

**SOURCE QUANTIFICATION OF INAPPROPRIATE DISCHARGES TO
STORM DRAINAGE SYSTEMS**

by

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ABSTRACT

Identifying and eliminating non-stormwater discharges to storm sewers is an important and cost-effective control strategy for improving runoff water quality in non-point source water pollution-dominated receiving waters. According to the EPA, Inappropriate Discharge Detection and Elimination (IDDE) is an important control measure and the operator of a Phase II regulated MS4 is therefore required to include it in its stormwater management program to meet the conditions of its NPDES permit. In order to identify the possible sources of the inappropriate discharges, the evaluation of dry weather flows at storm drain outfalls is required by the NPDES. These field screening procedures can involve the monitoring of certain chemical and visual tracers that indicate potential sources of dry weather discharges. A statistical analysis of these tracers, which considers the chemical mass balance at the outfall, can be used to determine the specific source contributions to the dry weather discharges.

The purpose of this research work is to develop a chemical mass balance model with *Monte Carlo* statistical simulation to determine the most likely source components of these flows. The objective of this model is to estimate mass contributions of different identified sources for a mixed water quality data set. A “Library” file describes the characteristics of each potential source-water, such as mean, coefficient of variation and the type of distribution (Normal, Log-Normal or Uniform). A set of simultaneous equations are then formed by the model relating the data from this “Library” file with the concentrations of the tracers at the outfall of the storm drainage system, indicating the

mass balance at the outfall. This set of equations also incorporates an error term μ (μ), which indicates how well all likely sources are represented in the numerical solution. The solution of this set of simultaneous equations results in the relative mass contributions of the individual sources. Monte Carlo simulations are performed for each outfall observation. These simultaneous equations are solved using the Gaussian-Elimination method. A maximum of 10,000 runs is used to estimate the mass contributions of each source. Each run generates a value of the contribution of each source based on the statistical parameters for the tracers. Thus, an equal number of values of mass contributions are obtained in the form of the solution set for each set of simultaneous equations.

The output of this model is in the form of probability distribution plots for each potential source type selected for consideration and statistical summaries. The probability plots show the likelihood of occurrence of that particular source. The statistical summary shows the range of the solutions calculated for each source category and gives the value of the most likely fraction of flow for each source category (the 50th percentile value). The source category corresponding to the highest value of the fraction of flow can be assumed to be the most likely source of inappropriate discharges at the outfall being analyzed. This method results in determinations of several potential source flows, not just the most likely source as in other alternative evaluation methods. The statistical summary also shows the 95% range of the error term μ (μ), associated with the analysis. The value of μ (μ) is expected to be close to zero (small residuals) for good results.

The chemical mass balance model was to written using Microsoft Visual Basic 6.0.

Good agreement was obtained between the model predictions and field observations. The results of the model were also largely consistent with the other methods used in source identification. Thus, by using this model one can predict the most important contributors to the inappropriate discharges in storm drainage systems for each outfall being evaluated. This evaluation method quantifies multiple likely sources, along with an evaluation term, and can therefore be used with greater confidence than other evaluation methods that only identify a single most likely source.

CHAPTER 1

INTRODUCTION

1.1 Inappropriate Discharges

1.1.1 Definition

Inappropriate discharges, according to the National Pollutant Discharge Elimination System (NPDES) stormwater regulations, are defined as point source discharges of pollutants that are not composed entirely of stormwater, that are not covered by an existing NPDES permit, and that discharge through a municipal separate storm sewer system (MS4) (Theo Glanton, M.T. Garrett Jr., Bill Goloby September 1992. “The Illicit Connection- Is It the Problem,” Water Environment and Technology, pp. 63-68). Storm drainage systems are supposed to receive only the portion of precipitation, which drains from surfaces exposed to precipitation, and nothing else. Any discharge to the storm drainage system other than stormwater is considered to be unauthorized and an inappropriate discharge.

Unfortunately, urban stormwater runoff frequently contains inappropriate discharges. Identifying and eliminating these non-stormwater discharges to storm sewers is an important and very cost-effective control strategy. Anything that is placed into a storm drain goes directly into the receiving water. Inappropriate discharges are controllable sources of non-point source water pollution.

1.1.2 Potential Sources

Previous research on inappropriate discharges identified three categories of non-stormwater outfall discharges: pathogenic/toxicant, nuisance and aquatic life threatening, and clean water (Pitt et al.1993)

Among these, the most important category is for outfalls contributing pathogens or toxicants. The most likely sources for contamination in this category are sanitary, commercial or industrial wastewater non-stormwater discharges. Other residential area sources (besides sanitary wastewater) include inappropriate household toxicant disposal, automobile engine de-greasing, vehicle accident clean-up, and irrigation runoff from landscaped areas excessively treated with chemicals (fertilizers and pesticides). This source category could cause disease upon water contact or consumption and significant impacts on receiving water organisms. They may also cause significant water treatment problems for downstream consumers, especially if they contain soluble metal and organic toxicants.

Nuisance and aquatic life threatening pollutant sources can originate from residential areas and may include laundry wastes, landscape irrigation runoff, automobile washing, construction dewatering, and washing of ready-mix concrete trucks. These pollutants can cause excessive algal growths, tastes and odors in downstream water supplies, offensive coarse solids and floatables, and highly colored, turbid or odorous waters.

Clean water discharged through stormwater outfalls can originate from natural springs feeding urban creeks that have been diverted to storm drains, infiltrating groundwater, infiltrating domestic water from water line leaks, etc.

1.2 Problem Identification

1.2.1. Importance of Detection and Elimination of Inappropriate Discharges

Earlier researches (Montoya, 1987) identified several cases where pollutant levels in MS4s are much higher than they would otherwise be because of excessive amounts of contaminants that are introduced into the storm drainage system by various non-stormwater discharges.

Inappropriate discharges enter the storm drainage system through either direct connections (e.g., wastewater piping either mistakenly or deliberately connected to the storm drains) or indirect connections (e.g., infiltration into the MS4 from cracked sanitary systems, spills collected by drain outlets, or paint or used oil dumped directly into a drain). The result is untreated discharges that can contribute high levels of pollutants, including heavy metals, toxics, oil and grease, solvents, nutrients, viruses, and bacteria to receiving water bodies. Pollutant levels from these inappropriate discharges have been shown in EPA studies (EPA Draft # 833-F-00-007, January 2000, Storm Water Phase II Final Rule, Illicit Discharge Detection and Elimination Minimum Control Measure) to be high enough to significantly degrade receiving water quality and threaten aquatic life, and human health.

1.2.2. Developing and Implementing Detection and Elimination Procedures

Developing and implementing detection and elimination procedures for inappropriate discharges helps MS4 operators develop a thorough awareness of their systems. This in turn helps them to determine the types and sources of inappropriate discharges entering their system and to establish the legal, technical, and educational means needed to eliminate these discharges. Determining the sources could serve as a guideline for the MS4 operators to achieve this objective. Upon detecting a dry-weather discharge, the next step is to determine the source of the problem.

There have been numerous methods used to interpret the field screening data to identify the storm drainage outfalls with inappropriate discharges (Pitt, et al. 1993 and Lalor, Melinda 1994). There are two basic categories of these methods. The first is based on gross indicators of contamination. These methods include using obvious indicators of contamination and using a simple check list to identify the most significant sources. Only the most critical outfalls could be identified by these methods. The second method gives a quantifiable estimate of the sources. The matrix algebra method using fingerprinting schemes is the only method which gives a quantifiable estimate of the sources of contamination at a discharge location. Some case-studies (Washtenaw County Drain Commissioner and Washtenaw County Health Department. *Allen Creek Drain Water Quality Survey*- Status Report. September 1984 and Washtenaw County Statutory Drainage Board. *Huron River Pollution Abatement Program*. September 1987) have found that identifying only the critical outfalls leads to insufficient water quality

improvements. Moreover, these methods of identification give only the gross indicators of contamination and do not give a quantifiable estimate of the flow components. This may result in many incorrect determinations, or false negatives. For regulatory applications, false negatives can be a serious problem. Therefore, for all regulatory applications, a quantifiable estimate (with uncertainties) is recommended.

Quantification of sources also gives a clear understanding of the sources contributing to the inappropriate discharges at an outfall. As an illustration for the need of quantification, consider the following example using the model developed as part of this research..

Summary Table							
	Tap Water	Spring Water	Carwash Wa:	Laundry Wa:	Sewage Was	Irrigation Wa	Mu
2.5th %tile	-20.25	-27.23	-4.96	-0.73	-1.81	-12.81	-19.21
97.5th %tile	19.56	24.53	4.18	0.74	2.8	9.25	19.76
50th %tile	1.095	-0.18	-0.15	0.03	0.27	-0.155	-0.06

Figure 1.1

Figure 1.1 shows the summary table obtained as an output by the model during the analysis of outfall # 10a, collected on June 6th, 2002. As can be seen in the values listed for 50th percentile (the most likely mass fraction of the contributing sources as a result of the Monte Carlo simulation), there are two mass fraction values which are considerably higher than those for other sources (tap water and sewage wastewater). This indicates that these two sources could contribute considerably to the maximum flow at

the outfall. When examining the 95th percentile range for all 5 sources, the other sources are much less likely to be present, although the wide range for spring water indicates greater uncertainty for eliminating this potential source. These conclusions could only be made by using a quantifiable estimate such as this model. The other methods of problem identification can identify only one of these sources as the critical source, and can not identify the other sources. This would result in a likely false negative determination for the most important source, sewage contamination. Remedial actions based on the less quantifiable methods could thus lead to insufficient water quality improvements.

The matrix algebra method involves solving a set of simultaneous chemical mass balance equations for the mass fraction values at the outfall. These equations are formed using the “library” data (probability distributions of expected concentrations associated with each potential flow source) and the outfall data. If there was no variation in the library data (if each source had consistent concentrations) then solving one set of such equations would give a unique and correct value of the mass fraction at the outfall. But, since this is not the case, these equations have to be solved using a number of values of concentrations within the appropriate distributions of these concentration values. Monte Carlo simulation is used to accomplish this task.

1.2.3. Need for a Model

The implications of the uncertainties in the analyses are particularly important in the assessment of regulatory options relating to the selection of a strategy for the control of inappropriate discharges. The uncertainties leads to a risk in the prediction of the

correct source for any outfall data analyzed. In order to quantify the risk, thereby quantifying the probability of surety, we need a model capable of evaluating numerous possible outcomes. Monte Carlo simulation was selected for such a task for this research. One iteration of a simulation involves selection of a random value for each parameter being analyzed from a specified probability density function. A set of such iterations constitutes the complete simulation. To perform such complex tasks and to solve the chemical mass balance equations subsequently for each iteration, a computer model is necessary. Once the probability of correctness in the prediction of the source water is quantified, one can make a decision on the most likely inappropriate source(s) contributing to the outfall discharge. If such a quantitative assessment of uncertainty was not conducted, insufficient water quality improvements and misallocation of other resources could result.

1.3. Objective

The objective of this research was to develop a model for conducting the necessary uncertainty analyses. Probabilistic modeling is used in conjunction with Monte Carlo simulation to analyze the uncertainty in the calculations. A probabilistic description of the output is obtained in the form of a summary table and a cumulative distribution plot.

The specific objectives of this research included:

1. Develop and validate a model for source quantification of inappropriate dry-weather discharges from storm drainage systems.

2. Perform statistical analyses to rank the usefulness of chemical tracers to distinguish different flow sources.
3. Compare the results of this model with that of the other methods of source investigation for the Tuscaloosa data set.

1.4. Thesis Organization

Chapter 1, “Introduction,” provides an overview on the objectives and the tasks performed. Chapter 2, “Literature Review,” discusses the concepts of the chemical mass balance model and the simulation-modeling. Chapter 3, “Methodology,” describes the procedures followed in this research. Chapter 4, The “Results and Discussion,” presents the results and compares the different techniques. The concluding Chapter 5, “Conclusions and Recommendations”, analyzes the results from the model as compared to the field observations and other methods of source identification, and evaluates the applicability of this model to source quantification of inappropriate discharges. Appendices include the model user guide and the complete source code of the model.

CHAPTER 2

LITERATURE REVIEW

2.1. Types of Models

Most models used in scientific and engineering fields simulate real-life processes, in which an input data set is fed into the model, the model replicates the processes using some established relationships and formulae, and a corresponding output set is obtained. In urban stormwater management, there are three types of models that are commonly used: *hydrologic*, *hydraulic* and *water quality* models. Hydrologic models simulate rainfall-runoff processes. Hydraulic models typically take the output of a hydrologic model and provide information such as flow height, location, velocity, direction, and pressure of the flowing water. Water quality models typically simulate the various processes and interactions of water pollution.

In general, there are two approaches to modeling: the deterministic or probabilistic approaches. In the deterministic approach, the model is run for a single input parameter and a single output parameter is obtained. In the probabilistic modeling approach, the variation of the input parameter is taken into account along with the single deterministic value, and hence a probabilistic output is obtained. In the deterministic approach, the input and output are assumed to be certain and converge at a single value, while in the probabilistic approach, they are assumed to follow a probabilistic distribution and are represented by the probability distribution function.

2.2. *Water Quality Models*

Water quality models were recognized as an important link between waste discharges and water quality effects, and hence to water quality standards, when the U.S. Water Quality Act of 1965 was implemented (Neal E. Armstrong, March/April 2001). The primary water quality model at that time linked BOD discharges and receiving water dissolved oxygen levels because the focus of the Act was on protecting in-stream dissolved oxygen levels. Now, the U.S. Environmental Protection Agency is implementing Total Maximum Daily Loads (TMDLs), and there is a substantial demand for more complete water quality regulatory models to relate not only point source loads of pollutants, but also to relate nonpoint source loads to water quality in the receiving water. The TMDL development process may lessen discharge restrictions for point source loads because nonpoint sources are now included in the waste load allocation process, whereas initially they were not. Complex water quality models are therefore more important now than they were during 1965 (Neal E. Armstrong, March/April 2001).

Water quality models can reflect pollution from both point and nonpoint sources. However, they tend to have applications that are targeted toward specific pollutants, source types or receiving waters (Neal E. Armstrong, March/April 2001). Water quality predictions are not credible without adequate site-specific data for verification. An important aspect of many water quality models is that they can test pollution abatement controls (Neal E. Armstrong, March/April 2001).

2.3. Uncertainty in modeling

Uncertainty is defined as the measure of the reliability associated with a particular set of results (Yegnan, A., Williamson, D.G., Graettinger, A.J.). The uncertainty in modeling predictions is caused by any or all of the following results (Yegnan, A., Williamson, D.G., Graettinger, A.J.) :

1. Errors in the measurement/monitoring of the input parameters.
2. Insufficiency of the modeling data.
3. Model error.
4. Improper scenario to which the model is applied.
5. Spatial variability.
6. Temporal Variability.

The applicability of a model is dependent on the accuracy of the modeling result, which in turn depends on the certainty of the input and output parameters of a model. It is important to quantify and interpret model uncertainty in all disciplines (Dabberdt et al., 2000). Uncertainty issues arise in all engineering and scientific fields (Hanna et al., 1998). When impacts of pollutants having serious health impacts on the community are evaluated, the accuracy of the predictions are of the utmost importance because the results of the modeling will have serious implications on the human community. Especially in regulatory applications, where a conservative decision requires that the predicted value always be less than some limit, the lower boundary of the prediction interval may be more relevant than the mean of the predictions (Tiktak, et al., 1999).

There is a growing trend to move away from deterministic models to a probabilistic modeling approach where modelers will describe the range of likely events with their associated probabilities (Dabberdt and Miller, 2000). Quantification of uncertainty will help in further development of the model, directing future studies and guiding research.

Probabilistic modeling is usually more reliable than deterministic modeling, especially in regulatory modeling studies (Yegnan, A., Williamson, D.G., Graettinger, A.J.).

In general, when performing modeling studies, it is necessary to validate the accuracy of the modeling result by comparison with field observations. If the model results do not match the field observations, the model may be adjusted by changing internal modeling process parameters, so that its output more closely agrees with the field results. As a result, if one is using a deterministic approach, the model may require frequent (and meandering) calibrations. It has been shown that if a model is not calibrated for a particular scenario, its representation of the output may contain extreme inaccuracies (Pielke and Uliasz, 1998). Accounting for the variance in the model results may diminish the need for rigorous calibrations because the field data and the mean model result may be within a reasonable range with respect to the variance. Quantifying uncertainties helps to direct efforts to improve the accuracy of the modeling result.

It is found that input parameters significantly contribute to the uncertainty in modeling results. Research has been done in the past to evaluate the uncertainty in

modeling predictions due to variations in the input parameters in varied fields.

Graettinger and Dowding (1999) evaluated the uncertainty in subsurface parameters for site exploration studies. They demonstrated how an understanding and knowledge of input parameter uncertainty can help direct efforts for selecting boring locations for site explorations. Hamed, et al., (1995) evaluated the uncertainty of input parameters and its effect on quality of ground water downstream from a waste source. Ghosh, et al. (1995) evaluated uncertainty estimates for water quality models in watershed analyses due to variance in the independent input parameters. Burton and Pitt (2001) show how uncertainties in objectives and analysis tools all relate to the sampling efforts needed to calibrate and validate models and to support decisions.

2.4. Monte Carlo Simulation

The roots of Monte Carlo (MC) simulation were in theoretical statistics, but its applicability to a spectrum of practical problems accounts for its popularity. The term Monte Carlo, as applied to uncertainty analyses, was introduced by von Neumann, Metropolis, and Ulam at Los Alamos National Laboratories around 1940.

In MC simulations, the input parameter is described using a probability distribution and a single set of input data is randomly generated following this distribution. This single data set is run through the model and an output data set is obtained. The results of the run are stored and a new set of input data is generated. Multiple simulations, typically numbering in the thousands of runs, are carried out until the results of a new run

do not affect the probability distribution of the output variable. The number of simulations needed depends on the number of input parameters, the correlation between the input parameters, and the required confidence in the output probability distribution (Graettinger and Dowding, 2001).

2.5. Chemical Mass Balance Equation

The idea of using Chemical Mass Balance (CMB) models for receptor modeling was first introduced by Miller et al. and independently by Winchester and Nifong (Leon Jay Gleser, 1997). In order to successfully quantify the sources by using CMB models, all the potential sources that contribute to the mass received at the receptor site need to be identified and a source composition profile for each such source must be determined. In air pollution studies, collections of profiles corresponding to possible sources are called libraries (U.S. EPA, Receptor Model Composition Library, Report No. EPA 450/4-85-002, PB85-228823, 1988).

CMB models are used to describe the contributions of n sources to the masses of p chemical species measured at a receptor site and with the assumption that the relative amounts of chemical species remain approximately the same as the particles/gases travel from the sources to the receptors (Leon Jay Gleser, 1997). Thus, if C_i is the measured mass of species i , it is assumed

$$C_i = \sum_n (m_{ij}) (x_{ij}) + \epsilon_i, i = 1, \dots, p \text{ and } j = 1, \dots, n$$

Where C_i = the concentration of the i^{th} chemical species, m_{ij} is the mass fraction of species i from source j , and x_{ij} is the concentration of i^{th} chemical species in the j^{th} source type, and e_i is the residual of i^{th} chemical species not accounted for by the j sources.

The p -dimensional column vector

$$x_j = (x_{1j}, x_{2j}, \dots, x_{pj})'$$

is the source composition profile of source j , $j = 1, \dots, n$.

Source profiles are the set of concentration values of the chemical species that is contributed by each source type. These profiles are measured at times and places which represent the sampling at the receptors to be analyzed. Differences in these measurements are sought so that averages and standard deviations for the concentration values of the chemical species can be determined. The same chemical species are analyzed over different time intervals that correspond to high and low contributions expected at the location where the sources are to be quantified. The chemical species are assumed not to interact with each other in non-linear ways during transport from source to receptor so that the source material adds up to measured mass at the outfall. All the sources with a potential for contributing to the receptor measurements must be identified. (Judith C. Chow and John G. Watson, 2002)

The number of source types used in a CMB source quantification must be less than or equal to the number of chemical or physical properties measured at the outfall. The source profiles must also be sufficiently different from one another to be distinguished from one another at the outfall being analyzed. Although these requirements seem

restrictive, substantial deviations from them can be tolerated in practice, albeit with corresponding increases in the uncertainty of the source contribution estimates (Judith C. Chow and John G. Watson, 2002).

The general CMB model assumes conservation of mass. Of course, not all mass released from the sources reaches a particular outfall. Since it is of interest only to evaluate the proportions of the contaminated mass contributed by certain sources, all that is needed is that the same proportion of mass released by each source is received at the outfall. (Leon Jay Gleser, 1997)

CHAPTER 3

MODEL METHODOLOGY

3.1. Overview

The purpose of this chapter is to provide a structured approach to explaining the methodology adopted to develop the Chemical Mass Balance model used for this research. This model is used as an analytical tool to estimate the most likely sources of inappropriate discharges to storm drainage systems. The basic purpose of the model is to eliminate the uncertainty in source quantification resulting from the uncertainty of the tracer concentrations in the source library data. Figure 3.1 gives an outline of the methodology used in this model.

The analytical method involves the following steps:

1. Performing statistical analysis of the source library data of tracer concentrations to determine the mean value, coefficient of variation and the type of distribution for each potential source flow.
2. Formation of the Chemical Mass Balance Equations between the observed outfall data and the library data.
3. Selecting a suitable method for solving the system of Chemical Mass Balance Equations.
4. Monte Carlo Simulation of the parameters (tracer concentrations). Figure 3.2 gives the flow chart adopted for Monte Carlo Simulation.

5. Solving for the values of mass fractions contributed by each source for every set of simulated parameters.
6. Determine the 95% confidence value for the values of mass fractions so obtained and plot the cumulative distribution plots.
7. Identify the most likely source from the values obtained in step 6 and the cumulative distribution plots obtained as the output of the model.

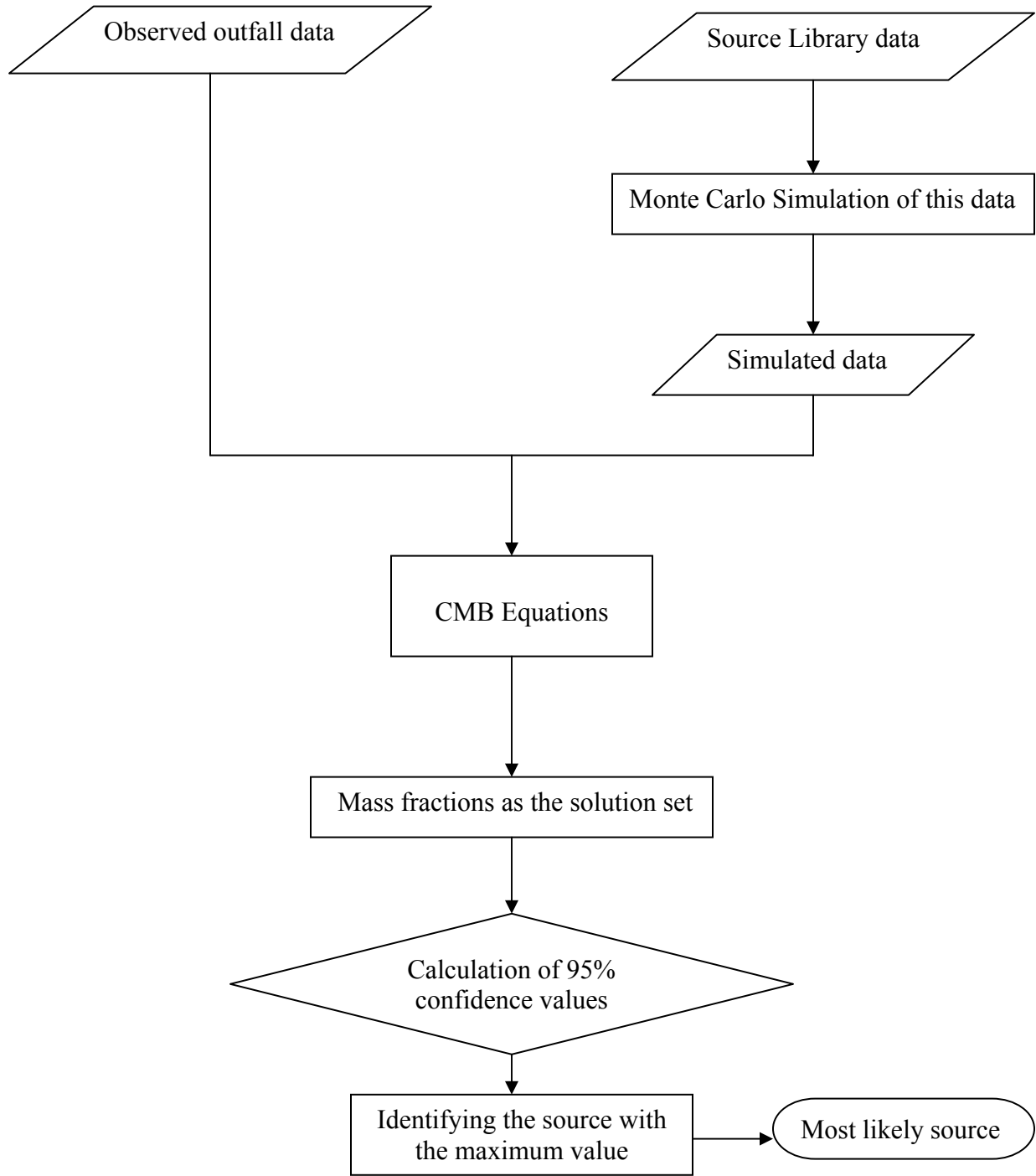
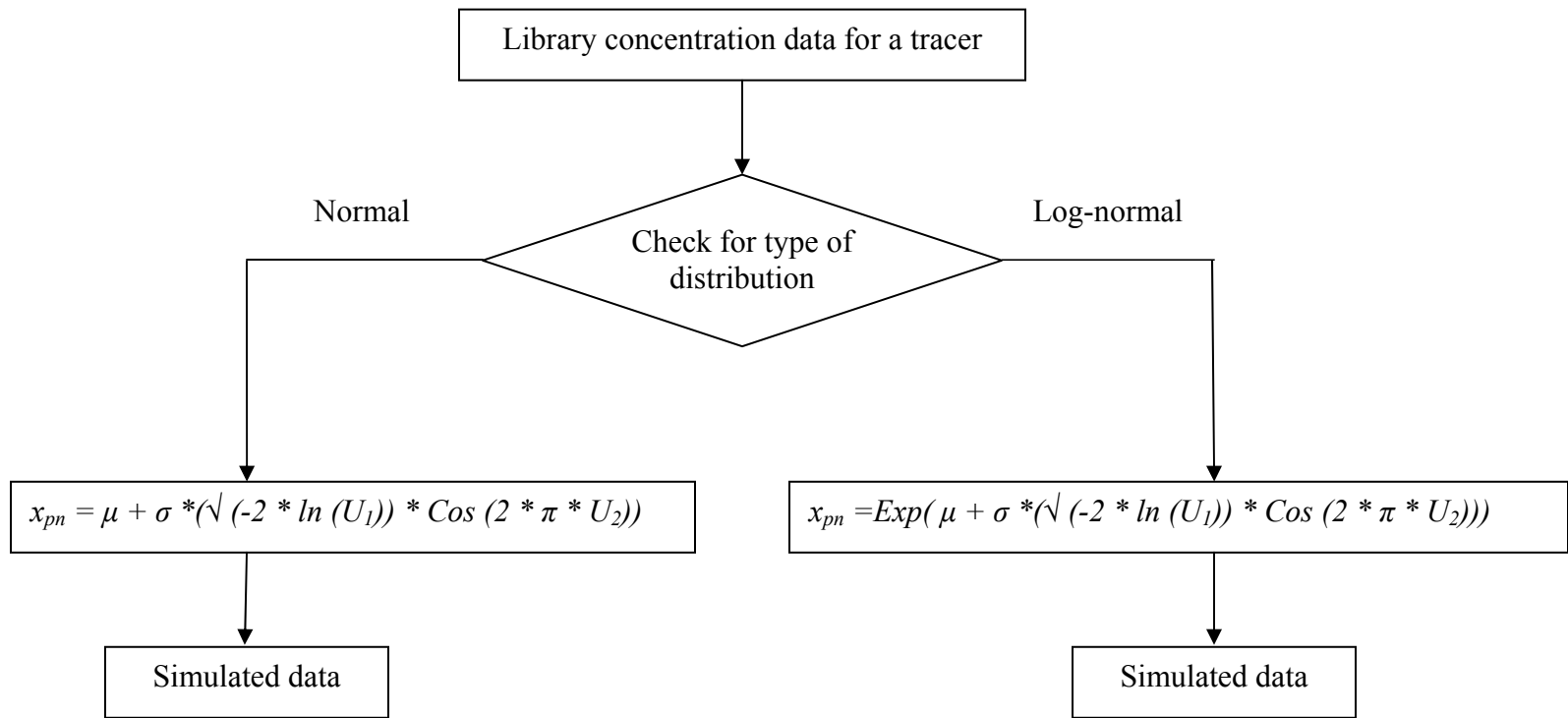


Figure 3.1: Outline of methodology



μ = Mean of Library concentration data for a tracer

σ = Standard Deviation

U_1, U_2 = Two independent uniformly generated random numbers

Figure 3.2: Monte Carlo Simulation of Library concentration data for a tracer

3.2. Library Data

This file contains all the information about the tracer parameters from the actual sources which contribute to the storm drainage system in the drainage area. This information includes concentrations of various parameters, their mean values, coefficient of variation values and the type of distribution.

3.2.1 Preparation of Library File

The purpose of this file is to give all the information necessary to conduct the Monte Carlo simulation. In order to build a useful data library for analyzing the outfall data it is important to determine the number of observations needed for each tracer parameter for each source category. The equation that can be used to calculate the number of samples needed (Cochran 1963) is given below:

$$\text{Number of samples} = 4(\text{standard deviation})^2/(\text{allowable error})^2 \quad (3.1)$$

This formula determines the number of samples needed to obtain a value within the range of sample mean, plus and minus the error, with a 95% level of confidence. This research also tested this approach by examining the number of MC runs needed to reduce the uncertainty of the model outcome to various results for the specific data obtained during the field trials.

In order to observe the uncertainty in the data for the concerned drainage system, the samples collected must be from various places and collected at various times.

This model was developed to read the library input data in a specific format only. The library file must be in a specific Excel file format. The data for each source category is stored in a separate Excel sheet and the Excel sheet is renamed using the name of the

source. Again all the information about each source category is stored in the corresponding Excel sheet in a specified format. The names along with the units of each tracer selected to characterize the corresponding source category are stored in the first column of the Excel sheet, starting with the second row. The mean values for the concentrations of the tracers are stored in the second column against the corresponding names. The corresponding coefficients of variation values are stored in the third column. The types of distribution are designated as L for log-normal distribution and N for normal distribution in the fourth column. The program reads these values from these locations of the excel file and feeds it into its necessary calculations. An example format is shown in Table 3.1.

Tracer	Mean Concentration	COV	Distribution
Conductivity (µmhos/cm)	274.67	0.46	N
Fluoride (mg/L)	1.23	1.57	L
Hardness (mg/L) CaCO ₃	71.17	0.27	N
Detergent (mg/L)	140.91	0.21	N
Fluorescence (mg/L as Tide)	90.98	0.47	N
Potassium (mg/L)	3.58	0.67	L
Ammonia (mg/L)	0.90	1.42	L
Color (Units)	128.00	0.80	N
Turbidity (NTU)	156.81	0.78	N
Boron (mg/L)	0.65	0.74	L
E-Coli (MPN)	250.79	2.30	L
Enterococci (MPN)	25.00	2.30	L

Table 3.1: Excel worksheet for Carwash Wastewater of Tuscaloosa Library File

Various statistical parameters such as mean, coefficient of variation and the type of distribution were calculated for all the parameters using MINITAB

statistical software. The decision about the type of distribution was made by observing the Anderson Darling p-value. If the p-value is greater than 0.05, then it is assumed to follow normal distribution, and if it is less than 0.05, a log-normal distribution was investigated, by examining the log-normal plots.

3.2.1.1 Preparation of Library File for Tuscaloosa

Equation (3.1) was used to calculate the number of samples for the library data analysis. In order to use this equation, an approximate number of samples was first assumed and allowable error was calculated. In this case, twelve samples were taken from all the sources as an approximation and the allowable error calculated for each parameter was within the 95% confidence level. Therefore, the approximation was proved to be correct.

3.3. Outfall Data

Inappropriate discharges into a storm drainage system can be corrected by monitoring the outfalls which emit non-stormwater discharges, and evaluating the characteristics of the discharged water to identify the likely sources of the flows. Hence, a systematic procedure has to be followed for this data acquisition.

3.3.1 Mapping and Preliminary Watershed Evaluation

By using all the available documented information, a preliminary survey is initially conducted to locate all the storm drainage outfalls. The drainage area for each outfall is then marked on a map, also showing the land uses for the area. Locations of septic tanks was also noted in the drainage area. These investigations can also be aided by

other relevant information and features such as location of streams and springs which contribute to uncontaminated or contaminated dry-weather flows. All this information serves as background information for the collection of outfall data.

3.3.2 Sampling of Outfalls

In order to ensure that stormwater flows are minimized in the dry-weather discharge sampling effort, samples are collected at least 48 hours after a previous storm. Other factors are also kept in mind while scheduling the sampling of outfalls in order to get a representative sample of a dry-weather discharge.

The sampling crew goes to the field completely equipped with field sampling and analysis equipment, equipment for marking and mapping the outfalls and all the necessary safety equipment.

3.3.3 Lab Testing of Outfall Samples

Each of the outfall samples collected are carefully analyzed in the lab for various selected parameters using prescribed standard methods for testing soon after their collection. The tracer parameters selected for analysis is by the following criteria:

1. Concentration of tracer parameters must be significantly different between sources.
2. There must be small variations in concentrations within each source category
3. They must be easily measured with adequate detection limits, good sensitivity and repeatability.

3.4. Model Algorithms

The algorithms of this model perform the following tasks:

1. Generates random values of concentrations for the tracers in a specified distribution in which the tracers are said to be distributed within the library file.
2. Forms the same number of Chemical Mass Balance Equations as the number of sources selected for evaluation.
3. Solves these Chemical Mass Balance Equations as many times as the number of simulation runs are selected to be performed in the analysis.
4. Calculates the 95% confidence values of the mass fraction values obtained as the solution set of the Chemical Mass Balance Equations.
5. Plots the cumulative distribution plots for the reported data in step 4.

3.4.1 Algorithm for Generating Random Values of Tracer Concentrations

1. Two independent random variables, U_1 and U_2 , are uniformly generated between zero and one. These numbers were generated by a built-in function of Visual Basic. These were initially tested to ensure that they were uniformly distributed by generating the output in Excel by a test program for generating these random numbers. Figure 3.3 shows the histogram as the output of this test and Table 3.2 shows the corresponding statistical summary. This proved that the distribution of the numbers generated by the built-in function of Visual Basic is uniform.

Histogram for Uniformly Generated Variable U_1 in Visual Basic

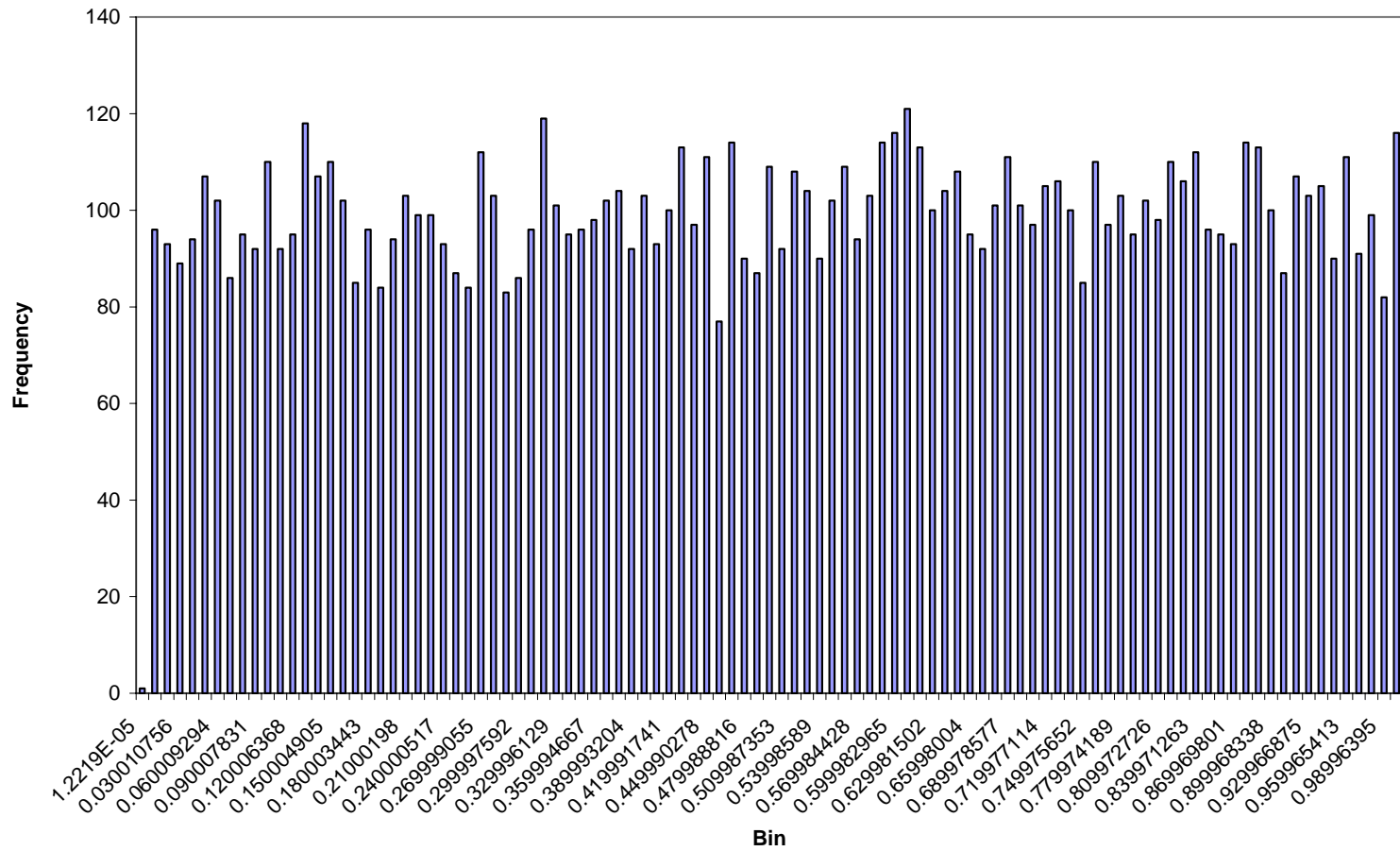


Figure 3.3: Histogram for Uniformly Generated Variable U_1 in Visual Basic

Statistics Summary for a uniformly generated variate U1 in VB	
Mean	0.504986901
Standard Error	0.002873593
Median	0.511018872
Mode	#N/A
Standard Deviation	0.287359277
Sample Variance	0.082575354
Kurtosis	1.189255908
Skewness	0.028707254
Range	0.999951243
Minimum	1.2219E-05
Maximum	0.999963462
Sum	5049.869013
Count	10000

Table 3.2: Statistical Summary for Uniformly Generated Variable U_1 in Visual Basic

2. For a selected tracer parameter, the values of the mean, the coefficient of variation, and the type of distribution are read from the selected Excel library file. In this step, the program accesses the Excel file selected by the user during the analysis.
3. The values of standard deviation are then computed by the following formula:
standard deviation $\sigma = (\text{COV}) \times (\text{mean})$.
4. If the tracer parameter has a normal distribution, a random value of the concentration of this tracer parameter is calculated by the following formula:

$$x_{pn} = \mu + \sigma * (\sqrt{-2 * \ln(U_1)}) * \text{Cos}(2 * \pi * U_2)$$

In order to test the distribution of the values generated in this step, a test program was run for this step alone, the output was taken in an Excel spreadsheet and a histogram was plotted. Figure 3.4 shows an example plotted histogram which has a normal distribution.

If the tracer parameter has a log-normal distribution, a random value of the concentration of this tracer parameter is calculated by the following formula:

$$x_{pn} = \text{Exp}(\mu + \sigma * (\sqrt{-2 * \ln(U_1)} * \text{Cos}(2 * \pi * U_2)))$$

The values of U_1 and U_2 in the formulae for random numbers in normal and log-normal distributions are different each time and are taken from step 1.

Figure 3.5 shows the histogram plotted during a test program for log-normal distributions. From this, it was again concluded that the random values generated by this formulae were in log-normal distribution.

Histogram for a variate generated by the program in normal distribution

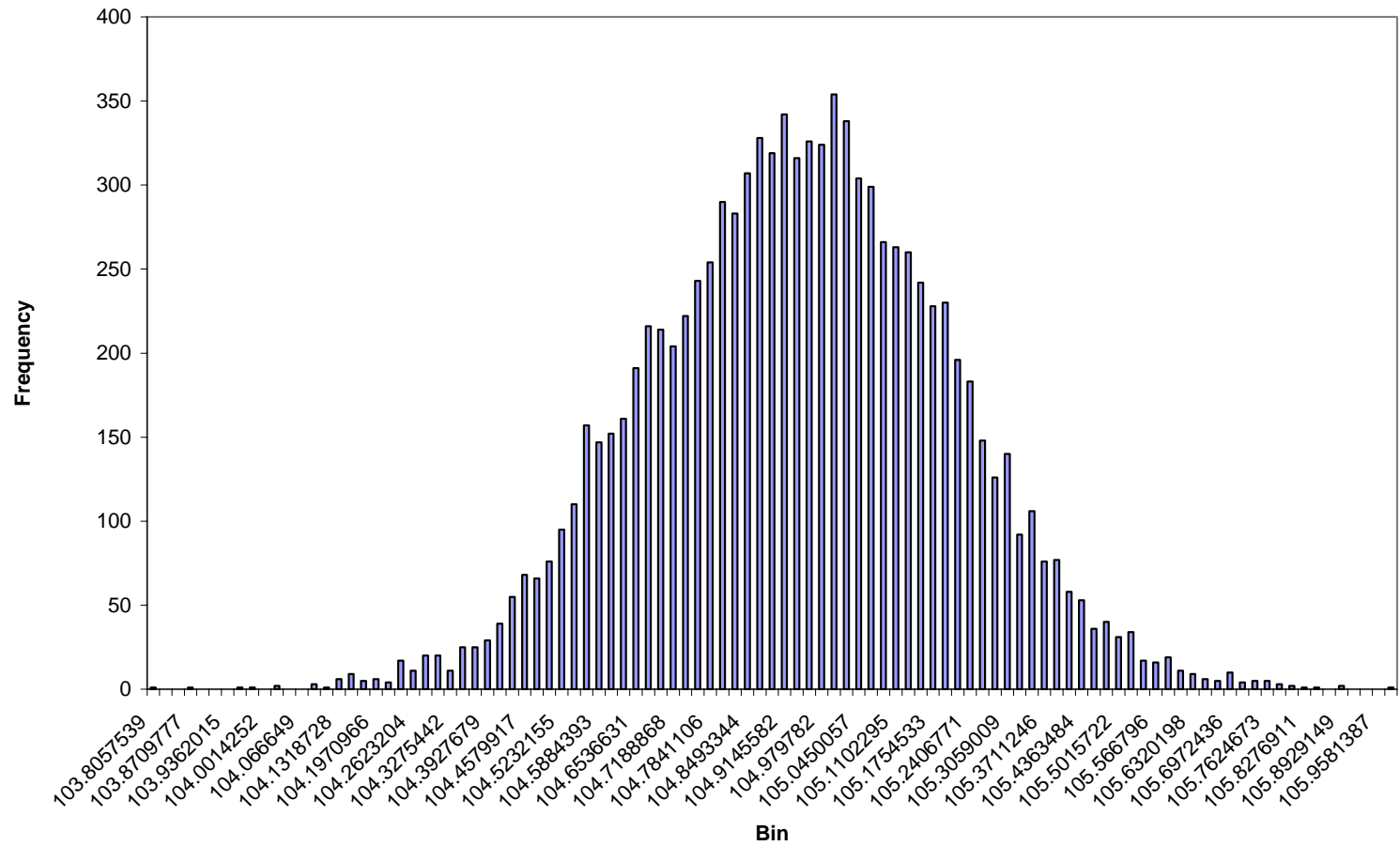


Figure 3.4: Histogram for a variate generated by the program in normal distribution

Histogram for a variate generated by the program in Log-normal distribution

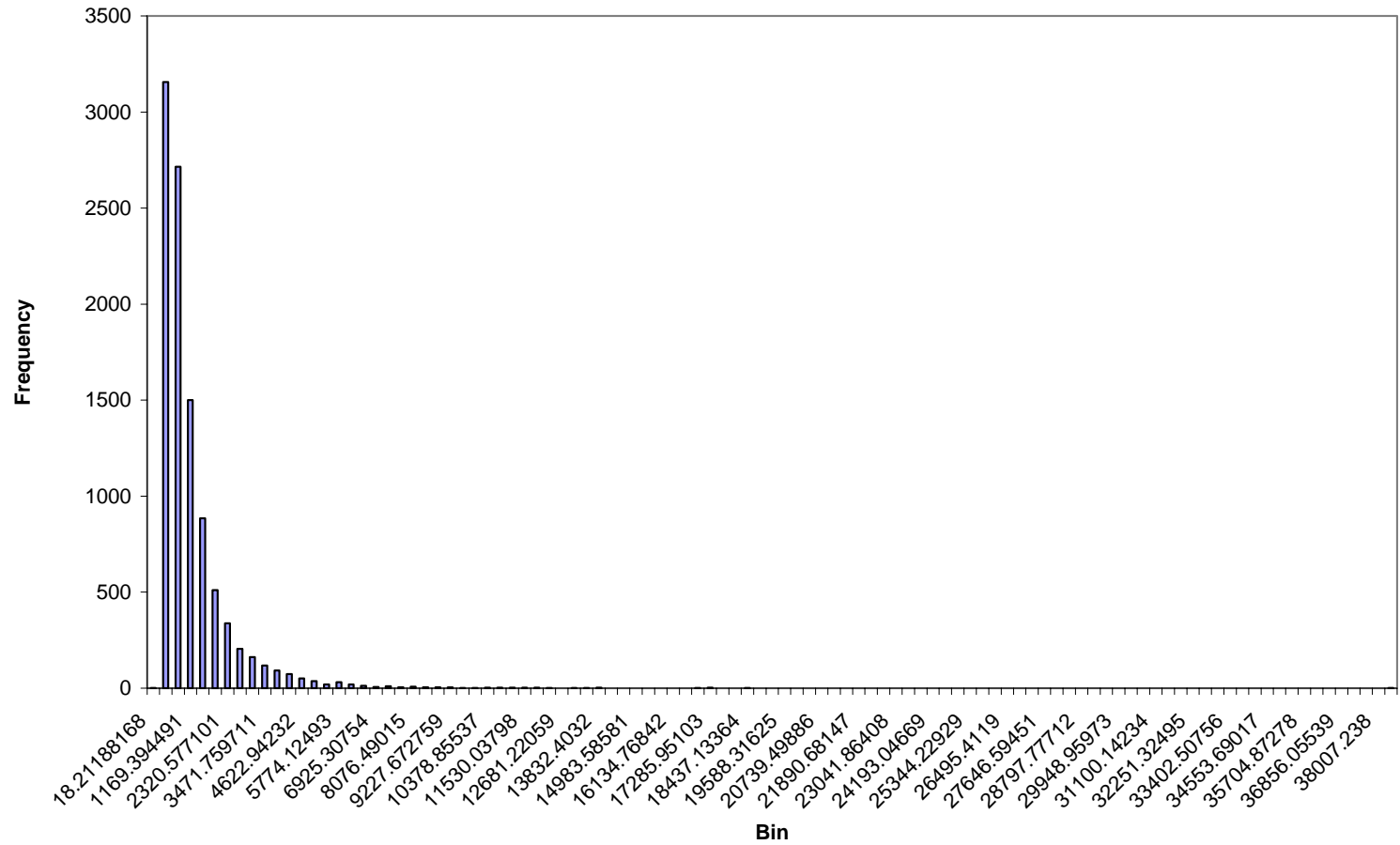


Figure 3.5: Histogram for a variate generated by the program in log-normal distribution

3.4.2 Formation of Chemical Mass Balance Equations

The chemical mass balance equation which is the basis for this model is as follows:

$$\sum_n (m_n) (x_{pn}) + \mu = C_p$$

m_n = the fraction of flow from source type n

x_{pn} = the concentration of tracer p in source type n

C_p = the concentration of tracer p in the outfall flow

μ = error term associated with tracer p

The Chemical Mass Balance Equation written in a matrix form is as follows:

$$\begin{bmatrix}
 x_{11} & x_{12} & x_{13} & \dots & x_{1n} & \mu \\
 x_{21} & x_{22} & x_{23} & \dots & x_{2n} & \mu \\
 x_{31} & x_{32} & x_{33} & \dots & x_{3n} & \mu \\
 \cdot & \cdot & \cdot & \dots & \cdot & \cdot \\
 \cdot & \cdot & \cdot & \dots & \cdot & \cdot \\
 \cdot & \cdot & \cdot & \dots & \cdot & \cdot \\
 \cdot & \cdot & \cdot & \dots & \cdot & \cdot \\
 x_{n1} & x_{n2} & x_{n3} & \dots & x_{nn} & \mu \\
 1 & 1 & 1 & \dots & 1 & 0
 \end{bmatrix}
 \begin{bmatrix}
 m_1 \\
 m_2 \\
 m_3 \\
 \cdot \\
 \cdot \\
 \cdot \\
 \cdot \\
 m_n \\
 1
 \end{bmatrix}
 =
 \begin{bmatrix}
 C_1 \\
 C_2 \\
 C_3 \\
 \cdot \\
 \cdot \\
 \cdot \\
 \cdot \\
 C_n \\
 1
 \end{bmatrix}$$

X
A
B

Here, the matrix “X” is the unknown matrix, which contains the mass fraction values. The program reads the values entered for the number of contributing sources to be evaluated and creates cells for each element of the matrix “A” and also creates cells for each element of matrix “B”. Each of these cells is numbered, so that the corresponding value is entered in the cell each time. The program then opens the Library Excel file, reads the corresponding value from the Excel file and enters into each of the cells formed for matrix “A”. The program then reads the values of “observed outfall tracer concentrations” entered by the user and then enters into the cells formed for matrix “B”. The Chemical Mass Balance Equation is thus formed by the program.

3.4.3. Algorithm for solving the Chemical Mass Balance Equations

This algorithm is based on the Gaussian Elimination method of solving simultaneous equations in matrix algebra. The following steps are involved in this method.

1. An augmented matrix is formed from the two known matrices “A” and “B” as shown below

$$\left[\begin{array}{ccccccc}
 x_{11} & x_{12} & x_{13} & \dots\dots & x_{1n} & \mu & C_1 \\
 x_{21} & x_{22} & x_{23} & \dots\dots & x_{2n} & \mu & C_2 \\
 x_{31} & x_{32} & x_{33} & \dots\dots & x_{3n} & \mu & C_3 \\
 \cdot & \cdot & \cdot & \dots\dots & \cdot & & \cdot \\
 \cdot & \cdot & \cdot & \dots\dots & \cdot & & \cdot \\
 \cdot & \cdot & \cdot & \dots\dots & \cdot & & \cdot \\
 \cdot & \cdot & \cdot & \dots\dots & \cdot & & \cdot \\
 x_{n1} & x_{n2} & x_{n3} & \dots\dots & x_{nn} & \mu & C_n \\
 1 & 1 & 1 & \dots\dots & 1 & 0 & 1
 \end{array} \right]$$

2. If a diagonal is drawn to the square matrix “B” of Figure the elements below the diagonal constitute the lower triangular matrix, and the elements above it constitute the upper triangular matrix. The next step in the algorithm is to make all the elements of the lower triangular matrix equal to zero. This is done by suitable row operations by using a multiplier called the ‘pivot’ (pp. 109-116, Allan D. Kraus, Matrices for Engineers). The last row of the augmented matrix then gives a solution to the last variable. The solution of the last variable is then substituted back into the preceding row to give the solution of another variable. The solutions of the two variables found so far are in turn substituted to the next preceding row to give the solution of another variable. This process is continued until the solution of all variables is found. This method is called ‘back-substitution’. This model was checked to solve up to a maximum of 7 x 7 matrix.

3.4.4. Algorithm for calculating the 95% confidence values

1. The program sorts the output by individual columns.
2. It then calculates the 2.5 percentile, the 97.5 percentile and the 50 percentile values individually. This is done by locating the corresponding value in the cell in the respective sorted column. This location is calculated in relation to the number of MC simulation value entered by the user. For example, if the number of MC simulations entered by the user is 100, the program picks the 2nd value and the 98th value from the respective sorted column for the 2.5th percentile and the 97.5th percentile value respectively.
3. The sorted columns are then plotted against the percentile values to get the cumulative distribution plots.

3.5. Visual Interface of the model

The model was designed in three Forms in Visual Basic. Input values are entered in the first and the second Forms. Output is obtained in the third Form. Figure 3.6 shows the first Form at design time. This form contains steps 1 to step 7 of the evaluation by model. In this form the following input variables are entered by the user:

1. Number of contributing sources to be evaluated
2. The Source Library file name
3. Number of MC runs for the evaluation

In step 2, the user is prompted to click a button to select a Library file from the desired location. The path of the selected file is displayed in the text box

against it. In step 4, the user is prompted to click a button to select the Sources and Tracers. On selecting the button, the sources corresponding to names of the worksheets in the Excel file selected are loaded dynamically through a Frame as in step-5 and the tracers corresponding to the names in the cells of Excel file selected, starting from the second row in the first column are loaded through another Frame as in step-6. On selecting this button, a dialog box also appears, indicating that the number of sources and tracers selected must be equal to that selected for evaluation (Figure 3.7 shows this dialog box).

The image shows a software interface titled "Form1" with a blue header bar. The main area has a light gray dotted background and contains several numbered steps and controls:

- 1. Enter Number of Contributing Sources to be Evaluated**: A text input field with a small square icon to its right.
- 2. Click to Select Library File**: A button with a white rectangular area to its right.
- 3. Enter Number of Monte Carlo runs for the evaluation [≤ 10000]**: A text input field.
- 4. Click to Select Sources and Tracers**: A button.
- 5. Select Sources**: A large vertical rectangular area containing a checkbox labeled "Check1".
- 6. Select Tracers**: A large vertical rectangular area containing a checkbox labeled "Check2".
- 7. Click to Continue to Next Step**: A button.
- Exit**: A button located at the bottom right of the form.

Figure 3.6: Design-time Form-1

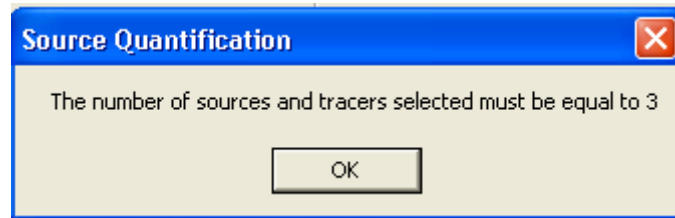


Figure 3.7: Dialog box prompting number of sources and tracers must be equal

The second Form prompts the user to enter the observed outfall tracer concentrations for only those selected in the first form. The text boxes against all the tracers not selected are all disabled. Figure 3.8 shows the second Form at design time.

The third Form contains a button in step-10 which prompts the user to save the output file at a selected location; the selected path is also displayed in an adjacent text box. On clicking the button in step-11, the program performs the MC simulation and displays the summary table with the 95% confidence values and also the Frame in step-12 is loaded, which prompts the user to select the source for which the cumulative distribution plot is needed. The Frame in step-12 loads all the sources selected for evaluation in Form-1 and there is a radio button next to each source so that the user can select a specific source. On selecting a radio button next to a specific source, a dialog box is used to save the graph in a selected location. The cumulative distribution plot for the selected source is then viewed in the picture frame of this Form. On clicking the “Print Graph” button, the graph can be printed. This form also contains a progress bar to show the

progress when the MC simulation is taking place and while plotting the cumulative distribution plots. Figure 3.9 shows the third Form at design time.

8. Enter Observed Outfall Tracer Concentrations

Tracer

9. Click to Continue to Next Step



Figure 3.8: Design-time Form-2

10. Save the Output File As

11. Click to **RUN Monte Carlo Simulation**

12. Select Source for Graph
 Option1

Print Graph

Exit Program

Summary Table

Click to Save Table As **Print Table**

Figure 3.9: Design-time Form -3

CHAPTER 4

RESULTS AND DISCUSSION

4.1. Introduction

This research developed a chemical mass balance model with *Monte Carlo* simulation using Microsoft's Visual Basic 6.0. The chemical mass balance model was developed and validated using actual field data collected from the Cribbs Mill Creek storm drainage outfalls, Tuscaloosa, Alabama. The Library File, which contains descriptions of possible source flows, was prepared from statistical summaries using source area sample data, also from the Tuscaloosa, AL, area. However, this model can be effectively used to assist any MS4 permit holder to comply with the NPDES Phase II regulations for any watershed, provided local source area flow data is available and with appropriate modifications to the Library File.

This chapter describes the validation procedure of the model and also presents results of the model as applied to the Cribbs Mill Creek storm drainage system.

4.2. Selection of suitable tracer parameters

The number of tracer parameters selected must equal the number of inappropriate sources selected in order to solve the matrix of simultaneous equations that are set up by the program. If only three inappropriate sources are expected, then only three tracers can be used. Similarly, if seven inappropriate sources are expected (the maximum number

that can be evaluated), then seven tracers must be selected. Therefore, it is important that the most efficient tracers be used for the analyses.

The tracer parameters used with the model must be suitably selected in order to successfully distinguish between the inappropriate discharge sources. It is important to select the tracers that are most efficient in distinguishing between flow sources. Mann-Whitney comparison analyses were therefore used for each parameter to compare all library groupings with each other in order to select the best tracers to use in the analyses. Comparisons were conducted by first grouping all library sample data into contaminated (carwash, sewage, and laundry wastewaters) and uncontaminated (irrigation, domestic tap, and spring water) groups. The results of these Mann-Whitney analyses are included in Appendix B. The Mann-Whitney analysis examines the ranks of the sorted concentrations in one source area, compared to all other source areas, a pair at a time. If the two sets of concentration values represent populations that are not significantly different from each other, then the sums of the ranks for the two sources will be similar in value. However, if the two sample sets represent populations that do differ for that particular parameter, the rank totals will be very different. Statistical tables are used to determine the likelihood that the two sets of concentrations are the same. The significance levels (“p”- values) resulting from these comparisons, obtained for a two tailed Mann Whitney test, adjusted for ties, are shown in Appendix B for each parameter. These calculations were conducted using Minitab statistical software. The “p”-values less

than 0.05 indicate that the differences between the compared sources were significant at the 95% confidence level.

The following are the resultant rankings of the tracer parameters, based on the number of “p”-values that were less than 0.05 when comparing the contaminated and uncontaminated flow sources:

1. Boron
2. Detergents
3. Turbidity
4. Fluorescence
5. Color
6. Ammonia
7. Potassium
8. Fluoride
9. Hardness
10. Conductivity

These rankings were determined by comparing the “p”-values for contaminated and uncontaminated sources, for each parameter. For example, by comparing the “p”-values for contaminated and uncontaminated sources for boron, nine out of all possible nine values are less than 0.05. Therefore, 100% of the contaminated sources differ significantly from the clean sources with respect to boron. Similarly, for detergents, all 18 out of the 18 possible values are also less than 0.05. Therefore,

100% of the contaminated sources differ significantly from the clean sources with respect to detergents. Boron is ranked above detergents on the above list because the “p”-values for the boron comparisons are smaller than that of detergent comparisons (although they are all less than 0.05). Thus, all the parameters are ranked by observing the percentage of contaminated sources which differ significantly from clean sources, and also the associated “p”-values.

When similar Mann-Whitney tests were conducted to distinguish between all inappropriate discharge sources, the rankings were somewhat different:

1. Boron
2. Ammonia
3. Potassium
4. Fluorescence
5. Detergents
6. Fluoride
7. Color
8. Turbidity
9. Hardness
10. Conductivity

The normal procedure would be to start at the top of the list and use the number of tracers needed for the specific problem. If a tracer parameter is not available, then skip it and select the next one on the list. It should be noted that pH is not included on this list because pH is not linearly additive (mixing an equal amount of two solutions having different pH values would not result in a solution having the average pH).

A Pearson Correlation matrix was also formed using Minitab statistical software for each of the sources and for all of the test parameters. One such matrix, formed for sewage wastewater is shown in Table 4.1. A strong relationship (Pearson Correlation coefficient $r = 0.89$) between ammonia and hardness can be seen from the table. This shows that ammonia and hardness are likely redundant when evaluating the possibility of sewage contamination. It may be more efficient to select only one of these tracer parameters. Pearson correlation tables for the other source areas are shown in Tables E.1 to E.5 in Appendix E.

Table 4.1 Pearson Correlation matrix for Sewage wastewater (dry weather)

	pH	Conduc	Turbid.	Color	Fluoride	Hardness	Deterg.	Fluoresc	Potass.	Ammon.
Conductivity	-0.467 0.351									
Turbidity	-0.378 0.460	0.323 0.532								
Color	-0.601 0.207	0.598 0.210	-0.252 0.630							
Fluoride	0.361 0.482	0.310 0.549	-0.100 0.851	0.306 0.555						
Hardness	0.575 0.232	-0.229 0.662	-0.396 0.437	-0.525 0.285	-0.346 0.502					
Detergents	-0.818 0.046	0.502 0.310	0.096 0.856	0.515 0.296	-0.496 0.317	-0.070 0.895				
Fluorescence	0.546 0.262	-0.838 0.037	-0.217 0.679	-0.432 0.392	0.174 0.741	-0.120 0.821	-0.808 0.052			
Potassium	-0.035 0.947	-0.310 0.550	0.219 0.677	-0.605 0.203	-0.753 0.084	0.519 0.292	0.340 0.510	-0.180 0.733		
Ammonia	0.822 0.045	-0.346 0.501	-0.634 0.177	-0.435 0.388	0.010 0.985	0.890 0.018	-0.405 0.426	0.184 0.727	0.154 0.770	
Ammonia/ Potassium	0.794 0.059	-0.194 0.713	-0.767 0.075	-0.122 0.819	0.327 0.527	0.664 0.150	-0.465 0.353	0.207 0.693	-0.231 0.660	0.917 0.010

Cell Contents: Pearson correlation, * = unknown
P-Value

4.3 Determining the appropriate number of MC runs

Another model use decision is the selection of the number of Monte Carlo runs to be made for an analysis. The model allows a maximum of 10,000 runs. However, if the maximum number is used for a complex condition (many potential sources), the run time can be extensive. For example, to evaluate 6 sources (and using the necessary 6 tracer parameters) with 10,000 runs, the computer time was 2 hours and 8 minutes (using a Pentium 4 computer with 1.60 GHz processing speed and 256 MB RAM). The computer run time was reduced to

11 minutes when the number of runs was reduced to 1000, with the other conditions remaining the same. Therefore, further experiments were conducted to determine the benefits of different runs lengths using a typical example.

The example shown in Table 4.2 was used to compare differences in the model outputs using different numbers of MC runs. In this example, the percentage contribution by the sources was assumed and the concentration of each tracer parameter was calculated. These calculated concentration values were then used in the model as the observed outfall concentrations, resulting in an exact and expected solution.

Source	Actual	10_runs	100_runs	1000_runs	10000_runs
Spring Water	80	79.5	82	81	81
Carwash Wastewater	10	8.5	4	5	5
Sewage Wastewater	10	6.5	14	13	13

Table 4.2 Calculated % contributions versus modeled % contributions for different number of runs (when Potassium, Fluorescence and Color were used as tracers)

Figures 4-1 through 4-3 are box and whisker plots that display the calculated ranges and medians of the calculated contributions of the source flows. Five trials were performed, with the number of MC simulations being 10, 100, 1000, and 10,000 runs.

% Contribution Vs No. of runs: Actual value = 80

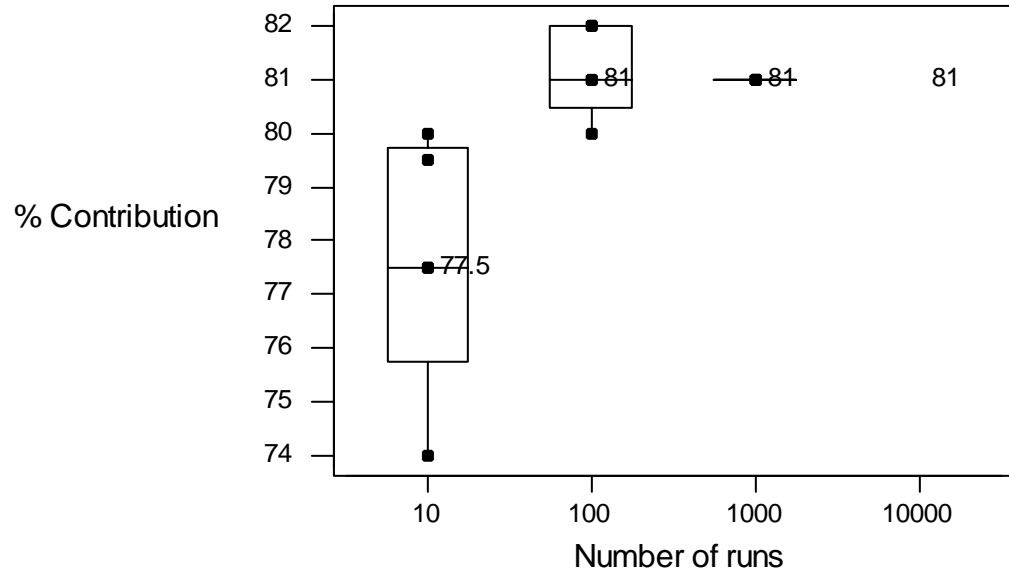


Figure 4.1: Percentage contribution by Spring Water

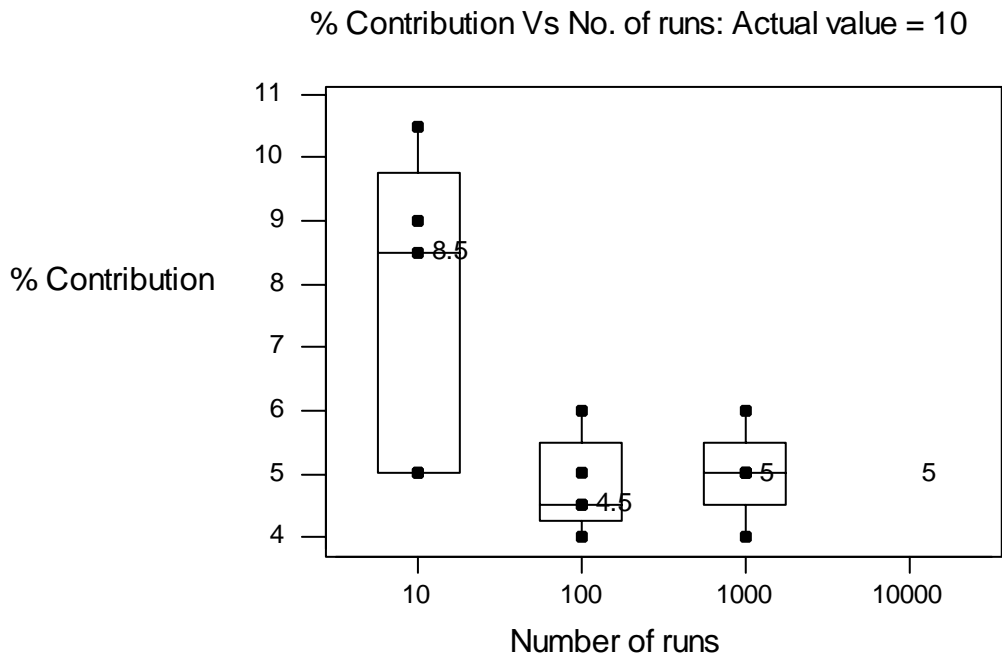


Figure 4.2: Percentage contribution by Carwash Wastewater

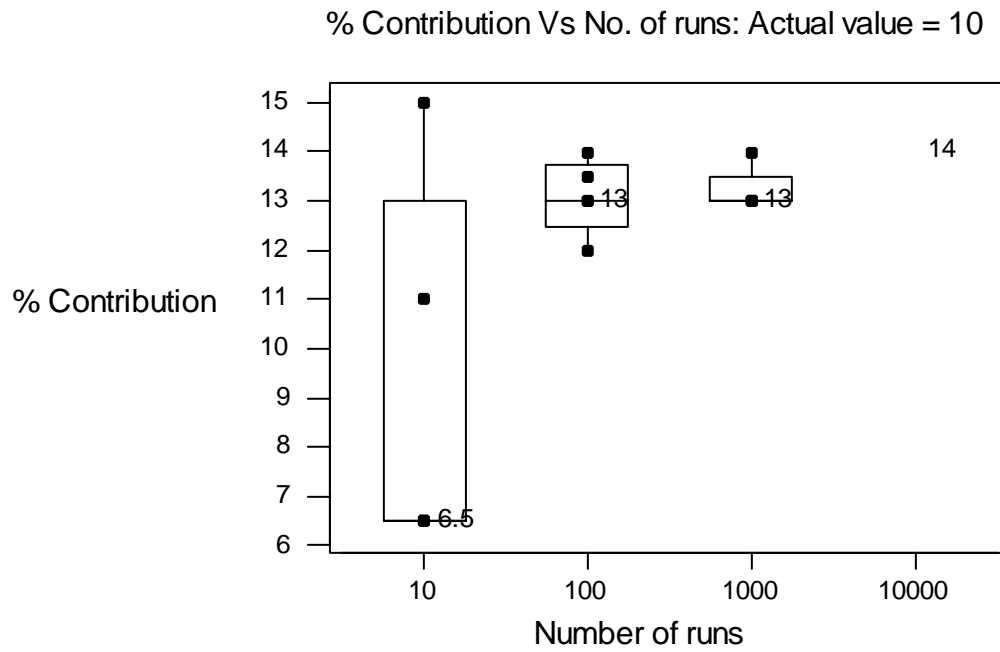


Figure 4.3: Percentage contribution by Sewage Wastewater

From Figures 4.1 to Figures 4.3, it can be seen that the mass fraction value using 1,000 runs is close to the actual value in most cases and very similar to the results obtained using the much longer 10,000 run simulations. Hence, it is concluded that selecting number of MC simulation runs as 1000 would give a reasonable value for the mass fraction. Therefore, the evaluations for this research used 1,000 runs. However, these conclusions should be checked for other areas and conditions.

Table 4.3 shows the analysis of the aforementioned example with different sets of tracers. This shows that results close to the actual value could be obtained for only one set of tracer, which must be identified.

Source	Actual	Run 1 (with Boron, Ammonia and Potassium)	Run 2 (with Ammonia, Potassium and Fluorescence)	Run 3 (with Potassium, Fluorescence and Color)
Spring Water	80	59	74	81
Carwash Wastewater	10	30	21	5
Sewage Wastewater	10	9	6	13

Table 4.3 Calculated % contributions versus modeled % contributions for different sets of tracers (1000 runs)

4.4. Validation Results

The model was initially tested by using mean concentrations from each source group and allowing for no variation in concentration values: the coefficient of variation values were therefore entered as 0 and the mean concentration values for each parameter within each source type were used in solving the equation sets. When the mean values for each potential source type were entered as observed outfall concentrations, the program correctly predicted the source of the sample, indicating that the model algorithm was working correctly. Figure 4.7 shows the summary table obtained during one of these analyses.

Summary Table							
	Tap Water	Spring Water	Carwash Wa:	Laundry Wa:	Sewage Was	Irrigation Wa	Mu
2.5th %tile	1	0	0	0	0	0	0
97.5th %tile	1	0	0	0	0	0	0
50th %tile	1	0	0	0	0	0	0

Figure 4.7: Check on the model algorithm using Tap water

In the next series of tests, the mean concentration values were entered in place of the observed tracer concentrations at outfall and the Monte Carlo component was tested by also using the coefficient of variation values from the library file. This test is the same as assuming 100% contribution of each source at the outfall, but considers the likely variations in source area contribution tracer concentrations. The results obtained by the model for these tests are shown in Table 4.4.

Table 4.4 Model Validation Using 100% of each Source

	Median mass fraction from each source						
Source	Tap Water	Spring Water	Carwash	Laundry	Sewage	Irrigation	μ
100% Tap Water	0.99	0	0	0	0	0.005	0
100% Spring Water	0.01	0.85	0.01	0	0	0.13	-0.02
100% Carwash	0.47	-0.29	0.82	0.02	0	0.1	0.18
100% Laundry	-2.01	-0.22	1.99	0.68	-0.02	0.54	0.27
100% Sewage	-0.21	-0.03	0.02	-0.01	0.9	0.37	0.04
100% Irrigation	0.19	0.13	-0.03	0.01	0.02	0.69	0.04

Tap Water

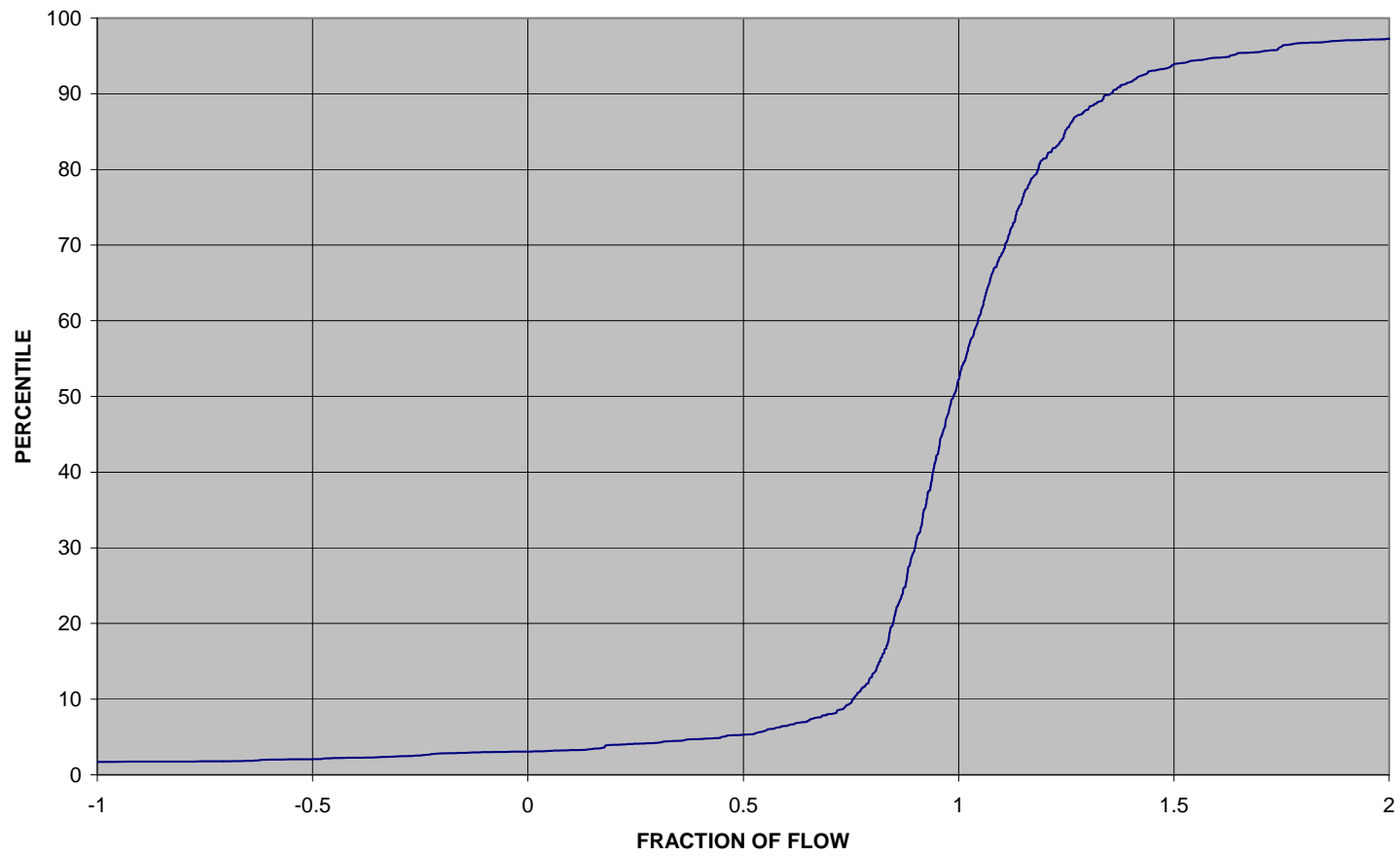


Figure 4.8 Cumulative distribution plot for 100% Tap water

Spring Water

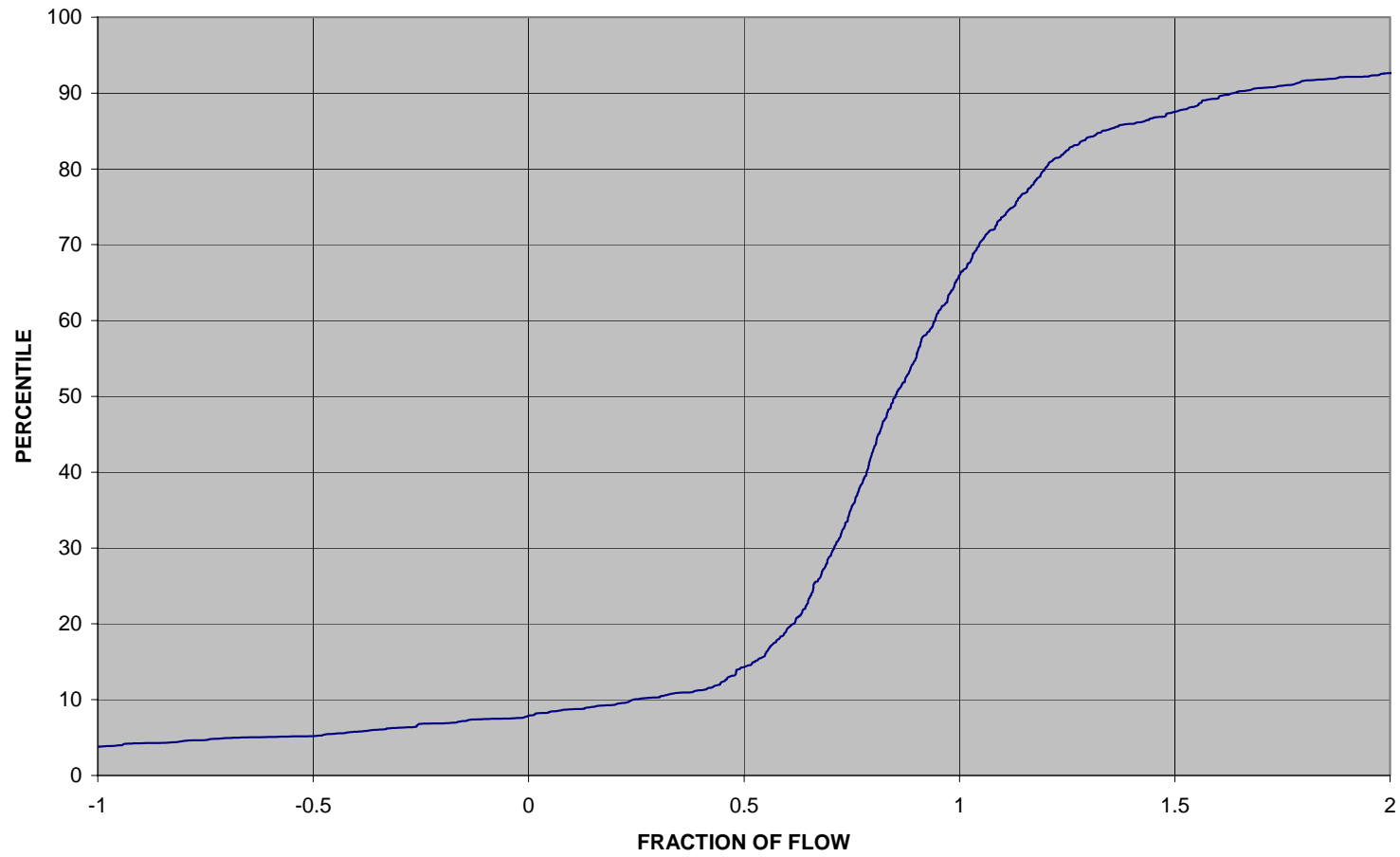


Figure 4.9 Cumulative distribution plot for 100% Spring water

Carwash Wastewater

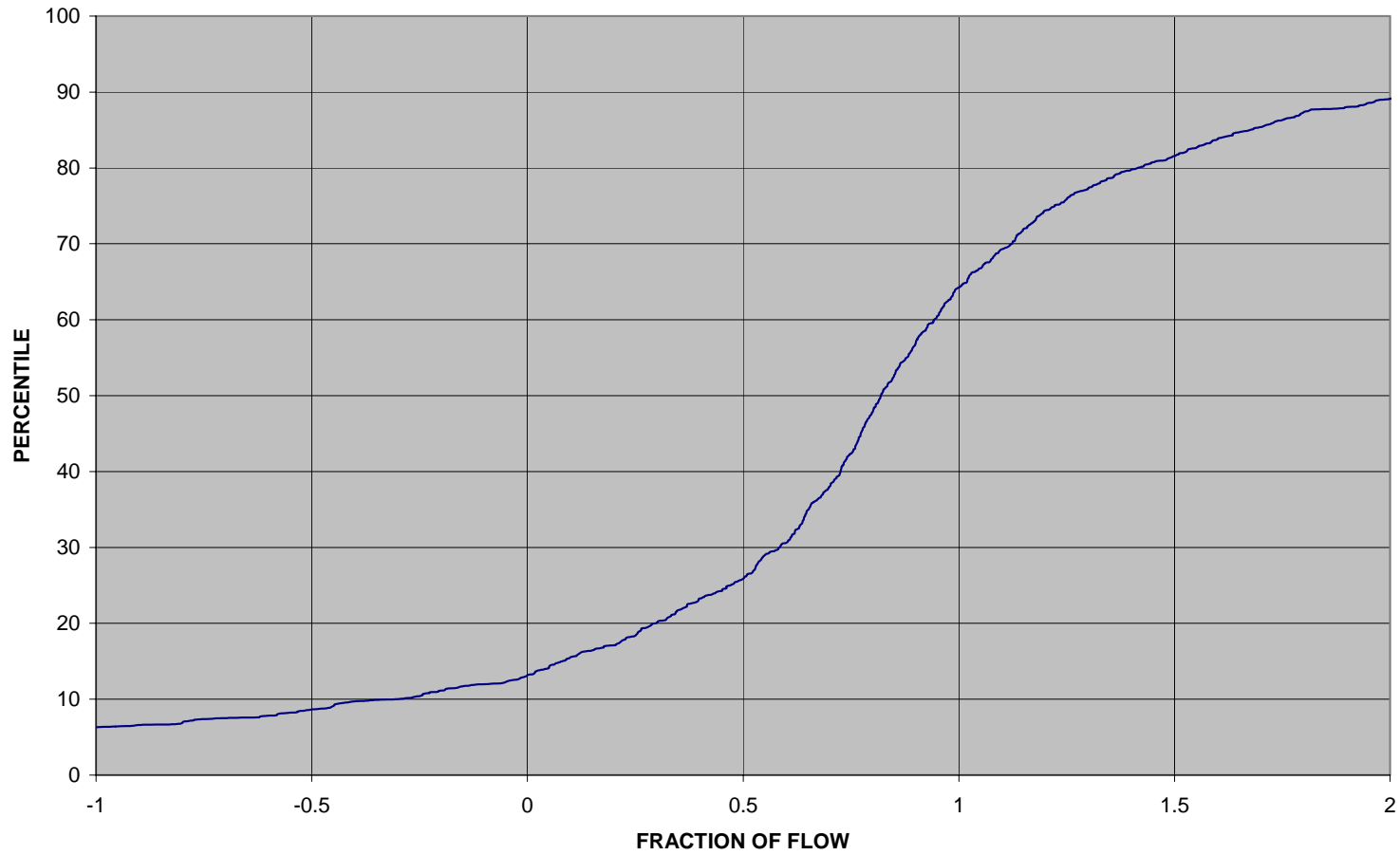


Figure 4.10 Cumulative distribution plot for 100% Carwash wastewater

Laundry Wastewater

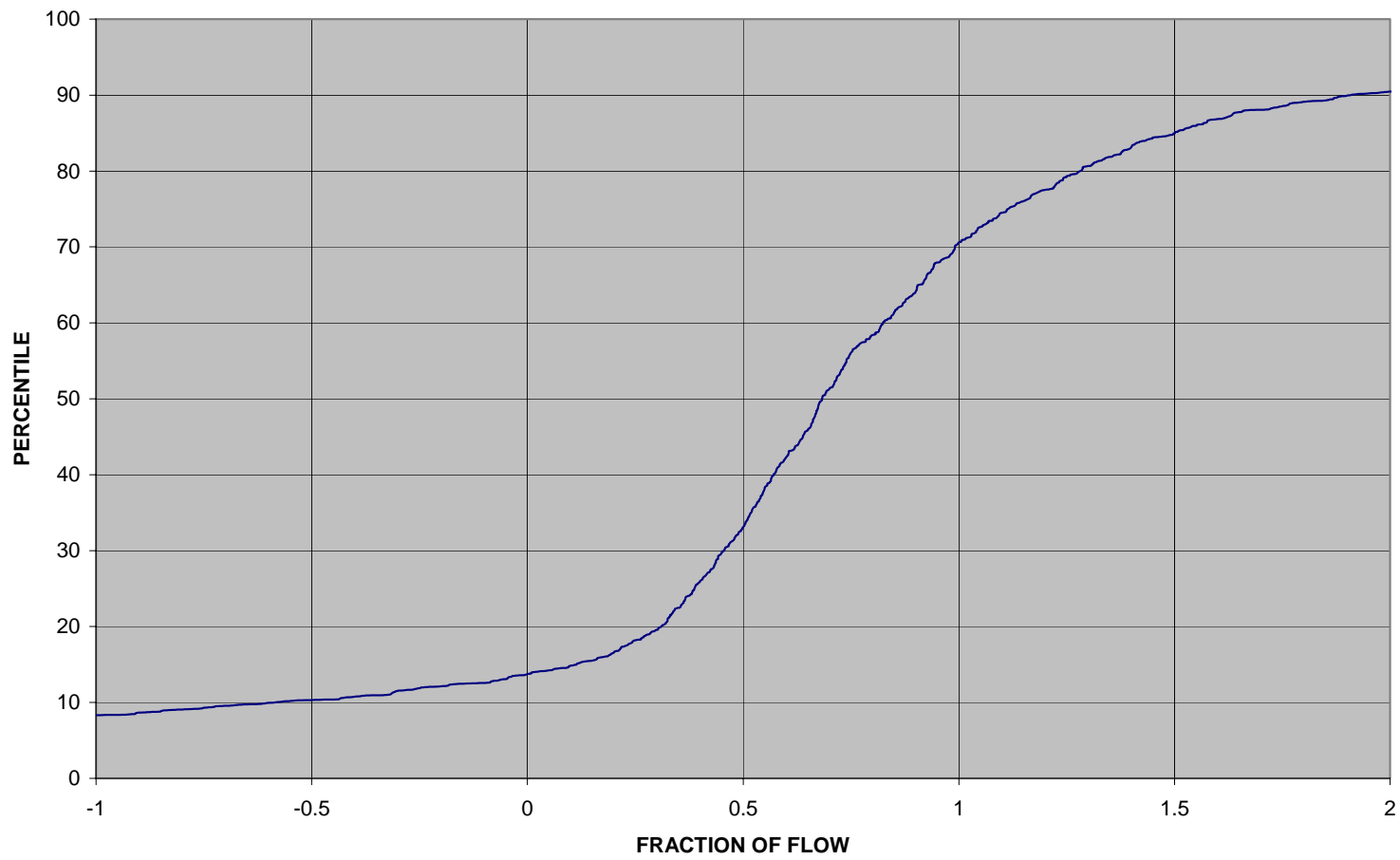


Figure 4.11 Cumulative distribution plot for 100% Laundry wastewater

Sewage Wastewater

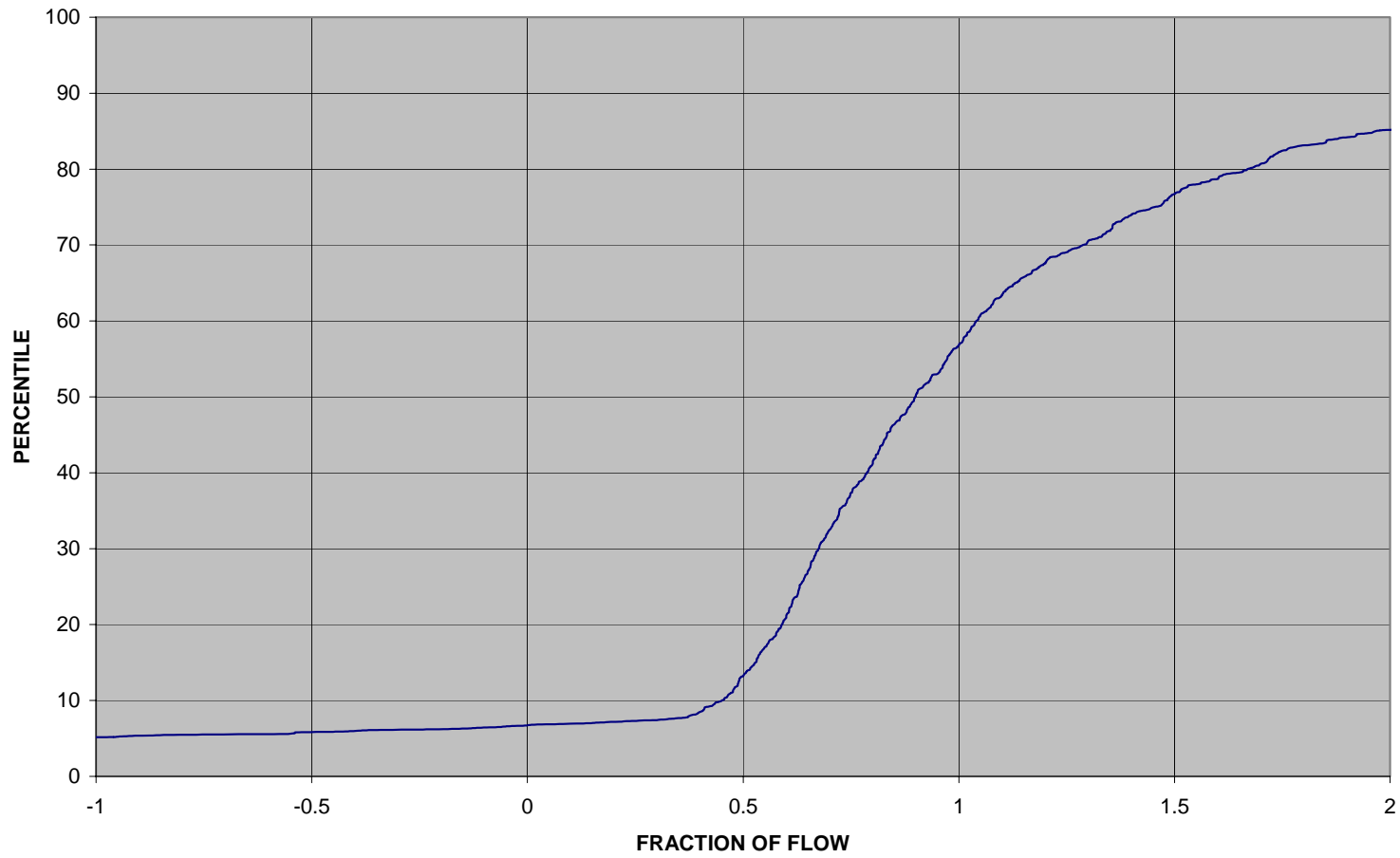


Figure 4.12 Cumulative distribution plot for 100% Sewage wastewater

Irrigation Water

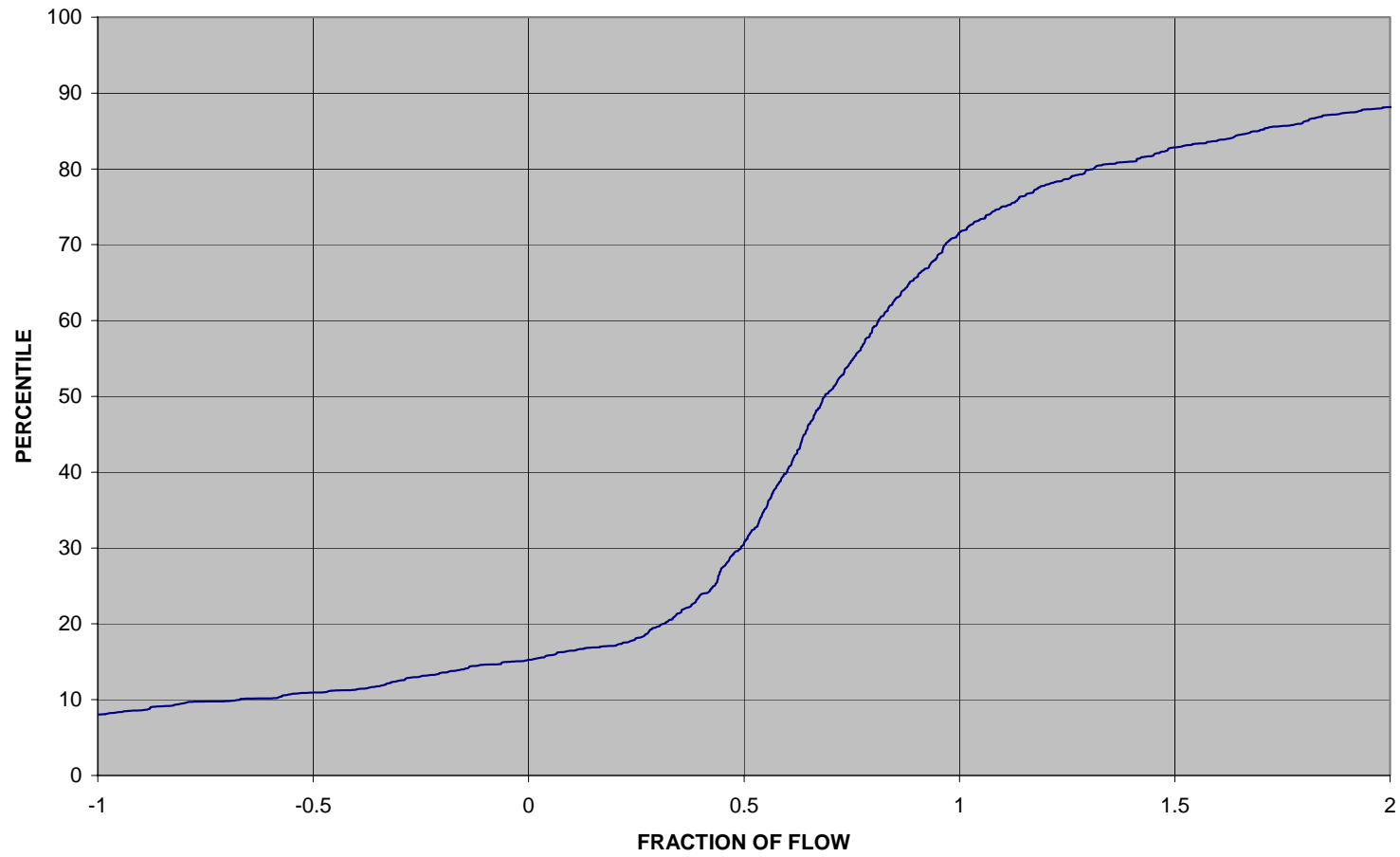


Figure 4.13 Cumulative distribution plot for 100% Irrigation water

Each row on Table 4.4 corresponds to a separate analysis using 1,000 Monte Carlo runs. The optimal results would have been for the 100% source water used to correspond to a 1.00 mass fraction for the same source water, all other sources to be 0.00, and for the sum of all sources to be 1.00 and the μ to be zero. This was not evident due to the uncertainty inherent in the probability distribution for the source water concentrations. However, in all cases, the correct source water is shown to have the largest median mass fraction. The best conditions appear when μ (mu) is small (less than 0.1) and there are no large negative mass fractions calculated. It is hard to believe any mass fraction less than about 0.5. Some source waters appeared to be predicted with better precision than others. Tap water and sewage wastewater were predicted with the least interference from other sources, while the carwash and laundry waters were overlapping. However, this test did show that the contribution by the source which had the highest value of the mass fraction was the most likely source. Figures 4.8 to 4.13 show the cumulative distribution plots obtained by the model for each 100% source.

Also, it can be seen from Table 4.4 that for the 100 % laundry case when the value of μ (mu) is far from zero the value of mass fraction of carwash (1.99) and laundry (0.68) show that either of them can be most likely source. Similarly for the 100 % carwash case when the value of μ (mu) is 0.18 the value of mass fraction of carwash (0.82) and tap water (0.47) show that either of them can be most likely source. Such situations can be avoided when alternate sets of tracers also tested.

4.5 Comparison of model predictions with other methods of source identification

During the field studies, a selection of ten outfalls having various potential source contributions were identified for the Cribbs Mill Creek watershed, Tuscaloosa, Alabama. Different methods of source identification were compared with the model predictions. The other methods of source identification considered (described in other project reports) were:

1. Physical observations method,
2. Detergents Contamination method, and
3. Flowchart method.

The outfalls were considered to be contaminated if the source waters predicted by the model were other than irrigation, tap, or spring water. Table 4.5 shows the comparison of the mass balance model predictions with the other methods. The physical observation method relies on obvious indicators such as highly colored or turbid water, gross floatables present near the outfall, etc. The detergents method considers an outfall to be contaminated if the concentration of detergents is ≥ 0.25 mg/L. The flow chart method considers an outfall to be contaminated if the likely source predicted by the flowchart method (using a number of chemical tracers, such as detergents, fluoride, boron, potassium, ammonia, and bacteria) is other than irrigation, tap, or spring water. These comparisons show that the predictions with respect to contamination are

consistent with the other methods of source identification. These ten outfalls are undergoing additional watershed investigations to further verify the model results. Initial results indicate that the mass balance predictions are accurate indicators of the source flows.

Appendix D shows the analysis of the outfall observations by the model for the Cribbs Mill Creek watershed, Tuscaloosa, Alabama conducted during the study period. During these surveys, 39 outfalls were sampled five times. All of the analysis methods were applied to these outfalls for comparison. Table D in Appendix is a summary of these comparisons.

OUTFALL #	PREDICTED FLOW QUALITY BY PHYSICAL OBSERVATIONS	PREDICTED FLOW QUALITY BY DETERGENTS CONTAMINATION CONTAMINATED IF ≥ 0.25 mg/L	PREDICTED FLOW QUALITY BY FLOW CHART METHOD	PREDICTED FLOW QUALITY BY MODEL (1st rank/2nd rank/3rd rank) (μ)
3	Contaminated (color, turbidity)	Contaminated	Washwater (Contaminated)	Spring water(1.78)/Laundry(0.02)/Sewage(0) (Contaminated) (0.49)
4	Contaminated (sediments)	Uncontaminated	Natural water (Uncontaminated)	Spring water(1.05)/Tap water(0.24)/Sewage(0.01) (Contaminated) (-0.11)
27	Contaminated (sediments)	Uncontaminated	Natural water (Uncontaminated)	Tap water(0.96)/Irrigation(0.21)/Sewage(0.02)(Contaminated) (-0.82)
31	Contaminated (color, turbidity, floatables)	Uncontaminated	Irrigation water (Uncontaminated)	Tap water(0.83)/Spring water(0.27)/Laundry(0.04) (Contaminated) (0)
36	Contaminated (sediments, damage to outfalls)	Contaminated	Washwater (Contaminated)	Tapwater(2.405)/Irrigation(1.27)/Carwash(0.27) (Contaminated) (-2.84)
39	Uncontaminated	Uncontaminated	Natural water (Uncontaminated)	Spring water(0.67)/Tap water(0.35)/Irrigation(0.01) (Uncontaminated) (-0.13)
45	Uncontaminated	Contaminated	Washwater (Contaminated)	Spring water(0.75)/Tap water(0.31)/Laundry(0.02) (Contaminated) (0.11)
49	Contaminated (color, turbidity)	Contaminated	Sanitary wastewater (Contaminated)	Tapwater(2.695)/Irrigation(0.88)/Sewage(0.25)(Contaminated) (-2.82)
53	Contaminated (sediments, damage to outfalls)	Contaminated	Washwater (Contaminated)	Spring water(0.76)/Tap water(0.27)/Carwash(0.04) (Contaminated) (-0.04)
55	Contaminated (sediments)	Contaminated	Washwater (Contaminated)	Tapwater(1.81)/Irrigation(0.6)/Carwash(0.1) (Contaminated) (-2.01)

Table 4.5: Comparison of model predictions with other methods

CHAPTER 5

CONCLUSIONS AND FUTURE WORK

5.1 Conclusions

The specific objectives of this research were to:

1. Develop and validate a model for source quantification of inappropriate dry-weather discharges from storm drainage systems.
2. Perform statistical analyses to rank the usefulness of chemical tracers to distinguish different flow sources.
3. Compare the results of this model with that of the other methods of source investigation for the Tuscaloosa data set.

The conclusions supported by this research are as follows:

1. False negative determinations of source area flows of inappropriate discharges to storm drainage systems can be reduced by using this model in conjunction with the other evaluation methods. The use of independent methods creates a weight-of-evidence approach that is more compelling than relying on a single, simplistic method. This model therefore results in additional insight into the local inappropriate discharge problem.
2. Quantification of the mass fractions likely contributing to an inappropriate discharge through the use of this model is very useful when the discharge is due to a mixture of sources. Other methods of source identification indicate the most likely contaminating source flow, while this model determines if multiple contaminating sources are present.

3. All of the outfalls and drainage areas in a storm drainage system should be examined for inappropriate discharges, not just the largest outfalls.

5.2 Recommended future research

Identification of non-stormwater discharges into the storm drainage system identified using this monitoring and modeling technique must be followed by further investigation to verify the actual sources, and to make necessary corrective action. Of course, this is relatively straight-forward as the type of inappropriate discharge is known. Depending on the type of problems identified, this verification procedure may require relative extensive mapping of the drainage system associated with the problem outfalls, and the characterization of the associated drainage areas. Further sampling at manholes at successive intervals in the drainage system would help narrow down the likely area affected by the inappropriate discharges.

Alternative combinations of tracers should be examined, as the tracer parameters used with the model can affect the calculated results. The tracer combinations that correspond to a value of μ close to zero, with no large negative mass fractions, and with relatively narrow ranges of calculated mass fractions, could be used to select the most appropriate set of tracer parameters, and possible inappropriate sources affecting an outfall. The model could therefore be further developed to perform this selection analysis as part of the analytical procedure. There are a very large number of combinations of tracers and source flows that can be examined. A complete evaluation would require an extremely long computational effort. The use of a genetic algorithm could be used to significantly reduce this

analytical burden. The following example shows the sensitivity of the calculations to the selection of tracers:

Table 5.1 and Figure 5.1 shows the analysis of the outfall sample collected at Pond Entrance-I on 9th October 2002.

Selected Tracers	Tap water	Spring water	Carwash	Laundry	Sewage	Irrigation	Mu
Conductivity, Fluoride, Hardness, Color, Turbidity, Boron	29.1	-19.84	1.465	-2.015	0.79	-4.93	3.27
Hardness, Detergents, Fluorescence, Potassium, Ammonia, E-coli	-1.21	2.09	-0.04	0.01	0.08	0	-2.15
Hardness, Detergents, Fluorescence, Potassium, Ammonia, Enterococci	-1.09	2.02	-0.06	0.01	0.08	0	-1.955
Fluoride, Hardness, Detergents, Fluorescence, Turbidity, Color	-1.36	2.3	-0.09	0.01	0.02	0.04	1.42
Conductivity, Fluoride, Hardness, Detergents, Fluorescence, Enterococci	-1.32	2.405	-0.09	0.02	0.01	0	1.41
Conductivity, Fluoride, Hardness, Detergents, Fluorescence, Potassium	-0.3	2.205	-0.3	0.05	0.04	-0.675	1.12
Fluoride, Hardness, Detergents, Fluorescence, Potassium, Enterococci	-0.39	2.105	-0.47	0.09	-0.24	0	1.11
Fluoride, Hardness, Detergents, Fluorescence, Potassium, E-Coli	-0.325	2.05	-0.45	0.09	-0.215	0.02	1.07
Fluoride, Hardness, Fluorescence, Potassium, Turbidity, E-Coli	-0.66	1.95	-0.3	0.04	-0.14	0.02	1.055
Boron, Ammonia, Potassium, Fluorescence, Detergents, Fluoride	1.035	-0.225	0.07	-0.01	0.04	0.09	-1
Conductivity, Fluoride, Hardness, Detergents, Fluorescence, E-Coli	-1.46	2.41	0.04	0	-0.02	0.01	0.905
Conductivity, Fluoride, Hardness, Detergents, Ammonia, E-Coli	-0.59	1.82	-0.36	0.06	-0.02	0.01	0.8
Fluoride, Detergents, Fluorescence, Potassium, Color, Turbidity	0.83	0.12	-0.05	0.01	0.03	0.075	-0.3
Fluoride, Detergents, Fluorescence, Potassium, Ammonia, Color	0.71	0.08	-0.06	0.01	0	0.26	-0.28
Conductivity, Fluoride, Hardness, Detergents, Boron, Enterococci	0.32	1.3	-0.75	0.12	0.05	0	0.17
Conductivity, Fluoride, Fluorescence, Potassium, Boron, E-Coli	0.51	0.4	0.05	0.02	-0.01	0.01	-0.04
Detergents, Fluorescence, Ammonia, Turbidity, Boron, Enterococci	0.34	0.785	-0.09	0.02	0	0	0.03

Table 5.1 Analysis by model of outfall sample collected at Pond Entrance-I for various combinations of tracers

Summary Table							
	Tap Water	Spring Water	Carwash Wa:	Laundry Wa:	Sewage Was	Irrigation Wa	Mu
2.5th %tile	-6.73	-10.89	-1.27	-0.18	-0.56	-2.47	-7.9
97.5th %tile	10.43	6.72	0.97	0.18	0.55	2.87	3.28
50th %tile	1.035	-0.225	0.07	-0.01	0.04	0.09	-1

Figure 5.1

This analysis was made by selecting the tracer parameters suggested by the Mann-Whitney analyses to distinguish between all the sources. However, this analysis resulted in a μ (μ) value that is not close to zero (-1), indicating that there could be excessive error in the evaluation. This error could possibly be minimized by selecting other tracer parameters and source flows. In this example, several combinations of tracers were tested in order to reduce the value of μ (μ). Table 5.1 shows the mass fraction values for the combinations of tracers tested out of a total possible number of combinations (=12C6=924 combinations), in the decreasing order of the position of μ (μ) from zero. It can be seen from the table that the problem of occurrence of unusually large mass fraction values and large negative mass contribution decreases as the μ (μ) value approaches zero.

Figure 5.2 shows the analysis results for one combination of tracers for which the μ (μ) value is very close to zero (0.03). The earlier analysis (Figure 5.1) indicated a major tap water source, with all the other source mass contributions close to zero. This analysis resulted in spring water as the major source, with possible tap water contributions also. In the analysis as shown in Figure 5.2, there was still a negative mass contribution determined, but it was very small.

Summary Table							
	Tap Water	Spring Water	Carwash Wa:	Laundry Wa:	Sewage Was	Irrigation Wa	Mu
2.5th %tile	-27.93	-38.1	-1.68	-0.29	-0.21	-0.02	-3.12
97.5th %tile	33.05	28.25	1.98	0.23	0.21	0.02	2.6
50th %tile	0.34	0.785	-0.09	0.02	0	0	0.03

Figure 5.2

5.3 Sensitivity analysis to the selection of tracers

In order to observe the sensitivity of the model to the selection of tracers, thereby to aid the development of a genetic algorithm as a recommended future research for this project, nine outfall samples were analyzed by the model, which are the same nine outfalls for which the verification exercise is being conducted, as a future research for this project. The results of the sensitivity analysis for these nine outfalls are included in Appendix G.

The following observations were made, while selecting the suitable combination of tracers in the process of reducing the value of μ (μ):

1. All the main representative tracers of each of the sources were selected for sure in an analysis. For example detergent or fluorescence or boron is a main

representative tracer for a washwater, so it was made sure that one of these tracers is selected during an analysis.

2. Taking the above into consideration, the tracers were selected as follows:
conductivity or hardness, fluoride, potassium or ammonia, detergent or fluorescence or boron, color or turbidity, Enterococci or E-Coli.
3. The combination of tracers selected during the analysis of the nine verification outfalls, for which the value of μ (mu) is closest to zero, indicates the sensitivity of the selection of tracers in this regard.

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APPENDIX A

Source Code

```
Private Sub Command1_Click()  
UnloadAll  
Form1.Show  
End Sub
```

```
Public Sub UnloadAll()  
Unload Form1  
Unload Form5  
Unload Form2  
End Sub
```

```
Private Sub MDIForm_Load()  
MDIForm1.Width = 30325  
MDIForm1.Height = 25545  
MDIForm1.Left = 10  
MDIForm1.Top = 10  
End Sub
```

```
Dim FName As String  
Dim TotSrc As Integer  
Dim TotTra As Integer
```

```
Private Sub Command2_Click()  
Dim n1 As Integer  
Dim str1 As String  
Dim ht As Integer  
Workbooks.Close  
Set vbexcel = CreateObject("Excel.application")  
With vbexcel  
.Visible = False  
.Workbooks.Open FileName:=Text10.Text 'opens the selected 'Library File'  
n1 = .Worksheets.Count  
TotSrc = n1 'Total number of sources in the 'Library File'  
ht = 500  
For i = 1 To n1  
str1 = .Worksheets(i).Name 'name of each source by the name of the worksheet  
Load Check1(i) 'loading each source name into the frame  
Check1(i).Caption = str1  
Check1(i).Visible = True  
Check1(i).Left = 250  
Check1(i).Top = ht  
ht = ht + 500  
Next  
ht = 500
```

```

For i = 1 To 20
If (.Worksheets(1).Cells(i + 1, 1) = "") Then
Else
Load Check2(i) ' loading each tracer name into the frame by those given in first column
Check2(i).Caption = .Worksheets(1).Cells(i + 1, 1)
Check2(i).Visible = True
Check2(i).Left = 250
Check2(i).Top = ht
ht = ht + 500
TotTra = i 'Total number of tracers in the 'Library File'
End If
Next
.Workbooks.Close
.Quit
End With
Frame1.Visible = True
Frame2.Visible = True
MsgBox " The number of sources and tracers selected must be equal to " & Text11.Text
& " ", , "Source Quantification"
Text2.Text = TotTra
Command6.Visible = True
End Sub

```

```

Private Sub Command6_Click() 'transition to form 2
Dim Nchecked, Tchecked, NOV As Integer
If (Text11.Text = "") Then
NOV = 0
Else
NOV = CInt(Text11.Text)
End If
If (NOV > 2 And NOV < 14) Then
Nchecked = 0
Tchecked = 0
For i = 1 To TotSrc
If (Check1(i)) Then
Nchecked = Nchecked + 1
End If
Next
For i = 1 To TotTra
If (Check2(i)) Then
Tchecked = Tchecked + 1
End If
Next
If (Nchecked = NOV And Tchecked = NOV) Then
Form1.Hide
Form5.Show

```



```

Else
MsgBox "The number of sources and tracers selected must be equal to " & NOV, ,
"Source Quantification"
End If
Else
Text11.Text = ""
Text11.SetFocus
End If
End Sub

```

```

Private Sub text11_LostFocus()
Dim NOV As Integer
Dim wd As Single
Dim ht As Single
NOV = CInt(Text11.Text) 'Number of contributing sources to be evaluated
wt = 1000
ht = 2000
i = (NOV + 1) * (NOV + 1)
For j = 1 To i
Load a11(j)
a11(j).Visible = False
a11(j).Top = ht
a11(j).Left = wt
wt = wt + 1000
If ((j Mod (NOV + 1)) = 0) Then
ht = ht + 300
wt = 1000
End If
Next
ht = 2000
wt = 2000 + (1000 * (NOV + 1))
For j = i + 1 To i + (NOV + 1)
Load a11(j)
a11(j).Visible = False
a11(j).Top = ht
a11(j).Left = wt
ht = ht + 300
Next
End Sub

```

```

Private Sub Command1_Click()
End
End Sub

```

```
Private Sub Command3_Click()
End
End Sub
```

```
Private Sub Command5_Click()
CommonDialog1.Filter = "Excel File(*.xls)|*.xls|All Files(*.*)|*.*"
CommonDialog1.ShowOpen
Text10.Text = CommonDialog1.FileName 'Library File
Fname = CommonDialog1.FileTitle
End Sub
```

```
Private Sub UpDown1_Change()

End Sub
```

```
Dim Fname As String
Dim TotSrc As Integer
Dim TotTra As Integer
Dim Sources(18) As String
Dim TracerS(18) As String
```

```
Private Sub Command1_Click()
Form5.Hide
Form2.Show
End Sub
```

```
Private Sub Form_Load()
Dim ht As Integer
Fname = Form1.CommonDialog1.FileTitle
Dim n1 As Integer
Dim str1 As String
Set vbexcel = CreateObject("Excel.application")
With vbexcel
.Visible = False
.Workbooks.Open FileName:=Form1.Text10.Text
n1 = .Worksheets.Count
TotSrc = n1 'Total number of sources in the 'Library File'
ht = 500
For i = 1 To 20
If (.Worksheets(1).Cells(i + 1, 1) = "") Then
Else
Load Label1(i)
```

```

Label1(i).Caption = .Worksheets(1).Cells(i + 1, 1)
Label1(i).Visible = True
Load Text1(i)
Text1(i).Visible = True
Label1(i).Left = 250
Label1(i).Top = ht
Text1(i).Left = 3480
Text1(i).Top = ht
ht = ht + 500
TotTra = i 'Total number of tracers in the 'Library File'
End If
Next
.Workbooks.Close
.Quit
End With
checkSources
checkTracers
End Sub

```

```

Public Sub checkTracers() 'greying' of text boxes to be disregarded
For i = 1 To TotTra
If Form1.Check2(i) Then
Text1(i).Enabled = True
TracerS(i) = Form1.Check2(i).Caption
Else
Text1(i).Enabled = False
Text1(i).BackColor = Grey
TracerS(i) = ""
End If
Next
End Sub

```

```

Public Sub checkSources()
For i = 1 To TotSrc
If Form1.Check1(i) Then
Sources(i) = Form1.Check1(i).Caption
Else
Sources(i) = ""
End If
Next
End Sub

```

```

Private Sub Label12_Click()

End Sub

```

```

Dim a() As Double
Dim g1() As Double
Dim g2() As Double
Dim g3() As Double
Dim g4() As Double
Dim g5() As Double
Dim g6() As Double
Dim g7() As Double
Dim g8() As Double
Dim g9() As Double
Dim g10() As Double
Dim g11() As Double
Dim g12() As Double
Dim g13() As Double
Dim dataGraph() As Double
Dim dataSheet() As Double
Dim AllData() As Double
Dim meansSrc() As Double
Dim Sources(18) As String
Dim TracerS(18) As String
Dim Means() As Single
Dim Covs() As Single
Dim TotSrc As Integer
Dim TotTra As Integer
Dim Distribution() As String
Dim insVal(18) As Single
Dim Mean, Cov As Single
Dim xlApp As Excel.Application 'Object for storing data in Excel
Dim xlBook As Excel.Workbook
Dim xlSheet As Excel.Worksheet
Dim Dentry As Integer
Dim Fname As String
Private xl As Excel.Application
Private xlwb As Excel.Workbook
Private xlsh As Excel.Worksheet
Private xlchart As Excel.Chart
Private Sub Command1_Click()
Dim Row1 As Integer
Set xlApp = New Excel.Application ' Assigning memory to object
Set xlBook = xlApp.Workbooks.Add
Set xlSheet = xlBook.Worksheets.Add
Dentry = CInt(Form1.Text1.Text) 'number of Monte Carlo runs for the evaluation entered
in form 1

```

```

n = CInt(Form1.Text11.Text) 'Number of contributing sources to be evaluated entered in
form 1
n = n + 1
ReDim a(n, n + 1) As Double
ReDim Tempmid(n, n) As Double
ReDim temp1(n, (n + 1)) As Double
ReDim temp2(n) As Double
ReDim answer(n) As Double
ReDim AllData(Dentry, n, n)
ReDim g1(Dentry, 2) As Double
ReDim g2(Dentry, 2) As Double
ReDim g3(Dentry, 2) As Double
ReDim g4(Dentry, 2) As Double
ReDim g5(Dentry, 2) As Double
ReDim g6(Dentry, 2) As Double
ReDim g7(Dentry, 2) As Double
ReDim g8(Dentry, 2) As Double
ReDim g9(Dentry, 2) As Double
ReDim g10(Dentry, 2) As Double
ReDim g11(Dentry, 2) As Double
ReDim g12(Dentry, 2) As Double
ReDim g13(Dentry, 2) As Double
ProgressBar1.Max = Dentry + 1
ProgressBar1.Min = 0
ProgressBar1.Visible = True
For Row1 = 1 To Dentry
ProgressBar1.Value = Row1
LogNormalDistribution 'getting the tracer conc. from library file and put the randomly
generated number according to distribution in the 'matrix cells'
k = 1
For i = 1 To n
For j = 1 To n
a(i, j) = CDbI(Form1.a11(k).Text)
AllData(Row1, i, j) = CDbI(Form1.a11(k).Text)
k = k + 1
Next
Next
k = (n * n) + 1
For i = 1 To n
a(i, n + 1) = CDbI(Form1.a11(k).Text)
k = k + 1
Next

k = 2
l = 1
For p = 1 To (n - 1)

```

```

Tempmid(p, p) = a(p, p)
For X = k To n
    temp1(X, l) = a(X, l)
For Y = 1 To (n + 1)
    a(X, Y) = (Tempmid(p, p) * a(X, Y) - temp1(X, l) * a(l, Y))
Next
Next
k = k + 1
l = l + 1
Next
If a(n, n) = 0 Then
MsgBox "Source Quantification is indeterminate for this set of tracers, please replace one
or more of the tracers", , "Source Quantification"
End
End If
answer(n) = a(n, n + 1) / a(n, n)
For i = (n - 1) To 1 Step -1
Sum = 0
For j = n To (i + 1) Step -1
    Sum = Sum + (a(i, j) * answer(j))
Next
If a(i, i) = 0 Then
MsgBox "Source Quantification is indeterminate for this set of tracers, please replace one
or more of the tracers", , "Source Quantification"
End
End If
answer(i) = (a(i, (n + 1)) - Sum) / a(i, i)
Next
For i = 1 To n
xlSheet.Cells(Row1, i).Value = answer(i) ' Putting values in the Output Excel file
Next
Next
xlSheet.SaveAs Text9.Text
xlBook.Close
xlApp.Quit
Set xlApp = Nothing
Workbooks.Close
Set xlBook = Nothing
Workbooks.Close
Set xlSheet = Nothing
Workbooks.Close
arrayGraph
Frame1.Visible = True
MSFlexGrid1.Cols = ((n + 1))
Count1 = 0
For i = 1 To 13

```

```

If Sources(i) = "" Then
Else
Count1 = Count1 + 1
MSFlexGrid1.row = 1
MSFlexGrid1.col = Count1
MSFlexGrid1.Text = Sources(i)
MSFlexGrid1.CellFontBold = True
End If
Next
ProgressBar1.Visible = False
Count1 = Count1 + 1
MSFlexGrid1.row = 1
MSFlexGrid1.col = Count1
MSFlexGrid1.Text = "Mu"
MSFlexGrid1.CellFontBold = True
flexData
End Sub
Public Function normalDistribution(Mean As Single, Cov As Single) As Double
Dim flip As Integer
Dim x1 As Double
Dim x2 As Double
    Randomize
    U1 = Rnd
    U2 = Rnd
    x1 = Mean + ((Cov * Mean) * (Sqr(-2 * (Log(U1) / Log(2.718282)))) * Cos(2 * 3.14 *
U2))
    normalDistribution = x1
End Function
Public Function funLogNormPolVal(Mean As Single, Cov As Single) As Double
Dim MeanY As Single
Dim VarianceY As Single
Dim U1 As Single
Dim U2 As Single
Dim NormValue As Single
Dim Y As Single
PolMean = Mean
POLCOV = Cov
If PolMean = 0 Then
funLogNormPolVal = 0 'POLVAL
Exit Function
End If
MeanY = Log(PolMean) - (1 / 2 * Log(POLCOV ^ 2 + 1))
VarianceY = Log(POLCOV ^ 2 + 1)
U1 = Rnd
U2 = Rnd
NormValue = (-2 * Log(U1)) ^ (1 / 2) * Cos(2 * 3.14159265359 * U2)

```

```

Y = NormValue * Sqr(VarianceY) + MeanY
funLogNormPolVal = Exp(Y) 'POLVAL
End Function

```

```

Public Sub insertConstants() 'entering observed outfall tracer concentrations
Dim Ct1, St, NOV, Ed As Integer
Ct1 = 1
For i = 1 To TotTra
If Form1.Check2(i) Then
insVal(Ct1) = Form5.Text1(i)
Ct1 = Ct1 + 1
End If
Next
NOV = CInt(Form1.Text11.Text)
St = ((NOV + 1) * (NOV + 1)) + 1
For i = 1 To NOV
Form1.a11(St).Text = insVal(i)
St = St + 1
Next
Form1.a11(St).Text = CDBl(1)
End Sub

```

```

Public Sub LogNormalDistribution() 'getting the tracer conc. from library file and put the
randomly generated number according to distribution in the 'matrix cells'
Dim Src1(18) As Single
Dim Tra1(18) As Single
Dim Count1, Count2 As Integer
Dim max1 As Integer
max1 = CInt(Form1.Text11.Text)
ReDim Means(max1, max1)
ReDim Covs(max1, max1)
ReDim Distribution(max1, max1)
Set vbexcel = CreateObject("Excel.application")
Count1 = 1
Count2 = 1
For i = 1 To TotSrc
If Sources(i) = "" Then
Else
Src1(Count1) = i
Count1 = Count1 + 1
End If
Next
For i = 1 To TotTra
If TracerS(i) = "" Then
Else

```



```

Tra1(Count2) = i
Count2 = Count2 + 1
End If
Next
With vbexcel
.Visible = False
.Workbooks.Open FileName:=Form1.Text10.Text
For j = 1 To max1
.Worksheets(Src1(j)).Activate
For i = 1 To max1
Means(i, j) = .Worksheets(Src1(j)).Cells(Tra1(i) + 1, 2)
Covs(i, j) = .Worksheets(Src1(j)).Cells(Tra1(i) + 1, 3)
Distribution(i, j) = .Worksheets(Src1(j)).Cells(Tra1(i) + 1, 4)
Next
Next
Next
.Workbooks.Close
.Quit
End With
Count1 = 1
For k = 1 To max1
For p = 1 To max1
If Distribution(k, p) = "L" Then
Form1.a11(Count1).Text = CStr(funLogNormPolVal(Means(k, p), Covs(k, p)))
ElseIf Distribution(k, p) = "N" Then
Form1.a11(Count1).Text = CStr(normalDistribution(Means(k, p), Covs(k, p)))
Else
Form1.a11(Count1).Text = CStr(normalDistribution(Means(k, p), Covs(k, p)))
End If
Form1.a11(Count1).Enabled = False
Count1 = Count1 + 1
Next
Form1.a11(Count1).Text = CDBl(1)
Form1.a11(Count1).Enabled = False
Count1 = Count1 + 1
Next

For i = 1 To max1
Form1.a11(Count1).Text = 1
Count1 = Count1 + 1
Next
Form1.a11((max1 + 1) * (max1 + 1)).Text = CDBl(0)
insertConstants
Command1.Enabled = True
End Sub

```

```

Public Sub valuesNormalDistribution()
Dim Src1(18) As Single
Dim Tra1(18) As Single
Dim Count1, Count2 As Integer
Dim max1 As Integer
max1 = CInt(Form1.Text11.Text)
ReDim Means(max1, max1)
ReDim Covs(max1, max1)
Count1 = 1
Count2 = 1
For i = 1 To TotSrc
If Sources(i) = "" Then
Else
Src1(Count1) = i
Count1 = Count1 + 1
End If
Next
For i = 1 To TotTra
If TracerS(i) = "" Then
Else
Tra1(Count2) = i
Count2 = Count2 + 1
End If
Next
Workbooks.Close
Set vbexcel = CreateObject("Excel.application")
With vbexcel
.Visible = False
.Workbooks.Open FileName:=Form1.Text10.Text
For j = 1 To max1
.Worksheets(Src1(j)).Activate
For i = 1 To max1
Means(i, j) = .Worksheets(Src1(j)).Cells(Tra1(i) + 1, 2)
Covs(i, j) = .Worksheets(Src1(j)).Cells(Tra1(i) + 1, 3)
Next
Next
Next
.Workbooks.Close
.Quit
End With
Count1 = 1
For k = 1 To max1
For p = 1 To max1
Form1.a11(Count1).Text = CStr(normalDistribution(Means(k, p), Covs(k, p)))
Form1.a11(Count1).Enabled = False
Count1 = Count1 + 1
Next
Next

```

```

    Next
insertConstants
Command1.Enabled = True
End Sub
Public Sub arrayGraph()
Dim g1() As Double
Dim g2() As Double
Dim g3() As Double
Dim g4() As Double
Dim g5() As Double
Dim g6() As Double
Dim g7() As Double
Dim g8() As Double
Dim g9() As Double
Dim g10() As Double
Dim g11() As Double
Dim g12() As Double
Dim g13() As Double
Dim ht As Double
Dim noGraphs(20) As String
ht = 925
k = 1
For i = 1 To TotSrc
If Sources(i) = "" Then
Else
noGraphs(k) = Sources(i)
k = k + 1
End If
Next
Option1(0).Caption = noGraphs(1)
For i = 1 To k - 1
Load Option1(i)
Option1(i).Top = ht
ht = ht + 525
If i = k - 1 Then
Option1(i).Caption = "Mu"
Else
Option1(i).Caption = noGraphs(i + 1)
End If
Option1(i).Visible = True
Next
End Sub

Private Sub Command2_Click()
CommonDialog1.Filter = "Excel File(*.xls)|*.xls|All Files(*.*)|*.*"
CommonDialog1.ShowSave

```

```

Text9.Text = CommonDialog1.FileName
If Text9.Text = "" Then
Command2.SetFocus
Else
Fname = CommonDialog1.FileTitle
Command1.Enabled = True
End If
End Sub

Private Sub Command3_Click()
Workbooks.Close
Unload Form1
Unload Form2
Unload Form5
End
End Sub
Function faIndex(row As Integer, col As Integer) As Long
faIndex = row * MSFlexGrid1.Cols + col
End Function
Private Sub Command4_Click()
Dim i As Integer
Dim j As Integer
Dim k As Integer
Dim l As Integer
CommonDialog3.Filter = "Excel File(*.xls)|*.xls|All Files(*.*)|*.*"
CommonDialog3.ShowSave
Text1.Text = CommonDialog3.FileName
Fname = CommonDialog3.FileTitle
If Text1.Text = "" Then
Command4.SetFocus
Else
Fname = CommonDialog3.FileTitle
Command6.Enabled = True
End If
Workbooks.Close
Set xlApp = New Excel.Application ' Assigning memory to object
Set xlBook = xlApp.Workbooks.Add
Set xlSheet = xlBook.Worksheets.Add
xlSheet.Cells(2, 1).Value = "2.5th %tile"
xlSheet.Cells(3, 1).Value = "97.5th %tile"
xlSheet.Cells(4, 1).Value = "50th %tile"
n = CInt(Form1.Text11.Text)
n = n + 1
For i = 1 To 4
For j = 1 To n
MSFlexGrid1.row = i

```

```

MSFlexGrid1.col = j
xlSheet.Cells(i, j + 1).Value = MSFlexGrid1.Text
Next
Next
xlSheet.SaveAs Text1.Text
xlBook.Close
xlApp.Quit
Set xlApp = Nothing
Workbooks.Close
Set xlBook = Nothing
Workbooks.Close
Set xlSheet = Nothing
Workbooks.Close
End Sub

```

```

Private Sub Command5_Click()
Set vbexcel = CreateObject("Excel.application")
With vbexcel
.Visible = False
.Workbooks.Open FileName:=CommonDialog2.FileName
.Charts("Chart1").PrintOut
.Workbooks.Close
.Quit
End With
End Sub

```

```

Private Sub Command6_Click()
Set vbexcel = CreateObject("Excel.application")
With vbexcel
.Visible = False
.Workbooks.Open FileName:=CommonDialog3.FileName
.Worksheets("Sheet4").PrintOut
.Workbooks.Close
.Quit
End With
End Sub

```

```

Private Sub Form_Load()
Dim ht As Integer
Fname = Form1.CommonDialog1.FileName
Dim n1 As Integer
Dim str1 As String
Set vbexcel = CreateObject("Excel.application")
With vbexcel
.Visible = False
.Workbooks.Open FileName:=Form1.Text10.Text

```

```

n1 = .Worksheets.Count
TotSrc = n1
.Workbooks.Close
.Quit
End With
TotTra = CInt(Form1.Text2.Text)
checkSources
checkTracers
End Sub

Private Sub Option1_Click(Index As Integer)
Dim r1 As Range
Dim rg As String
Dim a(2, 2) As Double
Dim St, Ed As Double
ReDim dataGraph(Dentry - 1, 1) As Double
Dim tempNo As Double
Fname = CommonDialog1.FileName
St = 1
Set vbexcel = CreateObject("Excel.application")
With vbexcel
.Visible = False
.Workbooks.Open FileName:=Text9.Text
.Worksheets(1).Activate
Dentry = CInt(Form1.Text1.Text)
n = CInt(Form1.Text11.Text)
n = n + 1
ProgressBar1.Max = Dentry
ProgressBar1.Visible = True
For i = 0 To Dentry - 1
ProgressBar1.Value = i
dataGraph(i, 1) = (((i + 1) * 100) / Dentry)
dataGraph(i, 0) = .Worksheets(1).Cells(i + 1, (Index + 1))
Next
ProgressBar1.Visible = False
For i = 0 To (Dentry - 2)
For j = i To Dentry - 1
If dataGraph(i, 0) > dataGraph(j, 0) Then
tempNo = dataGraph(j, 0)
dataGraph(j, 0) = dataGraph(i, 0)
dataGraph(i, 0) = tempNo
End If
Next
Next
.Workbooks.Close
.Quit

```

```

End With
Set xlApp = New Excel.Application ' Assigning memory to object
Set xlBook = xlApp.Workbooks.Add
Set xlSheet = xlBook.Worksheets.Add
ProgressBar1.Visible = True
For i = 1 To Dentry
ProgressBar1.Value = i
xlSheet.Cells(i, 1).Value = dataGraph(i - 1, 0)
xlSheet.Cells(i, 2).Value = dataGraph(i - 1, 1)
Next
ProgressBar1.Visible = False
Ed = Dentry
rg = CStr("A" & St & ":" & "B" & Ed)
Set r1 = xlSheet.Range(rg)
r1.Select
Set xlchart = xlApp.Charts.Add()
xlchart.Activate
xlchart.ChartType = xlXYScatterSmoothNoMarkers
xlchart.PlotBy = xlColumns
xlchart.Legend.Clear
xlchart.HasTitle = True
xlchart.ChartTitle.Text = Option1(Index).Caption
xlchart.Axes(xlCategory).MinimumScale = -1
xlchart.Axes(xlCategory).MaximumScale = 2
xlchart.Axes(xlValue).MinimumScale = 0
xlchart.Axes(xlValue).MaximumScale = 100
xlchart.Axes(xlCategory).CrossesAt = -1
xlchart.Axes(xlCategory).HasTitle = True
xlchart.Axes(xlCategory).AxisTitle.Text = "FRACTION OF FLOW"
xlchart.Axes(xlCategory).HasMajorGridlines = True
xlchart.Axes(xlValue).HasTitle = True
xlchart.Axes(xlValue).AxisTitle.Text = "PERCENTILE"
CommonDialog2.Filter = "Excel File(*.xls)|*.xls|All Files(*.*)|*.*"
CommonDialog2.ShowSave
With Picture1
.LinkMode = vbLinkNone
.LinkTopic = "Excel|chart1"
.LinkItem = chart1
.LinkMode = vbLinkAutomatic
End With
Text18.Text = CommonDialog2.FileName
xlSheet.SaveAs Text18.Text
xlBook.Close
xlApp.Quit
Set r1 = Nothing
Set xlApp = Nothing

```

```

Set xlBook = Nothing
Set xlSheet = Nothing
Set xlchart = Nothing
Workbooks.Close
Set vbexcel = CreateObject("Excel.application")
With vbexcel
.Visible = False
.Workbooks.Open FileName:=Text18.Text
a(1, 1) = .Worksheets(1).Cells(1, 1)
.Workbooks.Close
.Quit
End With
Set vbexcel = Nothing
End Sub

```

```

Public Sub flexData()
Dim NPer, FPer, TPer As Integer
ReDim dataSheet(Dentry, 16) As Double
Dim tempNo As Double
Dentry = CInt(Form1.Text1.Text)
n = CInt(Form1.Text11.Text)
n = n + 1
MSFlexGrid1.AllowUserResizing = flexResizeBoth
MSFlexGrid1.AddItem ("2.5th %tile")
MSFlexGrid1.CellFontBold = True
MSFlexGrid1.Font = Bold
MSFlexGrid1.AddItem ("97.5th %tile")
MSFlexGrid1.CellFontBold = True
MSFlexGrid1.AddItem ("50th %tile")
MSFlexGrid1.CellFontBold = True
Set vbexcel = CreateObject("Excel.application")
With vbexcel
.Visible = False
.Workbooks.Open FileName:=Text9.Text
For j = 1 To n
For i = 1 To Dentry
dataSheet(i, j) = .Worksheets(1).Cells(i, j)
Next
Next
.Workbooks.Close
.Quit
End With
For k = 1 To n 'Sorting
For i = 1 To (Dentry - 1)
For j = i To Dentry
If dataSheet(i, k) > dataSheet(j, k) Then

```



```

tempNo = dataSheet(j, k)
dataSheet(j, k) = dataSheet(i, k)
dataSheet(i, k) = tempNo
End If
Next
Next
Next

tmp = (0.025 * Dentry) - CInt(0.025 * Dentry)
If tmp > 0 Then
tmp = tmp
Else
tmp = (1 + tmp)
End If
TPer = (0.025 * Dentry) - tmp
MSFlexGrid1.CellFontBold = True

tmp = (0.975 * Dentry) - CInt(0.975 * Dentry)
If tmp > 0 Then
tmp = tmp
Else
tmp = (1 + tmp)
End If
NPer = (0.975 * Dentry) - tmp + 1
MSFlexGrid1.CellFontBold = True

tmp = (0.5 * Dentry) - CInt(0.5 * Dentry)
If tmp > 0 Then
tmp = tmp
Else
tmp = 1 + tmp
End If
FPer = (0.5 * Dentry) - tmp
MSFlexGrid1.CellFontBold = True

ProgressBar1.Max = n
ProgressBar1.Min = 0
ProgressBar1.Visible = True

For i = 1 To n
ProgressBar1.Value = i
MSFlexGrid1.row = 2
MSFlexGrid1.col = i
MSFlexGrid1.Text = Round(dataSheet(TPer, i), 2)
MSFlexGrid1.CellFontBold = True
Next

```

```

For i = 1 To n
MSFlexGrid1.ColWidth(i) = 1200
Next
For i = 1 To n
MSFlexGrid1.row = 3
MSFlexGrid1.col = i
MSFlexGrid1.Text = Round(dataSheet(NPer, i), 2)
MSFlexGrid1.CellFontBold = True
Next

Sum = 0
For i = 1 To n
MSFlexGrid1.row = 4
MSFlexGrid1.col = i
If (Dentry Mod 2) = 0 Then
MSFlexGrid1.Text = (Round(dataSheet(FPer, i), 2) + Round(dataSheet(FPer + 1, i), 2)) /
2
Else
MSFlexGrid1.Text = Round(dataSheet(FPer, i), 2)
End If
MSFlexGrid1.CellFontBold = True
Sum = Sum + dataSheet(FPer, i)
Next
ProgressBar1.Visible = False
End Sub

Public Sub checkTracers()
For i = 1 To TotTra
If Form1.Check2(i) Then

TracerS(i) = Form1.Check2(i).Caption
Else

TracerS(i) = ""
End If
Next
End Sub

Public Sub checkSources()
For i = 1 To TotSrc
If Form1.Check1(i) Then
Sources(i) = Form1.Check1(i).Caption
Else
Sources(i) = ""
End If

```

```
Next  
Form2.Option1(0).Caption = Form1.Check1(1).Caption  
End Sub
```

```
Public Sub UnloadAll()  
Unload Form1  
Unload Form5  
Unload Form2  
End Sub
```

```
Private Sub Text2_Change(Index As Integer)  
  
End Sub
```

APPENDIX B

Mann-Whitney Test Results

Table B.1 Mann-Whitney test p-values for pH

	Tap Water	Spring Water	Irrigation	Laundry	Carwash	Industrial	Industrial (Cintas)	Sewage (Dry weather)	Sewage (Wet weather)
Tap Water	1	0.0000	0.0003	0.9309	0.2362	0.0001	0.0112	0.0009	0.0009
Spring Water		1	0.0000	0.0004	0.0001	0.0549	0.0115	0.044	0.0027
Irrigation			1	0.2361	0.5443	0.0014	0.0115	0.0031	0.0065
Laundry				1	0.5635	0.0085	0.0171	0.0215	0.0276
Carwash					1	0.0050	0.0115	0.0148	0.0604
Industrial						1.0000	0.0162	0.6364	0.1738
Industrial (Cintas)							1.0000	0.0282	0.0275
Sewage (Dry weather)								1.0000	0.3367
Sewage (Wet weather)									1

Note: p-values < 0.05 indicate significant difference

Table B.2 Mann-Whitney test p-values for Conductivity

	Tap Water	Spring Water	Irrigation	Laundry	Carwash	Industrial	Industrial (Cintas)	Sewage (Dry weather)	Sewage (Wet weather)
Tap Water	1	0.5632	0.0001	0.0001	0.0007	0.2135	0.4269	0.0009	0.0009
Spring Water		1	0.0118	0.0002	0.0035	0.2135	0.4269	0.0009	0.0009
Irrigation			1	0.0101	0.0594	0.3366	0.4252	0.0009	0.0016
Laundry				1	0.0998	0.3196	0.6134	0.0057	0.0274
Carwash					1	0.8869	0.4269	0.0012	0.0023
Industrial						1.0000	0.3083	0.0080	0.0249
Industrial (Cintas)							1.0000	0.5186	1.0000
Sewage (Dry weather)								1.0000	0.1727
Sewage (Wet weather)									1

Note: p-values < 0.05 indicate significant difference

Table B.3 Mann-Whitney test p-values for Turbidity

	Tap Water	Spring Water	Irrigation	Laundry	Carwash	Industrial	Industrial (Cintas)	Sewage (Dry weather)	Sewage (Wet weather)
Tap Water	1	0.0043	0.0004	0.0004	0.0006	0.0009	0.021	0.0026	0.0026
Spring Water		1	0.2366	0.0001	0.002	0.0062	0.0115	0.0017	0.0009
Irrigation			1	0.0029	0.0404	0.0597	0.0172	0.01	0.0057
Laundry				1	0.5067	0.5223	0.0115	0.9253	0.4824
Carwash					1	0.9151	0.0115	0.8883	0.2814
Industrial						1.0000	0.0162	0.7683	0.1753
Industrial (Cintas)							1.0000	0.0282	0.0282
Sewage (Dry weather)								1.0000	0.3785
Wet									1

Note: p-values < 0.05 indicate significant difference

Table B.4 Mann-Whitney test p-values for Color

	Tap Water	Spring Water	Irrigation	Laundry	Carwash	Industrial	Sewage (Dry weather)	Sewage (Wet weather)
Tap Water	1	>0.1	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Spring Water		1	0.0007	0.0001	0.0001	0.0003	0.0002	0.0002
Irrigation			1	0.8375	0.0016	0.8302	0.0008	0.0008
Laundry				1	0.0484	0.5292	0.0124	0.0208
Carwash					1	0.1485	0.2202	0.6805
Industrial						1.0000	0.0404	0.0711
Sewage (Dry weather)							1.0000	0.4620
Sewage (Wet weather)								1

Note: p-values < 0.05 indicate significant difference

Table B.5 Mann-Whitney test p-values for Fluoride

	Tap Water	Spring Water	Irrigation	Laundry	Carwash	Industrial	Sewage (Dry weather)	Sewage (Wet weather)
Tap Water	1	0.0001	0.0002	1	0.1694	0.0007	0.0013	0.0011
Spring Water		1	0.0001	0.0003	0.009	0.9058	0.0008	0.2388
Irrigation			1	0.0261	0.8174	0.1317	0.7071	0.0012
Laundry				1	0.5095	0.0061	0.0490	0.0057
Carwash					1	0.0748	0.5505	0.1286
Industrial						1.0000	0.2698	0.4752
Sewage (Dry weather)							1.0000	0.0050
Sewage (Wet weather)								1

Note: p-values < 0.05 indicate significant difference

Table B.6 Mann-Whitney test p-values for Hardness

	Tap Water	Spring Water	Irrigation	Laundry	Carwash	Industrial	Industrial (Cintas)	Sewage (Dry weather)	Sewage (Wet weather)
Tap Water	1	0.0177	0.6856	0.5629	0.0024	0.0008	0.0427	0.8143	0.8143
Spring Water		1	0.0004	0.0241	0.0006	0.0187	0.4256	0.0662	0.0048
Irrigation			1	0.2023	0.0013	0.0001	0.0139	0.5414	0.1432
Laundry				1	0.0008	0.9251	0.0966	0.9250	0.0015
Carwash					1	0.0015	0.0360	0.0113	0.0057
Industrial						1.0000	0.1924	0.0031	0.0018
Industrial (Cintas)							1.0000	0.0518	0.0275
Sewage (Dry weather)								1.0000	0.8085
Sewage (Wet weather)									1

Note: p-values < 0.05 indicate significant difference

Table B.7 Mann-Whitney test p-values for Detergent

	Tap Water	Spring Water	Irrigation	Laundry	Carwash	Industrial	Industrial (CINTAS)	Sewage (Dry weather)	Sewage (Wet weather)
Tap Water	1	>0.1	>0.1	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Spring Water		1	>0.1	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Irrigation			1	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Laundry				1	0.0000	0.0001	0.0114	0.0008	0.0008
Carwash					1	0.0002	0.0122	0.0017	0.0007
Industrial						1.0000	1.0000	0.0923	0.5119
Industrial (CINTAS)							1.0000	0.1756	0.5097
Sewage (Dry weather)								1.0000	0.0103
Sewage (Wet weather)									1

Note: p-values < 0.05 indicate significant difference

Table B.8 Mann-Whitney test p-values for Fluorescence

	Tap Water	Spring Water	Irrigation	Laundry	Carwash	Industrial	Industrial (CINTAS)	Sewage (Dry weather)	Sewage (Wet weather)
Tap Water	1	0.0572	0.0004	0.0005	0.0005	0.001	0.0227	0.0034	0.0034
Spring Water		1	0.0001	0	0.0001	0.0001	0.0172	0.0009	0.0009
Irrigation			1	0	0.0689	0.0001	0.6131	0.0009	0.0009
Laundry				1	0	0.0012	0.0115	0.0009	0.0009
Carwash					1	0.0016	0.8286	0.0017	0.0009
Industrial						1.0000	0.0961	0.5959	0.7683
Industrial (CINTAS)							1.0000	0.5186	0.2453
Sewage (Dry weather)								1.0000	0.2298
Sewage (Wet weather)									1

Note: p-values < 0.05 indicate significant difference

Table B.9 Mann-Whitney test p-values for Potassium

	Tap Water	Spring Water	Irrigation	Laundry	Carwash	Industrial	Industrial (CINTAS)	Sewage (Dry weather)	Sewage (Wet weather)
Tap Water	1	0.0005	0.0001	0.0001	0.0002	0.0001	0.0056	0.0005	0.0005
Spring Water		1	0.0206	0.1569	1	0.0001	0.0098	0.0007	0.0007
Irrigation			1	0.9302	0.0599	0.0004	0.0112	0.0019	0.001
Laundry				1	0.2107	0.0004	0.0107	0.0466	0.0655
Carwash					1	0.0002	0.0094	0.0012	0.0009
Industrial						1.0000	0.1384	0.0154	0.0154
Industrial (CINTAS)							1.0000	0.0269	0.0269
Sewage (Dry weather)								1.0000	0.8698
Sewage (Wet weather)									1

Note: p-values < 0.05 indicate significant difference

Table B.10 Mann-Whitney test p-values for Ammonia

	Tap Water	Spring Water	Irrigation	Laundry	Carwash	Industrial	Industrial (CINTAS)	Sewage (Dry weather)	Sewage (Wet weather)
Tap Water	1	0.3588	0.0022	0.0023	0.0228	0.0019	0.0357	0.0050	0.0050
Spring Water		1	0.0001	0	0.0008	0.0001	0.0105	0.0008	0.0008
Irrigation			1	0.0259	0.2392	0.0514	0.0114	0.001	0.001
Laundry				1	0.0035	0.5222	0.1283	0.0009	0.0009
Carwash					1	0.0085	0.0115	0.0009	0.0009
Industrial						1.0000	0.6433	0.0027	0.0018
Industrial (CINTAS)							1.0000	0.0282	0.0275
Sewage (Dry weather)								1.0000	0.5745
Sewage (Wet weather)									1

Note: p-values < 0.05 indicate significant difference

Table B.11 Mann-Whitney test p-values for Ammonia-Potassium ratio

	Tap Water	Spring Water	Irrigation	Laundry	Carwash	Industrial	Industrial (CINTAS)	Sewage (Dry weather)	Sewage (Wet weather)
Tap Water	1	0.136	0.0158	0.0052	0.0443	0.252	0.0955	0.0056	0.0056
Spring Water		1	0.001	0.0001	0.0005	0.0251	0.0362	0.0009	0.0009
Irrigation			1	0.0363	0.8534	0.5433	0.6404	0.003	0.0011
Laundry				1	0.0566	0.0302	0.0969	0.0244	0.01
Carwash					1	0.4993	0.5153	0.0023	0.0009
Industrial						1.0000	1.0000	0.0039	0.0018
Industrial (CINTAS)							1.0000	0.0282	0.0282
Sewage (Dry weather)								1.0000	0.5752
Sewage (Wet weather)									1

Note: p-values < 0.05 indicate significant difference

Table B.12 Mann-Whitney test p-values for Boron

	Tap Water	Spring Water	Irrigation	Laundry	Carwash	Sewage (Wet weather)
Tap Water	1	0.7936	0.0188	0.0007	0.0049	0.0026
Spring Water		1	0.0091	0.0006	0.0035	0.0025
Irrigation			1	0.0001	0.0061	0.0009
Laundry				1	0.0956	0.2544
Carwash					1	0.0442
Sewage (Wet weather)						1

Note: p-values < 0.05 indicate significant difference

Table B.13 Mann-Whitney test p-values for E-coli

	Tap Water	Spring Water	Irrigation	Laundry	Carwash	Industrial	Sewage (Wet weather)
Tap Water	1	<0.001	<0.001	<0.001	<0.001	0.025	<0.001
Spring Water		1	0.0008	0.276	0.0152	0.4816	0.0012
Irrigation			1	0.0009	0.0152	0.0695	0.0007
Laundry				1	0.028	0.1689	0.0008
Carwash					1	0.6718	0.0009
Industrial						1.0000	0.0046
Sewage (Wet weather)							1

Note: p-values < 0.05 indicate significant difference

Table B.14 Mann-Whitney test p-values for Enterococci

	Tap Water	Spring Water	Irrigation	Carwash	Industrial	Industrial (Cintas)	Sewage (Wet weather)
Tap Water	1	<0.001	<0.001	<0.001	<0.001	0.025	<0.001
Spring Water		1	0.0007	1	0.5949	0.621	0.0013
Irrigation			1	0.0026	0.0266	0.0335	0.0005
Carwash				1	1.0000	0.9253	0.0008
Industrial					1.0000	0.7311	0.0034
Industrial (Cintas)						1.0000	0.0635
Sewage (Wet weather)							1

Note: p-values < 0.05 indicate significant difference

APPENDIX C

Analysis Results for Outfall Samples from Cribbs Mill Creek watershed, Tuscaloosa, Alabama

Table C Analysis Results for Outfall Samples from Cribbs Mill Creek watershed, Tuscaloosa, Alabama

OUTFALL #	Date of collection	pH	SPECIFIC CONDUCTIVITY Micro S/cm	TEMPERATURE F	COLOR APHA Platinum Cobalt Units	FLOURIDE mg/L	HARDNESS mg/L CaCO3 in 100ml	DETERGENTS ppm	FLORESCENCE ppm	Boron mg/l	POTASSIUM ppm	TURBIDITY NTU	AMMONIA mg/L	Bacteria		
														Total Coliform(MPN)	E-Coli(MPN)	Enterrococi(MPN)
1	4/17/2002	6.72	67	N/A	5	0.09	27.4	0	9.19		1	0.797	0			
	2/18/2003	6.36	54	58	0	0.2	52	0	11.08	0.01	3	3.26	0.01	866.4	206.3	1
	3/31/2003	6.9	97		5	0.21	19	0	9.24	0.06	1	2.41	-0.01	>2419.2	>2419.2	8
3	4/17/2002	6.36	50	N/A	5	0.15	18.8	0	3.41		2	3.12	0.01			
	5/31/2002	6.48	68	56	0	0.11	12.6	0	16.51		0	9	0.03			
	10/9/2002	6.3	64	65	95	0.08	21.45	1.5	4.46	0.59	1	3.53	0.03	>2419.2	>2419.2	6
	2/18/2003	7.5	77	58	0	0	52	0	21.76	0.35	5	5.3	0	275.5	143.9	6.2
	3/31/2003	7.1	230		10	0.09	17	0	10.46	0.08	4	15.6	0.01	1413.6	325.5	48.3
3a	5/31/2002	7.02	134	58	0	0.02	18.6	0	7.37		0	5.66	0.02			
	10/3/2002	6.65	160	65	0	0.57	32.75	0	9.61	0.03	2	2.62	0.04	>2419.2	130.1	3
	2/18/2003	7.34	137	58	0	0.57	76	0	15.69	0.11	4	2.25	0.03	>2419.2	166.4	28.5
	3/31/2003	7.79	138		10	0.52	49	0	14.42	0.08	2	7.39	0.04	>2419.2	29.2	36.3
3b	5/31/2002	6.69	117	58	5	0.14	15.4	0	14.27		1	4.56	0			
	10/3/2002	7.18	105	65	0	0.01	26	0	10.18	0.01	1	3.3	0.06	>2419.2	5.2	<1
	2/18/2003	7.25	111	56	0	0.11	52	0	22.97	0.14	3	5.25	0.02	139.6	18.5	<1
	3/31/2003	7.29	128		5	-0.22	46	0	12.56	0.04	1	5.34	0.01	980.4	111.9	98.8
3c	5/31/2002	5.62	51	58	6	0.07	22.8	0	0.98		2	8.86	0			
	10/3/2002	6.03	48	65	0	0.02	6.25	0	0.68	0.02	0	0.35	0.01	<1	<1	<1
	2/18/2003	6.55	58	56	0	0.23	52	0	2.63	0.06	2	0.52	0	<1	<1	<1
	3/31/2003	6.42	56		5	0.08	20	0	1.72	0.04	1	2.24	-0.01	<1	<1	<1

Table C Continued

OUTFALL #	Date of collection	pH	SPECIFIC CONDUCTIVITY Micro S/cm	TEMPERATURE F	COLOR APHA Platinum Cobalt Units	FLOURIDE mg/L	HARDNESS mg/L CaCO3 in 100ml	DETERGENTS ppm	FLORESCENCE ppm	Boron mg/l	POTASSIUM ppm	TURBIDITY NTU	AMMONIA mg/L	Bacteria		
														Total Coliform(MPN)	E-Coli(MPN)	Enterrococci(MPN)
3d	6/4/2002	6.23	54	56	10	0.11	12	0	7.92		1	3.36	0			
	10/9/2002	6.74	54	65	0	0	9.65	0	3.65	0.06	2	1.04	0.01	>2419.2	272.3	142.3
	2/19/2003	6.29	63	56	0	0.19	44	0	10.15	0.03	2	2.34	0.01	344.8	160.7	39.1
3e	6/4/2002	6.31	37	56	9	0.07	8	0	6.03		0	1.22	0			
	2/19/2003	6.21	49	56	0	0.15	48	0	13.51	0.15	1	0.516	0	148.3	3.1	<1
	4/1/2003	7	53		15	0.05	12	0	9.22	0.04	3	13.4	0.19	57.3	1	<1
4	4/22/2002	6.90	45	N/A	0	0.09	14	0	1.95		0	0.507	0			
	6/4/2002	6.05	44	58	4	0.1	12	0	1.35		0	10.3	0			
	10/9/2002	7.09	50	65	0	0	12.25	0	3.73	0	1	0.5	0	>2419.2	12.1	17.9
	2/19/2003	7.16	80	58	0	0.09	48	0	5.45	0.04	1	0.56	0	290.9	3	1
	4/1/2003	7.29	65		5	0.03	20	0	4.52	0.08	1	0.427	0.15	387.3	1	2
5	4/22/2002	7.10	140	N/A	6	0.07	62.8	0	4.89		2	1.63	0.06			
	6/4/2002	7.26	190	56	2	0.09	80.8	0	6.18		1	44.5	0			
	2/19/2003	6.98	143	60	0	0.13	60	0	15.01	0.05	2	3.47	0	344.8	12.1	10.8
	4/1/2003	7.39	139		10	0.01	51	0	7.88	0.06	1	7.19	0.03	1553.1	3.1	4.1
9	4/22/2002	7.20	123	N/A	4	0.85	38.4	0	4.62		2	1.73	0			
10a	6/6/2002	6.57	440	60	0	0.97	18.2	0.25	82.82		2	2.36	8			
12	4/25/2002	6.99	127	N/A	6	1	40	0	0.07		2	1.02	0.01			
	6/6/2002	6.83	128	60	0	0.94	12.4	0	0.99		4	10.3	0.01			
23	4/25/2002	6.53	112	N/A	5	0.08	1.7	0	13.68		0	9.82	17			
	6/10/2002	5.79	85	60	5	0.14	33.6	0	9.29		0	23.3	14			

Table C Continued

OUTFALL #	Date of collection	pH	SPECIFIC CONDUCTIVITY Micro S/cm	TEMPERATURE F	COLOR APHA Platinum Cobalt Units	FLOURIDE mg/L	HARDNESS mg/L CaCO3 in 100ml	DETERGENTS ppm	FLORESCENCE ppm	Boron mg/l	POTASSIUM ppm	TURBIDITY NTU	AMMONIA mg/L	Bacteria		
														Total Coliform(MPN)	E-Coli(MPN)	Enterococci(MPN)
24	4/25/2002	7.38	91	N/A	5	0.04	0	0	25.19		0	3.48	10.5			
	6/10/2002	6.83	76	58	5	0.05	22.4	0	7.65		0	20.5	9			
26a	6/11/2002	6.57	720	56	9	0.37	38.4	0.25	6.3		1	25.33	0.08			
	2/19/2003	7.69	83	60	42	0.15	48	0	51.54	0.1	2	7.4	0.01	1299.7	387.3	23.5
27	4/26/2002	6.35	92	N/A	0	0.18	27.2	0	10.37		1	3.39	0.18			
	6/11/2002	6.15	92	60	12	0.34	2.4	0	15.97		1	2.36	0.31			
	10/14/2002	7.28	126	65	0	0.66	22	0.125	35.57	0.04	2	4.65	0.1	>2419.2	1203.3	100.8
	2/24/2003	7.02	90	60	0	0.18	56	0	34.47	LD	1	10.1	0.02	435.2	63.1	5.2
	4/17/2003	7.2	100		20	0.23	32	0	22.56	0.12	1	6.36	0.06	>2419.2	410.6	3
27a	10/14/2002	5.86	36	65	0	0.16	9.5	0	59.13	0.16	2	24.1	0.02	>2419.2	172.3	11.6
	4/17/2003	6.12	101		25	-0.02	15	0	32.24	0.19	1	51.1	0.01	>2419.2	547.5	21.8
28	2/24/2003	7.25	67	56	10	0.16	48	0	37.71	LD	2	8.36	0	547.5	224.7	7.3
29a	10/14/2002	5.76	52	65	20	0.16	8.5	0	34.56	0.17	1	27.6	0.1	>2419.2	2419.2	116
	3/4/2003	6.08	67	56	20	0.04	28	0	40.22	0.2	1	13.8	0.04	140.1	12.2	<1
31	4/26/2002	6.53	137	N/A	5	0.8	43.2	0.25	16.53		2	12.2	0.67			
	6/17/2002	6.31	133	60	8	0.3	0	0	34.38		2	1.23	0.27			
	10/14/2002	6.56	151	65	0	0.14	31.5	0.125	59.81	0.2	2	29	0.14	>2419.2	125	10.7
	3/4/2003	6.64	150	58	15	0.61	54	0	76.45	0.09	1	10.5	0.04	488.4	68.3	<1
	4/17/2003	6.11	70		30	0.72	20	0.125	57.85	0.13	1	22.1	0.02	770.1	33.6	9.2
31a	4/17/2003	6.9	230		210	-0.09	97	0	12.24	1.04	3	750	0.14	>2419.2	60.5	33.2

Table C Continued

OUTFALL #	Date of collection	pH	SPECIFIC CONDUCTIVITY Micro S/cm	TEMPERATURE F	COLOR APHA Platinum Cobalt Units	FLOURIDE mg/L	HARDNESS mg/L CaCO3 in 100ml	DETERGENTS ppm	FLORESCENCE ppm	Boron mg/l	POTASSIUM ppm	TURBIDITY NTU	AMMONIA mg/L	Bacteria		
														Total Coliform(MPN)	E-Coli(MPN)	Enterrococci(MPN)
33	4/26/2002	5.98	56	N/A	9	0.09	16.8	0	8.9		2	11.8	0.09			
	6/17/2002	6.39	60	60	10	0.37	20.2	0	68.35		0	9.8	0.08	1		
	3/4/2003	5.81	66	56	10	0.09	25	0	34.57	0.05	2	18.9	0.02	140.1	3	2
	4/17/2003	9.46	131		5	0.17	21	0	18.46	0.2	2	2.65	0.02	>2419.2	5.2	21.3
36	4/26/2002	7.19	450	N/A	100	0.09	243.2	0.15	57.42		4	133	0.26	1		
	6/19/2002	7.09	640	56	100	0.16	212.6	0.25	32.83		0	122.6	0.1			
	10/17/2002	7.45	410	65	0	0.13	102.25	0	5.45	0.06	4	25	0	>2419.2	61.3	3
	3/5/2003	7.45	430	58	10	0.08	185	0	49.92	0.11	2	1.08	0	>2419.2	1	3.1
	4/17/2003	7.59	430		70	0.14	230	0.125	34.42	0.15	2	58.6	0.03	>2419.2	22.8	25.3
37a	6/19/2002	7.43	260	56	100	0.1	21.8	0	7.37		0	100.23	0.02			
	10/17/2002	7.90	360	65	0	0.21	72.25	0	3.36	0.06	3	2.47	0.09	>2419.2	24.3	2
	3/5/2003	7.63	320	60	10	0.12	129	0	13.46	0.11	2	9.72	0.15	76.6	1	12
	4/17/2003	7.79	370		5	0.16	128	0	15.46	0.09	1	3.29	0.12	290.9	1	4.1
38	4/29/2002	5.99	59	N/A	20	0.11	24.8	0	3.79		2	5.32	0.01			
	6/24/2002	6.31	70	56	15	0.06	18.6	0	13.4		1	5.44	0.08			
	10/17/2002	6.74	122	65	0	0.18	26.25	0	24.55	0.15	2	9.86	0.06	>2419.2	866.4	>2419.2
39	4/29/2002	6.63	220	N/A	19	0.16	109.2	0	11.66		2	10.8	0.08			
	6/24/2002	6.66	200	58	20	0.04	100.2	0	4.42		4	10.3	0			
	10/17/2002	7.28	230	65	0	0.24	51	0	12.25	0.01	2	2.24	0.01	>2419.2	178.9	112.4
	3/5/2003	7.36	260	60	5	0.09	120	0	27.24	0.11	2	0.413	0.01	178.9	<1	1
	4/17/2003	7.39	250		5	0.13	120	0	34.46	0.02	2	0.409	0	>2419.2	38.6	12

Table C Continued

OUTFALL #	Date of collection	pH	SPECIFIC CONDUCTIVITY Micro S/cm	TEMPERATURE F	COLOR APHA Platinum Cobalt Units	FLOURIDE mg/L	HARDNESS mg/L CaCO3 in 100ml	DETERGENTS ppm	FLORESCENCE ppm	Boron mg/l	POTASSIUM ppm	TURBIDITY NTU	AMMONIA mg/L	Bacteria		
														Total Coliform(MPN)	E-Coli(MPN)	Enterrococci(MPN)
45	5/8/2002	6.44	134	N/A	15	0.34	51.2	12.5	8.96		2	42.2	0.01			
	6/24/2002	7.34	166	60	15	0.19	44.8	10	6.86		2	40	0.02			
	10/18/2002	8.16	270	65	20	2.17	44.5	0	13.65	0.29	2	29	0.33	>2419.2	37.4	3.1
	3/5/2003	6.99	165	60	15	0.41	65	3	35.44	0.24	2	7.04	0.01	>2419.2	74.4	14.6
	7	153			10	0.09	51	2.5	42.32	0.04	2	6.11	-0.02	980.4	8.6	<1
49	5/8/2002	7.18	123	N/A	100	0.35	25.6	0.25	55.55		1	29.3	5	1		
	6/24/2002	7.08	36	60	100	0.48	20.4	0	14.02		2	33.6	0.35			
	4/18/2003	7.89	113		15	0.13	28	0.25	35.06	0.15	0	6.83	6	325.5	<1	<1
53	5/8/2002	6.07	74	N/A	20	0.01	23.6	0	2.93		2	15	0.35			
	6/24/2002	6.14	72	58	20	0.1	22.4	0	2.41		1	12.4	0.17			
	10/18/2002	6.92	94	65	0	0.22	16.25	15	95.65	0.13	2	5.03	0.11	>2419.2	16.6	18.7
	3/5/2003	6.63	78	58	5	0.1	39	0	9.44	0.15	2	0.5	0.1	488.4	<1	<1
	4/18/2003	6.7	82		10	-0.37	25	0	12.46	0.11	1	4.19	0.07	1413.6	1	<1
55	5/8/2002	5.99	101	N/A	46	0.04	40.8	0	11.11		3	34.5	0.08			
	6/24/2002	6.48	112	58	44	0.07	46.6	0.25	28.42		0	34.6	0.06			
	10/18/2002	7.19	98	65	20	0.17	41	0	4.45	0.07	2	19.3	0.27	>2419.2	2419.9	727
	3/5/2003	6.63	128	56	15	0.1	41	0	54.21	0.08	1	9.76	0.43	>2419.3	1	12.2
	4/18/2003	6.8	105		260	0.95	38	0	18.76	0.85	1	3187	0.1	>2419.2	307.6	10.5

Table C Continued

OUTFALL #	Date of collection	pH	SPECIFIC CONDUCTIVITY Micro S/cm	TEMPERATURE F	COLOR APHA Platinum Cobalt Units	FLOURIDE mg/L	HARDNESS mg/L CaCO3 in 100ml	DETERGENTS ppm	FLORESCENCE ppm	Boron mg/l	POTASSIUM ppm	TURBIDITY NTU	AMMONIA mg/L	Bacteria		
														Total Coliform(MPN)	E-Coli(MPN)	Enterococci(MPN)
61	10/18/2002	7.99	193	65	0	0.86	29.5	0	3.36	0.07	2	19	0.1	>2419.2	124.6	228.2
65	10/18/2002	7.59	181	65	0	0.95	40	0	9.96	0.15	1	4.23	0.01	>2419.2	307.6	172.3
66	5/10/2002	7.1	390	N/A	0	0.14	187.6	1	5.3		2	2.86	-0.2			
73	5/10/2002	7.01	71	N/A	30	0.18	26.4	0.25	15.16		1	21.7	0.11			
	7/2/2002	6.05	72	58	30	0.13	29.8	0	21.37		0	20.3	0.09			
Creek sample I	10/14/2002	7.81	174	65	10	0.5	6	0	18.86	0.17	2	4.91	0.04	>2419.2	410.6	4.1
Creek Sample II	10/18/2002	7.89	168	65	10	0.12	6.75	0	24.42	0.15	2	2.9	0.07	>2419.2	686.7	517.2
Pond Entrance I	10/9/2002	7.46	145	65	0	0.52	3.5	0.125	32.08	0.13	2	1.49	0.02	>2419.2	579.4	113.3
	2/19/2003	6.99	65	56	0	0.06	48	0	17.26	0.12	1	3.91	0.01	2	<1	<1
		7.1	100		30	0.49	33	0	18.42	0.16	2	35.3	0.01	>2419.2	261.3	2
Pond Entrance II	10/14/2002	7.28	111	65	0	0.7	3	0	18.59	0.02	2	3.14	0.01	29.2	2	3
		7.69	137		35	0.14	39	0	12.76	0.1	2	0.9	0	2419.2	240	3.1
Pond Outlet	10/14/2002	7.19	115	65	0	0.47	5	0	37.48	0.05	2	1.6	0.14	1986.3	47.5	<1
	2/19/2003	7.34	84	56	30	0.07	48	0	76.44	0.12	2	22	0.03	>2419.2	275.5	4.1
		7.4	127		25	0.11	43	0	32.24	0.11	1	4.73	0.06	2419.2	21.8	<1

APPENDIX D

**Analysis Results by all methods for Outfall Samples from Cribbs Mill Creek
watershed, Tuscaloosa, Alabama**

Table D Analysis Results by all methods for Outfall Samples from Cribbs Mill Creek watershed, Tuscaloosa, Alabama

OUTFALL #	QUANTIFICATION BY MODEL						μ	MOST LIKELY SOURCE by Model	Problem Indicated by Physical Observations	Detergents contamination Yes if ≥ 0.25 mg/L	Flow Chart method, Most Likely Source
	TAP WATER	SPRING WATER	CAR WASH WASTEWATER	LAUNDRY WASTEWATER	SEWAGE WASTEWATER	IRRIGATION WATER					
1	0.86	0.07	0.01	0	0.02	0.04	-0.79	Tap Water	NO	NO	NATURAL WATER SOURCE
	0.21	0.67	0.01	0	0	0.14	-0.14	Spring Water	NO	NO	NATURAL WATER SOURCE
	0.37	0.86	-0.04	0.01	0.01	-0.21	-0.07	Spring Water	NO		NATURAL WATER SOURCE
3	0.52	0.45	0.02	0	0.01	0.01	-0.43	Tap Water	NO	NO	NATURAL WATER SOURCE
	1.19	-0.24	-0.02	0.01	0.03	0.02	-1.01	Tap Water	NO	NO	NATURAL WATER SOURCE
	-0.24	1.78	-0.06	0.02	0	-0.47	0.49	Spring Water	YES (color, turbidity)	YES	WASHWATER SOURCE
	-0.5	1.215	0	0	-0.02	0.32	0.21	Spring Water	YES (color)	NO	WASHWATER SOURCE
	-0.07	0.83	0.02	-0.01	-0.01	0.25	-0.07	Spring Water	YES (color)		NATURAL WATER SOURCE
3a	1.11	-0.1	0	0	0.04	-0.07	-1	Tap Water	NO	NO	NATURAL WATER SOURCE
	0.65	0.27	0	0	0	0.08	-0.11	Tap Water	NO	NO	NATURAL WATER SOURCE
	0.35	0.22	0.03	-0.01	-0.01	0.41	-0.05	Tap Water	NO	NO	NATURAL WATER SOURCE
	0.56	0.4	-0.02	0	0	0.07	-0.06	Tap Water	NO		NATURAL WATER SOURCE
3b	0.895	-0.02	0	0	0.02	0.09	-0.79	Tap Water	NO	NO	NATURAL WATER SOURCE
	0.24	1.05	-0.05	0.01	0.01	-0.24	-0.11	Spring Water	YES (sediment)	NO	NATURAL WATER SOURCE
	-0.01	0.935	-0.03	0.01	0	0.12	0.01	Spring Water	YES (sediment)	NO	NATURAL WATER SOURCE
	0.2	1.13	-0.06	0.01	0.01	-0.24	-0.08	Spring Water	YES (sediment)		NATURAL WATER SOURCE
3c	0.5	0.49	0.02	0	0.01	-0.01	-0.48	Tap Water	NO	NO	NATURAL WATER SOURCE
	0.33	1.13	-0.05	0.01	0.02	-0.46	-0.1	Spring Water	YES (sediment)	NO	NATURAL WATER SOURCE
	0.3	0.76	0.01	0	0	-0.04	-0.08	Spring Water	YES (sediment)	NO	NATURAL WATER SOURCE
	0.26	1.01	-0.03	0.01	0.01	-0.25	-0.08	Spring Water	YES (sediment)		NATURAL WATER SOURCE

Table D Continued

OUTFALL #	QUANTIFICATION BY MODEL							μ	MOST LIKELY SOURCE by Model	Problem Indicated by Physical Observations	Detergents contamination Yes if ≥ 0.25 mg/L	Flow Chart method, Most Likely Source
	TAP WATER	SPRING WATER	CAR WASH WASTEWATER	LAUNDRY WASTEWATER	SEWAGE WASTEWATER	IRRIGATION WATER	Mass Fraction values obtained by model					
3d	0.935	-0.07	0.03	0	0.03	0.08	-0.86	Tap Water	NO	NO	NATURAL WATER SOURCE	
	0.07	1.06	0	0	0	-0.08	-0.07	Spring Water	NO	NO	NATURAL WATER SOURCE	
	0.28	0.78	-0.01	0	0	-0.02	-0.11	Spring Water	NO	NO	NATURAL WATER SOURCE	
3e	1.24	-0.35	0.03	0	0.04	0.02	-1.14	Tap Water	NO	NO	NATURAL WATER SOURCE	
	0.81	0.17	-0.02	0	0.02	0.02	-0.66	Tap Water	YES (sediment)	NO	NATURAL WATER SOURCE	
	0.04	0.9	0.01	0	0.01	0.08	-0.11	Spring Water	YES (sediment)		NATURAL WATER SOURCE	
4	1.12	-0.05	0.01	0	0.03	-0.115	-0.92	Tap Water	YES (sediment)	NO	NATURAL WATER SOURCE	
	1.16	-0.15	0.02	0	0.03	-0.07	-0.97	Tap Water	YES (sediment)	NO	NATURAL WATER SOURCE	
	0.22	1.06	-0.03	0.01	0.01	-0.24	0.125	Spring Water	YES (sediment)	NO	NATURAL WATER SOURCE	
	0.27	1.01	-0.04	0.01	0.01	-0.25	-0.08	Spring Water	YES (sediment)	NO	NATURAL WATER SOURCE	
	0.2	1.13	-0.04	0.01	0.01	-0.3	-0.05	Spring Water	YES (sediment)		NATURAL WATER SOURCE	
5	0.47	0.48	0.02	0	0.02	0.02	-0.46	Spring Water	YES (sediment)	NO	NATURAL WATER SOURCE	
	0.79	0.2	0	0	0.02	-0.02	-0.69	Tap Water	NO	NO	NATURAL WATER SOURCE	
	0.19	0.87	-0.02	0.01	0	0	-0.08	Spring Water	NO	NO	NATURAL WATER SOURCE	
	0.16	1.1	-0.04	0.01	0.01	-0.23	-0.07	Spring Water	NO		NATURAL WATER SOURCE	
9	0.79	0.13	0.01	0	-0.01	0.08	0.04	Tap Water	NO	NO	TAP WATER SOURCE	
10a	1.095	-0.18	-0.15	0.03	0.27	-0.155	-0.06	Tap Water	YES (sediment)	YES	SANITARY WASTEWATER SOURCE	
12	0.83	0.07	0.02	0	-0.01	0.08	0.14	Tap Water	NO	NO	TAP WATER SOURCE	
	-0.03	1.02	0	0	-0.04	0.06	0.84	Spring Water	NO	NO	TAP WATER SOURCE	

Table D Continued

OUTFALL #	QUANTIFICATION BY MODEL						μ	MOST LIKELY SOURCE by Model	Problem Indicated by Physical Observations	Detergents contamination Yes if ≥ 0.25 mg/L	Flow Chart method, Most Likely Source
	TAP WATER	SPRING WATER	CAR WASH WASTEWATER	LAUNDRY WASTEWATER	SEWAGE WASTEWATER	IRRIGATION WATER					
23	0.19	0.87	-0.02	0.01	0	0	-0.08	Spring Water	YES (sediment)	NO	NATURAL WATER SOURCE
	1.28	0.71	0.02	-0.01	0.515	-1.675	-0.59	Tap Water	NO	NO	NATURAL WATER SOURCE
24	1.26	0.38	-0.02	0	0.4	-1.1	-0.77	Tap Water	NO	NO	NATURAL WATER SOURCE
	1.075	0.56	0.02	-0.01	0.35	-1.155	0.655	Tap Water	YES (color, turbidity)	NO	NATURAL WATER SOURCE
26a	1.03	-0.15	0.03	0	0.02	0.055	-0.665	Tap Water	YES (sediment)	YES	WASHWATER SOURCE
	0.235	0.9	-0.15	0.03	0	0.03	-0.03	Spring Water	YES (sediment)	NO	NATURAL WATER SOURCE
27	0.84	0.17	-0.01	0	0.02	-0.02	-0.61	Tap Water	YES (sediment)	NO	NATURAL WATER SOURCE
	1.05	-0.29	0.02	0	0.03	0.18	-0.76	Tap Water	NO	NO	NATURAL WATER SOURCE
	0.74	0.125	-0.08	0.02	0	0.17	-0.11	Tap Water	NO	NO	IRRIGATION WATER SOURCE
	0.965	-0.16	-0.06	0.01	0.02	0.21	-0.82	Tap Water	YES	NO	NATURAL WATER SOURCE
	0.35	0.93	-0.09	0.02	0.01	-0.18	0	Spring Water	YES		NATURAL WATER SOURCE
27a	0.19	0.92	-0.17	0.04	0	0.05	0.03	Spring Water	NO	NO	NATURAL WATER SOURCE
	0.09	1.27	-0.14	0.03	0	-0.24	0.07	Spring Water	NO	NO	NATURAL WATER SOURCE
28	0.745	-0.09	-0.04	0.01	0.01	0.4	-0.74	Tap Water	NO	NO	NATURAL WATER SOURCE
29a	0.25	1.06	-0.11	0.03	0.01	-0.19	0.04	Spring Water	YES (color, turbidity)	NO	NATURAL WATER SOURCE
	0.11	1.24	-0.16	0.03	0	-0.22	0.08	Spring Water	YES (color, turbidity, floatables)	NO	NATURAL WATER SOURCE

Table D Continued

OUTFALL #	QUANTIFICATION BY MODEL						μ	MOST LIKELY SOURCE by Model	Problem Indicated by Physical Observations	Detergents contamination Yes if ≥ 0.25 mg/L	Flow Chart method, Most Likely Source
	TAP WATER	SPRING WATER	CAR WASH WASTEWATER	LAUNDRY WASTEWATER	SEWAGE WASTEWATER	IRRIGATION WATER					
31	0.8	0.08	-0.01	0	0.02	0.11	-0.05	Tap Water	YES (sediment)	YES	WASHWATER SOURCE
	0.76	-0.025	-0.04	0.01	0.02	0.31	-0.56	Tap Water	NO	NO	IRRIGATION WATER SOURCE
	0.13	1.02	-0.18	0.04	0	0	0.08	Spring Water	YES (sediment)	NO	NATURAL WATER SOURCE
	0.775	0.29	-0.25	0.05	0	0.07	-0.06	Tap Water	YES (color, turbidity, floatables)	NO	IRRIGATION WATER SOURCE
	0.83	0.27	-0.18	0.04	0	-0.01	0	Tap Water	YES (color, turbidity, floatables)	NO	IRRIGATION WATER SOURCE
31a	-0.93	2.41	-0.07	0.01	-0.02	-0.305	0.96	Spring Water	YES (color, turbidity, floatables)	NO	WASHWATER SOURCE
33	0.56	0.33	0.02	0	0.02	0.09	-0.555	Tap Water	YES (sediment)	NO	NATURAL WATER SOURCE
	1.69	-1.28	-0.1	0.02	0.04	0.64	1.425	Tap Water	YES (color, turbidity)	NO	IRRIGATION WATER SOURCE
	0.19	0.88	-0.08	0.02	0	0.04	-0.09	Spring Water	YES (sediment)	NO	NATURAL WATER SOURCE
	0.12	1.01	-0.05	0.01	0	-0.06	0.08	Spring Water	YES (sediment)	NO	NATURAL WATER SOURCE
36	0.66	-1.29	0.27	-0.05	0.02	1.46	-1.5	Irrigation Water	NO	NO	NATURAL WATER SOURCE
	2.405	-3.125	0.27	-0.05	0.07	1.27	-2.84	Tap Water	YES (sediment)	YES	WASHWATER SOURCE
	-0.025	0.78	0.04	-0.01	0	0.22	-0.09	Spring Water	YES (sediment)	NO	NATURAL WATER SOURCE
	0.17	0.97	-0.15	0.03	0	0.05	-0.03	Spring Water	YES (color, turbidity, floatables)	NO	NATURAL WATER SOURCE
	0.16	0.965	-0.1	0.02	0	-0.03	0.02	Spring Water	YES (sediment)	NO	NATURAL WATER SOURCE
37a	2.405	-2.92	0.34	-0.06	0.07	0.955	-2.87	Tap Water	NO	NO	NATURAL WATER SOURCE
	0.07	0.985	0	0	0	-0.03	0.07	Spring Water	NO	NO	NATURAL WATER SOURCE
	0.15	0.95	-0.03	0.01	0.01	-0.04	-0.02	Spring Water	NO	NO	NATURAL WATER SOURCE
	0.31	0.925	-0.07	0.01	0.01	-0.185	-0.04	Spring Water	NO	NO	NATURAL WATER SOURCE

Table D Continued

OUTFALL #	QUANTIFICATION BY MODEL						μ	MOST LIKELY SOURCE by Model	Problem Indicated by Physical Observations	Detergents contamination Yes if ≥ 0.25 mg/L	Flow Chart method, Most Likely Source
	TAP WATER	SPRING WATER	CAR WASH WASTEWATER	LAUNDRY WASTEWATER	SEWAGE WASTEWATER	IRRIGATION WATER					
38	0.7	0.035	0.07	-0.01	0.02	0.18	-0.75	Tap Water	NO	NO	NATURAL WATER SOURCE
	1	-0.24	0.03	-0.01	0.03	0.17	-1	Tap Water	NO	NO	NATURAL WATER SOURCE
	0.18	0.91	-0.06	0.01	0	-0.01	0.02	Spring Water	NO	NO	NATURAL WATER SOURCE
39	0.67	0.02	0.06	-0.01	0.02	0.22	-0.7	Tap Water	NO	NO	NATURAL WATER SOURCE
	0	0.795	0.07	-0.01	0	0.25	-0.24	Spring Water	NO	NO	NATURAL WATER SOURCE
	0.35	0.67	-0.02	0	0	0.01	-0.13	Spring Water	NO	NO	NATURAL WATER SOURCE
	0.11	0.98	-0.07	0.02	0	0	-0.02	Spring Water	NO	NO	NATURAL WATER SOURCE
	0.27	0.775	-0.09	0.02	0	0.05	-0.11	Spring Water	NO	NO	NATURAL WATER SOURCE
45	0.57	0.36	0.09	0	0.01	-0.01	-0.32	Tap Water	NO	YES	WASHWATER SOURCE
	0.53	0.42	0.09	0	0.01	-0.02	-0.43	Tap Water	NO	YES	WASHWATER SOURCE
	1.96	-1.51	0.03	-0.01	-0.01	0.45	0.11	Tap Water	NO	NO	TAP WATER SOURCE
	0.31	0.75	-0.07	0.02	-0.01	0.02	0.11	Spring Water	NO	YES	WASHWATER SOURCE
	0.2	0.835	-0.09	0.02	0	0.05	-0.11	Spring Water	NO	YES	WASHWATER SOURCE
49	2.695	-3.125	0.23	-0.04	0.25	0.88	-2.82	Tap Water	YES (color, turbidity)	YES	SANITARY WASTEWATER SOURCE
	1.745	-2.295	0.36	-0.07	0.05	1.11	-2.08	Tap Water	YES (oil sheen)	NO	NATURAL WATER SOURCE
	0.645	1.04	-0.08	0.02	0.25	-0.9	-0.13	Spring Water	YES (oil sheen)	YES	Waste or Wash Water Source

Table D Continued

OUTFALL #	QUANTIFICATION BY MODEL						μ	MOST LIKELY SOURCE by Model	Problem Indicated by Physical Observations	Detergents contamination Yes if ≥ 0.25 mg/L	Flow Chart method, Most Likely Source
	TAP WATER	SPRING WATER	CAR WASH WASTEWATER	LAUNDRY WASTEWATER	SEWAGE WASTEWATER	IRRIGATION WATER					
53	0.645	0.16	0.07	-0.01	0.03	0.11	-0.75	Tap Water	YES (sediment)	NO	NATURAL WATER SOURCE
	1.035	-0.225	0.07	-0.01	0.04	0.09	-1	Tap Water	YES (sediment)	NO	NATURAL WATER SOURCE
	0.27	0.76	-0.17	0.06	0	0.04	-0.04	Spring Water	YES (sediment)	YES	WASHWATER SOURCE
	0.08	1.06	-0.02	0	0	-0.08	0.02	Spring Water	NO	NO	NATURAL WATER SOURCE
	0.15	1.24	-0.06	0.01	0.01	-0.3	-0.01	Spring Water	NO	NO	NATURAL WATER SOURCE
55	0.58	-0.26	0.14	-0.03	0.02	0.52	-0.94	Tap Water	YES (sediment)	NO	NATURAL WATER SOURCE
	1.81	-1.595	0.1	-0.02	0.06	0.6	-2.01	Tap Water	YES (sediment)	YES	WASHWATER SOURCE
	0.24	0.84	0	0	0.01	-0.09	-0.07	Spring Water	YES (sediment)	NO	NATURAL WATER SOURCE
	0.33	1	-0.19	0.04	0.02	-0.175	-0.05	Spring Water	YES (floatables)	NO	NATURAL WATER SOURCE
	0.44	0.98	-0.12	0.02	-0.01	-0.29	0.74	Spring Water	YES (floatables)		WASHWATER SOURCE
61	0.885	-0.03	0.02	0	0	0.12	-0.08	Tap Water	YES (oil sheen)	NO	TAP WATER SOURCE
65	1.02	0	-0.03	0.01	0	-0.02	0.01	Tap Water	NO	NO	TAP WATER SOURCE
66	0.41	0.63	0	0	0.01	-0.04	-0.29	Spring Water	NO	YES	WASHWATER SOURCE
73	1.21	-0.77	0.07	-0.01	0.04	0.42	-1.24	Tap Water	YES (sediment)	YES	WASHWATER SOURCE
	1.65	-1.18	0.06	-0.01	0.05	0.39	-1.63	Tap Water	YES (sediment)	NO	NATURAL WATER SOURCE

Table D Continued

				QUANTIFICATION BY MODEL							
OUTFALL #				Mass Fraction values obtained by model							
	TAP WATER	SPRING WATER	CAR WASH WASTEWATER	LAUNDRY WASTEWATER	SEWAGE WASTEWATER	IRRIGATION WATER	μ	MOST LIKELY SOURCE by Model	Problem Indicated by Physical Observations	Detergents contamination Yes if ≥ 0.25 mg/L	Flow Chart method, Most Likely Source
Creek sample I	0.47	0.53	-0.04	0.01	0	0.04	0.04	Spring Water	NO	NO	NATURAL WATER SOURCE
Creek Sample II	0.12	0.99	-0.07	0.01	0	-0.03	0.02	Spring Water	NO	NO	NATURAL WATER SOURCE
Pond Entrance I	1.035	-0.225	0.07	-0.01	0.04	0.09	-1	Tap Water	NO	NO	IRRIGATION WATER SOURCE
	0.2	1.14	-0.08	0.02	0	-0.23	0	Spring Water	NO	NO	NATURAL WATER SOURCE
	0.47	0.54	-0.04	0.01	0	0.05	0.02	Spring Water	NO	NO	NATURAL WATER SOURCE
Pond Entrance II	0.78	0.08	-0.02	0.01	0	0.14	-0.13	Tap Water	NO	NO	TAP WATER SOURCE
	0.17	0.92	-0.03	0.01	0	-0.05	-0.03	Spring Water	NO	NO	NATURAL WATER SOURCE
Pond Outlet	0.55	0.37	-0.09	0.02	0	0.12	-0.1	Tap Water	NO	NO	IRRIGATION WATER SOURCE
	0.155	0.98	-0.23	0.05	0	0.04	-0.02	Spring Water	NO	NO	NATURAL WATER SOURCE
	0.26	1.06	-0.13	0.03	0.01	-0.19	-0.01	Spring Water	NO	NO	NATURAL WATER SOURCE

APPENDIX E

**Pearson Correlation Matrices for all the Potential Sources of the Cribbs Mill Creek
Watershed, Tuscaloosa, Alabama**

Table E.1 Pearson Correlation matrix for Tap water

	pH	Conduc.	Turbid.	Color	Fluoride	Hardness	Deterg.	Fluoresc	Potass.	Ammon.	NH4/Potassium	Boron	E-Coli
Conductivity	-0.599 0.040												
Turbidity	0.313 0.494	0.407 0.365											
Color	* *	* *	* *										
Fluoride	0.471 0.144	-0.285 0.395	0.384 0.452	* *									
Hardness	0.628 0.029	-0.612 0.035	-0.681 0.092	* *	0.040 0.907								
Detergents	* *	* *	* *	* *	* *	* *							
Fluorescence	0.651 0.114	0.031 0.948	0.795 0.032	* *	0.830 0.041	-0.707 0.076	* *						
Potassium	-0.570 0.053	0.456 0.136	0.315 0.492	* *	0.176 0.604	-0.599 0.040	* *	0.195 0.675					
Ammonia	-0.531 0.076	-0.012 0.969	-0.365 0.420	* *	0.128 0.708	-0.331 0.293	* *	-0.052 0.912	0.452 0.140				
Ammonia/Potassium	-0.823 0.177	-0.886 0.114	-0.683 0.317	* *	-0.929 0.071	0.813 0.187	* *	-0.815 0.185	-0.847 0.153	0.784 0.216			
Boron	0.287 0.532	-0.247 0.593	-0.075 0.873	* *	0.793 0.060	-0.161 0.730	* *	0.362 0.424	0.492 0.262	0.490 0.265	-0.303 0.697		
E. Coli	* *	* *	* *	* *	* *	* *	* *	* *	* *	* *	* *	* *	
Enterococci	* *	* *	* *	* *	* *	* *	* *	* *	* *	* *	* *	* *	* *

Cell Contents: Pearson correlation, * = unknown
P-Value

Table E.2 Pearson Correlation matrix for Spring water

	pH	Conduc.	Turbid.	Color	Fluoride	Hardness	Deterg.	Fluoresc	Potass.	Ammon.	NH4/Potassium	Boron	E-Coli
Conductivity	0.619 0.032												
Turbidity	-0.125 0.700	-0.466 0.127											
Color	0.435 0.158	0.421 0.172	-0.029 0.929										
Fluoride	0.243 0.447	0.062 0.848	-0.590 0.043	-0.087 0.789									
Hardness	-0.033 0.920	0.222 0.488	-0.704 0.011	0.163 0.612	0.479 0.115								
Detergents	* *	* *	* *	* *	* *	* *							
Fluorescence	-0.020 0.951	-0.228 0.476	-0.143 0.657	0.092 0.777	0.191 0.553	0.005 0.988	* *						
Potassium	-0.498 0.100	-0.056 0.862	0.066 0.839	-0.215 0.501	0.014 0.965	-0.336 0.286	* *	-0.084 0.796					
Ammonia	-0.114 0.725	-0.017 0.959	-0.165 0.608	-0.032 0.920	0.065 0.840	0.386 0.215	* *	-0.166 0.606	-0.273 0.390				
Ammonia/Potassium	-0.060 0.854	-0.072 0.825	-0.038 0.906	-0.007 0.984	0.024 0.941	0.317 0.315	* *	-0.166 0.607	-0.332 0.291	0.986 0.000			
Boron	0.601 0.154	0.461 0.298	0.692 0.085	0.379 0.402	-0.221 0.634	-0.570 0.182	* *	0.229 0.622	-0.366 0.419	0.217 0.641	0.289 0.529		
E. Coli	0.164 0.673	0.120 0.758	-0.190 0.625	-0.191 0.623	0.318 0.405	0.265 0.491	* *	-0.265 0.491	-0.159 0.683	0.778 0.014	0.789 0.012	0.443 0.320	
Enterococci	0.138 0.724	0.078 0.842	-0.075 0.848	-0.058 0.882	0.119 0.760	0.257 0.504	* *	-0.254 0.509	-0.282 0.463	0.893 0.001	0.916 0.001	0.479 0.277	0.960 0.000

Cell Contents: Pearson correlation, * = unknown
P-Value

Table E.3 Pearson Correlation matrix for Carwash wastewater

	pH	Conduc.	Turbid.	Color	Fluoride	Hardness	Deterg.	Fluoresc	Potass.	Ammon.	NH4/Potassium	Boron	E-Coli
Conductivity	0.479 0.116												
Turbidity	-0.086 0.790	0.556 0.061											
Color	0.140 0.663	0.653 0.021	0.644 0.024										
Fluoride	-0.137 0.671	-0.071 0.826	0.407 0.189	-0.034 0.916									
Hardness	0.470 0.123	-0.098 0.762	-0.358 0.253	-0.298 0.347	0.060 0.852								
Detergents	-0.215 0.525	-0.563 0.071	-0.463 0.151	-0.148 0.665	-0.066 0.848	-0.041 0.904							
Fluorescence	-0.365 0.243	0.033 0.918	0.423 0.170	0.550 0.064	-0.046 0.886	-0.404 0.193	-0.144 0.672						
Potassium	-0.265 0.405	0.101 0.755	-0.010 0.976	0.186 0.562	-0.206 0.520	-0.089 0.784	-0.128 0.708	0.325 0.302					
Ammonia	0.521 0.082	0.535 0.073	0.083 0.798	-0.081 0.803	-0.180 0.575	0.161 0.616	-0.635 0.036	-0.035 0.915	-0.036 0.911				
Ammonia/Potassium	0.545 0.067	0.533 0.075	0.133 0.681	-0.084 0.796	-0.140 0.665	0.105 0.746	-0.613 0.045	-0.075 0.816	-0.174 0.589	0.985 0.000			
Boron	0.453 0.189	0.929 0.000	0.538 0.109	0.617 0.057	-0.204 0.571	0.044 0.904	-0.665 0.036	0.153 0.672	0.006 0.987	0.606 0.063	0.597 0.069		
E. Coli	-0.232 0.467	0.445 0.147	0.301 0.342	0.262 0.411	-0.371 0.235	-0.282 0.375	-0.254 0.452	-0.092 0.777	0.117 0.718	0.046 0.886	0.047 0.885	0.529 0.116	
Enterococci	0.033 0.918	0.296 0.350	0.096 0.766	-0.010 0.976	0.286 0.368	0.067 0.837	-0.440 0.176	-0.071 0.826	0.441 0.152	0.358 0.254	0.312 0.323	0.283 0.429	0.539 0.070

Cell Contents: Pearson correlation, * = unknown
P-Value

Table E.4 Pearson Correlation matrix for Laundry wastewater

	pH	Conduc.	Turbid.	Color	Fluoride	Hardness	Deterg.	Fluoresc	Potass.	Ammon.	NH4/Potassium	Boron	E-Coli
Conductivity	0.023 0.944												
Turbidity	0.692 0.013	-0.084 0.795											
Color	-0.059 0.856	-0.131 0.684	-0.254 0.425										
Fluoride	0.064 0.844	-0.235 0.463	0.222 0.488	-0.568 0.054									
Hardness	0.720 0.008	0.434 0.158	0.391 0.208	0.280 0.378	-0.337 0.284								
Detergents	-0.069 0.831	0.369 0.238	0.153 0.636	-0.676 0.016	0.099 0.761	-0.295 0.352							
Fluorescence	-0.397 0.202	0.359 0.252	-0.183 0.568	0.398 0.201	-0.708 0.010	0.095 0.770	-0.035 0.913						
Potassium	0.356 0.256	0.072 0.825	0.521 0.083	-0.139 0.666	-0.265 0.405	0.297 0.348	0.393 0.206	0.033 0.918					
Ammonia	-0.139 0.667	-0.309 0.328	-0.222 0.488	0.510 0.090	-0.372 0.234	0.188 0.559	-0.774 0.003	0.269 0.398	-0.233 0.465				
Ammonia/Potassium	-0.184 0.568	-0.335 0.287	-0.247 0.439	0.480 0.114	0.080 0.806	0.098 0.762	-0.884 0.000	0.015 0.964	-0.535 0.073	0.823 0.001			
Boron	-0.299 0.402	-0.146 0.688	-0.085 0.815	0.752 0.012	-0.249 0.488	0.222 0.537	-0.621 0.055	0.506 0.136	-0.422 0.225	0.444 0.199	0.576 0.081		
E. Coli	-0.410 0.239	0.059 0.871	0.050 0.892	-0.272 0.447	0.042 0.907	-0.565 0.089	0.279 0.435	0.301 0.399	0.528 0.117	-0.260 0.469	-0.284 0.427	-0.163 0.653	
Enterococci	* *	* *	* *	* *	* *	* *	* *	* *	* *	* *	* *	* *	* *

Cell Contents: Pearson correlation, * = unknown
P-Value

Table E.5 Pearson Correlation matrix for Irrigation water

	pH	Conduc.	Turbid.	Color	Fluoride	Hardness	Deterg.	Fluoresc	Potass.	Ammon.	NH4/Potassium	Boron	E-Coli
Conductivity	0.724 0.012												
Turbidity	-0.345 0.273	0.047 0.891											
Color	-0.483 0.112	-0.194 0.568	0.342 0.276										
Fluoride	0.307 0.332	0.189 0.579	-0.598 0.040	-0.592 0.042									
Hardness	0.498 0.099	0.400 0.223	-0.133 0.681	-0.514 0.087	0.670 0.017								
Detergents	* *	* *	* *	* *	* *	* *							
Fluorescence	0.153 0.636	0.380 0.250	0.055 0.866	0.123 0.704	-0.301 0.342	-0.427 0.166	* *						
Potassium	-0.092 0.775	0.327 0.326	-0.109 0.736	0.198 0.538	0.297 0.349	0.303 0.338	* *	-0.321 0.308					
Ammonia	-0.333 0.289	-0.408 0.212	-0.058 0.857	0.509 0.091	-0.369 0.238	-0.411 0.184	* *	-0.068 0.833	0.181 0.574				
Ammonia/Potassium	-0.323 0.333	-0.636 0.048	-0.077 0.823	0.363 0.273	-0.519 0.102	-0.626 0.039	* *	0.046 0.892	-0.422 0.196	0.721 0.012			
Boron	-0.262 0.410	0.266 0.429	0.774 0.003	0.597 0.040	-0.693 0.013	-0.253 0.428	* *	0.362 0.247	0.148 0.647	-0.012 0.969	-0.145 0.671		
E. Coli	-0.111 0.732	0.345 0.299	0.061 0.852	0.417 0.178	0.234 0.464	0.262 0.410	* *	0.161 0.616	0.493 0.104	-0.171 0.596	-0.511 0.108	0.390 0.210	
Enterococci	-0.071 0.827	-0.017 0.959	-0.050 0.877	0.199 0.535	0.224 0.484	0.312 0.324	* *	-0.086 0.789	0.208 0.517	-0.009 0.979	-0.028 0.935	0.076 0.814	0.694 0.012

Cell Contents: Pearson correlation, * = unknown
P-Value

APPENDIX-F

User Guide for the Inappropriate Discharges Chemical Mass Balance Model (CMBM, version 1.1)

User Guide for the Inappropriate Discharges Chemical Mass Balance Model (CMBM, version 1.1)

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Overview of the Model

The Chemical Mass Balance Model (CMBM) estimates the most likely source components that contribute to outfall flows during dry weather. In order to use the model, the user must have a Library File in the form of an Excel file in a specified format. This library file describes the concentration characteristics of potential local contributing flows. In CMBM, the user selects the sources to be evaluated for an outfall, enters the values of the concentrations of the tracers measured at the outfall, and obtains a plot of the most likely source component in tabular form, and in probability plots.

Installation of the Model

Initially, the user must first install the model by inserting the disk and then clicking the 'setup.exe' icon and following the on-screen instructions.

Model Inputs

The user enters the following:

1. The potential sources to be evaluated for a particular outfall. The number of sources is entered in the first form and the user must then select the same number of sources and tracers when the lists of the sources and tracers are loaded.
2. The source library file containing source flow characteristics (median, COV, and distribution type) for the Monte Carlo statistical simulations.
3. The tracer parameters for these sources and outfall contained in the library file. The user selects the specific tracers to be used from the check boxes when they are loaded in the first form.
4. The number of Monte Carlo simulations that are to be used by the model, up to 10,000 runs.
5. The observed outfall concentrations of the selected tracer parameters measured for a particular outfall (in the second form of the model). Press the continue button when these concentrations are entered.

Re-run Program

1. Enter Number of Contributing Sources to be Evaluated 2. Click to Select Library File

3. Enter Number of Monte Carlo runs for the evaluation [≤ 10000] 4. Click to Select Sources and Tracers

5. Select Sources

- Tap Water
- Spring Water
- Carwash Wastewater
- Laundry Wastewater
- Sewage Wastewater
- Irrigation Water

6. Select Tracers

- Conductivity ($\mu\text{hos/cm}$)
- Fluoride (mg/L)
- Hardness (mg/L) CaCO₃
- Detergent (mg/L)
- Fluorescence (mg/L as Tide)
- Potassium (mg/L)
- Ammonia (mg/L)
- Color (Units)
- Turbidity (NTU)
- Boron (mg/L)
- E-Coli (MPN)
- Enterococci (MPN)

7. Click to Continue to Next Step

Figure F.1: Form-1 (Model inputs)

8. Enter Observed Outfall Tracer Concentrations	
Conductivity (µmhos/cm)	<input type="text"/>
Fluoride (mg/L)	<input type="text" value="0.97"/>
Hardness (mg/L) CaCO3	<input type="text"/>
Detergent (mg/L)	<input type="text" value="0.25"/>
Fluorescence (mg/L as Tide)	<input type="text" value="82.82"/>
Potassium (mg/L)	<input type="text" value="2"/>
Ammonia (mg/L)	<input type="text" value="8"/>
Color (Units)	<input type="text" value="0"/>
Turbidity (NTU)	<input type="text"/>
Boron (mg/L)	<input type="text"/>
E-Coli (MPN)	<input type="text"/>
Enterococci (MPN)	<input type="text"/>

Re-run Program

9. Click to Continue to Next Step

Figure F.2: Form-2 (Model inputs)

Model Outputs

The output of the model is in two forms, namely:

- A summary table lists the 95th percentile confidence interval (the 2.5th and the 97.5th percentile values) and the 50th percentile (median) values of the mass fraction for each source contributing to the outfall dry weather flow, as calculated by the chemical mass balance model and using the number of Monte Carlo simulations specified. This table also shows these values for an error term, μ (Mu). This table can be saved and printed by selecting the options in the third form. In order to print the table (a small Excel spreadsheet), it must first be saved in a particular location on the computer.
- A probability plot of the calculated mass fractions for each selected source flow and also for the error term, μ (Mu). This figure can be saved and printed by selecting the options in the third form. In order to print each figure, they must first be selected and saved in a particular location on the computer.

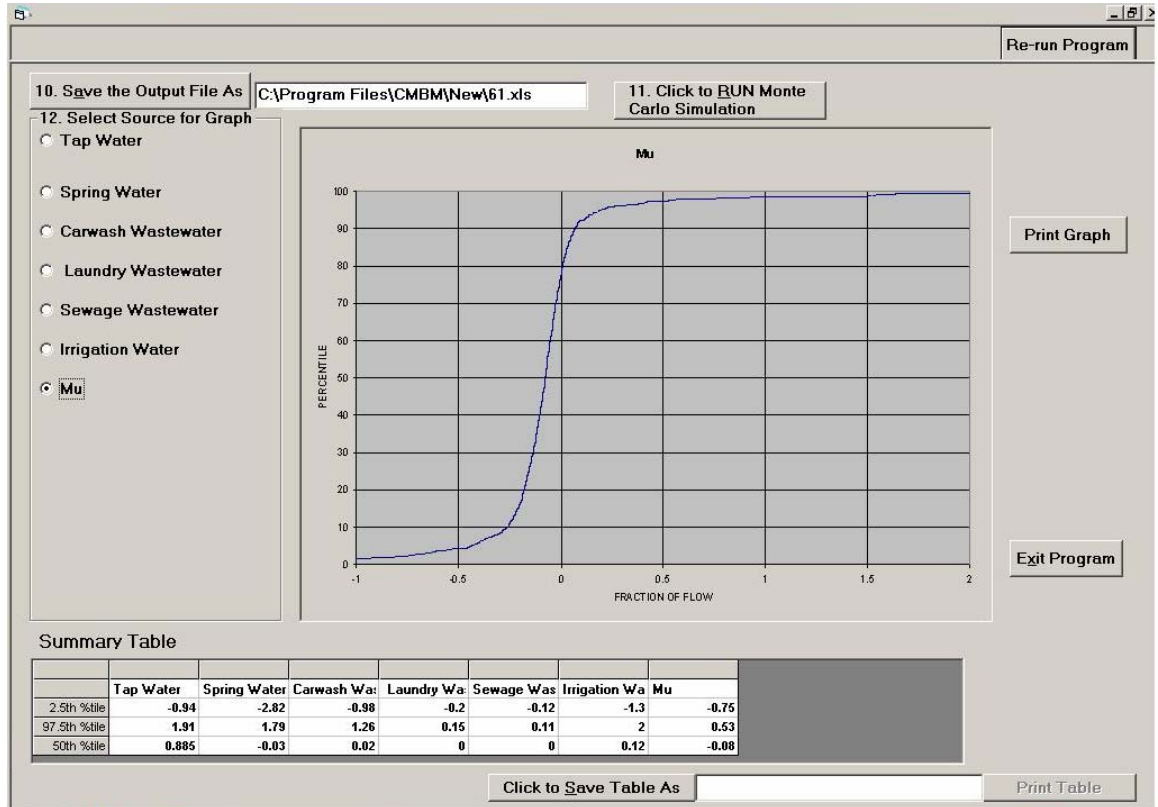


Figure F.3: Form-3 (Model output)

Library File Format

This model recognizes the source file for evaluation only if it is in a specific format in an Excel spreadsheet.

- The data for each source is entered in an Excel file.
- The first column of the excel data sheet must contain the names of the tracers, starting with the second row, the second column must contain values of mean concentration, the third column, the coefficient of variation, and the fourth column the type of distribution. “N” is for “normal”, or Gaussian, distributions, while “L” if for log-normal distributions. Figure 4 is an example spreadsheet file for source area library flows.

Tracer	Mean Concentration	COV	Distribution
Conductivity ($\mu\text{mhos/cm}$)	274.67	0.46	N
Fluoride (mg/L)	1.23	1.57	L
Hardness (mg/L) CaCO_3	71.17	0.27	N
Detergent (mg/L)	140.91	0.21	N
Fluorescence (mg/L as Tide)	90.98	0.47	N
Potassium (mg/L)	3.58	0.67	L
Ammonia (mg/L)	0.90	1.42	L
Color (Units)	100.00	0.01	N
Turbidity (NTU)	156.81	0.78	N
Boron (mg/L)	0.65	0.74	L
E-Coli (MPN)	100.00	0.00	L
Enterococci (MPN)	10.00	0.00	L

Figure F.4: Excel sheet in Library File

In the first form

- Navigation from one step to another can be done by either using the mouse or the ‘tab’ button.
- Changing the value entered for ‘Number of contributing sources to be evaluated’ and after entering subsequent steps will likely result in an error message. If the user wishes to change this value after starting on later forms, the user must use the ‘Re-run Program’ button and re-enter the earlier forms.
- The model can run up to seven sources and tracers in a single trial.

In the third form

- The user must first save the output file to run the Monte Carlo simulation.
- The user must first save the graph to view or print it.
- The user must first save the table to print it.
- If the table cannot be viewed properly, it can be resized by the user.

Example Problems

Example 1

Let an outfall be considered which has the same data for the tracer parameters as observed at the sewage treatment plant (which is the same as the library data for sewage wastewater). This means that the model must predict the most likely source component to be sewage and with a predicted fraction of flow for sewage close to one.

The library file used here is the Birmingham library file: 'Library_BHM.xls' (which is included with the program). Let the number of Monte Carlo simulations considered be 1000, the number of sources selected for evaluation be 4 (sewage wastewater, tap water, spring water, and landscape irrigation runoff). The tracers selected are conductivity, fluoride, potassium and ammonia. Figure 5 shows these corresponding entries, while Figure 6 shows the Excel spreadsheet for the library file used.

Figure 7 shows the entries made in the second form. It should be noted that the values for the tracers entered are the same as those in the library file for sewage.

Figure 8 shows the output form. The 50th percentile value for Sewage Wastewater flow in the summary table is 1.06, while the 95 percent confidence interval is 0.52 to 2.69. This table shows that the most likely source at the outfall being analyzed is therefore Sewage Wastewater, which is the same as the initial assumption. Also, the fraction of flow that is sewage is 1.06, very close to the 1.0. Also, the 50th percentile value for the error term μ

(indicated in the table as μ) is -0.01, very close to zero, indicating good agreement. The potential mass contributions for the other source flows are also close to zero.

Re-run Program

1. Enter Number of Contributing Sources to be Evaluated 2. Click to Select Library File

3. Enter Number of Monte Carlo runs for the evaluation [≤ 10000] 4. Click to Select Sources and Tracers

5. Select Sources

- Spring Water
- Tap Water
- Sewage Wastewater
- Commercial Carwash Wastewater
- Landscape Irrigation Water
- Infiltrating Groundwater
- Septic Tank Discharge
- Commercial Laundry Wastewater
- Plating Bath Wastewater
- Radiator Flushing Water

6. Select Tracers

- Conductivity ($\mu\text{mhos/cm}$)
- Fluoride (mg/L)
- Hardness (mg/L CaCO₃)
- Detergent (mg/L)
- Fluorescence (% scale)
- Potassium (mg/L)
- Ammonia (mg/L)
- Color (units)

7. Click to Continue to Next Step

Exit

Figure F.5: Form1 (Input for Example 1)

Tracer	Mean Concentration	COV	Distribution
Conductivity (µmhos/cm)	419.86	0.13	N
Fluoride (mg/L)	0.76	0.23	N
Hardness (mg/L CaCO ₃)	142.92	0.11	N
Detergent (mg/L)	1.5	0.82	N
Fluorescence (% scale)	250.89	0.2	N
Potassium (mg/L)	5.97	0.23	N
Ammonia (mg/L)	9.92	0.34	L
Color (units)	37.89	0.55	N

Figure F.6: Library File Excel Sheet (Sewage Wastewater)

8. Enter Observed Outfall Tracer Concentrations

Conductivity (µmhos/cm)

Fluoride (mg/L)

Hardness (mg/L CaCO₃)

Detergent (mg/L)

Fluorescence (% scale)

Potassium (mg/L)

Ammonia (mg/L)

Color (units)

9. Click to Continue to Next Step

Re-run Program

Figure F.7: Form 2 (Input)

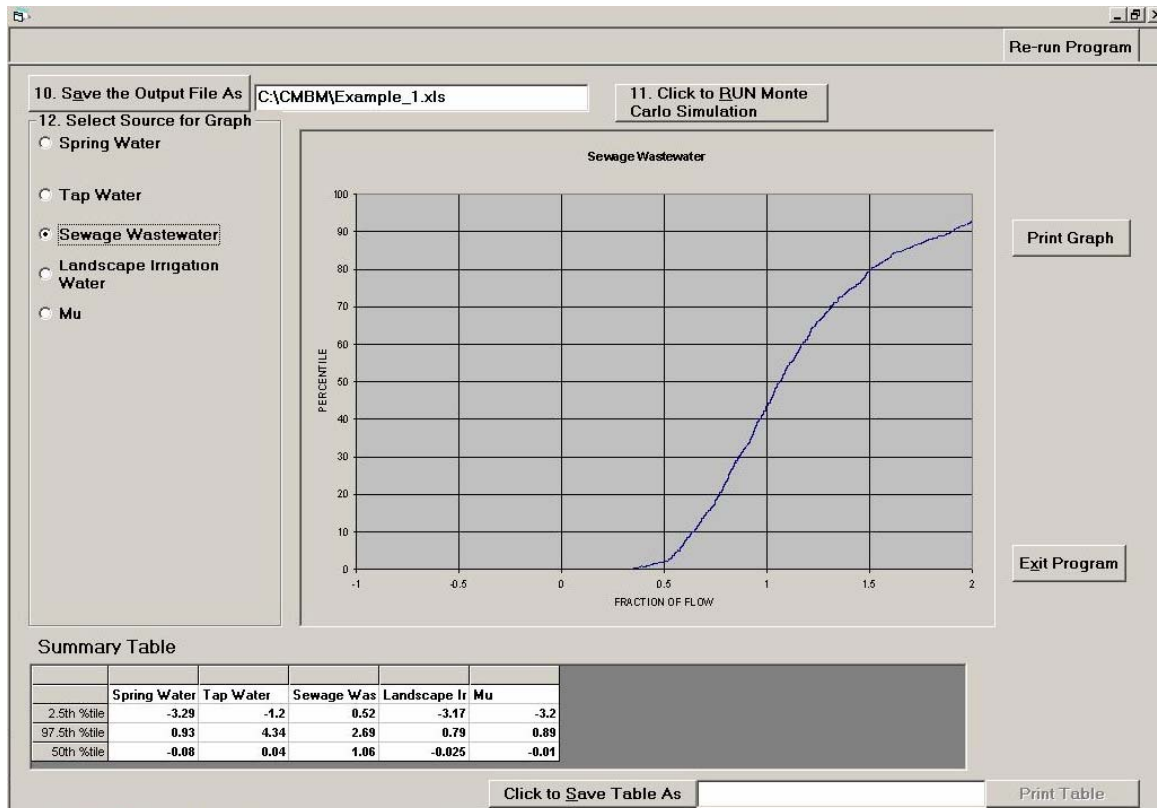


Figure F.8: Form 3 (Output for Example 1)

Example 2

In this example, seven possible source types and seven tracer parameters are selected, based on sample data from outfall # 20 in Birmingham, AL, collected on March 3, 1993.

The library file used in this example is also the Birmingham library file: 'Library_BHM.xls'. Let the number of Monte Carlo simulations be 1000, the number of sources selected for evaluation be 7 (spring water, tap water, sewage wastewater, commercial carwash wastewater, landscape irrigation water, infiltrating groundwater, and septic tank discharge). The seven tracers selected are conductivity, fluoride, hardness, detergents, fluorescence, potassium, and ammonia.

Figure 9 shows all the corresponding entries using this information. Figure 10 shows the entries made in the second form. Figure 11 shows the output form. The fraction of flow as indicated for the 50th percentile value for tap water on the summary table is the highest value (0.72) compared to the other potential source flows. This indicates that the most likely source at the outfall is tap water, as verified through field observations. The spring

water mass fraction is also relatively high (0.42), indicating that this source water may also be present.

The screenshot shows a software window titled "Re-run Program" with the following input fields and options:

- 1. Enter Number of Contributing Sources to be Evaluated:
- 2. Click to Select Library File:
- 3. Enter Number of Monte Carlo runs for the evaluation [≤ 10000]:
- 4. Click to Select Sources and Tracers: (button)
- 5. Select Sources:
 - Spring Water
 - Tap Water
 - Sewage Wastewater
 - Commercial Carwash Wastewater
 - Landscape Irrigation Water
 - Infiltrating Groundwater
 - Septic Tank Discharge
 - Commercial Laundry Wastewater
 - Plating Bath Wastewater
 - Radiator Flushing Water
- 6. Select Tracers:
 - Conductivity ($\mu\text{hos/cm}$)
 - Fluoride (mg/L)
 - Hardness (mg/L CaCO₃)
 - Detergent (mg/L)
 - Fluorescence (% scale)
 - Potassium (mg/L)
 - Ammonia (mg/L)
 - Color (units)
- 7. Click to Continue to Next Step: (button)
- Exit: (button)

Figure F.9: Form 1 (Input for Example 2)

The image shows a software window titled "8. Enter Observed Outfall Tracer Concentrations". In the top right corner of the window, there is a button labeled "Re-run Program". The main area contains a list of parameters with corresponding input fields:

Parameter	Value
Conductivity ($\mu\text{mhos/cm}$)	188
Fluoride (mg/L)	0.61
Hardness (mg/L CaCO_3)	127
Detergent (mg/L)	0
Fluorescence (% scale)	13
Potassium (mg/L)	1.98
Ammonia (mg/L)	0.03
Color (units)	

At the bottom center of the window, there is a button labeled "9. Click to Continue to Next Step".

Figure F.10: Form 2 (Input for Example 2)

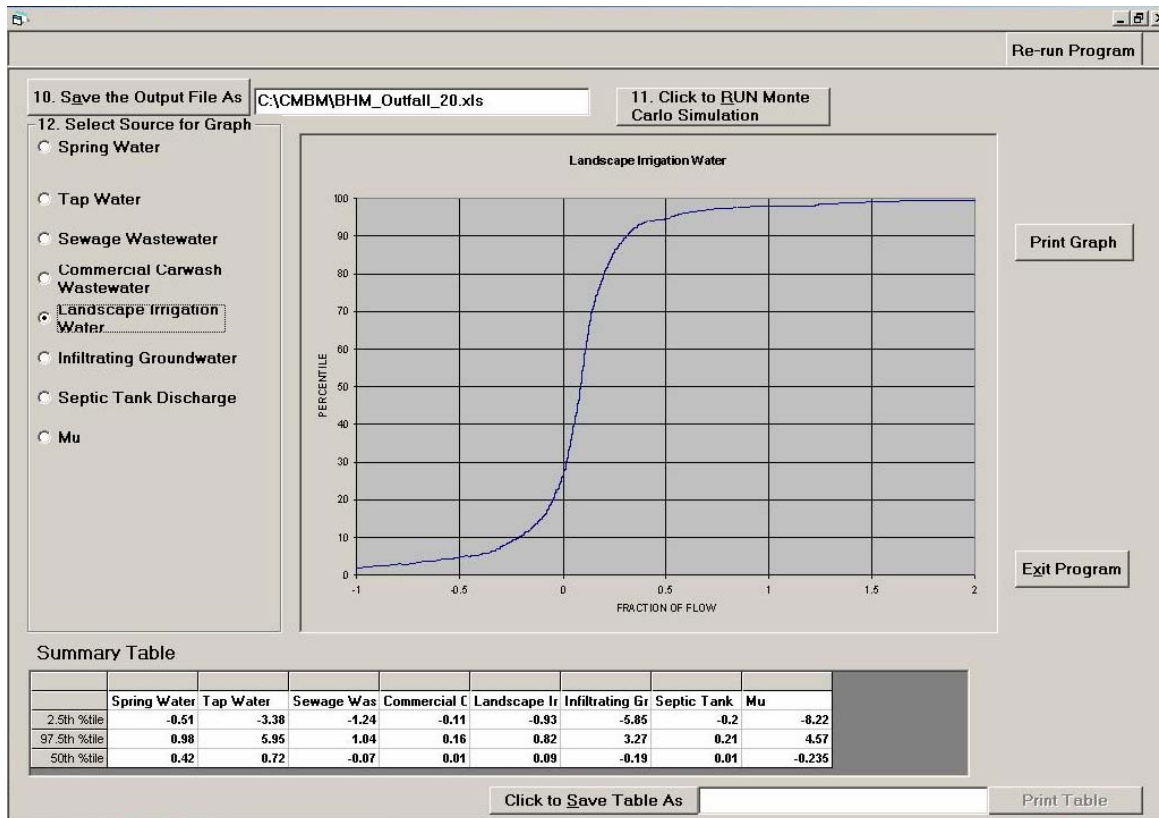


Figure F.11: Form 3 (Output for Example 2)

APPENDIX-G

Results of the Sensitivity Analysis by model for the verification outfalls

Selected Tracers	Tap water	Spring water	Carwash	Laundry	Sewage	Irrigation	Mu
Fluoride, Detergents, Fluorescence, Ammonia, Color, Enterococci	2.515	-3.15	0.33	-0.05	0.09	0.575	-2.93
Fluoride, Detergents, Fluorescence, Potassium, Ammonia, Color	1.71	-2.145	0.35	-0.06	0.06	0.9	-2.24
Hardness, Detergents, Fluorescence, Potassium, Ammonia, Enterococci	-0.4	1.27	0.05	-0.01	0.07	0	-2.01
Fluoride, Detergents, Fluorescence, Potassium, Color, Turbidity	1.455	-1.035	0.32	-0.05	0.185	0.26	-1.75
Fluoride, Detergents, Fluorescence, Potassium, Boron, Enterococci	-0.53	1.85	-0.14	0.03	-0.25	0	0.68
Conductivity, Fluoride, Hardness, Detergents, Boron, Enterococci	-0.53	1.69	-0.18	0.03	-0.06	0	0.535
Conductivity, Fluoride, Fluorescence, Potassium, Boron, Enterococci	-0.35	1.38	-0.04	0.01	-0.11	0	0.51
Fluoride, Detergents, Fluorescence, Potassium, Ammonia, Boron,	-0.27	1.82	-0.08	0.02	-0.01	-0.43	0.5
Fluoride, Detergents, Fluorescence, Ammonia, Boron, Enterococci	-0.65	1.64	0.01	0	-0.02	0	0.5
Conductivity, Detergents, Fluorescence, Ammonia, Boron, Enterococci	1.43	-0.315	-0.03	0.01	-0.02	0	0.49
Detergents, Fluorescence, Ammonia, Turbidity, Boron, Enterococci	0.58	0.45	0	0	-0.02	0	0.47
Conductivity, Fluoride, Hardness, Color, Turbidity, Boron	-1.04	1.33	0.2	-0.12	-0.05	0.47	0.34
Conductivity, Fluoride, Hardness, Detergents, Fluorescence, Enterococci	-0.46	1.55	-0.03	0.01	-0.06	0	0.33
Conductivity, Fluoride, Hardness, Detergents, Fluorescence, Potassium	-0.02	1.5	-0.16	0.03	-0.05	-0.3	0.195
Fluoride, Hardness, Detergents, Fluorescence, Color, Turbidity	-0.745	-0.965	0.2	-0.04	0.285	-0.08	-0.185
Fluoride, Hardness, Detergents, Fluorescence, Potassium, Enterococci	-0.05	1.45	-0.21	0.04	-0.18	0	0.165

Table G.1 Analysis by model of outfall sample collected at outfall # 3 for various combinations of tracers

Selected Tracers	Tap water	Spring water	Carwash	Laundry	Sewage	Irrigation	Mu
Hardness, Detergents, Fluorescence, Potassium, Ammonia, Enterococci	-0.76	1.55	0.04	-0.01	0.08	0	-2.32
Hardness, Detergents, Fluorescence, Potassium, Ammonia, E-coli	-0.72	1.635	0.05	-0.01	0.08	-0.01	-2.12
Fluoride, Detergents, Fluorescence, Potassium, Color, Turbidity	0.83	0.14	0	0	0	0.02	-0.81
Fluoride, Detergents, Fluorescence, Potassium, Ammonia, Color	0.745	0.32	0	0	0.02	-0.08	-0.71
Fluoride, Hardness, Detergents, Fluorescence, Turbidity, Color	-0.84	1.91	-0.02	0	-0.02	-0.025	0.55
Conductivity, Fluoride, Hardness, Detergents, Fluorescence, Enterococci	-0.75	1.92	-0.06	0.01	-0.08	0	0.55
Conductivity, Fluoride, Hardness, Detergents, Fluorescence, E-Coli	-0.8	1.89	-0.06	0.01	-0.08	0.01	0.53
Conductivity, Fluoride, Hardness, Detergents, Ammonia, E-Coli	-0.56	1.78	-0.42	0.07	-0.02	0	0.425
Conductivity, Fluoride, Hardness, Detergents, Fluorescence, Potassium	-0.11	1.85	-0.21	0.04	-0.04	-0.49	0.33
Fluoride, Hardness, Detergents, Fluorescence, Potassium, E-Coli	-0.09	1.7	-0.31	0.06	-0.21	0.01	0.295
Fluoride, Hardness, Detergents, Fluorescence, Potassium, Enterococci	-0.17	1.75	-0.31	0.06	-0.21	0	0.29
Fluoride, Hardness, Fluorescence, Potassium, Turbidity, E-Coli	-0.395	1.635	-0.21	0.02	-0.13	0.01	0.26
Detergents, Fluorescence, Ammonia, Turbidity, Boron, Enterococci	1	0	0	0	0	0	-0.14
Boron, Ammonia, Potassium, Fluorescence, Detergents, Fluoride	0.24	1.055	-0.03	0.01	0.01	-0.25	-0.13

Conductivity, Fluoride, Hardness, Color, Turbidity, Boron	-0.92	1.71	-0.05	-0.075	-0.04	-0.14	0.08
Conductivity, Fluoride, Fluorescence, Potassium, Boron, E-Coli	0.115	0.825	-0.07	0.01	-0.09	0.01	-0.08
Conductivity, Fluoride, Hardness, Detergents, Boron, Enterococci	-0.16	1.54	-0.485	0.08	-0.06	0	0.06

Table G.2 Analysis by model of outfall sample collected at outfall # 4 for various combinations of tracers

Selected Tracers	Tap water	Spring water	Carwash	Laundry	Sewage	Irrigation	Mu
Conductivity, Hardness, Fluorescence, Turbidity, E-Coli, Enterococci	0.65	0.52	-0.145	0.02	0	0	10.29
Conductivity, Hardness, Color, Turbidity, E-Coli, Enterococci	0.59	0.52	0	-0.08	0	0	6.19
Conductivity, Hardness, Detergents, Turbidity, E-Coli, Enterococci	0.975	0.16	-0.09	0	0	0	5.485
Conductivity, Fluoride, Detergents, Color, E-Coli, Enterococci	1.61	-0.625	0.01	0	0	0	-1.28
Fluoride, Detergents, Fluorescence, Potassium, Ammonia, Color	0.92	-0.12	-0.06	0.01	0.02	0.22	-0.79
E-Coli, Detergents, Fluorescence, Potassium, Ammonia, Fluoride	0.88	0.17	-0.09	0.02	0.02	0	-0.62
Fluoride, Detergents, Fluorescence, Potassium, Ammonia, Enterococci	0.88	0.15	-0.09	0.02	0.02	0	-0.62
Conductivity, Fluoride, Hardness, Turbidity, E-Coli, Enterococci	0.8	0.21	0.105	-0.11	0	0	-0.615
Conductivity, Detergents, Fluorescence, Potassium, E-Coli, Enterococci	0.54	0.57	-0.11	0.02	0	0	-0.53
Conductivity, Detergents, Fluorescence, Potassium, Ammonia, Enterococci	1.37	-0.245	-0.17	0.03	-0.03	0	0.515

Conductivity, Detergents, Fluorescence, Potassium, Ammonia, E-Coli	1.32	-0.18	-0.165	0.03	-0.03	0	0.48
Conductivity, Fluoride, Detergents, Fluorescence, E-Coli, Enterococci	0.62	0.4	-0.11	0.02	0	0	-0.445
Conductivity, Fluoride, Color, Turbidity, E-Coli, Enterococci	0.58	0.47	0.01	-0.03	0	0	-0.375
Conductivity, Hardness, Potassium, Turbidity, E-Coli, Enterococci	0.82	0.2	0.08	-0.07	0	0	-0.355
Conductivity, Fluorescence, Potassium, Ammonia, E-Coli, Enterococci	1.18	-0.04	-0.19	0.03	0	0	-0.1
Conductivity, Hardness, Ammonia, Turbidity, E-Coli, Enterococci	0.785	0.27	0.08	-0.09	0	0	0.085

Table G.3 Analysis by model of outfall sample collected at outfall # 27 for various combinations of tracers

Selected Tracers	Tap water	Spring water	Carwash	Laundry	Sewage	Irrigation	Mu
Hardness, Detergents, Fluorescence, Potassium, Ammonia, Enterococci	-0.52	1.43	-0.1	0.02	0.13	0	-3.525
Hardness, Detergents, Fluorescence, Potassium, Ammonia, E-coli	-0.43	1.39	-0.09	0.02	0.13	-0.01	-3.14
Fluoride, Detergents, Fluorescence, Potassium, Ammonia, Color	1.73	-1.655	-0.02	0	0.02	0.835	-1.27
Conductivity, Fluoride, Hardness, Detergents, Fluorescence, Enterococci	-0.365	1.655	-0.25	0.05	-0.045	0	1.1
Conductivity, Fluoride, Hardness, Detergents, Fluorescence, E-Coli	-0.4	1.65	-0.25	0.05	-0.04	0	1.08
Fluoride, Hardness, Detergents, Fluorescence, Color, Turbidity	-0.91	1.425	-0.06	0.01	0.12	0.375	0.995
Conductivity, Fluoride, Hardness, Detergents, Ammonia, E-Coli	-0.13	1.34	-0.32	0.05	-0.03	0	0.81
Fluoride, Detergents, Fluorescence, Potassium, Color, Turbidity	1.475	-0.805	-0.01	0	0.22	0.1	-0.79

Conductivity, Fluoride, Hardness, Detergents, Fluorescence, Potassium	0.27	1.42	-0.385	0.07	-0.04	-0.235	0.77
Fluoride, Hardness, Detergents, Fluorescence, Potassium, Enterococci	0.42	1.34	-0.46	0.09	-0.16	0	0.64
Fluoride, Hardness, Fluorescence, Potassium, Turbidity, E-Coli	-0.03	1.21	-0.16	0.05	-0.13	0.01	0.63
Fluoride, Hardness, Detergents, Fluorescence, Potassium, E-Coli	0.545	1.18	-0.45	0.08	-0.12	0.01	0.52
Conductivity, Fluoride, Hardness, Color, Turbidity, Boron	0	1.17	0.1	-0.11	-0.02	-0.11	0.225
Conductivity, Fluoride, Hardness, Detergents, Boron, Enterococci	0.54	0.91	-0.41	0.065	-0.04	0	0.17
Conductivity, Fluoride, Fluorescence, Potassium, Boron, E-Coli	0.8	0.18	-0.01	0.05	-0.07	0.01	-0.05
Detergents, Fluorescence, Ammonia, Turbidity, Boron, Enterococci	-1.295	2.445	-0.15	0.03	0	0	0.04
Fluoride, Detergents, Fluorescence, Potassium, Ammonia, Boron	0.84	0.29	-0.18	0.04	0	-0.02	-0.02

Table G.4 Analysis by model of outfall sample collected at outfall # 31 for various combinations of tracers

Selected Tracers	Tap water	Spring water	Carwash	Laundry	Sewage	Irrigation	Mu
Fluoride, Hardness, Detergents, Fluorescence, Turbidity, Enterococci	7.17	-7.755	0.43	-0.09	0.61	-0.01	-6.58
Fluoride, Hardness, Detergents, Ammonia, Turbidity, Enterococci	6.785	-7.01	0.98	-0.19	0.19	0	-5.89
Conductivity, Hardness, Detergents, Potassium, Turbidity, Enterococci	7.06	-7.375	0.96	-0.19	0.27	0	5.66
Fluoride, Hardness, Detergents, Potassium, Turbidity, Enterococci	5.67	-6.25	1.07	-0.22	0.83	-0.01	-5.35
Conductivity, Hardness, Fluorescence, Potassium, Turbidity, Enterococci	7.145	-7.435	0.83	-0.04	0.22	0	5.265

Conductivity, Hardness, Detergents, Ammonia, Turbidity, Enterococci	7.35	-7.695	1.105	-0.2	0.21	0	-4.82
Conductivity, Fluoride, Hardness, Detergents, Potassium, Enterococci	1.5	-3.365	3.65	-0.595	0.09	0	-2.66
Fluoride, Detergents, Fluorescence, Potassium, Boron	2.635	-4.98	0.36	0.61	-0.03	1.75	-2.095
Conductivity, Fluoride, Hardness, Color, Turbidity, Boron	1.88	-5.22	0.23	0.65	-0.06	2.195	-1.865
Conductivity, Fluoride, Hardness, Potassium, Boron, Enterococci	0.77	-3.61	3.675	0.05	-0.075	0	-1.74
Fluoride, Hardness, Potassium, Turbidity, Boron, Enterococci	3.41	-4.17	2.23	-0.75	0.5	0	-1.49
Conductivity, Fluoride, Hardness, Detergents, Boron, Enterococci	0.405	-2.745	4.14	-0.68	-0.065	0	-1.035
Conductivity, Fluoride, Detergents, Potassium, Turbidity, Enterococci	1.015	-0.31	0.17	-0.03	0.22	0	-1.02
Conductivity, Hardness, Potassium, Turbidity, Boron, Enterococci	5.37	-5.49	1.59	-0.81	0.37	0	-0.35
Conductivity, Fluoride, Fluorescence, Ammonia, Boron, Enterococci	-0.105	0.335	1.12	-0.05	0.01	0	-0.3
Conductivity, Fluoride, Fluorescence, Potassium, Boron, Enterococci	0.38	0.05	0.485	-0.03	0.17	0	-0.27

Table G.5 Analysis by model of outfall sample collected at outfall # 36 for various combinations of tracers

Selected Tracers	Tap water	Spring water	Carwash	Laundry	Sewage	Irrigation	Mu
Conductivity, Hardness, Detergents, Ammonia, Turbidity, Enterococci	0.86	0.02	-0.03	0.01	0.08	0	-1.84

Conductivity, Hardness, Fluorescence, Potassium, Turbidity, Enterococci	0.79	0.165	-0.03	0	0.08	0	-0.545
Conductivity, Fluoride, Hardness, Detergents, Turbidity, Enterococci	0.75	0.22	-0.02	0	0.06	0	-0.51
Conductivity, Fluoride, Fluorescence, Potassium, Turbidity, Enterococci	0.79	0.18	-0.05	0	0.08	0	-0.495
Fluoride, Hardness, Detergents, Fluorescence, Turbidity, Enterococci	0.7	0.3	-0.01	0	0.01	0	-0.44
Fluoride, Hardness, Detergents, Ammonia, Turbidity, Enterococci	0.67	0.33	-0.01	0	0.01	0	-0.42
Conductivity, Hardness, Detergents, Potassium, Turbidity, Enterococci	0.775	0.16	-0.04	0.01	0.07	0	-0.395
Conductivity, Fluoride, Hardness, Detergents, Fluorescence, Enterococci	0.49	0.4	0.04	-0.01	0.07	0	-0.37
Fluoride, Hardness, Detergents, Potassium, Turbidity, Enterococci	0.53	0.44	0.02	0	0	0	-0.33
Conductivity, Fluoride, Hardness, Potassium, Boron, Enterococci	0.39	0.37	0.16	0.055	0.04	0	-0.3
Conductivity, Fluoride, Hardness, Turbidity, Boron, Enterococci	0.43	0.52	0.01	-0.01	0.06	0	-0.2
Fluoride, Hardness, Potassium, Turbidity, Boron, Enterococci	0.4	0.53	0.05	0.01	-0.01	0	-0.15

Table G.6 Analysis by model of outfall sample collected at outfall # 39 for various combinations of tracers

Selected Tracers	Tap water	Spring water	Carwash	Laundry	Sewage	Irrigation	Mu
Fluoride, Hardness, Detergents, Fluorescence, Potassium, Enterococci	1	-0.32	0.11	-0.02	0.185	0	-0.74
Fluoride, Hardness, Detergents, Fluorescence, Color, Turbidity	1.01	-0.44	0	0	0.05	0.31	-0.73
Fluoride, Hardness, Detergents, Fluorescence, Potassium, E-Coli	1	-0.34	0.11	-0.02	0.2	-0.02	-0.7
Conductivity, Fluoride, Hardness, Detergents, Fluorescence, Enterococci	1.2	-0.18	-0.05	0.02	0.03	0	-0.63
Fluoride, Detergents, Fluorescence, Potassium, Ammonia, Color	0.86	-0.25	0	0.01	0.01	0.4	-0.605
Conductivity, Fluoride, Hardness, Detergents, Fluorescence, Potassium	0.83	-0.31	0.01	0	0	0.43	-0.6
Conductivity, Fluoride, Hardness, Detergents, Fluorescence, E-Coli	1.16	-0.13	-0.06	0.02	0.02	0	-0.58
Hardness, Detergents, Fluorescence, Potassium, Ammonia, E-coli	0.985	0.01	-0.07	0.02	-0.02	0	0.56
Conductivity, Fluoride, Hardness, Detergents, Ammonia, E-Coli	0.96	-0.07	0.17	-0.02	0.01	0	-0.545
Fluoride, Detergents, Fluorescence, Potassium, Color, Turbidity	0.85	-0.08	-0.01	0.01	0.08	0.14	-0.535
Hardness, Detergents, Fluorescence, Potassium, Ammonia, Enterococci	0.975	0	-0.07	0.02	-0.02	0	0.525
Fluoride, Hardness, Fluorescence, Potassium, Turbidity, E-Coli	0.87	-0.025	0.08	0.02	0.04	0	-0.49
Detergents, Fluorescence, Ammonia, Turbidity, Boron, Enterococci	-0.075	1.17	-0.08	0.02	-0.01	0	0.12
Conductivity, Fluoride, Hardness, Detergents, Boron, Enterococci	0.31	0.75	-0.07	0.02	-0.01	0.02	0.11
Fluoride, Detergents, Fluorescence, Potassium, Ammonia, Boron	0.34	0.75	-0.08	0.02	-0.01	0.01	0.105
Conductivity, Fluoride, Hardness, Color, Turbidity, Boron	0.375	-0.03	0.05	-0.01	-0.02	0.495	-0.1
Conductivity, Fluoride, Fluorescence, Potassium, Boron, E-Coli	0.3	0.575	0.1	0.02	0	0	0.03
Conductivity, Fluoride, Hardness, Detergents, Boron, Enterococci	0.34	0.275	0.5	-0.07	0	0	-0.01

Table G.7 Analysis by model of outfall sample collected at outfall # 45 for various combinations of tracers

Selected Tracers	Tap water	Spring water	Carwash	Laundry	Sewage	Irrigation	Mu
Conductivity, Fluoride, Hardness, Detergents, Fluorescence, Enterococci	-0.66	1.905	-0.26	0.07	-0.02	0	0.73
Conductivity, Fluoride, Hardness, Detergents, Fluorescence, E-Coli	-0.53	1.73	-0.23	0.07	-0.03	0	0.67
Conductivity, Fluoride, Hardness, Detergents, Ammonia, Enterococci	-0.325	1.5	-0.325	0.07	-0.01	0	0.46
Conductivity, Fluoride, Hardness, Detergents, Boron, Enterococci	0.035	1.33	-0.42	0.08	-0.025	0	0.13
Conductivity, Fluoride, Hardness, Fluorescence, Potassium, Enterococci	0.175	1.175	-0.48	0.08	-0.02	0	0.13
Conductivity, Fluoride, Hardness, Detergents, Potassium, Enterococci	0.2	1.16	-0.44	0.09	-0.03	0	0.07

Table G.8 Analysis by model of outfall sample collected at outfall # 53 for various combinations of tracers

Selected Tracers	Tap water	Spring water	Carwash	Laundry	Sewage	Irrigation	Mu
Conductivity, Fluoride, Hardness, Fluorescence, Turbidity, Enterococci	0.19	0.77	0.07	0	-0.04	0.01	-0.21
Conductivity, Fluoride, Hardness, Detergents, Fluorescence, Enterococci	0.29	0.76	-0.02	0.01	-0.03	0	-0.205
Conductivity, Fluoride, Hardness, Detergents, Fluorescence, E-Coli	0.21	0.75	-0.01	0	-0.03	0.04	-0.2
Conductivity, Fluoride, Fluorescence, Potassium, Enterococci	0.255	0.73	0	0	-0.04	0	-0.18
Conductivity, Fluoride, Hardness, Detergents, Turbidity, Enterococci	0.195	0.8	0.06	-0.01	-0.04	0	-0.155
Conductivity, Fluoride, Hardness, Potassium, Boron, Enterococci	0.18	0.79	0.02	0.05	-0.05	0	-0.09
Conductivity, Fluoride, Hardness, Turbidity, Boron, Enterococci	0.18	0.81	0.02	0.05	-0.04	0	-0.09

Conductivity, Fluoride, Hardness, Ammonia, Boron, Enterococci	0.1	0.91	-0.05	-0.03	0.01	0	0
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Table G.9 Analysis by model of outfall sample collected at outfall # 55 for various combinations of tracers