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Project Report No. 262

MULTIPLE POINT EFFLUENT SAMPLING AT THE METROPOLITAN WASTEWATER TREATMENT PLANT, ST. PAUL, MINNESOTA

by

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Prepared for

Metropolitan Waste Control Commission
St. Paul, Minnesota

July 1987

ABSTRACT

The concentration time series measured in a sectional model of the Metropolitan Wastewater Treatment Plant (WWTP) dechlorination basin was coupled with field measurements to predict the benefits of multiple transverse sampling points. The measured time series was used to generate synthetic time series representing the composite samples from two, three and four sampling points located in a cross section transverse to the flow. The analysis of this data indicates how much the multiple sampling points integrate transverse gradients, decrease the necessary time to obtain a "representative" sample and decrease the deviation of a 1 second grab sample from a true mean value.

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I. INTRODUCTION

The Metropolitan Waste Control Commission has previously experienced difficulties with the mixing at the Metropolitan WWTP dechlorination basin (McConnell, 1986). A 1:12 sectional model was constructed at the St. Anthony Falls Hydraulic Laboratory to study corrective measures. Basin modifications included redesigning the SO_2 diffusers to include four rows of injection jets at right angles to the flow and the placement of a column wall within the basin. Details are given in a report by Stefan and Johnson (1986). Additional work with the model included the determination of the best sampling in a vertical longitudinal section. The data provided information on "representative" locations, minimum sampling time required to obtain representative samples, and the maximum deviation of a grab sample from the true mean (Stefan, 1987).

Within the chlorine contact channel, dechlorination basin and effluent channel (Fig 1.) concentration gradients can also exist transverse to the direction of flow. A single sampling point may therefore not characterize the entire effluent. A single sampling point may also be subject to the temporal variations resulting from both horizontal and vertical concentration gradients in a turbulent flow. Composite samples from several sampling points located in a transverse cross section would integrate the transverse variability and dampen the temporal variations. The purpose of this study is to provide an estimate of the benefits of multiple sampling points using the sectional model data. The potential benefits of multiple sampling points located transversely in the effluent channel are: 1) the integration of transverse gradients, 2) the decrease in required sampling time to obtain "representative" samples, and 3) the production of grab samples with small deviation from the true mean concentration.

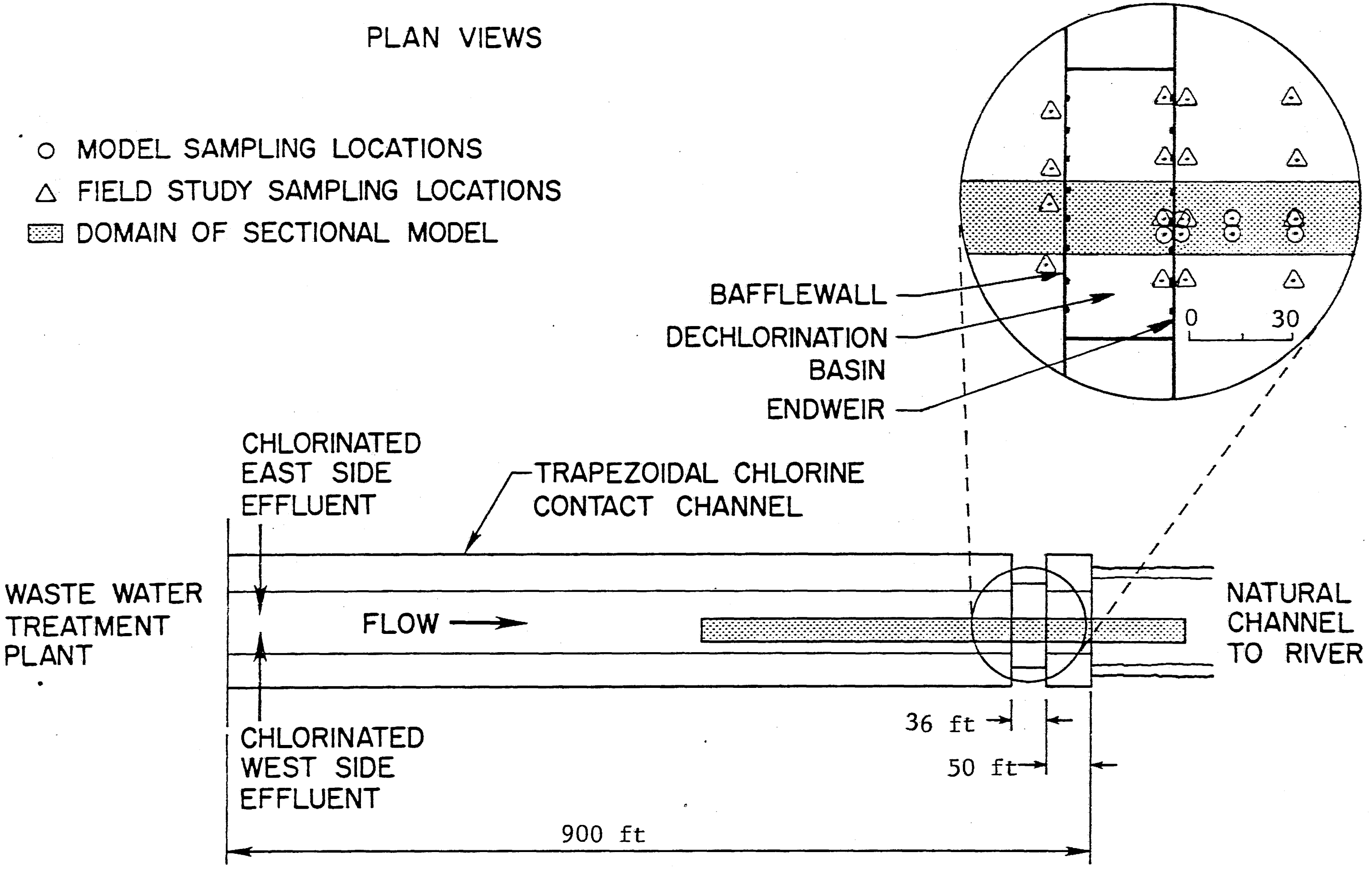


Figure 1. Schematic of effluent channel, dechlorination basin, and data collection sites.

II. OBJECTIVE

The purpose of this study is to determine from sectional model data the sampling time required to obtain representative samples from composites of two, three, and four transversely located sampling intakes in the Metropolitan WWTP final effluent channel.

III. STUDY PROCEDURE

The use of a sectional model to study concentration variations in the prototype presupposes that the turbulent flow features in the dechlorination basin and downstream from it depend primarily on vertical depth scales rather than horizontal ones. Vertical longitudinal slices through the flow field at a sufficient horizontal distance apart are expected to produce turbulent concentration fluctuations of similar statistical characteristics, but individual time series are expected to be uncorrelated. This independence (of adjacent transverse sampling points) is neccessary if benefits in terms of damped fluctuations and shorter sampling times are to be realized from multiple sampling points. Since data were taken in two longitudinal sections within the sectional model (Figure 1) a cross correlation could be done on concentrations at two points separated transversely in space. The cross correlation will indicate if no correlation exists, but will not prove correlation. Appendix I gives equations and an explanation of the correlation coefficient. Strictly interpreted, the cross-correlation requires that the concentration time series data is taken simultaneously at adjacent points. If it can be assumed that the time series is cyclic, however, the cross correlation can be conducted, even though the time series records were not taken simultaneously by lagging one record with respect to the other, until the cyclic concentration pattern comes "in phase."

If concentrations at transverse sampling points are not correlated, the time series record of a single sampling point can represent the time series at other points spaced transversely in the channel. The generation of a synthetic concentration time series requires that the series used to be independent in time. This independence can be accomplished by lagging the time series with itself. The minimum lag time required can be determined from the autocorrelation coefficient. An explanation of the autocorrelation function is contained in Appendix II.

The minimum lag time found from the autocorrelation will be used to create a data set representing the composited intake from more than one sampling intake. In addition to lagging the data record, a weighting factor will be introduced to account for the transverse gradients in mean concentrations measured in the field (Appendix IV). The synthetic composite time series can be generated from the measured data by the equation:

$$C_i = \frac{1}{N} \sum_{j=1}^{N_p} W_j \, C_{i+k(j-1)} \qquad (1)$$

where i = integers from 1 to $N_s - k(N_p - 1)$

N_s = number of data points

N_p = number of transverse sampling intakes

k = the number of data points the record is lagged

C_i = concentration data point i

W_j = weighting factor which incorporates field measurements of mean concentration gradients.

The synthetic time series will be used 1) to determine the minimum sampling time required for a given tolerance, and 2) to determine the maximum deviation of a grab sample from a true cross-sectional mean. Since it has previously been recommended that the sampling will be done 40 feet downstream from the weir, the data from that cross section will be analyzed.

IV. RESULTS

A. Sectional Model Data Analysis

1. Cross-correlation of time series from adjacent locations in a transverse section

Multiple transverse sampling points will dampen temporal concentration fluctuations and thereby decrease the necessary sampling time if the concentration time series is uncorrelated in space. The correlation coefficient was calculated to test for noncorrelation between the time series taken at two sampling points. The cross-correlation calculations were done for data records taken at the same elevation but at different transverse locations (pier and midweir.) The correlation coefficient was calculated for lag times up to 1/3 of the data record length. Figures 2, 3 and 4 show examples of the cross-correlation coefficient as a function of lag time. The concentration time series were correlated for elevations of 686.9, 685, 681.5 ft above MSL. The flow rate was 300 mgd with the normal tailwater pool at 687' AMSL. Figure 2 indicates that there is no correlation between the two points near the water surface. At other elevations (685' and 681.5') a periodic fluctuation of the correlation coefficient with lag time is evident (Fig. 3 and 4). This is identified as instrument noise which becomes significant as the concentration becomes constant. Since the transverse sampling points will probably be placed at least four times farther apart (Fig. 1) than the points tested in this model, no correlation between concentration fluctuation points separated by that distance in transverse direction exists.

2. Autocorrelation of time series

The autocorrelation was calculated for data taken 40 feet downstream from the weir at midweir. Examples of time series data are shown in Figs. 5A and 6A. The autocorrelation was calculated to find the lag time required for independence in time. For illustration, the autocorrelation coefficient is plotted as a function of lag time for elevations of 686.9' and 685' for a flow rate of 300 mgd and with the normal tailwater pool (Fig 5B and 6B). The autocorrelation coefficient calculated from the data exhibits periodic fluctuations with lag time. This periodic fluctuation of the autocorrelation with lag time may be the result of small amplitude fluctuations in the concentration time series (Figs. 5A and 6A) which become significant as the concentration becomes constant. It is not apparent whether the fluctuations are flow related or merely instrument noise. The variation of frequency with flow rate and tailwater stage (Table 1) would be indicative of variations in dye concentration while the regularity of the fluctuation suggests that it is a result of electrical noise.

The purpose of the autocorrelation is to find a lag time required for independence of the data with time. The high frequency fluctuations mask the lag time computation. The elimination of these fluctuations was

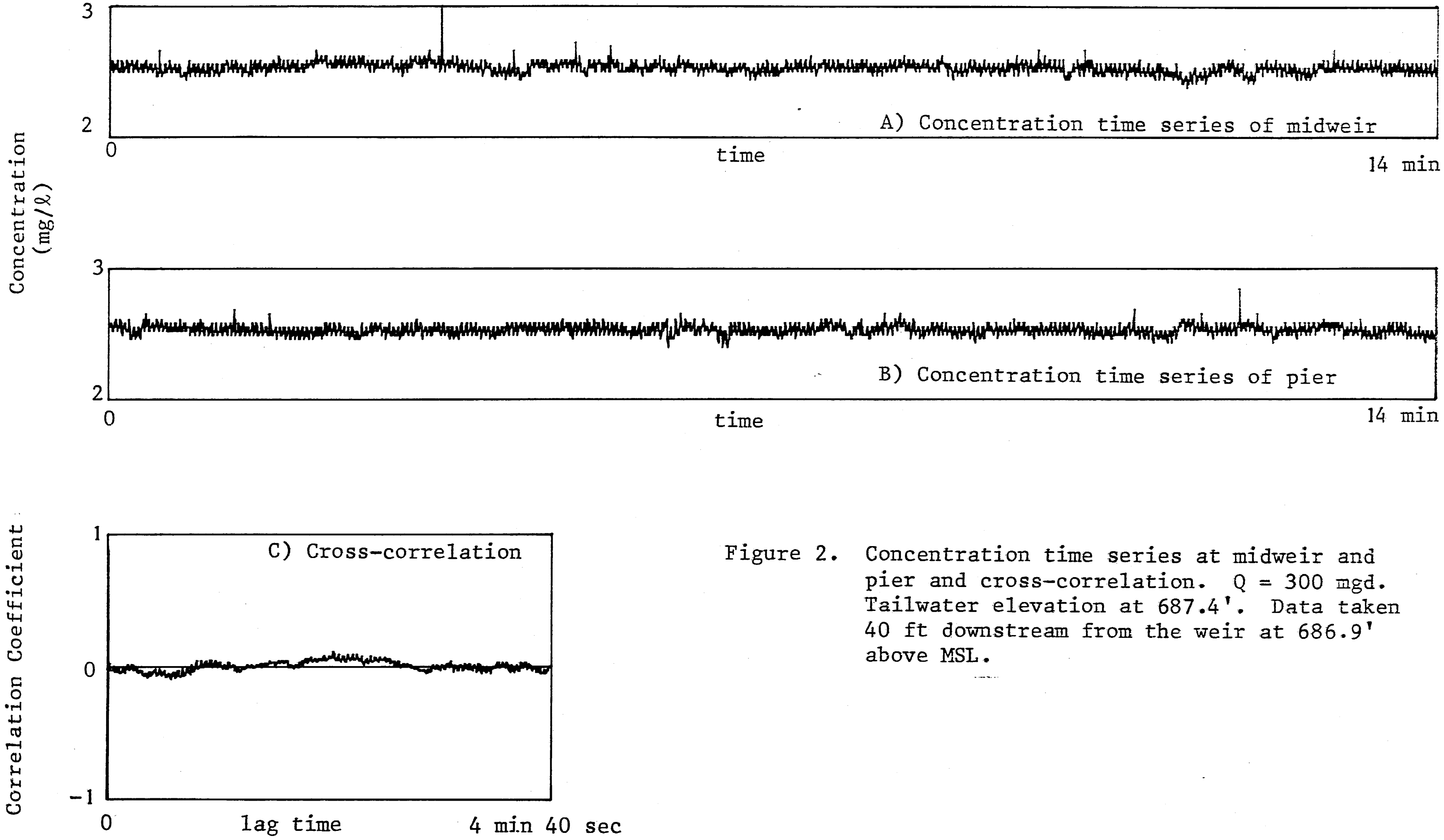


Figure 2. Concentration time series at midweir and pier and cross-correlation. Q = 300 mgd. Tailwater elevation at 687.4'. Data taken 40 ft downstream from the weir at 686.9' above MSL.

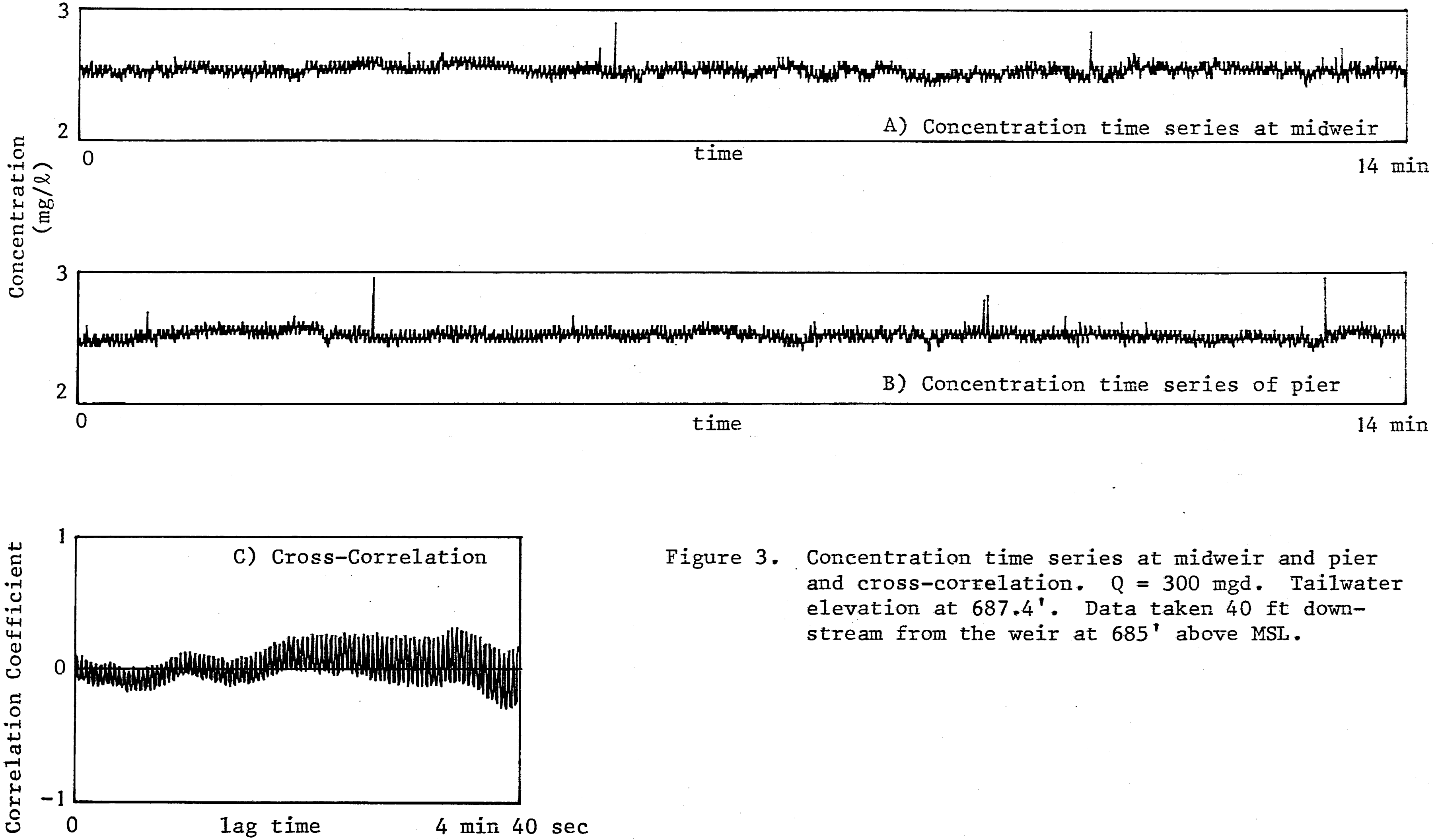
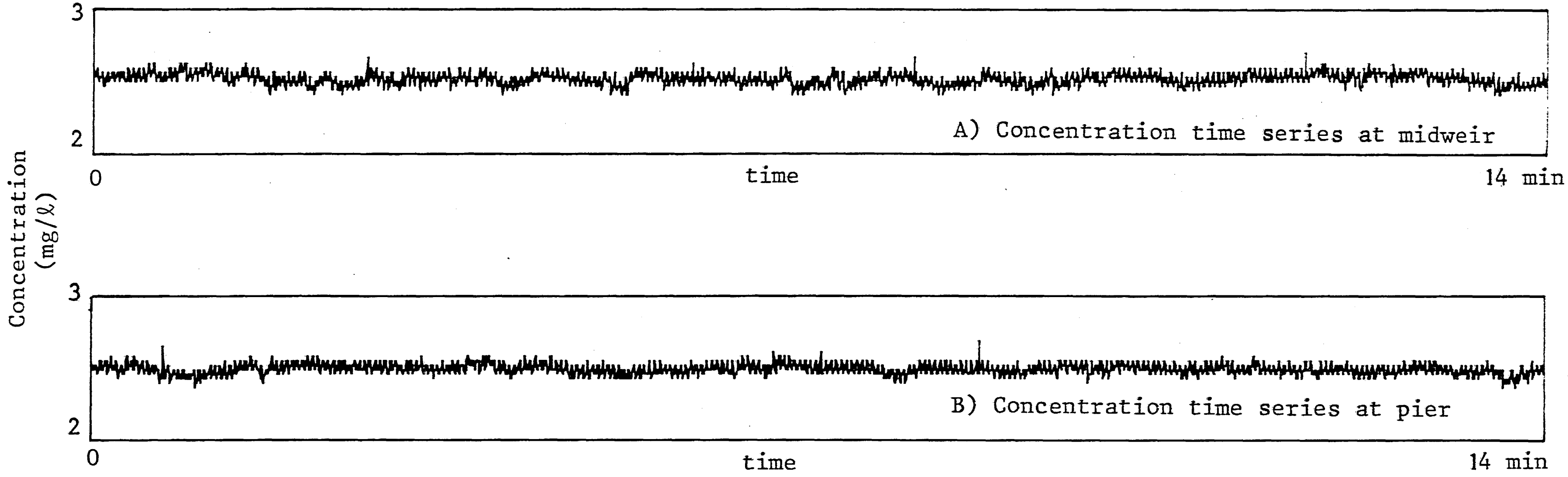


Figure 3. Concentration time series at midweir and pier and cross-correlation. Q = 300 mgd. Tailwater elevation at 687.4'. Data taken 40 ft downstream from the weir at 685' above MSL.



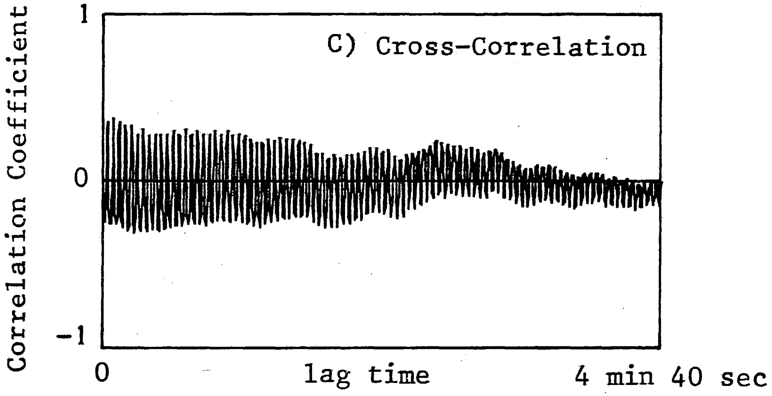


Figure 4. Concentration time series at midweir and pier and cross-correlation. Q = 300 mgd. Tailwater Elevation at 687.4'. Data taken 40 ft downstream from the weir at 681.5' above MSL.

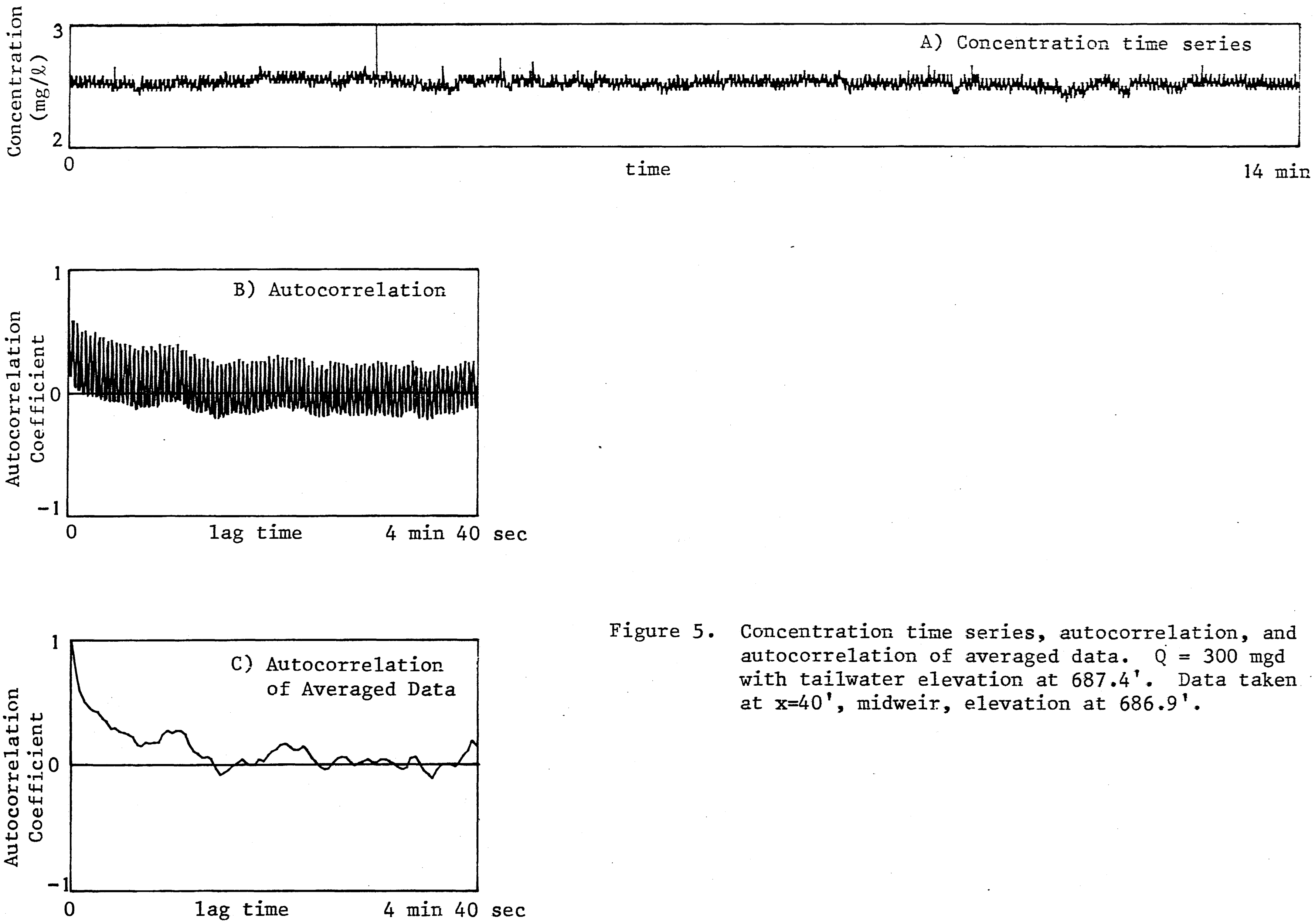


Figure 5. Concentration time series, autocorrelation, and autocorrelation of averaged data. Q = 300 mgd with tailwater elevation at 687.4'. Data taken at x=40', midweir, elevation at 686.9'.

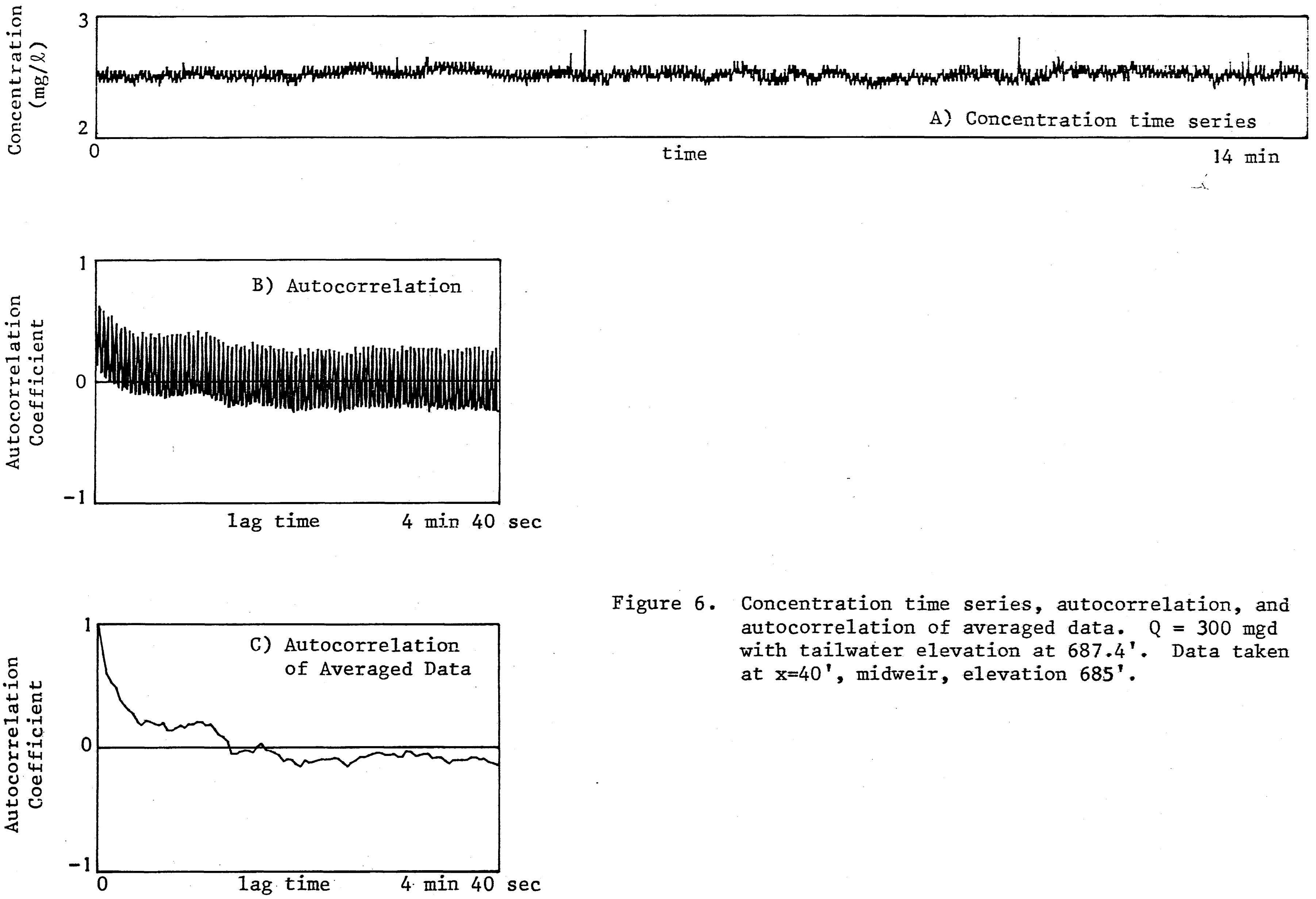


Figure 6. Concentration time series, autocorrelation, and autocorrelation of averaged data. Q = 300 mgd with tailwater elevation at 687.4'. Data taken at x=40', midweir, elevation 685'.

TABLE 1 - AUTO CORRELATION FUNCTION FLUCTUATION FREQUENCY AND LAG TIME USED IN DATA SYNTHESIS.

(All points 40 feet downstream from the weir and midweir)

Flow Rate	Tailwater Elevation	Sample Point Equation	Frequency of Fluctuation	Lag Time Used
(mgd)	(ft)	(ft)	(S^{-1})	(sec)
175	687.2	685	.454	140
175	687.2	686.8	.450	140
175	693	685	.218	105
175	693	692.4	.228	105
300	687.4	685	.336	105
300	687.4	686.9	.337	105
300	693	685	.296	70
300	693	692.4	.294	70
650	687.4	685	.348	70
650	687.4	686.9	.343	70
650	693	685	.459	105
650	693	692.5	.457	70

accomplished by averaging the data over each cycle. Examples of the autocorrelation coefficient obtained from this averaged data is shown Figs. 5C and 6C. A lag time was chosen visually from these plots. Table 1 lists the lag time chosen for all points and flow conditions tested.

3. Synthesis of composite sample

Once the minimum required lag time is obtained from the autocorrelation a composite sample record can be synthesized from a single record. This composite record was obtained by summing the time series with itself at a lag equal to the required minimum given in Table 1. Composite records were created representing two, three and four transverse sampling points by use of one, two, or three lag times. The synthesis also made use of mean concentration gradients measured in a transverse direction at the Metropolitan WWTP. Amplitudes of concentration records were amplified or dampened by application of weight coefficient which represent mean concentration at the sampling points relative to the cross-sectional mean. These coefficients were measured by dye studies at the Metropolitan WWTP which are described in Appendix IV. The weight factors are listed in Table 2 and were used in conjunction with Eq. 1 to generate the composite concentration records for two, three, and four sampling locations in a cross section.

The weighing factors were selected from Tables 2 and 3 of Appendix IV and describe adverse conditions found in the field studies. The procedure is described in Appendix III. Figure 7 shows the measured time series (7A) for one point and the synthetic records for two, three, and four transverse points (Figs. 7B, C, D) for one flow condition (Q = 300 mgd, normal tailwater).

4. Sampling duration and grab sample error

The synthetic concentration time series representing the composite of two, three, and four samples in a cross section 40 ft downstream from the weir were used to calculate required sampling durations and the grab sample deviations. This was accomplished by calculating sliding means through the data record for sampling periods of 480, 240, 120, 60, 30, 15, 8, 4, 2 and 1 sec. Table 3 gives the sampling duration necessary to obtain tolerance levels (defined as the maximum deviation from the full record mean) of 1, 2, 4 and 9 percent. For all flow conditions and locations tested, the composite of four sampling points requires the shortest sampling duration to obtain samples within a given tolerance. This is most evident at the 1% tolerance level where the sampling time decreases from 480 to 8 seconds.

The deviation of grab sample concentrations from the record mean is the smallest with four transverse sample locations. The greatest reduction in sample deviation occurs at normal tailwater elevations (~ 687') and at high flow (650 mgd) where the maximum deviation of a grab sample from four transverse points is about one-fourth of that from one sample point. (See Table 4.)

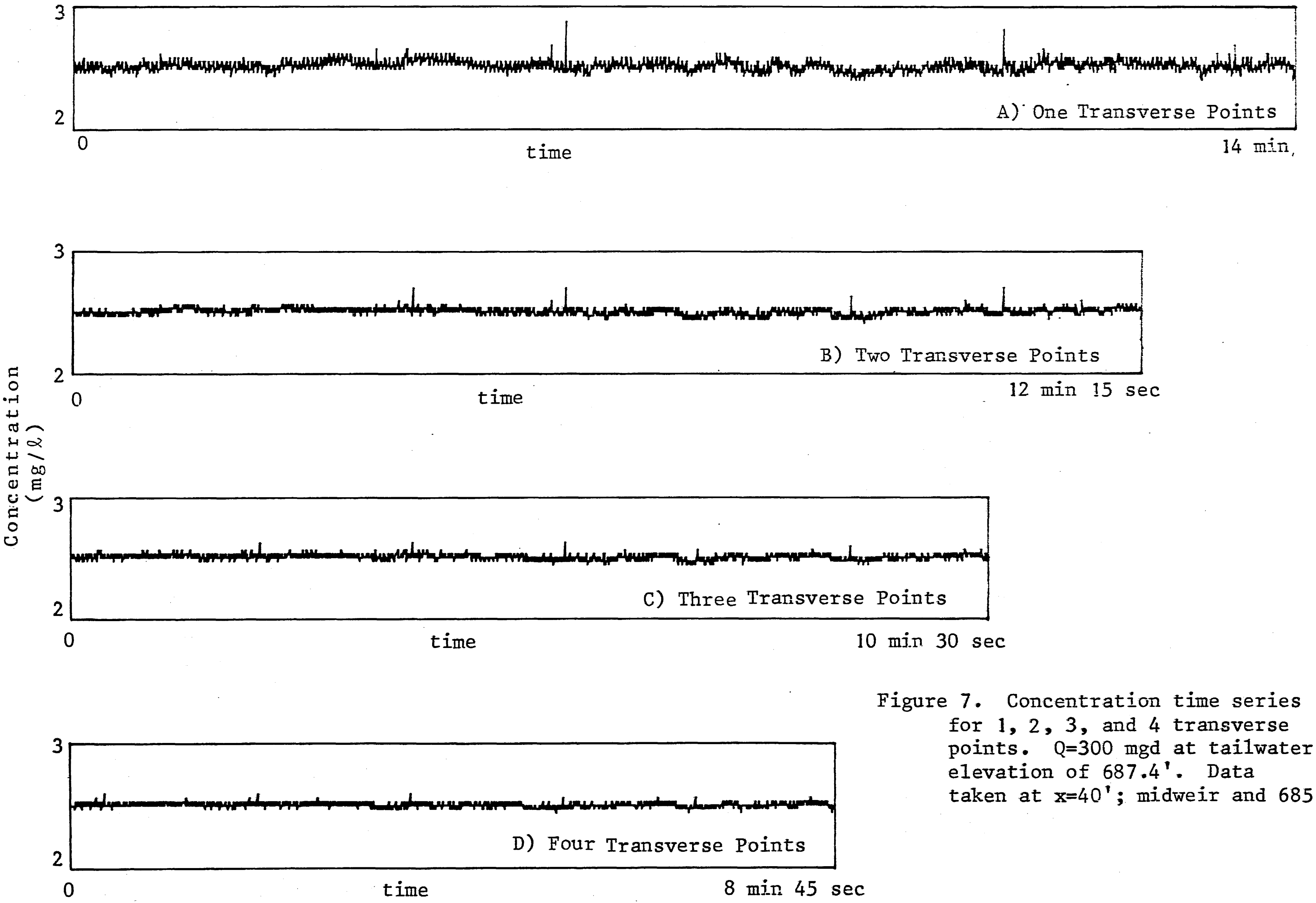


Figure 7. Concentration time series for 1, 2, 3, and 4 transverse points. Q=300 mgd at tailwater elevation of 687.4'. Data taken at x=40'; midweir and 685'.

TABLE 2 - WEIGHING FACTORS USED IN EQUATION 1

Number of Transverse Sampling Points	Weighing Factors			
	W_1	W_2	W_3	W_4
2	105.5	94		
3	108	99.5	92	
4	108	103	96	92

TABLE 3. SAMPLING DURATION (SECONDS) REQUIRED TO LIMIT THE MAXIMUM DEVIATION TO 1, 2, 4, OR 9 PERCENT OF THE RECORD MEAN.

(40 ft downstream from weir)

Sampling Point Elevation (ft AMSL)	Flowrate (mgd)	Number of Sampling Points in Cross Section	SAMPLING DURATION (SEC)							
			MAXIMUM DEVIATION FROM RECORD MEAN (%)							
			1	2	4	9	1	2	4	9
			TAILWATER EL. ~ 687'				TAILWATER EL. ~ 693'			
685	175	1	480	–	15	<1	15	1	–	–
		2	240	120	1	–	4	1	–	–
		3	60	1	–	–	1	–	–	–
		4	8	1	–	–	1	–	–	–
	300	1	240	15	2	<1	15	2	1	–
		2	60	4	1	–	2	1	–	–
		3	15	2	<1	–	2	1	–	–
		4	8	1	–	–	1	–	–	–
	650	1	60	30	8	4	60	15	2	<1
		2	30	15	4	2	15	2	<1	–
		3	15	8	2	<1	8	1	–	–
		4	8	–	2	<1	2	1	–	–
WS-0.5	175	1	480	240	2	<1	15	1	–	–
		2	120	4	<1	–	8	1	–	–
		3	60	2	<1	–	4	1	–	–
		4	8	1	–	–	2	1	–	–
	300	1	240	30	4	2	30	15	8	<1
		2	60	8	2	1	15	8	1	–
		3	8	2	1	–	8	2	<1	–
		4	8	2	<1	–	4	1	–	–
	650	1	60	30	15	<4	120	30	4	<1
		2	30	8	2	–	60	30	2	<1
		3	15	4	2	<1	30	8	2	<1
		4	4	2	–	<1	15	8	1	–

TABLE 4. DEVIATION FROM RECORD MEAN FOR ONE SECOND SAMPLING DURATION.

(40 ft downstream from weir)

Sampling Point Elevation (ft AMSL)	Flow rate (mgd)	Number of Sampling Points in Cross Section	DEVIATION FROM RECORD MEAN (%)	
			TAILWATER ELEVATION ~ 687'	TAILWATER ELEVATION ~ 693'
685	175	1	7	2
		2	4	2
		3	2	1
		4	2	1
	300	1	5	4
		2	4	2
		3	3	1
		4	2	1
	650	1	22	5
		2	11	3
		3	8	2
		4	6	2
WS-0.5	175	1	5	2
		2	3	2
		3	3	2
		4	2	2
	300	1	11	6
		2	7	4
		3	4	3
		4	2	2
	650	1	21	7
		2	10	6
		3	7	5
		4	5	4

B. Interpretation of Field Data

Although the compositing of effluent from multiple transverse sampling points does reduce the required sampling time for the 1-2% tolerance levels, the sampling time at the 4% tolerance level changes little (from 15 to 2 seconds). This decrease in sampling time alone may not justify multiple sampling points. The transverse concentration gradient observed in the field studies may be the most important factor in the determination of the number and placement of transverse samplers. The MWCC memo of April 30, 1987 by Claude Anderson (Appendix IV) gives the results of a field study documenting transverse gradients in and downstream of the dechlorination basin. These field measurements are analyzed here in order to determine the best number of transverse sampling points.

The field measurements indicate that there are transverse mean concentration gradients in the channel 40 feet downstream from the weir. In order to estimate the ability of multiple sampling points to capture a "representative" sample within these concentration gradients, Table 5 was constructed. Table 5 gives the mean and standard deviation of the daily concentration measurements 40 feet downstream from the weir for Runs 6-19. (Appendix IV). These calculations were conducted for field points 13, 14, 15 and 16 and all possible averages of two and three of these points.

The first four rows of Table 5 give the mean concentrations and standard deviations of four single sampling points which represent the variations in concentration which a single sampling point would detect on a day to day basis. Although a single sampling point experiences small fluctuations during the sampling (standard deviation averages 2.4%) the fluctuations on a day to day basis can be higher (standard deviation is greater than 4%). Ninety-five percent of the daily measurements would be in the range from 88% to 111%.

Table 5 also gives similar results for all possible average of two and three of the field sampling points. The daily samples taken from two points could vary from 92% to 108%. The daily samples from three sampling points could vary from 97 to 104%

Calculating averages for four sampling points is meaningless since the normalized averages were computed using these measurements. The effectiveness of four sampling points can best be determined by comparing the theoretical dye concentration to the measured dye concentration. This was done by Claude Anderson (Appendix IV) and varies from 98.5% to 100.6% for runs 13 to 19.

The analysis of the field tests are based on 14 data sets taken at nearly the same flow conditions. Additional data and more extreme flow conditions could reveal greater scatter in the data.

TABLE 5. MEANS, STANDARD DEVIATIONS, AND 95% RANGE OF CONCENTRATIONS FROM 1, 2, OR 3 SAMPLING POINTS--BASED ON FIELD DATA COLLECTED 40 FT DOWNSTREAM FROM WEIR

Number of Points Averaged	Field Points Used in Averaging	Mean (%)	Standard Deviation (%)	Range of μ ± 2σ (%)	Spread of μ ± 2σ (%)
1	13	103	3.9	111-88	23
1	14	100	3.3		
1	15	100	3.1		
1	16	97	4.3		
2	13, 14	102	3.2	108-93	15
2	13, 15	102	1.2		
2	13, 16	100	1.6		
2	14, 15	100	1.5		
2	14, 16	98	1.1		
2	15, 16	99	3.1		
3	13, 14, 15	101	1.5	104-97	7
3	13, 14, 16	100	1.2		
3	13, 15, 16	100	1.1		
3	14, 15, 16	99	1.2		

V. CONCLUSIONS

Dye concentration measurements taken in a 1:12 scale sectional model of the Metropolitan WWTP dechlorination basin were analyzed to predict the benefits of multiple transverse sampling points. The data from the sectional model weighted with field measurements was used to synthesize data records representing composite samples from two, three, and four sampling points located in the same cross section (40 ft downstream from the weir). Stochastic analysis was performed on the data for three flows (175 mgd, 300 mgd and 650 mgd), two tailwater elevations (~ 687' and ~ 693' AMSL) and two sampling elevations (685' and 0.5 ft below W.S.)

The results are summarized in Tables 3 and 4 and can be interpreted as follows:

(a) There appears to be a large difference between sampling at low and high tailwater stage.

(b) To achieve similar "representativeness" (measured in terms of concentration deviation from a true cross-sectional and time average), sampling duration can be reduced as the flow is increased when the tailwater is low. The reverse is true at high tailwater stage.

(c) Increasing the number of sampling points from 1 to 2 or 3 or 4 permits reduced sampling duration when high accuracies (deviations of 1 to 2%) are desired. If deviations greater than 4% are acceptable, the sampling duration can be kept at 15 seconds or less to obtain a representative sample, and the number of sampling points is not crucial.

(d) A very important consideration in the selection of the numbers of sampling points in addition to time-averaging described under (c) above, is the existence of mean concentration gradients in the transverse direction to the flow, as seen in the field studies. To capture that gradient, several sampling stations (~ 4) seem sufficient as concluded in Appendix IV.

A simple statistical analysis of the data in Table 3 in Appendix IV indicates that the time averaged concentration at any one point deviates as much as 12% from the true cross-sectional mean at the 95% confidence level. The value drops to 8% for the composite of two sampling locations and to 4% for the composite of three sampling stations.

(e) The representativeness of a 1 second grab sample has been found to depend on tailwater elevation, flow rate, and number of simultaneous sampling points (see Table 4). If only one sampling point is used the deviation from the record mean can be as high as 22% at low tailwater and 7% at high tailwater. A dependence on flow rate exists. If four simultaneous sampling points are used, the above values drop to 6% and 4%, respectively.

REFERENCES

McConnell, H. L., "Engineering Report on the Dechlorination Facilities at MWTP, June-October 1986." Metropolitan Waste Control Commission, St. Paul, Minnesota, Engineering/Construction Dept., Dec 16, 1986.

Stefan,, H. G. and Johnson, T. R., "Dechlorination Basin Hydraulics," Project Report No. 250, St. Anthony Falls Hydraulic Laboratory, University of Minnesota, October 1986.

Stefan, H. G. and Johnson, T. R., "Effluent Sampling Location and Duration Study for the Metropolitan Wastewater Treatment Plant, St. Paul, Minnesota," Project Report No. 259, St. Anthony Falls Hydraulic Laboratory, University of Minnesota, June 1987.

APPENDIX I - CORRELATION FUNCTION

The correlation coefficient of two series can be defined as the covariance divided by the product of the standard deviation of those series, or

$$\rho_{x,y} = \frac{\sigma_{x,y}}{\sigma_x \sigma_y}$$

where

$$\sigma_{x,y} = \int_{-\infty}^{\infty} \int_{-\infty}^{\infty} (x - \mu_x)(y - \mu_y) P_{x,y}(x,y)\,dx\,dy$$

$$\mu_x = \int_{-\infty}^{\infty} x\,P_x(x)dx$$

$$\sigma_x^2 = \int_{-\infty}^{\infty} (x - \mu_x)^2\,P_x(x)dx$$

$$\mu y = \int_{-\infty}^{\infty} y\,P_y(y)dy$$

$$\sigma_y^2 = \int_{-\infty}^{\infty} (x - \mu_y)^2 P_y(y)dy$$

The sample estimate of these parameters, ρ_{xy}, $\sigma_{x,y}$, μ_x, μ_y, $\sigma^2{}_x$, $\sigma^2{}_y$ are r_{xy}, $S_{x,y}$, $\overline{x}$, $\overline{y}$, $S^2{}_x$, $S^2{}_y$.

Therefore,

$$\mu_x \approx \overline{x} = \sum_{i=1}^{n} x_i/n$$

$$\mu_y \approx \overline{y} = \sum_{i=1}^{n} y_i/n$$

$$\sigma_x^2 \approx S_x^2 = \sum_{i=1}^{n} (x_i - \overline{x})^2/n-1)$$

$$\sigma_y^2 \approx S_y^2 = \sum_{i=1}^{n} (y_i - \overline{y})^2/(n-1)$$

$$\sigma_{xy} \approx S_{xy} = \sum_{i=1}^{n} (x_i - \overline{x})(y_i - \overline{y})/(n-1)$$

$$\rho_{xy} \approx r_{xy} = \frac{\sum_{i=1}^{n} (x_i - \overline{x})(y_i - \overline{y})/n-1}{\left(\sum_{i=1}^{n} (x_i - \overline{x})^2/(n-1)\right)^{1/2} \left(\sum_{i=1}^{n} (y_i - \overline{y})^2/(n-1)\right)^{1/2}}$$

where

n = number of descrete samples.

x_i, y_i = the i^{th} descrete sample of x and y series, respectively.

The equation for r_{xy} can be rearranged, eliminating $\overline{x}$ and $\overline{y}$ such that

$$r_{xy} = \frac{\sum_{i=1}^{n} x_i y_i - \Sigma x_i \, \Sigma y_i/n}{\left(\Sigma x_i^2 - (\Sigma x_i)^2/n\right)^{1/2} \left(\Sigma y_i^2 - (\Sigma y_i)^2/n\right)^{1/2}}$$

The correlation function $\rho_{x,y}$ = 1 indicates perfect correlation; $\rho_{x,y}$ = 0 indicates no correlation.

APPENDIX II - AUTOCORRELATION

An autocorrelation is the correlation of observations at one time period with observation in a preceding time period. The autocorrelation coefficient $\rho(k)$ can be estimated by $r(k)$ is much like the correlation coefficient described in Appendix I except the observations come from the same series, separated by a time lag, or

$$r(k) = \frac{\sum_{i=1}^{n-k} x_i x_{i+1} - \sum_{i=1}^{n-k} x_i \sum_{i=1}^{n-k} x_{i+k}/(n-k)}{\left[\sum_{i=1}^{n-k} x_i^2 - \left(\sum_{i=1}^{n-k} x_i\right)^2/(n-k)\right]^{1/2} \left[\sum_{i=1}^{n-k} x_{i+k} - \left(\sum_{i=1}^{n-k} x_{i+k}\right)^2/(n-k)\right]^{1/2}}$$

where n = number of discrete samples

x_i = the i^{th} discrete sample

k = lag (number of discrete samples between series considered)

$\rho(k) = 1$ indicates a perfect correlation (this happens always at $k = 0$, i.e. $\rho(0) = 1$) and $\rho(k) = 0$ indicates no correlation.

APPENDIX III - WEIGHING FACTORS USED IN EQUATION 1

The weighing factors chosen in the synthesis of the composite time series (using Eq. 1) were based on the field data in Appendix IV. The most extreme case listed was Run #10 where transverse concentration gradient was nearly linear from 108% to 92% across the channel. For the synthesis of the composite record modeling four transverse sampling points, the field results for points 13, 14, 15 and 16 were used directly on weighing factors. For three sampling points, the field points 13 and 16 were used for factors W_1 and W_3 while the average of the center two field points (14, 15) was used for W_2. The weighing factors chosen for the modeling of two transverse points were the average of field points 13 and 14 for W_1 and the average of field points 15 and 16 for W_2. Figure 8 illustrates this schematically.

Number of Transverse Points

1 W_1 = Average of #14 and #15 = 99.5

2 W_1 = Average of #13 and #14 = 105.5
W_2 = Average of #15 and #16 = 94

3 W_1 = #13 = 108
W_2 = Average of #14 and #15 = 99.5
W3 = #16 = 92

4 W_1 = #13 = 108
W_2 = #14 = 103
W_3 = #15 = 96
W_4 = #16 = 92

FIELD MEASUREMENTS

#13 = 108
#14 = 103
#15 = 96
#16 = 92

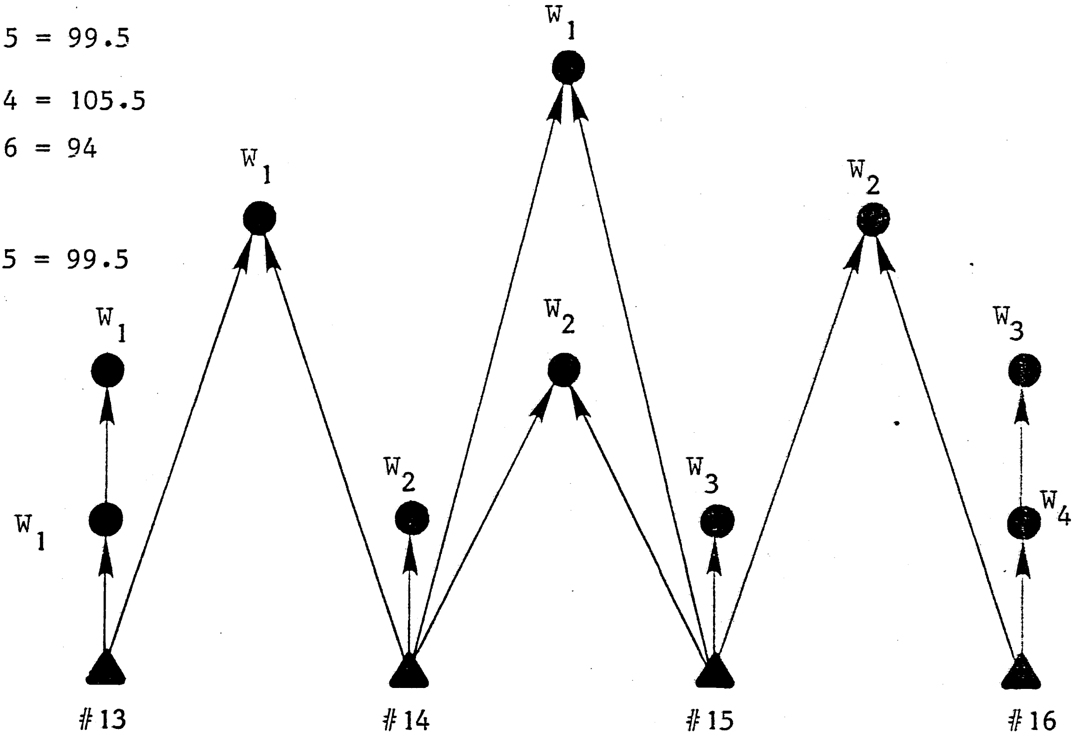


Figure 8. Schematic of the method of determining weighting factors.

APPENDIX IV

Received 5/5/87

METROPOLITAN
WASTE
CONTROL
COMMISSION

Office Memorandum

April 30, 1987

TO: H.Boyer

FROM: C. Anderson

RE: Metro Dechlorination Basin
Transverse Gradient Measurement

Recently, tests have been conducted as part of a study evaluating the Metro Plant's dechlorinated effluent sampling system. The University of Minnesota, using a scale model of the dechlorination basins center section, evaluated the vertical and longitudinal mixing characteristics of the basin. Using dye dilution procedures and cross sectional sampling, the MWCC measured transverse concentration gradients in the basin.

The existing sampling system consists of two sets of four sample lines spaced across the channel. One set is in the chlorine contact channel upstream of the dechlorination basin and sulfur dioxide diffusers. The second set is located in the dechlorination basin upstream of the effluent weir. Four sample pumps located in the adjacent effluent sampling building are used to take a continuous sample from both cross sections. Each pump pulls sample from two locations. The discharge from two pumps is then combined to get a composite sample of the cross section. The sample lines are equipped with valves, so individual samples can be collected by temporarily shutting off one of the two inlet lines to each pump.

A total of 19 tests were completed. For each test, a chemical metering pump was set up to inject dye into the north sulfur dioxide diffuser. This diffuser consisted of three drop pipes, each with a flow meter, and two longitudinal perforated diffuser pipes. According to these flow meters, the sulfur dioxide solution feed rates were approximately the same through each drop pipe during these tests.

Samples were collected from the existing dechlorinated effluent sample lines as well as from temporary sample lines set up at two cross sections for this test. One set of sample lines was placed along the existing walkway over the effluent weir. This resulted in samples being collected approximately 5 ft downstream of the effluent weir. A second cross section was obtained by fastening sample lines to a cable stretched across the channel 40 ft downstream of the effluent weir. All sample lines were set to remove sample from near mid-depth, approximately 3 ft above the channel bottom. The four transverse locations were chosen to be approximately inline with the existing effluent samplers. The location of the sampling points are shown in Figure 1. The temporary sample lines were constructed of inch polyethylene tubing. Each of the sample lines was connected to a flexible impeller pump. The samples were collected in 50 ml polyethylene vials. The dye concentration was determined with a Turner Designs Model 10 Fluorometer.

Before any dye was added, samples were taken to allow determination of the background fluorescence. After the dye pump ran for 15 minutes, grab samples were collected consecutively at the appropriate locations. Approximately 5-seconds was required to fill a sample vial. The samples were taken at 30 second or 1 minute intervals, for a total of 20 samples at each location. Table 1 describes the samples collected for each run. Using the results obtained from the individual sampling locations, a mean concentration was calculated for each cross section at each sample time, to generate an arithmetically composited sample.

The dye concentration data was normalized by dividing each individual sample concentration by the mean concentration of all the samples collected at the downstream station for a given run. The mean of the data collected at the cross section 5-ft downstream was used to normalize the data for Runs 1-5 while the cross section 40 ft downstream of the weir was used for Runs 6-19. Using the actual concentrations and normalized concentrations, a mean and standard deviation was calculated for each sample location. These concentrations for each sample and each location are available as an Appendix.

Using the wastewater flow rate and dye pumping rate a theoretical dye concentration in the dechlorination basin can be calculated. Wastewater flow rates can be obtained from flow meters located in the east and west effluent channel or by summing the mixed liquor flow rates to all operating aeration basins, and subtracting the return sludge and waste sludge flows. When this was done, the flow rates obtained from the two procedures, often did not agree. While Runs 13-19 were being conducted, the east and west channel flow rates were measured using dye dilution. These were independent dye tests done at the same time as the dye test in dechlorination, but set up not to interfere with the downstream test. The results of these tests are summarized in Table 2. The theoretical dye concentration was calculated using the flow rates obtained from the dye dilution procedure.

The normalized mean and standard deviations of each run at each sample point are listed in Table 3 and Table 4. The means for each point at each cross section are again presented in Figures 2-4.

Based on this set of data collected, it appears that:

1. Transverse gradients exist at all cross sections. At the 40 ft downstream cross section, differences from the high and low individual site to the mean averaged ±5%.

2. The variability in concentration with time, as measured by the standard deviation of the composited cross sectional samples, decreased with distance downstream. It went from 2.2 percent upstream of the weir to 1.9 percent at the 5-ft downstream locations, to 1.4 percent at the 40-ft downstream location.

3. Using four sample points, relatively good agreement was found for the theoretical concentration and the measured concentration at the 40-ft downstream location.

The previous work done at SAFHL determined that a subsurface sample collected at the 40 ft downstream site was the preferred location under the widest variety of operating conditions. Due to the existence of transverse concentration gradients found in the tests described here, a sampling system incorporating multiple sampling points will be necessary to obtain a representative sample. From reviewing these test results, it appears that four locations will probably be sufficient to collect a representative sample. However, further work will be conducted at SAFHL to determine the relationship between the number of sampling points, and the required sample duration to obtain a sample within selected limits of the true concentration.

cc. R. Polta
M. Hensel
J. Hart
H. McConnel
H. Stefan, SAFHL

Table 1. Description of Sampling.

Run	Interval	Sampling Stations*
1	30 sec	Comp. 5-8,9,10,10a,11,12 (two pumps & sample
2	30 sec	Comp. 5-8,9,10,10a,11,12 lines at Sta. 10)
3	30 sec	5,6,7,8,9,10,11,12
4	30 sec	5,6,7,8, Comp. 5-8,9,10,11,12
5	30 sec	5,6,7,8, Comp. 5-8,9,10,11,12
6	1 min	5,6,7,8,9,10,12,13,14,15,16
7	1 min	7,8,9,10,11,12,13,14,15,16
8	1 min	5,6,7,8,9,10,11,12,13,14,15,16
9	1 min	5,6,7,8,9,10,11,12,13,14,15,16
10	1 min	5,6,7,8,9,10,11,12,13,14,15,16
11	1 min	5,6,7,8,9,10,11,12,13,14,15,16
12	30 sec	13,14,15,16
13	30 sec	13,14,15,16
14	30 sec	13,14,15,16
15	30 sec	13,14,15,16
16	30 sec	13,14,15,16
17	30 sec	13,14,15,16
18	30 sec	13,14,15,16
19	30 sec	13,14,15,16

*See Figure 1 for locations

TABLE 2. FLOW RATE COMPARISONS

RUN	DATE	TIME	AERATION BASIN METERS			EFFLUENT CHANNEL METERS			DYE DILUTION PROCEDURE			CROSS SECTION MEAN DYE CONCENTRATION			
			EAST	WEST	TOTAL	EAST	WEST	TOTAL	EAST	WEST	TOTAL	5-8	9-12	13-16	THEOR.
1	02/23/87	10:06	141	104	245							70.8	72.6		
2	02/24/87	11:50	95	91	186	140	94	234				58.4	59.4		
3	02/26/87	14:35	133	96	229	135	87	222				61.8	56.4		
4	03/02/87	14:55	157	101	258	167	101	268				80.5	74.5		
5	03/04/87	13:15	130	92	222	97	95	192				96.8	91.1		
6	03/16/87	13:20	162	126	288	169	93	262				35.8	33.5	34.2	
7	03/17/87	13:15	125	101	226	144	71	215				44.1	44.6	44.1	
8	03/18/87	13:30	149	113	262	170	94	264				37.1	37.4	37.7	
9	03/24/87	11:00	131	112	243	149	100	249				46.9	48.4	47.6	
10	03/25/87	13:15	175	105	280	127	138	265				42.5	41.7	42.4	
11	03/26/87	13:05	126	131	257	133	95	228				40.4	42.2	42.6	
12	03/31/87	14:35	116	137	253	121	122	243						41.1	
13	04/01/87	11:05	111	108	219	110	102	212	111	101	212			50.1	50.1
14	04/02/87	13:15	132	135	267	125	109	234	109	101	211			39.8	39.6
15	04/03/87	13:40	139	131	270	140	99	239	108	91	199			40.1	40.6
16	04/06/87	14:15	138	143	281	107	120	227	108	122	230			26.9	27.3
17	04/07/87	13:45	140	129	269	136	117	253	103	111	214			30.2	30.5
18	04/08/87	09:15	104	104	208	93	67	160	76	67	143			42.8	43.1
19	04/09/87	09:00	96	64	160	90	72	162	69	70	139			84.7	84.2

TABLE 3. NORMALIZED SAMPLE MEAN CONCENTRATIONS

	EXISTING DECHLOR SAMPLERS					5 FT DOWNSTREAM OF WEIR					40 FT DOWNSTREAM OF WEIR			
RUN	E WALL (8)	E CNTR (7)	W CNTR (5)	W WALL (6)	COMPOSITE 5-8	E WALL (9)	E CNTR 10	W CNTR (11)	W WALL (12)	COMPOSITE (9-12)	E WALL (13)	E CNTR (14)	W CNTR (15)	W WALL (16)
1					0.98	0.79	1.08	1.12	1.01					
2					0.98	0.88	1.15	1.09	0.88					
3	1.05	1.06	1.14	1.14	1.10	0.73	1.11	1.16	1.00					
4	1.06	1.08	1.09	1.09	1.08	1.01	1.03	1.06	0.91					
5	1.14	0.97	1.11	1.04	1.06	1.06	1.00	0.99	0.95					
6	0.99	0.97	1.11	1.11	1.05	1.00	0.99		0.95	0.98	0.94	0.98	1.04	1.03
7	1.03	0.97				1.07	0.97	1.06	0.95	1.01	1.02	0.97	1.03	0.98
8	0.98	0.97	1.03	0.95	0.98	1.08	1.01	0.97	0.91	0.99	0.98	0.94	1.04	1.04
9	1.00	1.00	0.99	0.94	0.98	1.06	1.02	1.02	0.97	1.02	1.09	1.01	0.95	0.96
10	1.02	1.06	0.97	0.97	1.00	1.08	1.04	0.97	0.86	0.99	1.08	1.03	0.96	0.92
11	0.98	1.00	0.88	0.93	0.95	1.11	1.09	0.93	0.82	0.99	1.07	1.06	0.98	0.90
12											1.04	1.02	1.02	0.92
13											1.01	1.01	1.04	0.94
14											1.03	1.03	1.00	0.94
15											1.02	1.02	0.98	0.99
16											1.03	0.99	1.00	0.98
17											1.05	1.01	1.00	0.95
18											1.02	0.95	1.03	1.01
19											1.04	0.99	0.97	1.01
AVE	1.03	1.01	1.04	1.02	1.02	0.99	1.04	1.04	0.93	1.00	1.03	1.00	1.00	0.97

TABLE 4. NORMALIZED SAMPLE STANDARD DEVIATIONS

	EXISTING DECHLOR SAMPLERS					5 FT DOWNSTREAM OF WEIR					40 FT DOWNSTREAM OF WEIR				
RUN	E WALL (8)	E CNTR (7)	W CNTR (5)	W WALL (6)	COMPOSITE 5-8	E WALL (9)	E CNTR 10	W CNTR (11)	W WALL (12)	COMPOSITE (9-12)	E WALL (13)	E CNTR (14)	W CNTR (15)	W WALL (16)	COMPOSITE (13-16)
1					0.021	0.045	0.023	0.016	0.029	0.016					
2					0.022	0.039	0.028	0.022	0.032	0.011					
3	0.039	0.033	0.071	0.060	0.039	0.022	0.038	0.034	0.042	0.024					
4	0.024	0.022	0.028	0.027	0.010	0.036	0.023	0.027	0.033	0.010					
5	0.045	0.032	0.036	0.033	0.021	0.080	0.024	0.034	0.042	0.027					
6	0.072	0.046	0.047	0.046	0.034	0.062	0.035		0.035	0.024	0.041	0.018	0.019	0.027	0.016
7	0.053	0.034				0.033	0.028	0.021	0.029	0.013	0.025	0.012	0.017	0.029	0.012
8	0.044	0.036	0.038	0.043	0.015	0.075	0.045	0.031	0.028	0.028	0.028	0.013	0.038	0.021	0.013
9	0.046	0.053	0.032	0.061	0.025	0.049	0.040	0.035	0.025	0.014	0.022	0.017	0.033	0.035	0.012
10	0.037	0.050	0.047	0.037	0.017	0.044	0.035	0.054	0.034	0.023	0.034	0.031	0.022	0.025	0.009
11	0.038	0.036	0.037	0.046	0.016	0.054	0.029	0.042	0.025	0.025	0.047	0.024	0.030	0.023	0.019
12											0.017	0.017	0.015	0.023	0.010
13											0.027	0.024	0.023	0.031	0.012
14											0.018	0.026	0.011	0.014	0.009
15											0.019	0.017	0.021	0.016	0.012
16											0.026	0.029	0.024	0.022	0.011
17											0.025	0.023	0.016	0.011	0.013
18											0.043	0.007	0.027	0.040	0.024
19											0.029	0.017	0.031	0.028	0.016
AVE	0.044	0.038	0.042	0.044	0.022	0.049	0.031	0.031	0.032	0.019	0.029	0.020	0.023	0.024	0.014

FIGURE 1. DYE STUDY SAMPLING LOCATIONS

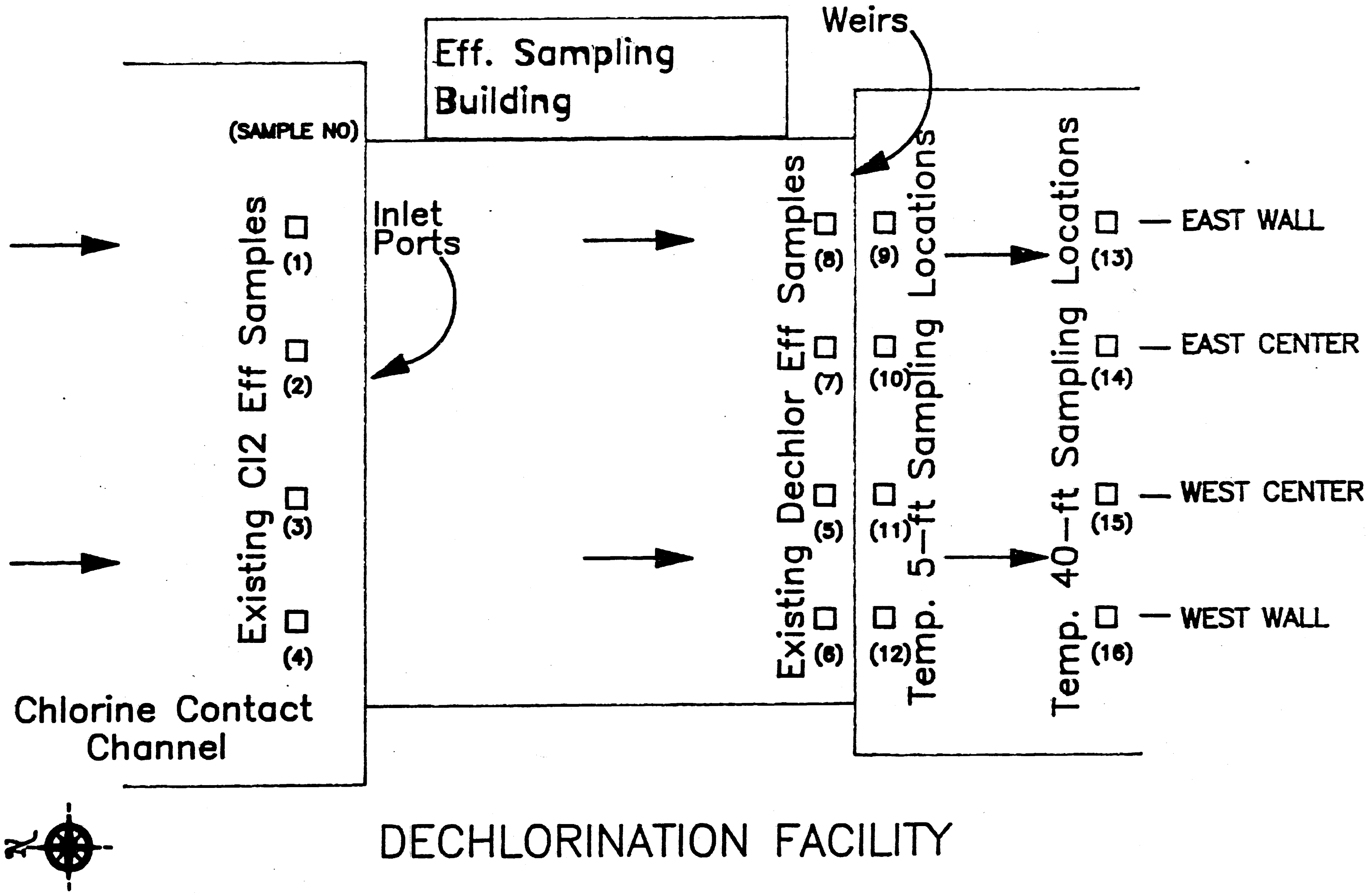


FIGURE 2. CROSS–CHANNEL CONCENTRATION GRADIENTS

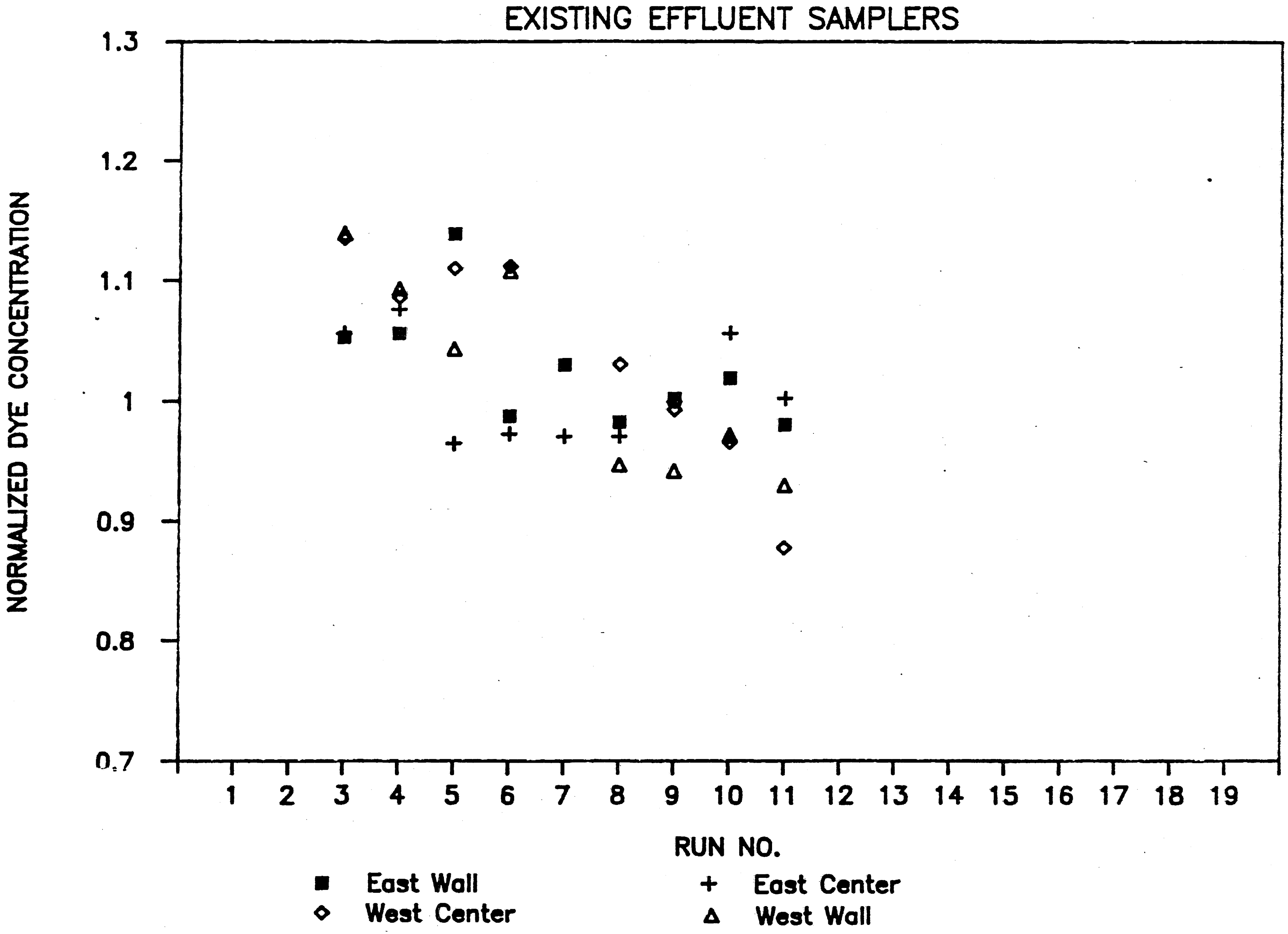


FIGURE 3. CROSS–CHANNEL CONCENTRATION GRADIENTS

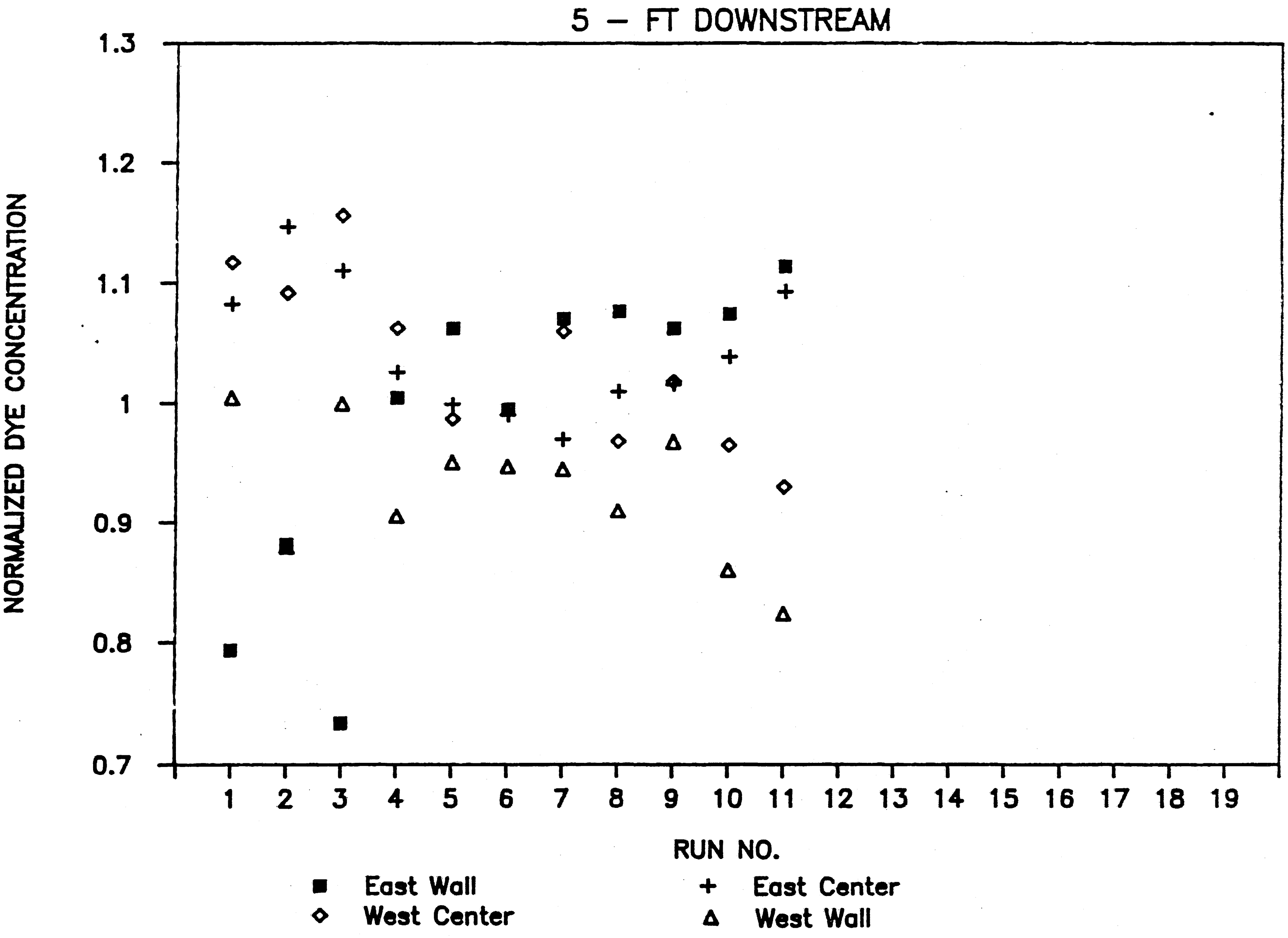


FIGURE 4. CROSS-CHANNEL CONCENTRATION GRADIENTS