Protecting Our Water Environment

Metropolitan Water Reclamation District of Greater Chicago

RESEARCH AND DEVELOPMENT DEPARTMENT

REPORT NO. 04-10

ESTIMATION OF THE ESCHERICHIA COLI TO FECAL COLIFORM RATIO IN WASTEWATER EFLUENTS AND AMBIENT WATERS OF THE METROPOLITAN WATER RECLAMATION DISTRICT OF GREATER CHICAGO

July 2004

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ESTIMATION OF THE *ESCHERICHIA COLI* TO FECAL COLIFORM RATIO IN WASTEWATER EFFLUENTS AND AMBIENT WATERS OF THE METROPOLITAN WATER RECLAMATION DISTRICT OF GREATER CHICAGO

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ACKNOWLEDGEMENTS

Dr. Prakasam Tata, Assistant Director of Research and Development, Environmental Monitoring and Research Division (retired), is acknowledged for having the foresight to direct that this study be done. All microbiological analyses were conducted by Andrea Maka, Laboratory Technician II; Kathy Jackowski, Laboratory Technician II; and Dave Roberts, Laboratory Technician I. This report was reviewed by Bernard Sawyer, Assistant Director of Research and Development, Environmental Monitoring and Research Division. This report was typed by Ms. Joan Scrima.

DISCLAIMER

Mention of proprietary equipment and chemicals in this report does not constitute endorsement by the Metropolitan Water Reclamation District of Greater Chicago.

SUMMARY AND CONCLUSIONS

In 2000 the Metropolitan Water Reclamation District of Greater Chicago (District) began developing a database containing the results of *Escherichia coli* (EC) and fecal coliform (FC) analyses conducted on chlorinated and unchlorinated water reclamation plant (WRP) effluent samples and ambient water samples from the Des Plaines River, Chicago River and Calumet River watersheds, and Lake Michigan. It was hoped that this database would facilitate the comparison of EC densities with the District's historical database of FC densities. This would be useful as upcoming United States Environmental Protection Agency (USEPA) regulations mandate the use of EC for assessing bacterial water quality. The results of 2,910 analyses from 91 sample points were entered into the database between 2000 and 2003.

Six different statistical approaches were considered to determine the best estimator of the EC/FC ratio, referred to as R, for each sample type, including the quotient of the arithmetic means of measured EC and FC densities, the means of the quotients of individual EC/FC values, regression analysis, maximum likelihood estimators (based on the joint distribution of the random variables EC and FC), the quotient of the geometric means (GMs) of measured EC and FC densities, and uniformly minimum variance unbiased (UMVU) estimators. These estimators are referred to as R_1, R_2, R_3, R_4, R_5, and R_6, respectively, in this report. Values of R calculated for the different sample types were compared statistically. The findings of this study are listed below.

1. The results of this and other studies to date indicate that the EC to FC ratio in polluted ambient water is not constant. The ratio of EC to FC in polluted ambient water is variable and would be influenced by a number of factors, including the type of water body and the source of pollution.

2. The EC/FC ratio, R, was shown to be lognormally distributed. Therefore, the UMVU estimator of R was derived from the data using the method of Shimuzu (1988). The values of R calculated with the UMVU estimator (R_6) are 0.84 (WRP unchlorinated effluent), 0.97 (WRP chlorinated effluent), 0.93 (Calumet River Watershed), 0.83 (Chicago River Watershed), 0.92 (Des Plaines River Watershed), and 0.56 (Lake Michigan). In terms of MSE, R_6 is as good an estimator as any

of the other estimators used. As discussed later, the UMVU estimator is unique, and there is no other estimator which will be unbiased and have less variance. Since there is an UMVU estimator for the lognormal distribution, it should be used when possible, as it is the best estimator of R.

3. The statistical methods and criteria used in this study may be appropriate in finding other ratios, for example, specific pathogen to FC or EC ratios, especially those used in risk analysis studies, where the best estimate of the ratio would be necessary.

4 The use of the quotient of the arithmetic means of EC and FC to find R (R_1) is not appropriate for this data set.

5. The mean of the quotients of the individual EC/FC values (R_2), in terms of mean square error (MSE), is as good an estimator as any of the other estimators used. Using this estimator the values of R were calculated to be 0.84 (WRP unchlorinated effluent), 0.97 (WRP chlorinated effluent), 1.04 (Calumet River Watershed), 0.84

(Chicago River Watershed), 0.93 (Des Plaines River Watershed), and 0.53 (Lake Michigan). These values are in close agreement with those obtained using the maximum likelihood estimator, (R_4), and the UMVU estimator (R_6). These results indicate that R_2 can be a useful estimator for certain purposes.

6. Regression analysis (R_3), in terms of MSE, is not the best estimator of R (the EC/FC ratio), but high R^2 (the sample coefficient of determination) values (ranging from 0.84 for the Des Plaines River Watershed and Lake Michigan to 0.98 for the Calumet River Watershed) indicate that it can be a useful estimator, especially for predicting EC densities from known FC densities. Using this estimator the values of R were calculated to be 0.75 (WRP unchlorinated effluent), 1.03 (WRP chlorinated effluent), 0.76 (Calumet River Watershed), 0.43 (Chicago River Watershed), 0.68 (Des Plaines River Watershed), and 0.78 (Lake Michigan).

7. The maximum likelihood estimate of R is obtained from the properties of the lognormal distribution

(R_4). Using this estimator the values of R were calculated to be 0.84 (WRP unchlorinated effluent), 0.97 (WRP chlorinated effluent), 0.93 (Calumet River Watershed), 0.83 (Chicago River Watershed), 0.92 (Des Plaines River Watershed), and 0.57 (Lake Michigan). The lower and upper 95 percent confidence intervals for the respective sample types were calculated to be 0.79 to 0.90, 0.95 to 1.00, 0.83 to 1.00, 0.79 to 0.88, 0.87 to 0.98, and 0.45 to 0.69. In terms of MSE, R_4 is as good an estimator as any of the other estimators used.

8. Using the ratio of the geometric mean of EC to the geometric mean of FC (R_5) to estimate R for this data set was found to be inappropriate because it ignores the variance of R calculated from the lognormal distribution, and it usually results in an underestimation of R.

9. As discussed later, for ease of calculation it may be appropriate in many cases to use the maximum likelihood estimator (R_4) to determine R, but the UMVU estimator should be used when the best estimate of R is required because there is

no other estimator which will be unbiased and have less variance. For ease of calculation it may also be appropriate in some cases to use R_2 to calculate R, if the joint distribution of the random variables EC and FC is unknown.

10. The value of R calculated from the data for Lake Michigan samples, using both R_4 and R_5, is significantly lower ($p = 0.05$) than the values of R for all of the other sample types. There is no significant difference between the R values calculated for the other sample types.

11. The best estimates of R (i.e., calculated using UMVUE or R_6) reported here for District WRP effluents and river samples are relatively high, ranging from 0.84 to 0.97, indicating that proposed effluent and ambient water quality standards based upon EC may be more difficult to meet than those currently based upon FC. For example, an FC limit of 400 cfu/100 mL is currently used for a General Use water quality standard in Illinois. Current USEPA guidance recommends that it be replaced by an EC limit of

235 cfu/100 mL representing an assumed EC/FC ratio of 0.59.

INTRODUCTION

Role of the District in the Prevention of Waterborne Disease

The District plays an important role in the prevention of waterborne disease. In fact, the District was created in 1889 for this very purpose. The dramatic decrease in waterborne disease in Chicago as a result of the District's activities is a matter of public record (Lue-Hing, 1992).

Monitoring WRP Effluent and Ambient Waters for FC

Today the District owns and operates seven WRPs. These WRPs remove pathogenic microorganisms as well as toxins produced by microorganisms from wastewater. The District monitors WRP effluents for FC as required by National Pollutant Discharge Elimination System (NPDES) Permits. Fecal coliforms have been the generally used, although not always the generally accepted, indicator of the sanitary quality of environmental waters since the mid-1970s (Fujioka, 2002). Their presence in water indicates fecal contamination and that pathogens might be present. Historically, coliform bacteria (including FC) were used as the basis of water quality standards in the United States. Other indicators proposed over the years included fecal streptococci, enterococci, *Clostridium perfringens*, *Staphylococcus aureus*, and *Escherichia coli* (EC).

Ambient water monitoring for bacteria is generally not required in NPDES permits, although in special cases it could be required. Ambient water monitoring for bacteria is not required in the District's NPDES permits. Nevertheless, the District monitors receiving waters and other ambient waters in the District for FC. Ambient microbiological water quality standards in Illinois are currently based upon FC. The Illinois Swimming Pool and Bathing Beach Code (77 Illinois Administrative Code 820) (Bathing Beach Code) presently allows for the monitoring of either EC or FC levels. The District monitors Lake Michigan for FC and EC following river reversals to the lake.

USEPA Ambient Water Quality Criteria for Bacteria - 1986

In the early 1970s the USEPA recognized that the use of coliforms, including FC, as a basis for water quality standards had certain limitations. Therefore, the USEPA studied the relationships between swimming-associated illnesses and the ambient densities of indicator bacteria and published the results (Cabelli, 1983 and DuFour, 1984). These studies demonstrated a direct relationship between the density of EC and enterococci in ambient waters and the incidence of swimmer-associated gastroenteritis. As a result of these studies the

USEPA concluded that FC, the indicator group which it had recommended up until that time, was inadequate (Federal Register Volume 49 Number 102, May 24, 1984). The USEPA concluded that:

1. Enterococcus has a far better correlation with swimming-associated illnesses in both marine and fresh waters than does FC; and
2. EC has a correlation in fresh waters equal to the enterococcus, but does not correlate as well in marine waters.

As a result of the Cabelli and Dufour studies, the USEPA (1986) recommended EC or enterococci for monitoring the microbial quality of freshwaters. In 2000, the USEPA announced the intention "to promulgate federal water quality standards, with the goal of assuring that the USEPA recommended 1986 bacteria water quality criteria apply in all States, Territories, and authorized Tribes, as appropriate, by 2003" (USEPA, 2000a). Parenthetically, a risk analysis study by Wade et al. (2003) supports the USEPA conclusion that EC is a better predictor of gastrointestinal illness than other bacterial indicators including FC.

Development of a Database of EC to FC Ratios

In 2000, the USEPA published guidance to assist the states in the implementation of the ambient water quality criteria for bacteria which it recommended in 1986. Anticipating that the Illinois Pollution Control Board (IPCB) will eventually adopt bacteriological water quality standards based upon EC, the District began developing a database of EC to FC ratios during 2000. It was hoped that this database would facilitate the comparison of EC densities with the District's historical database of FC densities. The results of 2,910 analyses from 91 sample points were entered into this database between 2000 and 2003. The data collected during that four-year period were analyzed statistically, and EC to FC ratios were calculated for WRP effluents, rivers/waterways, and Lake Michigan (post-river reversals). The results are presented in this report.

Analytical Methods

It is appropriate to discuss how the analytical methods were chosen for this study. The USEPA previously adopted methods for monitoring FC in effluents and ambient waters. These methods are shown in 40 CFR Part 136. At the time this study began there were no USEPA approved methods for EC in ambient waters or wastewater. Guidance recommended m-TEC or modified m-TEC for EC in ambient waters (USEPA, 2000). At the time this study was initiated the decision was made to use the m-TEC method to measure EC concentrations in wastewater and ambient river waters, because this was the only method recommended by the USEPA for ambient waters. As mentioned, there was no guidance published by the USEPA for measuring EC concentrations in wastewater effluents, but it seemed prudent to use the same method used for the ambient waters.

The Quanti-Tray 2000 (IDEXX Laboratories, Westbrook, Maine) method was used to measure EC in samples of Lake Michigan because this is the method used by the Illinois Department of Public Health (IDPH) and the Chicago Park District for Lake Michigan beach monitoring. Fecal coliforms in Lake Michigan were measured using the 7-hour test (APHA, 1992a). This method was adopted many years ago by the District to monitor Lake Michigan beaches for microbial contamination following river reversals because results are available after 7 hours as compared to 24 hours for the standard test with m-FC agar (APHA, 1992b). The 7-hour test is not a USEPA approved method.

The USEPA approved test methods for EC for ambient water quality monitoring after the data for this study were collected [Federal Register July 21, 2003, (Volume 68, Number

139) pages 43271-43283]. The analytical methods approved for monitoring EC in ambient waters include the m-TEC, modified m-TEC, and the Quanti-Tray 2000. The USEPA is currently in the process of trying to validate EC methods for use with wastewater effluent and plans to propose them by the end of 2004 [Federal Register July 21, 2003, (Volume 68, Number 139) pages 43271-43283].

The analytical methods used could theoretically effect the EC/FC ratio. It was not the purpose of this study to determine how methods would effect this ratio. However, some parallel data were collected using different methods to measure both EC and FC concentrations.

Statistical Approach

Standard Methods (1992d) states that "the preferred statistic for summarizing microbiological data is the geometric mean (GM)." This recommendation is based upon the fact that bacterial counts are often lognormally distributed. Standard Methods (1992d) also states that "the best estimate of central tendency of lognormal data is the GM." This statement is not always true, and it is discussed in the Results and Discussion section of the report. For most purposes the use of the GM to express microbial density is appropriate. However, this is not always the case. In this study no assumptions about the distribution of the data or the best way to estimate the central tendency were made.

In this study six different approaches were considered to determine the best estimator of the EC/FC ratio, or R, for each sample type, including the use of the arithmetic means of measured EC and FC densities, the means of the quotients of individual EC/FC values, regression estimate, maximum likelihood estimators (based on the joint distribution of the random variables EC and FC), GMs of measured EC and FC densities, and UMVU estimators. These estimators, referred to as R_1, R_2, R_3, R_4, R_5, and R_6, respectively, are described in the Materials and Methods section of this report. All of these approaches are discussed in the Results and Discussion section of this report.

OBJECTIVES

This study was undertaken in 2000 with the overall objective of developing a database of EC to FC ratios to facilitate the comparison of EC and FC data collected in the District. The following specific objectives were identified in the planning to meet the overall objective:

1. To determine both the EC and FC densities in the following types of samples: effluent from the District's seven WRPs; ambient water samples from the District's man-made waterways; ambient water samples from other rivers in the Chicagoland area; ambient water samples collected from Lake Michigan following river reversals to Lake Michigan.
2. To determine the best statistical approach, from an analysis of the collected data, for determining the EC to FC ratios, and to calculate the EC to FC ratios for the various sample types listed above.
3. To compare the EC to FC ratios computed from the data for the various sample types listed above.

MATERIALS AND METHODS

Sampling Sites and Number of Samples

The sampling sites and the number of samples collected at each site are listed in Table 1. The locations of the sites are shown in Figures 1, 2, and 3.

Sample Collection, Transport, and Receiving

Water samples were collected in sterile 175 mL capacity polypropylene plastic bottles containing the following sterile reagents: 0.30 mL of a 15 percent solution of the disodium salt of ethylenediaminetetraacetic acid, and 0.1 mL of a 10 percent solution of sodium thiosulfate. Samples of WRP effluent were collected by Maintenance and Operations personnel (MWRDGC, 2003a,b,c,d,e). Water samples from rivers, creeks, and man-made waterways were collected by Industrial Waste Division personnel as part of the District's Ambient Water Quality Study (MWRDGC, 2002). All water samples from Lake Michigan were collected after heavy storms by Industrial Waste Division personnel (MWRDGC, 1994).

After collection, all samples were placed on ice and transported to the District's Analytical Microbiology Laboratory. All samples collected for purposes of NPDES Permit

METROPOLITAN WATER RECLAMATION DISTRICT OF GREATER CHICAGO

TABLE 1

SAMPLE SOURCES AND NUMBERS

Sample Source	Number of Samples
UNCHLORINATED WRP EFFLUENT	
North Side WRP (final outfall)	40
Stickney WRP (final outfall)	17
John E. Egan WRP (final outfall)	19
Hanover Park WRP (final outfall)	19
James C. Kirie WRP (final outfall)	19
CHLORINATED WRP EFFLUENT	
John E. Egan WRP (de-chlorinated final outfall)	180
Hanover Park WRP (de-chlorinated final outfall)	184
James C. Kirie WRP (de-chlorinated final outfall)	184
DES PLAINES RIVER WATERSHED	
Station 12 / Buffalo Creek at Lake-Cook Rd.	7
Station 13 / Des Plaines River at Lake-Cook Rd.	8
Station 17 / Des Plaines River at Oakton St.	9
Station 18 / Salt Creek at Devon Ave.	9
Station 19 / Des Plaines River at Belmont Ave.	10

METROPOLITAN WATER RECLAMATION DISTRICT OF GREATER CHICAGO

TABLE 1 (Continued)

SAMPLE SOURCES AND NUMBERS

Sample Source	Number of Samples
Station 20 / Des Plaines River at Roosevelt Rd.	8
Station 21 / Salt Creek at Brookfield Ave.	4
Station 22 / Des Plaines River at Ogden Ave.	7
Station 23 / Des Plaines River at Willow Springs Rd.	6
Station 24 / Salt Creek at Wolf Rd.	9
Station 29 / Des Plaines River at Stephen St.	8
Station 63 / West Branch DuPage River at Longmeadow Lane	8
Station 64 / West Branch DuPage River at Lake St.	27
Station 77 / Higgins Creek at Elmhurst Rd.	19
Station 78 / Higgins Creek at Willie Rd.	31
Station 79 / Salt Creek at Higgins Rd.	19
Station 80 / Salt Creek at Arlington Heights Rd.	28
Station 89 / West Branch DuPage River at Walnut Ave.	29
Station 90 / Poplar Creek at Route 19	7
Station 91 / Des Plaines River at Material Services Rd.	8
CHICAGO RIVER WATERSHED AND SANITARY AND SHIP CANAL	
Station 100 / Chicago River at Wells St.	8
Station 101 / North Shore Channel at Foster Ave.	9
Station 102 / North Shore Channel at Oakton St.	8

METROPOLITAN WATER RECLAMATION DISTRICT OF GREATER CHICAGO

TABLE 1 (Continued)

SAMPLE SOURCES AND NUMBERS

Sample Source	Number of Samples
Station 103 / West Fork North Branch Chicago River at Golf Rd.	7
Station 104 / North Branch Chicago River at Glenview Rd.	5
Station 105 / Skokie River at Frontage Rd.	8
Station 106 / West Fork North Branch Chicago River at Dundee Rd.	2
Station 107 / Chicago Sanitary and Ship Canal at Western Ave.	5
Station 108 / South Branch Chicago River at Loomis St.	7
Station 31 / Middle Fork North Branch Chicago River at Lake-Cook Rd.	7
Station 32 / Skokie River at Lake-Cook Rd.	7
Station 34 / North Branch Chicago River at Dempster St.	8
Station 35 / North Shore Channel at Central Ave.	7
Station 36 / North Shore Channel at Touhy Ave.	9
Station 37 / North Branch Chicago River at Wilson Ave.	7
Station 39 / South Branch Chicago River at Madison St.	8
Station 41 / Chicago Sanitary and Ship Canal at Harlem Ave.	7
Station 42 / Chicago Sanitary and Ship Canal at Route 83	7
Station 46 / North Branch Chicago River at Grand Ave.	8
Station 48 / Chicago Sanitary and Ship Canal at Stephen St.	7
Station 73 / North Branch Chicago River at Diversey Parkway	8
Station 74 / Chicago River at Lake Shore Drive	7
Station 75 / Chicago Sanitary and Ship Canal at Cicero Ave.	7

METROPOLITAN WATER RECLAMATION DISTRICT OF GREATER CHICAGO

TABLE 1 (Continued)

SAMPLE SOURCES AND NUMBERS

Sample Source	Number of Samples
Station 92 / Chicago Sanitary and Ship Canal at Lockport Locks	8
Station 96 / North Branch Chicago River at Albany Ave.	7
Station 99 / South Fork South Branch Chicago River at Archer Ave.	8
Station 40 / Chicago Sanitary and Ship Canal at Damen Ave.	1
CALUMET RIVER WATERSHED	
Station 43 / Cal-Sag Channel at Route 83	10
Station 49 / Calumet River at Ewing Ave.	9
Station 50 / Wolf Lake at Burnham Ave.	8
Station 52 / Little Calumet River at Wentworth Ave.	8
Station 54 / Thorn Creek at Joe Orr Rd.	6
Station 55 / Calumet River at 130th St.	8
Station 56 / Little Calumet River at Indiana Ave.	7
Station 57 / Little Calumet River at Ashland Ave.	8
Station 58 / Cal-Sag Channel at Ashland Ave.	9
Station 59 / Cal-Sag Channel at Cicero Ave.	9
Station 76 / Little Calumet at Halsted St.	8
Station 86 / Grand Calumet River at Burnham Ave.	7
Station 97 / Thorn Creek at 170th St.	8

METROPOLITAN WATER RECLAMATION DISTRICT OF GREATER CHICAGO

TABLE 1 (Continued)

SAMPLE SOURCES AND NUMBERS

Sample Source	Number of Samples
CHICAGO AREA LAKE MICHIGAN BEACHES	
Calumet Beach	9
Rainbow Beach	10
North Ave. Beach	3
Oak Street Beach	3
31st Street Beach	4
Kenilworth Beach	6
Wilmette Beach	6
Gillson Beach	6
Lighthouse Beach	5
Dempster Beach	6
CHICAGO AREA LAKE MICHIGAN SHORELINE (NOT BEACHES)	
Iroquois Landing	7
Monroe Harbor Mouth	3
Adler Planetarium	3
Wilmette Harbor Mouth	2
Northwestern University Observatory	2

METROPOLITAN WATER RECLAMATION DISTRICT OF GREATER CHICAGO

TABLE 1 (Continued)

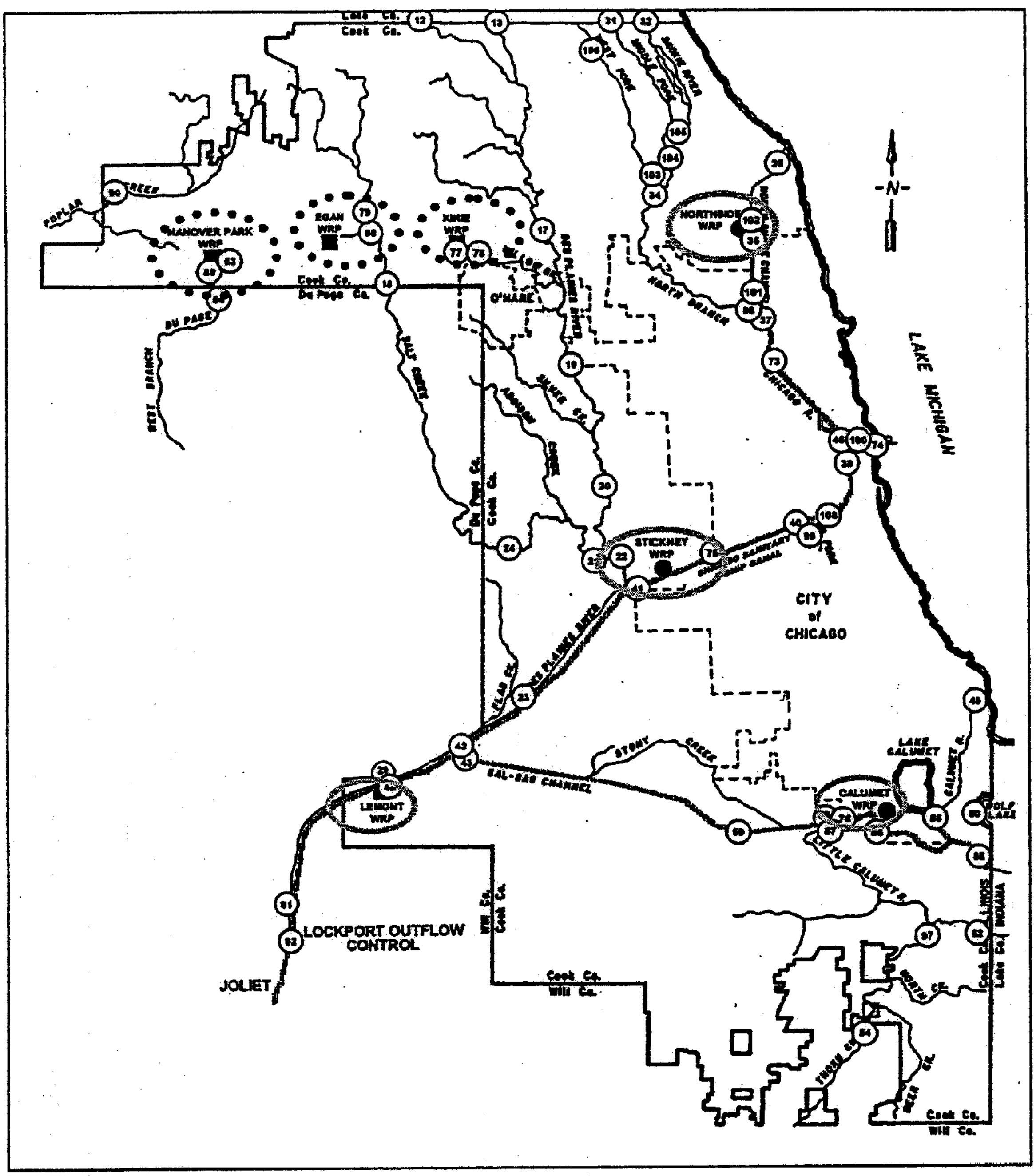
SAMPLE SOURCES AND NUMBERS

Sample Source	Number of Samples
CHICAGO AREA LAKE MICHIGAN OPEN WATER	
Calumet River Mouth	3
1 mile north of Calumet River Mouth	3
1 mile northeast of Calumet River Mouth	3
1 mile east of Calumet River Mouth	3
¾ mile southeast of Calumet River Mouth	3
1 mile south of Calumet River Mouth	3
Howard Slip	3
Chicago River Mouth	1
1 mile north of Chicago River Mouth	1
1 mile northeast of Chicago River Mouth	1
1 mile east of Chicago River Mouth	1
1 mile southeast of Chicago River Mouth	1
1 mile south of Chicago River Mouth	1
North Shore Channel Mouth	1
1 mile north of North Shore Channel Mouth	1
1 mile northeast of North Shore Channel Mouth	1
1 mile east of North Shore Channel Mouth	1
1 mile southeast of North Shore Channel Mouth	1
1 mile south of North Shore Channel Mouth	1

METROPOLITAN WATER RECLAMATION DISTRICT OF GREATER CHICAGO

FIGURE 1

MAP OF COOK COUNTY SHOWING WATER RECLAMATION PLANTS



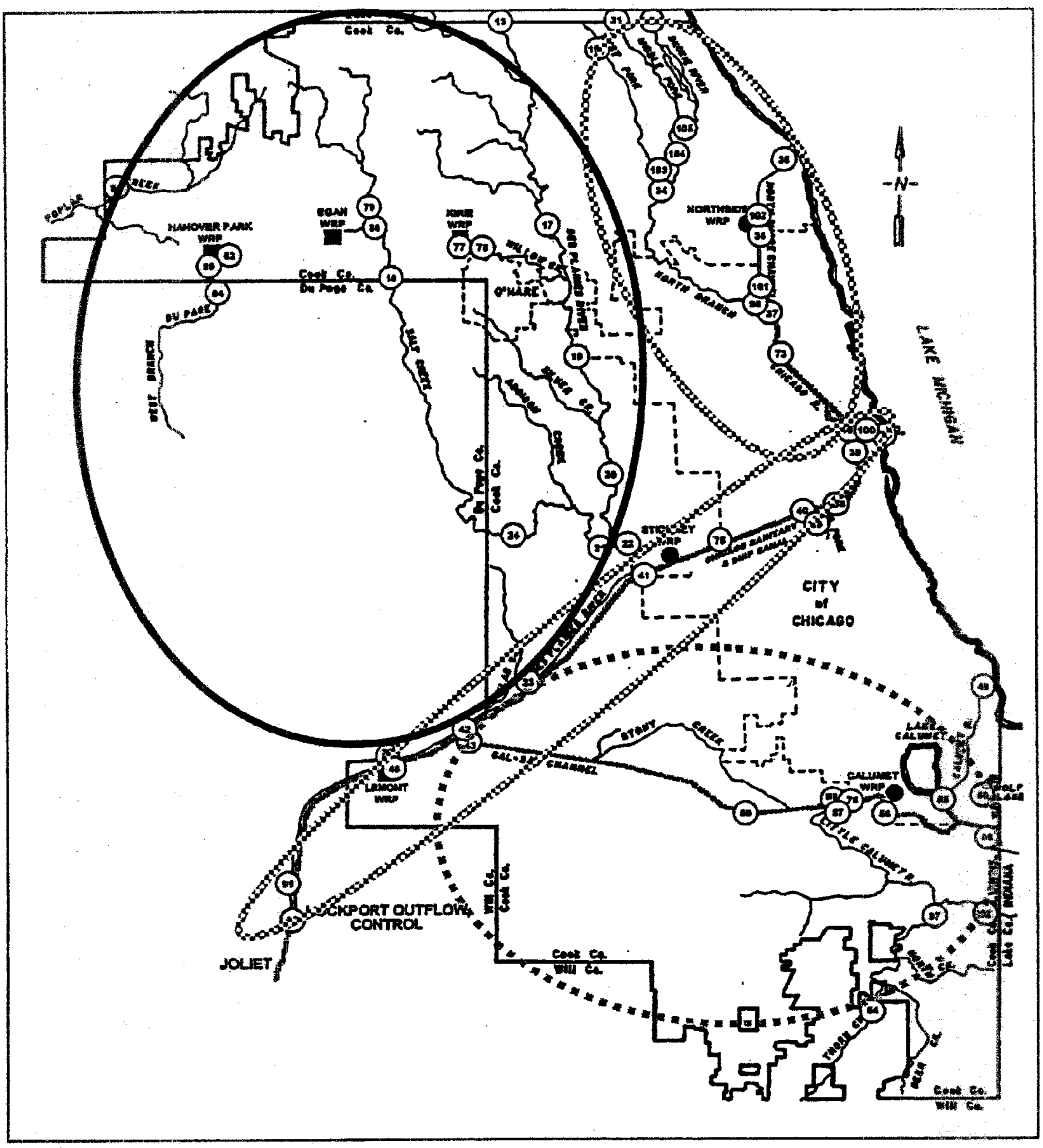
= Seasonally chlorinating WRPs.

= Non chlorinating WRPs.

METROPOLITAN WATER RECLAMATION DISTRICT OF GREATER CHICAGO

FIGURE 2

MAP SHOWING COOK COUNTY WATERSHED AREAS SAMPLED



Des Plaines River Watershed

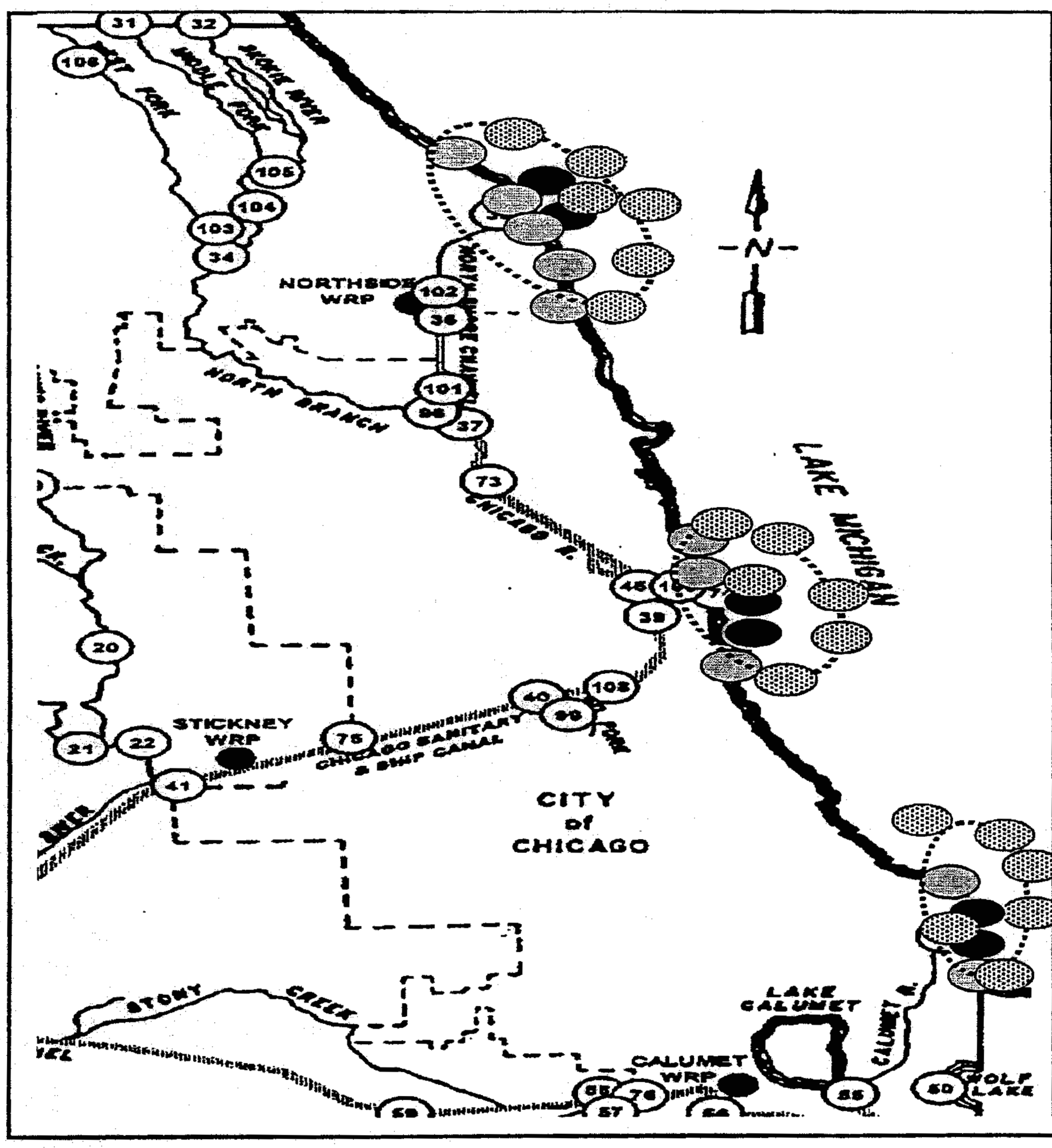
Chicago River Watershed and Sanitary & Ship Canal

Calumet River Watershed

METROPOLITAN WATER RECLAMATION DISTRICT OF GREATER CHICAGO

FIGURE 3

MAP SHOWING CHICAGO AREA LAKE MICHIGAN SAMPLE LOCATIONS



Beach Sample

Shoreline (not beach) Sample

Open water (boat collected) Sample

compliance or the District's Ambient Water Quality Study were processed within six hours. All other samples were processed within 24 hours.

Microbiological Analysis

Water reclamation plant effluents and samples from the Chicago area man-made waterways and river systems were analyzed for EC using SM 9213 D.3, SM 18^{th} ed., (APHA, 1992c) (the m-Tec procedure). Fecal coliform densities in these samples were determined using SM 9222 D, SM 18^{th} ed., (APHA, 1992b) (the FC membrane filtration procedure). This procedure is also referred to as the 24-hour FC method in this report. Water samples from Lake Michigan were analyzed for EC using the Quanti-Tray 2000 method (IDEXX Laboratories, Inc., Westbrook, Maine) and for FC using SM 9211 B, SM 18^{th} ed. (APHA, 1992a) (the 7-hour test). This procedure is also referred to as the 7-hour FC method in this report. Data are expressed as the number of FC or EC per 100 mL sample except for the Quanti-Tray method, for which the results are expressed as EC MPN per 100 mL sample.

CONFIRMATION OF COLONIES

After incubation for 24 $\pm$ 2 hours at 44.5 $\pm$ 0.2°C, blue colonies on m-FC agar were considered presumptive for FC. After incubation for 7 hours at 41 $\pm$ 0.5°C, yellow colonies on 7-hour FC agar were considered presumptive for FC. Presumptive FC colonies were transferred to EC medium for verification (APHA, 1992b). After incubation for 2 hours at 35 $\pm$ 0.5°C and 22 hours at 44.5 $\pm$ 0.2°C yellow colonies on m-TEC agar were tested for urease; urease negative yellow colonies were considered presumptive for EC. Presumptive EC colonies were verified as specified by the USEPA (2000b).

Statistical Analysis

PRECISION

Sixteen samples were analyzed for EC using the m-TEC method and for FC using m-FC agar (the 24-hour FC method). Three samples were analyzed for EC using the Quanti-Tray method and for FC using the 7-hour FC method. Seven replicate analyses were conducted on each of these samples. Coefficients of variation (CVs) were calculated from the results.

COMPARISON OF METHODS

EC densities were measured in three split samples using both the Quanti-Tray method and the m-TEC method. FC densities were measured in three split samples using both the 7-hour FC method and the 24-hour FC method. Seven replicate analyses were conducted on each of these samples. The EC values measured with the Quanti-Tray were regressed against the EC values measured with the m-TEC method. Similarly, the FC values measured with the 7-hour FC method were regressed against the FC values measured with the 24-hour FC method. The F-test was used to test the following hypotheses:

H_0: $\beta = 0$ and

H_0: $\beta = 1$

Paired t-test analyses were also used to test the equality of the methods.

TEST FOR NORMALITY

Raw and ln transformed EC and FC concentrations were tested for normality with the Kolmogorov-Smirnov (K-S) test (Gibbons and Chakraborti, 1992).

ESTIMATION OF THE EC/FC RATIO

Six candidate estimators of the EC/FC ratio, or R, were considered for each sample type. The efficacies of all six estimators, referred to as R_1, R_2, R_3, R_4, R_5, and R_6 in this report, were evaluated in terms of mean square error (MSE) criteria and other criteria discussed by Rao (2002), including sufficiency, consistency, completeness, and bias, to determine the best estimator of R. These estimators are described below:

1. The mean of measured EC densities ($\overline{EC}$) was divided by the mean of measured FC densities ($\overline{FC}$), that is

   $$R_1 = \frac{\overline{EC}}{\overline{FC}} \qquad \text{(Equation) 1}$$

2. The mean of the quotients of the individual EC/FC values was calculated, that is, $r_i = EC_i/FC_i$, $FC_i > 0$, n is the number of observations, and

   $$R_2 = 1/n\sum r_i \qquad \text{(Equation 2)}$$

3. A simple linear model was derived from the data and is related by the equation

   $$EC = a + bFC \qquad \text{(Equation 3)}$$

   where a and b are least square estimates of α, the y-intercept, and β, the slope, respectively. In this case if a = 0 then

   $$R_3 = b. \qquad \text{(Equation 4)}$$

   If a $\neq$ 0 or the assumptions necessary for linear regression are not met, then the EC/FC ratio can not be estimated this way. The significance of all regression models was tested.

4. The joint distribution of the random variables EC and FC was studied, and the sampling distribution of the EC/FC ratio was used to calculate the maximum likelihood estimator, referred to as R_4 in this report. (In this case, the sampling distribution had to be determined from the data first. See the sub-section entitled "R_4" in the Results and Discussion section below and Appendix BII.)

5. The GM of measured EC densities, GM (EC), was divided by the GM of FC densities, GM(FC), that is

$$R_5 = \frac{GM(EC)}{GM(FC)} \qquad \text{(Equation 5)}$$

6. Uniformly minimum variance unbiased estimators of R for each sample type were obtained with the method of Shimuzu (1988). (The distribution of R had to be determined before this method of deriving the UMVU estimators could be chosen. See Results and Discussion below and Appendices BII and BIII.) A macro program was written in SAS

to calculate R using the UMVU estimators. The SAS program is shown in Appendix BIV.

PROBABILITY STATEMENTS

The probabilities that the value realized by the random variable R for the different sample types is less than or equal to the mean (R_4), median (R_5), and the UMVU estimator (R_6) were calculated by integration of the lognormal distribution curve of EC/FC or R.

SUFFICIENCY, BIAS, AND COMPLETENESS

All estimators were evaluated for sufficiency, bias, and completeness. See Appendix BI.

CONSISTENCY

All estimators were tested for consistency by simulation studies using the SAS subprogram "Simulation." See Appendix BI.

RESULTS AND DISCUSSION

EC and FC Data

The EC and FC densities measured in unchlorinated and chlorinated WRP effluent samples are shown in Table AI-1 and Table AI-2, respectively. The EC and FC densities measured in river/waterway samples are shown in Table AI-3 (Calumet River Watershed), Table AI-4 (Chicago River Watershed), and Table AI-5 (Des Plaines River Watershed). The EC and FC densities measured in post-reversal Lake Michigan samples are shown in Table AI-6.

CONFIRMATION OF COLONIES

The results of colony confirmation tests are shown in Table 2. Ninety-eight percent of the presumptive FC colonies picked from m-FC agar were confirmed as FC. Eighty-seven percent of the presumptive FC colonies picked from 7-hour FC agar were confirmed as FC. Almost 83 percent (82.8) of the presumptive EC colonies picked from m-TEC agar were confirmed as EC.

Statistical Analysis

PRECISION

The CVs for the m-TEC EC analysis are shown in Tables AII-1 and AII-2. The CVs for the Quanti-Tray EC analysis are

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TABLE 2

RESULTS OF COLONY CONFIRMATION TESTS[1]

Analysis	Primary Isolation Medium	Number of Colonies Picked	Number of Colonies Confirmed	Percent Confirmed
FC	m-FC	100	98	98.0
	7-hour FC	23	20	87.0
EC	m-TEC	99	82	82.8
	Quanti-Tray 2000™, MPN	NA[2]	NA[2]	NA[2]

[1]Biochemical confirmation tests:
FC: growth and gas in EC medium at 44.5°C after 24 hours.
EC: urease negative, oxidase negative, indole positive, Simmons' citrate negative, and growth and gas in EC medium at 44.5°C after 24 hours.
[2]Not applicable.

shown in Table AII-2. The CVs for the 24-hour FC analysis are shown in Tables AII-1 and AII-3. The CVs for the 7-hour FC analysis are shown in Table AII-3.

The average CV for the EC values measured with the m-TEC method was 19.9, and the range was from 5.7 to 64.8. The average CV for the EC values measured with the Quanti-Tray method was 25.5, and the range was from 19.8 to 32.5. The average CV for the FC values measured with the 24-hour method was 15.8, and the range was from 3.5 to 47.2. The average CV for the FC values measured with the 7-hour method was 25.5, and the range was from 7.6 to 59.4.

The relatively high CV values at the higher end of the ranges listed above might be explained by the way the CVs were calculated. That is, the CVs were calculated from the final analytical results, not from the number of colonies observed on the plates. This method of calculating the CVs gives a more appropriate measure of the precision associated with each method. However, it should be remembered that when the plates used to calculate the final results for a particular set of replicate analyses have a smaller number of colonies, then the variability associated with these replicate analyses will be higher.

(There is an acceptable range of the number of colonies on a plate to be counted for each method. For example, the range for the 24-hour FC method is 20 to 60 colonies per plate. Refer to the referenced methods. However, when the number of colonies on a plate is lower than lowest number in the acceptable range, the methods still allow results to be calculated. It is the variability in the lower numbers of colonies on the replicate plates that can account for greater variability in the final results. This can be understood by looking at the raw data shown in Tables AII-1 through AII-3.)

COMPARISON OF THE EC ENUMERATION METHODS

The results obtained with the Quanti-Tray (EC_1) are almost identical to those obtained with the m-TEC method (EC_2) (Figure 4). The slope of the regression equation "$EC_1 = a + bEC_2$" was calculated to be 1.016, and the R^2 value was calculated to be 0.994. The intercept was found to be insignificant. Results of the F-test, $\beta = 0$, $p = 0.00$, and $\beta = 1$, $p = 0.38$, show that there is no difference between the Quanti-Tray results and the m-TEC results. Results of the paired t-test also indicate that there is no significant difference between the EC values measured with the Quanti-Tray and the EC values measured with the m-TEC method ($p = 0.21$).

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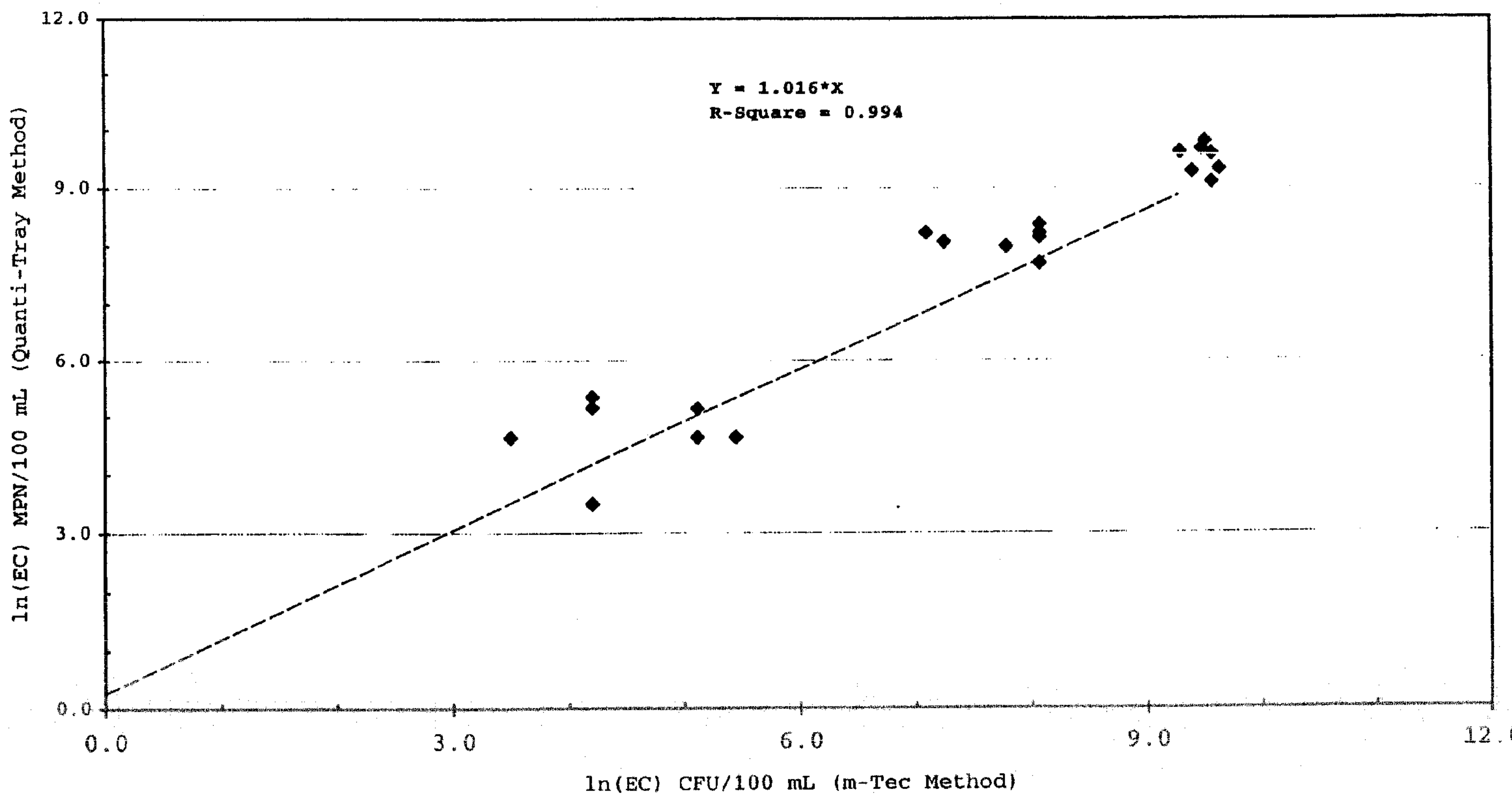
FIGURE 4

QUANTI-TRAY EC VERSUS M-TEC EC



COMPARISON OF THE FC ENUMERATION METHODS

The results obtained with the 7-hour FC method (FC_1) are almost identical to those obtained with the 24-hour FC method (FC_2) (Figure 5). The slope of the regression line "$FC_1 = a + bFC_2$" was calculated to be 1.008, and the R^2 value was calculated to be 0.996. The intercept was found to be insignificant. Results of the F-test, $\beta = 0$, $p = 0.00$, and $\beta = 1$, $p = 0.53$, show that there is no significant difference between the results measured by the two methods. Results of the paired t-test also indicate that there is no significant difference between the FC values measured with the 7-hour test and the 24-hour test ($p = 0.84$).

TEST FOR NORMALITY

Results of the K-S test, shown in Table 3, indicate that both the measured EC densities and the measured FC densities in samples of District WRP unchlorinated and chlorinated effluents, rivers/waterways, and Lake Michigan are all lognormally distributed. As a consequence $\ln(R) = \ln(EC/FC)$, also expressed as $\ln(R) = \ln(EC) - \ln(FC)$, is normally distributed by the properties of the normal distribution. The mathematical proof is shown in Appendix BII. Therefore, R is lognormally distributed. The basic statistics are shown in Table 4.

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FIGURE 5

7-HOUR FC VERSUS 24-HOUR FC

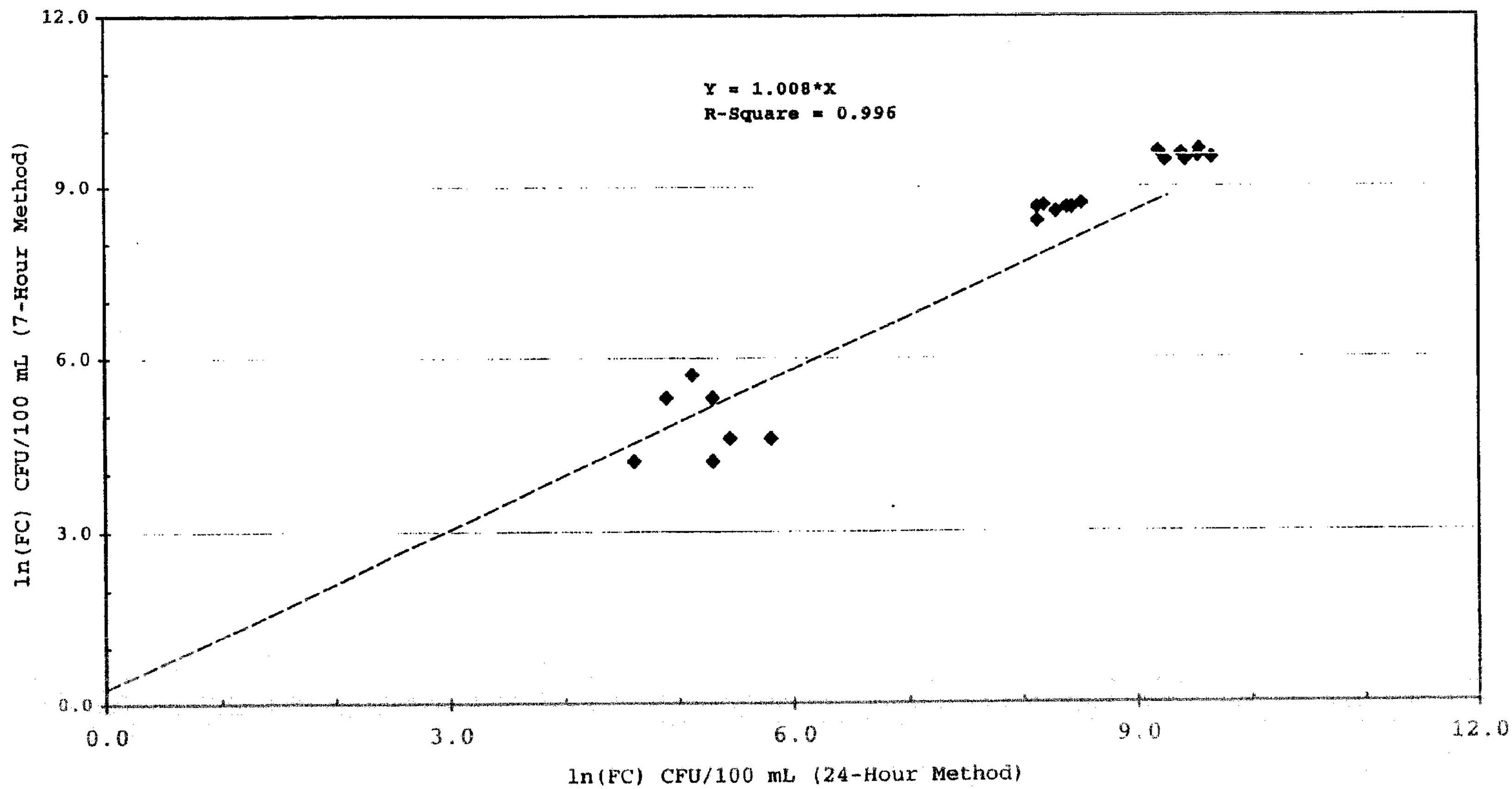

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TABLE 3

RESULTS OF THE KOLMOGOROV-SMIRNOV TEST FOR NORMALITY

Sampling Location[1]	Variable Tested[2]	Significance Probability[3]
WRP Unchlorinated Effluent	EC	0.001
	FC	0.000
	Ln(EC)	0.882[a]
	Ln(FC)	0.799[a]
WRP Chlorinated Effluent	EC	0.046
	FC	0.033
	Ln(EC)	0.983[a]
	Ln(FC)	0.991[a]
Calumet River	EC	0.000
	FC	0.000
	Ln(EC)	0.900[a]
	Ln(FC)	0.608[a]
Chicago River	EC	0.000
	FC	0.000
	Ln(EC)	0.633[a]
	Ln(FC)	0.578[a]
Des Plaines River	EC	0.000
	FC	0.000
	Ln(EC)	0.820[a]
	Ln(FC)	0.795[a]
Lake Michigan	EC	0.000
	FC	0.000
	Ln(EC)	0.874[a]
	Ln(FC)	0.875[a]

[1]See Table 1 and Figures 1-3.
[2]EC = Escherichia coli densities; FC = fecal coliform densities; Ln(EC) = natural logarithms of EC; Ln(FC) = natural logarithms of FC.
[3]A significance probability of >0.05 means that the population of the respective variable is normally distributed. (HO Tested: Variables are normally distributed.)
[a]Ln(R) = Ln(EC/FC) is normally distributed as a consequence of the fact that Ln(EC) and Ln(FC) are normally distributed. The mathematical proof is shown in Appendix BII.

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TABLE 4

BASIC STATISTICS[1]

Sampling Location	Ln(EC)		Ln(FC)		ρ^a
	Mean	s	Mean	s	
WRP Unchlorinated Effluent	8.404	1.181	8.641	1.172	0.95
WRP Chlorinated Effluent	2.380	0.452	2.452	0.566	0.84
Calumet River	5.507	2.315	5.745	2.350	0.97
Chicago River	6.492	1.942	6.739	1.936	0.98
Des Plaines River	6.188	1.864	6.390	1.839	0.97
Lake Michigan	3.819	2.543	4.978	1.960	0.91

[1] Ln(EC) = natural logarithm of measured EC densities; Ln(FC) = natural logarithms of measured FC densities; s = standard deviation; ρ = sample correlation coefficient (ln[EC], ln[FC]).

[a] An estimate of ρ, an index that quantifies the linear relationship between a pair of variables. The coefficient takes values between -1 and 1, with the sign indicating the direction of the relationship and the numerical magnitude its strength. Values of -1 or 1 indicate that the sample values fall on a straight line.

ESTIMATOR R_1

Values of R calculated using R_1 and the corresponding MSE values are shown in Tables 5 and 6, respectively. The MSE values associated with the R_1 estimates are greater than those associated with either R_2, R_4, or R_6. Therefore, in terms of MSE, R_1 is not the best estimator of the EC/FC ratio. This was expected, given that bacterial data are usually not normally distributed, as pointed out in the Introduction section of this report, and that the data were shown to be lognormally distributed with the K-S test. Values of R calculated using R_1, which range from 0.70 for Lake Michigan to 0.91 for WRP chlorinated effluent, do not compare favorably with those calculated with either R_2 or R_4. Estimator R_1 is not sufficient; it is not consistent, that is, R_1 does not approach R as $n \rightarrow \infty$; it is not unbiased, that is, $E(\log R_1) \neq E(\log R)$; and it is not complete (Table 7). Estimator R_1 was included in this study mainly to facilitate comparison with other studies, since some investigators report mean FC values. See Pitt (1998), for example.

ESTIMATOR R_2

Values of R calculated using R_2, and the corresponding MSE values, are shown in Tables 5 and 6, respectively. In

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TABLE 5

VALUES OF THE EC/FC RATIO, R, ESTIMATED FROM THE DATA USING SIX DIFFERENT APPROACHES

Sampling Location	ESTIMATOR[1]					
	R_1	R_2	R_3	R_4	R_5	R_6
WRP Unchlorinated Effluent	0.80	0.84	0.75	0.84	0.79	0.84
WRP Chlorinated Effluent	0.91	0.97	1.03	0.97	0.93	0.97
Calumet River Watershed	0.77	1.04	0.76	0.93	0.79	0.93
Chicago River Watershed	0.69	0.84	0.43	0.83	0.78	0.83
Des Plaines River Watershed	0.77	0.93	0.68	0.92	0.82	0.92
Lake Michigan	0.70	0.53	0.78	0.57	0.31	0.56

[1]See Materials and Methods Section.

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TABLE 6

COMPARISON OF THE MEAN SQUARED ERRORS[1] OBTAINED USING SIX DIFFERENT ESTIMATORS TO CALCULATE THE EC/FC RATIO[2]

Sampling Location	Estimator					
	R_1	R_2	R_3	R_4	R_5	R_6
WRP Unchlorinated Effluent	0.109	0.107	0.115	0.107	0.110	0.107
WRP Chlorinated Effluent	0.057	0.054	0.058	0.054	0.055	0.054
Calumet River	3.328	3.256	3.330	3.266	3.317	3.266
Chicago River	0.167	0.144	0.311	0.144	0.147	0.144
Des Plaines River	0.351	0.327	0.387	0.327	0.338	0.327
Lake Michigan	0.399	0.372	0.432	0.373	0.419	0.373

[1]Mean squared error is the expected value of the square of the difference between an estimator and the true value of a parameter.
[2]See Materials and Methods Section.

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TABLE 7

EVALUATION OF THE ESTIMATORS FOR SUFFICIENCY, CONSISTENCY, BIAS, AND COMPLETENESS[1]

Property of Estimator[2]	Estimator					
	R_1	R_2	R_3	R_4	R_5	R_6
Sufficient	No	No[3]	No	Yes	Yes	Yes
Consistent	No	No	Yes	Yes	No	Yes
Unbiased	No	No	Yes	No	No	Yes
Complete	No	No[3]	No	Yes	No	Yes

[1]See Materials and Methods and Appendix BI.
[2]Caution: The properties shown here refer to the estimators for R = EC/FC. Properties of estimators for EC or for FC individually are sometimes different.
[3]If the distribution of R is known to be lognormal, then R_2 is sufficient and complete. However, no assumptions about the distribution of the data were made.

terms of MSE, R_2 is as good an estimator as any of the other estimators used. Values of R calculated using R_2, which range from a low of 0.53 for Lake Michigan to 1.04 for Calumet River, are in good agreement with the R values calculated with R_4, the maximum likelihood estimator (see below), and R_6, the UMVU estimator (see below). These results indicate that R_2 can be a useful estimator for certain purposes, especially when the distribution of R = EC/FC is unknown. However, estimator R_2 is not sufficient, consistent, unbiased, or complete (Table 7). The usefulness of the R_2 estimator is discussed later.

ESTIMATOR R_3

The results of regression analysis are shown in Table 8. In each case the value of "a" in Equation 3 was found to be 0. The R^2 (sample coefficient of determination) values were all relatively high, ranging from 0.84 for the Des Plaines River and Lake Michigan to 0.98 for the Calumet River. These results indicate that the use of regression to estimate EC/FC or R is acceptable, and that the use of regression to estimate EC, when FC values are known, is also acceptable. The values of "b" (equation 3), all estimates of R (R_3 in this report as described above) and shown again in Table 5, range from 0.43

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TABLE 8

REGRESSION OF EC VERSUS FC

Sampling Location	Regression Equations[1]	$R^{2,a}$
WRP Unchlorinated Effluent	EC = 0.75444 x FC	0.94
WRP Chlorinated Effluent	EC = 1.02733 x FC	0.95
Calumet River Watershed	EC = 0.76398 x FC	0.98
Chicago River Watershed	EC = 0.42852 x FC	0.92
Des Plaines River Watershed	EC = 0.68088 x FC	0.84
Lake Michigan	EC = 0.77528 x FC	0.84

[1]EC = a + b x FC. In every case "a" was found to be equal to 0.
[a]R^2 is usually referred to as the sample coefficient of determination. R^2 expresses the proportion of the total variation in the values of the variable EC that can be accounted for or explained by a linear relationship with the values of the random variable FC.

for the Chicago River to 1.03 for WRP chlorinated effluent. The Mean Squared Errors (MSEs) are shown in Table 6. Estimator R_3 is not sufficient or complete, but it is consistent (Table 7). Estimator R_3 is unbiased (Table 7) because it is the least squares estimate of "b" (Walpole and Meyers, 1989). In terms of MSE, R_3 is not the best estimator, but the high R^2 values indicate that it can be a useful estimator, especially when the distribution of R = EC/FC is unknown.

Furthermore, inferences can be drawn using regression analysis, or R_3, as long as 1) the variance of the residuals is constant and does not depend on any parameter; 2) the residuals are independent; and 3) the residuals are normally distributed (USEPA, 1997). These assumptions were not tested because R_2, R_4, and R_6 were shown to be the best estimators in terms of MSE, and no inferences were made in this report using the results of regression analysis, or R_3.

ESTIMATOR R_4

It follows from the lognormal distribution of both EC and FC (Table 3) that EC/FC or R is also lognormally distributed. The mathematical proof is shown in Appendix BII. The natural logarithms of the EC densities were found to be highly correlated with the natural logarithms of FC densities for all sample types (Table 4). The respective sample correlation coefficients ($\hat{\rho}$) were 0.95 (unchlorinated effluent), 0.84 (chlorinated effluent), 0.97 (Calumet River), 0.98 (Chicago River), 0.97 (Des Plaines River), and 0.91 (Lake Michigan). These high values of $\hat{\rho}$ suggested the possibility that the distribution of R = EC/FC might be bivariate lognormal. This possibility was explored, as explained in Appendix BII, and was found not to be the case. Quantile-Quantile (Q-Q) plots of the collected data, shown in Appendix BII, and the results of the K-S test (Table 3), show that the distribution of R is univariate lognormal.

Maximum Likelihood Estimation. From the properties of the lognormal distribution, in random variable notation, it follows that

$$R_4 = \exp[\hat{\mu}_1 - \hat{\mu}_2 + \frac{1}{2}(\hat{\sigma}_1^2 - 2\hat{\rho}\hat{\sigma}_1\hat{\sigma}_2 + \hat{\sigma}_2^2)] \qquad \text{(Equation 6)}$$

Where

$\hat{\mu}_1$ = sample mean of ln(EC)

$\hat{\mu}_2$ = sample mean of ln(FC)

$\hat{\sigma}_1^2$ = sample variance of ln(EC)

$\hat{\sigma}_2^2$ = sample variance of ln(FC)

$\hat{\sigma}_1$ = standard deviation of ln(EC)

$\hat{\sigma}_2$ = standard deviation of ln(FC)

$\hat{\rho}$ = sample correlation coefficient between ln(EC) and ln(FC)

(In Equation 6 the term "$2\hat{\rho}\hat{\sigma}_1\hat{\sigma}_2$" is equal to the covariance [ln(EC), ln(FC)] and the term "$\frac{1}{2}(\hat{\sigma}_1^2 - 2\hat{\rho}\hat{\sigma}_1\hat{\sigma}_2 + \sigma_2^2)$" is equal to the variance of R.) See Appendix BII for a discussion of the maximum likelihood estimator.

Values of R calculated using R_4, and the corresponding MSE values, are shown in Tables 5 and 6, respectively. Values of R calculated using R_4 range from a low of 0.56 for Lake Michigan to 0.97 for WRP chlorinated effluent. In terms of MSE, R_4 is as good an estimator as any of the other estimators used. Estimator R_4 is sufficient, complete, and consistent, but it is not unbiased (Table 7). The usefulness of this estimator is discussed later.

ESTIMATOR R_5

Values of R calculated using R_5, and the corresponding MSE values, are shown in Tables 5 and 6, respectively. Values of R calculated using R_5 range from a low of 0.30 for Lake Michigan to 0.93 for WRP chlorinated effluent. In terms of MSE, R_5 is not as good an estimator as either R_2, R_4, or R_6. Furthermore, the use of R_5 to estimate the EC to FC ratio for this data set may be inappropriate for the following reasons. It is not consistent or unbiased, and it will underestimate R since, from Equation 6, the following is always true:

$$\hat{\sigma}_1^2 - 2\hat{\rho}\hat{\sigma}_1\hat{\sigma}_2 + \hat{\sigma}_2^2 > 0.$$

Therefore, the use of GM(EC)/GM(FC) to estimate R is appropriate only in the following special case, from Equation 6, when

$$(\hat{\mu}_1 - \hat{\mu}_2) + \tfrac{1}{2}(\hat{\sigma}_1^2 - 2\hat{\rho}\hat{\sigma}_1\hat{\sigma}_2 + \hat{\sigma}_2^2) \geq 0 \quad \text{(Equation 7)}$$

since in this case R_4 must be greater than 1, and the use of R_5 would be appropriate to get a realistic measure of the center. Otherwise, the use of GM(EC)/GM(FC) to estimate R will result in a gross underestimation in most cases. This is discussed later.

ESTIMATOR R_6

Since R was shown to be lognormally distributed, the method of Shimuzu (1988) was followed to find R_6, the UMVU estimator. The method for deriving the UMVU estimators is discussed in Appendix BIII. Values of R for the different sample types calculated using R_6, and the corresponding MSE values, are shown in Tables 5 and 6, respectively. Values of R calculated using R_6 range from a low of 0.56 for Lake Michigan to 0.97 for WRP chlorinated effluent. In terms of MSE, R_6 is as good as any of the other estimators used. Estimator R_6 is the only estimator which is sufficient, consistent, complete, and unbiased.

COMPARISON OF ESTIMATORS R_1, R_2, R_3, R_4, R_5, and R_6

The MSEs shown in Table 6 indicate that the estimators R_2, R_4, and R_6 are better estimators than R_1, R_3, and R_5. These results also indicate that R_2, R_4, and R_6 are equally good as estimators of R. If the joint distribution of the random variables EC and FC is unknown, R_2 can be used to calculate a good estimate of R. Given that the use of R_4 or R_6 to estimate R allows inferences to be drawn from the data it follows, therefore, that R_4 or R_6 should be used to estimate R, if possible.

As discussed in Appendix BIII, the UMVU estimator, R_6, is unique, and there is no other estimator which will be unbiased and have less variance. (If an estimator is unbiased, then the MSE is simply the variance of the estimator. For biased estimators the MSE is equal to the sum of the variance and the square of the bias.) Therefore, the authors of this report consider the UMVU estimator to be the best estimator of R.

Derivation of UMVU estimators, which involves generalized hypergeometric functions, is difficult. Therefore, it is not something that is routinely done. However, since there is an UMVU estimator for the lognormal distribution, it should be used to estimate R when the best estimate of R is required. A copy of the SAS program used to calculate the UMVU estimators for this study can be obtained from the authors.

The estimator R_4 will give a good estimate of R so long as the special condition shown in Equation 7 is true. The "common sense condition" shown in Equation 7 follows from the definition of EC as a subset of FC, making it impossible for the actual value of R to be greater than 1. Values calculated from the data using Equation 7 were all less than 0 and are shown in Table 9.

The application of this special condition in the analysis of the experimental data ensures that any artifacts in the data collection will not result in a value for R which is greater than 1. This is theoretically possible, given the properties of the lognormal distribution, especially when the variance is high. [See Evans, Hastings, and Peacock, (1993) for examples of how variance influences the skewness of the lognormal distribution.] Said *et al.* (2003), discussing the possibility of measured EC values exceeding measured FC values, stated that this may be attributed to the separation of non-FC and the resuscitation step in the EC method (m-TEC), that is, incubation for two hours at 35°C before incubation for 22 hours at 44.5°C, which allows stressed organisms to be

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TABLE 9

VALUES OF CONDITION FACTORS CALCULATED FROM THE DATA[1,2]

Sample Location	Condition Factor[3]
Unchlorinated Effluent	-0.17044
Chlorinated Effluent	-0.02585
Calumet River Watershed	-0.06765
Chicago River Watershed	-0.18045
Des Plaines River Watershed	-0.08190
Lake Michigan	-0.58498

[1]See Results and Discussion Section.

[2]Condition factor = $(\hat{\mu}_1 - \hat{\mu}_2) + \frac{1}{2}(\hat{\sigma}_1^2 - 2\hat{\rho}\hat{\sigma}_1\hat{\sigma}_2 + \hat{\sigma}_2^2)$
where

$\hat{\mu}_1$ = sample mean of ln(EC)

$\hat{\mu}_2$ = sample mean of ln(FC)

$\hat{\sigma}_1^2$ = sample variance of ln(EC)

$\hat{\sigma}_2^2$ = sample variance of ln(FC)

$\hat{\sigma}_1$ = standard deviation of ln(EC)

$\hat{\sigma}_2$ = standard deviation of ln(FC)

$\hat{\rho}$ = sample correlation coefficient between ln(EC) and ln(FC)

[3]Values ≤ 0 support the use of R_6, R_4, and R_2 over R_5.

recovered. The lower incubation temperature for the Quanti-Tray 2000, could also result in higher EC counts.

Percentiles of R based on integration of the lognormal distribution curves of EC/FC or R are shown in Table 10. The percentiles for R_2 are essentially the same as those shown for R_4 and R_6. The percentiles for R_4, the mean, and R_6, the UMVU estimate, are both higher than those for R_5, the median. These data further support the use of both R_4 and R_6 over R_5 to estimate R in all cases for this study. Percentiles greater than 75 percent may indicate that the use of R_5 would be more appropriate than R_2, R_4, or R_6 in a particular case because this would suggest that the distribution is too skewed to use one of these estimators. This was not the case for this data set.

Therefore, these findings indicate that the simple mathematical calculations involved in using estimator R_2 may suffice for most purposes, and R_4 or R_6 should be used if a better estimate is required or inferences are to be made. The use of R_5 will not be appropriate in most cases. As also discussed above, however, the UMVU estimator should be used when the best estimate of R is required. The statistical methods and criteria used in this study may be appropriate in finding other ratios, for example, specific pathogen to FC or EC ratios, especially those used in risk analysis studies, where

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TABLE 10

PERCENTILES BASED ON INTEGRATION OF THE LOGNORMAL DISTRIBUTION CURVE OF EC/FC OR R

Sample Location	Probability Statements			
	Pr[EC/FC $\leq R_2$]	Pr[EC/FC $\leq R_4$]	Pr[EC/FC $\leq R_5$]	Pr[EC/FC $\leq R_6$]
Unchlorinated Effluent	57[a]	57[b]	50[c]	57[d]
Chlorinated Effluent	55[a]	56[b]	50[c]	56[d]
Calumet River Watershed	68[a]	61[b]	50[c]	61[d]
Chicago River Watershed	58[a]	57[b]	50[c]	57[d]
Des Plaines River Watershed	60[a]	60[b]	50[c]	60[d]
Lake Michigan	68[a]	71[b]	50[c]	70[d]

[a]Percentile or percent of values equal to or below EC/FC estimated from the means of the quotients of the individual EC/FC values.
[b]Percentile or percent of values equal to or below EC/FC estimated from the properties of the lognormal distribution.
[c]Percentile or percent of values equal to or below EC/FC estimated using the GM. By definition the values are all 50 percent because the GM of a lognormal distribution is always the median value.
[d]Percentile or percent of values equal to or below EC/FC estimated using the UMVU estimator.

the best estimate of the ratio would be necessary. The findings presented here are consistent with the remarks of Haas (1996) that the proper (and precise) estimation of microorganism average density in environmental samples (and placing confidence intervals on the average density) may require special methods.

COMPARISON OF THE R VALUES OBTAINED FOR THE DIFFERENT SAMPLE TYPES

The confidence intervals of R for the different sample types using estimators R_4 and R_5 are shown in Table 11. Using R_4, the EC/FC ratios (Table 5) and 95 percent confidence intervals for unchlorinated and chlorinated effluent samples were calculated from the data to be 0.84 (0.80 - 0.89) and 0.97 (0.95 - 1.0), respectively. Using R_4, the EC/FC ratios and 95 percent confidence intervals for samples from the Calumet, Chicago, and Des Plaines Rivers were calculated from the data to be 0.93 (0.85 - 1.0), 0.83 (0.80 - 0.87), and 0.92 (0.88 - 0.97), respectively. Using R_4, the mean EC/FC ratio and 95 percent confidence interval for post-diversion samples from Lake Michigan were calculated from the data to be 0.56 (0.47 - 0.66).

Using R_5, the mean EC/FC ratios for unchlorinated and chlorinated effluent samples were calculated from the data to

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TABLE 11

COMPARISON OF CONFIDENCE INTERVALS OF R VALUES FOR DIFFERENT SAMPLE TYPES CALCULATED USING THE ESTIMATORS R_4 AND R_5[a,b,c]

Sampling Location	R_4		R_5		Statistical Grouping
	Lower 95%	Upper 95%	Lower 95%	Upper 95%	
WRP Unchlorinated Effluent	0.79	0.90	0.74	0.84	A
WRP Chlorinated Effluent	0.95	1.00	0.91	0.95	A
Calumet River	0.83	1.00	0.70	0.88	A
Chicago River	0.79	0.88	0.74	0.82	A
Des Plaines River	0.87	0.98	0.77	0.87	A
Lake Michigan	0.45	0.69	0.25	0.37	B[d]

[a]See Materials and Methods Section.
[b]Values of R_4 and R_5 are shown in Table 5.
[c]Confidence intervals for R_4 and R_5 are not symmetric due to the lognormal distribution of R, that is, ln(R) = ln(EC/FC) is normally distributed. See Appendix BII.
[1]There is no significant difference between R values with common letters.
[d]R for Lake Michigan samples is significantly lower ($p = 0.05$) than the R values calculated for all other sample types.

be 0.79 (0.75 - 0.83) and 0.93 (0.91 - 0.95), respectively. Using R_5, the mean EC/FC ratios for samples from the Calumet, Chicago, and Des Plaines Rivers were calculated from the data to be 0.79 (0.72 - 0.87), 0.78 (0.75 - 0.82), and 0.82 (0.77 - 0.86), respectively. Using R_5, the mean EC/FC ratio for post-diversion samples from Lake Michigan was calculated from the data to be 0.30 (0.25 - 0.36). Estimates of the mean EC/FC ratios and 95 percent confidence intervals made using R_5 were all lower than the corresponding estimates using R_4, as was predicted. The data in Table 11 indicate that the value of R calculated from the data for Lake Michigan samples is significantly lower ($p = 0.05$) than the values of R for all of the other sample types, and that there is no significant difference between the R values calculated for the other sample types.

Other Studies

Elmund *et al.* 1999, reported values of .49 (.44 - .54) and .74 (.71 - .77) for the EC/FC ratios in the effluents from two wastewater treatment plants in Fort Collins, Colorado. These values are lower than the values reported here (Table 5). Parenthetically, consideration of the methods used to determine EC and FC concentrations is essential in comparing results reported in different studies. For example, Elmund et al. 1999, used the Quanti-Tray technique to determine EC concentrations, while the EC results for effluent and waterway/river samples in this report were obtained with the m-TEC method, [which was the only method recommended by the USEPA for enumerating EC in ambient water (USEPA, 2000) when this study was conducted]. Therefore, the results reported by Elmund et al. 1999, are not strictly comparable to the results reported here.

Reported values of the EC/FC ratio for various polluted water bodies range from 0.36 to 1 (Elmund *et al.*, 1999) (Ferley *et al.*, 1989) (Calderon *et al.*, 1991) (Terrio, 1994). The EC/FC ratios calculated from the data in this report using all six estimators, R_1, R_2, R_3, R_4, R_5, and R_6 all fall within this range. Thus, the results of this and other studies to date indicate that the EC to FC ratio in polluted ambient water is not constant. The ratio of EC to FC in polluted ambient water is variable and would be influenced by a number of factors, including the type of water body and the source of pollution. See Geldreich (1990).

Implications for the District

With the approval by the USEPA in 2003 of analytical methods for the enumeration of EC in ambient waters and the expected approval of analytical methods for the enumeration of EC in wastewater in 2004, it can be anticipated that the indicator EC will soon be used in a regulatory context. The State of Illinois must develop water quality standards based upon USEPA's water quality criteria for bacteria by April 2004. When this is done, it is anticipated that the Illinois Environmental Protection Agency will replace FC limits in District NPDES permits and water quality standards with EC limits.

The EC/FC ratios reported here for District WRP effluents and waterway/river samples are relatively high, ranging from 0.79 to 1.00, indicating that proposed effluent and ambient water quality standards based upon EC may be more difficult to meet than those currently based upon FC. For example, an FC limit of 500 cfu/100 mL was previously used for beach closings. This has been replaced by an EC limit of 235 cfu/100 mL representing an assumed EC/FC ratio of 0.47.

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APPENDIX AI

FC AND EC DATA FOR ALL LOCATIONS

METROPOLITAN WATER RECLAMATION DISTRICT OF GREATER CHICAGO

TABLE AI-1

FC AND EC DENSITITES IN UNCHLORINATED WRP EFFLUENT SAMPLES

Sample Type	Sample Date	FC/100mL (24-hour Test)	EC/100mL (m-TEC)
North Side WRP Effluent	5/23/00	8700	5100
	9/19/00	16000	11000
	9/26/00	14000	7200
	10/3/00	21000	13000
	10/10/00	15000	14000
	10/17/00	48000	37000
	10/24/00	13000	7600
	10/31/00	16000	10000
	11/8/00	9900	4800
	12/5/00	8000	2800
	1/2/01	11000	7000
	2/6/01	2800	3600
	3/6/01	7600	4800
	4/3/01	5700	3200
	4/10/01	12000	11000
	5/1/01	9000	6800
	6/5/01	6900	3700
	7/3/01	20000	7400
	8/7/01	38000	25000
	11/13/01	21000	12000
	1/15/02	9900	8900
	2/5/02	10000	11000
	3/12/02	5900	3800
	4/2/02	20000	16000
	5/7/02	9200	8300
	6/4/02	74000	56000
	7/2/02	20000	14000
	8/6/02	26000	31000
	9/10/02	24000	25000
	9/17/02	32000	23000
	10/1/02	21000	18000
	10/8/02	28000	29000
	11/12/02	17000	16000
	12/3/02	29000	26000
	1/7/03	8400	6300
	2/4/03	11000	25000
	3/4/03	4900	4800

METROPOLITAN WATER RECLAMATION DISTRICT OF GREATER CHICAGO

TABLE AI-1 (Continued)

FC AND EC DENSITITES IN UNCHLORINATED WRP EFFLUENT SAMPLES

Sample Type	Sample Date	FC/100mL (24-hour Test)	EC/100mL (m-TEC)
North Side WRP Effluent (Cont.)	4/1/03	22000	22000
	5/6/03	7100	5800
	6/3/03	6700	5800
Stickney WRP Effluent	3/13/00	8000	11000
	5/22/00	8800	5700
	12/4/01	22000	11000
	6/17/02	12000	12000
	6/24/02	23000	15000
	7/1/02	16000	13000
	8/12/02	12000	11000
	9/9/02	35000	28000
	10/7/02	23000	20000
	11/12/02	16000	16000
	12/2/02	4600	5100
	1/6/03	6000	3900
	2/3/03	5700	4400
	3/3/03	2700	2000
	4/7/03	11000	8100
	5/5/03	6200	5200
	6/2/03	9000	6500
John E. Egan WRP Effluent	11/8/00	6400	3200
	12/5/00	2700	1400
	1/9/01	1400	1400
	2/6/01	800	600
	3/6/01	8900	6900
	4/3/01	8700	5900
	4/10/01	11000	9800
	11/13/01	2500	1500
	12/4/01	1400	1500
	1/8/02	2200	1700
	2/5/02	1800	1400
	3/12/02	3200	2000

METROPOLITAN WATER RECLAMATION DISTRICT OF GREATER CHICAGO

TABLE AI-1 (Continued)

FC AND EC DENSITITES IN UNCHLORINATED WRP EFFLUENT SAMPLES

Sample Type	Sample Date	FC/100mL (24-hour Test)	EC/100mL (m-TEC)
John E. Egan WRP Effluent (Cont.)	4/2/02	1900	1000
	11/12/02	2400	2500
	12/3/02	400	900
	1/7/03	200	260
	2/4/03	5400	4500
	3/4/03	1700	1900
	4/1/03	1800	1300
Hanover Park WRP Effluent	11/8/00	1400	700
	12/5/00	2500	1300
	1/2/01	6400	4300
	2/6/01	1700	1300
	3/6/01	2500	1400
	4/3/01	3900	2700
	4/10/01	4800	6000
	11/13/01	3500	3200
	12/4/01	2200	2000
	1/15/02	5000	4200
	2/5/02	600	1000
	3/12/02	14000	13000
	4/2/02	3200	2000
	11/12/02	5300	5600
	12/3/02	2000	2200
	1/7/03	9300	9400
	2/4/03	3800	5200
	3/4/03	4900	3800
	4/01/03	3800	3700
James C. Kirie WRP Effluent	11/8/00	66000	36000
	12/5/00	1400	500
	1/2/01	3500	3400
	2/6/01	1500	500
	3/6/01	990	1600
	4/3/01	2200	990
	4/10/01	7400	8200

METROPOLITAN WATER RECLAMATION DISTRICT OF GREATER CHICAGO

TABLE AI-1 (Continued)

FC AND EC DENSITITES IN UNCHLORINATED WRP EFFLUENT SAMPLES

Sample Type	Sample Date	FC/100mL (24-hour Test)	EC/100mL (m-TEC)
James C. Kirie WRP Effluent (Cont.)	11/13/01	1300	300
	12/4/01	2300	1500
	1/8/02	1500	1200
	2/5/02	1300	3000
	3/12/02	2700	2100
	4/2/02	1600	1400
	11/12/02	990	1400
	12/3/02	700	500
	1/7/03	700	1000
	2/4/03	700	700
	3/4/03	1400	1200
	4/1/03	400	400

METROPOLITAN WATER RECLAMATION DISTRICT OF GREATER CHICAGO

TABLE AI-2

FC AND EC DENSITITES IN CHLORINATED WRP EFFLUENT SAMPLES

Sample Type	Sample Date	FC/100mL (24-hour Test)	EC/100mL (m-TEC)
John E. Egan WRP Effluent	5/23/00	<10	<10
	9/18/00	<10	<10
	9/19/00	<10	<10
	9/20/00	<10	<10
	9/21/00	<10	<10
	9/25/00	<10	<10
	9/27/00	9	<10
	9/28/00	<10	<10
	9/29/00	<10	<10
	10/2/00	<10	<10
	10/3/00	20	<10
	10/4/00	<10	<10
	10/5/00	<10	<10
	10/9/00	<10	<10
	10/10/00	<10	<10
	10/11/00	20	<10
	10/14/00	<10	<10
	10/16/00	20	<10
	10/17/00	<10	<10
	10/18/00	<10	<10
	10/19/00	<10	<10
	10/23/00	<10	9
	10/24/00	20	<10
	10/25/00	9	<10
	10/26/00	<10	<10
	10/30/00	<10	9
	10/31/00	<10	<10
	5/1/01	<10	<10
	5/2/01	<10	<10
	5/3/01	<10	<10
	5/7/01	<10	9
	5/8/01	<10	<10
	5/9/01	<10	<10
	5/10/01	<10	<10
	5/14/01	9	<10

METROPOLITAN WATER RECLAMATION DISTRICT OF GREATER CHICAGO

TABLE AI-2 (Continued)

FC AND EC DENSITITES IN CHLORINATED WRP EFFLUENT SAMPLES

Sample Type	Sample Date	FC/100mL (24-hour Test)	EC/100mL (m-TEC)
John E. Egan WRP Effluent (Cont.)	5/15/01	<10	<10
	5/16/01	<10	<10
	5/17/01	<10	9
	5/21/01	<10	<10
	5/22/01	20	<10
	5/23/01	<10	<10
	5/24/01	<10	<10
	5/29/01	<10	<10
	5/30/01	<10	<10
	5/31/01	9	9
	6/1/01	40	20
	6/4/01	<10	9
	6/5/01	20	20
	6/6/01	<10	<10
	6/7/01	<10	<10
	6/11/01	<10	<10
	6/12/01	<10	<10
	6/13/01	<10	<10
	6/14/01	<10	<10
	6/18/01	<10	<10
	6/19/01	<10	<10
	6/20/01	<10	<10
	6/21/01	<10	<10
	6/25/01	<10	<10
	6/26/01	<10	<10
	6/27/01	<10	<10
	6/28/01	<10	<10
	7/2/01	<10	<10
	7/3/01	<10	<10
	7/5/01	20	<10
	7/6/01	<10	<10
	7/9/01	<10	<10
	7/10/01	<10	<10
	7/11/01	<10	<10
	7/12/01	<10	<10
	7/16/01	40	9

METROPOLITAN WATER RECLAMATION DISTRICT OF GREATER CHICAGO

TABLE AI-2 (Continued)

FC AND EC DENSITITES IN CHLORINATED WRP EFFLUENT SAMPLES

Sample Type	Sample Date	FC/100mL (24-hour Test)	EC/100mL (m-TEC)
John E. Egan WRP Effluent (Cont.)	7/17/01	9	9
	7/18/01	50	20
	7/19/01	20	20
	7/23/01	9	9
	7/24/01	9	<10
	7/25/01	9	<10
	7/26/01	30	9
	7/30/01	9	<10
	7/31/01	9	<10
	8/1/01	<10	<10
	8/2/01	<10	<10
	8/6/01	<10	<10
	8/7/01	<10	<10
	8/8/01	<10	<10
	8/13/01	9	<10
	8/14/01	<10	<10
	8/15/01	<10	<10
	8/16/01	9	<10
	8/20/01	<10	<10
	8/21/01	<10	<10
	5/1/02	<10	<10
	5/2/02	<10	<10
	5/6/02	<10	<10
	5/7/02	<10	9
	5/8/02	<10	<10
	5/9/02	9	<10
	5/13/02	<10	<10
	5/14/02	<10	<10
	5/15/02	<10	<10
	5/16/02	<10	<10
	5/20/02	<10	<10
	5/21/02	<10	<10
	5/22/02	<10	<10
	5/23/02	<10	<10
	5/29/02	<10	<10

METROPOLITAN WATER RECLAMATION DISTRICT OF GREATER CHICAGO

TABLE AI-2 (Continued)

FC AND EC DENSITITES IN CHLORINATED WRP EFFLUENT SAMPLES

Sample Type	Sample Date	FC/100mL (24-hour Test)	EC/100mL (m-TEC)
John E. Egan WRP Effluent (Cont.)	5/30/02	<10	<10
	6/3/02	<10	<10
	6/4/02	<10	<10
	6/5/02	9	<10
	6/6/02	<10	<10
	6/10/02	<10	<10
	6/11/02	<10	<10
	6/12/02	<10	<10
	6/13/02	<10	<10
	6/17/02	<10	<10
	6/18/02	<10	<10
	6/19/02	<10	<10
	6/20/02	<10	<10
	6/24/02	<10	<10
	6/25/02	<10	<10
	6/26/02	9	<10
	6/27/02	<10	9
	7/5/02	<10	<10
	7/9/02	9	<10
	7/10/02	<10	<10
	7/11/02	<10	<10
	7/15/02	<10	9
	7/16/02	<10	20
	7/17/02	40	<10
	7/18/02	9	<10
	7/22/02	9	<10
	7/23/02	20	9
	7/24/02	40	40
	7/25/02	<10	<10
	7/29/02	450	270
	7/30/02	60	60
	7/31/02	<10	<10
	8/1/02	30	9
	8/5/02	<10	<10
	8/6/02	<10	<10
	8/7/02	<10	<10

METROPOLITAN WATER RECLAMATION DISTRICT OF GREATER CHICAGO

TABLE AI-2 (Continued)

FC AND EC DENSITITES IN CHLORINATED WRP EFFLUENT SAMPLES

Sample Type	Sample Date	FC/100mL (24-hour Test)	EC/100mL (m-TEC)
John E. Egan WRP Effluent (Cont.)	8/8/02	<10	<10
	8/12/02	<10	<10
	8/13/02	<10	<10
	8/14/02	<10	<10
	8/15/02	<10	<10
	9/9/02	<10	<10
	9/10/02	<10	<10
	9/11/02	40	30
	9/12/02	<10	<10
	9/16/02	80	30
	9/17/02	40	<10
	9/18/02	<10	<10
	9/19/02	<10	<10
	9/23/02	<10	<10
	9/24/02	<10	<10
	9/25/02	<10	<10
	9/26/02	<10	<10
	9/30/02	<10	9
	10/1/02	<10	<10
	10/2/02	<10	<10
	10/3/02	<10	<10
	10/7/02	<10	<10
	10/8/02	<10	<10
	10/9/02	<10	<10
	10/10/02	40	9
	10/14/02	180	30
	10/15/02	150	110
	10/16/02	30	<10
	10/17/02	9	<10
	10/21/02	<10	<10
	10/22/02	<10	<10
	10/23/02	<10	<10
	10/24/02	<10	<10
	10/28/02	<10	<10
	10/29/02	<10	<10
	10/30/02	<10	<10

METROPOLITAN WATER RECLAMATION DISTRICT OF GREATER CHICAGO

TABLE AI-2 (Continued)

FC AND EC DENSITITES IN CHLORINATED WRP EFFLUENT SAMPLES

Sample Type	Sample Date	FC/100mL (24-hour Test)	EC/100mL (m-TEC)
John E. Egan WRP Effluent (Cont.)	10/31/02	<10	<10
	5/1/03	30	<10
Hanover Park WRP Effluent	5/23/00	<10	<10
	9/18/00	30	9
	9/19/00	30	<10
	9/20/00	<10	<10
	9/21/00	<10	<10
	9/25/00	<10	<10
	9/26/00	<10	<10
	9/27/00	9	<10
	9/28/00	<10	<10
	10/2/00	<10	<10
	10/3/00	<10	<10
	10/4/00	<10	<10
	10/5/00	<10	<10
	10/9/00	<10	<10
	10/10/00	<10	<10
	10/11/00	<10	<10
	10/14/00	<10	<10
	10/16/00	9	<10
	10/17/00	<10	<10
	10/18/00	<10	<10
	10/19/00	<10	<10
	10/23/00	<10	<10
	10/24/00	<10	<10
	10/25/00	<10	<10
	10/26/00	<10	<10
	10/30/00	<10	<10
	10/31/00	<10	<10
	5/1/01	<10	<10
	5/2/01	<10	<10
	5/3/01	<10	<10

METROPOLITAN WATER RECLAMATION DISTRICT OF GREATER CHICAGO

TABLE AI-2 (Continued)

FC AND EC DENSITITES IN CHLORINATED WRP EFFLUENT SAMPLES

Sample Type	Sample Date	FC/100mL (24-hour Test)	EC/100mL (m-TEC)
Hanover Park WRP Effluent (Cont.)	5/7/01	9	<10
	5/8/01	9	9
	5/9/01	<10	9
	5/10/01	<10	<10
	5/14/01	<10	<10
	5/15/01	<10	<10
	5/16/01	<10	9
	5/17/01	30	9
	5/21/01	40	20
	5/22/01	<10	<10
	5/23/01	<10	<10
	5/24/01	<10	<10
	5/29/01	<10	<10
	5/30/01	<10	9
	5/31/01	<10	9
	6/1/01	<10	<10
	6/4/01	30	9
	6/5/01	<10	<10
	6/6/01	<10	<10
	6/7/01	<10	<10
	6/11/01	<10	<10
	6/12/01	99	40
	6/13/01	<10	<10
	6/14/01	<10	9
	6/18/01	99	40
	6/19/01	<10	<10
	6/20/01	<10	<10
	6/21/01	<10	<10
	6/25/01	<10	9
	6/26/01	<10	<10
	6/27/01	<10	<10
	6/28/01	9	<10
	7/2/01	9	<10
	7/3/01	<10	9
	7/5/01	<10	<10

METROPOLITAN WATER RECLAMATION DISTRICT OF GREATER CHICAGO

TABLE AI-2 (Continued)

FC AND EC DENSITITES IN CHLORINATED WRP EFFLUENT SAMPLES

Sample Type	Sample Date	FC/100mL (24-hour Test)	EC/100mL (m-TEC)
Hanover Park WRP Effluent (Cont.)	7/6/01	<10	<10
	7/9/01	<10	<10
	7/10/01	<10	<10
	7/11/01	<10	<10
	7/12/01	<10	<10
	7/16/01	<10	<10
	7/17/01	<10	<10
	7/18/01	20	<10
	7/19/01	<10	<10
	7/23/01	<10	<10
	7/24/01	9	9
	7/25/01	9	<10
	7/26/01	<10	<10
	7/30/01	<10	<10
	7/31/01	20	<10
	8/1/01	9	<10
	8/2/01	<10	<10
	8/6/01	20	<10
	8/7/01	<10	<10
	8/8/01	40	30
	8/13/01	30	<10
	8/14/01	40	<10
	8/15/01	<10	<10
	8/16/01	<10	<10
	8/20/01	<10	<10
	8/21/01	40	40
	5/1/02	<10	<10
	5/2/02	<10	<10
	5/6/02	<10	<10
	5/7/02	<10	9
	5/8/02	<10	<10
	5/9/92	<10	<10
	5/13/02	<10	<10
	5/14/02	<10	<10
	5/15/02	<10	<10

METROPOLITAN WATER RECLAMATION DISTRICT OF GREATER CHICAGO

TABLE AI-2 (Continued)

FC AND EC DENSITITES IN CHLORINATED WRP EFFLUENT SAMPLES

Sample Type	Sample Date	FC/100mL (24-hour Test)	EC/100mL (m-TEC)
Hanover Park WRP Effluent (Cont.)	5/16/02	<10	<10
	5/20/02	<10	<10
	5/21/02	9	<10
	5/22/02	<10	<10
	5/23/02	<10	<10
	5/28/02	<10	<10
	5/29/02	<10	<10
	5/30/02	<10	<10
	6/3/02	<10	<10
	6/4/02	<10	9
	6/5/02	<10	<10
	6/6/02	<10	<10
	6/10/02	<10	9
	6/11/02	9	9
	6/12/02	30	30
	6/13/02	<10	<10
	6/17/02	<10	<10
	6/18/02	<10	<10
	6/19/02	<10	<10
	6/20/02	<10	<10
	6/24/02	9	<10
	6/25/02	80	9
	6/26/02	<10	<10
	6/27/02	<10	<10
	7/1/02	<10	<10
	7/2/02	<10	<10
	7/3/02	<10	<10
	7/5/02	<10	<10
	7/9/02	<10	<10
	7/10/02	<10	<10
	7/11/02	<10	<10
	7/15/02	<10	9
	7/16/02	<10	<10
	7/17/02	<10	<10
	7/18/02	<10	<10
	7/22/02	<10	<10

METROPOLITAN WATER RECLAMATION DISTRICT OF GREATER CHICAGO

TABLE AI-2 (Continued)

FC AND EC DENSITITES IN CHLORINATED WRP EFFLUENT SAMPLES

Sample Type	Sample Date	FC/100mL (24-hour Test)	EC/100mL (m-TEC)
Hanover Park WRP Effluent (Cont.)	7/23/02	<10	<10
	7/24/02	<10	<10
	7/25/02	<10	<10
	7/29/02	410	200
	7/30/02	<10	9
	7/31/02	<10	<10
	8/1/02	<10	<10
	8/5/02	<10	<10
	8/6/02	<10	<10
	8/7/02	<10	<10
	8/8/02	<10	<10
	8/12/02	<10	<10
	8/13/02	<10	<10
	8/14/02	<10	<10
	8/15/02	9	<10
	9/9/02	<10	9
	9/10/02	30	9
	9/11/02	<10	<10
	9/12/02	<10	<10
	9/16/02	<10	<10
	9/17/02	20	9
	9/18/02	20	<10
	9/19/02	<10	<10
	9/23/02	<10	<10
	9/24/02	<10	<10
	9/25/02	<10	<10
	9/26/02	<10	<10
	9/30/02	<10	<10
	10/1/02	<10	<10
	10/2/02	<10	<10
	10/3/02	<10	<10
	10/7/02	<10	<10
	10/8/02	<10	<10
	10/9/02	9	<10
	10/10/02	<10	<10
	10/14/02	<10	<10

METROPOLITAN WATER RECLAMATION DISTRICT OF GREATER CHICAGO

TABLE AI-2 (Continued)

FC AND EC DENSITITES IN CHLORINATED WRP EFFLUENT SAMPLES

Sample Type	Sample Date	FC/100mL (24-hour Test)	EC/100mL (m-TEC)
Hanover Park WRP Effluent (Cont.)	10/15/02	<10	<10
	10/16/02	<10	<10
	10/17/02	<10	<10
	10/21/02	<10	<10
	10/22/02	9	<10
	10/23/02	<10	9
	10/24/02	<10	<10
	10/28/02	<10	<10
	10/29/02	<10	<10
	10/30/02	<10	<10
	10/31/02	<10	<10
	5/1/03	9	20
James C. Kirie WRP Effluent	5/23/00	<10	<10
	9/18/00	<10	<10
	9/19/00	<10	<10
	9/20/00	<10	<10
	9/21/00	9	9
	9/25/00	30	<10
	9/26/00	<10	<10
	9/27/00	<10	<10
	9/28/00	9	9
	10/2/00	9	<10
	10/3/00	9	<10
	10/4/00	40	30
	10/5/00	30	30
	10/9/00	<10	<10
	10/10/00	<10	<10
	10/11/00	<10	<10
	10/14/00	<10	<10
	10/16/00	<10	<10
	10/17/00	<10	<10
	10/18/00	30	40
	10/19/00	9	9

METROPOLITAN WATER RECLAMATION DISTRICT OF GREATER CHICAGO

TABLE AI-2 (Continued)

FC AND EC DENSITITES IN CHLORINATED WRP EFFLUENT SAMPLES

Sample Type	Sample Date	FC/100mL (24-hour Test)	EC/100mL (m-TEC)
James C. Kirie WRP Effluent (Cont.)	10/23/00	<10	9
	10/24/00	<10	<10
	10/25/00	9	<10
	10/26/00	<10	<10
	10/30/00	9	<10
	10/31/00	<10	9
	5/1/01	<10	<10
	5/2/01	<10	<10
	5/3/01	<10	<10
	5/7/01	<10	<10
	5/8/01	9	<10
	5/9/01	<10	9
	5/10/01	<10	<10
	5/14/01	9	<10
	5/15/01	<10	<10
	5/16/01	<10	9
	5/17/01	140	70
	5/21/01	<10	<10
	5/22/01	9	<10
	5/23/01	<10	<10
	5/24/01	<10	<10
	5/29/01	<10	<10
	5/30/01	<10	<10
	5/31/01	<10	9
	6/1/01	<10	9
	6/4/01	<10	<10
	6/5/01	9	9
	6/6/01	<10	<10
	6/7/01	<10	<10
	6/11/01	<10	<10
	6/12/01	<10	<10
	6/13/01	<10	<10
	6/14/01	<10	<10
	6/18/01	<10	<10
	6/19/01	<10	<10

METROPOLITAN WATER RECLAMATION DISTRICT OF GREATER CHICAGO

TABLE AI-2 (Continued)

FC AND EC DENSITITES IN CHLORINATED WRP EFFLUENT SAMPLES

Sample Type	Sample Date	FC/100mL (24-hour Test)	EC/100mL (m-TEC)
James C. Kirie WRP Effluent (Cont.)	6/20/01	<10	9
	6/21/01	<10	<10
	6/25/01	<10	9
	6/26/01	<10	<10
	6/27/01	<10	<10
	6/28/01	<10	9
	7/2/01	<10	<10
	7/3/01	<10	<10
	7/5/01	<10	<10
	7/6/01	<10	<10
	7/9/01	<10	<10
	7/10/01	<10	<10
	7/11/01	<10	<10
	7/12/01	<10	<10
	7/16/01	<10	<10
	7/17/01	9	9
	7/18/01	<10	<10
	7/19/01	<10	<10
	7/23/01	<10	<10
	7/24/01	<10	<10
	7/25/01	<10	<10
	7/26/01	<10	<10
	7/30/01	<10	<10
	7/31/01	<10	<10
	8/1/01	<10	<10
	8/2/01	<10	<10
	8/6/01	<10	<10
	8/7/01	<10	<10
	8/8/01	<10	<10
	8/13/01	9	9
	8/14/01	<10	<10
	8/15/01	<10	<10
	8/16/01	20	<10
	8/20/01	9	<10
	8/21/01	<10	<10

METROPOLITAN WATER RECLAMATION DISTRICT OF GREATER CHICAGO

TABLE AI-2 (Continued)

FC AND EC DENSITITES IN CHLORINATED WRP EFFLUENT SAMPLES

Sample Type	Sample Date	FC/100mL (24-hour Test)	EC/100mL (m-TEC)
James C. Kirie WRP			
Effluent (Cont.)	5/1/02	<10	<10
	5/2/02	9	<10
	5/6/02	<10	<10
	5/7/02	<10	<10
	5/8/02	9	<10
	5/9/02	<10	9
	5/13/02	100	90
	5/14/02	9	30
	5/15/02	20	<10
	5/16/02	<10	<10
	5/20/02	9	9
	5/21/02	<10	9
	5/22/02	<10	9
	5/23/02	<10	<10
	5/28/02	<10	<10
	5/29/02	9	<10
	5/30/02	<10	<10
	6/3/02	<10	<10
	6/4/02	9	9
	6/5/02	20	<10
	6/6/02	20	20
	6/10/02	<10	<10
	6/11/02	<10	9
	6/12/02	9	<10
	6/13/02	<10	<10
	6/17/02	9	<10
	6/18/02	<10	9
	6/19/02	<10	9
	6/20/02	<10	<10
	6/24/02	<10	<10
	6/25/02	<10	<10
	6/26/02	<10	9
	6/27/02	<10	<10
	7/1/02	<10	<10
	7/2/02	<10	<10
	7/3/02	<10	<10

METROPOLITAN WATER RECLAMATION DISTRICT OF GREATER CHICAGO

TABLE AI-2 (Continued)

FC AND EC DENSITITES IN CHLORINATED WRP EFFLUENT SAMPLES

Sample Type	Sample Date	FC/100mL (24-hour Test)	EC/100mL (m-TEC)
James C. Kirie WRP Effluent (Cont.)	7/5/02	<10	<10
	7/9/02	<10	20
	7/10/02	30	9
	7/11/02	30	20
	7/15/02	<10	<10
	7/16/02	<10	<10
	7/17/02	<10	<10
	7/18/02	9	<10
	7/22/02	9	9
	7/23/02	<10	<10
	7/24/02	<10	<10
	7/25/02	<10	<10
	7/29/02	20	<10
	7/30/02	9	<10
	7/31/02	9	<10
	8/1/02	<10	9
	8/5/02	<10	<10
	8/6/02	<10	<10
	8/7/02	<10	<10
	8/8/02	<10	<10
	8/12/02	20	<10
	8/13/02	<10	<10
	8/14/02	120	40
	8/15/02	9	<10
	9/9/02	20	20
	9/10/02	9	9
	9/11/02	9	20
	9/12/02	<10	<10
	9/16/02	<10	<10
	9/17/02	<10	<10
	9/18/02	<10	<10
	9/19/02	<10	<10
	9/23/02	<10	9
	9/24/02	<10	<10
	9/25/02	<10	<10
	9/26/02	<10	<10

METROPOLITAN WATER RECLAMATION DISTRICT OF GREATER CHICAGO

TABLE AI-2 (Continued)

FC AND EC DENSITITES IN CHLORINATED WRP EFFLUENT SAMPLES

Sample Type	Sample Date	FC/100mL (24-hour Test)	EC/100mL (m-TEC)
James C. Kirie WRP Effluent (Cont.)	9/30/02	<10	<10
	10/1/02	<10	<10
	10/2/02	<10	<10
	10/3/02	<10	<10
	10/7/02	<10	9
	10/8/02	<10	<10
	10/9/02	<10	<10
	10/10/02	<10	<10
	10/14/02	<10	<10
	10/15/02	<10	<10
	10/16/02	<10	<10
	10/17/02	<10	<10
	10/21/02	<10	<10
	10/22/02	<10	<10
	10/23/02	<10	<10
	10/24/02	<10	<10
	10/28/02	<10	<10
	10/29/02	<10	<10
	10/30/02	<10	<10
	10/31/02	9	<10
	5/1/03	<10	9

METROPOLITAN WATER RECLAMATION DISTRICT OF GREATER CHICAGO

TABLE AI-3

FC AND EC DENSITITES IN CALUMET RIVER WATERSHED SAMPLES

Sample Point	Sample Date	FC/100mL (24-hour Test)	EC/100mL (m-TEC)
D.C.[1] 43 Route 83, Cal-Sag Channel	6/5/00	290	200
	3/26/01	9	9
	5/29/01	3400	2400
	11/26/01	280	140
	2/25/02	600	620
	5/28/02	20	9
	8/26/02	210	140
	11/25/02	70	40
	2/24/03	9	9
	5/27/03	<10	20
D.C. 49 Ewing Ave., Calumet River	6/5/00	60	20
	3/26/01	9	<10
	6/25/01	<10	<10
	12/26/01	<10	<10
	4/22/02	<10	<10
	7/22/02	20	<10
	10/28/02	<10	<10
	1/27/03	<10	<10
	4/28/03	<10	<10
D.C. 50 Burnham Ave., (Ave "O"), Wolf Lake	6/5/00	70	40
	3/26/01	40	<10
	6/25/01	30	9
	4/22/02	9	<10
	7/22/02	<10	20
	10/28/02	<10	9

METROPOLITAN WATER RECLAMATION DISTRICT OF GREATER CHICAGO

TABLE AI-3 (Continued)

FC AND EC DENSITITES IN CALUMET RIVER WATERSHED SAMPLES

Sample Point	Sample Date	FC/100mL (24-hour Test)	EC/100mL (m-TEC)
D.C. 50 Burnham Ave., (Ave "O"), Wolf Lake (Cont.)	1/27/03	130	100
	4/28/03	20	40
D.C. 52 Wentworth Ave., Little Calumet River	6/5/00	21000	20000
	4/23/01	2200	2000
	7/23/01	8000	6800
	2/25/02	2000	2900
	5/28/02	530	540
	8/26/02	480	340
	11/25/02	1200	960
	5/27/03	520	380
D.C. 54 Joe Orr Rd., Thorn Creek	6/5/00	12000	9200
	4/23/01	800	560
	7/23/01	6000	3200
	2/25/02	2700	2000
	8/26/02	300	260
	2/24/03	280	200
D.C. 55 130th St., Calumet River	6/5/00	230	60
	3/26/01	<10	<10
	6/25/01	60	<10
	12/26/01	<10	<10
	4/22/02	60	40

METROPOLITAN WATER RECLAMATION DISTRICT OF GREATER CHICAGO

TABLE AI-3 (Continued)

FC AND EC DENSITITES IN CALUMET RIVER WATERSHED SAMPLES

Sample Point	Sample Date	FC/100mL (24-hour Test)	EC/100mL (m-TEC)
D.C. 55 130th St., Calumet River (Cont.)	7/22/02	9	<10
	10/28/02	<10	<10
	4/28/03	9	<10
D.C. 56 Indiana Ave., Little Calumet River	6/5/00	220	110
	5/29/01	9	40
	11/26/01	2900	1300
	4/22/02	70	70
	7/22/02	50	40
	10/28/02	990	920
	4/28/03	70	40
D.C. 57 Ashland Ave., Little Calumet River	6/5/00	11000	5500
	4/23/01	1200	940
	7/23/01	150	2800
	2/25/02	760	590
	5/28/02	410	300
	8/26/02	2900	3000
	11/25/02	430	270
	5/27/03	5700	2500
D.C. 58 Ashland Ave., Cal-Sag Channel	6/5/00	60000	60000
	5/29/01	1800	1200
	11/26/01	5700	5900
	2/25/02	980	850

METROPOLITAN WATER RECLAMATION DISTRICT OF GREATER CHICAGO

TABLE AI-3 (Continued)

FC AND EC DENSITITES IN CALUMET RIVER WATERSHED SAMPLES

Sample Point	Sample Date	FC/100mL (24-hour Test)	EC/100mL (m-TEC)
D.C. 58 Ashland Ave., Cal-Sag Channel (Cont.)	5/28/02	560	380
	8/26/02	650	540
	11/25/02	1300	1300
	2/24/03	570	720
	5/27/03	380	260
D.C. 59 Cicero Ave., Cal-Sag Channel	6/5/00	570	580
	3/26/01	50	30
	5/29/01	2000	1100
	11/26/01	830	600
	2/25/02	590	700
	5/28/02	200	180
	8/26/02	800	730
	11/25/02	690	680
	5/27/03	90	20
D.C. 76 Halsted St., Little Calumet River	6/5/00	2900	2700
	5/29/01	10000	2500
	11/26/01	7000	4200
	4/22/02	3600	3800
	7/22/02	2000	1200
	10/28/02	2200	1700
	1/27/03	3600	1400
	4/28/03	2100	1400

METROPOLITAN WATER RECLAMATION DISTRICT OF GREATER CHICAGO

TABLE AI-3 (Continued)

FC AND EC DENSITITES IN CALUMET RIVER WATERSHED SAMPLES

Sample Point	Sample Date	FC/100mL (24-hour Test)	EC/100mL (m-TEC)
D.C. 86 Burnham Ave., Grand Calumet River	6/5/00	150000	110000
	3/26/01	80	30
	6/25/01	330	220
	4/22/02	20000	7900
	7/22/02	350	330
	10/28/02	200	120
	4/28/03	200	170
D.C. 97 170th St., Thorn Creek	4/23/01	2000	610
	7/23/01	11000	8200
	2/25/02	610	520
	5/28/02	400	360
	8/26/02	320	380
	11/25/02	1200	1100
	2/24/03	860	2400
	5/27/03	210	270

[1]D.C. = datum code (for District use).

METROPOLITAN WATER RECLAMATION DISTRICT OF GREATER CHICAGO

TABLE AI-4

FC AND EC DENSITITES IN CHICAGO RIVER WATERSHED SAMPLES

Sample Point	Sample Date	FC/100mL (24-hour Test)	EC/100mL (m-TEC)
D.C.[1] 31, Lake-Cook Rd., Middle Fork, No. Branch	3/12/01	450	300
	6/11/01	520	400
	12/10/01	650	850
	4/8/02	630	460
	7/8/02	430	490
	10/14/02	380	350
	4/14/03	120	210
D.C. 32, Lake-Cook Rd., Skokie River	3/12/01	740	450
	6/11/01	11000	3500
	12/10/01	480	470
	4/8/02	1300	1100
	7/8/02	1300	990
	10/14/02	260	180
	4/14/03	320	200
D.C. 34 Dempster St., No. Branch	4/9/01	490	330
	7/9/01	2200	2000
	4/8/02	550	390
	7/8/02	1200	1200
	10/14/02	940	580
	11/12/02	810	760
	1/13/03	6200	5600
	4/14/03	260	240

METROPOLITAN WATER RECLAMATION DISTRICT OF GREATER CHICAGO

TABLE AI-4 (Continued)

FC AND EC DENSITITES IN CHICAGO RIVER WATERSHED SAMPLES

Sample Point	Sample Date	FC/100mL (24-hour Test)	EC/100mL (m-TEC)
D.C. 35 Central Ave., No. Shore Channel	5/14/01	4	4
	8/13/01	2200	800
	11/13/01	1400	840
	5/13/02	6900	6400
	8/12/02	620	660
	11/12/02	3100	3000
	5/12/03	3700	3900
D.C. 36 Touhy Ave., No. Shore Channel	5/14/01	<10	<10
	8/13/01	12000	7700
	11/13/01	11000	8300
	2/11/02	8600	6900
	5/13/02	8000	8000
	8/12/02	12000	10000
	11/12/02	12000	15000
	2/10/03	14000	10000
	5/12/03	4600	3100
D.C. 37 Wilson Ave., No. Branch	4/9/01	5600	3700
	7/9/01	5300	3100
	2/11/02	7600	4800
	8/12/02	10000	10000
	11/12/02	17000	16000
	2/10/03	8200	7600
	5/12/03	5400	4300

METROPOLITAN WATER RECLAMATION DISTRICT OF GREATER CHICAGO

TABLE AI-4 (Continued)

FC AND EC DENSITITES IN CHICAGO RIVER WATERSHED SAMPLES

Sample Point	Sample Date	FC/100mL (24-hour Test)	EC/100mL (m-TEC)
D.C. 39 Madison St., So. Branch	3/19/01	2000	730
	6/18/01	220	99
	12/17/01	4000	1000
	4/15/02	1000	750
	7/15/02	170	170
	10/21/02	2300	2100
	1/21/03	1000	903
	4/21/03	600	290
D.C. 40 Damen Ave., Chicago Sanitary & Ship Canal (CSSC)	2/18/03	110	30
D.C. 41 Harlem Ave., CSSC	7/16/01	4800	3000
	2/19/02	3100	2000
	5/20/02	5300	5200
	8/19/02	1400	1100
	11/18/02	5900	6400
	2/18/03	1400	1400
	5/19/03	5000	2600
D.C. 42 Route 83, CSSC	7/16/01	3000	1100
	2/19/02	160	140
	5/20/02	1200	1200
	8/19/02	1400	1200
	11/18/02	1200	1300
	2/18/03	330	310
	5/19/03	940	860

METROPOLITAN WATER RECLAMATION DISTRICT OF GREATER CHICAGO

TABLE AI-4 (Continued)

FC AND EC DENSITITES IN CHICAGO RIVER WATERSHED SAMPLES

Sample Point	Sample Date	FC/100mL (24-hour Test)	EC/100mL (m-TEC)
D.C. 46 Grand Ave., No. Branch	4/9/01	970	630
	7/9/01	2800	2000
	2/11/02	10000	8900
	5/13/02	9000	10000
	8/12/02	780	490
	11/12/02	500	470
	2/10/03	2000	1000
	5/12/03	35000	25000
D.C. 48 Stephen St., CSSC	7/16/01	300	340
	2/19/02	200	170
	5/20/02	560	500
	8/19/02	900	620
	11/18/02	2000	1500
	2/18/03	140	90
	5/19/03	530	280
D.C. 73 Diversey Pkwy., No. Branch	4/9/01	2800	2300
	7/9/01	3300	3000
	2/11/02	8500	5200
	5/13/02	11000	8300
	8/12/02	4000	4000
	11/12/02	12000	12000
	2/10/03	5700	5400
	5/12/03	3000	3000

METROPOLITAN WATER RECLAMATION DISTRICT OF GREATER CHICAGO

TABLE AI-4 (Continued)

FC AND EC DENSITITES IN CHICAGO RIVER WATERSHED SAMPLES

Sample Point	Sample Date	FC/100mL (24-hour Test)	EC/100mL (m-TEC)
D.C. 74 Lake Shore Dr., Chicago River	3/19/01	9	<10
	6/18/01	<10	<10
	12/17/01	400	140
	4/15/02	110	60
	7/15/02	50	30
	10/21/02	9	<10
	4/21/03	50	30
D.C. 75 Cicero Ave., CSSC	7/16/01	110	50
	2/19/02	60	40
	5/20/02	760	780
	8/19/02	260	300
	11/18/02	530	270
	2/18/03	20	9
	5/19/03	90	90
D.C. 92 Lockport Locks, CSSC	4/19/01	200	160
	7/19/01	100	30
	2/19/02	80	50
	5/20/02	350	220
	8/19/02	530	320
	11/18/02	270	280
	2/18/03	20	40
	5/19/03	60	30
D.C. 96 Albany Ave., No. Branch	4/9/01	42000	39000
	7/9/01	2900	2300

METROPOLITAN WATER RECLAMATION DISTRICT OF GREATER CHICAGO

TABLE AI-4 (Continued)

FC AND EC DENSITITES IN CHICAGO RIVER WATERSHED SAMPLES

Sample Point	Sample Date	FC/100mL (24-hour Test)	EC/100mL (m-TEC)
D.C. 96 Albany Ave., No. Branch (Cont.)	4/8/02	5700	3600
	7/8/02	860	670
	10/14/02	870	670
	1/13/03	670	410
	4/14/03	3500	3700
D.C. 99 Archer Ave., So. Fork, So. Branch	3/19/01	610	340
	6/18/01	5300	4600
	12/17/01	350	340
	4/15/02	370	300
	7/15/02	510	370
	10/21/02	90	50
	1/21/03	50	20
	4/21/03	100	160
D.C. 100 Wells St., Chicago River	3/19/01	460	310
	6/18/01	9	40
	12/17/01	460	430
	4/15/02	280	190
	7/15/02	50	50
	10/21/02	7700	6700
	1/21/03	270	350
	4/21/03	210	130
D.C. 101 Foster Ave., No. Shore Channel	5/14/01	9600	9600
	8/13/01	11000	9600
	11/13/01	10000	7500

METROPOLITAN WATER RECLAMATION DISTRICT OF GREATER CHICAGO

TABLE AI-4 (Continued)

FC AND EC DENSITITES IN CHICAGO RIVER WATERSHED SAMPLES

Sample Point	Sample Date	FC/100mL (24-hour Test)	EC/100mL (m-TEC)
D.C. 101 Foster Ave., No. Shore Channel (Cont.)	2/11/02	8700	7000
	5/13/02	31000	23000
	8/12/02	11000	10000
	11/12/02	16000	25000
	2/10/03	13000	11000
	5/12/03	5900	3900
D.C. 102 Oakton St., No. Shore Channel	5/14/01	600	400
	8/13/01	1100	640
	11/13/01	90	40
	2/11/02	260	180
	8/12/02	740	740
	11/12/02	11000	21000
	2/10/03	4500	4100
	5/12/03	350000	140000
D.C. 103 Golf Rd., West Fork, No. Branch	3/12/01	1000	630
	6/11/01	540	330
	12/10/01	1200	760
	4/8/02	1200	1200
	7/8/02	310	210
	10/14/02	1400	1000
	4/14/03	500	370
D.C. 104 Glenview Rd., No. Branch	4/9/01	380	360
	7/9/01	2300	1100

METROPOLITAN WATER RECLAMATION DISTRICT OF GREATER CHICAGO

TABLE AI-4 (Continued)

FC AND EC DENSITITES IN CHICAGO RIVER WATERSHED SAMPLES

Sample Point	Sample Date	FC/100mL (24-hour Test)	EC/100mL (m-TEC)
D.C. 104 Glenview Rd., No. Branch (Cont.)	4/8/02	190	210
	10/14/02	450	390
	4/14/03	170	180
D.C. 105 Frontage Rd., Skokie River	3/12/01	21000	13000
	6/11/01	190	140
	12/10/01	160	140
	4/8/02	360	280
	7/8/02	960	900
	10/14/02	220	230
	1/13/03	50	50
	4/14/03	40	50
D.C. 106 Dundee Rd., West Fork, No. Branch	3/12/01	2400	2200
	6/11/01	1100	690
D.C. 107 Western Ave., CSSC	7/16/01	110	100
	2/19/02	110	130
	5/20/02	1500	1700
	8/19/02	560	440
	11/18/02	100	140
D.C. 108 Loomis St., So. Branch	6/18/01	150	80
	12/17/01	550	420
	4/15/02	300	140

METROPOLITAN WATER RECLAMATION DISTRICT OF GREATER CHICAGO

TABLE AI-4 (Continued)

FC AND EC DENSITITES IN CHICAGO RIVER WATERSHED SAMPLES

Sample Point	Sample Date	FC/100mL (24-hour Test)	EC/100mL (m-TEC)
D.C. 108 Loomis St., So. Branch (Cont.)	7/15/02	280	240
	10/21/02	180	180
	1/21/03	120	90
	4/21/03	20	9

[1]D.C. = datum code (for District use).

METROPOLITAN WATER RECLAMATION DISTRICT OF GREATER CHICAGO

TABLE AI-5

FC AND EC DENSITITES IN DES PLAINES RIVER WATERSHED SAMPLES

Sample Point	Sample Date	FC/100mL (24-hour Test)	EC/100mL (m-TEC)
D.C.[1] 12 Lake-Cook Rd., Buffalo Creek	4/24/00	150	220
	4/2/01	99	50
	6/4/01	320	140
	1/7/02	210	100
	4/1/02	<10	20
	10/7/02	700	520
	4/7/03	570	320
D.C. 13 Lake-Cook Rd.	4/24/00	220	370
	3/5/01	150	140
	12/3/01	350	220
	3/4/02	390	260
	6/3/02	160	140
	9/3/02	6600	6700
	3/3/03	720	750
	6/2/03	140	150
D.C. 17 Oakton St.	4/24/00	330	270
	3/5/01	180	120
	6/4/01	250	160
	12/3/01	320	330
	3/4/02	140	100
	6/3/02	180	140
	9/3/02	3000	1800
	12/2/02	3900	430
	6/2/03	270	180

METROPOLITAN WATER RECLAMATION DISTRICT OF GREATER CHICAGO

TABLE AI-5 (Continued)

FC AND EC DENSITITES IN DES PLAINES RIVER WATERSHED SAMPLES

Sample Point	Sample Date	FC/100mL (24-hour Test)	EC/100mL (m-TEC)
D.C. 18 Devon Ave., Salt Creek	4/24/00	550	500
	4/2/01	4600	3900
	7/2/01	3700	4000
	5/6/02	110	120
	8/5/02	6000	5700
	11/4/02	1900	2200
	2/3/03	5700	5200
	4/7/03	1400	940
	5/5/03	630	620
D.C. 19 Belmont Ave.	4/24/00	920	1700
	3/5/01	220	90
	6/4/01	500	270
	12/3/01	330	340
	3/4/02	920	690
	6/3/02	70	120
	9/3/02	3100	2200
	12/2/02	5500	3700
	3/3/03	160	120
	6/2/03	280	240
D.C. 20 Roosevelt Rd.	4/24/00	2000	4200
	3/5/01	330	200
	6/4/01	200	400
	12/3/01	1200	920
	3/4/02	240	200
	6/3/02	1600	1100
	12/2/02	1000	5900

METROPOLITAN WATER RECLAMATION DISTRICT OF GREATER CHICAGO

TABLE AI-5 (Continued)

FC AND EC DENSITITES IN DES PLAINES RIVER WATERSHED SAMPLES

Sample Point	Sample Date	FC/100mL (24-hour Test)	EC/100mL (m-TEC)
D.C. 20 Roosevelt Rd., (Cont.)	6/2/03	4900	2000
D.C. 21 Brookfield Ave., Salt Creek	4/24/00	1200	1400
	4/2/01	460	390
	7/2/01	430	360
	2/4/02	750	330
D.C. 22 Ogden Ave.	4/24/00	2000	3300
	12/3/01	2500	1300
	3/4/02	570	240
	6/3/02	200	310
	9/3/02	48000	10000
	12/2/02	750	660
	3/3/03	180	30
D.C. 23 Willow Springs Road	4/24/00	1200	2000
	12/3/01	460	290
	6/3/02	140	150
	9/3/02	11000	7200
	12/2/02	150	120
	6/2/03	890	840
D.C. 24 Wolf Rd., Salt Creek	4/24/00	2000	2600
	4/2/01	140	99
	7/2/01	40	9
	2/4/02	390	350
	5/6/02	210	190

METROPOLITAN WATER RECLAMATION DISTRICT OF GREATER CHICAGO

TABLE AI-5 (Continued)

FC AND EC DENSITITES IN DES PLAINES RIVER WATERSHED SAMPLES

Sample Point	Sample Date	FC/100mL (24-hour Test)	EC/100mL (m-TEC)
D.C. 24 Wolf Rd., Salt Creek (Cont.)	8/5/02	660	800
	11/4/02	200	240
	2/3/03	5000	3800
	5/5/03	8300	6400
D.C. 29 Stephen St.	4/24/00	500	1200
	12/3/01	570	500
	3/4/02	920	370
	6/3/02	90	50
	9/3/02	4100	2600
	12/2/02	4000	3500
	3/3/03	50	20
	6/2/03	350	260
D.C. 63 Longmeadow Ln., West Branch DuPage River	4/24/00	340	210
	9/25/00	3200	3600
	10/23/00	8700	5300
	11/27/00	1800	1200
	2/26/01	1000	760
	5/7/01	5800	4800
	6/4/01	500	990
	12/3/01	460	420
D.C. 64 Lake St., West Branch DuPage River	4/24/00	1200	1300
	9/25/00	33000	42000
	10/23/00	380	240
	11/27/00	3500	3200

METROPOLITAN WATER RECLAMATION DISTRICT OF GREATER CHICAGO

TABLE AI-5 (Continued)

FC AND EC DENSITITES IN DES PLAINES RIVER WATERSHED SAMPLES

Sample Point	Sample Date	FC/100mL (24-hour Test)	EC/100mL (m-TEC)
D.C. 64 Lake St., West Branch DuPage River (Cont.)	1/29/01	38000	12000
	4/2/01	3300	2600
	5/7/01	2900	2100
	6/4/01	410	200
	7/2/01	600	400
	8/6/01	3000	4200
	12/3/01	4100	2300
	1/7/02	5600	3400
	2/4/02	2100	1600
	3/4/02	4600	3200
	4/1/02	1100	800
	5/6/02	90	90
	6/3/02	140	130
	7/1/02	730	600
	8/5/02	43000	34000
	9/3/02	2500	3200
	11/4/02	3400	2300
	1/6/03	1600	2000
	2/3/03	3700	2900
	3/3/03	2000	2500
	4/7/03	2900	2100
	5/5/03	2300	2100
	6/2/03	190	140
D.C. 77 Elmhurst Rd., Higgins Creek	4/24/00	220	410
	9/25/00	450	530
	10/23/00	190	110
	11/27/00	680	420

METROPOLITAN WATER RECLAMATION DISTRICT OF GREATER CHICAGO

TABLE AI-5 (Continued)

FC AND EC DENSITITES IN DES PLAINES RIVER WATERSHED SAMPLES

Sample Point	Sample Date	FC/100mL (24-hour Test)	EC/100mL (m-TEC)
D.C. 77 Elmhurst Rd., Higgins Creek (Cont.)	1/29/01	330	220
	2/26/01	290	140
	3/5/01	9	<10
	5/7/01	40000	28000
	6/4/01	690	360
	7/2/01	170	290
	8/6/01	160	60
	12/3/01	1100	870
	3/4/02	40	40
	4/1/02	20	20
	5/6/02	2000	2100
	9/3/02	37000	26000
	10/7/02	2900	2400
	2/3/03	4000	2500
	5/5/03	3800	7400
D.C. 78 Wille Rd., Higgins Creek	4/24/00	1100	1500
	9/25/00	40	20
	10/23/00	30	20
	11/27/00	1700	1000
	12/18/00	3300	1300
	1/29/01	750	660
	2/26/01	2000	2900
	3/5/01	1800	1500
	4/2/01	870	670
	5/7/01	760	660
	6/4/01	40	9
	7/2/01	9	<10
	8/6/01	30	20
	12/3/01	3400	1500

METROPOLITAN WATER RECLAMATION DISTRICT OF GREATER CHICAGO

TABLE AI-5 (Continued)

FC AND EC DENSITITES IN DES PLAINES RIVER WATERSHED SAMPLES

Sample Point	Sample Date	FC/100mL (24-hour Test)	EC/100mL (m-TEC)
D.C. 78 Wille Rd., Higgins Creek (Cont.)	1/7/02	2100	830
	2/4/02	1800	2700
	3/4/02	5300	5100
	4/1/02	2100	1200
	5/6/02	50	40
	6/3/02	<10	<10
	8/5/02	20000	17000
	9/3/02	1000	810
	10/7/02	130	99
	11/4/02	1400	1100
	12/2/02	190	720
	1/6/03	400	400
	2/3/03	1500	1600
	3/3/03	760	610
	4/7/03	860	650
	5/5/03	320	770
	6/2/03	<10	<10
D.C. 79 Higgins Rd., Salt Creek	4/24/00	260	70
	9/25/00	2000	1300
	10/23/00	50	70
	11/27/00	20	<10
	4/2/01	<10	<10
	5/7/01	40	9
	6/4/01	410	500
	8/6/01	<10	<10
	12/3/01	210	180
	4/1/02	40	<10
	5/6/02	60	40
	6/3/02	40	40

METROPOLITAN WATER RECLAMATION DISTRICT OF GREATER CHICAGO

TABLE AI-5 (Continued)

FC AND EC DENSITITES IN DES PLAINES RIVER WATERSHED SAMPLES

Sample Point	Sample Date	FC/100mL (24-hour Test)	EC/100mL (m-TEC)
D.C. 79 Higgins Rd., Salt Creek (Cont.)	8/5/02	30	60
	9/3/02	7700	8600
	10/7/02	440	250
	11/4/02	<10	9
	4/7/03	260	130
	5/5/03	2600	2800
	6/2/03	140	140
D.C. 80 Arlington Heights Rd., Salt Creek	4/24/00	470	450
	9/25/00	1300	2300
	10/23/00	40	20
	11/27/00	1000	390
	12/18/00	830	620
	1/29/01	1700	1400
	2/26/01	920	900
	4/2/01	4400	4100
	5/7/01	70	60
	6/4/01	40	80
	7/2/01	3000	1400
	8/6/01	110	50
	12/3/01	910	470
	1/7/02	1900	1400
	2/4/02	850	780
	3/4/02	2500	1600
	4/1/02	460	240
	5/6/02	20	9
	6/3/02	40	40
	7/1/02	220	150
	8/5/02	260	240
	9/3/02	180	140

METROPOLITAN WATER RECLAMATION DISTRICT OF GREATER CHICAGO

TABLE AI-5 (Continued)

FC AND EC DENSITITES IN DES PLAINES RIVER WATERSHED SAMPLES

Sample Point	Sample Date	FC/100mL (24-hour Test)	EC/100mL (m-TEC)
D.C. 80 Arlington Heights Rd., Salt Creek (Cont.)	1/6/03	1000	1000
	2/3/03	5200	7700
	3/3/03	1300	1200
	4/7/03	680	530
	5/5/03	130	120
	6/2/03	130	110
D.C. 89 Walnut Ave., West Branch, DuPage River	4/24/00	240	230
	9/25/00	3500	2500
	10/23/00	200	200
	11/27/00	3900	3300
	12/18/00	5200	3800
	1/29/01	60000	50000
	2/26/01	1200	970
	4/2/01	3000	2300
	5/7/01	1100	1200
	6/4/01	210	170
	7/2/01	130	140
	8/6/01	340	160
	12/3/01	2800	2100
	1/7/02	20000	12000
	2/4/02	2300	2400
	3/4/02	4100	3700
	4/1/02	3000	2700
	5/6/02	20	30
	6/3/02	360	350
	7/1/02	300	300
	8/5/02	34000	21000
	9/3/02	2000	2200

METROPOLITAN WATER RECLAMATION DISTRICT OF GREATER CHICAGO

TABLE AI-5 (Continued)

FC AND EC DENSITITES IN DES PLAINES RIVER WATERSHED SAMPLES

Sample Point	Sample Date	FC/100mL (24-hour Test)	EC/100mL (m-TEC)
D.C. 89 Walnut Ave., West Branch, DuPage River (Cont.)	10/7/02	180	110
	11/4/02	9400	6700
	1/6/03	5900	5600
	2/3/03	5800	4700
	3/3/03	4500	2800
	4/7/03	3000	2700
	5/5/03	500	2100
D.C. 90 Route 19, Poplar Creek	5/7/01	1400	700
	8/6/01	80	90
	4/1/02	<10	<10
	7/1/02	190	220
	10/7/02	240	250
	1/6/03	20	20
	4/7/03	60	110
D.C. 91 Material Services Road	3/8/01	2000	1900
	6/7/01	1400	610
	12/6/01	380	230
	6/3/02	60	40
	9/3/02	60	140
	12/2/02	200	130
	3/3/03	500	290
	6/2/03	130	90

[1]D.C. = datum code (for District use).

METROPOLITAN WATER RECLAMATION DISTRICT OF GREATER CHICAGO

TABLE AI-6

FC AND EC DENSITIES IN POST-BYPASS LAKE MICHIGAN SAMPLES

Sample Point	Sample Date	FC/100mL (7-hour Test)	EC MPN/100mL (Quanti-Tray)
Iroquois Landing	8/2/01	9	1
	8/2/01	110	77
	8/25/01	99	147
	8/26/01	<10	6
	10/14/01	230	8
	10/14/01	<10	4
	8/22/02	200	<1
Calumet Beach	6/25/00	<10	11
	8/2/01	80	40
	8/2/01	140	141
	8/3/01	90	44
	8/25/01	1000	1300
	8/26/01	2000	1203
	10/14/01	20	9
	10/14/01	180	40
	8/22/02	210	17
Rainbow Beach	6/25/00	160	70
	6/25/00	30	4
	8/2/01	140	60
	8/2/01	1300	1733
	8/3/01	920	276
	8/25/01	220	135
	8/26/01	290	148
	10/14/01	200	52
	10/14/01	170	70
	8/22/02	570	50
North Ave. Beach	8/3/01	980	64
	8/22/02	40	12
	8/23/02	160	78

METROPOLITAN WATER RECLAMATION DISTRICT OF GREATER CHICAGO

TABLE AI-6 (Continued)

FC AND EC DENSITIES IN POST-BYPASS LAKE MICHIGAN SAMPLES

Sample Point	Sample Date	FC/100mL (7-hour Test)	EC MPN/100mL (Quanti-Tray)
31st St. Beach	8/2/01	20	1
	8/2/01	4500	1046
	8/22/02	60	4
	8/23/02	5400	1733
Adler Planetarium	8/2/01	2400	1733
	8/3/01	3600	1300
	8/23/02	420	326
Monroe Harbor Mouth	8/3/01	140	59
	8/22/02	320	44
	8/23/02	790	461
Oak St. Beach	8/3/01	1600	2419
	8/22/02	110	10
	8/23/02	70	18
Wilmette Harbor Mouth	8/22/02	7500	4610
	8/23/02	13000	13000
Kenilworth Beach	8/3/01	220	80
	8/3/01	70	231
	8/31/01	130	20
	8/31/01	580	360
	8/22/02	70	31
	8/23/02	40	16
Wilmette Beach	8/3/01	1600	1986
	8/3/01	620	2419
	8/31/01	1500	150
	8/31/01	310	280

METROPOLITAN WATER RECLAMATION DISTRICT OF GREATER CHICAGO

TABLE AI-6 (Continued)

FC AND EC DENSITITES IN POST-BYPASS LAKE MICHIGAN SAMPLES

Sample Point	Sample Date	FC/100mL (7-hour Test)	EC MPN/100mL (Quanti-Tray)
Wilmette Beach (Cont.)	8/22/02	1200	199
	8/23/02	90	24
Gillson Beach	8/3/01	2600	579
	8/3/01	400	866
	8/31/01	1900	260
	8/31/01	800	300
	8/22/02	680	240
	8/23/02	80	32
Lighthouse Beach	8/3/01	560	687
	8/3/01	1000	1046
	8/31/01	860	210
	8/22/02	3900	2850
	8/23/02	120	71
Northwestern Univ. Observatory	8/22/02	5400	5480
	8/23/02	100	63
Dempster Beach	8/3/01	720	816
	8/3/01	770	1733
	8/31/01	360	93
	8/31/01	1400	150
	8/22/02	350	15
	8/23/02	80	39
Lake at Calumet River Mouth	6/26/00	9	2
	9/13/00	110	29
	8/27/01	<10	2

METROPOLITAN WATER RECLAMATION DISTRICT OF GREATER CHICAGO

TABLE AI-6 (Continued)

FC AND EC DENSITITES IN POST-BYPASS LAKE MICHIGAN SAMPLES

Sample Point	Sample Date	FC/100mL (7-hour Test)	EC MPN/100mL (Quanti-Tray)
1 Mile North of Calumet River Mouth	6/26/00	<10	<1
	9/13/00	80	31
	8/27/01	<10	5
1 Mile Northeast of Calumet River Mouth	6/26/00	<10	<1
	9/13/00	70	4
	8/27/01	<10	3
1 Mile East of Calumet River Mouth	6/26/00	9	<1
	9/13/00	80	27
	8/27/01	<10	<1
3/4 Mile Southeast of Calumet River Mouth	6/26/00	<10	<1
	9/13/00	<10	3
	8/27/01	<10	<1
1 Mile South of Calumet River Mouth	6/26/00	<10	<1
	9/13/00	<10	6
	8/27/01	<10	<1
Howard Slip on Calumet River	6/26/00	220	50
	9/13/00	740	980
	8/27/01	90	53

METROPOLITAN WATER RECLAMATION DISTRICT OF GREATER CHICAGO

TABLE AI-6 (Continued)

FC AND EC DENSITITES IN POST-BYPASS LAKE MICHIGAN SAMPLES

Sample Point	Sample Date	FC/100mL (7-hour Test)	EC MPN/100mL (Quanti-Tray)
Lake at Chicago River Mouth	8/3/01	240	158
1 Mile North of Chicago River Mouth	8/3/01	9	8
1 Mile Northeast of Chicago River Mouth	8/3/01	30	8
1 Mile East of Chicago River Mouth	8/3/01	<10	1
1 Mile Southeast of Chicago River Mouth	8/3/01	<10	<1
1 Mile South of Chicago River Mouth	8/3/01	20	<1
Lake at North Shore Channel Mouth	8/3/01	760	866
1 Mile North of North Shore Channel Mouth	8/3/01	140	33
1 Mile Northeast of North Shore Channel Mouth	8/3/01	<10	<1
1 Mile East of North Shore Channel Mouth	8/3/01	<10	<1
1 Mile Southeast of North Shore Channel Mouth	8/3/01	<10	<1
1 Mile South of North Shore Channel Mouth	8/3/01	<10	<1

APPENDIX AII

FC AND EC QUALITY CONTROL DATA

METROPOLITAN WATER RECLAMATION DISTRICT OF GREATER CHICAGO

TABLE AII-1

PRECISION STUDY ON SPLIT SAMPLES:
FC (24-HOUR TEST) AND EC (m-TEC)

Replicate	Date	Sample Point	FC/100mL (24-hour Test)	EC/100mL (m-TEC)
1	11/26/02	Egan WRP	400	400
2			1200	1000
3			1000	400
4			600	600
5			800	400
6			400	800
7			400	600
Mean			685.7	600.0
SD			323.7	230.9
CV			47.2	38.5
1	11/26/02	Egan WRP	1800	1600
2			2000	1200
3			1200	1400
4			2000	1400
5			1400	600
6			1800	1600
7			1200	1600
Mean			1628.6	1342.9
SD			354.56	359.89
CV			21.8	26.8
1	11/26/02	Hanover Park WRP	5400	4600
2			3200	4200
3			4800	3600
4			7000	4000
5			4600	4600
6			4000	4400
7			4600	5400
Mean			4800.0	4400.0
SD			1188.8	565.7
CV			24.8	12.9
1	11/26/02	Hanover Park WRP	5300	3700
2			4500	4000
3			4200	3800
4			4500	2800
5			5100	3700
6			5200	3600
7			4500	3700

METROPOLITAN WATER RECLAMATION DISTRICT OF GREATER CHICAGO

TABLE AII-1 (Continued)

PRECISION STUDY ON SPLIT SAMPLES:
FC (24-HOUR TEST) AND EC (m-TEC)

Replicate	Date	Sample Point	FC/100mL (24-hour Test)	EC/100mL (m-TEC)
		Hanover Park WRP		
Mean	11/26/02	(Cont.)	4757.1	3614.3
SD			431.5	380.5
CV			9.1	10.5
1	12/3/02	North Side WRP	30000	31000
2			28000	35000
3			21000	34000
4			26000	31000
5			28000	32000
6			25000	24000
7			29000	36000
Mean			26714.3	31857.1
SD			3039.4	3976.1
CV			11.4	12.5
1	12/3/02	North Side WRP	23400	21000
2			23000	23400
3			21400	26400
4			22600	25000
5			23600	24400
6			23000	24800
7			23800	25000
Mean			22971.4	24285.7
SD			803.6	1700.4
CV			3.5	7.0
1	12/9/02	Stickney WRP	6400	5600
2			6000	7400
3			7200	7000
4			6200	6200
5			5000	5800
6			7200	6000
7			7400	7000
Mean			6485.7	6428.6
SD			855.2	696.9
CV			13.2	10.8

METROPOLITAN WATER RECLAMATION DISTRICT OF GREATER CHICAGO

TABLE AII-1 (Continued)

PRECISION STUDY ON SPLIT SAMPLES:
FC (24-HOUR TEST) AND EC (m-TEC)

Replicate	Date	Sample Point	FC/100mL (24-hour Test)	EC/100mL (m-TEC)
1	12/9/02	Stickney WRP	5900	8300
2			6600	5100
3			7100	5900
4			6000	6500
5			5200	6700
6			5300	5600
7			6400	4600
Mean			6071.4	6100.0
SD			687.3	1217.9
CV			11.3	20.0
1	12/9/02	Station 101	4800	6200
2			6000	4400
3			7000	5200
4			5400	5000
5			5800	5600
6			6000	3600
7			5200	5000
Mean			5742.9	5000.0
SD			709.1	832.7
CV			12.3	16.7
1	12/9/02	Station 101	4600	5300
2			5100	4600
3			4900	5100
4			4600	5200
5			5200	4800
6			4900	4000
7			5400	4400
Mean			4957.1	4771.4
SD			299.2	471.6
CV			6.0	9.9
1	12/9/02	Station 102	3400	3700
2			3200	2400
3			3800	3400
4			3400	2000
5			3400	3700
6			3700	3200
7			3900	3200

TABLE AII-1 (Continued)

PRECISION STUDY ON SPLIT SAMPLES:
FC (24-HOUR TEST) AND EC (m-TEC)

Replicate	Date	Sample Point	FC/100mL (24-hour Test)	EC/100mL (m-TEC)
Mean	12/9/02	Station 102 (Cont.)	3542.9	3085.7
SD			257.3	649.2
CV			7.3	21.0
1	12/16/02	Station 39	400	520
2			440	560
3			480	420
4			400	400
5			420	400
6			400	460
7			460	540
Mean			428.6	471.4
SD			32.4	68.2
CV			7.6	14.5
1	12/16/02	Station 41	3800	4000
2			3600	4400
3			3900	4100
4			4100	3900
5			3400	4600
6			3800	4200
7			3700	4300
Mean			3757.1	4214.3
SD			222.5	241.0
CV			5.9	5.7

METROPOLITAN WATER RECLAMATION DISTRICT OF GREATER CHICAGO

TABLE AII-2

PRECISION AND METHOD COMPARISON STUDY ON SPLIT SAMPLES:
EC (m-TEC) AND EC (QUANTI-TRAY)

Replicate	Date	Sample Point	EC/100mL (m-TEC)	EC/100mL (Quanti-Tray)
1	6/16/03	Calumet WRP	1400	3160
2			3200	3700
3			3200	4260
4			3200	2200
5			1200	3700
6			3200	3420
7			2400	2920
Mean			2542.9	3337.1
SD			899.7	660.9
CV			35.4	19.8
1	6/16/03	Lemont WRP	14200	14660
2			14200	9000
3			15200	11260
4			12000	10760
5			10800	15080
6			13400	18120
7			13000	15880
Mean			13257.1	13537.1
SD			1486.4	3256.2
CV			11.2	24.1
1	6/16/03	Des Plaines River Station 48	167	103
2			233	103
3			67	<33
4			67	210
5			33	103
6			167	170
7			67	173
Mean			114.4	143.7
SD			74.1	46.7
CV			64.8	32.5

METROPOLITAN WATER RECLAMATION DISTRICT OF GREATER CHICAGO

TABLE AII-3

PRECISION AND METHOD COMPARISON STUDY ON SPLIT SAMPLES: FC (24-HOUR TEST) AND FC (7-HOUR TEST)

Replicate	Date	Sample Point	FC/100mL (24-hour Test)	FC/100mL (7-hour Test)
1	6/16/03	Calumet WRP	4000	5200
2			4600	5600
3			3600	5800
4			4400	5600
5			3400	4400
6			5000	6000
7			3400	5600
Mean			4057.1	5457.1
SD			629.4	525.5
CV			15.5	9.6
1	6/16/03	Lemont WRP	14000	15800
2			12400	13000
3			15600	13600
4			9800	15200
5			10400	13000
6			12000	14600
7			13800	14000
Mean			12571.4	14171.4
SD			2060.5	1079.7
CV			16.4	7.6
1	6/16/03	Des Plaines River Station 48	100	67
2			200	200
3			333	100
4			167	300
5			200	67
6			133	200
7			233	100
Mean			195.1	147.7
SD			75.5	87.8
CV			38.7	59.4

APPENDIX BI

SUFFICIENCY, CONSISTENCY, COMPLETENESS, AND BIAS

SUFFICIENCY, CONSISTENCY, BIAS, AND COMPLETENESS

Sufficiency

A sufficient estimator summarizes all the information contained in a sample of observations about a particular parameter. In more formal terms this can be expressed using the conditional distribution of a sample given the estimator and the parameter $f(y|s, \theta)$, in the sense that s is sufficient for θ if this conditional distribution does not depend on θ (Stuart and Ord, 1991).

Let $X_1, X_2, \ldots, X_n$ denote a random sample of size n from a distribution that has probability distribution function (pdf) $f(x;\theta)$. Let $Y_1 = u_1(X_1, X_2, \ldots, X_n)$ be a statistic whose pdf is $g_1(y_1;\theta)$. Then Y_1 is a sufficient statistic for θ if and only if

$$\frac{f(x_1;\theta)\, f(x_2;\theta) \ldots f(x_n;\theta)}{g_1[u_1(x_1, x_2, \ldots, x_n);\theta]} = H(x_1, x_2, \ldots, x_n),$$

where $H(x_1, x_2, \ldots, x_n)$ does not depend upon θ for every fixed value of $y_1 = u_1(x_1, x_2, \ldots, x_n)$. All estimators are evaluated for sufficiency where possible.

Consistency

Consistency is a term used for a particular property of an estimator, namely that its bias tends to be zero as sample size increases (Stuart and Ord, 1991).

Let $X_1, X_2, \ldots, X_n$ denote a random sample of size n from a distribution that has probability distribution function (pdf) $f(x;\theta)$. Let $Y_1 = u_1(X_1, X_2, \ldots, X_n)$ be a statistic whose pdf is $g_1(y_1;\theta)$. Let $E(y_1) = f(n;\theta)$, a function of sample size n and parameter θ. If $\lim_{n\to\infty} E(y_1) = \theta$, then $Y_1 = u_1(X_1, X_2, \ldots, X_n)$ is a consistent estimator of θ.

Unfortunately, it was not possible to find a consistent estimator in a straight forward way as explained in the definition. Therefore, a simulation technique was used to determine whether any of our estimators approaches to R as sample size increases.

Bias

Bias, in general terms, refers to deviation of results or inferences from the truth, or process leading to such deviation. In estimation bias is usually measured by the difference between a parameter estimate, $\hat{\theta}$, and its expected value. An unbiased estimator is an estimator θ of a parameter, θ, such that $E(\hat{\theta}) = \theta$ (Stuart and Ord, 1991). All estimators are biased except for the UMVU estimator (Finney, 1941).

Completeness Property

A sufficient statistic is said to be complete if no function of it has zero expectation unless it is zero almost everywhere with respect to each of the measures $\theta \epsilon \Omega$. If a complete sufficient statistic exists, then every function of it is an UMVUE of its expected value.

For the normal distribution with mean μ and variance σ^2, $\overline{x}$ is sufficient and complete for μ since $E(U(\overline{x})) \neq 0$ for every measure of μ unless $U(\overline{x}) = 0$, and $s^2 = \sum (x_i - \overline{x})^2/(n-1)$ is sufficient and complete for σ^2 for the same reason. Since the distributions of $\overline{x}$ and s^2 are independent, the statistic $T = \overline{x} + 0.5s^2$ is jointly sufficient and complete for $\tau = \mu + 0.5\sigma^2$. Therefore, $W = e^{\overline{x}+0.5s^2}$, the maximum likelihood estimator of e^τ, is jointly sufficient and complete for e^τ. If $E(f(\overline{x}; s^2)) = e^\tau$ then $f(\overline{x}; s^2)$ is UMVUE for e^τ.

Following the method of Finney (1941), Shimizu (1981) showed th at the UMVUE of e^{τ} is given by

$$f(\overline{x};s^2) = e^{\overline{x}} * oF_1\left(\frac{n-1}{2};\frac{n-1}{4n}S^2\right)$$

Where $oF_1(\alpha;z)$ is a hypergeometric function of order (0,1) in $(\alpha;z)$ defined by

$$oF_1(\alpha;z) = \begin{cases} \sum_{j=1}^{\infty} \frac{\Gamma(\alpha)\, z^j}{\Gamma(\alpha+J)\,\Gamma(j+1)}, & j\geq 1 \\ 1, & j=0 \end{cases}$$

APPENDIX BII

DISTRIBUTION OF THE EC/FC RATIO

DISTRIBUTION OF THE EC/FC RATIO

Analysis of the data showed that Y = Log(EC) and X=Log(FC) are both normally distributed (Table 3), and X and Y are significantly correlated (Table 4). We can therefore, postulate that X and Y follow a bivariate normal distribution. However, it does not guarantee that X and Y have a normal distribution even if X and Y are individually normally distributed, and X and Y are highly correlated. We, therefore, explored the possibility of the distribution of the random variable Z=log(EC) -Log(FC).

In an effort to find out the distribution of the EC and FC ratio, we first tested X=EC and Y=FC data for normality by the Kolmogorov-Smirnov(K-S) test. Results of the K-S test show that neither EC data nor FC data came from a normally distributed population. However, the same test shows that U=log(EC) and V=Log(FC) data came from two normal populations, and that U and V are highly correlated. We can postulate that U and V have a joint bivariate normal distribution. We can, therefore, find the distribution of R=X/Y by using the properties of a moment generating function of Bivariate normal distribution. If the random variables U and V have joint density given by

$$f(u,v) = \frac{1}{2\pi\sigma_1\sigma_2\sqrt{1-\rho^2}} \exp\left[-\frac{1}{2(1-\rho^2)}\left[\left(\frac{u-\mu_1}{\sigma_1}\right)^2 - 2\rho\frac{(u-\mu_1)(v-\mu_2)}{\sigma_1\sigma_2} + \left(\frac{v-\mu_2}{\sigma_2}\right)^2\right]\right],$$

$$-\infty<u<\infty,\ -\infty<v<\infty$$

where μ_1, μ_2 are respectively the means and σ_1, σ_2 are respectively the standard deviations of the random variables U and V, and ρ is the correlation coefficient between U and V. The moment generating function of the random variables U and V is given by

$$E\left[\exp\left(t_1 u + t_2 v\right)\right] = \exp\left[\mu_1 t_1 + \mu_2 t_2 + \frac{1}{2}\left(\sigma_1{}^2 t_1{}^2 + 2\rho\sigma_1\sigma_2 t_1 t_2 + \sigma_2{}^2 t_2{}^2\right)\right]$$

$f(u) = \dfrac{1}{\sqrt{2\pi}\sigma_1} \exp\left[-\dfrac{1}{2\sigma_1^2}\left(\dfrac{u-\mu_1}{\sigma_1}\right)^2\right]$ is called the marginal distribution

of the random variable U, its moment generating function is given by

$$M_u(t) = \exp\left(\mu_1 t + \frac{\sigma_1^2 t^2}{2}\right) \qquad (1)$$

Similarly, $f(v) = \dfrac{1}{\sqrt{2\pi}\sigma_2} \exp\left[-\dfrac{1}{2\sigma_2^2}\left(\dfrac{v-\mu_2}{\sigma_2}\right)^2\right]$ is called the marginal

distribution of the random variable V, its moment generating function is given by

$$M_u(t) = \exp\left(\mu_2 t + \frac{\sigma_2^2 t^2}{2} \right). \qquad (2)$$

Let W = U - V, then the moment generating function of the random variable W is given by

$$M_w(t) = E\left[\exp\left[t(u-v)\right]\right] = \int_{-\infty}^{\infty}\int_{-\infty}^{\infty} \exp\left[t(u-v)\right] f(u,v)\, du\, dv$$

After evaluating the definite integral we have

$$M_w(t) = \exp\left((\mu_1-\mu_2)\, t - \frac{1}{2}\, (\sigma_1^2 - 2\rho\sigma_1\sigma_2 + \sigma_2^2)\, t^2 \right) \qquad (3)$$

Now if we compare (3) with (1) or (2), we immediately recognize that $M_w(t)$ is the moment generating function of a Univariate normally distributed random variable with mean $\mu_1-\mu_2$ and variance $\sigma_1^2-2\rho\sigma_1\sigma_2+\sigma_2^2$. Therefore, the random variable W has a Univariate normal distribution with mean $\mu_1-\mu_2$ and variance $\sigma_1^2-2\rho\sigma_1\sigma_2+\sigma_2^2$.

Since W = U - V then W = Log(X) - Log(Y) or W=Log(X/Y) or X/Y = exp(W) or R=Exp(W) as defined earlier. Since W is normally distributed, the R has a Univariate Lognormal distribution with mean

$\mu_r = \exp\left[(\mu_1 - \mu_2) + \frac{1}{2} (\sigma_1^2 - 2\rho\sigma_1\sigma_2 + \sigma_2^2) \right]$. The maximum likelihood estimator of the mean of R = EC/FC is given by

$$\hat{R} = \exp\left[(\hat{\mu}_1 - \hat{\mu}_2) + \frac{1}{2} (\hat{\sigma}_1^2 - 2\hat{\rho}\hat{\sigma}_1\hat{\sigma}_2 + \hat{\sigma}_2^2) \right] \tag{4}$$

However, if U and V are correlated and individually normally distributed, this is a good indication that the joint distribution of U and V would be bivariate normal, but is not a guarantee. There are many possibilities of departure from Multivariate normality, and no single procedure is likely to be robust with respect to the departures from the Multivariate normality assumption. Unfortunately, there is no exact test available to test for the multivariate or bivariate normality. Multivariate or bivariate normality is usually checked by a Q-Q plot. To test for the multivariate normality, Mardia suggested a test based on the measures of skewness and kurtosis. Mardia's test is good if the dimension of Multivariate data is higher than 2, which means that Mardia's test may not be appropriate for bivariate normality test. Joint bivariate normality of log(EC) and log(FC) data was assessed by Q-Q Plots (<u>Figures BII-1 - BII-6</u>), and tested by Kolmogorov-Smirnov method. Both methods show that log(EC) and log(FC) data did not come from a bivariate normal population.

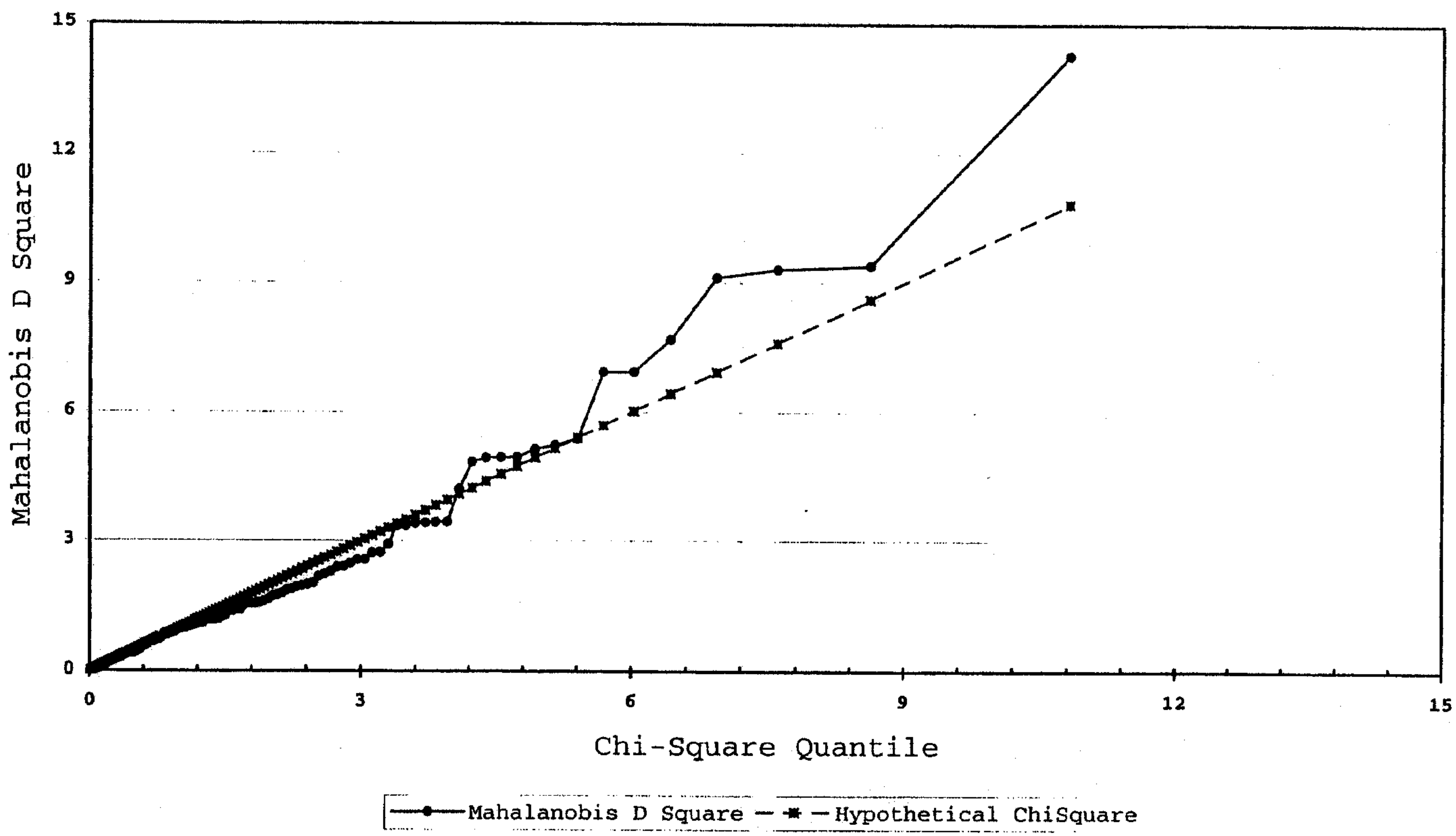
We have, therefore, taken a slightly different approach since our objective is to come up with the distribution of U - V, thereby the distribution of R. Since U and V are normally distributed, W = U - V is also normally distributed with mean $\mu_1-\mu_2$ and variance $\sigma_1^2-2\rho\sigma_1\sigma_2+\sigma_2^2$. The data were tested for the normality of the random variable W, and showed that W came from a normally distributed population.

Since W = U - V or W = Log(X) - Log(Y) or W=Log(X/Y) are normally distributed the random variable R=exp(W) or R=X/Y is lognormally distributed. Hence the maximum likelihood estimate of the mean of ratio R would be achieved by (4).

METROPOLITAN WATER RECLAMATION DISTRICT OF GREATER CHICAGO

FIGURE BII-1

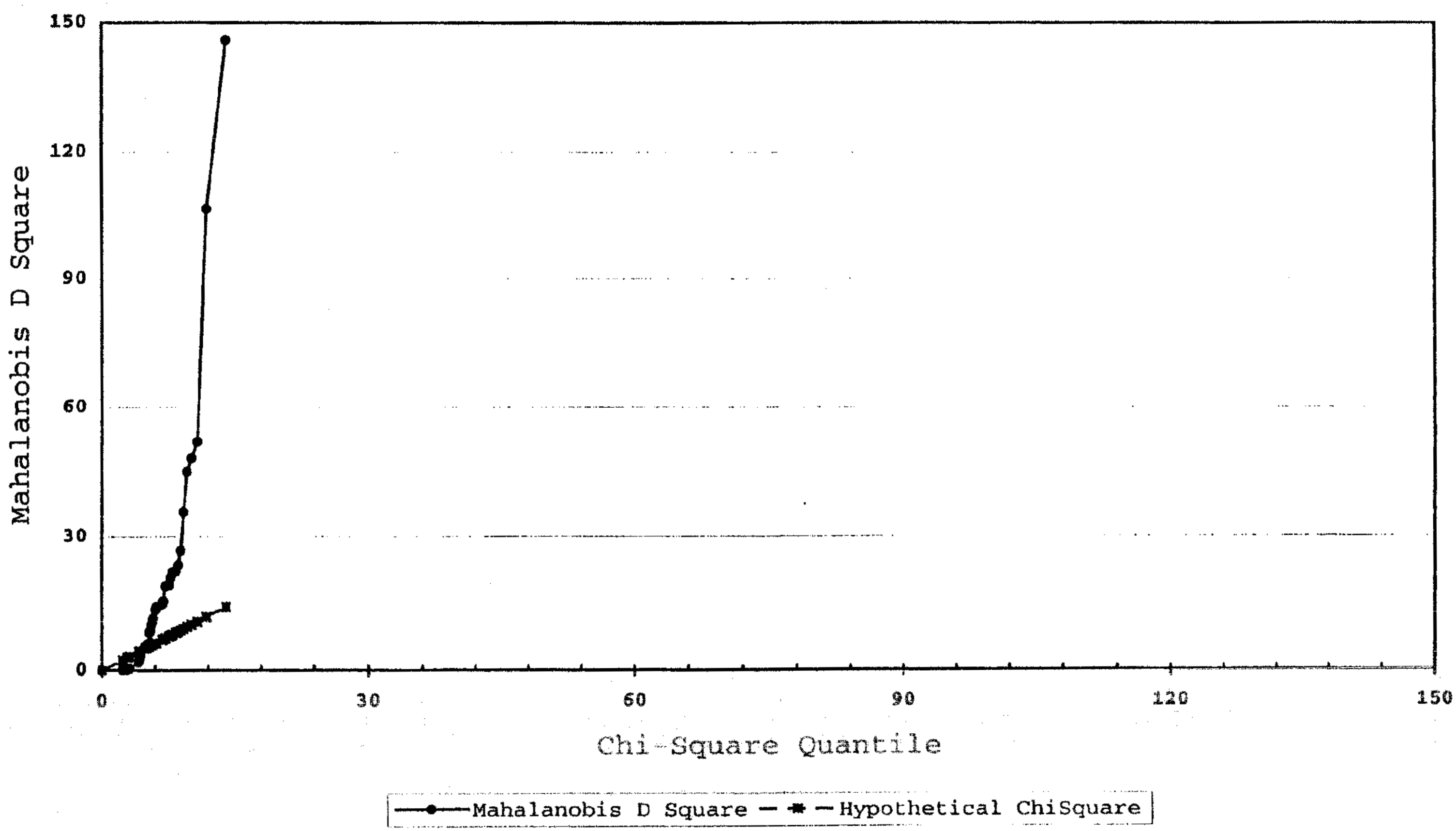
ASSESSING BIVARIATE NORMALITY OF [LOG(EC),LOG(FC)] BY QQ PLOT
AND KOLMOGOROV-SMIRNOV METHOD: P-VALUE = 0.4774
FOR WRP UNCHLORINATED EFFLUENT



METROPOLITAN WATER RECLAMATION DISTRICT OF GREATER CHICAGO

FIGURE BII-2

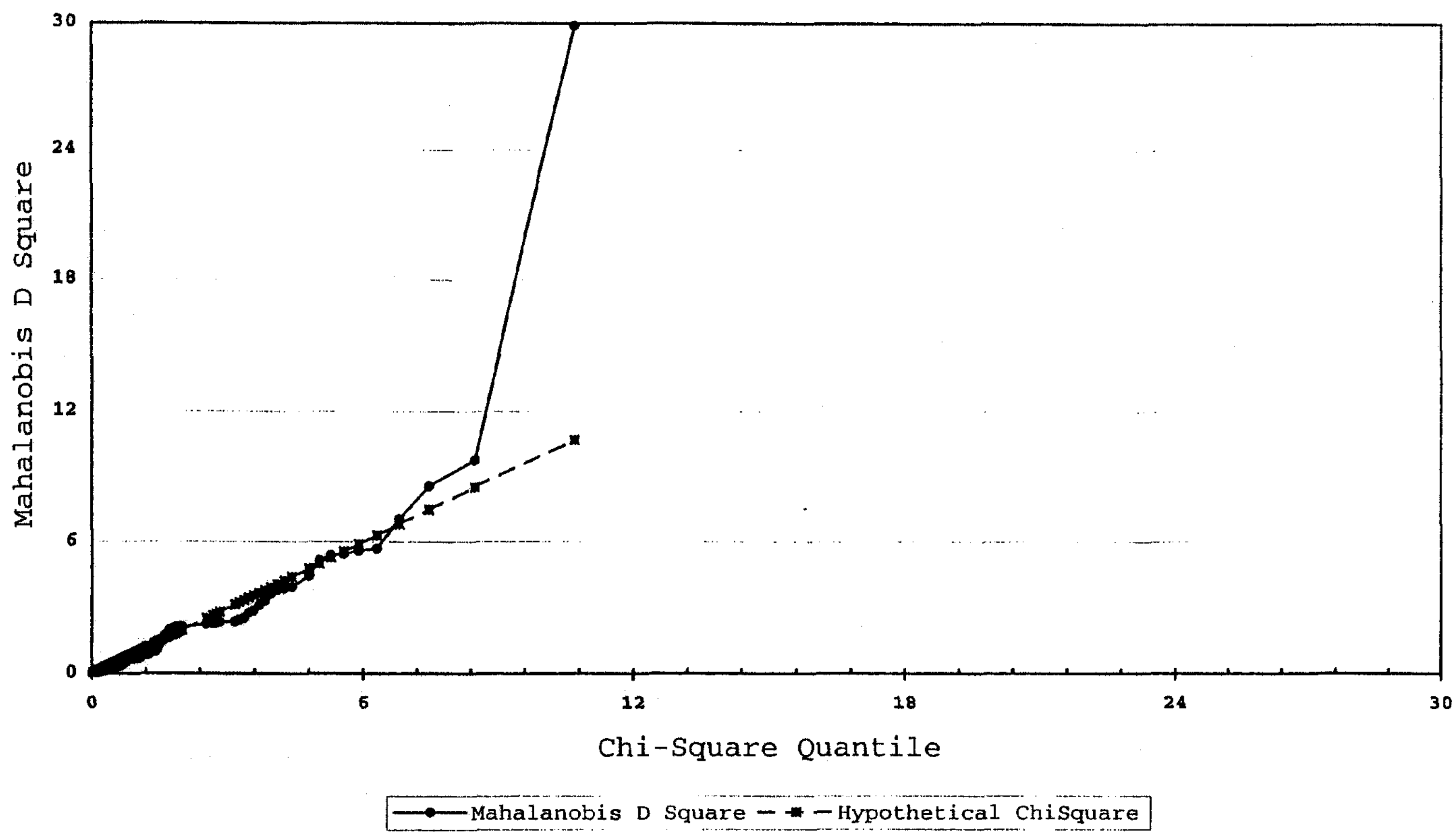
ASSESSING BIVARIATE NORMALITY OF [LOG(EC),LOG(FC)] BY QQ PLOT
AND KOLMOGOROV-SMIRNOV METHOD: P-VALUE = 0.0000
FOR WRP CHLORINATED EFFLUENT



METROPOLITAN WATER RECLAMATION DISTRICT OF GREATER CHICAGO

FIGURE BII-3

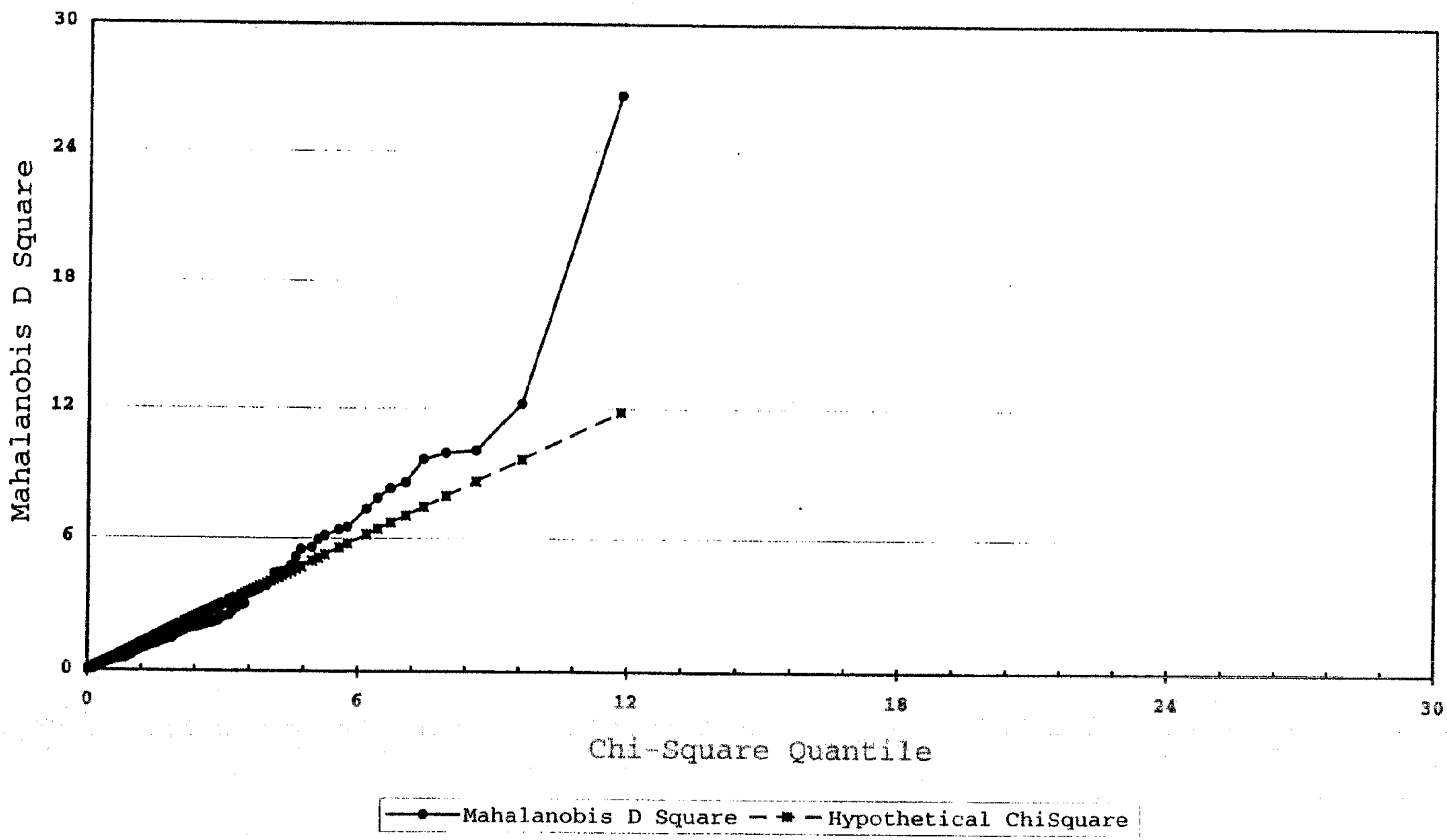
ASSESSING BIVARIATE NORMALITY OF [LOG(EC),LOG(FC)] BY QQ PLOT
AND KOLMOGOROV-SMIRNOV METHOD: P-VALUE = 0.0384
FOR CALUMET RIVER WATERSHED



METROPOLITAN WATER RECLAMATION DISTRICT OF GREATER CHICAGO

FIGURE BII-4

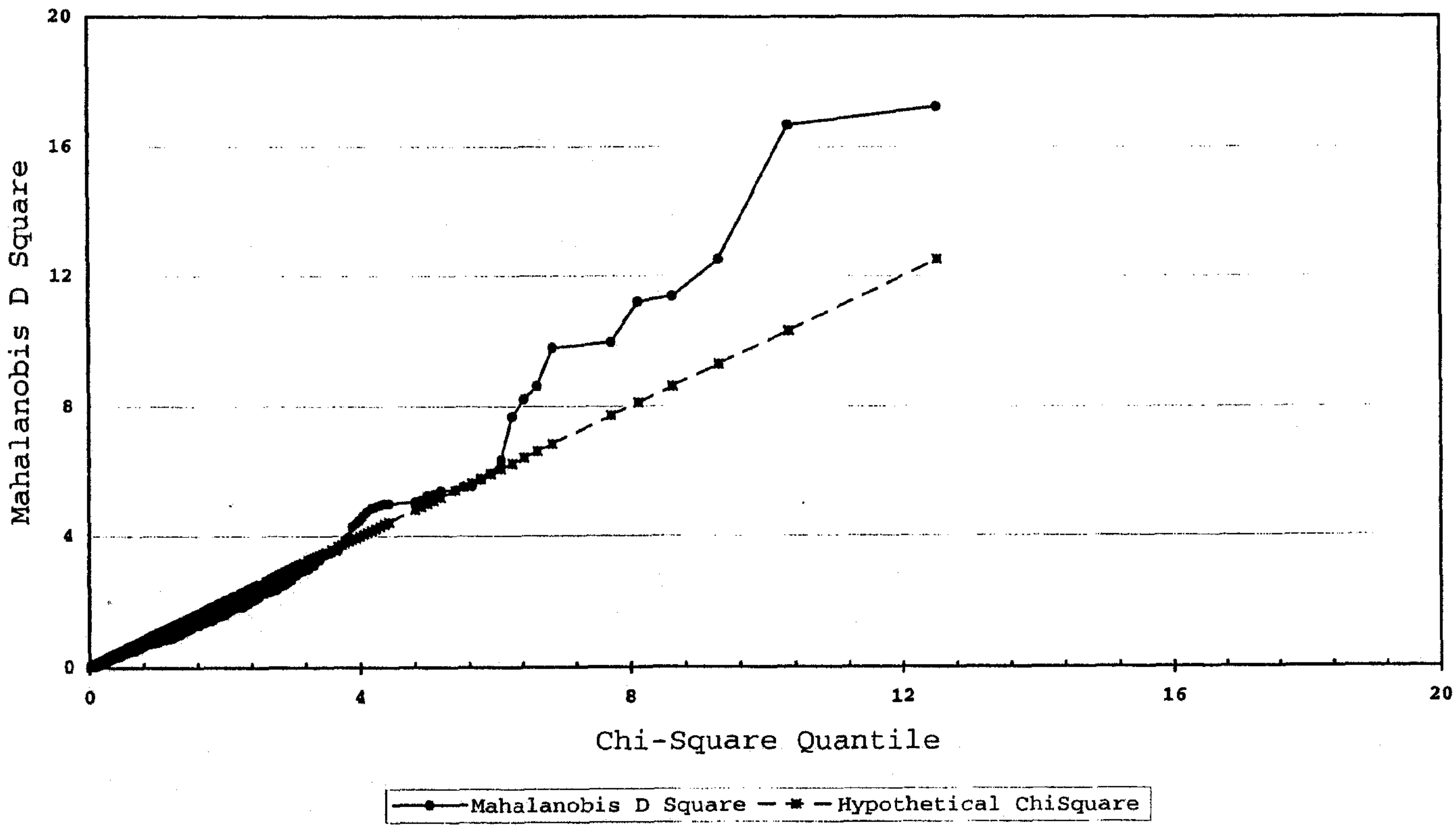
ASSESSING BIVARIATE NORMALITY OF [LOG(EC),LOG(FC)] BY QQ PLOT
AND KOLMOGOROV-SMIRNOV METHOD: P-VALUE = 0.0343
FOR CHICAGO RIVER WATERSHED



METROPOLITAN WATER RECLAMATION DISTRICT OF GREATER CHICAGO

FIGURE BII-5

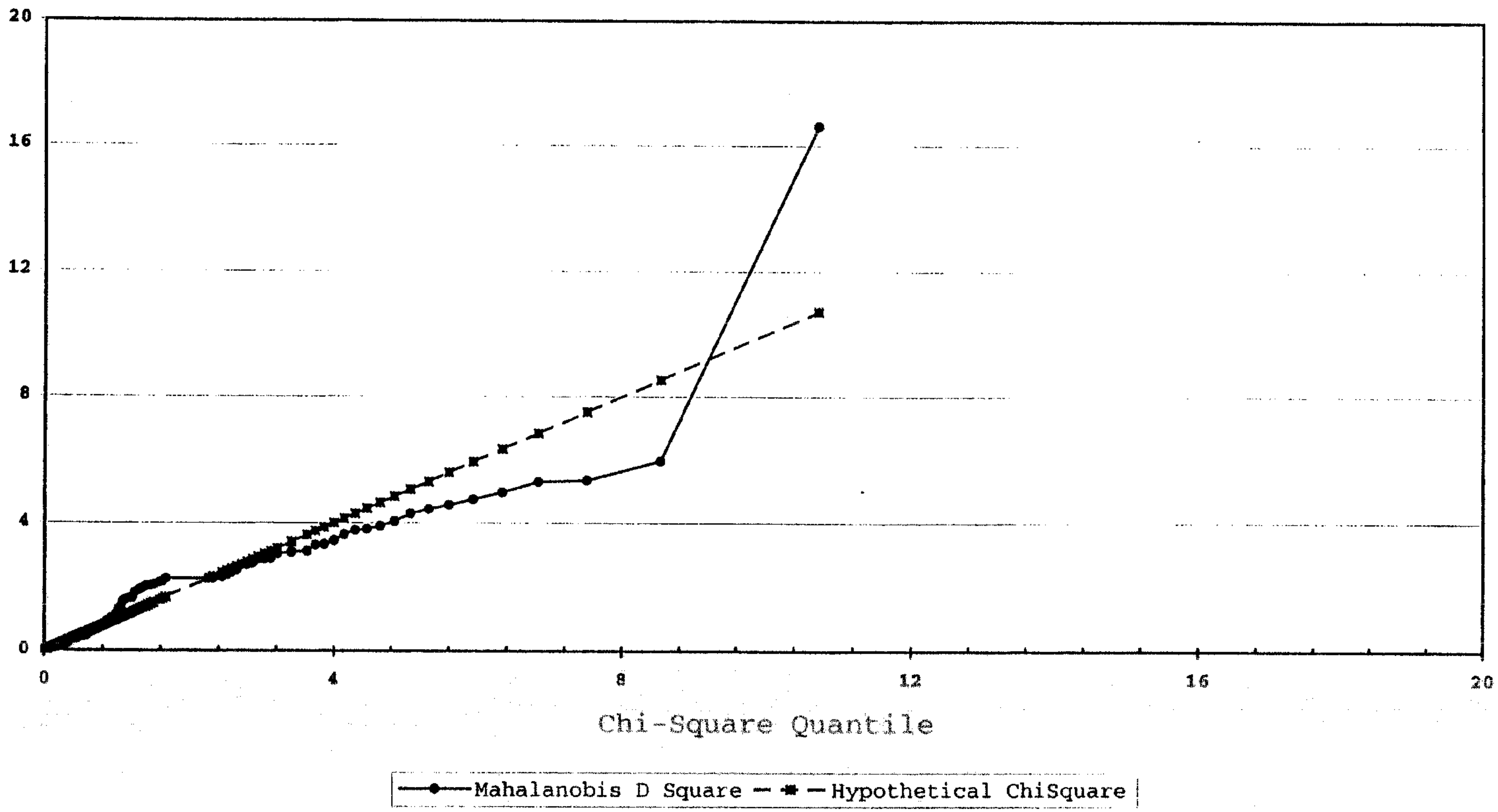
ASSESSING BIVARIATE NORMALITY OF [LOG(EC),LOG(FC)] BY QQ PLOT AND KOLMOGOROV-SMIRNOV METHOD: P-VALUE = 0.0130 FOR DES PLAINES RIVER WATERSHED



METROPOLITAN WATER RECLAMATION DISTRICT OF GREATER CHICAGO

FIGURE BII-6

ASSESSING BIVARIATE NORMALITY OF [LOG(EC),LOG(FC)] BY QQ PLOT
AND KOLMOGOROV-SMIRNOV METHOD: P-VALUE = 0.0716
FOR LAKE MICHIGAN



APPENDIX BIII

DERIVATION OF THE UMVU ESTMATOR FOR EC/FC

DERIVATION OF THE UMVU ESTIMATOR FOR EC/FC

Let us consider $\theta_{a,b,c}=\sigma^{2c}e^{(a\mu+b\sigma^2)}$, where $\theta_{a,b,c}$ is a function of the mean of lognormal distribution for given constants such that $a,b,c\in\Re$. If a=1, b=0.5, and c=0 then $\theta=e^{(\mu+\frac{1}{2}\sigma^2)}$ is equal to ratio R = EC/FC where $\mu=\mu_1-\mu_2$, and μ_1 is the mean of log(EC), and μ_2 is the mean of log(FC), and σ is the standard deviation of log(R)= log(EC) - log(FC)

Suppose we have an estimator $\hat{\theta}_{a,b,c}$ of $\theta_{a,b,c}$ so that $E\left(\hat{\theta}_{a,b,c}\right)=\theta_{a,b,c}$. Then, $\hat{\theta}_{a,b,c}$ is called an unbiased estimator of $\theta_{a,b,c}$. If we can have p unbiased estimators such as $\hat{\theta}_{1(a,b,c)}$, $\hat{\theta}_{2(a,b,c)}$, $\hat{\theta}_{3(a,b,c)}$, ... $\hat{\theta}_{p(a,b,c)}$ of $\theta_{a,b,c}$, but $\hat{\theta}_{a,b,c}$ has the least variance among variances of all p unbiased estimators, then $\hat{\theta}_{a,b,c}$ is called a uniformly minimum variance unbiased estimator (UMVUE) of $\theta_{a,b,c}$. Our problem is to find $\hat{\theta}_{a,b,c}$.

Let us define $\overline{Y}=\overline{Y}_1-\overline{Y}_2$, where $\overline{Y}_1$ is the sample mean of log(EC)and $\overline{Y}_2$ is the sample mean of log(FC). Also, let us define $S_Y=(n-1)*(s_1^2+s_2^2-2rs_1s_2)$, where n is the sample size, s_1^2 is the sample variance of log(EC), s_2^2 is the sample variance of log(FC), and r is the sample correlation between log(EC) and log(FC). If we define $Y_i=\log(EC)-\log(FC)$, then

$$S_Y=(n-1)*(s_1^2+s_2^2-2rs_1s_2)=\sum_{i=1}^{n}(Y_i-\overline{Y})^2.$$

Following the method of finding UMVUE we came up with

$$\hat{\theta}_{a,b,c} = \frac{\Gamma((n-1)/2)}{\Gamma((n-1)/2+c)} * e^{a\bar{Y}} * \left(\frac{S_Y}{2}\right)^c * F\left(\frac{n-1}{2}+c, \frac{2bn-a^2}{4n} S_Y\right)$$

Where

$$F(\alpha, z) = \begin{cases} \sum_{j=1}^{\infty} \frac{\Gamma(\alpha)\, z^j}{\Gamma(\alpha+J)\,\Gamma(j+1)}, & j \geq 1 \\ 1, & j=0 \end{cases}$$

We observed that $\hat{\theta}_{a,b,c}$ is a function of sample mean and variance. We know that if log(EC) and log(FC) are normally distributed, then the sample mean is sufficient and complete for estimating μ, and so is the sample variance for σ^2. Since the sample mean and standard deviation are independently distributed, then the function $a\bar{Y}+bs^2$ are jointly sufficient and complete estimator of $a\mu+b\sigma^2$ for given constants $a, b \in \Re$. Thus, $\hat{\theta}_{a,b,c}$, the UMVUE is unique (Rao, 1965), and it means that there will be no other estimator which will be unbiased and have less variance than $\hat{\theta}_{a,b,c}$.

APPENDIX BIV

SAS MACRO PROGRAM FOR EVALUATING THE UMVU ESTIMATOR OF R

SAS MACRO PROGRAM

```
**********************Part 1******************;
options mlogic mprint symbolgen;
*Program to Evaluate the Minimum Variance Unbiased Estimator;
*(UMVUE)of R=EC/FC;

libname zz "F:\zmacroV8";
options mstored sasmstore=zz;

*Part 1 is a Marco Store Library. This Library must be created;
*(it is just like creating Directory and subdirectory). After;
*creating the Macro Library, the user run the following program;
*The following program is good for UMVUE of any function of the
*mean and variance of natural log transformed values from LogNormal;
```

*Distribution. If we define $\theta(a,b,c)=\sigma^{2c}e^{a\mu+b\sigma^2}$, a function of the;
*mean of a lognormal distribution, then the UMVUE for $\theta(a,b,c)$ is;
*given by;

$$* \frac{\Gamma((n-1)/2)}{\Gamma((n-1)/2+c)}\,(S_y/2)^c\, oF_1\left(\frac{n-1}{2}+c,\ \frac{2bn-a^2}{4n}S_y\right),\ \text{where;}$$

$$* \quad S_y=\sum_{i=1}^{n}(Y-\overline{Y})^2,\ \text{and}\ oF_1=\sum_{j=0}^{\infty}\frac{z^j}{(a_j)_j\, j!},\ \text{where ;}$$

$$* \quad (a_j)_j=\begin{cases} a(a+1)\ldots(a+j-1), & j\ge 1\\ 1, & j=1 \end{cases};$$

```
**********************Part 2******************;
 *In the UMVUELogNormMean Macro a,b,c are supplied constants as;
*needed, n=sample size, m=mean of logvalues Y = log(X), s= standard
*deviation of Y, and OuDataUMVUE is the output Data.;

 %macro UMVUELogNormMean(a,b,c,n,m,s,OutDataUMVUE)/store;
 data _null_;
 sy=(&n.-1)*(&s.)**2;
 aa=(&n.-1)/2+&c.;
 z=(2*&b.*&n.-(&a.)**2)/(4*&n.)*sy;
 call symput("sy",compress(sy));
 call symput("aa",compress(aa));
 call symput("zzzzzz",compress(z));
 run;

 data _null_;
 LogG=Lgamma(&aa.+0);
 call symput("LG2",compress(logg));
```

```
run;

%let jjjjjj=1;
%let ite=100;

%do %until(&ite.<=0.0000001);
%let jjjjjjless=%eval(&jjjjjj.-1);

data _null_;
logG=lgamma(&aa.+&jjjjjj.+0);
call symput("LG1",compress(logg));
run;

data null;
LogG=lgamma(&jjjjjj.+1);
call symput("LG3",compress(logg));
run;


Data Fnc&jjjjjj.;
logF=(&jjjjjj.)*log(&zzzzzz.)- &lg1.+&lg2.-&lg3.;
F=exp(logf);
drop logf;
run;

%if &jjjjjj.>1 %then %do;
  data fnc&jjjjjj.;
  set fnc&jjjjjjless. fnc&jjjjjj.;
  run;
%end;

data _null_;
set fnc&jjjjjj.;
jjjjjj=&jjjjjj.+1;
f=int(f*10000000)/10000000;
call symput("ite",compress(f));
call symput("jjjjjj",compress(jjjjjj));
run;
%END;
%let jjjjjjless=%eval(&jjjjjj.-1);
```

```
data null;
retain Sum 1;
set fnc&jjjjjjless.;
sum+f;
n1=(&n.-1)/2;
n2=&c.+(&n.-1)/2;
It=&jjjjj.-1;
call symput("sum",compress(sum));
call symput("n1",compress(n1));
call symput("n2",compress(n2));
run;

data _null_;
LogG=lgamma(&n1.+0);
call symput("LLG1",compress(logg));
run;

data _null_;
LogG=lgamma(&n2.+0);
call symput("LLG2",compress(logg));
run;


Data &OutDataUMVUE.;
UMVUE=exp(&llg1.-&llg2.)*exp(&a.*&m.)*(&sy./2)**&c.*&sum.;
run;
%mend;

*After Processing the Macro Program in part 2, the user must;
*delete the part 2 completely, and run the program in Part 3 with;
*exact position of the values required, and exact macro library;
*Reference;

************************ Part 3 *******************;
*This is an example only for testing;
libname zz "F:\zmacroV8";
options mstored sasmstore=zz;

data null;
%umvuelognormmean(1,0.5,0,30,-0.5,0.5,v)
```

```
run;
data null;
set v;
Gm=exp(-0.5);
MLE=exp(-0.5+0.5*(0.5)**2);
run;

proc print;
var mle gm;
run;
```