performed to determine if significant differences exist between seasons and between the number of pumps in operation. Also, statistical analyses were performed to ascertain whether the two outfall weirs at SEPA station 5 operate at similar efficiencies.

Comparisons of Events (Seasons) The effect of seasons on aeration by SEPA stations was studied by using the nonparametric Kruskal-Wallis, rank-order ANOVA test. The tests were performed for each pool at each SEPA station. The Kruskal-Wallis test compares median values and percentile ranges. The results for SEPA stations 3, 4, and 5 are presented in tables 18, 19, and 20, respectively. The statistical analyses showed that all the pools exhibited seasonal differences at all three stations. Consequently, the 25 and 75 percentiles along with the median values (50 percentile) are presented in tables 18-20. Also, included are the mean values ($\bar{\mathbf{X}}$).

The Dunn multiple comparison test was used to isolate seasonal differences within each SEPA station pool (tables 18, 19, and 20). Except for a few instances, differences in DO percent saturation occurred for almost all seasonal combinations irrespective of the pool location. For SEPA station 3, 19 of 24 combinations were different; for SEPA station 4, 21 of 24 combinations were different. Of the 54 possible combinations at SEPA station 5, 50 were different.

These results show that operating efficiencies can vary by season. This is especially true for the overall station efficiency. For SEPA station 4 and both SEPA station 5 outfalls, all seasonal combinations were different. The SEPA station 3 outfall data indicated that only the combination of events 2 and 3 produced similar overall operating efficiencies (table 18).

The following example ranks the median outlet DO saturation (P_o) by event for each station, with 1 representing the highest P_o and 4 the lowest P_o. The "C" and "S" represent the Cal-Sag Channel and Chicago Sanitary and Ship Canal, respectively, at SEPA station 5 for all the following listings.

Median P_o -ranking for SEPA Stations

Event	*3*	*4*	*5C*	*5S*
Summer	3	3	3	3
Fall	1	1	1	1
Spring	2	2	4	4
Early summer	4	4	2	2

This ranking shows a somewhat consistent trend between all stations, at least as to which events rank first and third. For all SEPA station outfalls, the late summer/early fall produced the highest P_o-values, and the mid-summer ranked third. The spring and early summer ranked second and fourth (last) for stations 3 and 4; the ranking for these events was reversed for both SEPA station 5 outfalls. Not unexpected is the fact the rankings were the same for outfalls 5C and 5S.

The differences between the highest and lowest seasonal mean and median DO percent saturation values for all four outfalls are as follows:

Seasonal High Minus Seasonal Low (P_o)

Outfall	*Mean*	*Median*
SEPA 3	2.53	2.31
SEPA 4	10.56	11.84
SEPA 5C	8.69	8.80
SEPA 5S	9.65	10.82

SEPA stations 4 and 5 show relatively large seasonal differences, but the seasonal effect at SEPA station 3 appears minimal. Sedimentation and macrophytic growth, particularly in the distribution pools of SEPA stations 4 and 5, may contribute to this seasonal phenomenon. The late-summer/early-fall period (event 2) would include the height of the growing season for rooted vascular aquatic plants in these systems.

Comparisons of Hydraulic (Pumping) Operations The different pumping rates were statistically analyzed using the Kruskal-Wallis ANOVA test (tables 21, 22, and 23). Statistical results were similar to those for the event analyses. All pools, at all stations showed significant changes in DO output with changes in the number of screw pumps in operation, although for the SEPA station pilot-study weir system Butts (1988) found that flow-rate changes had no effect on P_o.

The results of the Dunn tests indicated that, with a few exceptions, pumping-rate changes produced significant changes in DO concentration in all the pools at all three stations. SEPA stations 3 and 4 each had 12 possible pool-pumping combinations (tables 21-23). For SEPA station 3, 10 of 12 combinations were significantly different; for SEPA station 4, 11 of 12 combinations were significantly different. Of the possible 54 combinations at SEPA station 5, 52 were significantly different.

The following example ranks median outlet DO saturation (P_o) for the number of pumps in operation, with 1 representing the highest P_o:

Median P_o-Ranking for SEPA Stations

Number of pumps	*3*	*4*	*5C*	*5S*
1	1	1	4	4
2	1	3	3	3
3	3	1	2	2
4	-	-	1	1

For SEPA station 3, pumping rates 1 and 2 were both assigned 1 because the Dunn test indicated equality (table 21, Outfall). For the same reason, Is were assigned rates 1 and 3 for SEPA station 4 (table 22, Outfall).

Unlike seasonal variability, for which there is no control, the number of pumps in service and weir-unit-hydraulic loadings can be controlled by engineering design and/or operating procedures. The following tabulation shows the differences between the highest and lowest mean and median DO saturation values for all four outfalls.

Pumping Rate P_o Values High Minus Low
(percent saturation)

Outfall	*Mean*	*Median*
SEPA 3	1.46	1.89
SEPA 4	3.08	4.44
SEPA 5C	9.45	3.04
SEPA 5S	8.25	6.95

The pumping effects could be influenced by two factors: the pumps themselves or the hydraulic loadings at the weirs. To determine the origin of the difference, the effects of pump operation on the distribution pool was statistically tested. The DO percent saturation values in the distribution pools will be referred to as P_d.

The following tabulation shows the median P_d rankings by pumping rates, again with 1 indicating the highest ranking.

Median P_d-Ranking for SEPA Stations

	Stations		
Number of pumps	*3*	*4*	*5*
1	1	2	4
2	2	1	3
3	3	3	2
4			1

Differences between the highest and lowest mean and median values in the three SEPA station distribution pools are:

Pumping Rate P_d Values High minus Low
(percent saturation)

Distribution pool	*Mean*	*Median*
SEPA 3	**3.59**	**4.97**
SEPA 4	**15.22**	**8.91**
SEPA 5	**10.52**	**10.78**

For the three SEPA stations, the percentage increases in DO levels (or Pa-values) in the distribution pools, due to increases in pumping, are significantly higher than at the outfalls. The mean difference in P_o and P_d means due to screw pump operation are 5.56 and 9.78 percent, respectively; the respective median averages are 4.08 and 8.22 percent. The conclusion can be reached that the turbulence within the pumps and at their discharge points are responsible for most or all of the increased aeration. Increased turbulence at the weirs due to increased unit-hydraulic loadings appears to enhance reaeration very little. This corresponds to the finding reported by Butts (1988) in the scale-model study.

However, photosynthesis that occurs in the distribution pools has to be taken into account. The water quality monitors are located in the distribution pools far downstream of the pump outlets (figures 3, 4, and 5). Increased DO concentrations recorded at these locations include effects due to both pumping and photosynthesis. Because the distribution pool (channel) is underground in SEPA station 3 and not exposed to light (figure 3), little or no photosynthetic oxygen production would be expected. This appears to be the case, as documented by the data presented. The difference between the mean high and mean low P_d at SEPA station 3 is only 3.59 percent; these differences for SEPA stations 4 and 5 are 15.22 and 10.52 percent, respectively.

Comparison of SEPA Station Outfalls 5C and 5S. The basic geometric design of both SEPA station 5 outlets (Cal-Sag Channel and the Chicago Sanitary and Ship Canal) are the same. However, the Cal-Sag Channel outlet weirs are about half as long as the weirs on the Chicago Sanitary and Ship Canal (figures 5 and 11). Also, the flow patterns in the distribution pools leading to each outlet are different. The Cal-Sag Channel side of the distribution pool is heavily silted and supports a persistent growth of rooted aquatic vegetation. Consequently, a hypothesis was developed that outlets 5C and 5S produce different P_o-values.

This hypothesis was tested using the Mann-Whitney rank sum tests by combining all data measured during the different seasons and pump operations (table 24). The results indicate that the two outlets produced significantly different median *P*-values at all pool levels. The large sample size, plus the wide differences in variability between each sample group, accounted for the statistically significant differences. This situation is exemplified by the outfall-pool results. The Cal-Sag Channel outfall had a median of 101.30 percent saturation for 4,784 data points with a 25 to 75 percentile range of 5.05 percent. The Chicago Sanitary and Ship Canal outfall had a median of 100.22 percent saturation for 5,586 data points with a 25 to 75 percentile range of 8.08 percent. The statistical analysis shows that the outfall to the Chicago Sanitary and Ship Canal is a less efficient and more variable aerator than the Cal-Sag Channel outfall.

Comparison of Pools between SEPA Stations. Distribution pool mean and median DO saturation values and outfall-pool mean and median DO saturation values were statistically compared between SEPA stations. All seasonal and pumping values were combined for these analyses. Also, the data for both outfalls were combined to represent SEPA station 5 as a single unit. The results of the Kruskal-Wallis one-way ANOVA are summarized in table 25; similar results were derived using the *t*-test to test the equality of the means.

The results of these statistical analyses, combined with subjective observations, help identify and/or define physical and environmental factors that affect and distinguish operating conditions at the stations. The DO saturation values in all three SEPA station distribution pools and in all three SEPA station outfall pools are shown to be significantly different (table 25). The distribution pool DOs are theoretically controlled by two physical factors: the intake DO level (Pi as defined in equation 5) and the aeration mechanism. Consequently, if all three aeration mechanisms are the same (screw pumps in this case) then P_i should dictate P_d. Based on the total mean intake P_is in table 17, SEPA station 3 Pa should be the highest (it is not, table 25) and SEPA station 5 P_d should be the lowest (it is, table 25). Furthermore, P_d at SEPA station 5 also probably is less because the screw pump there is only 80 percent as long as the ones at SEPA stations 3 and 4 (table 1). The higher P_d-values in SEPA station 4 can be attributed to photosynthetic activity of aquatic plants that grow in sediment deposited in the distribution pool (figure 13).

The differences between the DO saturation levels between the SEPA station distribution pools (P_d) are lessened as water passes over the weirs. Note from table 26 that, although the three P_o-values are shown to be significantly different statistically, the absolute differences are minimal.

DISCUSSION

The amount of data that can be generated using continuous water quality monitors on a scale such as during this study can be staggering. Careful planning in selecting and applying the appropriate sampling design, data retrieval/storage procedures, and data reduction/analysis methods permitted the fullest benefit from the data and observations.

Overall, the SEPA stations operate at or above design expectations. However, some problems, both design and operational, exist that can be corrected at the present SEPA stations and in future designs. The results of the present study should result in future operational and capital savings. Three major considerations will be discussed:

- Effect of sedimentation and aquatic macrophytes on DO levels in the distribution pools.
- Effect of screw pump operation on SEPA aeration efficiencies.
- Evaluation and modification of SEPA station design.

Sedimentation and Aquatic Macrophytes

Sedimentation in the distribution pools (the pools into which the screw pumps discharge before water flows over the weirs) of SEPA stations 1, 4, and 5 and to a lesser degree in SEPA station 3 is a major problem. Also, sedimentation is a minor problem in the aeration pools (pools below weirs) of SEPA stations 1,3, and 4 and in the outfall pool of SEPA station 3. Typical sediment deposits in distribution pools are shown in figures 13, 32, and 33. Filamentous algae and macrophytes are abundant in these sediments (figure 34).

Photosynthesis has a pronounced effect on the oxygen balance in the distribution pool of SEPA station 4. The long-term effect is demonstrated by the average percent DO saturation values (P_d) shown in figure 24. The average P_d value at point A (screw pump outlet) is 84.3 percent compared to 89.7 percent at point E (upstream of the first weir). The percent DO saturation value would have been much higher had this pool not been treated twice with herbicides during the summer of 1996. Figure 35 shows higher DOs in the distribution pool during the summer of 1997 in the absence of chemical treatment.

Figure 25 shows a minimal effect on DO saturation values from photosynthesis in SEPA station 5, and large sediment deposits are found in the distribution pool. The sediment and macrophyte growth must be removed periodically to maintain the hydraulic characteristics of the SEPA station. If sediment deposition is left unchecked, the distribution pool eventually could fill up and reduce the volume capacity of the station.

Overall, photosynthesis in the distribution pools, although having some short-term positive effects, has no beneficial effects on the overall DO outputs in the SEPA stations. Figure 35 shows that the DO in the distribution pool of SEPA station 4 was 1.0 mg/L to 2.5 mg/L greater than it was in the outfall pool because supersaturated water is deaerated by the weirs at the same rate that subsaturated water is aerated. Also, photosynthesis essentially stopped on June 23, 1997, and DO saturation values dropped sharply from supersaturation to subsaturation values.

Several options are available for reducing sedimentation in the distribution pools of SEPA stations 4 and 5. One method is to modify pump operation during storm events. During the present study, heavy sediment deposition in the distribution pools at SEPA stations 4 and 5 occurred during intense rainfall when the waterway levels were being reduced. The intake of sediments during these periods probably accounts for much of the deposition. By ceasing pump operation during these major storm events, the import of sediment from the waterways could be reduced considerably.

A second option would be to remove the riprap in the distribution and aeration pools and replace them with a fabric lining or with hard, smooth asphalt or concrete bases. This should be done for all pools at SEPA stations 3 and 4 and the SEPA station 5 distribution pool. At the very least, the riprap should be removed, except around the pool edges at these stations.

Reducing sedimentation in the SEPA stations also would reduce aquatic vegetation. The aquatic vegetation observed in the SEPA stations use the deposited sediment as a substrate. By eliminating the substrate, the rooted aquatic vegetation will have nothing in which to anchor its roots.

As long as sedimentation occurs, an ecologically sound, well-managed program should be established to control rooted aquatic vegetation and filamentous algae. These aquatic plants reduce hydraulic efficiencies, facilitate further sedimentation, and provide no dependable increase in DO.

Future SEPA stations should be designed with sediment traps, similar to that schematically shown in figure 36, at the pump discharge point and possibly at the bottom of the first weir (beneath the waterfall). Sediment traps at weirs should be deeper than weir overflow penetration. This depth should be significantly greater than the water jet penetration estimate of three-tenths of the waterfall height (Nakasone, 1987). The pools, including the distribution pools, all should be very shallow (except for the trap areas) to promote continuous natural hydraulic flushing of "escaping" sediments through the remaining pool/weir areas. The entire pool should be constructed of concrete. All traps should be accessible to backhoes or endloaders for sediment removal during periods when the station is inoperable. Future designs similar to SEPA station 2 would probably not require special considerations in controlling or removing sediments and, therefore, are recommended. Basic unencumbered compact designs can be rendered aesthetically pleasing and still provide efficient aeration and hydraulics while essentially decreasing sediment deposition.

Supersaturated DO levels occurred at all five SEPA stations due to photosynthesis (figures 21-25). The average DO levels measured in all the aeration pools of SEPA station 1 exceeded 100 percent saturation during a number of the manual measurements. Even

SEPA station 2, with its compact design, exhibited supersaturated DO levels at least once during the manual measurements (figure 22). Although prolific aquatic vegetation is present in the aeration pools at SEPA station 3 (figure 34), the DO concentrations are only marginally effected by photosynthesis. Photosynthesis is most pronounced in SEPA station 4. The maximum manually measured DO saturation value observed exceeded 146 percent at point G (figure 24). SEPA station 5 appears to be least affected by photosynthetic activity. No supersaturated DO concentrations were observed in the distribution pool of SEPA station 5 (figure 25). This is surprising as the distribution pool is heavily silted and macrophytes were present in the pool throughout the study. Supersaturated values in the SEPA station 5 short aeration pools are difficult to explain, either by physical or biological processes.

Screw Pump Aeration

The screw pump shown in figure 37 contributes significantly to reaeration at SEPA stations 2, 3, 4, and 5. The pumps were expected to provide aeration, but not to the degree observed at the four SEPA stations equipped with screw pumps. Because the continuous monitors were placed immediately above the first weir (figures 4 and 5), which include the impact of photosynthesis, the DO data cannot be used to accurately predict or model the pump contributions at SEPA stations 4 and 5. The manually measured DO data at the A points (figures 21-25), which are near where the screw pumps discharge, must be used for evaluating pump effects on aeration at SEPA stations 1, 2, 4, and 5. The pumping contribution at SEPA station 1 is due to propeller pump operation (table 1). Because the distribution pool at SEPA station 3 is underground, the DO above the first weir probably represents the effect of pumping.

The relative effect of the contribution of the screw pumps and the steps on overall SEPA station aeration is presented below.

DO Contribution as **a Percent of Total**

SEPA station	*Screw pump plus photosynthesis*	*Weir*			
		1	*2*	*3*	*4*
3	55.8	27.5	12.6	–	4.1
4	75.8	9.3	6.8	-	8.1
5C	50.4	26.1	17.9	1.5	4.1
5S	50.5	27.2	14.8	7.2	0.3

The screw pumps, based on this very general analysis, appear to contribute somewhere between 50 and 60 percent of the total DO production in the SEPA station. The 75.8 percent value for SEPA station 4 is inflated because the distribution pool of this station frequently experiences high rates of photosynthesis, as previously discussed. The true affect of the screw pumps at SEPA station 4 probably mimics those of the other stations.

The pump contributions to DO saturation are given in weir-height equivalents to compare the effectiveness of the screw pumps with that of weirs. The weir-height equivalents were computed using equation 5 with P_i set equal to the mean intake values and P set equal to the mean A values shown on figures 21-25. For comparative purposes, the weir-height equivalents also were computed using the continuous monitoring data in table 17 and manually measured points near the top of the first weir, which would include the effects of photosynthesis. The overall results are given in table 26.

For the average manually measured conditions, the pump reaeration efficiencies range from a low equivalent equal to a 1.45 foot weir at SEPA station 5 to a high equivalent equal to a 10.29-foot weir at SEPA station 2. The difference between the A and B values represent the weir equivalent of the photosynthetic oxygen production input. The weir-height equivalent computations are very sensitive to small changes in P_o. For example, if P_o at SEPA station 5, measurement location A were 84.9 percent instead of 78.9 percent the weir-height equivalent would have been 6.39 feet instead of 1.45 feet.

The fact that the SEPA station 5 distribution pool DO variability is small (figure 25), indicating low photosynthesis activity, is surprising. Abundant aquatic vegetation was observed in the SEPA station 5 distribution pool throughout the study. As noted earlier, the SEPA 4 distribution pool harbors profuse algae and aquatic vegetation. The photosynthetic weir-height equivalent nearly equals that of the screw pump, 6.65 feet for the screw pump versus 5.93 feet for photosynthesis. The combined screw pump/photosynthetic equivalent of 16.26 feet, derived for the continuous monitoring results, is impressive. Unfortunately, this DO "reserve" is in the form of supersaturation, which is removed by the weirs in the same way that subsaturated water is aerated. This "reserve" cannot be saved without also reducing the capability of the weirs to aerate subsaturated water because deaeration occurs at the same rate as aeration. In other words, water is deaerated at 150 percent saturation at the same rate as water is aerated at 50 percent saturation. This "reserve" could be saved only by channeling the water around the weir during productivity in the pools. Furthermore, channeling around the weirs would decrease pool detention times, thereby effectively reducing potential photosynthetic activity.

Future Design Considerations

The sole use of equation 5 for predicting weir aeration efficiencies for designing future SEPA stations is invalid. It must be used in conjunction with an appropriate algorithm for predicting output as a result of pump reaeration (P_{op}). To estimate weir aeration, P_{op} should be substituted for P_i in equation 5. The legitimacy of using equation 5 for designing SEPA stations was established, to some degree, with data presented in tables 11 and 12 for SEPA station 3, and station 5 outfalls C and S, three locations relatively free of photosynthetic activity.

Intuitively, the best procedure for developing a screw-pump aeration prediction equation is to use statistical regression procedures to relate the intake DO, in the form of Pi. to the output P_{op}. This would have to be done for both 12-foot and 15-foot lift pumps.

Fortunately, continuous monitoring data, relatively free of photosynthetic effects, are available for both conditions: a 12-foot lift at SEPA station 5 and a 15-foot lift at SEPA station 3.

However, the relationships between P_i and P_{op} at both SEPA stations 3 and 5 are not as good as was expected. This is demonstrated by the plots of P_i versus P_{op} shown in figures 38 and 39. In fact, the statistical relationship between the two variables can be classified as poor for SEPA station 3 ($R = 0.56$) and very poor ($R = 0.39$) for SEPA station 5. This indicates that other intake characteristics influence the P_{op} value more than the screw pumps.

Another variable in addition to P_i could be identified, the number of operating pumps. Consequently, multiple regressions were performed using both the number of pumps (Q_p) and P_i as independent variables to predict P_{op}. This produced an $R = 0.69$ at SEPA station 3, and $R = 0.62$ at SEPA station 5. Both are improvements over using just P_i to predict P_{op}. The 15-foot lift equation at SEPA station 3 is:

$$P_{op} = 0.47\,P_i - 3.50\,Q_p + 61.19 \tag{10}$$

where

P_{op} = DO percent saturation at the pump outlet
P_i = DO percent saturation at the pump intake
Q_p = number of pumps operating
61.19 = intercept constant

The 12-foot lift equation at SEPA station 5 is as follows:

$$P_{op} = 0.03\,P_i + 3.47\,Q_p + 70.09 \tag{11}$$

However, neither of these equations is satisfactory for use in predicting pump aeration. Some peculiarities exist within the properties of each equation and between equations. For example, the Pi-coefficient in equation 11 (0.03) is insignificant; therefore, in reality, the equation is reduced to predicting P_{op} strictly on the basis of Q_p. This does not seem to be a logical design approach. Also, the pumping factor in equation 10 is negative, and in equation 11 it is positive.

As a result of this ambiguous output, a conservative generic equation (good for all pump lifts) has been developed and is recommended for future design. It is based on the regression output and attendent statistics derived for SEPA station 3. For the sake of conservatism, Q_p in equation 10 is set equal to 3 producing the following equation:

$$P_{op} = 0.47\,P_i + 50.69 \tag{12}$$

For the sake of ultraconservatism, or an added safety factor, equation 12 has been reduced by two standard errors of the estimate or by 2 x 2.75 = 5.50. Consequently, equation 12 reduces to:

$$\mathbf{P_{op} = 0.47\,P_i + 45.19} \qquad \mathbf{(13)}$$

or following rounding of coefficients:

$$\mathbf{P_{op} = 0.5\,P_i + 45} \qquad \mathbf{(14)}$$

Consequently, for an inlet DO of 50 percent, the intake/pump geometric configuration design of a new SEPA station would be credited with a P_{op} value of 70 percent. Note from table 17 that the mean P_{op} values for SEPA stations 3 and 5 were 86.25 and 79.30 percent, respectively. Crediting the pumps for anything greater than that predicted by equation 14 seems unwise as many additional factors at or in the intake influence changes in P_i than just the screw pumps. Future SEPA station intake structures may not aerate the water as vigorously as those in SEPA stations 2, 3, 4, and 5.

An example of a problem used to design a SEPA station is:

- Total station height: 12 ft
- Weir length: 260 ft
- Unit hydraulic loading: 1.38 cfs/ft = 622 gpm/ft = 0.89 mgd/ft (three screw pumps each with a capacity of 120 cfs)
- Intake DO = 3.0mg/L
- Intake temperature = 28.0° C

Based on equations 2 and 3, the intake DO percent saturation is:

$P_i = 3.0/7.55 = 0.40 = 40$ percent

Based on equation 14, the intake-structure/pump aeration contribution is:

$P_{op} = (0.5)(40) + 45 = 65$ percent

Based on equation 5, the weir structure contribution is:

- N = l $P_o = (0.32)(65) + (4.13)(l) + (0.81)(12) + 54.78$
  $P_o = 89.43$ percent

- N = 2 $P_o = (0.32)(65) + (4.13)(2) + (0.81)(12) + 54.78$
  $P_o = 93.56$ percent

- ' N = 3 $P_o = (0.32)(65) + (4.13)(3) + (0.81)(12) + 54.78$
  $P_o = 97.69$ percent

The three-step weir scenario (N = 3) produces a P_o-value that essentially equals the 5C and 5S mean values of 98.49 percent and 98.39 percent given in table 17 for an N = 4, H = 12 ft scenario. One less weir for a 12-foot lift results in significant savings in construction costs and in routine maintenance/operation costs.

SUMMARY AND CONCLUSIONS

A field study was conducted to evaluate the aeration efficiencies of SEPA stations 3, 4, and 5 during their full range of seasonal operation and their full range of practical pumping capacity. Four, two-week events were monitored during the spring, summer, and fall seasons using continuous remote water quality monitors to record DO/temperature at intervals ranging from 15 to 60 minutes while pumping rates were varied by using from one to three pumps. The results of the study show that the SEPA stations are operating at or above design specifications. The overall mean DO percent saturation at each step from intake to outfall were: for SEPA station 3, 68.6, 86.3, 95.0, 99.0, and 100.3 percent; for SEPA station 4, 66.3, 93.3, 95.6, 99.0, and 101.9 percent; for SEPA station 5, 59.8, 79.3, 89.4, 96.3, 96.9, and 98.5 percent on the Cal-Sag Channel side and 59.8, 79.3, 89.8, 95.5, 98.3, and 98.4 percent on the Chicago Sanitary and Ship Canal side. Although all SEPA stations produce high P_o values, the internal flow-through aeration patterns are distinctly different for each station. The screw pumps appear to contribute from 50 to 60 percent of the overall DO production in the SEPA stations based on the results of SEPA stations 3 and 5. The contribution of the screw pumps at SEPA station 4 is indeterminate because the DOs at the end of the distribution pool of this station are greatly influenced by photosynthesis.

Statistical analyses were used to ascertain if aeration efficiencies varied for different seasons and were affected by changing pumping rates. Four seasonal events were monitored at SEPA stations 3, 4, and 5: August 12-28, 1996; September 30-October 11,. 1996; April 30-May 9, 1997; and June 16-27, 1997. Flow rates associated with one-, two-, and three-pump operations also were evaluated. Statistically significant differences were found to exist between the means and medians of the seasonal P_o values. The highest mean P_o occurred in the fall at all three SEPA stations studied; the lowest mean P_o was in early summer at SEPA stations 3 and 4 and in spring at SEPA station 5. Similarly, aeration efficiencies were found to vary with changes in pumping rates or the changing of flow volumes through the SEPA stations. These differences in aeration efficiencies were attributed to screw-pump operation not to changes in hydraulic loadings at the weirs. Mean DO saturations at the outfalls for SEPA stations 3 and 4 were near or above 100 percent saturation for all pump settings. SEPA station 5 showed mean outfall DO saturation near or above 100 percent saturation for situations in which more than one pump was operated. However, with only one pump operating, the outfall DO saturation dropped to around 93 percent. The overall mean DO percent saturations for one-, two-, and three-pump operations were 101.02, 100.81, and 99.46, respectively, for SEPA station 3 and 101.26, 104.56, and 101.67, respectively, for SEPA station 4. The overall mean DO percent saturations for one-, two-, and three-pump operations at SEPA station 5 were 92.56, 100.13, 102.06, and 101.68, respectively for outfall C and 93.98, 98.73, 101.19, and 102.23, respectively, for outfall S. These results indicate that higher pumping rates do not necessarily increase DO levels in the outfall pools. In fact, of the five outfall pools, only SEPA station 5S exhibited a mean value greater than that which occurred in the previous pool. However, higher pumping rates do result in higher DO loads to the waterway. For example, the oxygen load discharge at SEPA station 3 when operating three pumps would be 2.95 times greater when operating one pump based on the overall mean results.

Additional studies were performed during each season to determine if the SEPA stations reduce BOD and/or nitrogen compounds. The results of these studies showed that no BOD was removed during operation of the three SEPA stations. Also, nitrogen compounds, ammonia, nitrite, nitrate, and total Kjeldahl nitrogen (NH_3, NO_2, NO_3, and TKN), were found to be unaffected during passage through the SEPA stations. Ambient water samples collected from the Cal-Sag Channel were aerated to saturation, and the DO was measured and compared to "book"-value concentrations. No statistically significant difference was found between the experimental and book-value DO saturation values.

Detailed analyses were made of the aeration characteristics and efficiencies of the screw pumps used to lift Cal-Sag Channel water 15 feet into SEPA stations 3 and 4 and 12 feet into SEPA station 5. The increase in DO between the SEPA intake headwall and the point at which the water leaves the pumps was significant. However, a statistical analysis of the data indicates that the overall geometric design of the intake structure, in combination with the screw pumps and not the screw pumps alone, probably accounts for the increased DO concentration. This study was not designed to isolate or partition degrees of aeration within SEPA station intake structures. Only a "black box" reaeration value can be reported based upon DO readings taken in the Cal-Sag Channel at each intake and at the outlet in the upper end of each distribution pool. Mean differences in DO percent saturation values between the intake and pump discharge for SEPA stations 3, 4, and 5 are 17.7, 21.8, and 19.6 percent, respectively.

A method for designing new SEPA stations was developed to incorporate the intake-structure/screw-pump reaeration contribution. Statistical analysis showed that the scale-model derived, weir-aeration prediction equation used to design the five existing SEPA stations is valid when applied to the weir portions of the stations. A design equation was statistically derived to predict intake-structure/screw-pump DO saturation percent output. These outputs are used as inputs into the weir design equation. A design problem and its solution are presented.

Sedimentation readily occurs at all three SEPA stations and directly affects operation and maintenance; it indirectly affects the aeration characteristics and DO resources within the SEPA stations. The riprap on the bottom of the pools reduces hydraulic efficiencies and promotes sedimentation in the distribution pools. Vascular, aquatic plants grow in the sediments, and filamentous algae attach to the riprap and sediment that frequently increase DO in the distribution pools to supersaturation levels through photosynthesis. Photosynthesis-induced supersaturation is particularly pronounced in the distribution pool at SEPA station 4. The DO concentrations may remain above saturation for periods in excess of nine to ten days in SEPA station 4. Periodic DO values in excess of 146 percent of saturation were recorded. Supersaturated DO levels decrease in the long distribution pool of SEPA station 4, but they seldom fall much below 100 percent of saturation at night during periods of peak photosynthetic activity. Unfortunately, the excess DO is "blown out" via deaeration at each successive weir, and little remains at the outfall. Serious consideration should be given to removing the existing riprap and installing a smooth fabric or cement lining. New SEPA designs should specify smooth linings and appropriately spaced sediment traps.

REFERENCES

American Society of Civil Engineers, Committee of Sanitary Engineering Research. 1960. Solubility of Atmospheric Oxygen in Water. *ASCE Journal of the Sanitary Engineering Division* SE7(86):41.

APHA, American Water Works Association, and Water Pollution Control Federation. 1992. *Standard Methods for the Examination of Water and Wastewater,* 18th edition. American Public Health Association, Inc., New York, NY.

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

Butts, T.A., and R.L. Evans. 1978. *Effect of Channel Dams on Dissolved Oxygen Concentration in Northeastern Illinois Streams.* Illinois State Water Survey Circular 132.

Butts, T.A., and R.L. Evans. 1980. *Aeration Characteristics of Flow Release Controls on Illinois Waterway Dams.* Illinois State Water Survey Circular 145.

Butts, T.A., D.B. Shackleford, and T.R. Bergerhouse. *Sidestream Elevated Pool Aeration (SEPA) Stations: Effects on In-stream Dissolved Oxygen.* Illinois State Water Survey Contract Report (in press).

Butts, T.A., D.B. Shackleford, and R.S. Larson. 1995. *Illinois Power Company Baldwin Power Plant Ash-Pond Effluent Boron Mixing with the Kaskaskia River.* Illinois State Water Survey Contract Report 588.

Elmore, H.L. 1955. Determinations of BOD by a Reaeration Technique. *Sewage and Industrial Wastes* 27(9): 993-1002.

Gameson, A.L.H. 1957. Weirs and the Aeration of Rivers. *Journal of the Institution of Water Engineers* 6(11):477.

Gameson, A.L.H., K.F. Vandyke, and C.G. Ogden. 1958. The Effect of Temperature on Aeration at Weirs. *Water and Water Engineering* 753(62):489.

Gaudy, A.F., and E.T. Gaudy. 1980. *Microbiology for Environmental Scientists and Engineers.* McGraw-Hill, New York, NY.

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.

Nakasone, H. 1987. Study of Aeration at Weirs and Cascades. *ASCE Journal of Environmental Engineering* 113 (1):64.

Water Research Centre. 1973. Aeration at Weirs. In *Notes on Water Pollution*. June, No. 61. Elder Way, Stevenage, Herts, England.

TABLES

Table 1. Engineering Design Features of SEPA Stations

Station			*Pumps*			*Weirs*			*Design maximum*
							Height (ft)		
No.	*Location*	*River mile*	*Type*	*No.*	*Size*	*No.*	*Per weir*	*Total*	*flow (cfs)*
1	Torrence Ave.	328.09	Propeller	4	100 cfs	4	3	12	400
2	127th St.	321.40	Screw	2	84-in.	4	3	12	87
3	Blue Island	318.00	Screw	4	120-in.	3	5	15	479
4	Worth	311.51	Screw	4	120-in.	3	5	15	479
5	Cal-Sag Jct.	303.57	Screw	5	120-in.	4	3	12	577

Table 2. Potential Errors in Oxygen Deficit Ratios Resulting from Inaccurate DO Measurements at Various Temperatures for C_a = 1.0mg/L and 7.4 mg/L: An Example

Temperature		*True values*				*Error values**			
(˚C)	*S*	C_a	C_b	*r*	5	C_a	C_b	r_e	$r_e/3.00$
15	10.03	1.00	7.02	3.00	10.13	0.90	7.12	3.07	1.02
	10.03	7.40	9.15	3.00	10.13	7.30	9.25	3.22	1.07
20	9.02	1.00	6.35	3.00	9.12	0.90	6.45	3.08	1.03
	9.02	7.40	8.48	3.00	9.12	7.30	8.58	3.37	1.12
25	8.18	1.00	5.79	3.00	8.28	0.90	5.89	3.09	1.03
	8.18	7.40	7.92	3.00	8.28	7.30	8.02	3.77	1.26
30	7.44	1.00	5.29	3.00	7.54	0.90	5.39	3.09	1.03
	7.44	7.40	7.43	3.00	7.54	7.30	7.53	24.00	8.00

Notes: * S = 0.1 mg/L greater than true value, C_a = 0.1 mg/L less than true value,
and C_b = 0.1 mg/L greater than true value
r_e = The deficit ratio computed after incorporating the error factors

Table 3. Rejection Criteria for Computed r-Values

From SEPA	*Locations within a SEPA station*									
3, 4, and 5	*Pool 1*		*Pool 2*		*Pool 3*		*Pool 4*		*outfall*	
locations	*Low*	*High*	*Low*	*High*	*Low*	*High*	*Low*	*High*	*Low*	*High*
SEPA stations 3 and 4										
Intake	1.3	6.2	2.1	8.5	4.6	11.0	-	-	4.6	12.0
Pool 1	-	-	1.3	4.5	2.1	7.5	-	-	4.6	10.0
2	-	-	-	-	1.3	4.5	-	-	2.1	7.5
3	-	-	-	-	-	-	-	-	1.3	4.5
SEPA station 5										
Intake	1.2	6.2	1.8	8.5	4.0	11.0	4.1	11.5	4.2	12.0
Pooll	-	-	1.2	4.5	1.7	7.5	4.0	10.0	4.0	11.0
2	-	-	-	-	1.2	4.5	1.7	7.5	4.0	10.0
3	-	-	-	-	-	-	1.2	4.5	1.7	7.5
4	-	-	-	-	-	-	-	-	1.2	4.5

Table 4. Schedule of Pump Operations

		No.	*Date (1996)*		*Time*				*No.*	*Date (1997)*		*Time*	
Event	*SEPA*	*pumps*	Start	*Stop*	*Start*	*Stop*	*Event*	*SEPA*	*pumps*	*Start*	*Stop*	*Start*	*Stop*
1	3	1	08/12	08/14	0800	0800	3	3	1	04/28	04/30	0800	0800
		2	08/14	08/19	0900	0800			2	04/30	05/05	0815	0800
		3	08/19	08/23	0900	1000			3	05/05	05/07	0815	0800
	4	1	08/12	08/14	0900	0900			0	05/07	05/09	0815	0800
		2	08/14	08/19	1000	0900		4	1	04/28	04/30	0900	0900
		3	08/19	08/23	1000	1000			2	04/30	05/02	0915	0900
	5	1	08/12	08/14	1000	1100			3	05/02	05/07	0915	0900
		2	08/14	08/19	1200	1000			0	05/07	05/09	0915	0900
		3	08/19	08/21	1100	1000		5	1	04/28	04/30	1000	1000
		4	08/21	08/23	1100	0900			2	04/30	05/05	1015	1000
2	3	1	09/30	10/02	0800	0800			3	05/05	05/07	1015	1000
		2	10/02	10/11	0900	1100			4	05/07	05/09	1015	1000
	4	1	09/30	10/02	1000	0900	4	3	1	06/16	06/18	0800	0800
		2	10/02	10/07	1000	0900			2	06/18	06/23	0815	0800
		3	10/07	10/11	1000	1000			3	06/23	06/27	0815	0800
	5	1	09/30	10/02	1119	1100		4	1	06/16	06/18	0900	0900
		2	10/02	10/07	1200	1100			2	06/18	06/23	0915	0900
		3	10/07	10/09	1200	1100			3	06/23	06/27	0915	0900
		4	10/09	10/11	1200	0800		5	1	06/16	06/18	1000	1000
									2	06/18	06/23	1015	1000
									3	06/23	06/25	1015	1000
									4	06/25	06/27	1015	1000

Table 5. Manual DO Measurement Locations for Correcting Monitor Measurements Using Equation 6

		Locations referenced to data spaces in appendix B forms					
	SEPA		*Distribution*	*Aerationpool*			
	station	*Inlet*	*pool*	*1*	*2*	*3*	*4*
	3	(4 ft + 6 ft)/2	B	(D + F)/2	(G + H)/2	(J + L)/2	-
	4	(4 ft + 6 ft)/2	E or D	I or H	J or K	L or M	-
H1	5C	Bottom	H1	M1	P1	S1	VI
	5S	-	-	I	N	Q	T

Notes: C = Cal-Sag Channel
S = Chicago Sanitary and Ship Canal

Table 6.. Comparison of Vertical Mean Concentrations with Walk-through DO Concentrations Measured at Intake Monitor Depths

	Intake DO values (mg/L) at SEPA station						
	3		*4*		*5*		
Statistic	*5 ft*	*Mean*	*5 ft*	*Mean*	*Bottom*	*Bottom (-1 ft)*	*Mean*
	5.21	5.24	4.66	4.57	3.53	3.42	3.75
	4.52	4.51	5.11	4.82	2.55	2.59	3.39
	5.49	5.37	4.08	3.82	3.34	3.32	3.35
	5.30	5.30	4.99	4.96	5.16	5.16	5.21
	6.30	6.08	5.93	6.63	6.60	6.46	6.54
	3.83	3.90	6.11	6.14	4.39	4.42	4.97
	6.10	6.00	4.25	4.22	3.82	3.81	3.76
	4.84	4.84	5.04	4.98	3.67	3.68	3.94
	5.91	5.73	4.38	4.44	3.54	4.53	4.91
	5.43	5.34	6.08	5.87	5.45	5.42	5.31
	5.77	5.75	4.52	4.51	5.63	5.64	5.71
	6.60	6.46	5.98	5.92	5.98	5.91	6.17
	7.14	6.92	5.70	5.74	5.91	5.79	5.80
	7.34	7.42	7.15	6.99	7.69	7.79	7.73
	6.30	6.26	7.32	7.21	6.45	6.43	6.62
	4.92	4.77	7.26	7.29	7.74	7.72	7.78
	5.47	5.47	7.58	7.58	4.67	4.73	4.86
			4.19	4.23	4.05	4.09	4.28
			6.34	6.09			
No. of samples =	17	17	19	19	18	18	18
Mean =	5.675	5.609	5.614	5.579	5.009	5.051	5.227
Variance =	0.831	0.772	1.329	1.390	2.318	2.184	1.882

Table 7. Selected Deficit Ratio (r) Values Measured at SEPA Station 4 Exemplifying Commonly Derived Extremes

		r-values between intake and pools				*r-values between pool*					
						1 and pools			*2 an>d pools*		
Date	*Time*	*1*	*2*	*3*	*Out*	*2*	*3*	*Out*	*3*	*Out*	*3 and out*
04/25/97	0645	2.0	5.5	6.2	13.7	2.7	3.0	6.7	1.1	2.5	2.2
(day)	0700	2.1	6.3	6.2	14.3	3.0	3.0	6.9	1.0	2.3	2.3
	0715	2.2	7.1	6.6	14.5	3.3	3.0	6.6	0.9	2.0	2.2
	0730	2.2	9.3	6.8	16.9	4.1	3.0	7.5	0.7	1.8	2.5
	0745	2.4	10.4	7.6	14.1	4.4	3.2	5.9	0.7	1.4	1.9
	0800	2.4	13.2	8.2	16.8	5.5	3.4	7.0	0.6	1.3	2.0
	0815	2.4	16.1	9.1	35.7	6.5	3.7	14.5	0.6	2.2	3.9
	0830	2.6	27.1	11.0	32.6	10.4	4.2	12.5	0.4	1.2	3.0
	0845	2.6	38.7	12.6	43.2	14.6	4.8	16.3	0.3	1.1	3.4
	0900	2.6	100.2	14.5	80.8	37.6	5.4	30.4	0.1	0.8	5.6
	0915	2.8	73.1	17.9	128.7	25.7	6.3	45.2	0.2	1.8	7.2
	0930	2.8	-122.9	22.8	-833.2	-43.1	8.0	-292.3	-0.2	6.8	-36.5
	0945	3.3	-41.9	23.5	30.3	-12.6	7.1	9.1	-0.6	-0.7	1.3
	1000	3.2	-35.2	44.8	566.8	-10.7	13.7	172.9	-1.3	-16.1	12.7
	1015	2.5	-32.0	60.9	252.6	-12.7	24.1	100.1	-1.9	-7.9	4.2
	1030	2.8	26.0	69.9	7.6	9.2	24.8	2.7	2.7	0.3	0.1
	1045	3.1	103.8	39.8	5.0	32.1	12.3	1.5	0.4	0.1	0.1
	1100	3.0	-40.3	27.8	31.1	-13.1	9.0	10.1	-0.7	-0.8	1.1
	1115	2.9	-41.0	124.7	4.1	-13.8	41.9	1.4	-3.0	-0.1	0.1
	1130	3.0	-22.3	43.8	3.2	-7.5	14.7	1.1	-2.0	-0.1	0.1
	1145	2.9	-18.21	65.0	6.6	-6.3	22.3	2.3	-3.6	-0.4	0.1
	1200	3.4	-28.3	68.1	4.4	-7.9	18.9	1.2	-2.4	-0.2	0.1
	1215	4.6	-12.0	-181.9	1.5	-2.6	-38.9	0.3	15.2	-0.1	-0.1
	1230	7.6	-8.8	8.0	1.7	-1.1	1.0	0.2	-0.9	-0.2	0.2
	1245	30.3	-2.3	7.3	1.1	-0.1	0.2	0.1	-3.2	-0.5	0.2
06/13/97	2100	7.4	4.7	20.2	78.7	0.6	2.7	10.6	4.3	16.6	3.9
(night)	2115	7.9	4.9	21.2	61.9	0.6	2.7	7.9	4.3	12.7	2.9
	2130	8.7	4.8	21.8	71.8	0.6	2.5	8.3	4.5	14.9	3.3
	2145	9.2	4.9	22.5	82.5	0.5	2.5	9.0	4.6	16.8	3.7
	2200	9.1	4.9	21.9	93.0	0.5	2.4	10.2	4.4	18.8	4.2
	2215	10.1	4.7	22.7	83.2	0.5	2.2	8.2	4.8	17.6	3.7
	2230	11.0	4.9	22.0	79.1	0.5	2.0	7.2	4.5	16.2	3.6
	2245	11.6	5.0	22.1	76.5	0.4	1.9	6.6	4.5	15.4	3.5
	2300	11.7	5.1	21.6	127.8	0.4	1.8	10.9	4.3	25.3	5.9
	2315	11.2	4.7	22.8	63.9	0.4	2.0	5.7	4.8	13.6	2.8
	2330	12.5	4.8	22.6	269.8	0.4	1.8	21.6	4.7	56.0	11.9
	2345	14.4	5.1	25.7	206.1	0.3	1.8	14.4	5.1	40.8	8.0
06/14/97	0000	17.8	5.0	21.7	182.2	0.2	1.2	10.2	4.4	36.5	8.4
	0015	21.8	5.1	26.5	164.2	0.2	1.2	7.5	5.2	32.4	6.2
	0030	22.0	5.0	23.9	162.3	0.2	1.1	7.4	4.8	32.8	6.8
	0045	21.6	5.1	25.5	563.4	0.2	1.2	26.1	5.0	110.0	22.1
	0100	22.4	5.2	26.9	187.0	0.2	1.2	8.4	5.2	36.1	6.9
	0115	29.2	5.2	24.7	169.8	0.2	0.9	5.8	4.8	32.9	6.9
	0130	24.9	5.1	25.3	583.3	0.2	1.0	23.4	5.0	115.4	23.1
	0145	27.0	5.2	27.8	433.5	0.2	1.0	16.0	5.4	83.7	15.6
	0200	25.5	5.2	32.8	634.1	0.2	1.3	24.8	6.3	121.4	19.3
	0215	22.0	5.1	31.4	928.9	0.2	1.4	42.2	6.2	182.4	29.6
	0230	22.8	5.2	32.4	-291.0	0.2	1.4	-12.8	6.2	-55.9	-9.0
	0245	23.6	5.1	32.3	-657.1	0.2	1.4	-27.9	6.3	-129.3	-20.4

Table 7. (Concluded)

		r-values between intake and pools				*r-values between pool 1 and pools*			*r-values between pool 2 and pools*		
Date	*Time*	*1*	*2*	*3*	*Out*	*2*	*3*	*Out*	*3*	*Out*	*3 and out*
	0300	24.3	5.2	34.8	-684.9	0.2	1.4	-28.2	6.7	-132.3	-19.7
	0315	23.7	5.3	33.1	-308.8	0.2	1.4	-13.0	6.3	-58.5	-9.3
	0330	24.5	5.3	38.1	-203.8	0.2	1.6	-8.3	7.1	-38.2	-5.4
	0345	22.9	5.3	38.2	-91.8	0.2	1.7	-4.0	7.2	-17.3	-2.4
	0400	27.1	5.3	37.8	-145.6	0.2	1.4	-5.4	7.2	-27.6	-3.9
	0415	29.1	5.3	41.1	-147.4	0.2	1.4	-5.1	7.8	-27.8	-3.6
	0430	31.3	5.4	41.9	-161.7	0.2	1.3	-5.2	7.8	-30.0	-3.9
	0445	50.7	5.5	44.2	-110.3	0.1	0.9	-2.2	8.0	-20.1	-2.5
	0500	54.0	5.6	48.9	-127.0	0.1	0.9	-2.4	8.7	-22.5	-2.6
	0515	67.6	5.6	65.7	-93.5	0.1	1.0	-1.4	11.8	-16.8	-1.4
	0530	405.3	5.9	54.4	-94.0	0.1	0.1	-0.2	9.3	-16.1	-1.7
	0545	-154.9	6.2	77.5	-64.2	0.1	•0.5	0.4	12.5	-10.4	-0.8
	0600	-63.6	6.6	124.1	-62.9	0.1	-1.9	1.0	18.9	-9.6	-0.5

Table 8. Experimental Dissolved Oxygen (DO) Saturation Values and Resultant β-Values

	Temperature (°C) at SEPA stations			*DO concentration (mg/L) at SEPA stations*						*β-values at SEPA stations*		
				3		*4*		*5*				
Date	*3*	*4*	*5*	*Exp*	*Cal*	*Exp*	*Cal*	*Exp*	*Cal*	*3*	*4*	*5*
08/12/96	23.5	23.5	25.0	8.10	8.19	8.10	8.19	8.00	7.95	0.989	0.989	1.006
08/14	24.0	24.0	24.5	8.00	8.11	7.80	8.11	7.95	8.03	0.986	0.962	0.990
08/14	-	-	23.5	-	-	-	-	8.15	8.19	-	-	0.995
08/16	23.0	24.0	23.0	8.30	8.27	7.80	8.11	8.30	8.27	1.004	0.962	1.004
08/19	25.0	24.0	25.0	7.90	7.95	7.90	8.11	8.00	7.95	0.994	0.974	1.006
08/21	-	25.5	-	-	-	8.10	7.87	-	-	-	1.029	-
08/23	24.0	25.5	25.5	8.00	8.11	8.05	7.87	8.00	7.87	0.099	1.023	1.017
09/30	18.0	17.5	15.0	9.20	9.17	9.55	9.27	9.75	9.80	1.003	1.030	0.995
10/02	20.0	19.5	18.0	8.80	8.79	8.95	8.89	8.95	9.17	1.001	1.007	0.976
10/04	16.0	17.5	14.5	9.80	9.58	9.85	9.27	10.00	9.91	1.023	1.063	1.009
10/07	16.5	17.0	16.0	9.45	9.48	9.50	9.37	9.15	9.58	0.997	1.014	0.955
10/09	14.0	14.0	14.5	9.90	10.02	9.75	10.02	9.35	9.91	0.998	0.973	0.944
10/11	13.0	13.5	14.5	9.95	10.26	10.30	10.14	9.85	9.91	0.970	1.016	0.994
04/28/97	13.5	13.0	12.0	9.95	10.14	9.90	10.26	9.65	10.50	0.981	0.966	0.919
04/30	15.5	14.5	14.5	9.30	9.69	9.60	9.91	9.50	9.91	0.960	0.969	0.958
05/02	15.0	14.5	14.0	9.30	9.80	10.05	9.91	9.80	10.02	0.949	1.014	0.978
05/05	14.5	13.0	14.0	9.45	9.91	9.65	10.26	9.90	10.02	0.954	0.941	0.988
05/07	17.0	16.5	14.0	9.00	9.37	9.26	9.48	10.00	10.02	0.961	0.976	0.998
05/09	-	-	13.5	-	-	-	-	9.95	10.14	-	-	0.981
06/27	24.0	24.5	26.0	8.14	8.11	7.97	8.03	7.97	7.80	1.004	0.993	1.021

Notes: Exp = Experimental

Cal = Calculated using equations 2 and 3

β = Water quality factor = Exp/Cal

Table 9. Selected Deficit Ratio (r) Values measured on April 25, 1997, at SEPA 4 Exemplifying Commonly Derived Extremes Adjusted to Experimental DO Saturation Values (β = 0.966)

	r-values between intake and pools				*r-values between pool*					
					1 *and pools*			*2 and pools*		
Time	*J*	*2*	*3*	*Out*	*2*	*3*	*Out*	*3*	*Out*	*3 and Out*
0645	2.3	9.5	12.0	-71.0	4.2	5.3	-31.3	1.3	-7.5	-5.9
0700	2.3	12.7	12.4	-52.4	5.5	5.3	-22.5	1.0	-4.1	-4.2
0715	2.5	17.0	13.9	-50.5	6.9	5.7	-20.6	0.8	-3.0	-3.6
0730	2.6	43.8	15.3	-32.9	17.1	5.9	-12.8	0.3	-0.7	-2.2
0745	2.7	101.0	20.4	-54.8	36.9	7.5	-20.0	0.2	-0.5	-2.7
0800	2.8	-66.9	28.6	-30.2	-23.8	10.2	-10.8	-0.4	0.5	-1.1
0815	2.9	-32.5	47.2	-14.6	-11.2	16.4	-5.1	-1.5	0.5	-0.3
0830	3.1	-17.4	459.7	-15.5	-5.6	148.0	-5.0	-26.4	0.9	0.0
0845	3.2	-13.8	-73.5	-13.3	-4.3	-23.1	-4.2	5.3	1.0	0.2
0900	3.2	-11.0	-39.4	-11.4	-3.4	-12.3	-3.6	3.6	1.0	0.3
0915	3.5	-11.7	-25.8	-10.9	-3.4	-7.4	-3.1	2.2	0.9	0.4
0930	3.5	-8.8	-17.7	-9.5	-2.5	-5.0	-2.7	2.0	1.1	0.5
0945	4.2	-8.4	-21.3	-17.5	-2.0	-5.0	-4.1	2.5	2.1	0.8
1000	4.2	-8.0	-14.3	-10.9	-1.9	-3.4	-2.6	1.8	1.4	0.8
1015	3.0	-7.5	-12.5	-10.7	-2.5	-4.2	-3.6	1.7	1.4	0.9
1030	3.5	-17.5	-12.0	21.6	-5.1	-3.5	6.2	0.7	-1.2	-1.8
1045	4.1	-11.9	-15.0	7.9	-2.9	-3.6	1.9	1.3	-0.7	-0.5
1100	3.9	-7.7	-15.7	-14.9	-2.0	-4.0	-3.8	2.1	1.9	0.9
1115	3.8	-7.5	-10.2	6.0	-2.0	-2.7	1.6	1.4	-0.8	-0.6
1130	3.8	-6.3	-11.8	4.2	-1.6	-3.1	1.1	1.9	-0.7	-0.4
1145	3.8	-5.6	-10.0	19.3	-1.5	-2.6	5.1	1.8	-3.5	-1.9
1200	4.9	-7.2	-12.0	6.6	-1.5	-2.5	1.4	1.7	-0.9	-0.6
1215	6.9	-5.5	-10.5	1.6	-0.8	-1.5	0.2	1.9	-0.3	-0.1
1230	19.5	-4.7	28.1	1.9	-0.2	1.4	0.1	-6.0	-0.4	0.1
1245	-8.9	-1.5	-72.8	1.1	0.2	8.2	-0.1	47.0	-0.7	0.0

Table 10. Comparison of Water Temperatures Manually Recorded at SEPA Stations for QA/QC Analyses

			Temperature values (˚C) at													
			Intake			*Pool*								*Outfall*		
				Sonde		*1*		*2*		*3*		*4*			*Sonde*	
Event	*Date*	*Time*	*Meter*	*1*	*2*	*Meter*	*Sonde*	*Meter*	*Sonde*	*Meter*	*Sonde*	*Meter*	*Sonde*	*Meter*	*1*	*2*
SEPA 3																
1	08/13/96	1358	24.8	24.96	-	24.3	24.40	24.4	24.43	24.4	24.46	n.a.	n.a.	24.4	24.49	24.48
	08/14	0903	24.3	24.31	-	24.2	24.26	24.2	24.30	24.2	24.31	n.a.	n.a.	24.2	24.28	24.27
	08/21	1445	25.3	25.33	-	25.0	25.07	25.0	25.10	25.0	25.14	n.a.	n.a.	25.0	25.10	24.08
	08/22	0815	24.7	24.80	-	24.6	24.79	24.7	24.78	24.7	24.80	n.a.	n.a.	24.7	24.81	24.80
2	*10/01	1702	19.4	19.32	19.47	19.3	19.30	19.3	19.32	19.3	19.34	n.a.	n.a.	19.3	19.36	19.33
	*10/02	0957	19.3	19.37	19.56	19.2	19.30	19.3	19.29	19.3	19.31	n.a.	n.a.	19.3	19.36	19.34
	*10/08	1210	16.3	17.18	17.37	16.3	17.21	16.3	17.20	16.3	17.30	n.a.	n.a.	16.2	17.24	17.21
3	*04/03/97	1416	15.3	15.25	15.21	15.7	15.13	15.5	15.14	15.3	15.16	n.a.	n.a.	15.3	15.15	15.18
	*05/07	0741	14.8	14.94	14.92	14.8	14.87	14.8	14.91	14.8	14.92	n.a.	n.a.	14.8	14.92	14.93
4	*06/17	1442	19.6	19.79	19.89	19.4	19.63	19.6	19.61	19.6	19.52	n.a.	n.a.	19.6	19.66	19.69
	*06/26	1427	24.1	24.21	24.47	23.7	23.81	23.7	23.81	23.8	23.64	n.a.	n.a.	23.8	23.85	23.86
	Mean		20.72	20.86	-	20.59	20.71	20.75	20.72	20.61	20.72	-	-	20.60	20.75	20.65
	Median		19.60	19.79	-	19.40	19.63	19.60	19.61	19.60	19.52	-	-	19.60	19.66	19.69
	*Mean		18.40	18.58	18.70	-	-	-	-	-	-	-	-	-	-	-
	*Median		19.30	19.32	19.47	-	-	-	-	-	-	-	-	-	-	-
SEPA 4																
1	08/13/96	1251	25.1	24.49	-	24.9	24.94	24.8	-	24.8	25.14	n.a.	n.a.	24.8	25.20	25.22
	08/14	1001	24.5	24.59	-	24.7	24.61	24.6	-	24.6	24.76	n.a.	n.a.	24.6	24.78	24.79
	08/21	1336	26.2	25.48	-	25.6	25.56	25.5	-	25.4	25.56	n.a.	n.a.	25.4	25.57	25.56
	08/22	1129	25.7	24.97	-	26.6	25.73	25.6	-	25.5	25.84	n.a.	n.a.	25.6	25.73	25.81
2	*10/01	1448	19.4	19.19	19.05	19.1	19.14	19.2	18.47	19.4	19.22	n.a.	n.a.	19.2	19.20	19.19
	*10/02	1213	19.0	19.12	19.13	19.0	19.13	19.0	19.13	19.0	19.22	n.a.	n.a.	19.0	19.14	19.11
	*10/09	1049	16.1	16.31	16.42	16.2	16.53	16.2	16.52	16.2	16.59	n.a.	n.a.	16.1	16.55	16.55
3	*05/01/97	1402	14.4	14.57	14.58	14.9	14.65	15.1	14.67	14.8	14.71	n.a.	n.a.	14.8	14.31	14.72
	*05/07	0909	14.6	14.77	14.79	14.8	14.84	14.7	14.80	14.9	14.84	n.a.	n.a.	14.8	14.41	14.82
4	*06/17	1246	19.9	20.00	20.17	20.8	20.11	20.1	20.42	20.0	20.40	n.a.	n.a.	20.6	20.50	20.49
	*06/26	1255	25.9	26.07	24.56	25.0	25.08	25.1	25.25	25.3	25.24	n.a.	n.a.	25.2	25.24	25.24
	Mean		20.98	20.87	-	21.05	20.94	20.90	-	20.90	21.05	-	-	20.92	20.97	21.05
	Median		19.90	20.00	-	20.80	20.11	20.10	-	20.00	20.40	-	-	20.60	20.50	20.49
	*Mean		18.79	18.58	18.39	-	-	18.79	18.47	-	-	-	-	-	-	-
	*Median		19.00	19.12	19.13	-	-	19.00	18.47	-	-	-	-	-	-	-

Table 10. (Concluded)

			Temperature values (˚C) at													
			Intake			*Pool*								*Outfall*		
				Sonde		*1*		*2*		*3*		*4*			*Sonde*	
Event	*Date*	*Time*	*Meter*	*I*	*2*	*Meter*	*Sonde*	*Meter*	*Sonde*	*Meter*	*Sonde*	*Meter*	*Sonde*	*Meter*	*1*	*2*
SEPA5C																
1	08/13/96	1112	24.5	24.61	24.61	24.8	24.80	24.8	-	24.8	24.93	24.8	24.92	24.8	24.97	25.09
	08/14	1101	24.7	24.65	24.64	26.2	25.01	26.2	-	26.2	24.97	26.2	24.90	26.2	24.92	25.09
	08/21	1201	25.0	24.96	25.06	25.2	25.35	25.2	-	25.2	25.38	25.2	25.38	25.2	25.38	25.52
	08/22	1352	25.7	25.73	25.70	25.7	25.86	25.7	-	25.7	25.81	25.7	25.79	25.7	25.83	25.94
2	10/01	1308	18.1	18.03	18.39	18.5	18.20	18.3	18.32	18.5	18.30	18.5	18.36	18.5	18.40	18.37
	10/02	1354	18.4	18.58	18.75	18.4	18.58	18.4	18.56	18.4	18.51	18.4	18.55	18.4	18.55	18.55
	10/09	9099	15.8	15.83	15.54	15.7	15.90	15.8	15.88	15.8	15.85	15.8	15.89	15.8	15.90	15.89
3	05/01/97	1221	14.2	14.27	14.29	14.4	14.45	14.4	14.50	14.4	14.54	14.4	14.55	14.4	14.53	14.59
	05/07	1038	14.5	-	14.31	14.4	14.50	14.4	14.52	14.4	10.52	14.4	14.52	14.4	14.57	14.53
	06/17	1127	20.0	20.04	20.12	20.1	20.33	20.2	20.77	20.2	20.36	20.2	20.64	20.2	20.65	20.67
4	06/26	1024	24.8	24.92	24.97	25.0	25.14	25.0	25.15	25.0	25.18	25.0	25.17	25.1	25.10	25.17
	Mean		20.52	20.56	20.58	20.77	20.74	18.07	18.24	20.78	20.40	20.78	20.79	20.79	20.78	20.86
	Median		20.00	20.04	20.12	20.10	20.33	18.30	18.32	20.20	20.36	20.20	20.64	20.20	20.65	20.67
SEPA5S																
1	08/13/96	1112	n.a.	n.a.	n.a.	n.a.	n.a.	24.7	24.83	24.7	24.81	24.7	24.79	24.7	24.86	24.92
	08/14	1101	n.a.	n.a.	n.a.	n.a.	n.a.	26.4	25.01	26.5	24.96	26.5	24.92	26.4	25.02	25.06
	08/21	1201	n.a.	n.a.	n.a.	n.a.	n.a.	25.1	25.48	25.1	25.45	25.1	25.32	25.1	25.50	25.59
	08/22	1352	n.a.	n.a.	n.a.	n.a.	n.a.	25.7	25.91	25.7	25.90	25.8	25.89	25.8	25.95	25.94
2	10/01	1308	n.a.	n.a.	n.a.	n.a.	n.a.	18.3	18.26	18.3	18.26	18.3	18.20	18.3	18.30	18.28
	10/02	1354	n.a.	n.a.	n.a.	n.a.	n.a.	18.4	18.52	18.4	18.51	18.4	18.51	18.4	18.53	18.51
	10/09	9099	n.a	n.a.	n.a.	n.a.	n.a.	15.8	15.91	15.8	15.91	15.8	15.90	15.8	15.93	15.92
3	05/01/97	1221	n.a.	n.a.	n.a.	n.a.	n.a.	14.5	14.59	14.4	14.51	14.5	14.45	14.3	14.55	14.50
	05/07	1038	n.a.	n.a.	n.a.	n.a.	n.a.	14.4	14.50	14.5	14.56	14.5	14.57	14.4	14.57	14.54
4	06/17	1127	n.a.	n.a.	n.a.	n.a.	n.a.	20.1	20.34	20.1	20.37	20.1	20.37	20.1	20.58	20.58
	06/26	1024	n.a.	n.a.	n.a.	n.a.	n.a.	25.0	25.15	25.0	25.16	25.0	25.14	25.0	25.17	25.15
	Mean							20.76	20.80	20.77	20.76	20.79	20.73	20.75	20.91	20.82
	Median							20.10	20.34	20.10	20.37	20.10	20.37	20.10	20.58	20.58

Notes: An asterisk (*) indicates means and medians calcuiated using duplicate sondes where available
n.a. indicates that data was not available
C = Cal-Sag Channel
S = Chicago Sanitary and Ship Canal

Table 11. Summary of Manually Measured DO/Temperature Values for Vertically Averaged Intake and Outfall Values

				Dissolved oxygen					
						Saturation percentage			*Aeration*
SEPA		*Temperature (˚C)*		*Concentration (mg/L)*		*Intake*	*Outfall (P_o)*		*case*
station	*Date*	*In*	*Out*	*Intake*	*Outfall*	*(Pi)*	*Observed*	*Equation 5*	*scenario*
1	08/10/95	23.8	24.0	8.41	8.74	99.4	103.8	112.8	*III*
	08/30	26.2	26.4	7.59	8.29	93.9	102.8	111.0	*III*
	08/31	26.3	26.2	7.27	8.26	90.0	102.4	109.8	*III*
	09/06	24.4	24.5	7.78	8.68	93.1	104.1	110.8	*III*
	07/08/96	22.6	22.3	8.02	8.88	91.9	102.3	110.4	*III*
	07/16	23.8	23.8	8.24	8.59	97.4	101.6	112.2	*III*
	07/23	24.3	24.6	6.18	8.50	73.9	102.0	104.7	*III*
	08/14	23.4	23.4	7.95	8.25	93.4	96.9	110.9	VII
	08/22	23.9	24.3	8.45	8.60	100.1	102.9	113.1	*II*
	10/02	19.3	19.4	8.74	9.48	94.7	102.9	111.3	*III*
2	08/10/95	26.4	25.8	7.84	7.91	97.4	97.3	112.2	*VI*
	08/30	26.6	26.5	8.96	8.87	88.9	110.3	109.5	*III*
	08/31	25.3	25.4	5.91	8.14	72.3	99.1	104.2	VII
	09/06	25.0	25.1	6.81	8.28	82.3	100.3	107.4	*III*
	07/09/96	24.0	23.7	7.01	8.35	83.4	98.6	107.7	VII
	07/16	24.1	24.0	7.26	8.11	86.6	96.2	108.7	VII
	07/23	23.4	22.9	3.50	8.30	41.2	96.6	94.2	VII
	08/14	24.0	24.1	5.38	7.86	63.9	93.6	101.5	VII
	08/22	24.7	24.8	6.42	8.62	77.3	103.8	105.8	*III*
	10/02	19.2	19.4	6.50	9.26	70.3	100.6	103.5	*III*
	10/09	17.6	17.6	7.26	9.19	76.1	96.3	105.4	VII
3	08/02/95	24.2	24.2	5.22	7.57	64.1	93.0	99.8	VII
	08/10	25.2	24.8	5.08	7.78	60.7	93.8	98.7	VII
	08/30	25.8	26.0	5.24	8.11	64.4	100.0	99.9	*III*
	08/31	25.5	25.5	4.51	8.16	54.9	99.7	96.9	VII
	09/06	25.1	25.2	5.37	8.12	65.1	98.4	100.2	VII
	07/09/96	22.9	22.8	5.30	8.41	61.4	97.6	99.0	VII
	07/16	24.2	23.9	6.08	8.19	72.5	97.1	102.5	VII
	07/23	22.2	22.2	3.90	8.21	44.7	97.2	93.6	VII
	08/13	24.6	24.4	6.00	7.85	72.2	93.9	102.4	VII
	08/14	24.2	24.2	4.84	7.87	57.6	93.7	97.8	VII
	08/21	25.2	25.0	5.73	8.27	69.6	100.1	101.6	*III*
	08/22	24.7	24.7	5.34	8.40	64.3	100.1	99.9	*III*
	10/01	19.4	19.3	5.75	9.11	62.4	98.8	99.3	VII
	10/02	19.3	19.3	6.46	9.63	70.0	104.3	101.7	*III*
	10/08	16.3	16.2	6.92	9.53	70.6	96.1	101.9	VII
	04/30/97	15.3	15.3	7.47	10.20	74.8	102.1	103.3	*III*
	05/07	14.8	14.8	6.26	9.75	61.8	96.3	99.1	VII
	06/17	19.6	19.6	4.77	8.59	51.4	93.6	95.8	VII
	06/26	23.9	23.8	5.41	8.07	64.1	95.4	99.8	VII

Table 11. (Continued)

SEPA station	*Date*	*Temperature (˚C)*		*Dissolved oxygen*					*Aeration case scenario*
				Concentration (mg/L)		*Saturation percentage*			
						Intake (P_i)	*Outfall (P_o)*		
		In	*Out*	*Intake*	*Outfall*		*criteria*	*Equation 5*	
4	08/02/95	23.7	23.7	4.54	8.77	55.4	106.8	97.0	*III*
	08/10	25.6	25.5	3.65	7.96	43.4	97.2	93.2	VII
	08/30	26.0	26.5	4.82	8.14	59.4	101.2	98.3	*III*
	08/31	25.6	25.5	3.82	8.05	46.7	98.3	94.3	VII
	09/06	24.8	24.8	4.96	8.11	59.8	97.7	98.5	VII
	07/09/96	23.7	23.7	6.63	8.30	79.1	98.0	104.6	VII
	07/16	24.4	24.3	6.13	8.11	73.6	96.8	102.9	VII
	07/23	22.0	22.0	4.25	8.42	48.5	96.3	94.8	VII
	08/13	24.9	24.8	4.98	7.85	60.2	94.8	98.6	VII
	08/14	25.5	24.6	4.44	8.01	53.3	96.3	96.4	VII
	08/21	26.1	25.4	5.87	8.46	72.2	103.1	102.4	*III*
	08/22	25.6	25.6	4.51	8.19	53.7	100.1	96.5	*III*
	10/01	19.3	19.2	5.92	8.63	64.1	93.5	99.8	VII
	10/02	19.0	19.0	5.74	9.98	61.6	107.6	99.0	*III*
	10/09	16.1	16.1	6.98	10.46	70.8	106.3	102.0	*III*
	05/01	14.4	14.8	7.29	9.75	71.4	96.2	102.2	VII
	05/07	14.6	14.8	7.58	9.81	74.6	96.8	103.2	VII
	06/17	19.9	20.6	4.22	8.97	46.5	100.1	94.5	*III*
	06/26	25.6	25.2	6.09	7.94	74.5	96.5	103.2	VII
5C	08/10/95	25.6	25.6	3.75	8.25	46.0	101.9	95.7	*III*
5S	08/10	25.6	25.6	3.75	8.29	46.0	101.3	95.7	*III*
5C	08/30	26.8	26.2	3.39	7.55	46.2	93.6	95.8	VII
5S	08/30	26.8	26.8	3.39	7.54	46.2	94.3	95.8	VII
5C	08/31	25.8	26.0	3.35	7.72	41.1	95.1	94.2	VII
5S	08/31	25.8	25.9	3.35	7.94	41.1	97.7	94.2	VII
5C	09/06	25.1	25.5	5.21	8.18	63.2	100.0	101.2	*III*
5S	09/06	25.1	25.5	5.21	7.94	63.2	97.2	101.2	VII
5C	07/09/96	24.4	24.2	6.54	8.05	78.2	96.1	106.0	VII
5S	07/09	24.4	24.3	6.54	8.29	78.2	99.1	106.0	VII
5C	07/16	24.2	24.1	4.97	8.38	59.2	99.6	100.0	VII
5S	07/16	24.2	24.0	4.97	8.54	59.2	101.5	100.0	*III*
5C	07/23	21.2	21.6	3.76	8.18	42.4	92.7	94.6	VII
5S	07/23	21.2	21.6	3.76	8.30	42.4	94.1	94.6	VII
5C	08/13	24.7	24.8	3.94	7.68	47.5	92.7	96.2	VII
5S	08/13	24.7	24.8	3.94	7.70	47.5	92.8	96.2	VII
5C	08/14	25.1	26.2	4.91	7.97	59.6	96.2	100.1	VII
5S	08/14	25.1	26.2	4.91	7.62	59.6	94.1	100.1	VII
5C	08/21	25.2	25.2	5.31	8.22	68.0	99.8	102.8	VII
5S	08/21	25.3	25.3	5.31	8.23	68.0	100.1	102.8	*III*

Table 11. (Concluded)

				Dissolved oxygen					
						Saturation percentage			*Aeration*
SEPA		*Temperature (°C)*		*Concentration (mg/L)*		*Intake*	*Outfall (P_o)*		*case*
station	*Date*	*In*	*Out*	*Intake*	*Outfall*	*(P_i)*	*Observed*	*Equation 5*	*scenario*
5C	08/22	25.8	25.7	5.71	8.40	70.1	103.0	103.5	*III*
5S	08/22	25.8	25.8	5.71	8.43	70.1	103.3	103.5	*III*
5C	10/01	18.3	18.5	6.17	9.46	65.6	100.7	102.0	*III*
5S	10/01	18.3	18.5	6.17	9.41	65.6	100.3	102.0	*III*
5C	10/02	18.5	18.4	5.80	9.20	61.8	98.0	100.8	VII
5S	10/02	18.5	18.4	5.80	9.45	61.8	100.6	100.8	*III*
5C	10/09	15.8	15.8	7.73	10.32	77.9	104.1	105.9	*III*
5S	10/09	15.8	15.8	7.73	10.38	77.9	104.8	105.9	*III*
5C	05/01/97	14.3	14.4	6.62	9.38	64.7	91.9	101.7	VII
5S	05/01	14.3	14.3	6.62	9.16	64.7	89.7	101.7	VII
5C	05/07	14.6	14.4	7.78	9.88	76.3	96.7	105.4	VII
5S	05/07	14.6	14.4	7.78	9.81	76.3	96.1	105.4	VII
5C	06/26	25.0	25.1	4.28	8.14	51.8	98.6	97.6	VII
5S	06/26	25.0	25.0	4.28	8.28	51.8	99.8	97.6	VII
5C	06/17	19.9	20.2	4.86	8.86	53.4	97.9	98.1	VII
5S	06/17	19.9	20.1	4.86	8.92	53.4	97.8	98.1	VII

Notes: The italicized cases indicate when theoretical considerations were violated
C = Cal-Sag Channel
S = Chicago Sanitary and Ship Canal

Table 12. Statistical Summary of Comparisons of Walk-Through Generated Observed (Obs) and Equation S Predicted (Pred) P_o Values

	Number of samples		*Mean*		*Standard deviation*		*t-value @0.05 level of significance*		
SEPA station	*Obs*	*Pred*	*Obs* ($\bar{X}_o$)	*Pred* ($\bar{X}_p$)	*Obs*	*Pred*	*Computed*	*Theoretical*	$\bar{X}_o = \bar{X}_p$
1	10	10	102.17	110.70	2.001	2.353	8.733	2.101	N
2	11	11	99.34	105.46	4.548	4.786	3.078	2.080	N
3	19	19	97.43	99.64	3.154	2.435	2.418	2.034	N
4	19	19	99.14	99.02	4.113	3.534	0.093	2.034	Y
5C	18	18	97.70	100.09	3.622	3.847	1.918	2.034	Y
5S	18	18	98.03	100.09	3.932	3.847	1.585	2.034	Y

Notes: $\bar{X}$ = mean
C = Cal-Sag Channel
S = Chicago Sanitary and Ship Canal

Table 13. Weir Box Aeration Experimentally Derived a -Values; Two-Way ANOVA Results, Events Versus SEPA Stations

Mean a -Values

	SEPA station			*Event*
Event	*3*	*4*	*5*	*mean*
1	0.562	0.583	0.603	0.583
2	0.485	0.490	0.612	0.529
3	0.652	0.666	0.655	0.658
Station mean	0.566	0.580	0.623	*0.590

Note: An asterisk (*) indicates overall mean

ANOVA Statistics

Source of variation	*Degrees of freedom*	*Sum of squares*	*Mean square*	*F-statistic*		*Accept equality @ P = 0.05*	
				Computed	*@ P = 0.05*	*yes*	*no*
Event	2	0.119	0.0596	6.944	3.21	-	X
Station	2	0.039	0.0192	2.236	3.21	X	-
Event x sta.	4	0.030	0.0075	0.868	2.59	X	-
Residual	45	0.386	0.0085				
Total	53	0.574	0.0108				

Table 14. Comparison of Experimental (Exp) Versus Calculated (Cal) Dissolved Oxygen Saturation Concentration (mg/L)

SEPA station	*No.*		*Median*		*Mean*		*Standard deviation*		*t-value*		*Hypothesis* $\bar{X}_1 = \bar{X}$ @ $P = 0.05$	
	Exp	*Cal*	*Exp*	*Cal*	*Exp* $(\bar{X}_1)$	*Cal* $(\bar{X}_2)$	*Exp*	*Cal*	*Calculated*	*@ P= 0.05*	*Accept*	*Reject*
3	17	17	9.20	9.37	8.973	9.115	0.757	0.833	0.520	2.120	X	-
4	18	18	9.38	9.27	9.004	9.059	0.906	0.913	0.181	2.110	X	-
5	19	19	9.35	9.80	9.064	9.208	0.842	0.978	0.485	2.101	X	-

Notes: $\bar{X}$ = Mean
Exp = Experimentally derived
Cal = Calculated using equations 2 and 3

Table 15. Summary of Nitrogen Changes through SEPA Stations

		Concentration (mg/L)								*Percentile*					
SEPA		*Minimum*		*Mean*		*Maximum*		*Standard dev*		*25*		*50*		*75*	
station	*No*	*In*	*Out*	*In*	*Out*	*In*	*Out*	*In*	*Out*	*In*	*Out*	*In*	*Out*	*In*	*Out*
Ammonia-N															
3	**28**	**0.20**	**0.15**	**0.700**	**0.688**	**1.46**	**1.43**	**0.360**	**0.344**	**0.410**	**0.415**	**0.625**	**0.625**	**0.965**	**0.970**
4	**28**	**0.25**	**0.22**	**0.601**	**0.603**	**2.29**	**2.39**	**0.406**	**0.422**	**0.365**	**0.350**	**0.505**	**0.515**	**0.645**	**0.685**
5C	**30**	**0.22**	**0.22**	**0.625**	**0.561**	**2.32**	**1.66**	**0.480**	**0.326**	**0.340**	**0.320**	**0.485**	**0.450**	**0.680**	**0.700**
5S	**30**		**0.21**		**0.558**		**1.82**		**0.349**		**0.320**		**0.445**		**0.680**
Nitrite-N															
3	**28**	**0.05**	**0.05**	**0.136**	**0.139**	**0.26**	**0.26**	**0.058**	**0.057**	**0.095**	**0.100**	**0.125**	**0.125**	**0.170**	**0.175**
4	**28**	**0.05**	**0.05**	**0.126**	**0.126**	**0.20**	**0.25**	**0.041**	**0.042**	**0.095**	**0.100**	**0.125**	**0.125**	**0.160**	**0.150**
5C	**30**	**0.06**	**0.06**	**0.148**	**0.149**	**0.38**	**0.38**	**0.067**	**0.066**	**0.100**	**0.110**	**0.130**	**0.130**	**0.160**	**0.170**
5S	**30**		**0.06**		**0.149**		**0.37**		**0.066**		**0.110**		**0.130**		**0.170**
Nitrate-N															
3	**28**	**1.25**	**1.23**	**3.048**	**3.048**	**6.33**	**6.32**	**1.627**	**1.628**	**1.765**	**1.745**	**2.360**	**2.360**	**4.630**	**4.580**
4	**28**	**1.24**	**1.26**	**3.098**	**3.083**	**6.48**	**6.15**	**1.626**	**1.573**	**1.730**	**1.745**	**2.520**	**2.575**	**4.405**	**4.420**
5C	**30**	**1.40**	**1.41**	**3.313**	**3.334**	**5.57**	**5.59**	**1.453**	**1.446**	**1.860**	**1.913**	**3.230**	**3.210**	**4.793**	**4.740**
5S	**30**		**1.42**		**3.322**		**5.58**		**1.442**		**1.915**		**3.210**		**4.773**
TKN															
3	**28**	**0.79**	**0.95**	**1.877**	**1.904**	**2.95**	**2.85**	**0.580**	**0.536**	**1390**	**1.550**	**1.780**	**1.815**	**2.295**	**2.295**
4	**28**	**1.02**	**0.99**	**1.774**	**1.817**	**4.06**	**4.01**	**0.600**	**0.636**	**1.410**	**1.405**	**1.735**	**1.755**	**1.965**	**2.040**
5C	**30**	**0.77**	**0.85**	**1.722**	**1.706**	**2.86**	**2.92**	**0.555**	**0.525**	**1.360**	**1.350**	**1.615**	**1.615**	**2.150**	**2.040**
5S	**30**		**0.83**		**1.665**		**2.89**		**0.494**		**1.320**		**1.560**		**2.000**
Total-N															
3	**28**	**2.09**	**2.23**	**5.061**	**5.091**	**9.54**	**9.43**	**2.265**	**2.221**	**3.250**	**3.395**	**4.265**	**4.300**	**7.095**	**7.050**
4	**28**	**2.31**	**2.30**	**4.998**	**4.915**	**10.74**	**10.41**	**2.267**	**2.251**	**3.235**	**3.250**	**4.380**	**4.455**	**6.530**	**6.610**
5C	**30**	**2.23**	**2.32**	**5.183**	**5.189**	**8.81**	**8.89**	**2.075**	**2.037**	**3.320**	**3.373**	**4.975**	**4.955**	**7.103**	**6.950**
5S	**30**		**2.31**		**5.136**		**8.84**		**2.002**		**3.345**		**4.900**		**6.943**

Notes: **C = Cal-Sag Channel**
S = Chicago Sanitary and Ship Canal
TKN = Total Kjeldahl nitrogen
Boldface inlet and outlet values were shown to be equal using statistical analysis.

Table 16. Summary of Statistical Analyses of 20-day Biochemical Oxygen Demand (BOD) Changes through SEPA Stations for Total BOD (TBOD), Carbonaceous BOD (CBOD), and Nitrogenous BOD (NBOD)

Median/Mean Statistics

			20-day BOD concentrations (mg/L)									
			Percentile								*Standard deviation*	
	No.		*25*		*Median*		*75*		*Mean*			
Type	*In*	*Out*	*In*	*Out*	*In* (m_i)	*Out* (m_o)	*In*	*Out*	*In* (X)	*Out*(X)	*In*	*Out*
TBOD	24	32	8.522	8.307	9.768	9.268	12.877	11.248	10.561	9.803	2.750	1.915
CBOD	24	32	6.633	6.332	7.562	7.010	7.933	8.112	7.414	7.185	1.386	1.179
NBOD	24	32	1.735	1.752	2.378	2.348	4.527	3.208	3.147	2.618	1.941	1.193

***t-test* Statistics**

		t-statistic		$\bar{X}_i = \bar{X}_o$	
Type	$\bar{X}_i - \bar{X}_o$	*Computed*	*@P = 0.05*	*Accept*	*Reject*
TBOD	0.758	1.217	1.985	*X*	-
CBOD	0.229	0.668	1.985	X	-
NBOD	0.529	1.259	1.985	X	-

Rank Sum Test

		t-statistic		$m_i = m_n$	
Type	$m_i - m_o$	*Computed*	*@* P = 0.05	*Accept*	*Reject*
TBOD	0.215	737.5	1085	X	-
CBOD	0.301	719.0	1085	X	-
NBOD	0.030	172.0	1085	X	-

Notes: $\bar{X}$ = mean
m = median

Table 17. Mean DO Values and Percent Saturation at SEPA Stations 3, 4, and 5 for Different Seasons and Pump Operation

		Dissolved oxygen									*Total number readings*
		Event				*Number of pumps*					
SEPA	***Location***	***Summer***	***Fall***	***Spring***	***Early summer***	***1***	***2***	***3***	***4***	***Mean***	
Percent saturation											
3	Intake	72.26	69.60	70.29	64.63	66.38	68.57	71.72	-	68.59	4691
	Pool 1	88.30	87.46	88.91	83.44	88.36	86.43	84.76	-	86.25	3196
	2	97.24	99.66	97.35	92.21	96.50	95.71	94.40	-	94.95	3186
	3	99.37	102.13	102.43	95.24	99.82	99.31	97.95	-	99.03	3186
	Outfall	100.20	101.00	101.84	99.31	101.02	100.81	99.46	-	100.32	6035
4	Intake	65.18	62.59	70.36	64.15	62.37	67.18	69.05	-	66.25	4940
	Pool 1	88.47	80.22	91.52	99.91	92.21	101.58	86.36	-	93.32	3354
	2	96.64	95.03	95.85	95.75	96.37	97.11	94.35	-	95.64	3354
	3	100.71	101.03	97.49	100.24	98.20	100.54	99.35	-	99.04	3354
	Outfall	101.02	108.50	97.94	103.00	101.26	104.56	101.67	-	101.85	5122
5	Intake	57.04	64.25	67.33	55.92	54.40	57.86	64.33	66.09	59.75	5071
	Pool 1	80.57	83.18	76.74	81.39	75.39	78.36	82.50	85.91	79.30	3379
	2C	88.81	88.20	87.68	92.00	86.89	88.66	91.61	92.89	89.40	3379
	3C	95/06	93.55	96.54	98.58	92.56	95.06	99.31	103.85	96.33	3379
	4C	97.49	100.95	94.75	99.49	95.05	97.22	99.59	99.96	96.90	3379
	Outfall C	100.55	104.31	95.34	99.10	92.56	100.13	102.06	101.68	98.49	5737
	2S	89.73	91.43	88.90	92.00	86.34	90.87	92.73	92.59	89.77	3379
	3S	92.61	96.69	91.68	99.87	90.97	95.75	98.56	97.67	95.48	3379
	4S	96.98	98.24	92.93	100.32	94.14	98.91	100.75	100.98	98.31	9364
	Outfall S	98.92	104.32	94.68	100.91	93.98	98.73	101.19	102.23	98.39	6758
Concentration (mg/L)											
3	Intake	5.81	6.40	7.02	5.49	6.39	6.52	6.52	-	6.41	4691
	Pool 1	7.09	8.03	8.86	7.17	8.21	7.89	7.32	-	7.87	3196
	2	7.82	9.17	9.70	7.85	8.96	8.74	8.15	-	8.66	3196
	3	7.99	9.39	10.25	8.20	9.28	9.09	8.48	-	9.05	3186
	Outfall	8.06	9.29	10.19	8.48	9.43	9.28	8.64	-	9.21	6035
4	Intake	5.23	5.80	6.86	5.46	5.79	6.28	6.59	-	6.20	4940
	Pool 1	7.06	7.43	8.92	8.66	8.38	8.94	7.87	-	8.47	3354
	2	7.75	8.81	9.59	8.12	8.76	8.58	8.56	-	8.70	3354
	3	8.08	9.38	9.72	8.51	8.92	8.87	9.01	-	9.00	3354
	Outfall	8.07	10.08	9.82	8.69	9.19	9.14	8.87	-	9.11	5122
S	Intake	4.55	5.98	6.59	4.79	4.84	5.12	5.53	5.62	5.32	5071
	Pool 1	6.41	7.75	7.64	6.81	6.83	7.12	7.34	7.60	7.19	3379
	2C	7.06	8.22	8.62	7.83	7.87	8.07	8.15	8.20	8.11	3379
	3C	7.56	8.72	9.64	8.17	8.39	8.66	8.83	9.21	8.76	3379
	4C	7.76	9.41	9.37	8.33	8.61	8.86	8.86	8.82	8.80	3379
	Outfall C	7.99	9.73	9.49	8.36	8.28	8.95	8.87	8.78	8.78	5737
	2S	7.14	8.52	8.71	7.74	7.83	8.29	8.24	8.17	8.15	3379
	3S	7.37	9.07	9.14	8.41	8.25	8.70	8.75	8.61	8.66	3379
	4S	7.72	9.15	9.39	8.39	8.30	8.64	8.51	8.46	8.55	2364
	Outfall S	7.86	9.72	9.46	8.47	8.51	8.98	8.99	9.02	8.93	6758

Notes: C = Cal-Sag Channel
S = Chicago Sanitary and Ship Canal

Table 18. Summary of Kruskal-Wallis, Rank-Order One-Way ANOVA Analysis Comparing Seasonal Operations by Pools Using Percent DO Saturation as the Variate for SEPA Station 3

Event	*n*	*ANOVA*								*Multiple comparisons (Dunn method)*					
						H-value		*Hypothesis:* $\tilde{x}_1 = \tilde{x}_2 = \tilde{x}_3 = \tilde{x}_4$ @ $P = 0.05$		*Events compared*	*Rank differences*	*Q-value*		*Hypothesis* $\tilde{x} = \tilde{x}_i$ @ $P = 0.05$	
		x_{25}	$\tilde{x}$	x_{75}	$\bar{x}$	*Calculated*	*@P = 0.05 & 3 df*	*Accept*	*Reject*			*Calculated*	*@P = 0.05 &3df*	*Accept*	*Reject*
														√	
Pool 1															
Summer	336	85.28	88.08	94.31	88.30					1-2	15	0.26	2.65		
Fall	338	86.37	90.04	91.79	87.46					1-3	66	1.37	2.65	√	
Spring	864	85.86	87.81	91.94	88.91					1-4	784	16.73	2.65		√
Early Summer	1052	81.31	82.97	85.92	83.44					2-3	81	1.69	2.65	√	
ANOVA Results						751	5.25		√	2-4	769	16.45	2.65		√
										3-4	850	24.76	2.65		√
Pool 2															
Summer	336	96.35	97.26	98.24	97.24					1-2	272	4.71	2.65		√
Fall	338	97.03	100.50	103.26	87.46					1-3	5	0.11	2.65	√	
Spring	864	95.69	96.91	99.67	97.35					1-4	1173	25.02	2.65		√
Early Summer	1052	91.38	92.49	93.27	92.21					2-3	276	5.76	2.65		√
ANOVA Results						1723	5.25		√	2-4	1444	30.88	2.65		√
										3-4	1167	34.00	2.65		√
Pool 3															
Summer	335	97.04	99.43	101.26	99.37					1-2	375	6.51	2.65		√
Fall	338	99.05	103.00	106.21	102.13					1-3	510	10.60	2.65		√
Spring	864	100.27	102.33	104.64	102.43					1-4	814	17.36	2.65		√
Early Summer	1052	94.43	95.62	96.41	95.24					2-3	135	2.81	2.65		√
ANOVA Results						1677	5.25		√	2-4	1189	25.45	2.65		√
										3-4	1324	38.58	2.65		√

Table 18. (Concluded)

						ANOVA				Multiple compartsons (Dunn method)					
						H-value		Hypothesis: $\tilde{x}_1 = \tilde{x}_2 = \tilde{x}_3 = \tilde{x}_4$ @ $P = 0.05$		Events compared	Rank differences	Q-value		Hypothesis $\tilde{x} = \tilde{x}_i$ @ $P = 0.05$	
Event	*n*	x_{25}	$\tilde{x}$	x_{75}	$\bar{x}$	*Calculated*	*@P=0.05 & 3 df*	*Accept*	*Reject*			*Calculated*	*@P=0.05 &3df*	*Accept*	*Reject*
Pool: Outfall															
Summer	336	99.07	100.65	101.32	100.20					1-2	724	7.76	2.65		√
Fall	676	100.08	101.92	103.62	101.00					1-3	805	9.66	2.65		√
Spring	1728	100.02	101.83	103.82	101.84					1-4	443	5.39	2.65		√
Early Summer	2104	97.64	99.61	101.25	99.31					2-3	81	1.27	2.65	√	
ANOVA Results						870	5.25		√	2-4	1167	18.88	2.65		√
										3-4	1248	27.48	2.65		√

Notes: $\bar{x}$ = mean

n = sample size

Table 19. Summary of Kruskal-Wallis, Rank-Order One-Way ANOVA Comparing Seasonal Operations by Pools Using Percent DO Saturation as the Variate for SEPA Station 4

		ANOVA								Multiple comparisons (Dunn method)					
						H-value		Hypothesis: $\tilde{x}_1 = \tilde{x}_2 = \tilde{x}_3 = \tilde{x}_4$ @ $P = 0.05$		Events		Q-value		Hypothesis $\tilde{x} = \tilde{x}_j$ @ $P = 0.05$	
Event	*n*	x_{25}	$\tilde{x}$	x_{75}	$\bar{x}$	*Calcu-lated*	*@P = 0.05 & 3 df*	*Accept*	*Reject*	*com-pared*	*Rank differences*	*Calcu-lated*	*@P = 0.05 & 3 df*	*Accept*	*Reject*
Pool 1															
Summer	336	84.54	89.83	92.96	88.47					1-2	532	9.15	2.65		√
Fall	336	75.14	83.29	86.83	80.22					1-3	268	5.54	2.65		√
Spring	864	89.29	92.17	93.45	91.52					1-4	542	11.51	2.65		√
Early Summer	1075	82.14	107.44	114.23	99.91					2-3	800	16.51	2.65		√
ANOVA Results						561		5.25	√	2-4	1075	22,81	2.65		√
										3-4	275	7.96	2.65		√
Pool 2															
Summer	336	94.56	95.79	97.66	96.64					1-2	307	5.31	2.65		√
Fall	336	91.72	94.39	98.36	95.03					1-3	172	3.66	2.65		√
Spring	864	93.66	95.39	97.40	95.85					1-4	93	1.99	2.65	√	
Early Summer	1063	94.38	95.59	96.91	95.75					2-3	135	2.81	2.65		√
ANOVA Results						34		5.25	√	2-4	214	4.56	2.65		√
										3-4	79	2.28	2.65	√	
Pool 3															
Summer	336	96.26	100.24	103.55	100.71					1-2	179	3.09	2.65		√
Fall	336	97.76	100.64	104.35	101.03					1-3	679	14.07	2.65		√
Spring	864	96.15	97.42	98.71	97.49					1-4	189	4.02	2.65		√
Early Summer	1063	99.56	100.73	102.08	100.24					2-3	858	17.77	2.65		√
ANOVA Results						721		5.25	√	2-4	10	0.21	2.65	√	
										3-4	867	25.24	2.65		√

Table 19. (Concluded)

						ANOVA				*Multiple comparisons (Dunn method)*					
						H-value		*Hypothesis:* $\tilde{x}_1 = \tilde{x}_2 = \tilde{x}_3 = \tilde{x}_4$ @ $P = 0.05$		*Events com- pared*	*Rank differences*	*Q-value*		*Hypothesis* $\tilde{x} = \tilde{x}_i$ @ $P = 0.05$	
Event	*n*	x_{25}	$\tilde{x}$	x_{75}	$\bar{x}$	*Calcu- lated*	*@P = & 3 df*	*Accept*	*Reject*			*Calcu- lated*	*@P = 0.05 &3df*	*Accept*	*Reject*
Pool: Outfall															
Summer	336	97.95	100.64	104.83	101.02					1-2	1736	22.50	2.65		√
Fall	672	107.38	109.68	111.18	108.50					1-3	962	12.96	2.65		√
Spring	8684	96.S9	97.84	99.39	97.94					1-4	504	7.44	2.65		√
Early Summer	2126	101.28	103.90	104.99	103.00					2-3	2698	45.44	2.65		√
ANOVA Results						2153	5.25		√	2-4	1231	24.11	2.65		√
										3-4	1466	31.49	2.65		√

Notes: **$\bar{x}$ = mean**
n = sample size

Table 20. Summary of Kruskal-Wallis, Rank-Order One-Way ANOVA Analysis Comparing Seasonal Operations by Pools Using Percent DO Saturation as the Variate for SEPA Station 5

		ANOVA								*Multiple comparisons (Dunn method)*					
						H-value		*Hypothesis:* $\tilde{x}_1 = \tilde{x}_2 = \tilde{x}_3 = \tilde{x}_4$ @ $P = 0.05$		*Events com-pared*	*Rank differences*	*Q-value*		*Hypothesis* $\tilde{x} = \tilde{x}_i$ @ $P = 0.05$	
Event	*n*	x_{25}	$\tilde{x}$	x_{75}	$\bar{x}$	*Calcu-lated*	*@P = 0.05 &3 df*	*Accept*	*Reject*			*Calcu-lated*	*@P = 0.05 & 3 df*	*Accept*	*Reject*
Pool 1															
Summer	336	75.83	79.93	84.11	80.57					1-2	383	6.13	2.65		√
Fall	333	79.35	84.39	87.46	83.18					1-3	521	10.33	2.65		√
Spring	1061	72.82	74.51	81.08	76.74					1-4	181	3.59	2.65		√
Early Summer	1063	80.02	82.12	84.08	81.39					2-3	904	17.84	2.65		√
ANOVA Results						542		5.25	√	2-4	201	3.97	2.65		√
										3-4	703	20.08	2.65		√
Pool 2C															
Summer	336	84.99	86.53	90.14	88.81					1-2	112	1.80	2.65	√	
Fall	333	85.77	87.84	90.93	88.20					1-3	47	0.92	2.65	√	
Spring	1061	85.74	86.95	90.19	87.68					1-4	978	19.38	2.65		√
Early Summer	1063	91.66	92.87	94.09	92.00					2-3	159	3.14	2.65		√
ANOVA Results						992		5.25	√	2-4	866	17.09	2.65		√
										3-4	1025	29.28	2.65		√
Pool 3C															
Summer	336	92.18	93.36	97.42	95.06					1-2	230	3.68	2.65		√
Fall	333	90.74	94.16	96.26	93.55					1-3	112	2.23	2.65	√	
Spring	1061	91.96	94.02	98.70	96.54					1-4	766	15.17	2.65		√
Early Summer	1063	97.43	99.68	101.48	98.58					2-3	342	6.75	2.65		√
ANOVA Results						602		5.25	√	2-4	995	19.65	2.65		√
										3-4	653	18.66	2.65		√

Table 20. (Continued)

		ANOVA								Multiple comparisons (Dunn method)					
						H-value		Hypothesis : $\tilde{x}_1 = \tilde{x}_2 = \tilde{x}_3 = \tilde{x}_4$ @ $P = 0.05$		Events compared	Rank differences	Q-value		Hypothesis $\tilde{x} = \tilde{x}_i$ @ $P = 0.05$	
Event	n	x_{25}	$\tilde{x}$	x_{75}	$\bar{x}$	Calculated	@P = 0.05 & 3 df	Accept	Reject			Calculated	@P - 0.05 &3df	Accept	Reject
Pool 4C															
Summer	336	95.07	96.12	99.35	97.49					1-2	912	14.63	2.65		√
Fall	333	100.04	100.95	101.74	100.95					1-3	517	10.23	2.65		√
Spring	1061	92.37	94.48	96.48	94.75					1-4	675	13.37	2.65		√
Early Summer	1063	99.35	100.41	101.26	99.49					2-3	1429	28.21	2.65		√
ANOVA Results						1483	5.25		√	2-4	237	4.69	2.65		√
										3-4	1191	34.05	2.65		√
Pool: Outfall C															
Summer	672	98.55	101.54	103.33	100.56					1-2	1152	15.25	2.65		√
Fall	666	102.03	104.15	106.50	104.31					1-3	1754	26.81	2.65		√
Spring	1326	92.80	95.35	98.06	95.62					1-4	203	3.32	2.65		√
Early Summer	2120	101.02	101.97	102.56	99.09					2-3	2905	44.29	2.65		√
ANOVA Results						2508	5.25		√	2-4	949	15.46	2.65		√
										3-4	1957	40.47	2.65		√
Pool 2S															
Summer	336	86.45	88.24	92.99	89.73					1-2	444	7.12	2.65		√
Fall	333	88.51	92.44	93.89	91.43					1-3	186	3.68	2.65		√
Spring	1061	88.04	89.52	90.54	88.90					1-4	793	15.71	2.65		√
Early Summer	1063	92.00	93.21	94.77	92.00					2-3	630	12.44	2.65		√
ANOVA Results						839	5.25		√	2-4	349	6.89	2.65		√
										3-4	979	27.97	2.65		√

Table 20. (Concluded)

	ANOVA									Multiple comparisons (Dunn method)					
						H-value		Hypothesis: $\tilde{x}_1 = \tilde{x}_2 = \tilde{x}_3 = \tilde{x}_4$ @ $P = 0.05$		Events com- pared	Rank differences	Q-value		Hypothesis $\tilde{x} = \tilde{x}_i$ @ $P = 0.05$	
Event	n	x_{25}	$\tilde{x}$	x_{75}	$\bar{x}$	Calcu- lated	@P = & 3 df	Accept	Reject			Calcu- lated	@P = 0.05 & 3 df	Accept	Reject
Pool 3S															
Summer	336	90.17	91.74	94.31	92.61					1-2	512	8.21	2.65		√
Fall	333	95.54	97.13	97.99	96.69					1-3	148	2.93	2.65		√
Spring	1061	88.55	90.88	94.63	91.68					1-4	1255	24.87	2.65		√
Early Summer	1063	100.84	101.70	102.36	99.87					2-3	660	13.02	2.65		√
ANOVA Results						1745		5.25	√	2-4	743	14.68	2.65		√
										3-4	1403	40.09	2.65		√
Pool 4S															
Summer	336	95.04	96.10	98.62	96.98					1-2	115	2.58	2.65	√	
Fall	333	97.35	98.98	100.49	98.24					1-3	379	8.01	2.65		√
Spring	265	90.92	93.56	95.43	92.93					1-4	666	18.46	2.65		√
Early Summer	1063	100.50	101.50	103.03	100.32					2-3	494	10.42	2.65		√
ANOVA Results						918		5.25	√	2-4	551	15.22	2.65		√
										3-4	1046	26.41	2.65		√
Pool: Outfall S															
Summer	672	96.13	98.04	101.56	98.92					1-2	1811	20.54	2.65		√
Fall	666	101.64	105.39	107.16	104.32					1-3	1282	17.95	2.65		√
Spring	2122	92.34	94.57	97.18	94.67					1-4	1230	17.23	2.65		√
Early Summer	2126	102.08	102.98	103.80	100.91					2-3	3092	43.17	2.65		√
ANOVA Results						3333		5.25	√	2-4	581	8.11	2.65		√
										3-4	2511	50.75	2.65		√

Notes:
$\bar{x}$ = mean
n = sample size
C = Cal-Sag Channel
S = Chicago Sanitary and Ship Canal

Table 21. Summary of Kruskal-Wallis, Rank-Order One-Way ANOVA Analysis Comparing Pumping Rates by Pools Using Percent DO Saturation as the Variate for SEPA Station 3

						ANOVA				*Multiple comparisons (Dunn method)*					
						H-value		**Hypothesis : $\tilde{x}_1 = \tilde{x}_2 = \tilde{x}_3 = \tilde{x}_4$ @ $P = 0.05$**		*Events*		*Q-value*		*Hypothesis* $\tilde{x} = \tilde{x}_i$ @ $P = 0.05$	
No. of pumps	*n*	x_{33}	$\tilde{x}$	x_{73}	$\bar{x}$	*Calcu- laled*	*@P = 0.05 & 2 df*	*Accept*	*Reject*	*com- pared*	*Rank differences*	*Calcu- lated*	*@P = 0.05 & 2 df*	*Accept*	*Reject*
Pool 1															
1	554	85.06	89.41	92.39	88.35					1-2	282	7.48	1.95		√
2	1368	83.24	86.29	90.87	86.43					1-3	576	13.41	1.95		√
3	668	82.52	84.44	87.25	84.76					2-3	295	8.35	1.95		√
ANOVA Results						181	4.75		√						
Pool 2															
1	554	92.29	98.02	100.43	96.49					1-2	151	4.00	1.95		√
2	1368	92.40	96.03	98.28	95.71					1-3	380	8.85	1.95		√
3	668	93.21	93.92	95.23	94.40					2-3	230	6.51	1.95		√
ANOVA Results						82	4.75		√						
Pool 3															
1	554	94.32	100.95	105.08	99.82					1-2	43	1.14	1.95		√
2	1367	95.46	99.83	102.39	99.31					1-3	187	4.35	1.95	√	
3	668	96.47	97.55	99.41	97.95					2-3	144	4.09	1.95		√
ANOVA Results						23	4.75		√						
Pool: Outfall															
1	1060	98.16	101.88	103.79	100.98					1-2	63	1.23	1.95	√	
2	2544	99.41	101.04	102.56	100.78					1-3	720	12.30	1.95		√
3	1240	98.34	99.99	101.15	99.52					2-3	656	13.56	1.95		√
ANOVA Results						217	4.75		√						

Notes: $\bar{x}$ = mean
n = sample size

Table 22. Summary of Kruskal-Wallis, Rank-Order One-Way ANOVA Analysis Comparing Pumping Rates by Pools Using Percent DO Saturation as the Variate for SEPA Station 4

		ANOVA								*Multiple comparisons (Dunn method)*					
						H-value		*Hypothesis:* $\tilde{x}_1 = \tilde{x}_2 = \tilde{x}_3 = \tilde{x}_4$ *@* $P = 0.05$		*Events*		*Q-value*		*Hypothesis* $\tilde{x} = \tilde{x}_i$ *@* $P = 0.05$	
No. of pumps	*n*	x_{25}	$\tilde{x}$	x_{75}	$\bar{x}$	*Calculated*	*@P = 0.05 & 2 df*	*Accept*	*Reject*	*compared*	*Rank differences*	*Calculated*	*@P = 0.05 & 2 df*	*Accept*	*Reject*
Pool 1															
1	636	84.02	89.82	106.56	92.21					1-2	553	14.21	1.95		√
2	912	92.61	96.81	114.16	101.58					1-3	330	8.73	1.95		√
3	1063	80.86	87.90	92.23	86.36					2-3	884	25.97	1.95		√
ANOVA Results						679	4.75		√						
Pool 2															
1	624	93.88	95.13	98.08	96.37					1-2	416	10.68	1.95		√
2	912	95.69	96.76	98.16	97.11					1-3	356	9.40	1.95		√
3	1063	93.08	94.38	95.72	94.35					2-3	772	22.80	1.95		√
ANOVA Results						520	4.75		√						
Pool 3															
1	624	95.86	98.01	99.84	98.20					1-2	677	17.36	1.95		√
2	912	98.51	101.06	102.44	100.54					1-3	335	8.85	1.95		√
3	1063	97.40	99.42	100.82	99.35					2-3	342	10.09	1.95		√
ANOVA Results						307	4.75		√						
Pool: Outfall															
1	936	98.13	101.47	103.83	101.67					1-2	901	18.78	1.95		√
2	1512	103.54	104.91	105.72	104.75					1-3	70	1.47	1.95	√	
3	1550	98.62	100.47	104.41	101.87					2-3	831	19.93	1.95		√
ANOVA Results						521	4.75		√						

Notes: $\bar{x}$ = mean
n = sample size

Table 23. Summary of Kruskal-Wallis, Rank-Order One-Way ANOVA Analysis Comparing Pumping Rates by Pools Using Percent DO Saturation as the Variate for SEPA Station S

		ANOVA								*Multiple comparisons (Dunn method)*					
						H-value		*Hypothesis* : $\tilde{x}_1 = \tilde{x}_2 = \tilde{x}_3 = \tilde{x}_4$ @ $P = 0.05$		*Events*		*Q-value*		*Hypothesis* $\tilde{x} = \tilde{x}_i$ @ $P = 0.05$	
No. of pumps	*n*	x_{25}	$\tilde{x}$	x_{75}	$\bar{x}$	*Calcu-lated*	*@P = 0.05 & 3 df*	*Accept*	*Reject*	*com-pared*	*Rank differences*	*Calcu-lated*	*@P = 0.05 & 3 df*	*Accept*	*Reject*
Pool 1															
1	622	72.92	74.95	78.84	75.39					1-2	378	9.48	2.65		√
2	1200	79.29	79.29	82.49	78.36					1-3	988	20.18	2.65		√
3	480	82.50	82.50	84.36	82.50					1-4	1510	31.02	2.65		√
4	491	85.73	85.73	87.58	85.91					2-3	610	14.02	2.65		√
ANOVA Results						1172		5.25	√	2-4	1132	26.21	2.65		√
										3-4	521	10.08	2.65		√
Pool 2C															
1	622	83.85	86.36	90.96	86.89					1-2	210	5.26	2.65		√
2	1200	85.83	87.67	91.85	88.66					1-3	803	16.39	2.65		√
3	480	89.75	91.86	93.40	91.61					1-4	1014	28.84	2.65		√
4	491	91.27	92.91	94.02	92.89					2-3	593	13.62	2.65		√
ANOVA Results						625		5.25	√	2-4	805	18.63	2.65		√
										3-4	212	4.09	2.65		√
Pool 3C															
1	622	91.32	92.62	95.48	92.56					1-2	340	8.54	2.65		√
2	1200	92.70	94.54	97.98	95.06					1-3	1139	23.24	2.65		√
3	480	97.08	100.74	101.70	99.31					1-4	1606	32.98	2.65		√
4	491	101.13	102.46	108.92	103.85					2-3	798	18.33	2.65		√
ANOVA Results						1444		5.25	√	2-4	1265	29.29	2.65		√
										3-4	467	9.02	2.65		√

Table 23. (Continued)

		ANOVA								Multiple comparisons (Dunn method)					
						H-value		Hypothesis : $\tilde{x}_1 = \tilde{x}_2 = \tilde{x}_3 = \tilde{x}_4$ @ $P = 0.05$		Events compared	Rank differences	Q-value		Hypothesis $\tilde{x} = \tilde{x}_i$ @ $P = 0.05$	
No. of pumps	n	x_{25}	$\tilde{x}$	x_{75}	$\bar{x}$	Calculated	@P = 0.05 & 3 df	Accept	Reject			Calculated	@P = 0.05 & 3 df	Accept	Reject
Pool 4C															
1	622	91.19	95.63	99.77	95.04					1-2	198	4.98	2.65		√
2	1200	94.43	97.66	99.89	97.22					1-3	715	14.60	2.65		√
3	480	98.58	99.58	101.11	99.59					1-4	911	18.72	2.65		√
4	491	97.58	101.37	102.35	99.96					2-3	517	11.87	2.65		√
ANOVA Results						495	5.25		√	2-4	713	16.50	2.65		√
										3-4	196	3.79	2.65		√
Pool: Outfall C															
1	1100	91.61	99.53	101.45	92.69					1-2	751		2.65		√
2	2038	97.53	101.13	102.14	100.29					1-3	1482		2.65		√
3	816	100.56	102.26	103.09	102.14					1-4	1537		2.65		√
4	830	99.12	102.57	104.20	101.95					2-3	731		2.65		√
ANOVA Results						803	5.25		√	2-4	786		2.65		√
										3-4	55		2.65	√	
Pool 2S															
1	622	84.69	87.13	91.00	86.34					1-2	628	15.77	2.65		√
2	1200	89.16	90.61	92.73	90.87					1-3	1114	22.75	2.65		√
3	480	90.71	92.67	95.26	92.73					1-4	1111	22.81	2.65		√
4	491	90.18	93.40	95.40	92.59					2-3	486	11.16	2.65		√
ANOVA Results						724	5.25		/	2-4	482	11.16	2.65		√
										3-4	4	0.08	2.65	√	

Table 23. (Concluded)

	ANOVA									Multiple comparisons (Dunn method)					
						H-value		Hypothesis: $\tilde{x}_1 = \tilde{x}_2 = \tilde{x}_3 = \tilde{x}_4$ @ $P = 0.05$				Q-value		Hypothesis $\tilde{x} = \tilde{x}_i$ @ $P = 0.05$	
No. of pumps	n	x_{25}	$\tilde{x}$	x_{75}	$\bar{x}$	Calculated	@P = 0.05 & 3 df	Accept	Reject	Events compared	Rank differences	Calculated	@P = 0.05 &3df	Accept	Reject
Pool 3S															
1	622	88.12	89.87	98.19	90.97					1-2	527	13.22	2.65		√
2	1200	90.73	95.09	101.99	95.75					1-3	904	18.45	2.65		√
3	480	96.39	98.14	101.92	98.56					1-4	686	14.09	2.65		√
4	491	95.84	98.26	100.63	97.67					2-3	377	8.66	2.65		√
ANOVA Results						387	5.25		√	2-4	159	3.68	2.65		√
										3-4	218	4.21	2.65		√
Pool 4S															
1	478	93.38	96.13	99.29	94.14					1-2	449	13.59	2.65		√
2	840	96.27	100.82	101.40	98.91					1-3	757	18.44	2.65		√
3	336	98.70	102.88	103.32	100.75					1-4	878	21.51	2.65		√
4	343	98.93	102.83	104.08	100.98					2-3	308	8.28	2.65		√
ANOVA Results						573	5.25		√	2-4	429	11.60	2.65		√
										3-4	121	2.73	2.65		√
Pool: Outfall S															
1	1244	92.15	96.35	101.15	93.98					1-2	831	14.75	2.65		√
2	2400	94.02	99.19	103.17	99.41					1-3	1572	22.69	2.65		√
3	960	98.18	101.80	103.96	101.19					1-4	1906	27.68	2.65		√
4	982	98.45	103.30	104.14	102.23					2-3	741	12.03	2.65		√
ANOVA Results						932	5.25		√	2-4	1075	17.60	2.65		√
										3-4	334	4.56	2.65		√

Notes:
$\bar{x}$ = mean
n = sample size
C = Cal-Sag Channel
S = Chicago Sanitary and Ship Canal

Table 24. Summary of Mann-Whitney Rank Sum Tests Comparing Cal-Sag Channel (C) and Chicago Sanitary and Ship Canal (S) Outfall Pools Using Percent DO Saturation (x) as the Variate

							t-value		*Hypothesis*	
Pool								*@P = 0.05*	$\tilde{x}_c = \tilde{x}_s$ @P = 0.05	
step	*Pool*	*n*	x_{25}	$\tilde{x}$	x_{75}	$\bar{x}$	*Calculated*	*& a df*	*Accept*	*Reject*
2	2C	2793	86.15	90.20	92.78	89.52				
	2S	2793	88.70	90.94	93.39	90.48	29.24	1.96		√
3	3C	2793	93.04	96.52	100.41	96.78				
	3S	2793	90.89	96.87	101.15	95.51	31.01	1.96		√
4	4C	2793	94.91	98.99	100.82	97.63				
	4S	1997	96.07	100.18	101.99	98.43	27.77	1.96		√
Outfall	Out C	4784	97.49	101.30	102.54	98.99				
	Out S	5586	95.16	100.22	103.24	98.71	40.63	1.96		√

Notes: $\bar{x}$ = mean
n = sample size

Table 25. Summary of Kruskal-Wallis Rank-Order One-Way ANOVA Analysis Comparing Distribution Pool and Outfall Pool DO Saturation (X) Between SEPA Stations

		ANOVA								Multiple comparison (Dunn method)					
						H-value		Hypothesis: $\tilde{x}_1 = \tilde{x}_2 = \tilde{x}_3 = \tilde{x}_4$ @ $P = 0.05$		SEPAs compared	Rank differences	O-value		Hypothesis $\tilde{x} = \tilde{x}_i$ @ $P = 0.05$	
SEPA	*n*	X_{25}	$\tilde{X}$	X_{75}	$\bar{X}$	*Calculated*	*@P = 0.05 2 df*	*Accept*	*Reject*			*Calculated*	*@P = 0.05 2 df*	*Accept*	*Reject*
Distribution Pool (P_d)															
3	3186	83.48	86.23	89.42	86.25					3-4	1153	16.28	1.95		√
4	3354	84.27	91.73	100.31	93.32					3-5	2769	39.16	1.95		√
5	3379	47.71	79.56	83.49	79.30					4-5	3922	56.20	1.95		√
ANOVA Results						2033	3.00		√						
Outfall Pool (P_o)															
3	6035	98.83	100.46	102.15	101.85					3-4	1143	10.68	1.95		√
4	5122	98.55	101.50	104.82	100.32					3-5	2151	16.58	1.95		√
5	12495	95.57	100.35	102.56	98.44					4-5	3294	29.08	1.95		√
ANOVA Results						559	3.00		√						

Notes: $\bar{X}$ = mean
n = sample size

Table 26. SEPA Station Pump Aeration Capacity in Terms of Weir Height Equivalents for N = 1 in Equation 5

			P_o		*Weir height equivalent (ft)*	
Database	*SEPA*	P_i	*A*	*B*	*A*	*B*
Walk through	1	92.8	96.1	97.3	9.25	10.73
	2	75.8	91.5		10.29	
	3	63.5	85.4	-	7.62	-
	4	62.5	84.3	89.1	6.65	12.58
	5	58.8	78.9	79.8	1.45	2.56
Continuous monitor	3	68.6	86.3	·	6.71	-
	4	66.3	-	93.3	-	16.26
	5	59.8	-	79.3	-	1.55

Notes: A = point of pump discharge
B = point above first weir

FIGURES

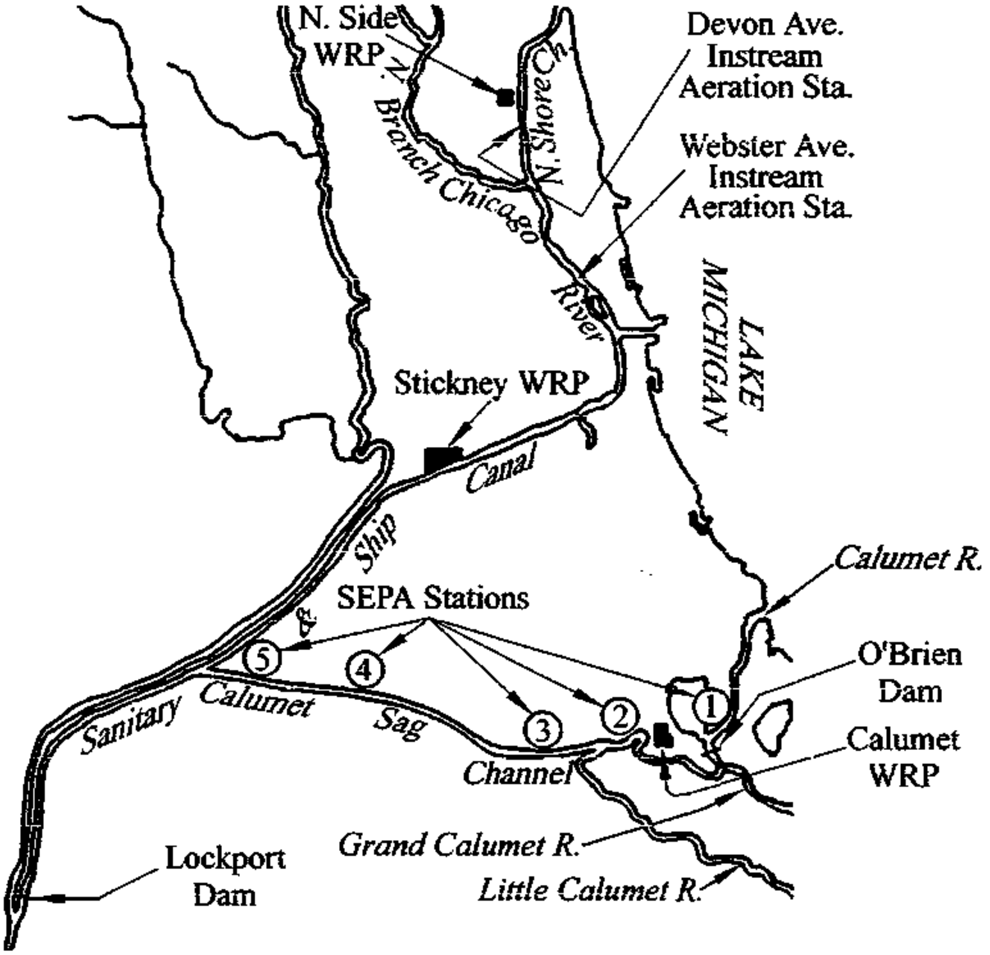
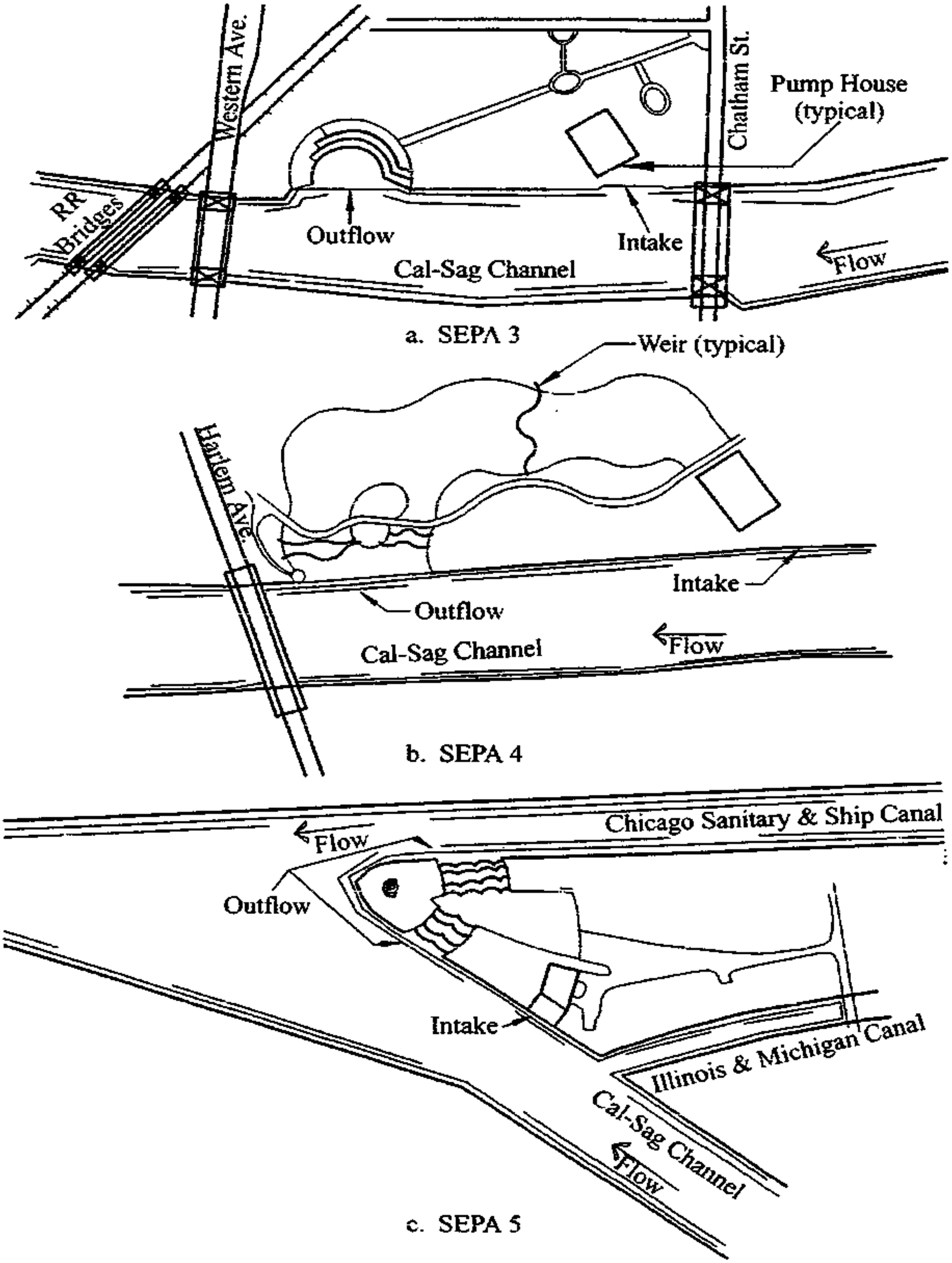


Figure 1. Chicago area waterways showing aeration stations and SEPA stations 1-5 (WRP = water reclamation plant)



a. SEPA 3

b. SEPA 4

c. SEPA 5

Figure 2. Vicinity area details of SEPA Stations 3 (a), 4 (b), and 5 (c)

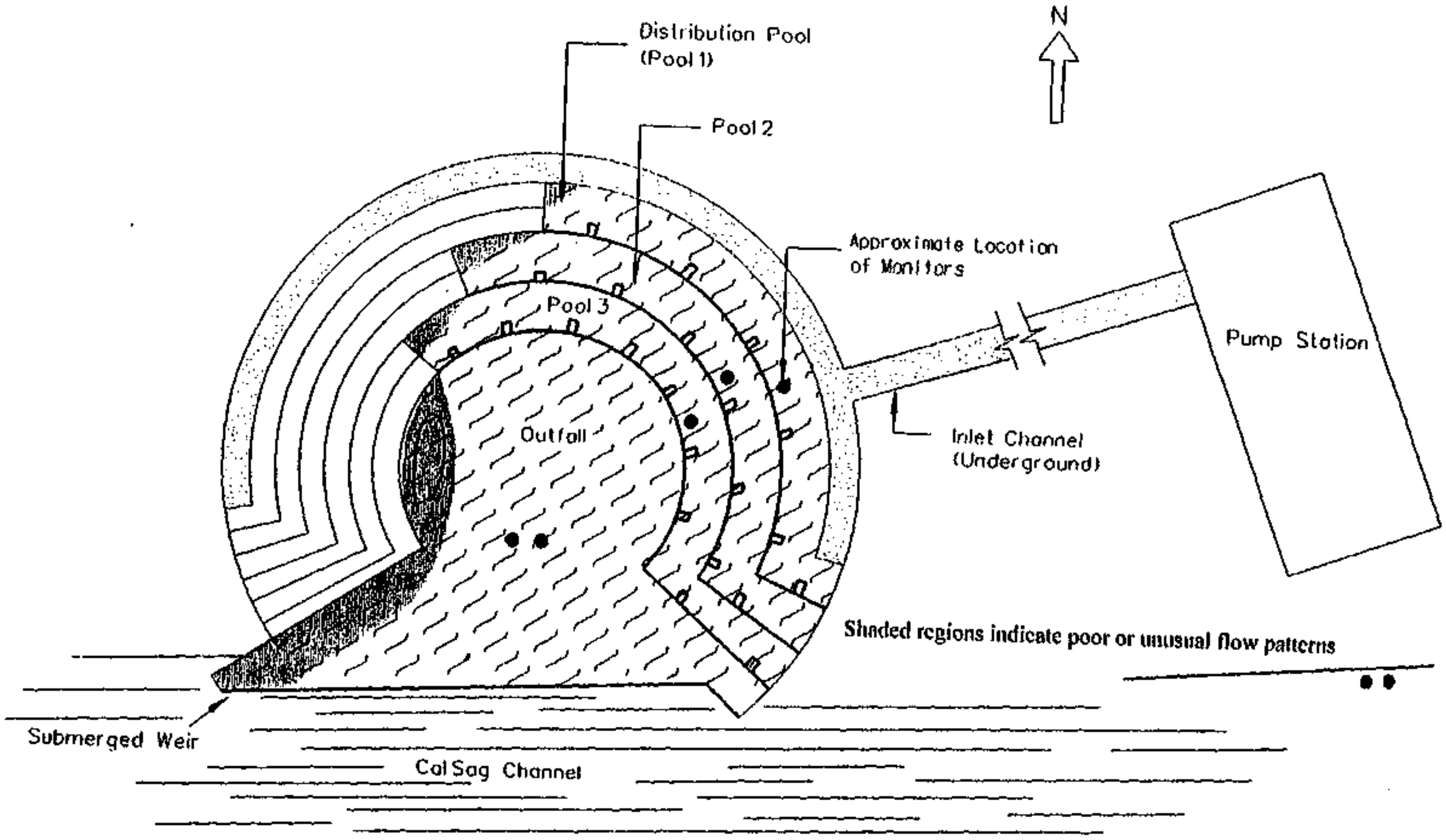


Figure 3. Plan view of geometric features of SEPA 3 showing location of continuous monitors

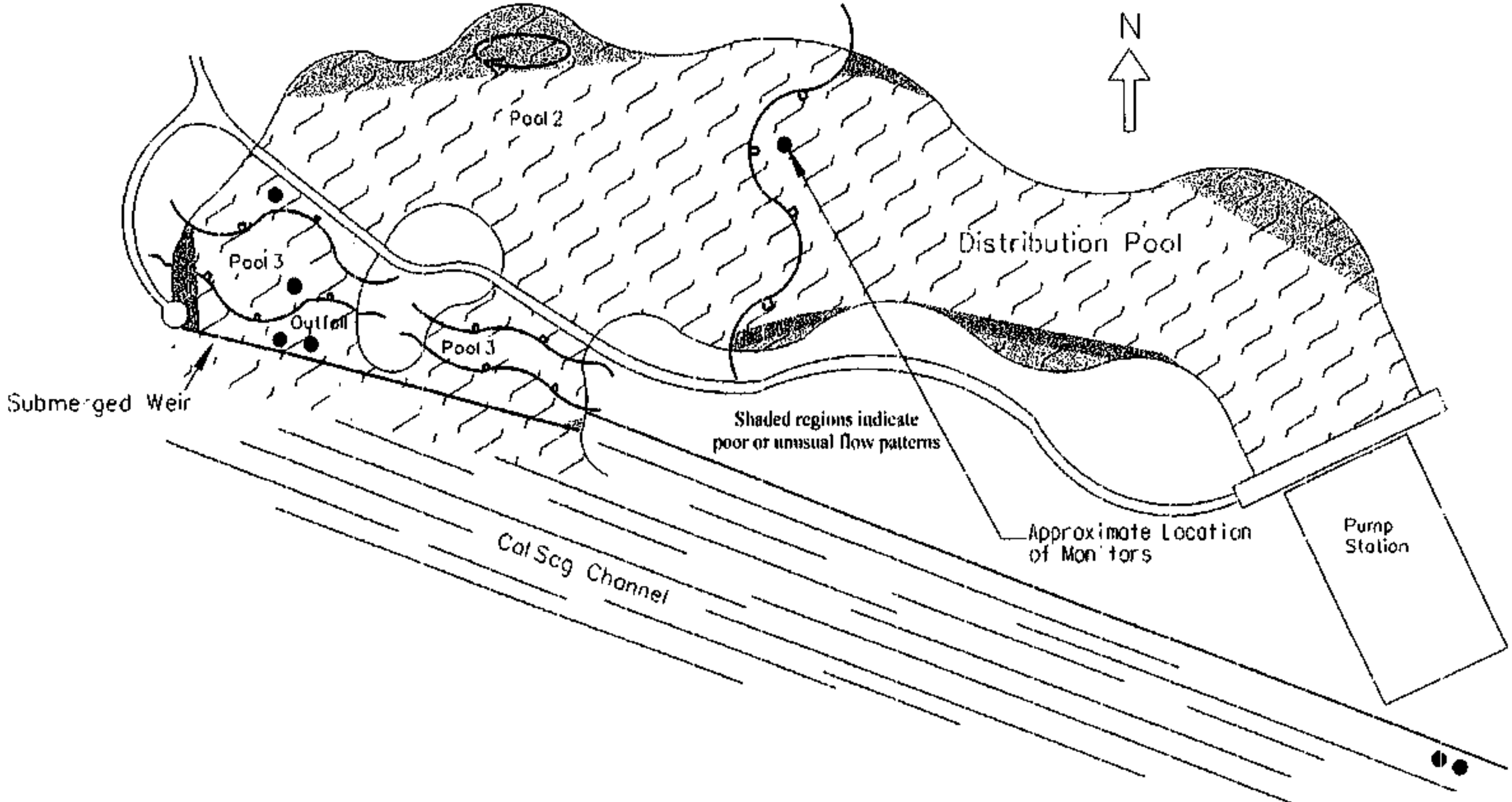
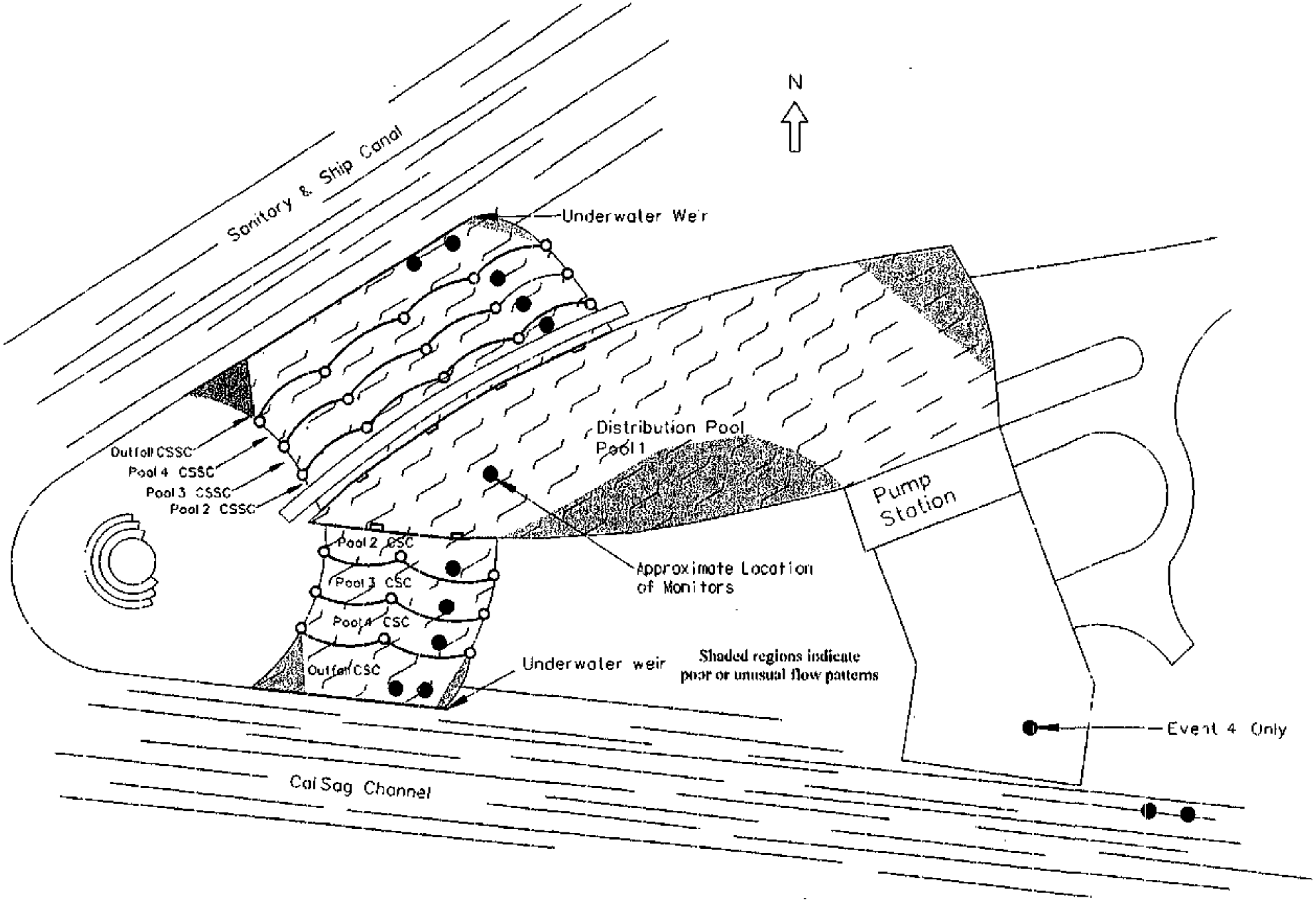


Figure 4. Plan view of geometric features of SEPA 4 showing location of continuous monitors



Shaded regions indicate poor or unusual flow patterns

Figure 5. Plan view of geometric features of SEPA 5 showing location of continuous monitors

Figure 6. SEPA Station discharge weir to Calumet River, summer 1996

Figure 7. SEPA Station 2 discharge weir to Little Calumet River, summer 1996

Figure 8. SEPA Station 3 discharge weir to Cal-Sag Channel, summer 1996


Figure 9. SEPA Station 4 weir 1 overflow, summer 1996

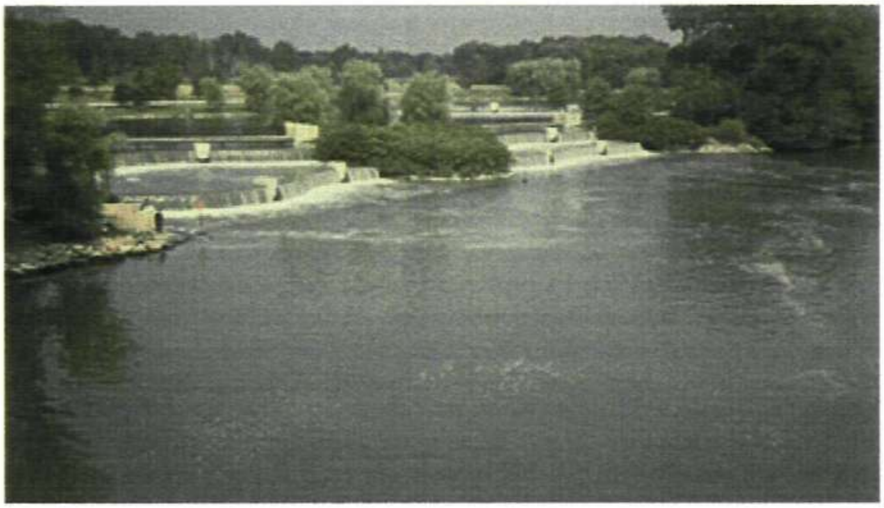


Figure 10. SEPA Station 4 discharge weirs to Cal-Sag Channel, summer 1996


Figure 11. SEPA Station 5 distribution pool, summer 1996

Figure 12. SEPA Station 5 discharge weir to Chicago Sanitary and Ship Canal, summer 1996

Figure 13. Sediment deposition in SEPA Station 4 distribution pool, spring 1995

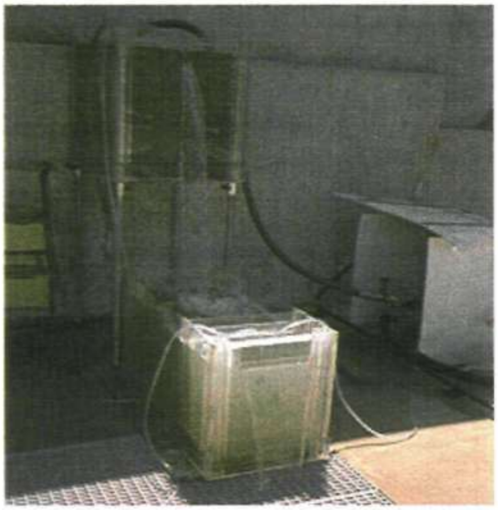


Figure 14. Standard weir box; SEPA Station 5

Figure 15. YSI stirrer - DO/temperature probe flotation board used during manual measurements

Figure 16. Double shrouded, duplicate in-line rigging used at SEPA Station 5 intake

Figure 17. In-SEPA station monitor riggings: events 1 and 2 (left), and 3 and 4 (right)

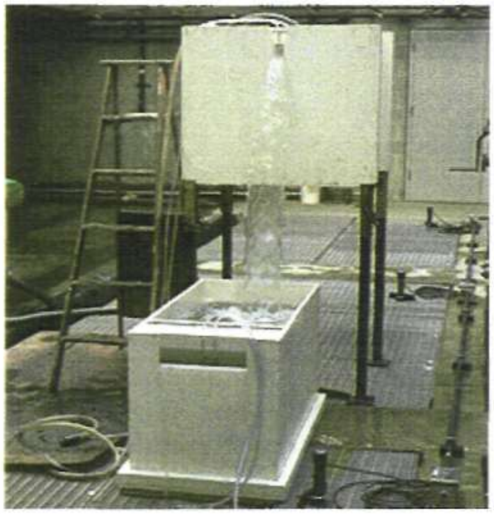


Figure 18. Plywood weir box, SEPA Station 3

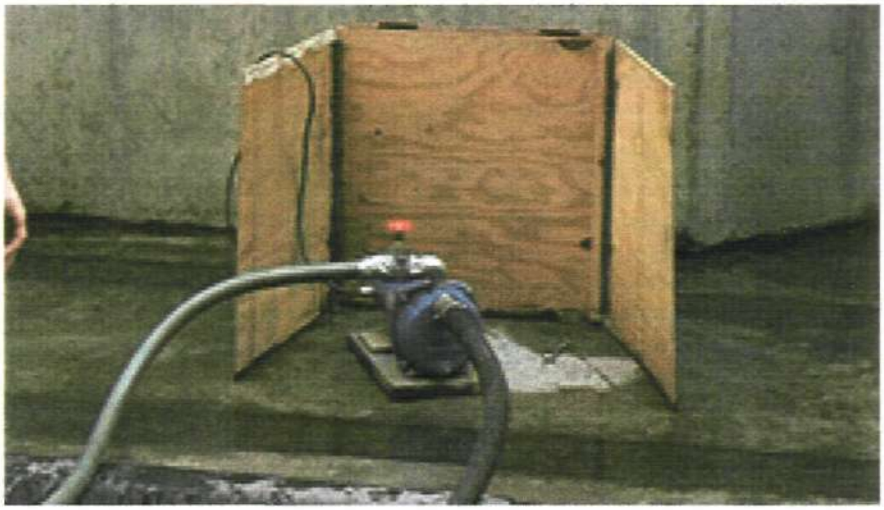


Figure 19. Electric, cast iron weir-box pump with suction and discharge hoses

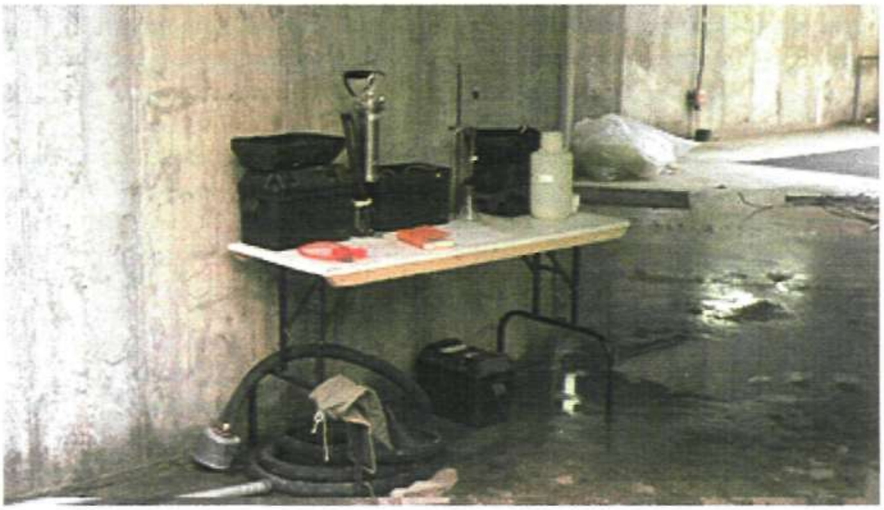


Figure 20. DO titration and saturation equipment for weir-box experiments

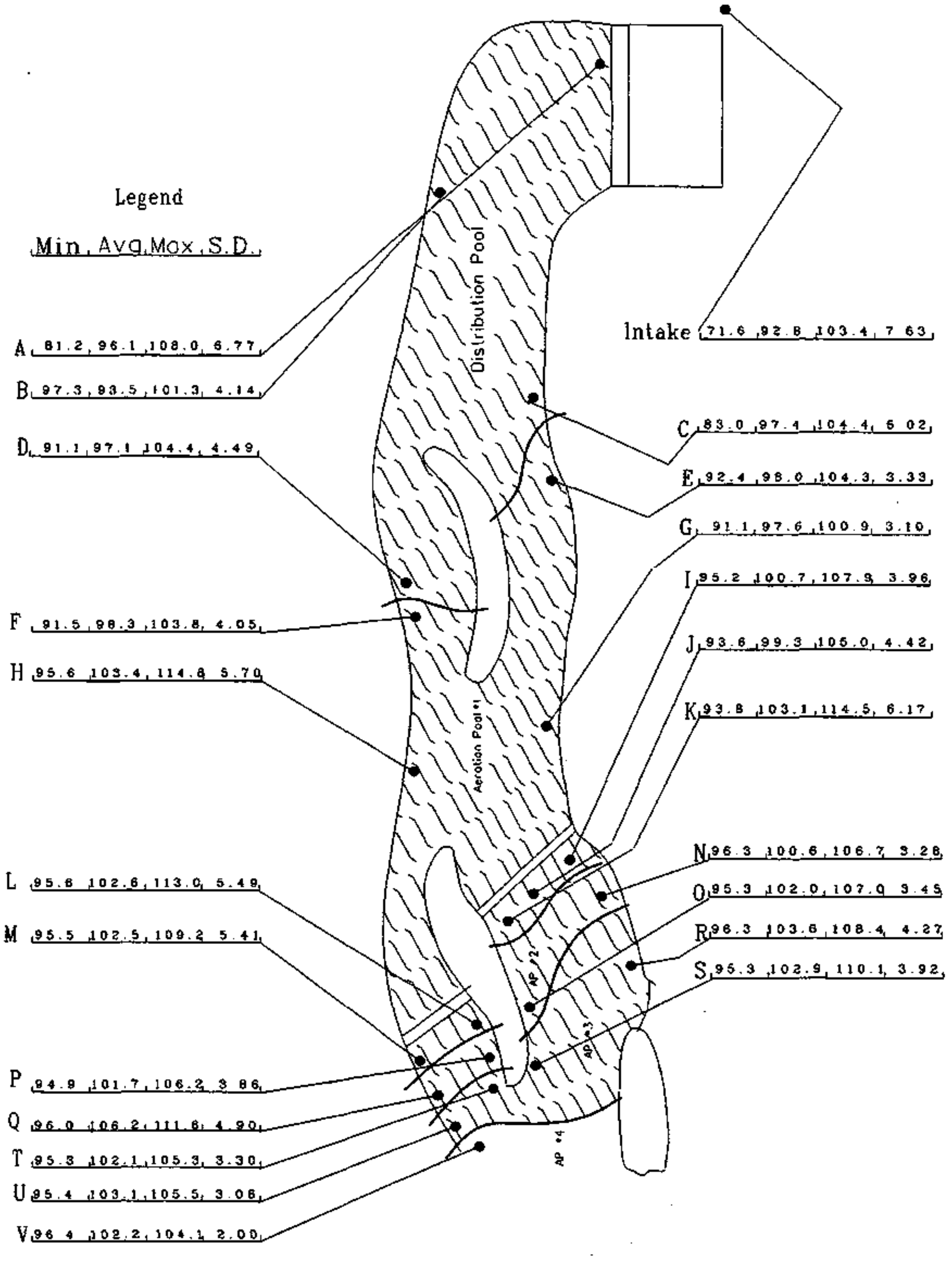


Figure 21. Statistical summary of DO percent saturation values recorded during manual measurements at SEPA 1

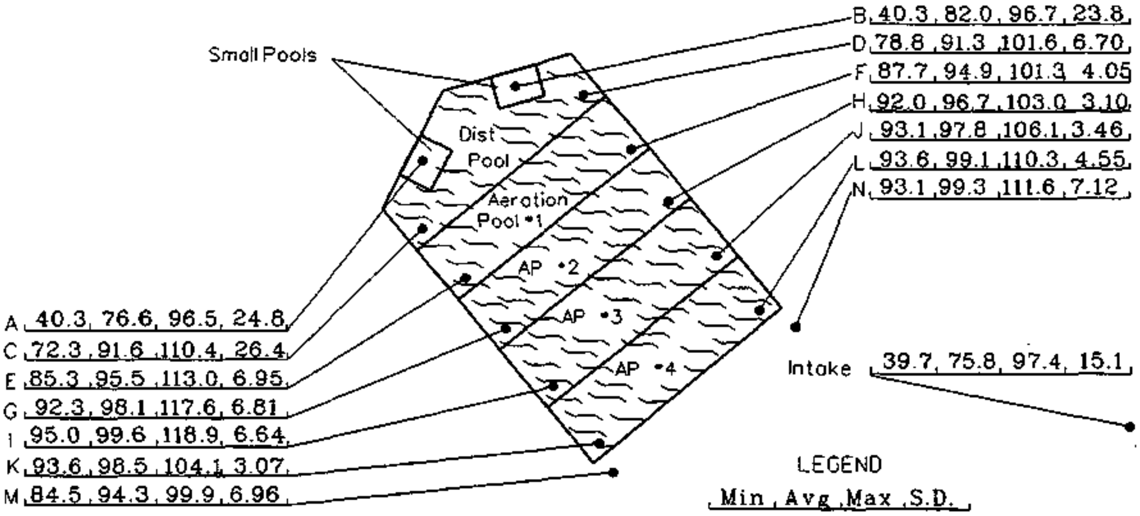


Figure 22. Statistical summary of DO percent saturation values recorded during manual measurements at SEPA 2

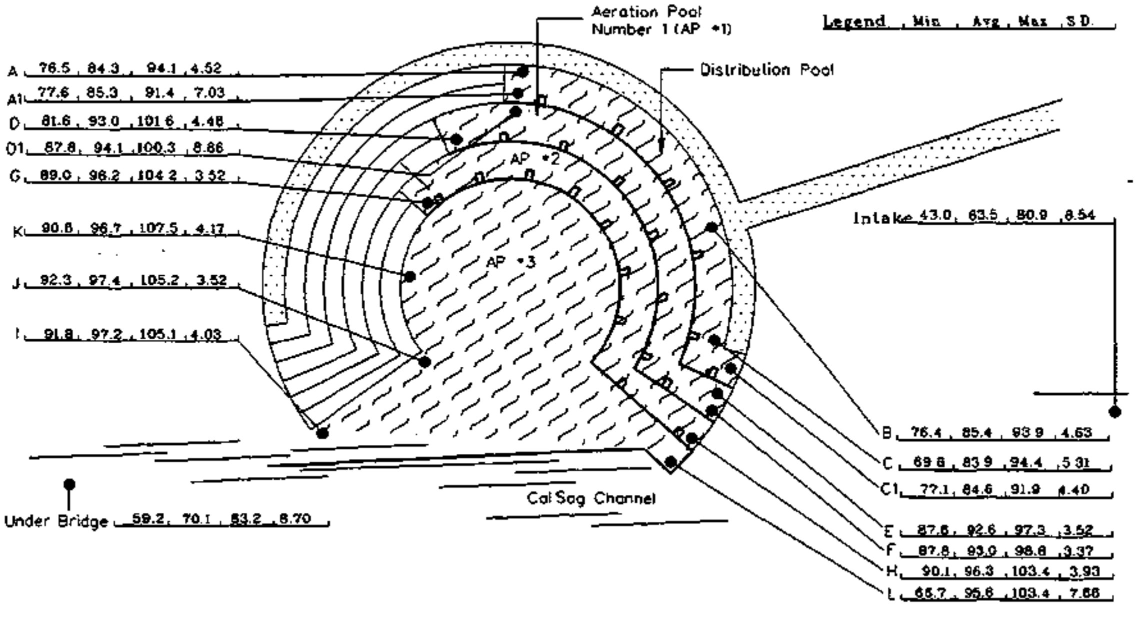


Figure 23. Statistical summary of DO percent saturation values recorded during manual measurements at SEPA 3

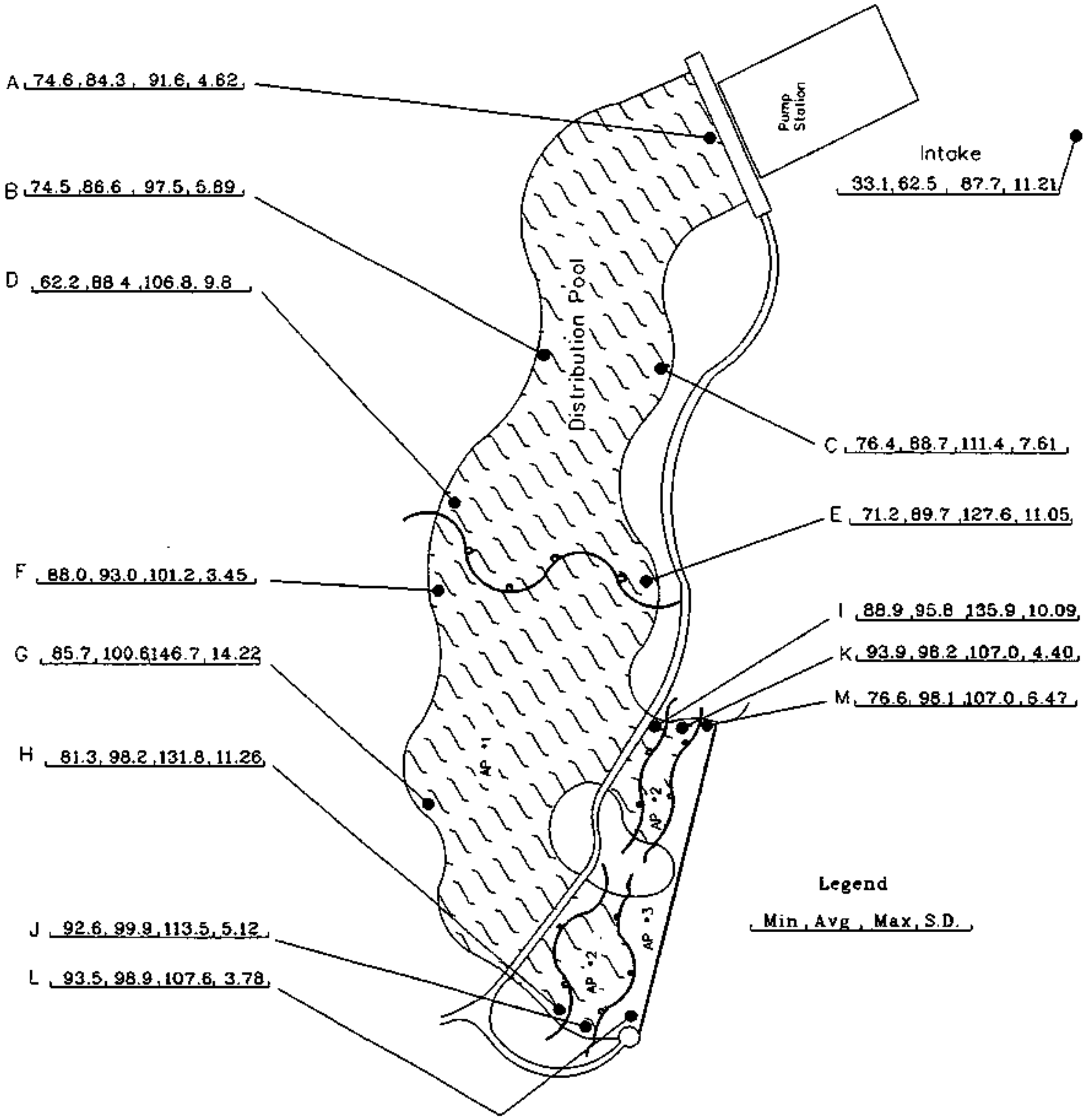


Figure 24. Statistical summary of DO percent saturation values recorded during manual measurements at SEPA 4

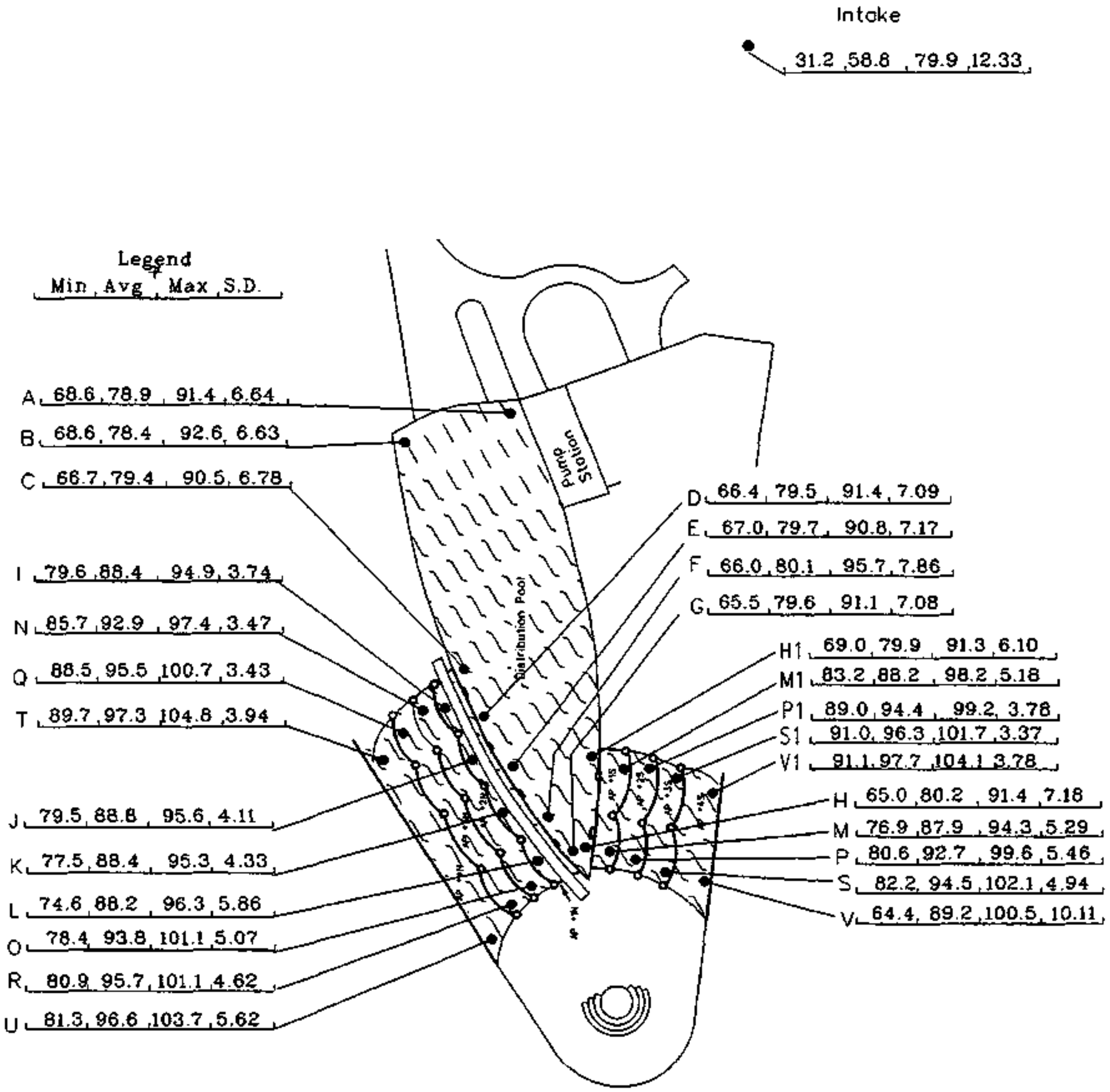
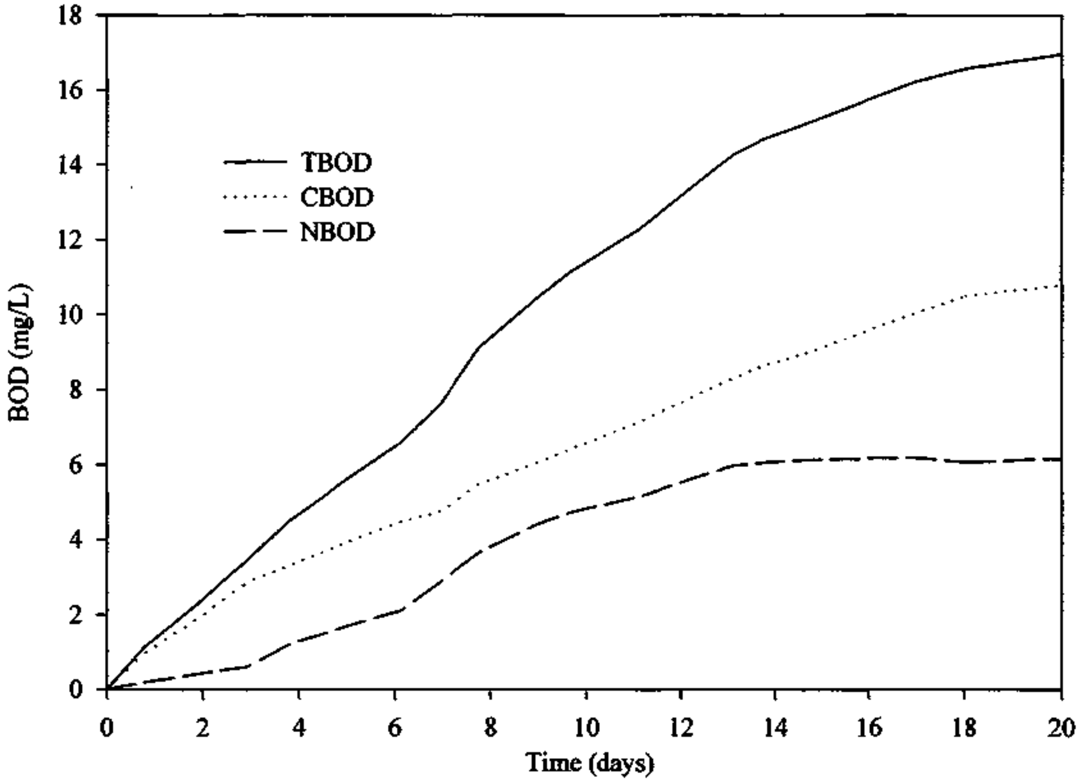


Figure 25. Statistical summary of DO percent saturation values recorded during manual measurements at SEPA 5

a. Beginning of Event



b. End of Event

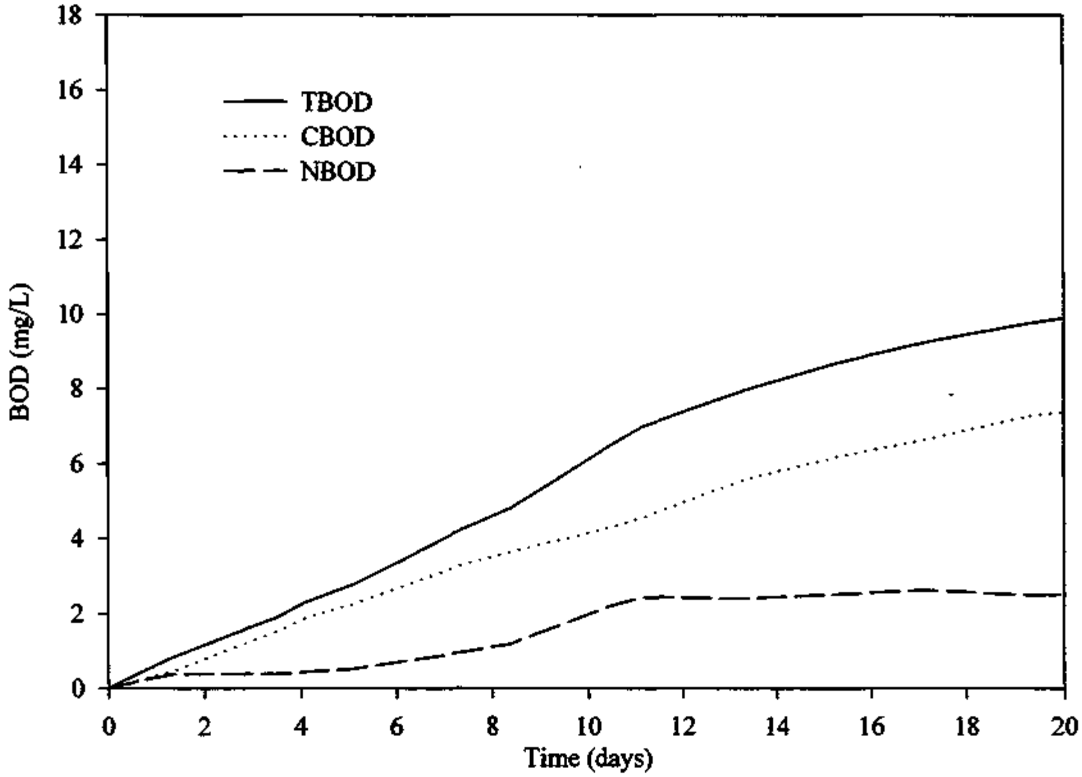
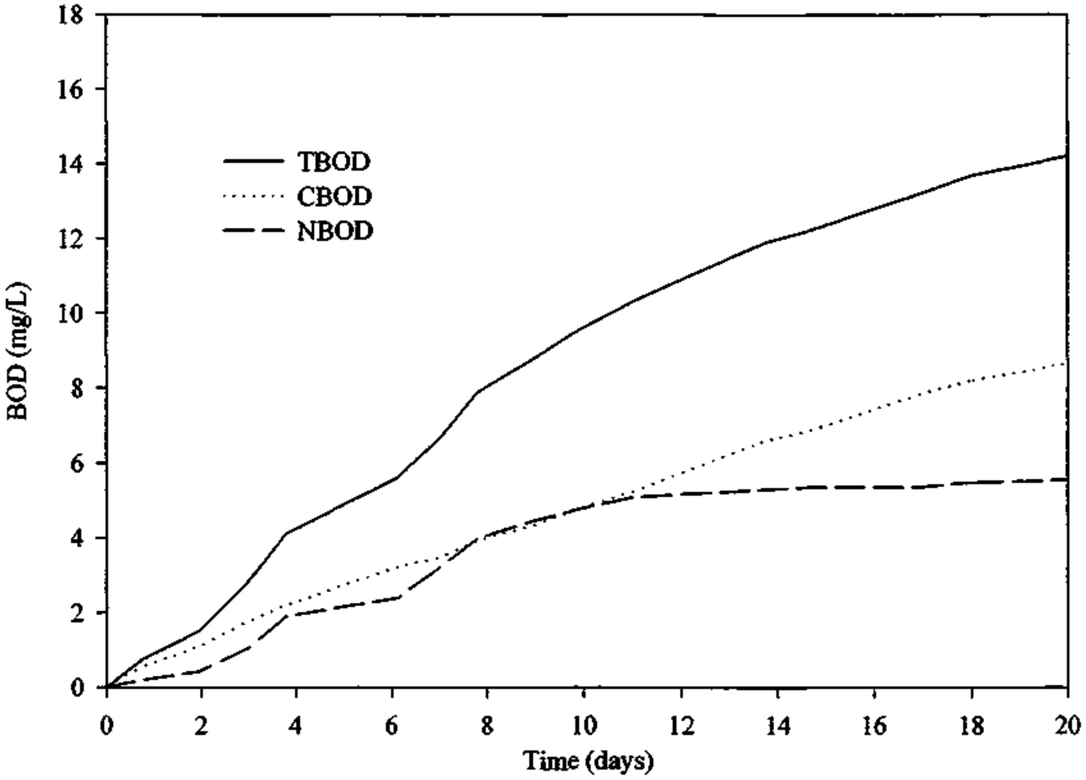


Figure 26. BOD at SEPA Station 4 intake at beginning and end of event 3

a. Beginning of Event



b. End of Event

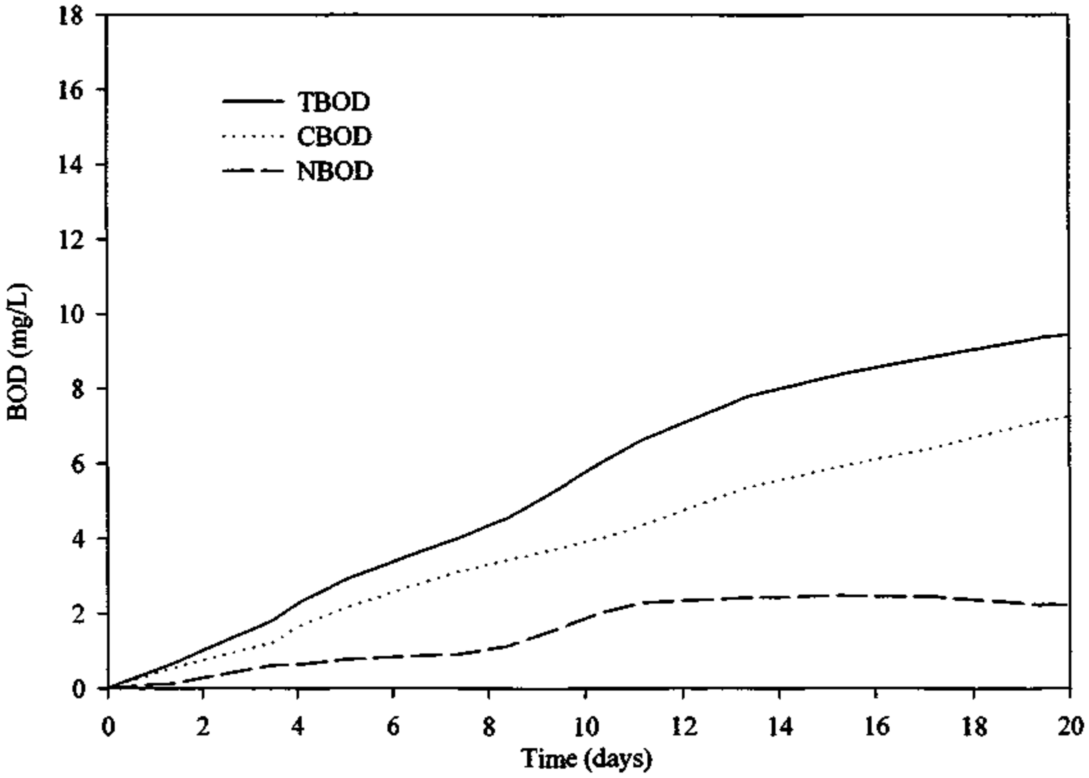


Figure 27. BOD at SEPA Station 4 outfall at beginning and end of event 3

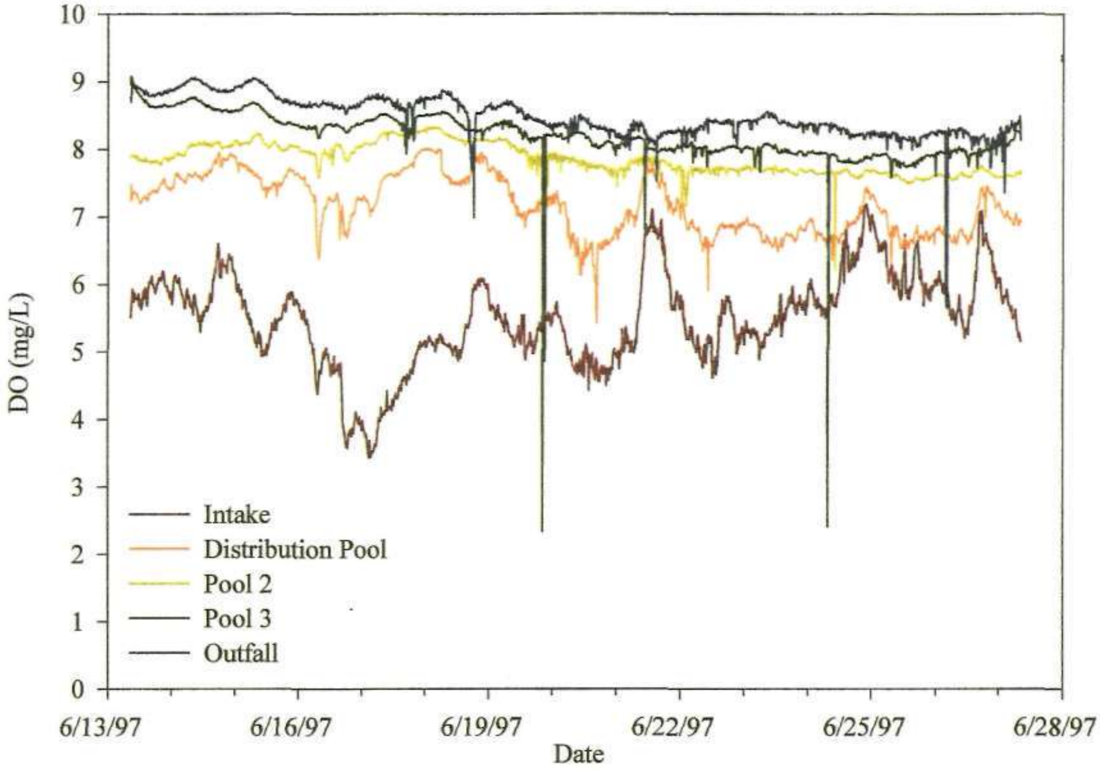


Figure 28. Continuous monitoring data showing DO concentration within SEPA Station 3 during June 1997

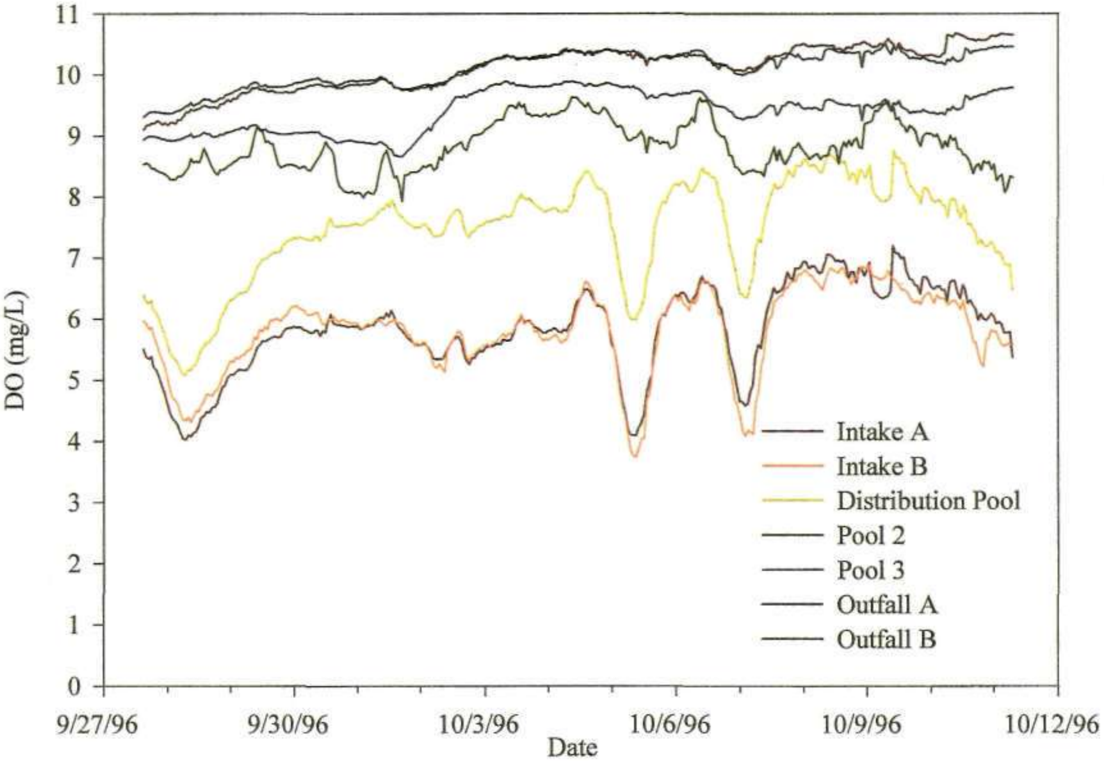


Figure 29. Continuous monitoring data showing DO concentration within SEPA Station 4 during October 1996

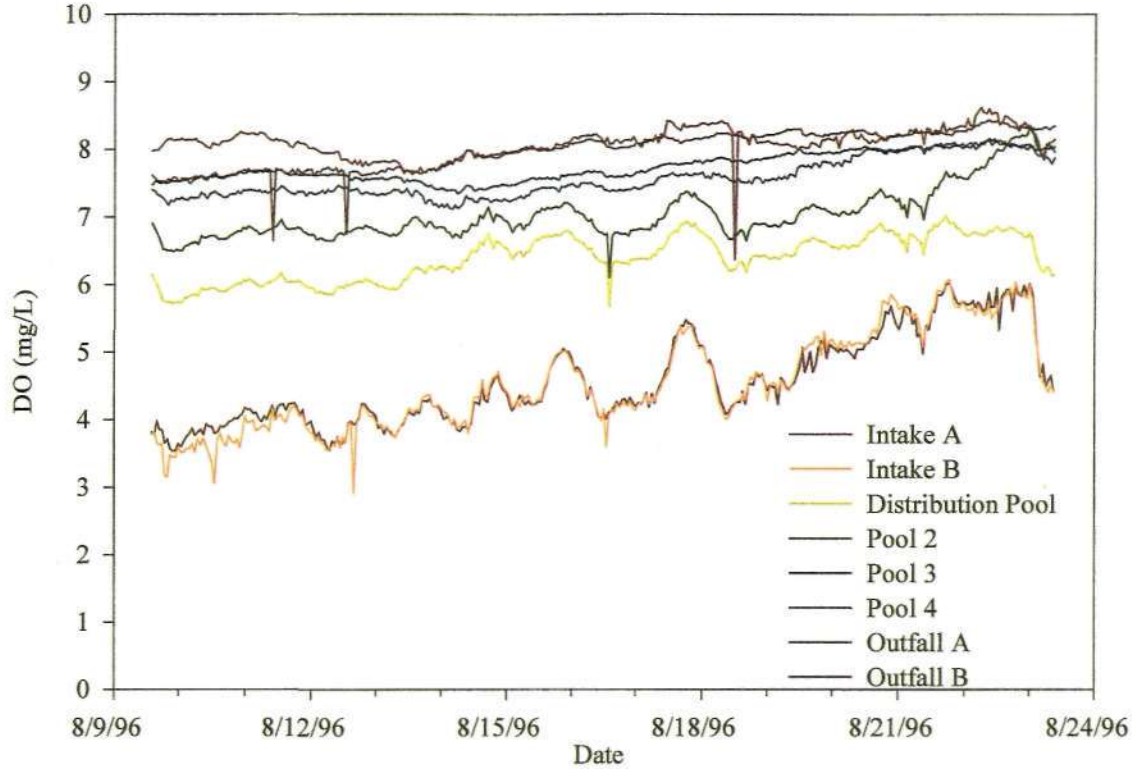


Figure 30. Continuous monitoring data showing DO concentrations within SEPA Station 5 for Cal-Sag Channel outfall weirs during August 1996

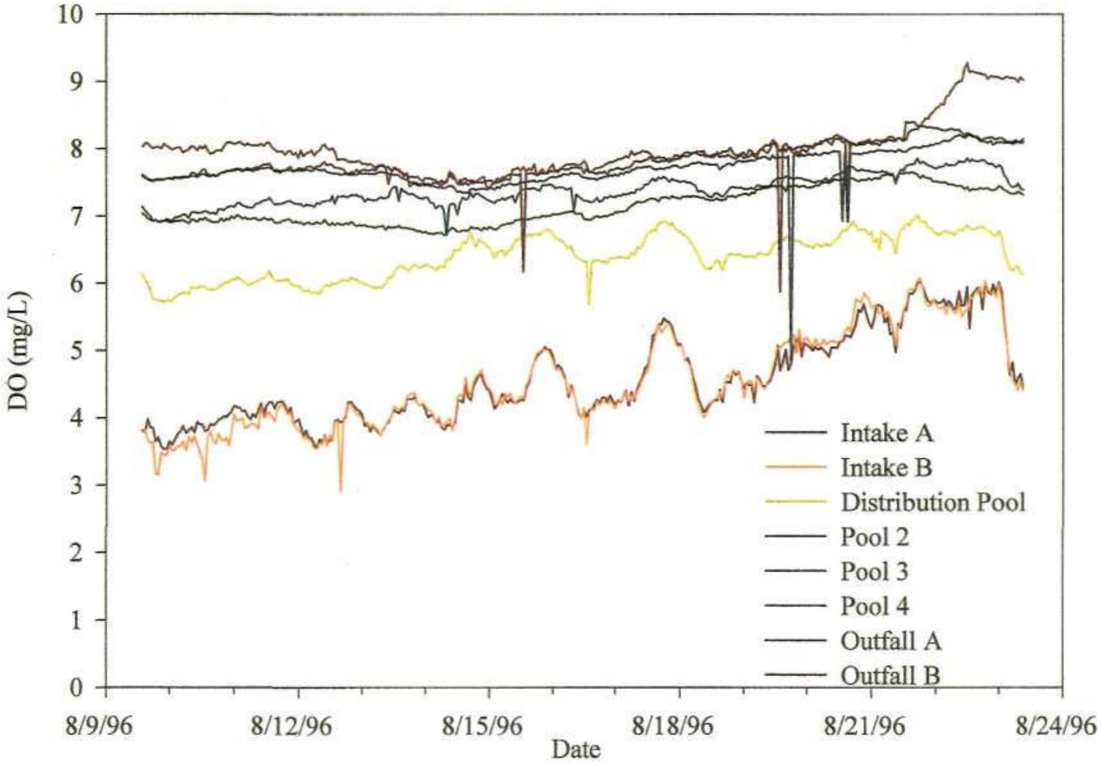


Figure 31. Continuous monitoring data showing DO concentrations within SEPA Station 5 for Chicago Sanitary and Ship Canal outfall weirs during August 1996

Figure 32. Sediment deposition in SEPA Station 4 distribution pool, spring 1996

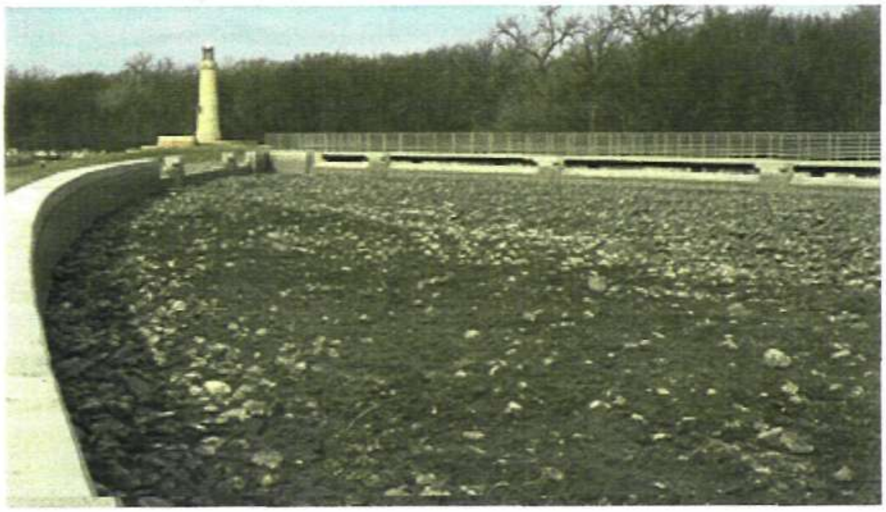


Figure 33. Sediment deposition in SEPA Station 5 distribution pool, spring 1996

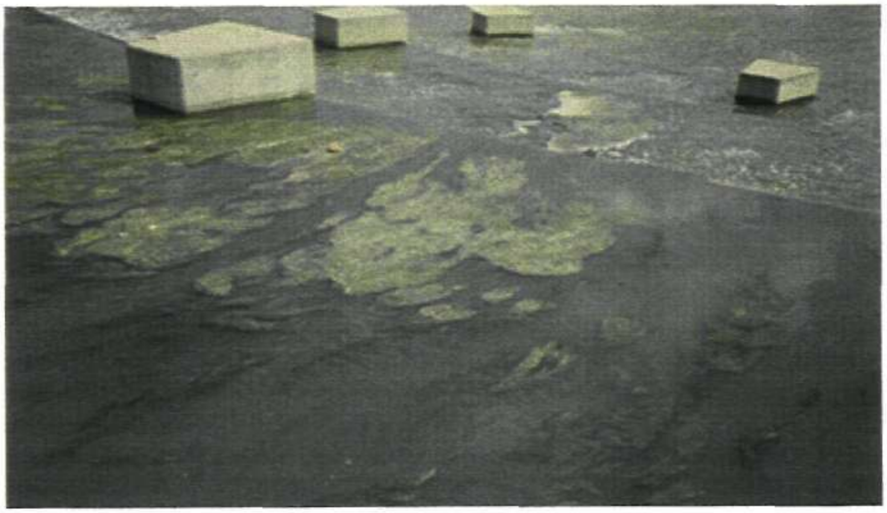


Figure 34. Filamentous algae and macrophyte growth in SEPA Station 3, summer 1996

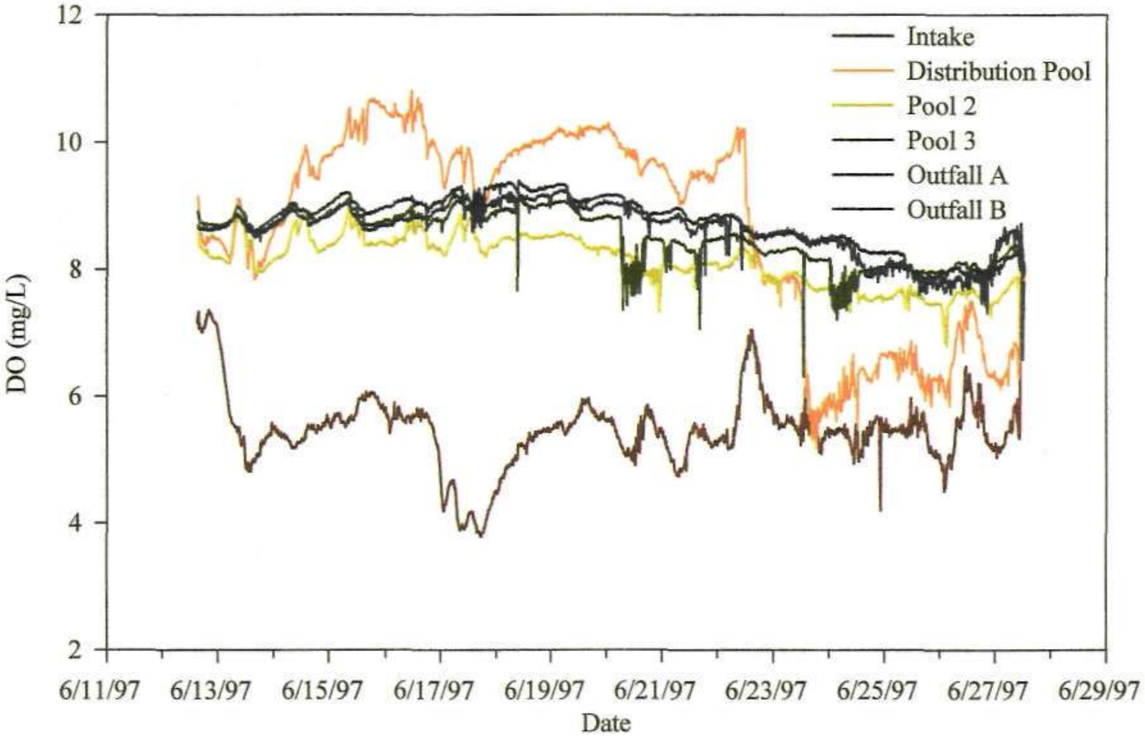


Figure 35. Continuous monitoring DO data showing the affects of photosynthesis in the distribution pool of SEPA Station 4 during June 1997

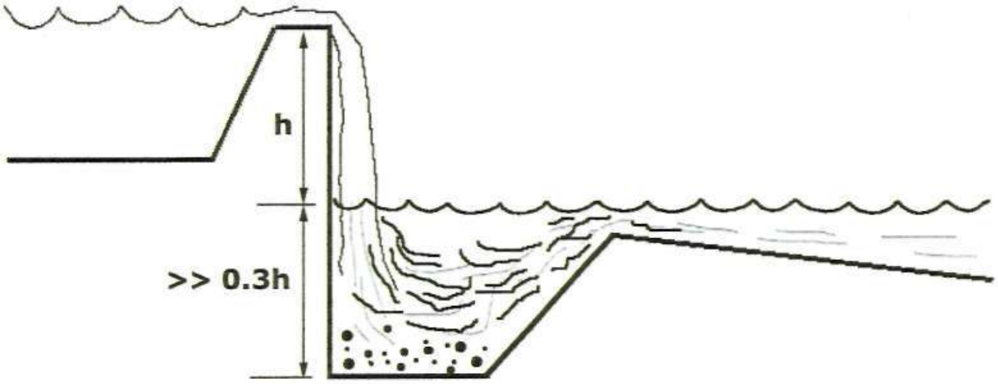


Figure 36. Proposed design of a sediment trap

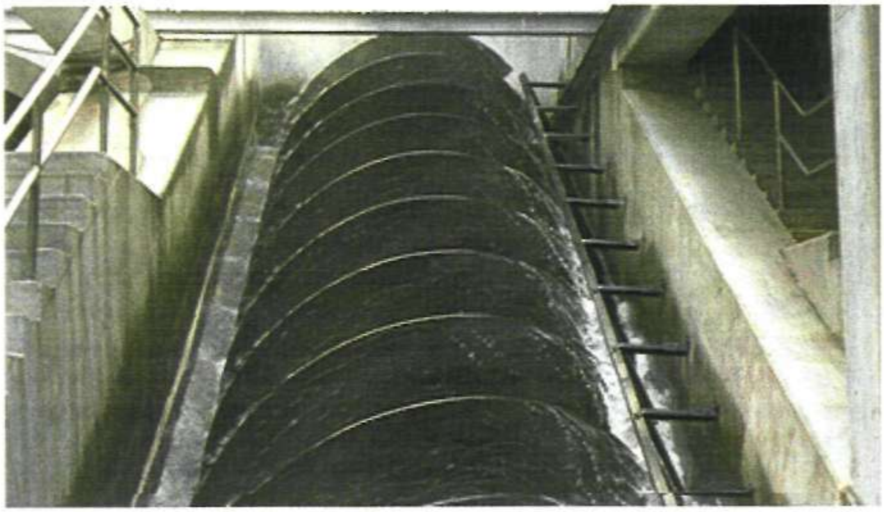


Figure 37. Typical screw pump used in SEPA stations

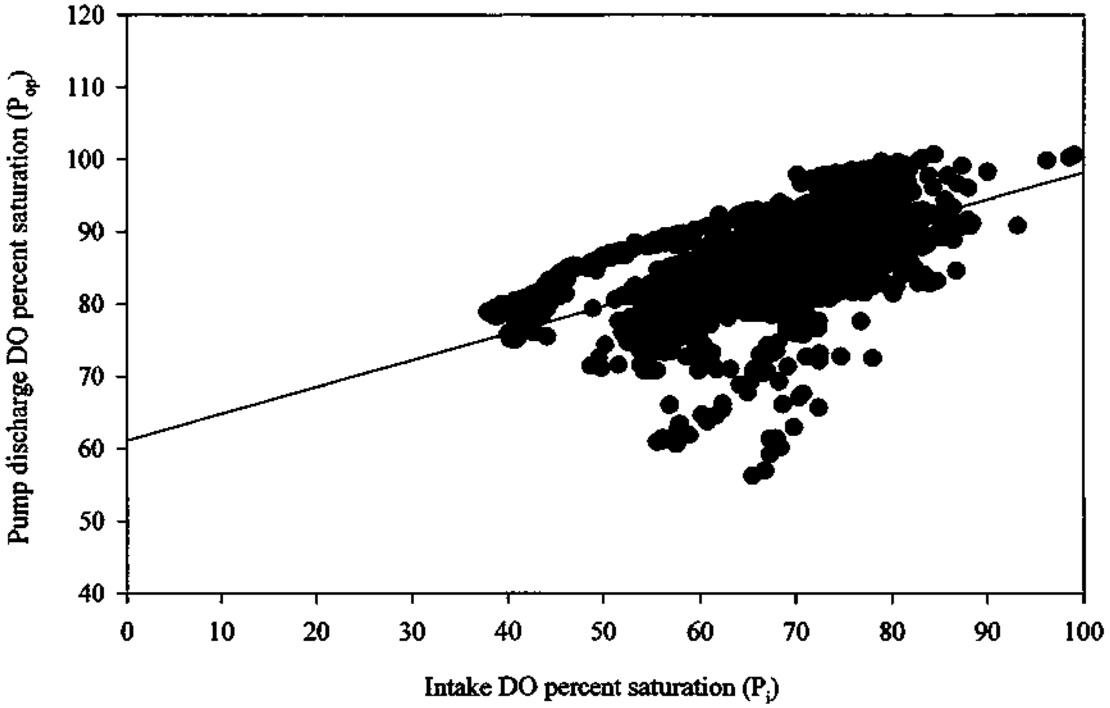


Figure 38. SEPA Station 3 15-foot screw pump reaeration correlation

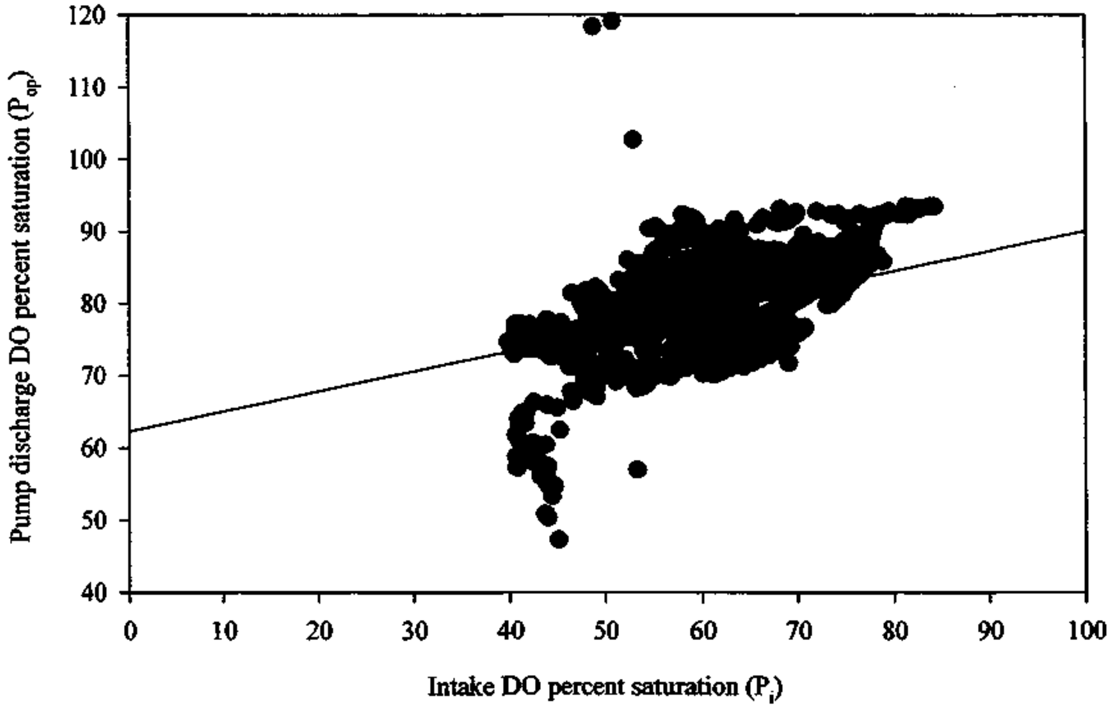


Figure 39. SEPA Station 5 12-foot screw pump reaeration correlation

Appendix A

YSI Model 6000UPS

Appendix A.
YSI Model 6000_{UFS}: Water Quality Monitor/Datalogger Specifications

General Specifications

- Medium: Fresh, sea, or polluted water
- Temperature: -5 to+45° C
- Computer interface: RS232, SDI-12
- Software: Works with a PC compatible with 3.5-inch or 5.25-inch high- or low-density floppy disks; 256K RAM minimum. Graphic card recommended.
- Depth: 0 to 500 feet
- Size 3.5-inch dia., 19.5-inch long, 6.5 pounds
- Internal logging memory: 256 kilobytes, 150,000 individual readings
- Power: 12VDC, 8 alkaline C cells; external 12VDC
- Battery life: 120 days; 90 days with DO; 45 days with DO and turbidity, at 15-minute logging intervals at 25° C

Typical Performance Specifications

	Specification			
Parameter	*Unit*	*Range*	*Resolution*	*Accuracy*
Dissolved oxygen	% Saturation	0 to 200	0.1	± 2%
Dissolved oxygen	mg/L	0 to 20	0.01	± 0.2 mg/L
Conductivity	mS/cm	0 to 100	0.01	± 0.5% +0.001 mS/cm
Temperature	° C	-5 to 45	0.01	± 0.15° C
PH	pH units	2 to 14	0.01	± 0.2
Salinity	ppt	0-70	0.01	greater of: ± 1%; 0.1 ppt
Turbidity	NTU	0-1000	0.1	greater of: ± 5%; 2 NTU

Notes: mS/cm = millisiemens/centimeter
ppt = parts per thousand
NTU = nephelometric turbidity units

Appendix A. (Continued)
YSI 6000_{UPG}: Water Quality Monitor/Datalogger:
Standard Operating Procedures

Presented are standard operating procedures (SOP) including quality assurance/quality control (QA/QC) procedures developed during this study for water quality monitor deployment. Although specifically referenced to the YSI 6000_{UPG} units, most of the information presented here is applicable to the DataSonde 1 and 3s and the YSI model 6920.

EQUIPMENT AND SUPPLY REQUIREMENTS

- IBM compatible PC
- DO Winkler kit
- Laboratory pH meter
- pH standard solutions
- Laboratory conductivity meter
- Conductivity standard solutions
- Temperature regulated water bath
- NIST-grade mercury thermometer
- Large water tank suitable for holding and submersing the maximum number of units expected to be deployed at one time.
- Voltmeter
- Razor knife
- 50x magnifying glass
- Log book, checklist, record sheets
- 5-gallon buckets
- Alcohol
- Cotton swabs
- Standard 1 mil DO membranes
- Saturated KC1 solution
- Size-C alkaline batteries (YSI 6000), size-D (DataSonde 1); size - AA (YSI 6920 and DS 3)
- Lightweight plastic wash tub
- Large scrub brush
- Small, soft-bristled scrub brush

PREPARATION FOR CALIBRATION

Approximately 45 minutes are required to prepare for the calibration of each instrument These procedures are to be performed at least 24 hours prior to actual calibration. A standard maintenance checklist is used to ensure quality and consistency over the course of a study.

The maintenance procedures include:

- Washing instrument exteriors using mild detergent or soapy water solution if necessary with large scrub brush
- Removing and cleaning probe guards
- Cleaning all probe exteriors with deionized (DI) water and/or alcohol if necessary
- Cleaning cable connection contacts
- Cleaning and lubricating all O-rings
- Cleaning conductivity electrodes with small, soft-bristled scrub brush
- Removing batteries from instrument compartment and cleaning compartment with compressed air
- Checking collectively, all eight batteries for minimum acceptable voltage
- Replacing all eight batteries if collective voltage is less than 10.5 V

Appendix A. (Continued)

- Testing voltage of all replacement batteries to ensure each has a minimum voltage of 1.5 V
- Replacing KC1 electrolyte and DO membranes
- Examining replaced membranes using a magnifying glass for tears, creases, holes, and air bubbles
- Installing clean probe guards with bottom open (i.e., bottom guard removed)
- Filling 5-gallon buckets with tap water for rinsing probes between calibration steps
- Draining and refilling holding tank with fresh tap water
- Immersing all instruments to be used vertically in holding tank.

CALIBRATION PROCEDURES

Prior to actual instrument calibration, calibration reagents are prepared; this requires 15 to 30 minutes of effort Approximately 75 minutes are required to calibrate each instrument. A standard calibration checklist and recording sheet is used to ensure quality and consistency over the course of the study.

Starting with the instrument submersed in a water-filled holding tank, the calibration procedure consists of:

- Removing units, as needed, from the holding tank and calibrating each probe (parameter) according to the procedures outlined in sections 3.1 (calibration tips) and 3.2 (calibration procedures) of the YSI *6000_{UPG} Multi-Parameter Water Quality Monitor Instruction Manual*, Endeco/YSI Incorporated, Environmental Monitoring Systems, 13 Atlantis Drive, Marion MA 02738, pp 3-1 through 3-8.
- Calibrating all monitors using a common batch of calibration reagents. However, difficult calibrations for a given parameter may be encountered. Try overcoming such occurrences by preparing and using a new set of reagents for that parameter.
- Running the monitor diagnostic function (following calibration) using YSI's PC 6000 software and recording the cell constant, DO gain, and DO charge. Acceptable ranges for these parameters are:

cell constant	5.0 + 0.4
DO gain	0.5 to 2.0
DO charge	25.0 to 75.0

This information is used to assess the quality of the calibration and whether the probes are functioning properly.

- Returning the monitor to the holding tank with it set to record parametric readings at five-minute intervals over a 15-minute period. Commensurate independent readings of DO, pH, temperature, conductivity, and, in some instances, turbidity are taken to determine if the instrument readings meet specifications. Also, these readings are to be used later in QA/QC computations to correct for instrument drift and probe fouling in the field. The independent readings are determined as follows:

DO	Winkler wet chemistry technique
pH	Orion lab pH meter
temperature	NIST grade mercury thermometer
conductivity	Labcraft lab conductivity meter
turbidity	Monitek nephelometer

The instrument parametric readings are viewed on the PC monitor screen as the independent readings are recorded.

- Setting the field data logging interval using the RUN menu in the YSI PC6000 software program when all calibration specifications are met
- Setting up a computer file for each instrument using no more than eight characters for identification.
- Labeling or identifying each unit using tape and an ink marker as to file location and/or in-stream deployment location.

- Leaving units submersed in holding tank until deployment from lab.

DEPLOYMENT FROM LAB

Approximately 60 minutes need to be allotted in the lab to prepare for transporting the instruments to the field. The units are fitted with two 3/8-inch soft-rubber collar-bushings secured with stainless-steel hose clamps, which act as protective shock absorbers during transportation and during in-stream deployment. The units are transported inside 6-inch, 30-inch long schedule 40 PVC tubes. Units are hung in the tubes from ½-inch hex-head bolts secured on the threaded sides with hitch pin clips and flat washers. The monitor probes should never be exposed to freezing conditions, and the units, as a whole, should never be directly exposed to the sun or other heated conditions when out of the water. During outdoor exposure to freezing conditions, the transport cups (a.k.a. DO calibration cups) should be filled with a saturated brine solution of common salt

To help maintain a moist environment, the calibration/transport cups are supplied with a small, thin piece of kitchen-type sponge which lays loose in the cup bottom. This arrangement is deficient in several aspects: because it is loose, it easily becomes lost or misplaced; because it is small, it readily dries out quickly; and because of the poor quality of material, it quickly deteriorates with use.

The factory-supplied loose-sponge method has been abandoned and replaced with a more voluminous and stable sponge insert. Circular pieces of ¼-inch thick rubber sponge have been cut to snugly fit into the bottom of the cup where it is glued with rubber cement On top of the sponge, ¼-inch thick Plexiglas rings with 2½-inch diameter center holes have been glued. The primary purpose of the rings is to provide free space between the sponge and the probe surfaces. This free space is needed as the bottom plate of the probe guards are not used. These protective plates restrict water movement past the probes and provide a media for undesirable biological film development in nutrient-rich water. The probe most vulnerable to in-stream damage, the DO probe, is protected by a ¼-inch wood-dowel rod spanning the diameter of the guard. An aluminum protective dowel was tried initially, but a transfer of electrons between the electrolyte in the probe cells and the metal set up galvanic activity, and deposits quickly built up along the metal rod.

Work tasks associated with the transfer of the monitors to the field include:

- Measuring DO, pH, conductivity, and temperature in the holding tank immediately before removal of the units. These measurements are for use later in performing QA/QC computations.
- Checking to ensure computer file identifications match the marked label on the monitor.
- Adding DI water to the transport cups until sponges are thoroughly saturated.
- Removing units from the tank and inserting cups over the probe guards and past the O-ring seals. The single mini set screws provided with each cup have all been removed and are not used during transport The screws tend to get lost during deployment, and the O-ring seal is more than sufficient to hold the cups in place.
- Inserting the monitors into the PVC transport tubes and carefully handling the tubes during movement from the lab to the transport vehicle.
- Maintaining a transport cup seal for a time period sufficient for the monitor to log at least four readings before in-stream placement Such measurements are useful in helping to trouble shoot "quirky or unusual" instrument malfunctions.

IN-STREAM PLACEMENT/RETRIEVAL

Tasks associated with field installing and removing of the monitors include:

- Removing the monitors from the transport shrouds when appropriate, and removing the transport (calibration) cups from the units when appropriate. At some installations, both the monitor and

Appendix A. (Concluded)

transport shroud are exchanged; for these situations, great care should be taken to remember to remove the transport cups.

- Taking water quality measurements for DO concentration, DO percent of saturation, temperature, pH, and conductivity at the in-stream monitor location before disturbing and/or removing in-place units. If an in-place unit is within ten minutes of a recording sequence, do not retrieve unit until the forthcoming measurement/recording has transpired. For insurance, allow a factor of safety of two to three minutes. These readings are for use later in performing QA/QC computations.
- Retrieving the in-place units, removing them from their protective shrouds, and inserting the replacement units into the shroud (or replacing the combined shroud/unit assembly when necessary). Inspect all pins, clips, and lines for wear and damage. Remove trash and biological growth from installation. Be sure safety line is attached directly to monitor wire handle.
- Returning units to the water being sure that the harness systems are free of entanglement and are stretched tight
- Taking water quality measurements reasonably close to the nearest scheduled unit recording time and recording time and date.
- Cleaning retrieved units with a scrub brush with water placed in the tub when in a boat or with water from a 5-gallon bucket when on shore. Care should be taken not to clean or disturb probes. Notes should be taken on general cleanliness of probes, including membrane integrity, periphytonic grown, and sediment deposition or accumulation.
- Placing the transport cup over the guard after making sure the cup sponge is moist Loose water should be removed from the cup to prevent accidental "cleaning" of the probes during handing and transport
- Placing monitors in protective shrouds and transporting them back to lab. Extremes in temperature should be avoided when staying over night in the field. During the summer, vehicles should be parked in the shade and left ventilated. During extreme freezing conditions, care should be taken to prevent the probes from freezing.

Notes: NIST = National Institute of Standards and Technology
DI = deionized water
PVC = polyvinyl chloride

Appendix B

DO/Temperature
Location/Measurement Recording Forms
and
SEPA Data Form

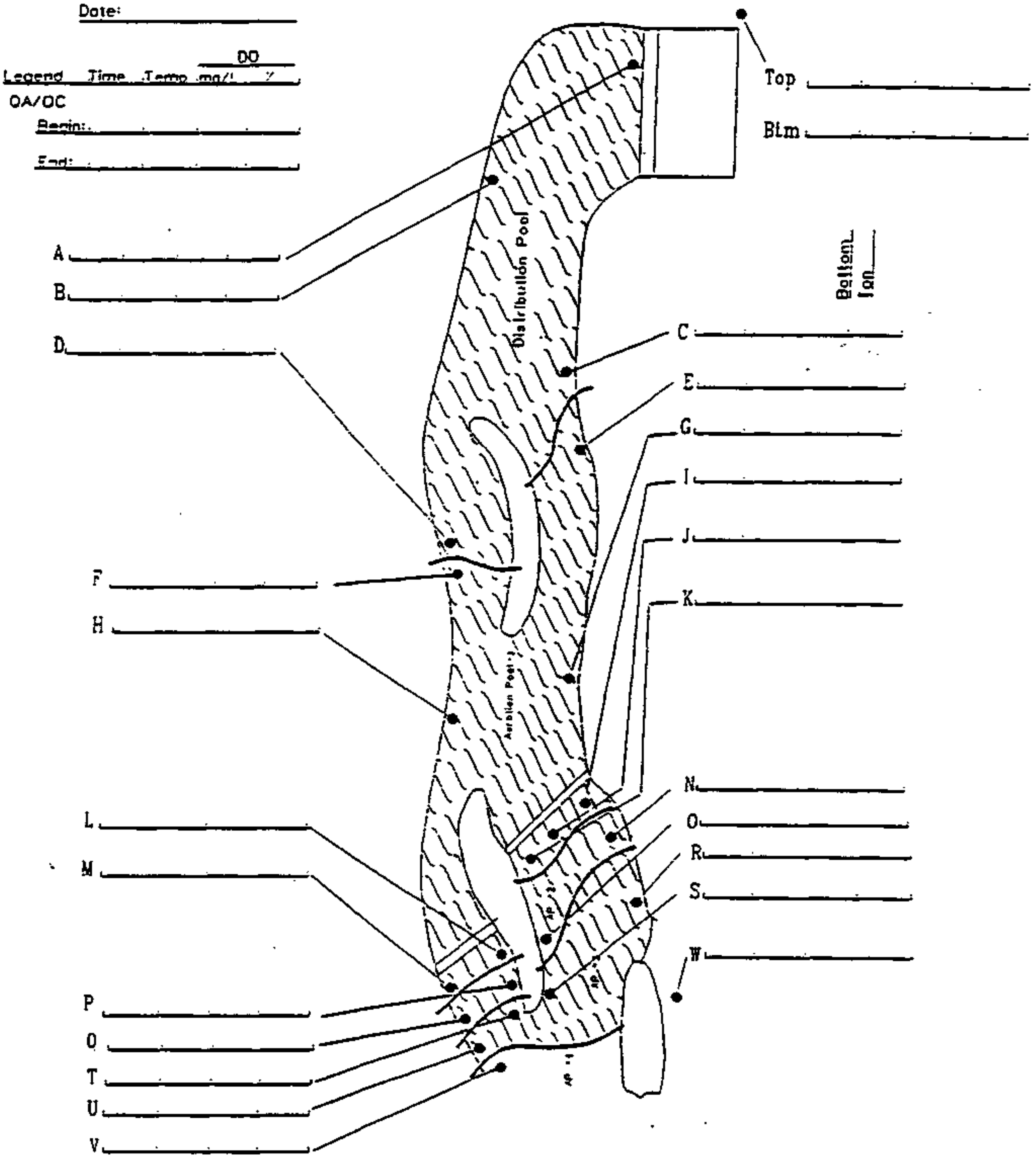
Date:

Legend Time Temp DO mg/l %

QA/QC

Begin:

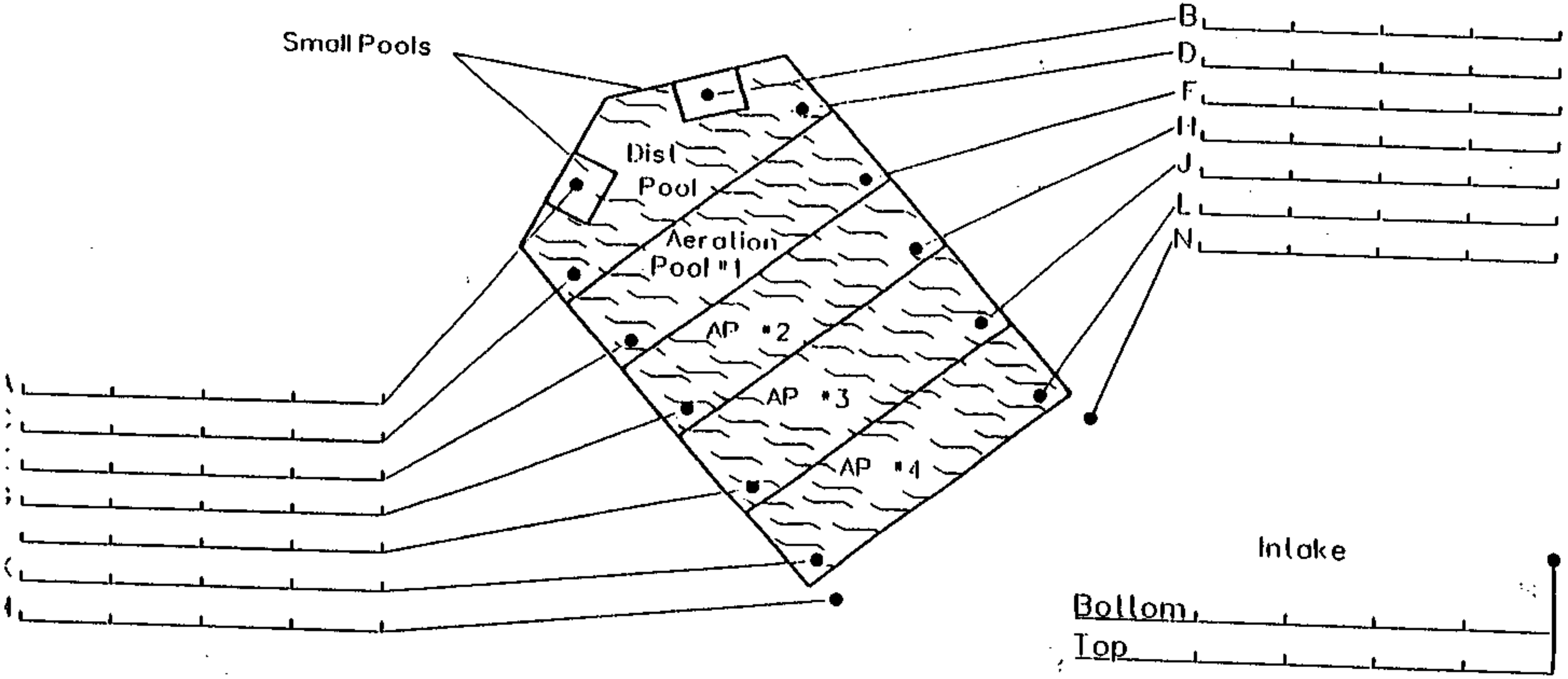
End:



SEPA Station 1

Date: ____________________

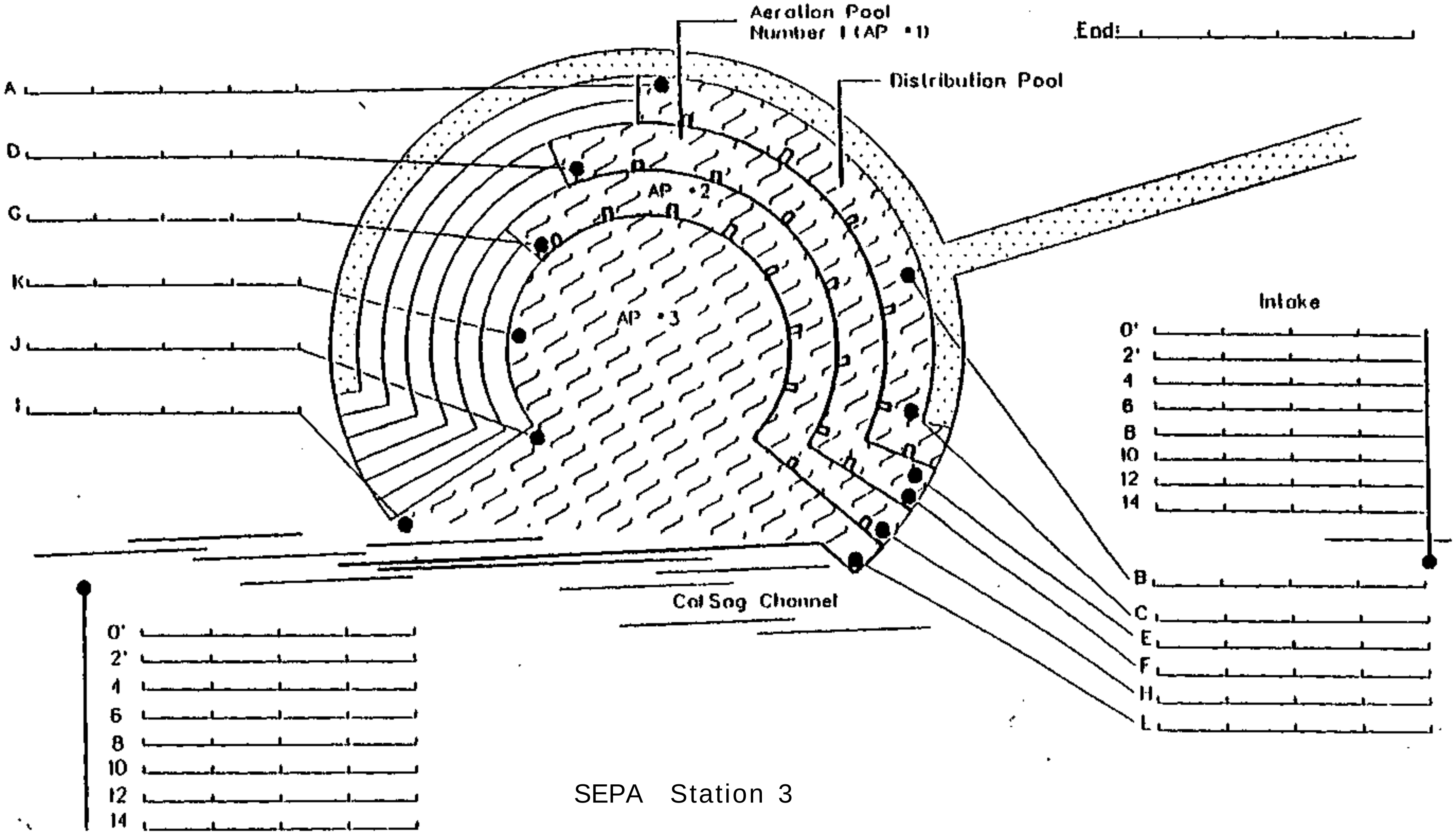
			DO	
Legend	Time	Temp	mg/L	%
QA/QC				
Begin:				
End:				



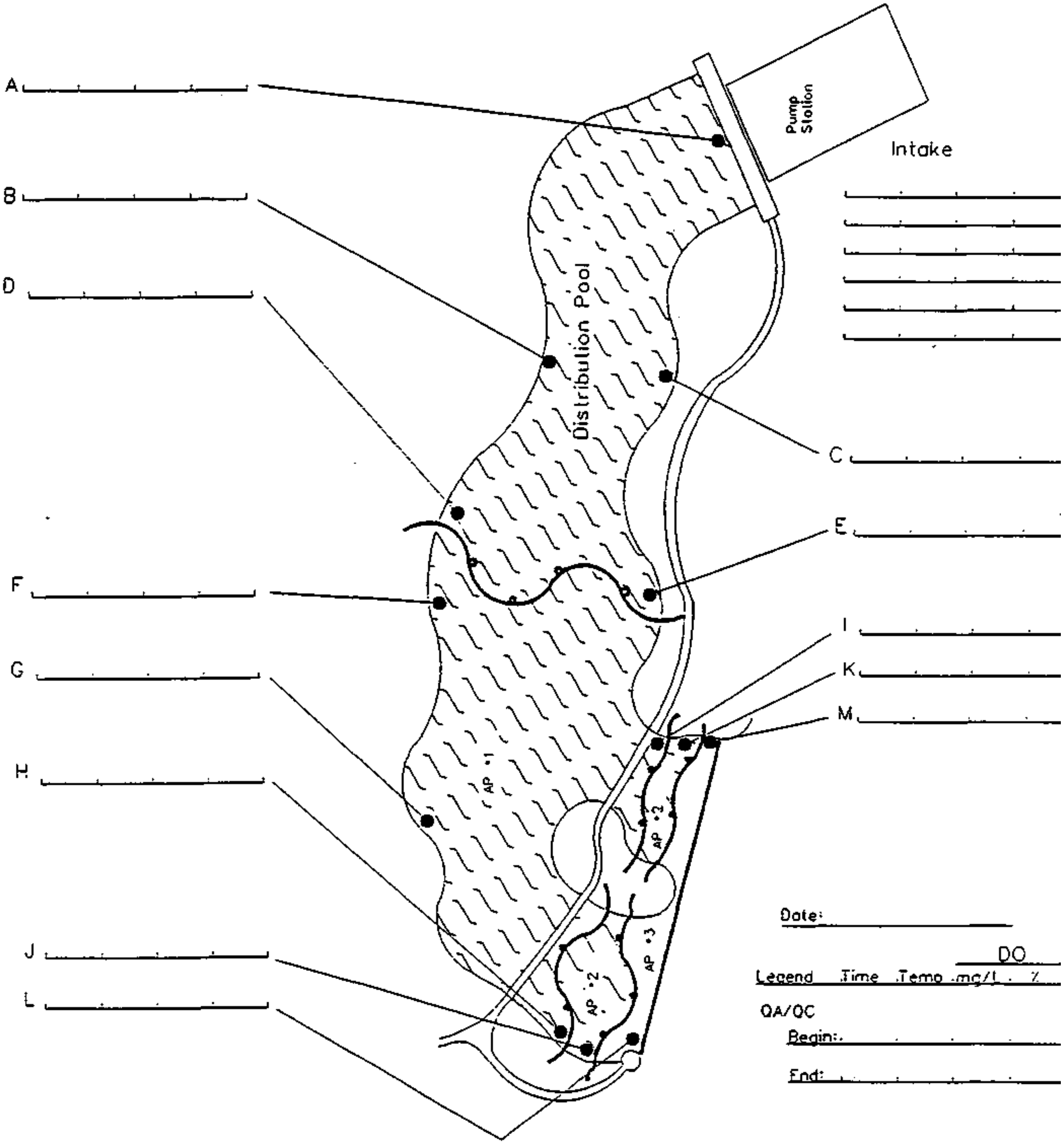
SEPA Station 2

Date: ______________

			DO	
Legend	Time	Temp	mg/L	%
QA/QC				
Begin:				
End:				



SEPA Station 3



SEPA Station 4

Date:

DO

Legend Time Temp mg/l %

QA/QC

Begin:

End:

Intake

0'

2

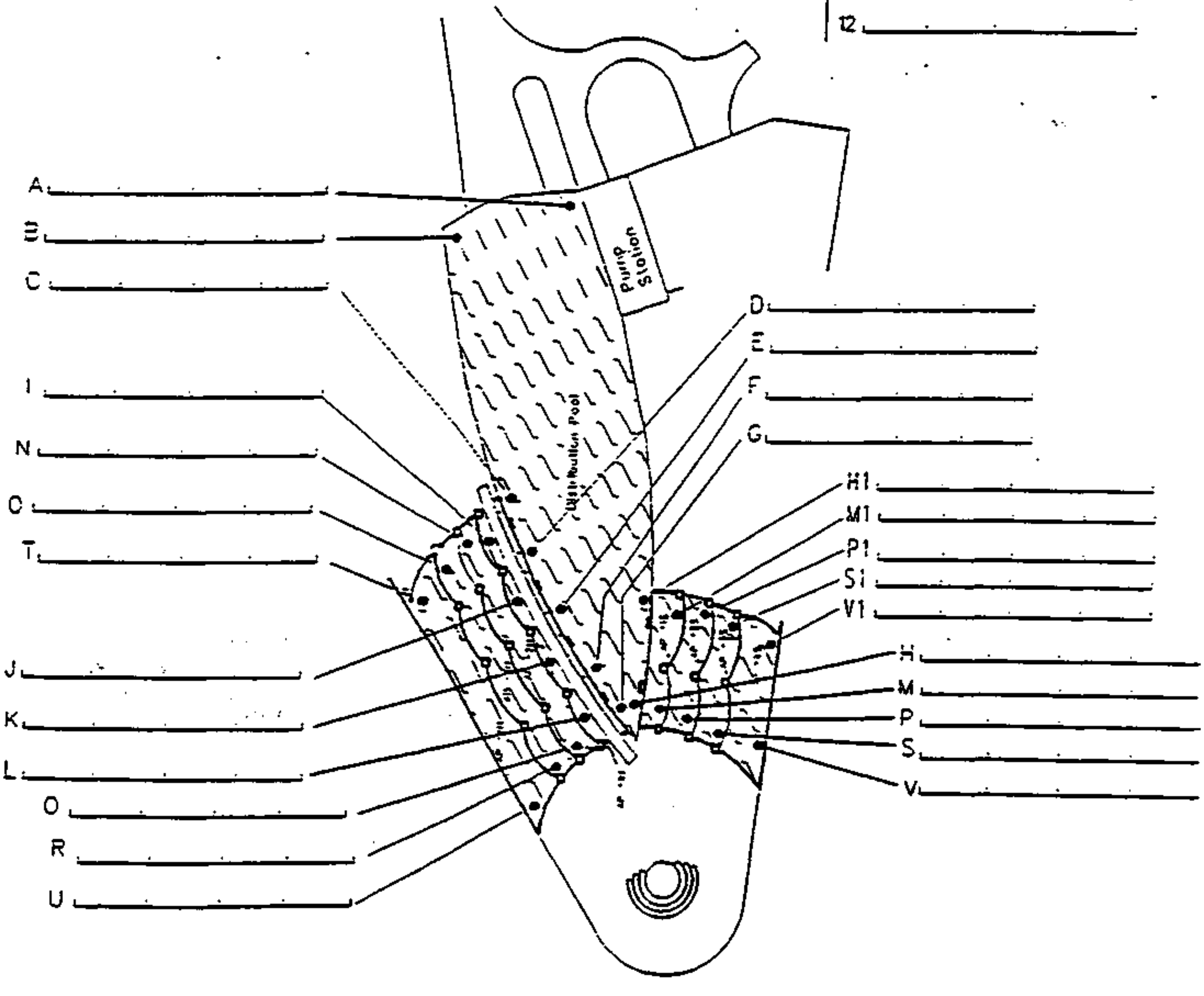
4

6

8

10

12



SEPA Station 5

Appendix B. (concluded)

SEPA Data Recording Form

SEPA Station No. ____________

Technician Name ____________

									Aeration Box - Dissolved Oxygen							
					DO Saturation				*Inlet*				*Outlet*			
						DO Conc.				*DO Conc.*				*DO Conc.*		
Date	*Pump Setting Run*	*No. SEPA Pumps*	*Nitrogen Sample Time*	*Time*	*Temp*	*1*	*2*	*3*	*Temp*	*1*	*2*	*3*	*Temp*	*1*	*2*	*3*
	1															
	2															
	3															
	4															
	Complete Shutdown for removal of monitors															

Appendix C

SEPA DO Saturation
and Weir-box Aeration Experimental Data

Appendix C. SEPA Station 3 DO Saturation and Weir-box Aeration Experimental Data

			DO saturation test results			Weir-box aeration results										
						Intake			Outfall			Average DO results (mg/L)				
			Temp	DO (mg/L)		Temp	DO (mg/L)		Temp	DO (mg/L)						
Event	Date	Time	(° C)	1	2	(° C)	1	2	(° C)	1	2	Sat	In	Out	r	a
1	08/12/96	1200	23.5	8.10	8.10	24.0	5.00	5.00	24.0	6.70	6.70	8.10	5.00	6.70	2.21	0.54
	08/14	0900	24.0	8.00	8.00	24.5	4.40	4.40	24.5	6.40	6.40	8.00	4.40	6.45	2.32	0.58
	08/16	0840	23.0	8.20	8.40	24.5	4.60	4.50	24.5	6.70	6.60	8.30	4.55	6.65	2.27	0.57
	08/19	0840	25.0	7.90	7.90	24.5	5.60	5.60	24.0	6.90	7.00	7.90	5.60	6.95	2.42	0.61
	08/23	0840	24.0	7.90	8.10	25.0	5.30	5.30	25.0	6.70	6.80	8.00	5.30	6.75	2.16	0.51
2	09/30	0815	18.0	9.20	9.20	18.5	5.70	5.80	18.5	7.60	7.60	9.20	5.75	7.60	2.16	0.58
	10/02	0820	20.0	8.80	8.80	19.5	5.70	5.80	19.5	7.30	7.40	8.80	5.75	7.35	2.10	0.53
	10/04	0815	16.0	9.80	9.80	18.0	5.90	5.80	18.0	7.70	7.60	9.80	5.85	7.65	1.84	0.44
	10/07	0725	16.5	9.40	9.50	18.5	6.50	6.50	18.5	7.60	7.70	9.45	6.50	7.65	1.64	033
	10/09	0815	14.0	9.90	9.90	17.0	6.10	6.10	17.0	7.80	7.90	9.90	6.10	7.85	1.85	0.48
	10/11	0715	13.0	9.90	10.00	16.0	5.60	5.70	16.0	7.70	7.80	9.95	5.65	7.75	1.95	0.55
3	04/28/97	0830	13.5	9.90	10.00	13.1	6.40	6.30	13.1	8.10	8.10	9.95	6.35	8.10	1.95	0.54
	04/30	0820	15.5	9.30	9.30	15.0	6.20	6.20	15.0	7.90	7.90	9.30	6.20	7.90	2.21	0.65
	05/02	0830	15.0	9.30	9.30	14.5	5.40	5.40	14.5	7.50	7.60	930	5.40	7.55	2.23	0.67
	05/05	0845	14.5	9.50	9.40	14.0	6.80	6.80	14.0	8.20	8.10	9.45	6.80	8.15	2.04	0.57
	05/07	0855	17.0	9.00	9.00	15.0	6.00	6.00	15.0	7.90	7.80	9.00	6.00	7.85	2.61	0.83
4	06/27	1015	24.0	8.17	8.11	24.0	4.60	4.68	24.0	6.60	6.69	8.14	4.64	6.68	2.39	0.61
														Average	2.14	0.56

Notes: r = deficit ratio defined by equation 1
a = water quality factor computed by equation 4
h = 1.26 meters (equation 4)
b = 1.0 (equation 4)

Appendix C. SEPA Station 4 DO Saturation and Weir-box Aeration Experimental Data

			DO saturation test results			*Weir-box aeration results*						*Average DO results (mg/L)*				
						Intake			*Outfall*							
			Temp (° C)	*DO (mg/L)*		*Temp (° C)*	*DO (mg/L)*		*Temp (° C)*	*DO (mg/L)*						
Event	*Date*	Time		*1*	*2*		*1*	*2*		*1*	*2*	*Sat*	*In*	*Out*	r	*a*
1	08/12/96	1040	23.5	8.20	8.00	24.0	4.10	4.00	24.0	6.10	6.20	8.10	4.05	6.15	2.08	0.47
	08/14	0905	24.0	7.90	7.70	25.0	4.30	4.20	25.0	6.50	6.40	7.80	1.25	6.45	2.63	0.71
	08/16	0850	24.0	7.80	7.80	25.0	5.40	5.40	24.5	7.00	6.90	7.80	5.40	6.95	2.82	0.79
	08/19	0850	24.0	8.00	7.80	24.3	5.00	5.00	24.3	6.60	6.60	7.90	5.00	6.60	2.23	0.53
	08/21	0850	25.5	8.20	8.00	25.5	4.90	5.10	25.5	6.60	6.70	8.10	5.00	6.65	2.14	0.48
	08/23	0845	25.5	8.10	8.00	26.0	4.80	4.80	26.0	6.60	6.60	8.05	4.80	6.60	2.24	0.52
2	09/30	0900	17.5	9.60	9.50	18.5	5.70	5.70	17.0	7.60	7.60	9.55	5.70	7.60	1.97	0.49
	10/02	0845	19.5	8.90	9.00	19.5	5.00	5.00	19.5	7.10	7.20	8.95	5.00	7.15	2.19	0.58
	10/04	0835	17.5	9.80	9.90	18.0	5.40	5.50	18.0	7.50	7.40	9.85	5.45	7.45	1.83	0.42
	10/07	0845	17.0	9.60	9.40	17.5	5.70	5.80	17.5	7.60	7.60	9.50	5.75	7.60	1.97	0.50
	10/09	0845	14.0	9.70	9.80	15.5	6.80	6.90	15.5	8.20	8.20	9.75	6.85	8.20	1.87	0.48
	10/11	0845	13.5	10.20	10.40	14.0	6.60	6.70	14.0	8.30	8.30	10.30	6.65	8.30	1.83	0.47
3	04/28/97	0845	13.0	9.80	10.00	13.5	6.80	6.80	13.5	8.60	8.50	9.90	6.80	8.55	2.30	0.74
	04/30	0915	14.5	9.50	9.70	15.5	6.70	6.70	15.5	8.30	8.20	9.60	6.70	8.25	2.15	0.63
	05/02	0830	14.5	10.00	10.10	14.0	6.70	6.70	14.0	8.20	8.30	10.05	6.70	8.25	1.86	0.47
	05/05	0830	13.0	9.60	9.70	14.5	7.00	7.00	14.5	8.40	8.50	9.65	7.00	8.45	2.21	0.69
	05/07	1015	16.5	9.30	9.20	15.0	7.60	7.60	15.0	8.60	8.60	9.25	7.60	8.60	2.54	0.80
4	06/27	1036	245	7.80	8.00	24.5	5.15	5.10	24.5	6.60	6.70	7.97	5.18	6.63	2.09	0.47
														Average	2.16	0.57

Notes: r = deficit ratio defined by equation 1

a = water quality factor computed by equation 4

h = 1.27 meters (equation 4)

b = 1.0 (equation 4)

Appendix C. SEPA Station 5 DO Saturation and Weir-box Aeration Experimental Data

			DO saturation test results			*Weir-box aeration results*						*Average DO results (mg/L)*				
						Intake			*Outfall*							
			Temp (° C)	*DO (mg/L)*		*Temp (° C)*	*DO (mg/L)*		*Temp (° C)*	*DO (mg/L)*						
Event	*Date*	*Time*		*1*	*2*		*1*	*2*		*1*	*2*	*Sat*	*In*	*Out*	*r*	*a*
1	08/12/96	1030	25.0	7.90	8.10	25.0	3.70	3.60	25.0	6.20	6.40	8.00	3.65	6.30	2.56	0.66
	08/14	0835	24.5	8.00	7.90	25.0	4.30	4.30	25.0	6.50	6.60	7.95	4.30	6.55	2.61	0.69
	08/14	0745	23.5	8.20	8.10	25.0	4.40	4.40	25.0	6.50	6.50	8.15	4.40	6.50	2.27	0.56
	08/16	0740	23.0	8.30	8.30	25.0	4.60	4.60	25.0	6.70	6.70	8.30	4.60	6.70	2.31	0.58
	08/19	0900	25.0	8.10	7.90	25.0	4.60	4.40	25.0	6.50	6.40	8.00	4.50	6.45	2.26	0.53
	08/23	0725	25.5	8.00	8.00	26.0	4.10	4.10	26.0	6.40	6.40	8.00	4.10	6.40	2.44	0.60
2	09/30	0705	15.0	9.80	9.70	17.0	4.30	4.30	17.0	7.30	7.50	9.75	4.30	7.40	2.32	0.71
	10/02	0845	18.0	9.00	8.90	18.5	5.70	5.80	18.5	7.50	7.60	8.95	5.75	7.55	2.29	0.64
	10/04	0700	14.5	10.00	10.00	17.5	5.10	5.20	17.5	7.50	7.60	10.00	5.15	7.55	1.98	0.54
	10/07	0845	16.0	9.10	9.20	18.0	5.20	5.10	18.0	7.20	7.20	9.15	5.15	7.20	2.05	0.55
	10/09	0815	14.5	9.40	9.30	15.5	6.30	6.20	15.5	8.00	7.90	9.35	6.25	7.95	2.21	0.67
	10/11	0840	14.5	9.90	9.80	15.0	6.20	6.20	15.0	8.00	8.10	9.85	6.20	8.05	2.03	0.56
3	04/28/97	0710	12.0	9.60	9.70	14.0	5.50	5.40	14.0	7.70	7.80	9.65	5.45	7.75	2.21	0.71
	04/30	0720	14.5	9.50	9.50	15.0	6.50	6.60	15.0	830	8.20	9.50	6.55	8.25	2.36	0.75
	05/02	0645	14.0	9.80	9.80	14.5	6.30	6.30	14.0	830	830	9.80	6.30	8.30	2.33	0.74
	05/05	0700	14.0	9.90	9.90	14.5	6.00	6.00	14.5	8.00	8.00	9.90	6.00	8.00	2.05	0.59
	05/07	0700	14.0	10.00	10.00	15.0	7.30	7.30	15.0	8.60	8.60	10.00	7.30	8.60	1.93	0.52
	05/09	0650	13.5	10.00	9.90	15.0	6.80	6.80	15.0	8.40	8.50	9.95	6.80	8.45	2.10	0.62
4	06/27	1130	26.0	8.00	8.20	26.0	4.90	4.80	26.0	8.40	6.50	9.97	4.90	6.47	2.04	0.43
													Average		2.13	0.65

Notes: r = deficit ratio defined by equation 1
a = water quality factor computed by equation 4
h = 1.27 meters (equation 4)
b = 1.0 (equation 4)

Appendix D

QA/QC Procedures for Continuous Monitor and DO/Temperature Meter Temperature Control

Appendix D. QA/QC Procedures for Continuous Monitor and DO/Temperature Meter Temperature Control

Prior to the initial deployment of each continuous monitor, basic mathematical statistical procedures are used to develop methodologies for accurately and precisely correcting the temperature readouts to National Institute of Standards Testing (NIST) referenced values. Three heating/cooling constant temperature water baths are available to use for finite control of water temperatures during calibration and QA/QC testing procedures. Each monitoring unit is evaluated using 110 separate temperature measurements between 14 and 34° C. This generates 110 sets of NIST-referenced, thermometer monitoring-unit (or DO/temperature meter) readings from which a linear regression equation is developed relating the NIST-thermometef reading to that of the monitoring unit, i.e.,

$$T_c = c + dT_o \quad (1)$$

where:

T_c = NIST thermometer reading in ° C
T_o = DataSonde temperature reading in ° C
c = Te-axis (y-axis) intercept in ° C
d = Slope of the regression line

The standard error of the estimate was derived using:

$$E = \sqrt{\frac{(T_{obs} - T_{comp})^2}{N-1}} \quad (2)$$

where:

E = standard error of estimate in ° C
T_{obs} = observed NIST thermometer reading in ° C
T_{comp} = temperature computed (T_c) using observed T_o in conjunction with equation 1
N = number of observations used to develop equation 1, i.e., normally

The regression coefficients (c and d) derived for each unit are used to correct the temperature readings. A 3E value was used for ascertaining if a unit was within quality control limits after its retrieval from use in the field.

The monitoring instruments retrieved from the field are returned to the lab for QA/QC testing. Three constant temperature baths are available that can be used for the QA/QC procedures in which temperatures are set at approximately 14, 24, and 34° C. The monitors are placed in a water bath, and NIST-calibrated thermometer readings are taken in concert with "real-time" D S temperatures viewed from a computer monitor.

A water quality monitor temperature probe is deemed "out of control" if the difference between the NIST reading and the monitor reading divided by 3E exceeded unity as represented by:

$$\frac{\text{NIST Reading - Monitor (or meter) reading}}{3E} > 1 \quad (3)$$

An ex post facto "out of control" situation is handled by recalibration, combining 110 sets of new data and the 110 old data sets to develop **a** new 220-set regression equation. This effectively averages the instrument drift over the life of its deployment

Appendix E

Biochemical Oxygen Demand Test Results

Appendix E. Biochemical Oxygen Demand Test Results for SEPA Stations

	SEPA station BOD (mg/L)																				
	3						*4*						*5*								
Time	*In*			*Out*			*In*			*Out*			*In*			*Out C*			*Out S*		
(days)	*T*	*C*	*N*	*T*	*C*	*N*	*T*	*C*	*N*	*T*	*C*	*N*	*T*	*C*	*N*	*T*	*C*	*N*	*T*	*C*	*N*
Event 1: 0 8/12/96																					
0.91	0.25	-	0.41	0.31	-	0.60	0.21	0.11	0.10	0.33	0.33	0.00	0.95	0.95	0.00	0.66	0.66	0.00	0.72	0.72	0.00
1.90	0.73	-	-	0.88	-	-	0.40	-	-	0.81	-	-	1.45	-	-	1.43	-	-	1.35	-	-
2.90	1.30	-	-	1.42	-	-	0.98	-	-	1.24	-	-	2.01	-	-	2.04	-	-	1.82	-	-
3.90	1.62	-	-	1.80	-	-	1.13	-	-	1.58	-	-	2.13	-	-	2.15	-	-	1.94	-	-
5.05	1.81	-	-	2.02	-	-	1.27	-	-	1.77	-	-	2.30	-	-	2.56	-	-	2.03	-	-
6.86	2.74	2.20	0.54	2.87	1.66	1.21	2.47	1.42	0.95	3.09	1.94	1.15	3.23	2.68	0.55	3.88	2.64	1.24	3.18	2.09	1.09
7.84	3.08	-	-	3.35	-	-	3.04	-	-	3.78	-	-	3.58	-	-	4.46	-	-	3.80	-	-
8.94	3.34	-	-	3.70	-	-	3.38	-	-	4.34	-	-	3.98	-	-	5.19	-	-	4.47	-	-
10.99	5.96	-	-	5.68	-	-	5.11	-	-	5.95	-	-	5.41	-	-	6.86	-	-	6.13	-	-
13.13	7.08	-	-	6.54	-	-	6.17	-	-	6.65	-	-	6.23	-	-	7.50	-	-	6.80	-	-
13.60	7.47	-	-	6.66	-	-	6.18	-	-	6.79	-	-	6.32	•	-	7.57	-	-	7.13	-	.
14.56	7.85	6.45	1.40	6.84	5.13	1.71	6.71	4.69	2.03	7.00	5.13	1.87	6.63	5.00	1.63	7.73	5.86	1.87	7.25	5.56	1.69
15.88	8.36	-	-	7.41	-	-	7.11	-	-	7.57	-	-	7.15	-	-	8.25	-	-	7.72	-	-
17.90	8.59	-	-	7.84	-	-	7.36	-	-	7.87	-	-	7.38	-	-	8.61	-	-	7.97	-	-
20.03	9.03	-	-	8.06	-	-	7.89	-	-	8.17	-	-	7.64	-	-	8.89	-	-	8.17	-	-
Event 1: 08/23/96																					
2.13	0.77	0.99	**0**	1.05	0.80	0.25	1.12	1.08	0.04	1.35	0.94	0.41	1.19	1.13	0.06	1.26	0.77	0.50	1.00	0.89	0.12
2.61	0.86	1.15	**0**	1.22	0.92	0.30	1.28	1.22	0.06	1.56	1.13	0.43	1.35	1.33	0.01	1.52	0.93	0.60	1.15	1.31	0.00
3.61	1.32	1.37	**0**	1.96	1.06	0.90	1.80	1.36	0.43	2.34	1.36	0.99	1.94	1.59	0.35	2.54	1.17	1.37	2.06	1.49	0.57
4.90	2.13	2.07	0.07	2.93	1.69	1.24	2.52	1.99	0.54	3.43	2.07	1.37	3.05	2.30	0.75	3.96	1.92	2.04	3.32	2.29	1.03
6.91	3.16	2.54	0.62	3.97	1.97	1.99	3.70	2.73	0.97	4.74	2.57	2.17	4.69	2.66	2.02	5.14	2.40	2.74	4.68	2.77	1.90
9.03	4.36	3.34	1.02	5.17	2.75	2.42	5.35	3.79	1.56	6.09	3.46	2.63	6.10	3.55	2.54	6.23	3.35	2.88	5.94	3.81	2.13
10.08	5.47	4.27	1.20	5.90	3.48	2.42	6.29	4.58	1.71	6.87	4.23	2.64	7.13	4.26	2.87	6.82	4.07	2.75	6.65	4.44	2.21
12.89	5.87	4.65	1.22	6.34	3.88	2.46	6.83	4.94	1.89	7.34	4.55	2.79	7.55	4.79	2.76	7.23	4.38	2.85	7.27	4.96	2.31
13.89	6.42	5.13	1.29	6.74	4.16	2.59	7.19	5.19	2.00	7.53	4.80	2.73	7.82	5.03	2.79	7.44	4.54	2.90	7.51	5.20	2.31
16.05	7.15	5.71	1.44	7.22	4.42	2.80	7.74	5.49	2.25	8.11	5.06	3.05	8.34	5.59	2.75	8.15	4.82	3.33	8.13	5.68	2.46
17.88	7.91	6.49	**1.41**	7.75	4.88	2.88	8.07	6.07	1.99	8.48	5.52	2.97	8.69	6.06	2.63	8.53	5.28	3.24	8.52	6.23	2.29
18.90	8.80	7.23	1.57	8.34	5.59	2.75	8.50	6.38	2.11	8.98	6.18	2.80	9.18	6.71	2.47	8.99	5.99	3.00	8.80	6.69	2.11
19.89	9.35	7.56	1.79	8.81	5.85	2.96	8.80	6.65	2.15	9.21	6.31	2.90	9.67	7.04	2.64	9.46	6.26	3.20	9.32	7.22	2.10

Appendix E. (Continued)

	SEPA station BOD (mg/L)																				
	3						*4*						*5*								
Time	*In*			*Out*			*In*			*Out*			*In*			*Out C*			Our S		
(days)	***T***	*C*	*N*	*T*	*C*	*N*	*T*	*C*	*N*	*T*	*C*	*N*	*T*	*C*	*N*	*T*	*C*	*N*	*T*	C	*N*
Event 2:09/30/96																					
1.03	0.30	0.14	0.16	0.05	0.05	0.00	0.33	0.18	0.15	0.35	0.06	0.28	0.48	0.25	0.23	0.55	0.19	0.36	0.50	0.10	0.40
1.99	1.55	1.70	0.00	1.16	1.46	0.00	0.95	1.10	0.00	1.03	0.97	0.06	1.23	1.24	0.00	1.26	1.33	0.00	1.35	1.13	0.22
3.02	2.18	2.30	0.00	1.51	1.70	0.00	1.17	1.17	0.01	1.48	1.04	0.43	1.89	1.51	0.38	1.93	1.68	0.25	2.19	1.39	0.79
4.04	2.61	2.88	0.00	1.93	2.21	0.00	1.52	1.54	0.00	1.85	1.36	0.49	2.82	2.10	0.72	2.92	2.31	0.61	3.29	1.89	1.40
6.05	3.74	3.73	0.01	2.90	2.90	0.00	2.38	2.03	0.35	2.72	1.84	0.88	5.00	2.99	2.01	5.11	3.39	1.72	5.07	2.77	2.30
7.02	4.32	3.98	0.34	3.40	3.20	0.20	2.86	2.25	0.61	3.24	2.14	1.10	5.75	3.37	2.39	5.97	3.84	2.14	5.83	3.17	2.65
8.03	4.94	4.35	0.59	3.74	3.35	0.39	3.29	2.47	0.82	3.72	2.32	1.39	6.63	3.94	2.69	6.73	4.48	2.25	6.69	3.76	2.93
9.02	5.63	4.61	1.03	4.23	3.42	0.81	3.84	2.61	1.23	4.16	2.44	1.72	7.48	4.28	3.20	7.51	4.90	2.61	7.56	4.10	3.46
12.10	6.83	5.40	1.43	4.78	3.86	0.92	4.49	3.02	1.47	4.79	2.85	1.93	8.74	5.12	3.62	8.58	5.62	2.96	8.67	4.87	3.80
13.88	7.59	6.02	1.57	5.38	3.35	1.04	4.89	3.33	1.56	5.43	3.22	2.21	9.47	5.88	3.60	9.55	6.69	2.86	9.66	5.77	3.89
15.03	7.76	6.27	1.49	5.60	4.61	0.99	5.10	3.73	1.37	5.59	3.73	1.85	9.66	6.17	3.49	9.79	6.98	2.81	10.04	6.24	3.80
16.01	7.96	6.37	1.58	5.76	4.76	1.00	5.64	3.79	1.85	5.71	3.85	1.85	9.83	6.28	3.59	9.97	7.17	2.80	10.20	6.34	3.85
17.02	8.57	6.89	1.88	6.25	5.13	1.12	6.11	4.24	1.87	6.18	4.10	2.08	10.28	6.61	3.67	10.41	7.57	2.84	10.67	6.77	3.90
17.99	9.02	6.69	2.33	6.62	5.38	1.23	6.55	4.60	1.95	6.56	4.39	2.17	11.10	6.94	4.16	10.85	7.97	2.87	11.17	7.16	4.01
20.06	9.58	7.59	1.99	7.37	5.93	1.44	7.37	5.09	2.28	7.40	4.90	2.50	11.57	7.69	3.88	11.87	8.77	3.10	12.02	8.02	4.01
Event 2: 10/11/96																					
0.97	1.34	0.62	0.72	0.66	0.33	0.33	0.99	0.89	0.10	1.05	0.68	0.37	0.44	0.11	0.33	0.17	0.01	0.16	0.24	0.16	0.08
2.76	4.10	2.08	2.02	2.29	1.20	1.09	3.25	2.59	0.66	2.16	1.40	0.76	1.38	0.34	1.04	0.36	0.08	0.28	0.83	0.47	0.36
3.90	5.05	2.76	2.29	3.44	1.89	1.55	4.66	3.31	1.35	3.37	2.09	1.28	2.37	0.82	1.55	0.83	0.26	0.57	1.56	1.03	0.53
4.90	6.13	2.92	3.21	4.21	2.06	2.15	5.93	3.57	2.37	4.31	2.28	2.03	3.19	0.96	2.23	1.29	0.41	0.88	2.78	1.21	1.58
5.89	6.81	3.42	3.38	5.07	2.75	2.32	7.33	3.95	3.38	5.11	2.66	2.45	3.51	1.18	2.33	1.93	0.62	1.31	3.51	1.54	1.97
6.87	7.52	3.94	3.57	5.81	3.12	2.69	8.60	4.36	4.24	5.71	3.07	2.65	3.89	1.45	2.44	2.57	0.83	1.73	4.08	1.87	2.21
8.89	9.84	5.05	4.79	6.81	3.77	3.03	10.94	5.16	5.78	7.02	3.69	3.33	5.66	2.05	3.61	4.31	1.40	2.91	4.96	2.36	2.60
11.84	11.28	6.17	5.11	7.73	5.25	2.48	12.61	6.56	6.05	8.63	4.98	3.65	6.40	2.90	3.50	4.89	2.68	2.21	5.92	3.47	2.45
12.88	11.86	6.36	5.50	8.38	5.44	2.94	13.33	6.75	6.58	9.27	5.32	3.95	7.05	3.22	3.83	5.62	3.04	2.58	6.55	3.82	2.73
13.87	12.21	6.60	5.61	8.73	5.66	3.07	14.05	6.91	7.14	9.87	5.62	4.25	7.69	3.53	4.16	6.47	3.41	3.06	7.23	4.15	3.08
16.07	12.70	6.98	5.72	9.09	6.03	3.05	14.58	7.13	7.45	10.09	6.09	4.00	8.62	3.88	4.74	7.19	3.90	3.28	7.76	4.76	3.00
16.93	13.03	7.89	5.14	9.35	6.89	2.46	14.75	7.35	7.40	10.46	6.52	3.94	8.99	4.13	4.86	7.51	4.17	3.35	8.11	5.19	2.92
17.66	13.31	8.12	5.18	9.53	7.07	2.46	15.07	7.48	7.59	10.64	6.80	3.84	9.29	4.34	4.95	7.91	4.38	3.53	8.48	5.54	2.94
19.90	13.63	8.46	5.17	9.86	7.46	2.40	15.49	7.74	7.75	10.%	7.30	3.66	9.86	4.63	5.23	8.32	4.80	3.53	9.10	5.88	3.22

Appendix E. (Continued)

	SEPA station BOD (mg/L)																				
	3						*4*						*5*								
Time	*In*			*Out*			*In*			*Out*			*In*			*Out C*			*Out S*		
(days)	*T*	*C*	*N*	*T*	*C*	*N*	*T*	*C*	*N*	*T*	*C*	*N*	*T*	*C*	*N*	*T*	*C*	*N*	*T*	*C*	*N*
Event 3: 04/28/97																					
0.77	0.69	0.57	0.11	0.57	0.57	0.00	1.11	0.94	0.17	0.76	0.57	0.19	0.58	0.48	0.10	0.65	0.63	0.03	0.41	0.75	0
1.94	1.74	1.11	0.62	1.40	1.03	0.37	2.34	1.93	0.41	1.50	1.08	0.42	1.10	0.92	0.17	1.26	1.13	0.13	0.93	1.35	0
2.95	2.42	1.50	0.92	2.22	1.75	0.47	3.48	2.88	0.61	2.80	1.76	1.04	1.70	1.37	0.33	1.74	1.50	0.24	1.48	1.76	0
3.78	3.10	2.12	0.98	3.03	2.45	0.57	4.48	3.29	1.19	4.10	2.20	1.90	2.41	1.83	0.58	2.29	1.88	0.41	2.32	2.42	0
6.12	5.54	3.22	2.32	4.74	3.08	1.66	6.58	4.48	2.11	5.61	3.22	2.39	3.97	2.89	1.08	6.08	3.42	2.66	5.19	3.67	1.52
6.97	6.33	3.40	2.92	5.64	3.25	2.39	7.64	4.75	2.88	6.65	3.46	3.19	5.06	3.06	2.00	7.23	3.70	3.53	6.43	3.93	2.50
7.76	7.55	3.93	3.62	6.75	3.63	3.12	9.10	5.46	3.64	7.85	3.91	3.95	6.64	3.47	3.17	8.28	4.12	4.15	7.42	4.30	3.12
9.00	8.60	4.30	4.30	7.82	4.05	3.77	10.46	6.05	4.41	8.83	4.35	4.47	8.10	3.83	4.27	9.10	4.52	4.58	8.37	4.67	3.70
9.68	9.16	4.60	4.56	8.41	4.33	4.07	11.15	6.42	4.73	9.39	4.69	4.70	9.09	4.13	4.96	9.54	4.84	4.69	8.83	4.96	3.87
11.10	10.27	5.63	4.64	9.30	5.01	4.29	12.26	7.12	5.14	10.31	5.23	5.08	10.40	4.68	5.72	10.16	5.31	4.84	9.57	5.51	4.06
13.12	11.24	6.09	5.15	10.65	5.92	4.72	14.27	8.30	5.97	11.56	6.31	5.24	12.68	5.65	7.04	11.09	6.30	4.79	10.37	6.43	3.94
13.76	11.61	6.32	5.29	10.90	6.20	4.70	14.68	8.64	6.04	11.90	6.60	5.29	12.99	5.93	7.06	11.39	6.60	4.78	10.60	6.67	3.93
14.71	11.87	6.57	5.31	11.18	6.48	4.70	15.11	8.98	6.13	12.23	6.88	5.35	13.26	6.22	7.04	11.59	6.81	4.77	10.85	6.93	3.92
16.98	12.84	7.25	5.58	11.91	7.37	4.53	16.22	10.03	6.19	13.21	7.85	5.36	14.02	7.20	6.81	12.45	7.69	4.76	11.63	7.91	3.72
18.04	13.23	7.61	5.62	12.32	7.77	4.55	16.57	10.50	6.06	13.70	8.21	5.48	14.30	7.54	6.76	12.87	8.02	4.94	12.28	8.26	4.02
20.08	13.68	7.98	5.70	12.64	8.17	4.47	16.98	10.81	6.17	14.22	8.68	5.55	14.70	7.88	6.82	13.39	8.18	5.21	13.09	8.67	4.42
Event 3: 05/07/97																					
1.37	0.84	0.72	0.12	1.03	0.99	0.03	0.83	0.46	0.38	0.66	0.54	0.12	1.48	1.23	0.25	1.70	1.67	0.02	1.35	1.58	0.00
3.47	2.17	1.99	0.18	2.37	2.05	0.32	1.86	1.49	0.37	1.81	1.21	0.60	1.93	1.59	0.34	2.15	1.98	0.17	1.70	1.86	0.00
4.10	2.46	2.31	0.14	2.69	2.51	0.19	2.28	1.86	0.42	2.32	1.69	0.63	2.40	1.94	0.46	2.58	2.26	0.32	2.06	2.13	0.00
5.07	2.74	2.61	0.14	3.39	2.84	0.54	2.74	2.23	0.51	2.93	2.17	0.76	4.32	3.20	1.12	4.39	3.41	0.97	3.73	3.27	0.46
7.33	4.21	3.53	0.68	4.99	3.96	1.03	4.21	3.27	0.94	4.00	3.10	0.90	4.98	3.54	1.43	5.05	3.76	1.29	4.25	3.70	0.55
8.39	4.66	3.92	0.74	5.60	4.32	1.28	4.80	3.63	1.17	4.54	3.42	1.12	6.08	4.18	1.90	6.28	4.32	1.96	5.59	4.39	1.20
10.43	5.66	4.36	1.30	6.68	4.89	1.79	6.44	4.27	2.17	6.08	4.03	2.05	6.59	4.50	2.09	6.92	4.70	2.23	6.20	4.84	1.35
11.15	6.16	4.79	1.36	7.15	5.21	1.94	6.99	4.56	2.43	6.61	4.34	2.28	7.68	5.49	2.19	8.07	5.73	2.34	7.43	6.22	1.21
13.34	7.97	5.91	2.06	8.37	6.28	2.09	7.96	5.58	2.39	7.79	5.37	2.42	8.38	6.20	2.17	8.71	6.39	2.32	8.10	6.89	1.21
15.33	8.77	6.45	2.32	9.07	6.82	2.25	8.69	6.18	2.51	8.38	5.92	2.46	8.95	6.85	2.10	9.29	6.96	2.33	8.79	7.55	1.24
17.17	9.53	6.92	2.61	9.67	7.30	2.38	9.24	6.63	2.61	8.84	6.40	2.44	9.58	7.70	1.89	9.89	7.71	2.18	9.41	8.28	1.13
19.33	9.91	7.42	2.49	10.20	7.90	2.30	9.76	7.27	2.49	9.35	7.11	2.23	9.71	7.87	1.83	10.02	7.88	2.14	9.53	8.44	1.08
20.29	10.04	7.57	2.48	10.34	8.05	2.29	9.95	7.44	2.51	9.47	7.28	2.19	9.88	8.00	1.89	10.19	7.99	2.20	9.68	8.52	1.16

Appendix E. (Concluded)

	SEPA station BOD (mg/L)																				
	3						4						5								
Time	In			Out			In			Out			In			Out C			Out S		
(days)	T	C	N	T	C	N	T	C	N	T	C	N	T	C	N	T	C	N	T	C	N
Event 4: 06/16/97																					
1.01	1.10	0.39	0.71	0.97	0.20	0.77	1.03	0.50	0.53	1.28	0.25	1.03	0.69	0.09	0.60	0.90	0.23	0.67	0.72	0.15	0.57
2.01	2.28	0.89	1.39	2.18	0.69	1.50	2.29	1.02	1.27	2.31	0.55	1.77	1.31	0.16	1.15	1.59	0.54	1.05	1.29	0.40	0.87
3.01	2.98	1.90	1.09	3.23	1.46	1.77	3.18	1.75	1.43	3.24	1.30	1.94	2.02	0.78	1.24	2.35	1.04	1.31	1.97	1.04	0.93
4.02	3.68	2.67	1.01	4.19	2.67	1.52	3.97	2.37	1.60	4.03	2.21	1.82	2.81	1.42	1.39	3.01	1.58	1.42	2.84	1.56	1.28
5.09	4.40	3.31	1.10	5.13	3.60	1.53	5.05	3.14	1.91	5.05	2.81	2.25	3.41	1.95	1.47	3.85	2.01	1.83	3.59	2.05	1.53
7.03	6.21	4.15	2.05	6.88	4.75	2.13	6.66	3.95	2.71	6.16	3.68	2.48	3.89	2.16	1.73	4.48	2.43	2.04	4.19	2.56	1.63
8.03	6.82	4.61	2.21	7.41	5.36	2.05	7.26	4.55	2.71	6.82	4.20	2.62	-	-	-	5.05	2.94	2.11	4.57	3.01	1.56
9.00	7.72	5.59	2.12	7.97	6.02	1.95	7.93	5.11	2.82	7.37	4.74	2.63	5.08	3.47	1.62	5.59	3.56	2.03	5.03	3.50	1.53
10.03	8.88	6.53	2.34	8.93	6.79	2.14	8.34	5.32	3.02	7.83	5.19	2.64	5.63	4.02	1.61	6.14	4.09	2.05	5.35	3.89	1.45
11.14	9.50	6.85	2.65	9.38	7.14	2.24	9.03	5.78	3.25	8.34	5.56	2.78	5.96	4.32	1.64	6.46	4.34	2.12	5.67	4.17	1.50
12.97	10.43	7.70	2.73	10.43	7.75	2.68	10.24	6.72	3.52	9.12	6.13	2.99	5.96	4.32	1.64	7.07	4.67	2.39	6.29	4.60	1.69
13.75	10.70	8.05	2.64	10.63	8.12	2.51	10.50	7.11	3.40	9.33	6.53	2.80	6.08	4.66	1.42	7.22	5.00	2.22	6.42	4.97	1.45
15.02	11.21	8.49	2.72	11.11	8.55	2.57	10.99	7.55	3.44	9.76	6.89	2.86	6.37	5.02	1.35	7.54	5.29	2.25	6.72	5.28	1.44
16.94	11.95	9.29	2.66	11.85	9.35	2.50	11.77	8.38	3.39	10.51	7.72	2.79	6.95	5.74	1.21	8.15	5.98	2.17	7.37	6.09	1.27
19.23	12.71	9.84	2.87	12.36	9.78	2.58	12.41	8.96	3.44	11.18	8.33	2.85	7.45	6.12	1.33	8.64	6.40	2.24	8.03	6.65	1.37
20.04	13.00	10.02	2.98	12.53	9.93	2.60	12.76	9.22	3.54	11.54	8.66	2.88	7.70	6.34	1.36	8.93	6.63	2.30	8.35	7.00	1.35
Event 4: 06/27/97																					
1.82	1.36	1.01	0.35	1.60	0.81	0.80	1.46	1.06	0.39	1.49	1.07	0.42	0.91	0.86	0.05	1.14	0.93	0.21	0.97	0.87	0.10
2.59	1.76	1.44	0.32	2.27	1.30	0.97	1.88	1.56	0.32	1.94	1.56	0.39	1.17	1.33	0.00	1.49	1.36	0.13	1.24	1.31	0.00
3.87	3.00	2.23	0.77	3.41	2.17	1.24	2.86	2.22	0.64	2.99	2.30	0.69	1.82	2.02	0.00	2.34	1.99	0.35	1.94	1.95	0.00
5.78	4.60	3.13	1.47	4.57	2.88	1.69	4.19	3.15	1.04	4.33	3.30	1.03	3.07	3.03	0.04	3.90	3.02	0.88	3.32	3.00	0.32
7.94	5.92	3.86	2.05	5.62	3.70	1.92	5.43	3.60	1.83	5.20	3.90	1.30	4.35	3.59	0.76	5.13	3.61	1.52	4.07	3.59	0.48
9.09	6.26	4.42	1.84	5.98	4.12	1.86	5.89	4.07	1.82	5.71	4.24	1.47	5.04	3.97	1.06	5.81	3.98	1.84	4.55	3.86	0.69
9.86	6.46	5.05	1.41	6.26	4.34	1.91	6.20	4.49	1.71	6.00	4.84	1.17	5.43	4.55	0.88	6.15	4.38	1.76	4.84	4.15	0.69
10.86	6.76	5.16	1.60	6.46	4.78	1.68	6.42	4.60	1.82	6.21	4.83	1.38	5.78	4.65	1.14	6.45	4.93	1.51	5.26	4.51	0.75
12.83	7.30	5.75	1.55	6.85	5.19	1.66	7.09	5.31	1.78	7.05	5.79	1.26	6.51	5.64	0.87	6.92	5.24	1.68	5.94	5.26	0.68
13.87	7.54	6.10	1.44	7.19	5.60	1.59	7.34	5.63	1.71	7.24	5.90	1.35	6.80	6.02	0.77	7.23	5.51	1.72	6.16	5.67	0.49
16.07	8.08	6.59	1.49	7.49	6.04	1.45	7.73	5.99	1.74	7.43	6.27	1.16	7.12	6.23	0.89	7.77	6.09	1.68	6.49	6.03	0.46
16.84	8.20	6.66	1.53	7.64	6.17	1.47	7.81	6.05	1.76	7.54	6.36	1.18	7.17	6.34	0.83	7.86	6.16	1.70	6.60	6.16	0.45
17.87	8.37	6.78	1.59	7.85	6.67	1.17	8.13	6.35	1.78	7.71	6.53	1.18	7.40	6.50	0.90	8.11	6.33	1.78	6.91	6.34	0.57
19.88	8.85	7.17	1.68	8.29	6.86	1.43	8.24	6.62	1.62	8.15	6.90	1.25	7.78	6.95	0.83	8.53	6.74	1.79	7.36	6.82	0.54

Notes: BOD = biochemical oxygen demand
T = total BOD
C = carbonaceous BOD
N = nitrogenous BOD

Appendix F

Walk-Through YSI Model 59
DO-Meter DO Readings Compared to
In-place, Continuous-Monitor DO Readings

Appendix F. Walk-Through YSI Model 59 DO-Meter DO Readings Compared to In-place Continuous-Monitor DO Readings: SEP A Station 3

			DO concentration (mg/L)						
			Intake		*Pool*			*Outfall*	
Date	*Time*	*Type of data*	*A*	*B*	*1*	*2*	*3*	*A*	*B*
08/13/96	1358	Monitor: raw	5.98	-	7.46	8.40	8.06	8.12	7.85
	to	Mon: Winkler corrected	5.43	-	6.92	8.20	7.70	7.69	7.82
	1415	Walk-through	6.63	6.63	7.15	7.76	7.91	7.85	7.85
08/14/96	0903	Monitor: raw	5.26	-	6.93	8.22	7.98	8.05	7.70
	to	Mon: Winkler corrected	4.73	-	6.41	8.03	7.62	7.62	7.69
	0916	Walk-through	5.13	5.13	6.88	7.52	7.81	7.87	7.87
08/21/96	1445	Monitor: raw	5.46	-	6.01	8.48	8.01	7.89	6.08
	to	Mon: Winkler corrected	4.89	-	5.68	8.35	7.72	7.55	6.26
	1506	Walk-through	5.99	5.99	7.44	7.85	8.07	8.23	8.23
08/22/96	0815	Monitor: raw	5.22	-	6.25	8.51	8.00	7.94	6.97
	to	Mon: Winkler corrected	4.86	-	5.94	8.39	7.72	7.61	7.17
	0831	Walk-through	5.43	5.43	7.21	7.68	8.16	8.40	8.40
10/01/96	1702	Monitor: raw	6.05	6.11	8.13	8.13	-	9.54	9.04
	to	Mon: Winkler corrected	6.61	5.85	7.68	7.68	-	8.95	8.53
	1720	Walk-through	5.77	5.77	8.23	8.64	8.98	9.11	9.11
10/02/96	0957	Monitor: raw	6.13	6.24	8.14	8.14	-	9.60	9.33
	to	Mon: Winkler corrected	6.78	5.99	7.72	7.72	-	9.04	8.81
	1016	Walk-through	6.60	6.60	8.67	9.24	9.58	9.63	9.63
10/08/96	1210	Monitor: raw	6.48	6.86	8.14	8.13	-	9.41	9:86
	to	Mon: Winkler corrected	7.56	6.78	7.88	7.87	-	9.11	9.21
	1224	Walk-through	7.14	7.14	8.16	9.05	9.35	9.53	9.53
04/30/97	1416	Monitor: raw	6.72	7.47	8.09	8.78	9.33	9.72	9.19
	to	Mon: Winkler corrected	6.52	7.02	7.71	8.52	9.25	9.48	8.93
	1437	Walk-through	7.39	7.39	9.16	9.80	10.25	10.20	10.20
05/07/97	0741	Monitor: raw	6.07	6.63	8.04	9.00	9.66	10.01	9.61
	to	Mon: Winkler corrected	5.87	6.32	7.68	8.70	9.50	9.72	9.30
	0806	Walk-through	6.30	6.30	8.23	9.20	9.60	9.75	9.75
06/17/97	1422	Monitor: raw	6.19	5.63	9.70	7.54	9.42	8.15	8.82
	to	Mon: Winkler corrected	6.28	5.46	9.13	7.71	9.28	8.05	8.11
	1446	Walk-through	4.92	4.92	7.63	8.20	8.38	8.59	8.59
06/26/97	1427	Monitor: raw	5.75	-	9.50	7.23	8.99	7.37	8.04
	to	Mon: Winkler corrected	6.13	-	8.97	7.69	8.96	7.78	9.00
	1448	Walk-through	5.47	5.47	7.00	7.68	7.94	8.07	8.07

Note: "Mon: Winkler corrected" is the raw monitor value corrected for a match-up, lab-tank Winkler

Appendix F. (Continued)
SEPA Station 4

			DO concentration (mg/L)						
			Intake		*Pool*			*Outfall*	
Date	*Time*	*Type of data*	*A*	*B*	*1*	*2*	*3*	*A*	*B*
08/13/96	1251	Monitor: raw	5.65	-	6.89	-	8.10	8.60	7.89
	to	Mon: Winkler corrected	5.14	-	6.59	-	7.89	8.48	7.51
	1302	Walk-through	5.04	-	7.62	7.79	7.78	7.85	7.85
08/14/96	1001	Monitor: raw	5.31	-	6.53	-	8.14	8.59	7.99
	to	Mon: Winkler corrected	4.84	-	6.22	-	7.92	8.49	7.58
	1014	Walk-through	4.38	-	7.27	7.60	7.82	8.01	8.01
08/21/96	1336	Monitor: raw	5.42	-	6.51	-	7.78	2.21	7.73
	to	Mon: Winkler corrected	5.06	-	6.15	-	7.62	2.26	7.17
	1357	Walk-through	5.94	-	7.58	7.77	8.40	8.46	8.46
08/22/96	1129	Monitor: raw	5.29	-	5.86	-	6.76	2.23	7.26
	to	Mon: Winkler corrected	4.93	-	5.49	-	6.60	2.28	6.68
	1141	Walk-through	4.52	-	6.83	7.49	8.23	8.19	8.19
10/01/96	1448	Monitor: raw	5.80	5.71	12.89	8.66	6.96	9.29	9.07
	to	Mon: Winkler corrected	5.54	4.35	6.43	8.40	6.63	9.08	8.64
	1603	Walk-through	5.98	5.98	7.80	8.65	8.74	8.63	8.63
10/02/96	1213	Monitor: raw	5.39	5.47	10.68	8.40	5.25	9.37	9.09
	to	Mon: Winkler corrected	5.14	3.39	4.61	8.21	4.93	9.17	8.66
	1234	Walk-through	5.70	5.70	7.76	8.84	9.62	9.98	9.98
10/09/96	1049	Monitor: raw	6.26	6.41	-	8.27	6.05	9.69	9.11
	to	Mon: Winkler corrected	6.23	3.52	-	8.20	5.77	9.66	8.83
	1127	Walk-through	7.15	7.15	8.69	9.28	9.54	10.46	10.46
05/01/97	1402	Monitor: raw	7.19	7.19	8.41	9.39	9.88	-	10.57
	to	Mon: Winkler corrected	7.17	7.00	8.23	9.19	9.47	-	10.03
	1428	Walk-through	7.26	7.26	9.57	9.94	9.80	9.75	9.75
05/07/97	0909	Monitor: raw	7.41	7.65	8.31	9.58	9.80	-	11.24
	to	Mon: Winkler corrected	7.46	7.49	8.07	9.26	9.39	-	10.44
	0935	Walk-through	7.58	7.58	9.19	9.42	9.87	-9.81	9.81
06/17/97	1246	Monitor: raw	3.94	3.83	9.88	8.00	8.73	8.50	8.13
	to	Mon: Winkler corrected	4.10	3.25	10.70	8.16	8.63	8.81	8.43
	1319	Walk-through	4.19	4.19	9.57	8.80	8.93	8.97	8.97
06/26/97	1255	Monitor: raw	6.09	6.55	6.98	7.48	8.67	7.15	7.54
	to	Mon: Winkler corrected	6.50	6.97	7.44	7.92	8.73	8.03	8.32
	1325	Walk-through	6.34	6.34	7.44	7.65	8.08	7.94	7.94

Note: "Mon: Winkler corrected" is the raw monitor value corrected for a match-up, lab-tank Winkler

Appendix F. (Continued)
SEPA Station 5, Cal-Sag Channel Outlet

			DO concentration (mg/L)							
			Intake		*Pool*				*Out fallC*	
Date	*Time*	*Type of data*	*A*	*B*	*1*	*2C*	*3C*	*4C*	*A*	*B*
08/13/96	1112	Monitor: raw	4.17	4.31	6.30	-	7.77	8.04	8.11	7.63
	to	Mon: Winkler corrected	3.61	3.63	5.85	-	7.35	7.67	7.61	8.35
	1136	Walk-through	3.67	3.67	6.14	6.94	7.39	7.55	7.68	7.68
08/14/96	1101	Monitor: raw	4.68	4.73	6.53	-	7.96	8.17	8.23	7.68
	to	Mon: Winkler corrected	4.12	4.08	6.12	-	7.52	7.81	7.74	8.41
	1115	Walk-through	3.54	3.54	6.50	6.89	7.26	7.43	7.97	7.97
08/21/96	1201	Monitor: raw	5.29	5.41	6.62	-	8.10	8.32	8.40	6.90
	to	Mon: Winkler corrected	4.76	4.86	6.49	-	7.64	7.98	7.95	7.70
	1212	Walk-through	5.45	5.45	6.84	7.36	8.05	8.04	8.22	8.22
08/22/96	1352	Monitor: raw	5.08	5.48	6.40	-	7.96	8.22	8.31	6.97
	to	Mon: Winkler corrected	4.54	4.95	6.32	-	7.50	7.88	7.86	7.79
	1406	Walk-through	5.63	5.63	6.82	8.01	8.11	8.08	8.40	8.40
10/01/96	1300	Monitor: raw	5.85	5.41	8.14	8.64	8.30	9.23	9.68	10.90
	to	Mon: Winkler corrected	5.53	4.31	7.94	8.57	3.68	6.34	9.28	9.80
	1308	Walk-through	5.98	5.98	8.58	8.85	9.24	9.41	9.46	9.46
10/02/96	1354	Monitor: raw	5.87	5.73	7.80	8.20	7.18	9.24	9.67	10.87
	to	Mon: Winkler corrected	5.57	4.34	7.22	8.23	3.10	6.55	9.30	9.85
	1427	Walk-through	5.91	5.91	7.51	7.83	8.77	9.04	9.20	9.20
10/09/96	0900	Monitor: raw	6.19	5.66	8.37	8.92	-	-	9.58	11.18
	to	Mon: Winkler corrected	6.01	2.43	8.06	8.96	-	-	9.40	10.68
	0910	Walk-through	7.69	7.69	8.37	8.94	9.33	9.58	10.32	10.32
05/01/97	1221	Monitor: raw	6.58	-	8.05	7.75	11.56	8.74	9.16	9.35
	to	Mon: Winkler corrected	6.36	-	8.30	8.00	10.85	8.91	9.37	9.93
	1237	Walk-through	6.45	6.45	8.13	8.66	9.09	9.24	9.38	9.38
05/07/97	1038	Monitor: raw	-	-	8.34	7.81	10.70	8.49	9.03	8.07
	to	Mon: Winkler corrected	-	-	8.64	8.18	9.83	8.87	9.32	8.64
	1054	Walk-through	7.74	7.74	8.82	9.26	9.62	9.86	9.88	9.88
06/17/97	1127	Monitor: raw	5.62	5.24	7.03	9.22	7.50	8.32	8.80	9.04
	to	Mon: Winkler corrected	5.22	5.03	7.02	8.73	7.87	9.08	8.65	9.11
	1145	Walk-through	4.67	4.67	8.05	8.49	8.70	8.79	8.86	8.86
06/26/97	1024	Monitor: raw	4.91	4.18	5.61	8.43	7.22	-	8.27	8.53
	to	Mon: Winkler corrected	5.01	4.30	5.95	7.81	7.53	-	8.22	8.73
	1044	Walk-through	4.05	4.05	6.49	7.36	8.12	8.13	8.14	8.14

Note: "Mon: Winkler corrected" is the raw monitor value corrected for a match-up, lab-tank Winkler

Appendix F. (Concluded)
SEPA Station 5, Chicago Sanitary and Ship Canal Outlet

			DO concentration (mg/L)							
			Intake		*Pool*				*Outfall*	
Date	*Time*	*Type of data*	*A*	*B*	*1*	*2*	*3*	*4*	*A*	*B*
08/13/96	1148	Monitor: raw	(see Cal-Sag			7.78	6.99	8.10	7.96	8.03
	to	Mon: Winkler corrected	outlet for intake			7.26	6.79	7.54	7.55	7.64
	1158	Walk-through	and Pool 1 data)			6.83	7.43	7.61	7.70	7.70
08/14/96	1124	Monitor: raw				7.92	7.11	8.18	8.03	7.97
	to	Mon: Winkler corrected				7.41	6.92	7.61	7.68	7.60
	1126	Walk-through				6.78	7.16	7.38	7.52	7.52
08/21/96	1122	Monitor: raw				8.04	7.44	8.20	8.03	7.81
	to	Mon: Winkler corrected				7.59	7.31	7.73	7.78	7.57
	1127	Walk-through				7.64	7.17	7.95	8.12	8.12
08/22/96	1317	Monitor: raw				7.89	7.31	8.14	7.97	6.95
	to	Mon: Winkler corrected				7.45	7.22	7.68	7.75	7.76
	1320	Walk-through				7.38	7.82	8.20	8.43	8.43
10/01/96	1324	Monitor: raw				8.80	9.83	9.53	10.63	9.56
	to	Mon: Winkler corrected				8.24	8.96	8.15	9.66	8.90
	1327	Walk-through				8.59	9.02	9.12	9.32	9.32
10/02/96	1317	Monitor: raw				8.71	9.67	9.49	10.61	9.50
	to	Mon: Winkler corrected				8.17	8.82	8.12	9.68	8.89
	1320	Walk-through				8.50	8.96	9.18	9.45	9.45
10/09/96	0917	Monitor: raw				8.73	9.98	9.83	11.00	9.78
	to	Mon: Winkler corrected				8.35	9.25	8.47	10.34	9.78
	0920	Walk-through				8.91	9.29	9.54	10.38	10.38
05/01/97	1245	Monitor: raw				7.99	9.54	9.98	9.15	9.89
	to	Mon: Winkler corrected				7.47	9.39	9.97	9.36	9.84
	1320	Walk-through				9.06	8.76	9.06	9.16	9.16
05/07/97	1102	Monitor: raw				7.69	8.69	8.97	9.01	9.67
	to	Mon: Winkler corrected				7.40	8.59	8.96	9.31	9.66
	1105	Walk-through				9.18	9.60	9.77	9.81	9.81
06/17/97	1153	Monitor: raw				8.43	8.51	8.29	8.44	8.20
	to	Mon: Winkler corrected				8.11	8.24	8.38	8.41	8.19
	1156	Walk-through				8.16	8.56	8.78	8.87	8.87
06/26/97	1051	Monitor: raw				7.50	8.27	7.95	8.08	7.25
	to	Mon: Winkler corrected				7.31	8.07	8.18	8.00	7.69
	1056	Walk-through				7.43	7.93	8.22	8.24	8.24

Note: "Mon:Winkler corrected" is the raw monitor value corrected for a match-up, lab-tank Winkler

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