STORMWATER RUNOFF QUALITY AND QUANTITY FROM SMALL WATERSHEDS IN AUSTIN, TX

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Prepared by

City of Austin
Watershed Protection and Development Review Department
Environmental Resource Management Division
Water Quality Monitoring Section

Project Team

Roger Glick, P.E., Ph.D., Section Manager
Truman Zhu, Data Analyses, Water Quantity
Baolin Bai, Data Analyses, Water Quality
James Hubka, Data Analyses, Data Processing and Database Development
Richard Robinson, Data Processing and Data Management
Sam Mahmoud, Field Data Collection and Data Management
Steve Manning, Field Data Collection and Data Management
Aboli Moezzi, Field Data Collection and Data Management
Jeff Selucky, Field Data Collection and Data Management

ERM Division Manager

Tom Ennis, P.E.

WPDR Department Management

Nancy L. McClintock, Assistant Director
Victoria J. L. Hsu, P.E., Director

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EXECUTIVE SUMMARY

The purpose of this report is to summarize stormwater data collected by the City of Austin with respect to runoff quality and quantity. This report examined data from 38 stormwater monitoring sites collected between 1984 and 2006.

The specific objectives and the corresponding scopes of the study are:

- Evaluate the stormwater runoff conditions for each monitoring site. Compute the mean runoff pollutant concentrations and the mean runoff volume to rainfall volume ratios (runoff coefficients) for the watershed above the monitoring site.

- Evaluate the impacts of land development on stormwater pollution. Establish relationships between mean runoff pollutant concentrations and percent impervious cover.

- Evaluate the impacts of urban development on stormwater quantity. Develop equations of runoff ratios versus percent impervious cover for non-recharge zones, and the Edwards Aquifer recharge zone.

- Compare the results of this study to prior studies and recommend changes to the City of Austin Environmental Criteria Manual as needed.

Stormwater Quantity

These data indicated that there is a positive correlation between the impervious fraction of the watershed and the fraction of rainfall that ends up as runoff. The fraction of rainfall that becomes runoff is referred to as the runoff coefficient or Rv developed over the entire monitoring period, not on individual events. The relationship between Rv and impervious cover is linear and differs significantly from the relationship currently found in the City of Austin Environmental Criteria Manual. Further, these analyses did not find a statistical difference in runoff relationships in the recharge zone and in areas that were not affected by recharge.

Stormwater Quality

The pollutant parameters included in this study are: 5-day biochemical oxygen demand (BOD), chemical oxygen demand (COD), total organic carbon (TOC), total suspended solids (TSS), volatile suspended solids (VSS), nitrate and nitrite (NO23), ammonia (NH3), total Kjeldahl nitrogen (TKN), total nitrogen (TN; theoretically, TN = NO2 + NO3 + TKN), total phosphorous (TP), dissolved phosphorous (DP), total cadmium (Cd), total copper (Cu), total lead (Pb), total zinc(Zn), fecal coliform (FCOL), and fecal streptococci (FSTR).

The data indicate that there is a statistically significant relationship between impervious cover and BOD, COD, Cu, DP, NH3, Pb, and Zn. These relationships may be used to estimate mean stormwater concentrations for these pollutants. The data further indicate the mean stormwater concentrations of five other pollutants (FCOL, NO23, TKN, TN, and TP) differed significantly between developed and undeveloped land use. The remaining five pollutants did not exhibit any statistically significant trend with impervious cover or development condition. These relationships differ significantly from those currently found in the City of Austin Environmental Criteria Manual.

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1 INTRODUCTION

The City of Austin (COA) has a long history of evaluating the effects of various types of development on water quality and quantity. The City participated in the Nationwide Urban Runoff Program (NURP) study in 1981. Austin's participation in the NURP study consisted of three monitoring sites, two residential and one control watershed (Engineering Science and COA, 1983). In 1983-84 COA and U.S. Geological Survey included monitoring of two water quality control systems as part of their annual Cooperative Monitoring Program (COA, 1984 and USGS, 1987). Both of these monitoring efforts were limited in both time and scope.

The City initiated a third stormwater monitoring program in 1985 (COA, 1985) to collect data to support a series of watershed management ordinances adopted by the City. This program initially planned to monitor eleven sites, including seven water quality controls of different types, over five years. The planned longer monitoring period was supposed to result in monitoring rainfall events that better reflected the rainfall patterns in the local area since the earlier monitoring programs focused mainly on smaller events. Due to various reasons, data were collected at only nine monitoring sites.

In the early 1990s Austin started a comprehensive monitoring program to address the complete stormwater monitoring needs of the City including ordinance verification and support, stormwater quality control evaluation, and compliance with state and federal permits (COA 1996). To date, this program has monitored 54 sites including 22 stormwater best management practices (BMPs) of various types. These monitoring sites represent runoff quality and quantity from smaller (<400 acres) watersheds that are predominated by a single land use. During the same time period, COA and USGS have continued their Cooperative Monitoring Program, which has focused mainly on flows and water quality in creeks, lakes, spring and aquifers (COA, 1996).

1.1 Objectives and Scope of the Study

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- Evaluate the impacts of urban development on stormwater quantity. Develop equations of runoff ratios versus percent impervious cover for non-recharge zones, and the Edwards Aquifer recharge zone.

- Compare the results of this study to prior studies and recommend changes to the City of Austin Environmental Criteria Manual as needed.

The pollutant parameters included in this study are: 5-day biochemical oxygen demand (BOD), chemical oxygen demand (COD), total organic carbon (TOC), total suspended solids (TSS), volatile suspended solids (VSS), nitrate and nitrite (NO23), ammonia (NH3), total Kjeldahl nitrogen (TKN), total nitrogen (TN; theoretically, TN = NO2 + NO3 + TKN), total phosphorous (TP), dissolved phosphorous (DP), total cadmium (Cd), total copper (Cu), total lead (Pb), total zinc(Zn), fecal coliform (FCOL), and fecal streptococci (FSTR). The unit of concentrations for fecal coliform and fecal streptococci are reported as colonies per 100 milliliters. The concentration units for metals are reported as micrograms or milligrams per liter, as noted. Other concentrations are reported as milligram per liter.

1.2 Definitions of Terms Used in this Study

The monitoring study uses some technical terms referred to throughout this report. The following definitions are provided to clarify these terms and to improve the readability of the report.

Percent Impervious Cover (PIC): PIC is the ratio of gross impervious area in a watershed to the total drainage area of the watershed, expressed as a percentage of the drainage area. Traditionally, PIC has often been used to represent the overall development condition of a watershed. The gross impervious cover is different from the connected impervious cover. While all parts of the connected impervious cover are directly connected to the drainage channels, a portion of the gross impervious area may be connected to the drainage channels through some pervious areas. For watersheds of the same amount of effective impervious cover, the gross impervious covers can be quite different. Estimating the connected impervious for a watershed can be quite difficult and was not attempted as a part of this study. There are no plans at this time to use connected impervious cover in later analyses since it may undergo undetected changes due to minor modifications by the land owner while gross impervious cover will not. There was also no attempt to differentiate types of impervious cover (streets or rooftops) even though the runoff water quality may vary depending on the source. While this information may be desirable, there is no practical way to achieve it with the data in this report or with field scale monitoring.

Event Mean Concentration (EMC): For this study, EMCs were computed as the sum of the load divided by the sum of the volume for an event. Instantaneous loading rates were computed by linearly interpolating the concentration between samples and multiplying by the flow rate. In cases where the first or last sample was not collected at the beginning or end of the event, the concentrations at those points were fixed to that of the closest sample. This study considers an EMC value as valid if the sampling for the event satisfies a specific quality control criterion, namely minimum score. In general, the sampling should cover not only the first flush of runoff but a major portion of the total volume of runoff generated from the event.

EMC Scoring: This study uses an EMC scoring methodology that examines the maximum volume between samples and the volume at the beginning and end of the event that were not sampled. Events are ordered based on these criteria and the best events are deemed "acceptable." The acceptable level is not fixed but is a sliding scaled based on the number of EMCs, thus allowing for a sufficient number of EMCs for analyses. As different types of events tend to result in different types of scoring problems, it is believed that this scoring scheme results in good quality data that is not biased toward any particular type of storm event.

Mean Concentration (MC): MC is an average concentration for specific runoff pollutant for a watershed. Many methods have been proposed to compute a mean concentration from event mean concentrations, and each has certain advantages and disadvantages. This report uses volume-weighted means represented by:

$$MC = \frac{\sum_{i=1}^{n} C_i V_i}{\sum_{j=1}^{n} V_j} \qquad [1.1]$$

where C is an EMC and V is a volume of runoff the associated event.

This representation of the mean is correct for computing loads; however, other methods may be used depending on the types of analyses. See Section 1.4 for a review of statistics used in this report, pros and cons for using different methods to compute environmental means and appropriate applications for such. SWQM has used other methods in other reports.

Runoff Ratio (Rv): Rv is defined as the ratio of stormwater runoff volume to storm rainfall volume for a given watershed. Individual event runoff ratios may be computed; however, they are strongly influenced by factors such as antecedent conditions and rainfall intensity as well as rainfall volume and impervious cover. Since the focus of this study is to estimate average annual runoff ratios, only those will be presented. As with mean concentrations, the most appropriate method to compute an unbiased mean from individual runoff ratios will be a rain-volume weighted mean represented by:

$$Rv = \frac{\sum_{i=1}^{n} RO_i}{\sum_{j=1}^{n} RF_j} \qquad [1.2]$$

where RO an the volume of runoff for the event and RF is volume of rainfall for the associated event.

Level of Significance: This study adopted the level of significance of $p = 0.05$ for a statistical test unless otherwise noted. If $p \leq 0.05$ is true, then the initial hypothesis is rejected and the relationship or difference is referred to as significant. If a weak relationship or difference exists, it may be reported with the corresponding level of significance.

1.3 **Environmental Statistics**

Various statistical methods and assumptions were used in the preparation of this report. This summary will present an explanation for methods used and the rationale behind their selection.

1.3.1 Estimating Parameters of Environmental Data

Many studies have proposed that environmental data are generally log-normally distributed (Gilbert, 1987). If this is the case, specific methods should be used to determine parameters (mean and variance) of the data and when performing statistical tests.

Determining data distribution

The first step in assessing data distribution is a visual inspection of the data (Law and Kelton, 1982). This is easily done by first sorting the data from smallest to largest, then plotting the data, x_i v. i/n where n is the number of points in the data set. This will result in the cumulative distribution of the data. The cumulative distribution function (CDF) for standard distributions (based on the parameters of the data) may be plotted on the same graph and visually compared to the distribution of the data. This has been done for the EMCs used in the Small Watershed report, sorted by pollutant (see Appendix A). It is clear from visual inspection that the data fit a log-normal distribution better than a normal distribution and therefore should be treated as such.

While it was not done with these data, goodness-of fit tests such as Kolmogorov-Smirnov (Law and Kelton, 1982 and Gilbert, 1987) could be performed to determine which distribution best fits the data. Given the results of the visual inspection, this was not required with these data.

Estimating Mean and Variance

Gilbert (1987) states there are four methods to estimate the mean, μ, and the variance, σ^2, for log-normally distributed data. The first is the simple arithmetic sample mean, $\bar{x}$. This is easy to compute and is a statistically unbiased estimator of the mean regardless of the underlying distribution. It is also the minimum variance unbiased (MVU) estimator if the underlying distribution is normal. If the underlying distribution is log-normal, it is not the MVU estimator and will be sensitive to large values. It has been suggested that $\bar{x}$ be used as the estimator for μ

Table 1.1: Data parameter estimations.

Pollutant	$\bar{x}$	s	H
BOD	16.03	47.10	2.94
Cd	0.714	1.442	2.02
COD	81.48	92.77	1.14
Cu	15.31	29.37	1.92
DP	0.178	0.197	1.11
FCOL	58570	185498	3.17
FSTR	118753	202622	1.71
NH3	0.267	0.328	1.23
NO23	0.580	0.452	0.78
Pb	24.54	36.16	1.47
TKN	1.724	1.705	0.99
TN	2.296	1.972	0.86
TOC	14.73	22.81	1.55
TP	0.433	0.457	1.05
TSS	165.1	194.3	1.18
VSS	40.07	49.44	1.23
Zn	112.9	137.8	1.22

if the coefficient of variation, η (σ/μ), is less that 1.2, presumably due to ease of computation. Table 1.1 contains $\bar{x}$, s, and η for each pollutant used in this study. The coefficient of variation for 10 of the seventeen pollutants exceeds 1.2, which would preclude using an arithmetic mean to estimate μ for those pollutants. For consistency sake, this method was not used for any pollutants.

It is tempting to estimate μ of a log-normal distribution using the geometric mean; however, the geometric mean is a bias estimator of the true mean of the data (Gilbert, 1987). While it was not used in these analyses, it may be presented in results of statistical analyses in other studies (East Austin, Golf Course, or other studies which performed statistical analyses on the EMC rater than the MC as was done in this report). For reference, the geometric mean is computed by taking the arithmetic mean of the log-transformed data, then transforming with the exponential.

A simplified method to estimate μ and σ^2 for log-normally distributed data was proposed by Driscoll (1989) and accepted by EPA as part of the NURP report. This method has been used by COA in the past. This method does have some bias, but the bias is minimized as *n* increases. One advantage of this method is it is simple to compute; however, with current computing capacities this is not an issue. This method reference in City data as the 'Driscoll mean' is defined as follows:

$$\hat{\mu} = e^{\left(\bar{y}+\frac{s_y^2}{2}\right)} \qquad [1.3]$$

and

$$\hat{\sigma}^2 = \hat{\mu}^2\left(e^{s_y^2} - 1\right) \qquad [1.4]$$

where,

$\hat{\mu}$ = the estimate of the mean of data from a log-normal distribution,

$\hat{\sigma}^2$ = the estimate of the variance of data from a log-normal distribution,

$\bar{y}$ = the arithmetic sample mean of the log transformed data, and

s_y^2 = the sample variance of the log transformed data.

While this method has been widely used in the past to compute the mean of log-normally distributed data, it still has some bias, particularly with smaller datasets (Gilbert, 1987). Gilbert presented a more completed method to compute the minimum variance estimator of the mean for log-normally distributed data. This method reference in City data as the 'Gilbert mean' is defined as follows:

$$\hat{\mu} = \left(e^{\bar{y}}\right)\Psi_n\left(\frac{s_y^2}{2}\right) \qquad [1.5]$$

and

$$\hat{\sigma}^2 = \left(e^{(2\bar{y})}\right)\left[\Psi_n\left(2s_y^2\right) - \Psi_n\left(\frac{s_y^2(n-2)}{n-1}\right)\right] \qquad [1.6]$$

All four of these methods may be used (and are computed by COA for reference) to estimate the mean and variance of environmental data. These may be useful in estimating the EMC for the next event; however, since the concentration of an EMC may be dependent on the size of the event, another non-statistical bias is introduced when computing the mean that of storm size.

This needs to be addressed if the goal is to predict long-term loads rather than an estimate of the next EMC. Since a small event may have a higher concentration but little runoff volume, it represents a small portion of the total load compared to a large event with a lower EMC. To address this, COA uses a volume-weighted mean to estimate the mean watershed concentration. Two issues arise when using this method. First, the distribution of sampled events should follow the distribution of rainfall events and second, a variance cannot be computed. COA strives to minimize bias in its sample collection to address the first issue. The second issue is less problematic since other methods of analysis are used when the analyses are using the EMC and a variance is required.

1.3.2 Model Significance and r^2

Statistics cannot be used to prove a hypothesis, only to reject one. Therefore, for analyses, a hypothesis, H, and a null hypothesis, H_0, need to be constructed is such a manner that one is the opposite of the other with the goal of rejecting H_0. In this case, H was impervious cover affecting MC concentration or Rv, and H_0 was impervious cover not affecting MC concentration or Rv. P>f is the probability that H_0 was rejected in error and H was accepted as a correct hypothesis. This is called a Type I error. For this study a level of significance of 0.05 was selected so if P>f is less than 0.05, H_0 was rejected and it was determined that impervious cover significantly affected Rv or MC for the pollutant in question. Otherwise, the null hypothesis was not rejected and it was determined that for that pollutant, impervious cover did not significantly affect impervious cover. While it was not addressed, there is a possibility of a Type II error, failing to reject the null hypothesis when it is false. With sufficient data, this is not usually a problem unless the variability is very high. (See discussion on TSS in this report.)

While P>f determined if impervious cover is a significant factor, r^2 is an estimate of how much variability in the data can be explained by impervious cover. As can be seen from these data, the level of significance may be very high but the portion of variability explained is proportionally small. This is due to many factors beyond the control of the study imparting variability into the data. These may include age of infrastructure, housekeeping, population density, chemical use, traffic patterns, and watershed size, among others. While each of these may contribute, it would be difficult for others to predict them for new developments when estimating future loads. Prior COA analyses indicated that these factors were also far less significant than impervious cover.

1.4 **Report Data**

The data used in this report were collected at the sites presented in Table 1.2 and Figure 1.1. The flow, rainfall and water quality data used in this report were collected between 1984 and 2004. Land uses are identified as follows: COMM is commercial, INDU is industrial, Mixed Use contains multiple land uses, MFR is multi-family residential, SFR is single-family residential, TRANS is transportation, and UNDV is undeveloped.

Table 1.2: Description of Monitoring Sites

SITE	Site Name	Imp. Cover	Area (ac)	Land Use	Recharge	Rv Analyses	WQ Analyses
BC	Bear Creek Near Lake Travis	3.00%	301.00	UNDV	No	Yes	Yes
BCU	Barton Creek, Undeveloped	0.07%	17.33	UNDV	Yes	Yes	Yes
BI	Brodie Oaks Influent	95.00%	30.90	COMM	Yes	No	Yes
BNI	Highway BMP #6 Influent	58.53%	4.93	TRANS	Yes	No	Yes
BRI	Barton Ridge Plaza Influent	80.32%	3.04	COMM	No	Yes	Yes
BSI	Highway BMP #5 Influent	64.20%	4.63	TRANS	Yes	Yes	Yes
BUA	Burton Road	82.00%	11.59	MFR	No	No	Yes
CMI	Central Market Influent	54.68%	100.03	Mixed Use	No	Yes	Yes
E7A	East Austin at East 7th	60.07%	29.28	INDU	No	Yes	Yes
EBA	East Austin at Belfast	40.36%	35.24	SFR	No	Yes	Yes
EHA	Holly & Anthony	43.42%	51.34	SFR	No	Yes	Yes
EMA	Mansell at Boggy Creek	42.04%	15.73	SFR	No	Yes	Yes
ERA	Robert Mueller Airport	46.00%	99.79	TRANS	No	Yes	Yes
FPI	Far West Pond Influent	56.94%	240.01	Mixed Use	No	No	Yes
FSU	Sycamore Creek at Republic of Texas	0.95%	235.01	UNDV	Yes	Yes	Yes
FWU	Windago Undeveloped	0.80%	45.90	UNDV	No	Yes	Yes
GPI	Gillis Park O/G Chamber Influent	55.37%	64.17	Mixed Use	No	No	Yes
HI	Highwood Apartments Influent	50.00%	3.00	MFR	Yes	Yes	Yes
HLA	Hart Lane	39.09%	329.14	SFR	Yes	No	Yes
HPA	Hyde Park at 41st St.	53.50%	42.58	SFR	No	Yes	Yes
JVI	Jollyville Road Pond Influent	94.36%	7.02	TRANS	Yes	Yes	Yes
LCA	Lost Creek Subd.	22.50%	209.87	SFR	No	Yes	Yes
LGA	Lost Creek Golf Course Undeveloped	0.72%	473.53	UNDV	No	Yes	Yes
LUA	Lavaca Urban	97.42%	13.65	COMM	No	Yes	Yes
MBA	Metric Blvd. Industrial	60.93%	202.94	INDU	No	Yes	Yes
MI	Maple Run Pond Influent	36.00%	27.80	SFR	Yes	No	Yes

Table 1.2 (cont.): Description of Monitoring Sites.

SITE	Site Name	Imp. Cover	Area (ac)	Land Use	Recharge	Rv Analyses	WQ Analyses
OFA	Spyglass Office Site	86.20%	1.54	COMM	Yes	Yes	Yes
RO	Rollingwood	26.39%	62.90	SFR	Yes	No	Yes
S1M	Hargraves Service Center	88.18%	5.87	INDU	No	Yes	Yes
SI	Barton Creek Square Mall Influent	86.00%	47.00	COMM	Yes	Yes	Yes
SWI	St. Elmo Wet Pond East Influent	60.43%	16.41	INDU	No	Yes	Yes
SWJ	St. Elmo Wet Pond West Influent	83.84%	5.82	INDU	No	No	Yes
TBA	Tar Branch	45.21%	49.42	SFR	No	Yes	Yes
TCA	Travis Country Channel	37.36%	40.71	SFR	Yes	Yes	Yes
TPA	Travis Country Pipe	41.45%	41.60	SFR	Yes	Yes	Yes
W5A	5th St. at Red River	87.08%	6.66	COMM	No	Yes	Yes
WBA	Wells Branch	30.59%	0.93	COMM	No	Yes	Yes
WCI	3rd Street at Neches	92.98%	16.85	COMM	No	No	Yes

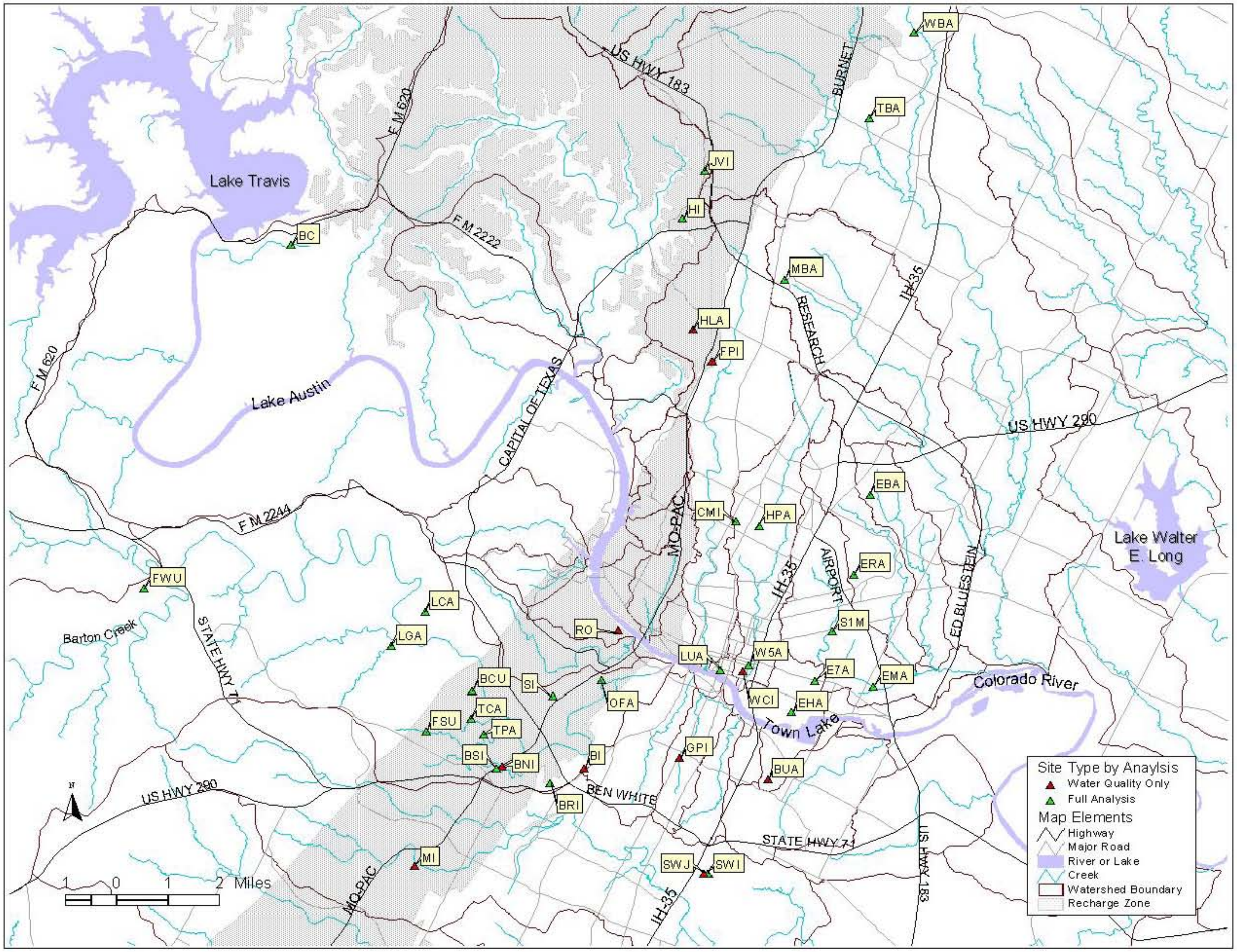

Figure 1.1. City of Austin Monitoring Stations.

2 DATA COLLECTION AND PROCESSING

The Stormwater Quality Monitoring Program (SWQM) has a detailed system for collecting, screening and processing water quality and quantity data. For ease of discussion, these data may be broken in to three main groups: flow data, rainfall data, and water quality data. A flow chart of the data management and processing used by SWQM may be found in Figure 2.1.

2.1 Flow Data

SWQM monitoring stations are equipped with automatic stage recorders and data loggers that measure and record stage in 1-minute increments. Stage may be measured using several different methods based on the conditions at the monitoring site; methods include pressure transducers, ultrasonic devices, and bubbler meters. SWQM uses bubbler meters in most instances because they have proven to be the most reliable for two main reasons. First, bubbler meters do not exhibit calibration problems that may be associated with pressure probes installed under normally dry conditions. This is important because installations at small watersheds do not normally have baseflow and are usually dry under non-storm conditions. In addition, it is difficult and time consuming to calibrate pressure probes that are installed in storm sewers that require confined-space entry procedures for service. Ultrasonic meters do not have the calibration drift problems associated with pressure probes, but they do require a minimum distance between the probe and the water surface, which may not be possible in some applications. Bubbler meters do have problems accurately measuring depth if the flow velocity surpasses approximately 5 fps, but otherwise they are accurate, reliable and easy to maintain. SWQM uses bubbler-type meters from a single supplier unless velocity problems exist and the flow measurement structure cannot be modified. In these cases, an area-velocity meter or an ultrasonic meter may be used, but these are rare cases.

Regardless of meter type, SWQM staff downloads level data from each meter on a regular basis and stores it on a central server. The level data are then loaded into a time-series database for further processing. SWQM uses the Hydstra/TS Time-Series Data Management module to store, screen, edit and process flow and level data. Hydstra/TS provides the tools for staff to dynamically verify data loggers were properly operating and recording data, thus reviewing large quantities of data in a short period of time. While screening level data, staff may delete spurious

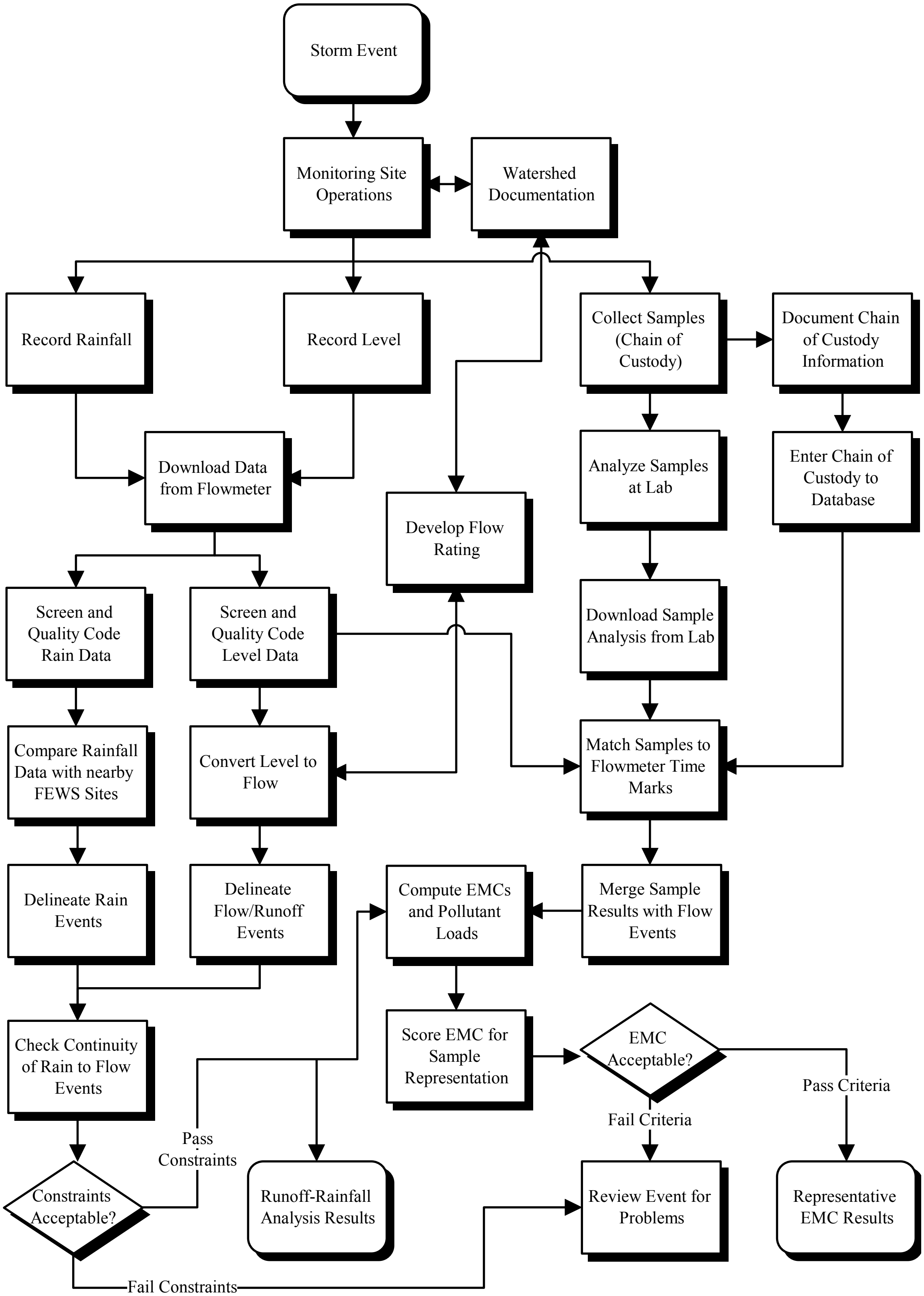

Figure 2.1. SWQM data processing and management flowchart.

points, adjust levels that are out of calibration, or simply code the data as unreliable. SWQM often installs multiple meters at each monitoring site to examine and verify site hydraulics and provide redundancy. If the data from the primary meter are unavailable, the data from the secondary meter may be used to complete the flow record. At this time staff also identifies the start and end times of flow events.

The start and end of a flow event depend on the type of measurement structure and the site characteristics. If the site uses a weir for the flow control, identifying the start and end of flow is quite easy: one simply identifies the time level corresponds to the crest of the weir and sets that as the start of flow or end of flow respectively. If the flow structure is a flume or open channel that is normally dry, the start of flow is set at the time some minimum depth, usually 0.1 ft, is reached and the end of flow is at the time when the level drops below that point. If the site in question normally has flow, or there is excessive flow after the end of rain due to groundwater flow, the start and end of the event are identified on a case by case basis. In all cases, City staff who are familiar with the site review the start and end of the event to verify their accuracy.

SWQM strives to measure flow as accurately as possible. In furtherance of this goal SWQM often installs standard flow measure structures including flumes, weirs or orifices. These structures are installed according to the manufacturers' specifications and standard practice. In cases where installing a structure is not feasible, SWQM uses open-channel flow techniques (Manning's equation, slope-area method, etc.) to estimate the stage-discharge relationships. When open-channel flow techniques are used to estimate flow, SWQM may also use a separate area-velocity meter to calibrate the flow at the site. Even taking these precautions, some sites may not have stage-discharge relationships that are accurate enough to measure flow sufficiently for use in runoff quality computations. In these cases, the data from the site will be excluded from runoff quantity computation but may still be used in runoff quality computations.

Once the data screening and other quality checks have been completed, Hydstra is used to compute the cumulative volume of runoff for each individual runoff event that has been delineated. These data are stored in a database for further processing and analyses.

2.2 **Rainfall Data**

SWQM collects rainfall data from several sources. Most SWQM stations are equipped with 0.01-inch tipping-bucket rain gauges. Data from these gauges are stored in the same data logger used for the stage data as one-minute cumulative rainfall depths. These data are downloaded and stored along with the stage data and screened in Hydstra/TS. Rainfall data are checked for spike or other extraneous data and for clogged or partially clogged rain gauges by comparing the data to the hydrograph and nearby rain gauges.

SWQM also collects rainfall data from the City's Flood Early Warning System (FEWS). FEWS stations are used primarily to predict flooding conditions and are equipped with 1-mm tipping-bucket rain gauges. These stations instantaneously report bucket tips to the FEWS central server via radio communication to be used for flood warnings. SWQM downloads these data monthly from the FEWS server to be used to supplement its own rainfall data. FEWS data are converted to one-minute rainfall depths in inches and screened to removed spikes and potential clogging.

After the data from each individual rain gauge have been screened and problematic data have been marked SWQM substitutes good rainfall data for missing or bad data from the nearest operable gauge. Substituted data are marked as such for future reference; a good quality is assigned if the data are from within 1.5 miles and an acceptable quality is assigned if the data are between 1.5 and 3 miles from the site in question. No substitution is allowed if there are no good data within three miles.

After each site has a complete, screened rainfall record, the start and end of individual rainfall events are delineated. Generally, an event must have a minimum of 0.04 inch (1 mm) of rainfall and should be followed by a 6-hour dry period. Note: up to 0.02 inches of rain are allowed during a dry period. These data are stored in a database for further processing and analyses.

2.3 **Water Quality Data**

The time each water quality sample is collected, whether automatic or manual, grab or composite aliquot, is recorded to link water quality results to the flow record. These sample times are stored in a database for further processing. Water quality results are transferred electronically from the analytical laboratory along with laboratory QA/QC results. The results are screened for statistical outliers that may be due to contamination or laboratory error. Laboratory QA/QC data for each samples are compared against control limits; results that fall outside control limits are flagged for further analyses.

Sample times are compared against previously recorded flow event starts and ends. If a sample falls outside a delineated flow event, staff may include the sample by adjusting the event start or end or by excluding the sample from computation if it is not representative of the flow event.

2.4 **Final Data Processing**

Once the individual components are processed, the final stage of processing reconciles any discrepancies. Rainfall events are compared with flow events to create a single start and end for each event. Sample times are checked to ensure samples fall within events. Other logical checks are performed to make sure events have been correctly screened. These include checking for flow before the start of rain or for rain after the end of flow, verifying that events do not overlap or that one event is not entirely contained within another event. Once these checks have been completed, event data are stored in a common database to be used to compute EMCs and Rvs. Water quality data are also loaded into Hydstra to be used for computing EMCs.

2.5 **Rv Computations**

Once the starts and ends of the flow and rainfall events have been reconciled, they are sent to Hydstra/TS, which returns values for cumulative rainfall and total flow during the event. These are stored in an external database and an event Rv may be computed. The mean site Rv is then computed as the sum of the depth of runoff divided by the sum of the depth of rainfall for all events that have both valid rainfall and flow, as described in Section 1.

2.6 **EMC Computations**

The computation of an EMC is more complex that the computation of an Rv for an event. The first step in computing an EMC is dealing with the unsampled potion of the event at the beginning and end of an event since samples are rarely collected precisely at beginning and end of flow. To account for this, “anchor” samples are place at the start and end of flow. For small

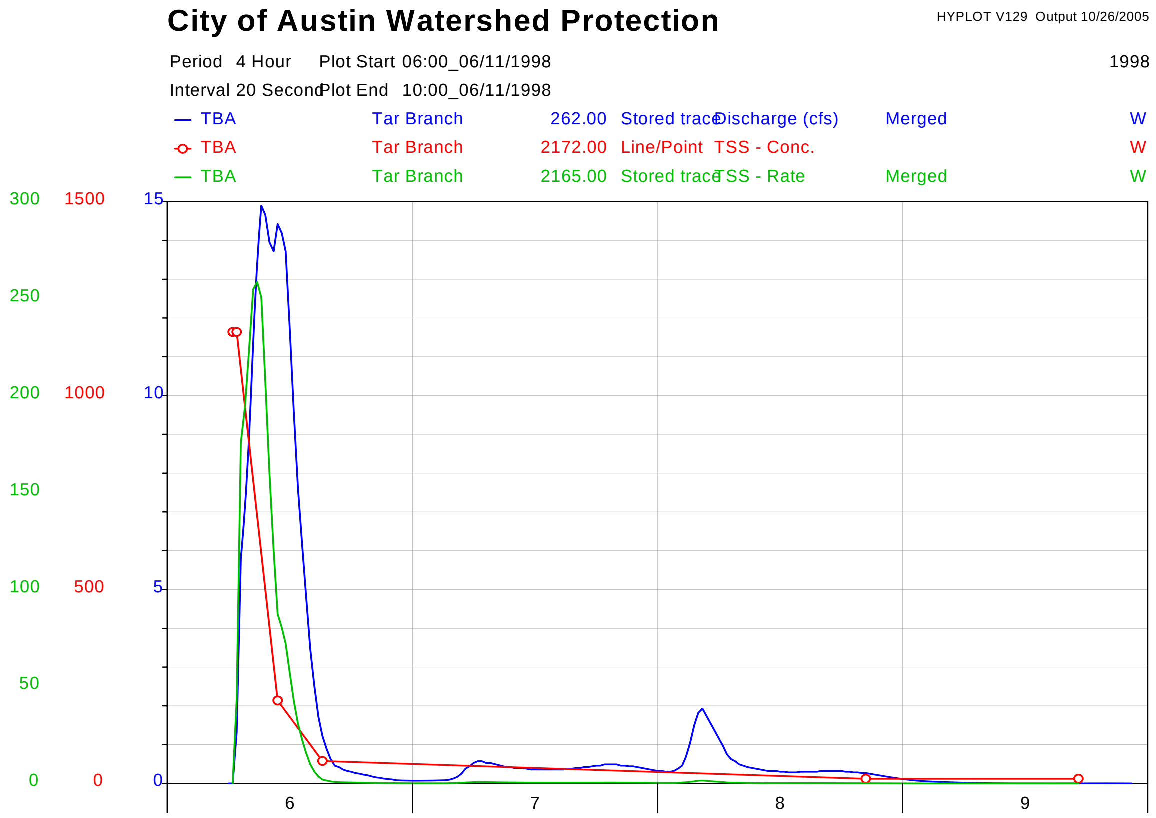

Figure 2.2. Hydrograph, water quality samples and pollutograph used to compute an EMC.

watersheds, the water quality of the first and last samples collected is assigned to the “anchor” sample at the start and end of the event respectively. While not part of this report, it should be noted that for larger watersheds that normally have baseflow, the water quality values for the anchor samples are set to be equal to the average baseflow samples for that site, assuming the baseflow average is less then the first or last sample respectively. Since each water quality sample represents a point in time, the assumption was made that water quality changes linearly between each sample. This assumption allows Hydstra/TS to construct a time-varying concentration record. This record is combined with the hydrograph to create a pollutograph, mass/time plotted against time. Once this is completed, Hydstra/TS computes a total load for the event. This process is repeated for each water quality parameter. Figure 2.2 is an example of combining the flow hydrograph and individual samples to create a pollutograph. Cumulative load and flow can be computed from these data.

Once the loads for the event have been computed, the EMCs for the event are computed in a manner similar to the Rv, total load of the event divided by the total volume of the event. The loads and EMCs are stored in an external database for later computations. The site mean concentrations (MC) are computed as the total load of acceptable events divided by the total volume of the same events. EMCs may be used for other analyses as needed.

SWQM evaluates each EMC to determine if the event was sufficiently sampled to be representative of the water quality during the event. Several items are checked during the event scoring including the volume sampled, the load sampled, the peak flow rate relative the flow rate at the time of sampling and the number of samples relative to the size of the event.

The first evaluation, the volume score, examines unsampled portions of the event. These analyses are divided into three components: 1) the portion of the event before the first sample, 2) the maximum portion of the event between each sample, and 3) the portion of the event after the last sample. The first sample is important because COA studies have shown that concentrations usually decrease after the “first-flush” for small urbanized watersheds. An initial score of 120 is assigned to the event and two points are deducted for every percent of the volume between the start of the event and the first sample. For the volume between samples, an initial score of 120 is assigned and 1 point is deducted for each percent of the volume represented by the largest gap between samples. The end of the events is scored similar to the intra-sample scoring; 120 is initially assigned as the score and one point is deducted for each percent of the volume after the last sample. The overall score is the minimum of the three components with the maximum set at 100.

The second evaluation, the load score, is computed by the same methodology as the volume score. However, the load score is not normally used to exclude events but may be used to flag an event for potential problems.

The next evaluation, the flow rate score, examines the flow rates at the time samples are collected relative to the maximum flow rate of the event. This score is important for pollutants that are related to erosion where concentrations may be related to the flow rate. The score is computed by taking the square root of the ratio of the maximum flow rate of the samples to maximum flow rate of the event and multiplying by 100.

The final evaluation determines if an adequate number of samples were analyzed for the size of the given runoff event. This analysis is more difficult than the others and is site specific. The initial assumptions were that the median-sized sampled runoff event at a site may be adequately characterized by four well-placed water quality samples; this event is arbitrarily assigned a score of 75. If the event size (runoff volume) is doubled, one additional sample is required to maintain a score of 75. One additional sample is required each time the volume of the runoff doubles. If the runoff volume is one-half the size of the average runoff event, only three samples are required to achieve a score of 75. The score is computed using the formula:

$$SampleScore = 75 + \left(10 * \left(EventSamples - \left(\left(\frac{\log\left(\frac{EventVolume}{MedianVolume} \right)}{\log(2)} \right) + 4 \right) \right) \right) \qquad [2.1]$$

An initial score is set as the volume score. One sample EMCs use the sample score only. For 2-sample EMCs, the score is the larger of the volume or sample score if the sample score is at least 50. For 3-sample EMCs the score is the larger of the sample or volume score if the volume score is at least 50. All EMCs are then checked against the flow rate score and it is used if it is lower than the other assigned score. WQM staff review all event scores and may override individual score components or the total score based on professional judgment and experience.

Once the score has been assigned, the level of acceptance is determined. Because environmental data are inherently variable, a sufficient number of samples are required to produce a valid mean of said data. Figures 2.3 and 2.4 are plots of EMCs and the volume-weighted mean for NO23 and TSS respectively at one site. It can be seen that as the number of EMCs increase, the variability of the mean decreases. Based on this, SWQM strives for a minimum of 10 EMCs to compute an MC. As such, the acceptable score for a site is based on a sliding scale. A score as low as 50 is acceptable if there are ten or fewer EMCs. A score of 70 is the minimum if there are thirty or more EMCs. Scores lower than 50 are never acceptable while scores greater than 70 are always acceptable. Data from unacceptable EMCs are preserved for possible use in other analyses.

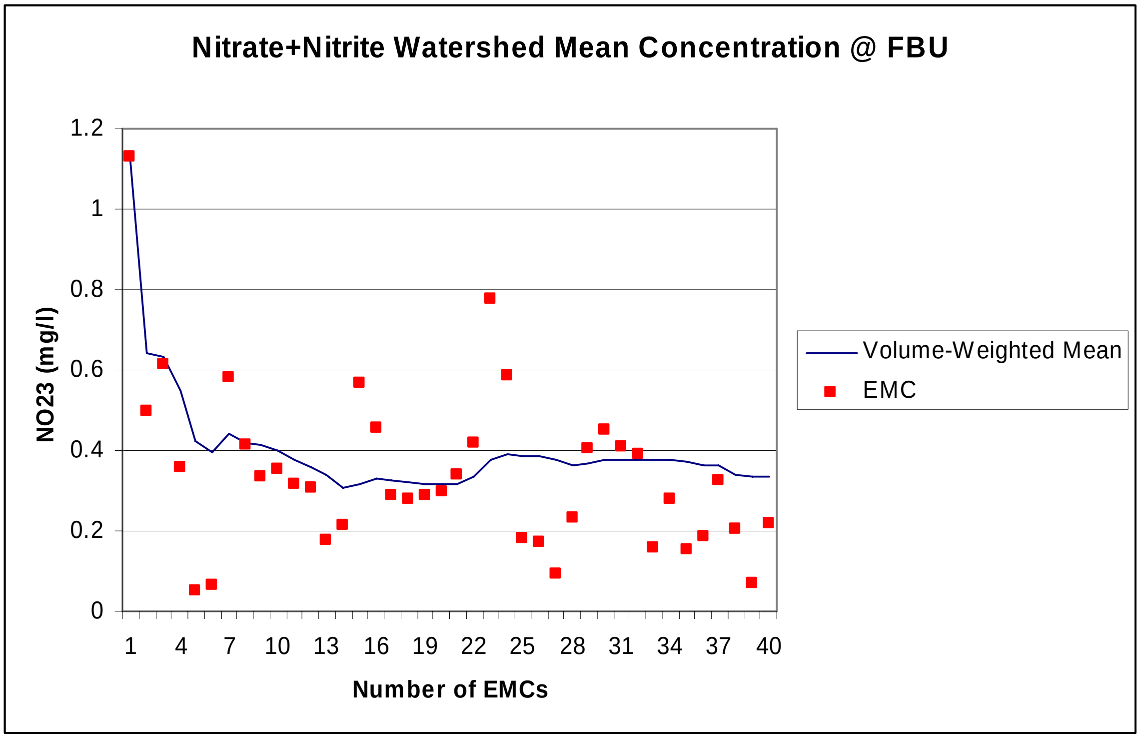

Figure 2.3. Nitrate+Nitrite watershed mean concentration computation.

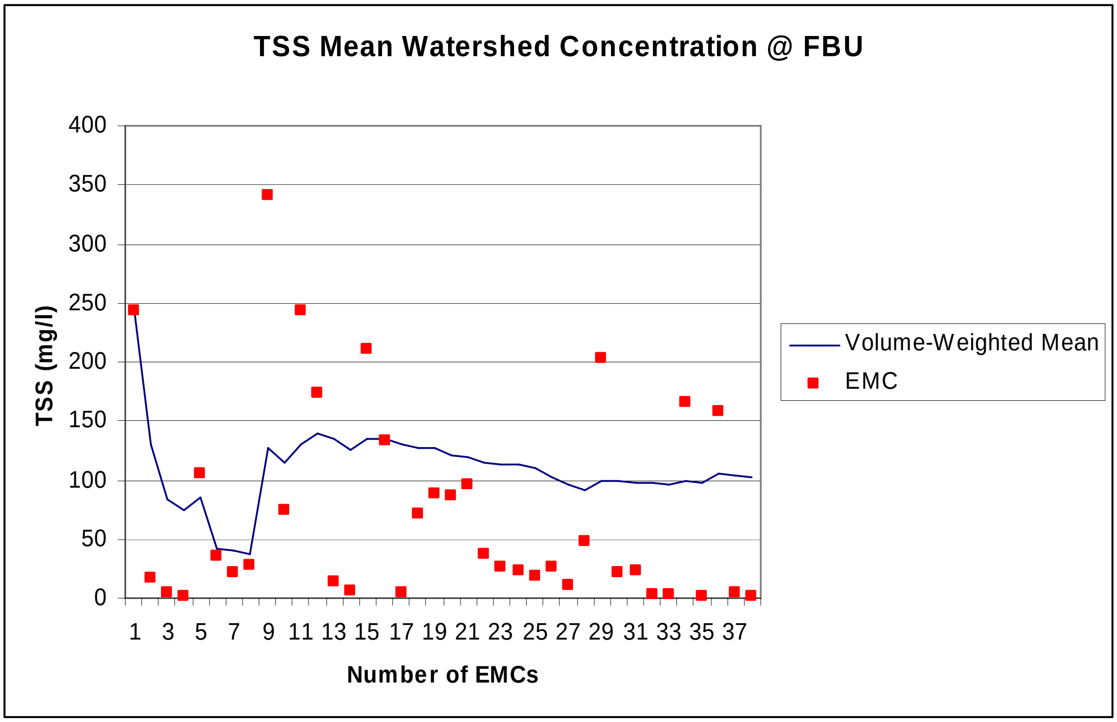

Figure 2.4. TSS watershed mean concentration computation.

3 WATER QUANTITY ANALYSES AND RESULTS

The City of Austin Stormwater Monitoring Program has been monitoring runoff from many watersheds over the past 20 years, resulting in a broad localized dataset of rainfall and runoff for analysis. The runoff ratio, Rv, for each watershed was computed based on these data for twenty-eight small watersheds in the Austin area. The computed runoff coefficients and the watershed characteristics are presented in Table 3.1 for all City of Austin watersheds used in these analyses.

Several curve-fitting models were applied to these data; the results of these analyses may be found in Appendix B. After comparing standard errors and correlation coefficients for the different models, it was found that a linear model produced one of the best fits and is one of the simplest models. The linear relationship and the quadratic relationship between runoff coefficient and impervious cover for all watersheds are shown in Figure 3.1. It is obvious that the two curves are very close each other and the T-test indicates that the second degree term in quadratic model is not significant. Therefore, the linear relationship is recommended to represent the relationship between runoff coefficient and impervious cover. The intercept of the linear model, where impervious cover is zero, results in a runoff coefficient of 0.0387. Table 3.2 has the recommended runoff coefficients, Rv, from zero to 100% impervious cover.

The City of Austin Environmental Criteria Manual (COA, 2004) (ECM) has included data to be used for estimating the average annual runoff based on impervious cover for a number of years. These data were based on early research by the City and best engineering judgment at the time. Figure 3.2 compares the data in the ECM with the linear regression for all watersheds. The ECM data, a quadratic relationship, fall outside the 95% confidence limit for the data used in this study, indicating a significant difference. The ECM model generally predicts a lower volume of runoff for a given impervious cover. Other studies including that by Barrett et al. (1998) also found this to be the case.

Table 3.1: Computed runoff coefficients and characteristics of watersheds

Site ID	Impervious Cover	Watershed Area (ac.)	Runoff Coefficient	Recharge Zone	No. of Events	Period of Monitoring
BC	0.030	301.00	0.008	No	46	1984-1991
BCU	0.001	17.33	0.020	Yes	430	1996-2004
BRI	0.803	3.04	0.781	No	323	1993-2002
BSI	0.642	4.63	0.716	Yes	121	1994-1997
CMI	0.547	100.03	0.303	No	287	1996-2002
E7A	0.601	29.28	0.381	No	249	1995-1999
EBA	0.404	35.24	0.106	No	221	1999-2003
EHA	0.434	51.34	0.417	No	432	1994-2003
EMA	0.420	15.73	0.508	No	227	1999-2003
ERA	0.460	99.79	0.379	No	259	1994-1999
FSU	0.064	329.75	0.071	Yes	381	1998-Present
FWU	0.008	45.90	0.044	No	191	1994-2001
HI	0.500	3.00	0.567	Yes	53	1985-1987
HPA	0.450	43.04	0.432	No	212	2000-2003
JV	0.944	7.02	0.694	Yes	499	1994-2002
LCA	0.225	209.87	0.135	No	270	1992-1999
LGA	0.007	481.07	0.077	No	293	1999-Present
LUA	0.974	13.65	0.629	No	237	1992-1998
MBA	0.609	202.94	0.415	No	130	1992-1995
OFA	0.862	1.54	0.738	Yes	145	1993-1997
S1M	0.882	5.87	0.489	No	184	1995-1999
SI	0.860	47.00	0.781	Yes	32	1985-1987
SWI	0.604	16.41	0.552	No	99	1995-1997
TBA	0.452	49.42	0.187	No	191	1996-2000
TCA	0.374	40.71	0.214	Yes	177	1993-1997
TPA	0.415	41.60	0.222	Yes	135	1993-1997
W5A	0.871	6.66	0.743	No	318	1993-1999
WBA	0.306	0.93	0.551	No	194	1999-2003

Table 3.2: Recommended runoff ratio Rv for recharge and non-recharge zones

Impervious Cover (%)	Runoff Coefficient
0	0.0347
10	0.1088
20	0.1829
30	0.2570
40	0.3311
50	0.4052
60	0.4793
70	0.5534
80	0.6276
90	0.7017
100	0.7758

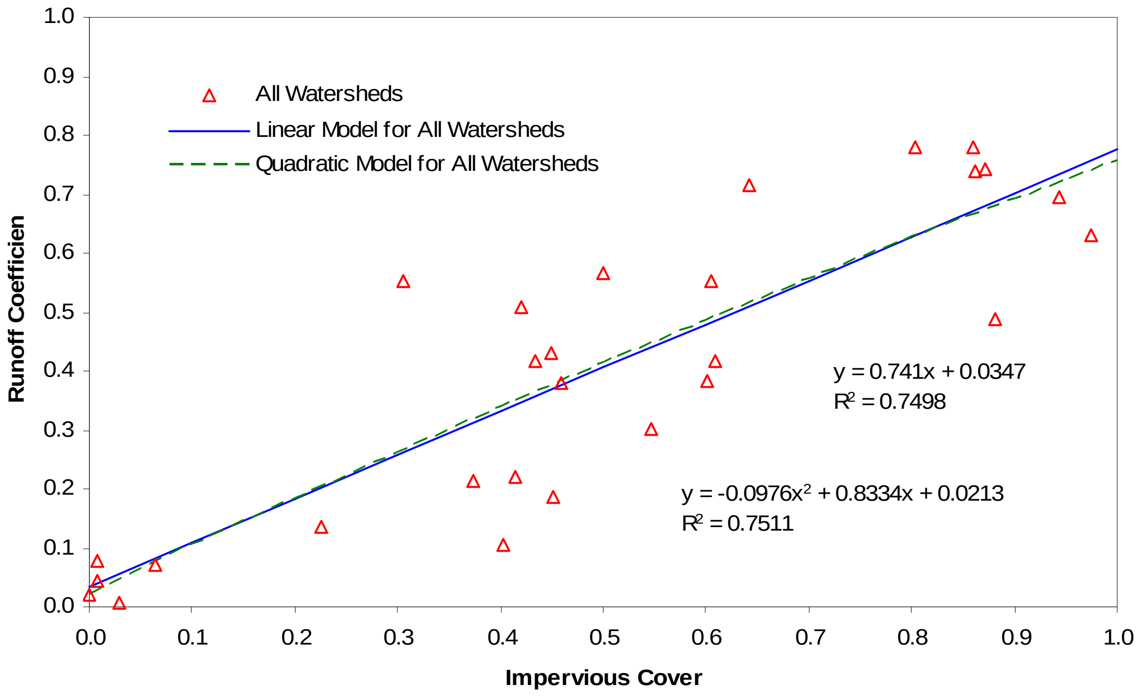

Figure 3.1: Relationship between runoff coefficient and impervious cover

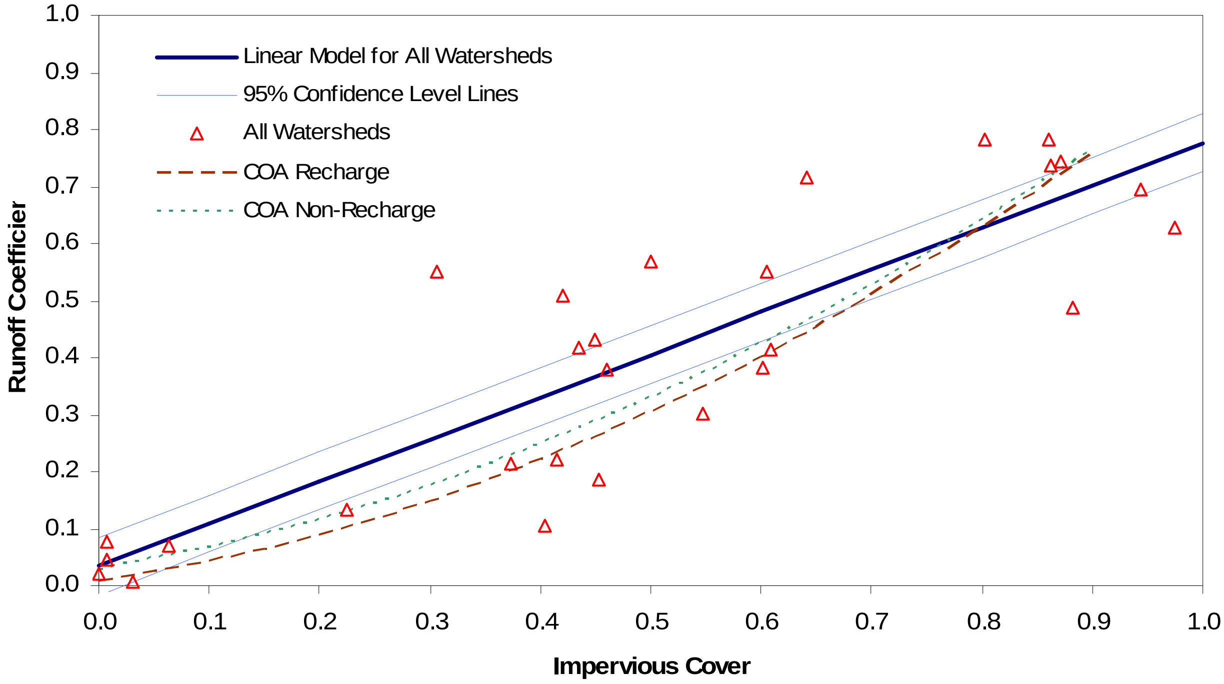

Figure 3.2: Comparison of runoff coefficient and impervious cover relationships with models in COA Environmental Criteria Manual

The runoff coefficient and impervious cover relationship is also compared with the model proposed by Barrett et al. (see Figure 3.3). This study was based in large part on City of Austin data; however it was a limited dataset. Because most part of Barrett, et al. model is within or nearly within the 95% confidence of the linear model from this study, the two models are not significantly different statistically. The Barrett et al. model is also a second-order polynomial model instead of a linear model. This model generally predicts lower runoff at lower impervious cover and greater runoff for impervious covers exceeding 60%.

The linear model for the relationship between runoff coefficient and impervious cover is further compared with data presented in an EPA Nationwide Urban Runoff Program (NURP) (Environmental Science and COA, 1983) report in the early 1980s (see Figure 3.4). It is can be seen that the linear models for NURP mean and median data are generally within 95% confidence of the linear model from this study. The mean NURP data result in a higher Rv at higher impervious cover and the median data result in a slightly lower Rv and slightly higher Rv at low and high impervious cover respectively. The NURP median data may be represented by

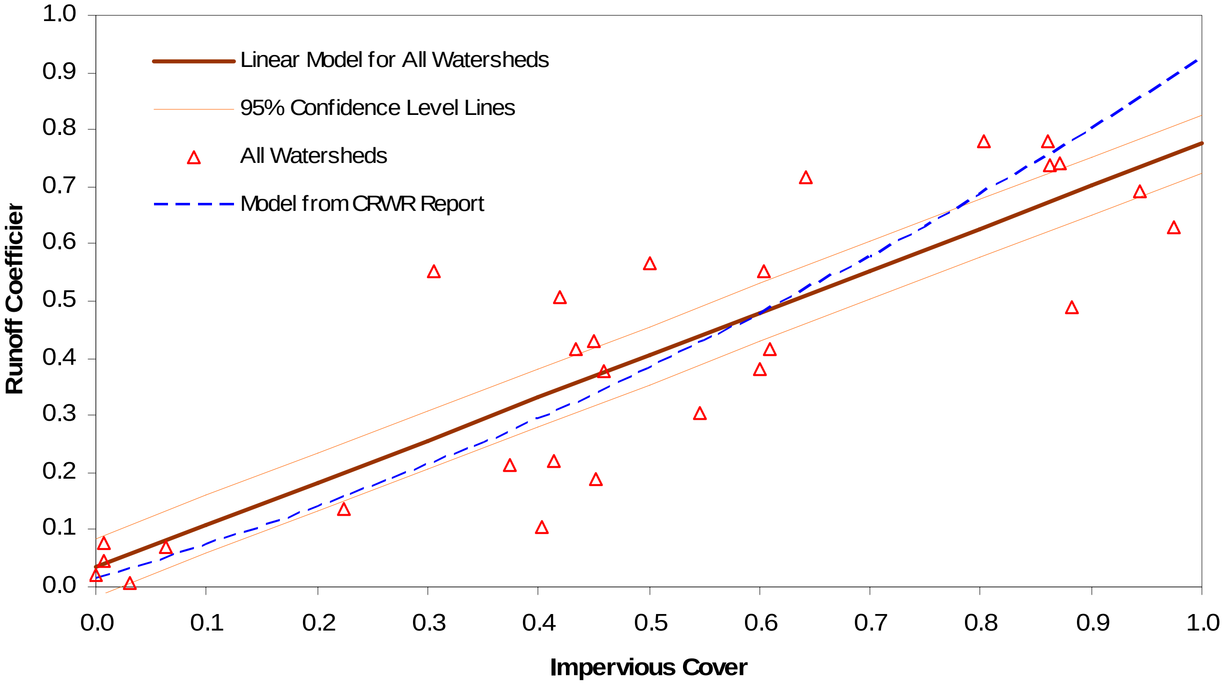

Figure 3.3: Comparison of runoff coefficient and impervious cover relationship with model recommended in Barrett et al.

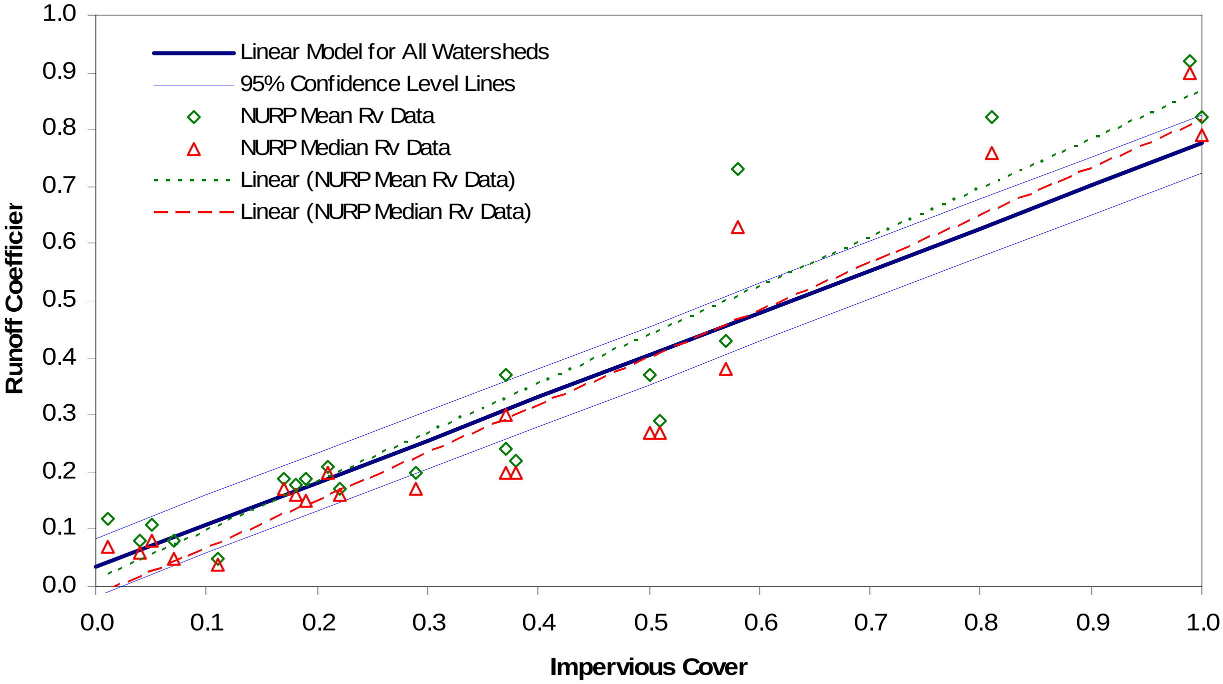

Figure 3.4: Comparison of runoff coefficient and impervious cover relationship with linear models based on EPA NURP data

the linear model presented in this study. While the NURP data were not collected in the Austin area, they were used to develop the original runoff rainfall relationships presented in the ECM. This may be one reason for the relationship currently in the ECM differing significantly from the one presented in this study. Additionally, SWQM cannot apply current QA/QC criteria to the NURP data; therefore the NURP data from other areas should not be included in any City of Austin data analyses.

Because of the significant difference between the new model based on WQM data in this study and models in City of Austin Environmental Criteria Manual, the runoff coefficient and impervious cover relationships for both Recharge Zone and Non-Recharge Zone in City of Austin Environmental Criteria Manual should be updated. It is recommended that the ECM be updated to reflect the data presented in Table 3.2 of this report.

Event Size

The runoff-rainfall ratios presented in this report are intended to be used to estimate average annual runoff volumes, in order to estimate loads and design water quality controls. However, at times these ratios have been used to estimate runoff from single events or from sub-daily rainfall. This is a misuse of these data since they do not take into account various factors including antecedent moisture conditions, initial abstraction or other physical parameters that affect runoff volumes.

To demonstrate this, mean runoff ratios were computed at each site for two rainfall classes, less that 0.75 inches and greater than or equal 0.75 inches. Regression analysis on these two datasets and impervious cover was performed and the resulting relationships compared (Figure 3.5). The correlation coefficient for large and small events was 0.86 and 0.83 respectively.

It can easily be seen that the data in Table 3.2 may reasonably represent large rainfall events with slight underestimations but will greatly overestimate runoff from smaller events. While it is known that other methods used for predicting event runoff in the Austin area produced errors, the NRCS curve number method, for example, greatly under-predicts runoff from small events. It is not recommended to use runoff ratios in this report to predict event runoff volumes at this time.

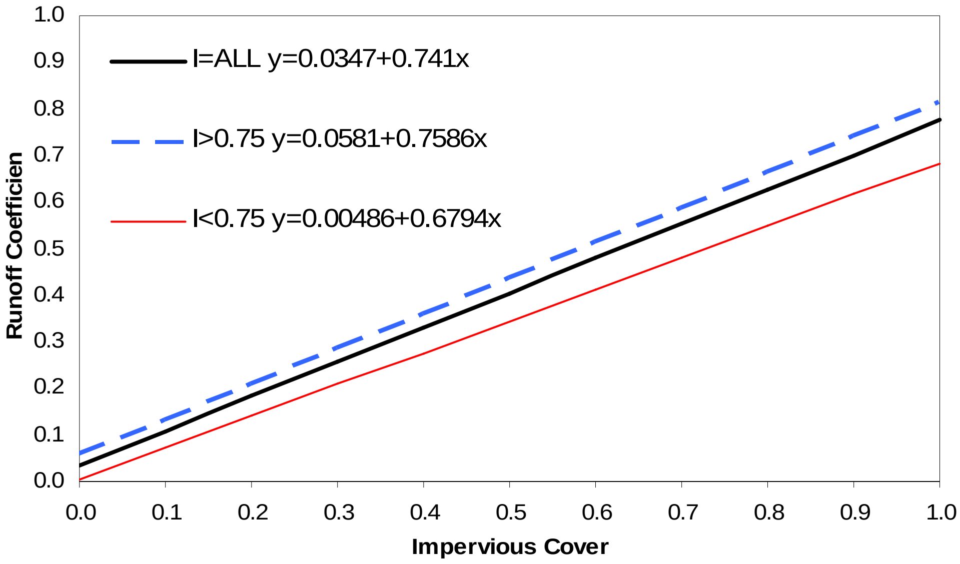

Figure 3.5: Runoff ratios for two rainfall classes (≥0.75 & <0.75 inches) compared to impervious cover and data presented in Table 3.2 and Figure 3.1.

4 WATER QUALITY ANALYSES AND RESULTS

This section examines the effects of urbanization on sixteen common water quality pollutants, notably the relationship between mean runoff concentration and impervious cover. In cases where impervious cover is not a significant explanatory variable for the concentration, differences between developed and undeveloped land will be examined. The data used in this report include nearly 14,000 event mean concentrations (EMC) collected between January 1984 and December 2004 at thirty-eight monitoring sites for the seventeen pollutants described in Section 1 of this report. The monitoring sites used for the water quality portion of this report are presented in Table 1.2.

4.1 Data Description

Table 4.1 is a summary of the number of EMCs at each station for each parameter used in this report and the monitoring period for each station. As previously mentioned, additional data were collected during the monitoring period but the quality of the EMC was not satisfactory and is not included in these analyses.

The mean watershed concentrations used in these analyses were computed as the total pollutant load for monitored events divided by the total runoff volume for the monitored events. This produces appropriate weighting for small and large runoff events. Other methods for computing mean concentrations may weight small events too high and large events too low. The mean watershed concentrations for each parameter are presented in Table 4.2.

An initial inspection of the data indicated that specific sites or parameters at a site may be outliers and not representative of a particular land use or impervious cover and should be omitted from these analyses. The EHA and EMA exhibited very high results for most pollutants, indicating the watersheds are not representative of the SFR land use and impervious cover typically seen in the Austin area. Additional analyses of these data (COA 2006) appear to indicate that watershed characteristics (age of infrastructure, general maintenance, demographics, etc.) may be influencing the water quality. The ERA watershed was a portion of Robert Mueller Airport and would not be representative of any other land use. As such, these three watersheds were omitted entirely from the analyses.

Table 4.1. Number of event mean concentrations for each parameter at each site.

Site	Period of Monitoring	Parameter																
		BOD	Cd	COD	Cu	DP	FCOL	FSTR	NH3	NO23	Pb	TKN	TN	TOC	TP	TSS	VSS	Zn
BC	1985-1990	20	---	20	21	---	21	21	21	21	21	18	18	20	20	21	---	21
BCU	1996-2004	12	25	24	25	23	10	10	24	24	25	24	24	24	24	24	24	25
BI	1985-1988	11	---	12	12	---	11	12	12	12	12	12	12	12	12	12	---	12
BNI	1994-1996	1	1	13	1	10	2	2	1	11	8	11	11	12	10	12	1	14
BRI	1993-1995	24	14	24	14	20	18	18	24	24	14	24	24	18	24	24	24	14
BSI	1994-1996	2	2	10	2	7	3	3	2	6	6	7	6	10	7	10	2	12
BUA	1993-1995	20	11	21	13	18	15	16	16	20	13	21	19	15	21	21	17	14
CMI	1997-2001	11	24	24	24	16	9	10	22	24	24	24	24	21	16	24	15	24
E7A	1995-1998	25	25	25	25	25	24	24	26	26	25	26	26	25	25	25	25	25
EBA	2000-2003	23	35	37	35	37	19	20	37	37	35	37	37	37	37	37	37	35
EHA	1995-2001	36	34	37	34	36	25	30	36	36	34	36	35	37	37	37	37	34
EMA	1999-2003	27	48	48	48	48	22	25	48	48	48	47	47	48	48	48	48	48
ERA	1994-1998	17	20	21	20	17	13	13	21	20	20	21	20	20	20	21	21	20
FPI	1997-1998	15	15	15	15	15	14	15	15	15	15	15	15	15	15	15	15	15
FSU	1998-Present	6	25	27	27	27	3	6	27	27	27	27	27	27	27	27	27	27
FWU	1994-1997	21	22	24	23	20	17	17	23	24	22	24	23	23	23	24	23	23
GPI	1994-1996	17	18	18	18	18	15	16	18	18	18	18	18	17	17	18	18	18
HI	1985-1987	18	---	19	19	---	17	18	19	19	19	17	17	19	18	19	---	19
HLA	1985-1995	21	1	21	19	2	20	20	21	21	19	21	21	20	21	21	2	19
HPA	2000-2003	18	27	28	27	28	11	13	25	28	27	28	28	25	28	28	26	27
JVI	1988-1998	30	17	33	33	15	27	30	32	30	33	31	30	29	33	34	16	33
LCA	1992-1996	25	12	28	20	25	23	21	21	26	20	28	26	21	28	24	19	21
LGA	2000-Present	7	24	25	25	24	6	6	25	25	25	25	25	25	25	25	25	25
LUA	1989-1994	30	7	31	24	25	24	28	25	31	23	31	30	25	31	31	20	23
MBA	1993-1995	27	15	27	18	27	19	20	25	27	18	27	27	25	27	26	25	18
MI	1984-1986	25	---	26	26	---	25	25	26	26	26	26	26	26	26	26	---	26
OFA	1993-1996	16	11	17	13	15	9	12	17	17	13	17	17	15	17	16	16	13
RO	1984-1988	15	---	16	15		15	16	16	16	15	16	16	16	16	16	---	15
S1M	1996-1999	28	29	29	29	29	27	27	29	28	29	29	28	29	28	29	29	29
SI	1985-1987	21	---	22	22	---	21	21	22	22	22	20	20	22	22	22	---	22

Table 4.1 (cont.). Number of event mean concentrations for each parameter at each site.

Site	Period of Monitoring	Parameter																
		BOD	Cd	COD	Cu	DP	FCOL	FSTR	NH3	NO23	Pb	TKN	TN	TOC	TP	TSS	VSS	Zn
SWI	1995-1996	12	13	13	13	10	6	7	13	12	13	13	12	12	13	13	13	13
SWJ	1995-1996	11	13	13	13	12	11	10	13	12	13	13	12	12	13	13	13	13
TBA	1996-2000	30	31	30	31	29	27	25	28	28	31	30	28	27	28	30	28	31
TCA	1993-1996	21	20	27	21	19	15	15	26	25	21	27	25	23	27	26	25	20
TPA	1993-1996	24	18	24	20	20	14	16	23	24	20	24	22	23	24	25	25	21
W5A	1993-1995	29	18	30	20	26	24	22	29	30	20	30	30	30	30	29	30	20
WBA	1999-2003	22	33	33	33	34	19	19	33	32	33	33	32	33	33	33	33	33
WCI	1995-1998	32	36	34	36	31	26	28	34	33	36	35	33	32	35	36	35	37

Table 4.2. Mean watershed concentrations at each site.

Sites	Parameters																
	BOD (mg/l)	Cd (ug/l)	COD (mg/l)	Cu (ug/l)	DP (mg/l)	FCOL (col/100ml)	FSTR (col/100ml)	NH3 (mg/l)	NO23 (mg/l)	Pb (ug/l)	TKN (mg/l)	TN (mg/l)	TOC (mg/l)	TP (mg/l)	TSS (mg/l)	VSS (mg/l)	Zn (ug/l)
BC	7.79	---	28.73	11.26	---	24517	8470	0.070	0.127	2.59	0.35	0.49	8.70	0.05	53.3	---	8.95
BCU	2.00	0.507	57.20	2.65	0.03	16688	36491	0.043	0.227	4.74	0.87	1.10	15.39	0.11	76.6	16.0	39.13
BI	8.10	---	22.60	5.35	---	20344	15601	0.234	0.296	21.73	0.60	0.90	11.15	0.09	54.5	---	47.20
BNI	2.50	0.200	49.46	2.50	0.09	2143	3619	0.085	0.555	15.86	1.05	1.61	6.56	0.28	308.3	9.5	46.28
BRI	6.42	0.547	54.96	6.14	0.14	42424	9562	0.186	0.535	8.89	1.32	1.85	7.59	0.27	200.9	25.8	50.08
BSI	2.57	0.546	39.99	6.19	0.06	660	8822	0.126	0.256	10.95	0.60	0.89	5.46	0.14	63.7	13.7	52.06
BUA	12.74	0.823	97.58	21.85	0.22	58219	53231	0.224	0.784	24.48	2.01	2.73	9.63	0.57	279.5	75.2	81.70
CMI	11.33	0.533	45.73	12.80	0.16	72584	78411	0.348	0.365	25.70	1.59	1.96	8.64	0.42	166.8	39.7	102.67
E7A	5.76	0.756	63.66	19.46	0.22	67859	138588	0.206	0.571	63.37	1.16	1.73	6.61	0.72	356.7	61.7	231.04
EBA	10.95	0.513	58.77	4.88	0.21	79981	144877	0.239	0.473	9.37	2.02	2.50	11.78	0.49	74.0	27.1	41.86
EHA	17.51	0.784	102.20	11.34	0.26	129774	386918	0.278	0.604	43.82	3.04	3.53	15.78	1.41	265.5	65.7	145.84
EMA	28.97	0.530	126.21	12.03	0.21	54567	465142	0.189	0.399	22.32	2.55	2.95	20.26	0.69	267.5	66.3	134.73
ERA	7.36	4.581	62.96	73.69	0.20	24159	50663	0.138	0.493	21.35	1.30	1.80	9.03	0.79	57.6	16.6	140.87
FPI	6.22	0.510	40.36	6.70	0.09	23518	105412	0.172	0.296	9.77	0.67	0.97	4.81	0.16	92.3	15.9	57.24
FSU	3.45	0.502	52.78	3.56	0.04	17062	36736	0.054	0.277	4.70	0.93	1.21	10.15	0.20	121.8	20.3	16.89

Table 4.2 (cont.). Mean watershed concentrations at each site.

Sites	Parameters																
	BOD (mg/l)	Cd (ug/l)	COD (mg/l)	Cu (ug/l)	DP (mg/l)	FCOL (col/100ml)	FSTR (col/100ml)	NH3 (mg/l)	NO23 (mg/l)	Pb (ug/l)	TKN (mg/l)	TN (mg/l)	TOC (mg/l)	TP (mg/l)	TSS (mg/l)	VSS (mg/l)	Zn (ug/l)
FWU	3.68	0.622	49.51	4.21	0.04	16971	66584	0.036	0.190	2.15	0.89	1.06	8.57	0.18	207.6	23.8	24.11
GPI	12.69	1.257	102.29	82.50	0.15	44165	130245	0.166	0.761	47.56	1.83	2.59	13.65	0.56	232.2	47.1	80.75
HI	7.41	---	31.83	9.12	---	24118	23484	0.356	0.221	10.30	0.70	0.94	6.16	0.20	109.7	---	35.69
HLA	9.64	0.303	23.93	14.36	0.05	108548	35935	0.239	0.655	51.63	0.68	1.33	7.07	0.22	151.0	15.9	52.78
HPA	16.30	0.508	66.37	5.85	0.21	104071	191199	0.165	0.461	19.24	1.70	2.16	16.00	0.45	97.5	34.5	91.54
JVI	5.52	0.584	56.47	14.78	0.09	3634	13428	0.322	0.355	35.60	0.94	1.30	11.61	0.23	222.4	22.7	114.08
LCA	5.80	0.299	48.99	19.20	0.09	39361	40270	0.144	0.572	6.33	1.21	1.80	5.96	0.29	145.7	47.7	46.13
LGA	1.29	0.505	22.92	3.52	0.02	5790	60581	0.031	0.297	4.01	0.35	0.64	6.93	0.08	90.5	10.3	12.18
LUA	9.45	0.965	91.29	23.25	0.37	25401	33344	0.327	0.428	99.62	1.51	1.96	15.13	0.43	161.4	69.4	278.47
MBA	10.10	1.157	57.51	8.97	0.11	14299	45242	0.172	0.447	21.31	1.25	1.70	8.71	0.45	304.5	41.4	85.59
MI	11.53	---	30.26	7.96	---	49676	32130	0.313	0.473	7.67	1.25	1.72	12.63	0.23	319.5	---	23.71
OFA	12.63	0.426	92.81	7.23	0.13	33567	17179	0.205	0.741	11.35	1.50	2.24	15.84	0.23	71.0	39.7	55.49
RO	6.97	---	23.38	6.96	---	14927	30830	0.140	1.333	15.80	0.90	2.23	13.40	0.31	414.2	---	36.60
S1M	6.06	0.572	61.29	8.99	0.12	37456	212301	0.149	0.526	16.42	1.07	1.43	11.23	0.21	70.0	16.0	49.76
SI	15.36	---	20.71	6.47	---	17032	14589	0.253	0.268	20.92	0.55	0.81	5.91	0.09	52.4	---	102.97
SWI	5.27	0.700	38.39	10.50	0.06	36062	43990	0.193	0.457	6.43	0.78	1.23	6.78	0.22	119.6	12.3	83.31
SWJ	8.03	0.472	48.78	11.72	0.03	24611	61239	0.315	0.674	8.91	1.29	1.85	8.56	0.17	73.8	12.5	113.02
TBA	8.55	0.678	59.99	5.09	0.15	51885	154661	0.204	0.485	12.57	1.20	1.71	7.26	0.45	178.3	28.6	66.40
TCA	4.65	0.630	41.08	5.77	0.14	74382	58528	0.112	0.304	5.52	0.92	1.28	8.63	0.23	47.9	11.4	17.87
TPA	10.27	0.839	61.40	6.79	0.24	75300	105462	0.266	0.607	6.38	1.68	2.35	8.65	0.42	106.8	30.4	37.06
W5A	24.67	0.769	136.66	25.22	0.23	84841	268587	0.308	0.644	46.54	2.41	3.11	17.54	0.64	155.0	72.2	213.15
WBA	7.95	0.507	37.33	6.57	0.19	25874	41891	0.341	0.906	8.40	1.73	2.64	7.05	0.39	86.8	27.6	143.80
WCI	8.88	0.615	75.07	14.19	0.16	21817	93636	0.662	0.578	34.62	1.46	1.95	10.70	0.48	93.5	22.5	193.81

In addition, the concentrations of copper at the GPI monitoring site were much higher than those at any other location, even though the other pollutants were in acceptable ranges. Thus, the mean concentration of copper at GPI was not included in the analyses. The approach channel at WBA had been constructed of galvanized steel, providing a source of potential zinc contamination. The zinc levels at this site were elevated. These data were not used in the analyses due to the potential for contamination.

4.2 **Data Analyses Procedures and Results**

The water quality in an individual stormwater runoff event may be affected by many variables associated with both the watershed (land use, impervious cover, size, slope, etc.) and the rainfall event itself (intensity of rainfall, depth of rainfall, antecedent conditions, etc.). Predicting pollutant concentrations for an individual event is a very complicated task and often not very accurate. The results of this study will help predict the average concentration in runoff based on watershed characteristics regardless of the rainfall event characteristics. As such, these data are intended for use in predicting long-term average annual loading from a site. These results should not normally be used for individual events.

The data analyses in this report were designed to determine if pollutants in stormwater runoff were affected by development. Two hypotheses were developed and tested for each of the pollutants in question. First, the mean pollutant concentration in stormwater runoff is related to impervious cover. This hypothesis was tested using regression analyses, more specifically the General Linear Model (GLM) procedure in SAS (SAS Institute, 1994). Watershed impervious cover was selected as the continuous independent variable and concentration as the dependent variable. Results of this analysis are presented in Table 4.3. Complete results of the SAS analyses may be found in Appendix C.

Second, the mean concentration in stormwater runoff from a developed (all land uses not classified as undeveloped) watershed is different from the mean concentration from a developed watershed. Once again, GLM was used for the analyses but with the development condition as a class variable. Commercial, industrial, mixed, transportation, single- and multi-family residential land uses were all combined as developed and compared to undeveloped watersheds using Duncan's mean separation test. This test was used to determine if runoff pollutant

Table 4.3: Results of regression modeling on site mean concentrations.

Pollutant	P > f	r^2	Intercept	Slope	*n*
BOD (mg/l)	0.0112	0.1793	4.88	6.50	35
CD (μg/l)	0.2067	0.0584	0.513	0.188	29
COD (mg/l)	0.0122	0.1806	34.28	34.25	34
CU (μg/l)	0.0111	0.1851	5.154	8.519	34
DP (mg/l)	0.0136	0.2054	0.066	0.123	29
FCOL (col/100ml)	0.8735	0.0008	37429	2658	35
FSTR (col/100ml)	0.4274	0.0192	53328	29302	35
NH3 (mg/l)	0.0003	0.3371	0.086	0.236	35
NO23 (mg/l)	0.3190	0.0301	0.417	0.137	35
PB (μg/l)	0.0029	0.2393	2.26	33.24	35
TKN (mg/l)	0.0698	0.0962	0.897	0.511	35
TN (mg/l)	0.1001	0.0798	1.332	0.605	35
TOC (mg/l)	0.3112	0.0311	8.66	2.00	35
TP (mg/l)	0.1135	0.0742	0.223	0.153	35
TSS (mg/l)	0.9832	0.0000	151.6	1.2	35
VSS (mg/l)	0.0652	0.1204	18.50	22.48	29
ZN (μg/l)	0.0002	0.3632	7.30	127.11	34

Table 4.4: Results of the means separation test on developed vs. undeveloped watersheds for parameters that did not have significant regression models. Constituents without common group letters differ significantly at the 0.05 level.

Pollutant	Developed		Undeveloped	
Cd (μg/l)	0.629	a	0.534	a
FCOL (col/100ml)	42625	a	16206	a
FSTR (col/100ml)	73543	a	41772	a
NO23 (mg/l)	0.541	a	0.224	b
TKN (mg/l)	1.240	a	0.678	b
TN (mg/l)	1.776	a	0.901	b
TOC (mg/l)	9.71	a	9.95	a
TP (mg/l)	0.337	a	0.122	b
TSS (mg/l)	161.8	a	103.6	a
VSS (mg/l)	32.39	a	17.62	a

concentrations differed between developed and undeveloped watersheds regardless of the effects of impervious cover. The results of these analyses are presented in Table 4.4.

4.3 **Discussion of Results**

The results in Table 4.3 indicate that the mean concentration of seven pollutants in stormwater runoff are significantly affected by the amount of impervious cover in the watershed at the 0.05 level; BOD, COD, Cu, DP, NH3, Pb, and Zn. For these seven pollutants, impervious cover could be a strong predictor of the average annual stormwater runoff concentration. Barrett, et al. (1998) found these same parameters correlate well with impervious cover using a preliminary City of Austin monitoring dataset. That study also found that TOC was also correlated with impervious cover but those results may have been influenced by the dataset used. It is recommended that the relationships in Table 4.3 and the figures and table following be used to predict the concentrations of BOD, COD, Cu, DP, NH3, Pb, and Zn.

While these regression models are significant, the coefficient of determination, r^2, is relatively low, ranging from 0.18 for BOD to 0.36 for Zn. This indicates other factors may be influencing the runoff concentrations. An earlier City of Austin study examining the effects of golf courses on water quality (COA, 2005) indicated that land uses may significantly affect water quality. Since land use is often strongly correlated with impervious cover, the addition of land use as a variable in the regression may not significantly increase the correlation of the model compared to the corresponding increase in model complexity. While this was not done as a part of this report, it may be pursued in subsequent studies.

Cd was the only metal not correlated with impervious cover. This may be due to the fact that results for Cd are often at or near detection limits, which may be masking some of the factors affecting runoff concentrations. This may have also impacted the results of the second part of the analyses as well.

Of the ten pollutants that did not significantly correlate with impervious cover, the mean concentration for four differed significantly between undeveloped and developed land uses at the 0.05 level (see Table 4.4). For these pollutants, NO3, TKN, TN, and TP, predicted values should be based solely on whether or not the watershed in question has been developed. FCOL exhibited a weaker difference between developed and undeveloped condition, differing significantly at the 0.10 level. It is recommended that the relationships in Table 4.4 and the figures and table following be used to predict the concentrations of FCOL, NO3, TKN, TN, and TP based on whether or not the parcel in question is developed (>1% impervious cover).

Of the 17 pollutants examined in this report Cd, FSTR, TOC, TSS and VSS exhibited no significant trends associated with impervious cover or development condition based on these analyses. Even though the concentration of these pollutants do not appear to change with development, the overall pollutant load will increase due to the increase in runoff associated with the change in impervious cover discussed earlier in this report. For these pollutants, the best prediction of runoff concentration is the mean for all sites as reported in the following figures and tables.

Past studies by the City (2005, 1990), as well as TCEQ rules, indicated that both TSS and VSS concentrations differ significantly between development conditions. The analyses used in this report could possibly be masking results or may be a result of how data are collected. Undeveloped sites usually only produce runoff that can be sampled during large events. The larger size of the events results in a larger weight in a volume-weighted mean. These events tend to be more erosive than smaller ones, and thus produce higher TSS and VSS concentrations. (Note: for small watersheds, a large event may correspond to a 4- to 6-month event, while for larger creek-sized watersheds these would be considered small events. In both cases, events of this size may be responsible for the majority of the erosion in the watershed.) While further study may be warranted, no further recommendation may be made with respect to developed and undeveloped concentration of TSS and VSS.

One caveat about these data: while certain types of development like golf courses, parks, or athletic fields may have a very low impervious cover, the runoff from these areas may be very different from runoff on undeveloped lands. This report assumes an impervious cover of approximately 1% to be undeveloped land. These relationships should not be used for managed turf areas or areas where additional nutrient loads (effluent irrigation areas) are applied.

These results differ significantly from those currently in the City of Austin Environmental Criteria Manual. It is recommended that the ECM be updated to reflect the most recent monitoring results as shown in Figures 4.1-17 and Tables 4.5-16 following.

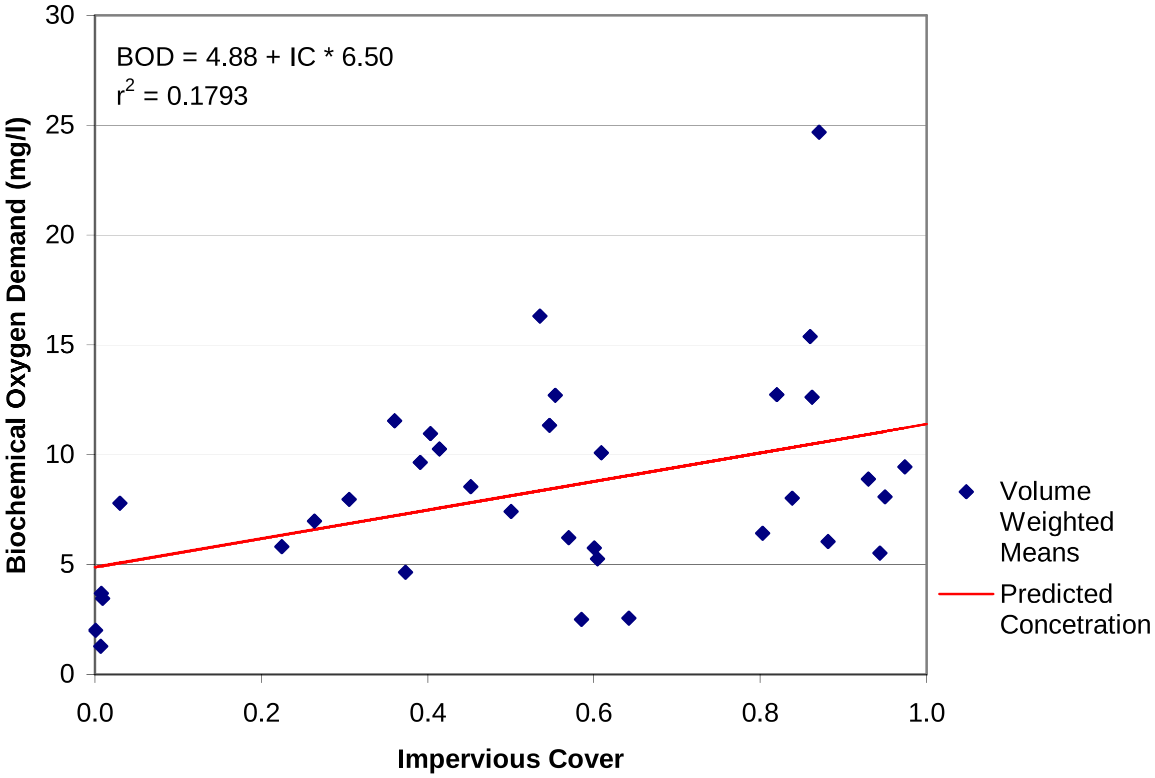

Figure 4.1: Bio-chemical oxygen demand (BOD) mean concentration versus impervious cover.

Table 4.5: Predicted bio-chemical oxygen demand (BOD) concentrations (mg/l).

Impervious Cover (%)	Predicted Concentration
0	4.88
1	4.94
5	5.21
10	5.53
15	5.86
20	6.18
30	6.83
40	7.48
50	8.13
60	8.78
70	9.43
80	10.08
90	10.73
100	11.38

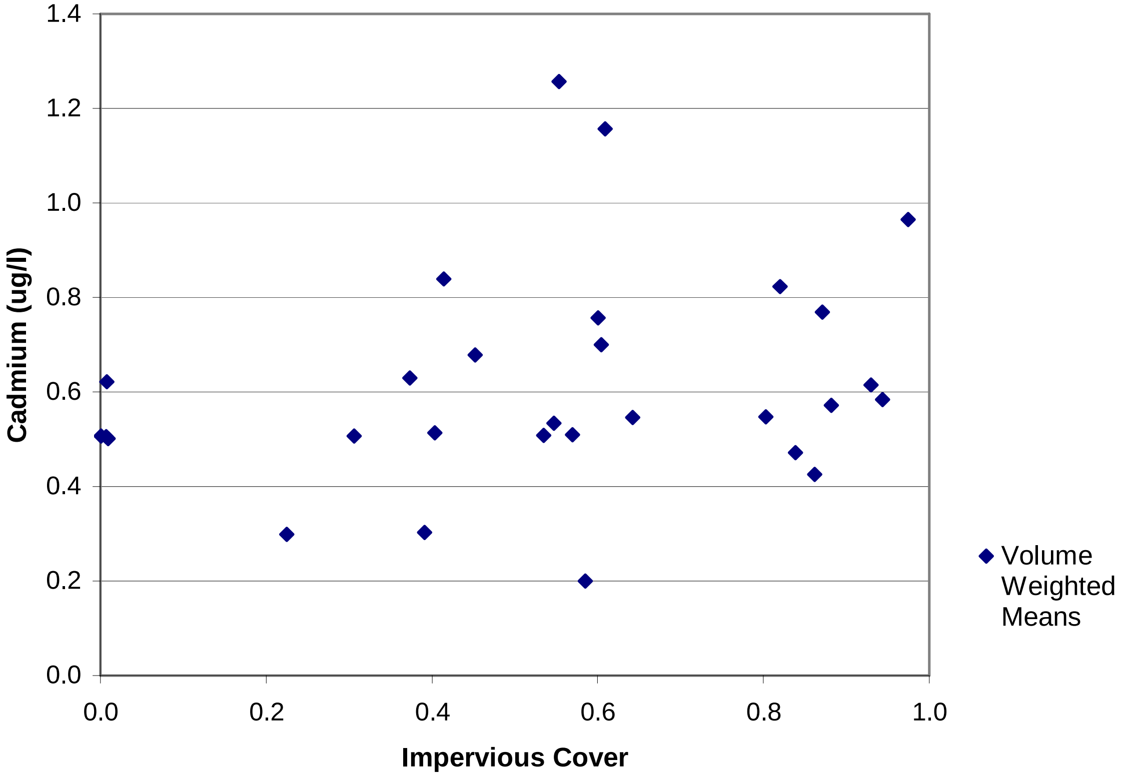

Figure 4.2: Cadmium (Cd) mean concentration versus impervious cover.

No significant relationship was found for cadmium based on impervious cover or development condition. It is recommended that the average mean concentration of 0.616 ug/l be used to represent the mean watershed concentration regardless of impervious cover or development condition.

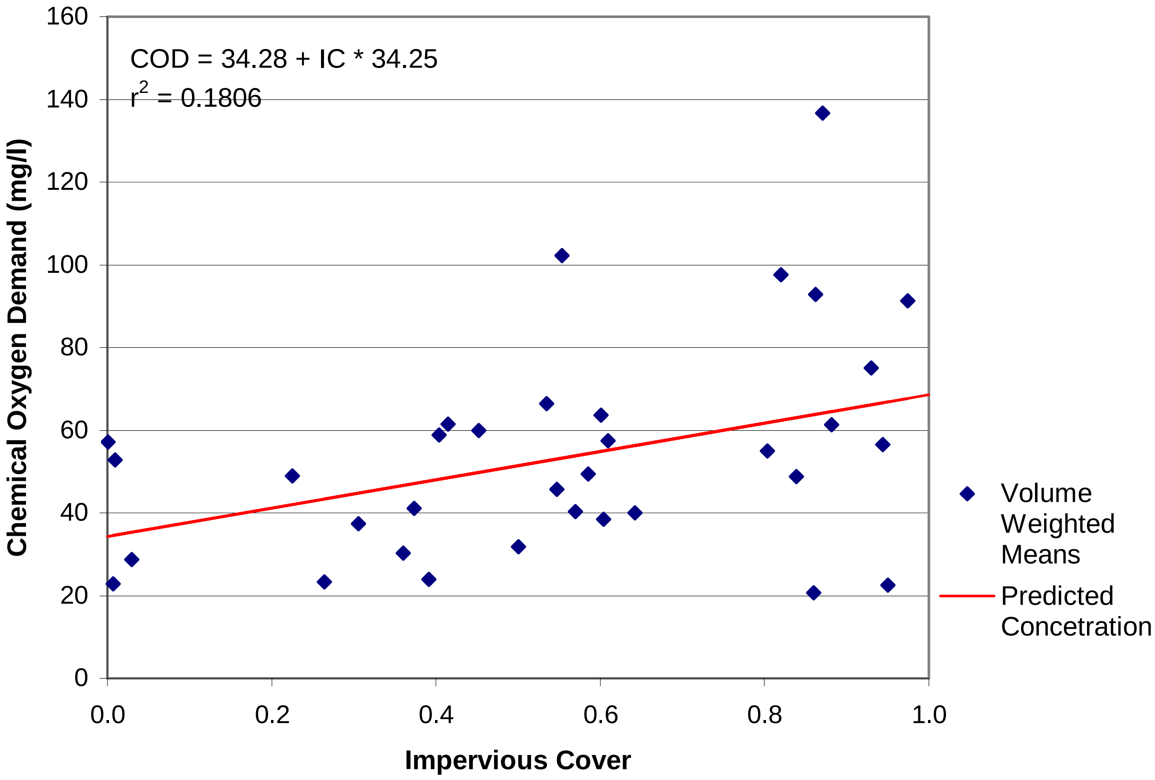

Figure 4.3: Chemical oxygen demand (COD) mean concentration versus impervious cover.

Table 4.6: Predicted chemical oxygen demand (COD) concentrations (mg/l).

Impervious Cover (%)	Predicted Concentration
0	34.28
1	34.62
5	35.99
10	37.70
15	39.42
20	41.13
30	44.56
40	47.99
50	51.41
60	54.84
70	58.27
80	61.70
90	65.13
100	68.55

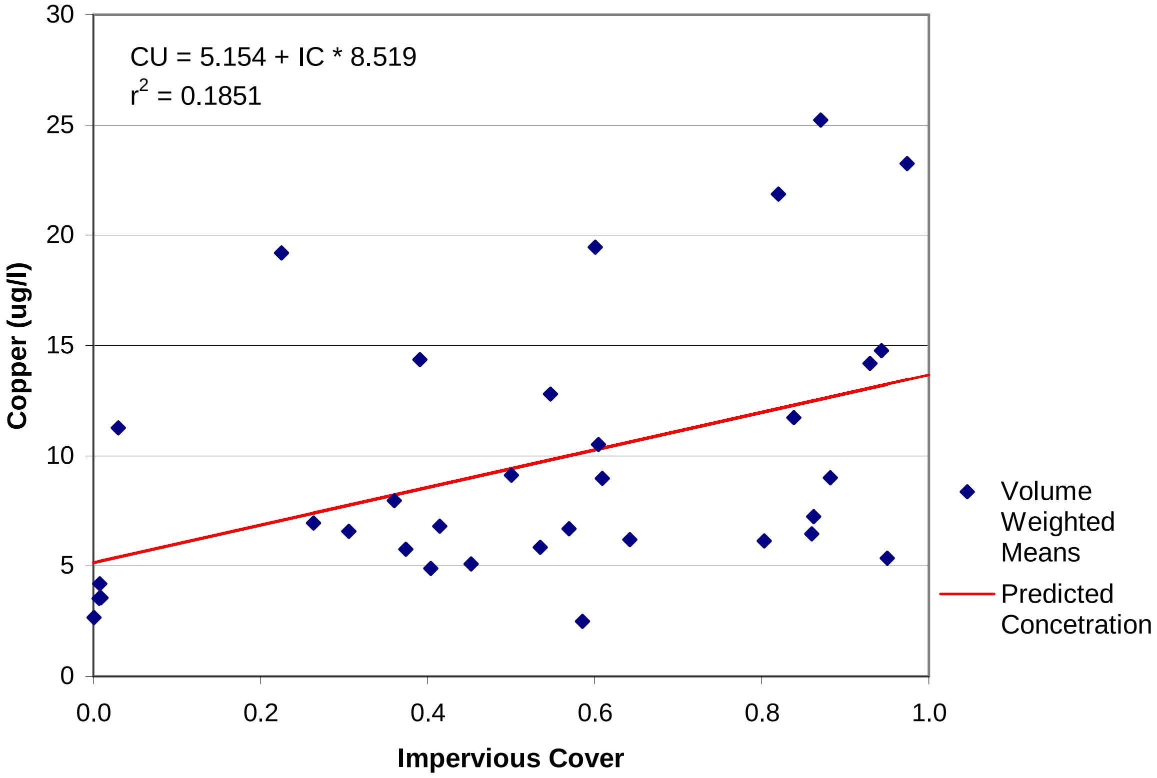

Figure 4.4: Copper (Cu) mean concentration versus impervious cover.

Table 4.7: Predicted copper (Cu) concentrations (ug/l).

Impervious Cover (%)	Predicted Concentration
0	5.15
1	5.24
5	5.58
10	6.01
15	6.43
20	6.86
30	7.71
40	8.56
50	9.41
60	10.27
70	11.12
80	11.97
90	12.82
100	13.67

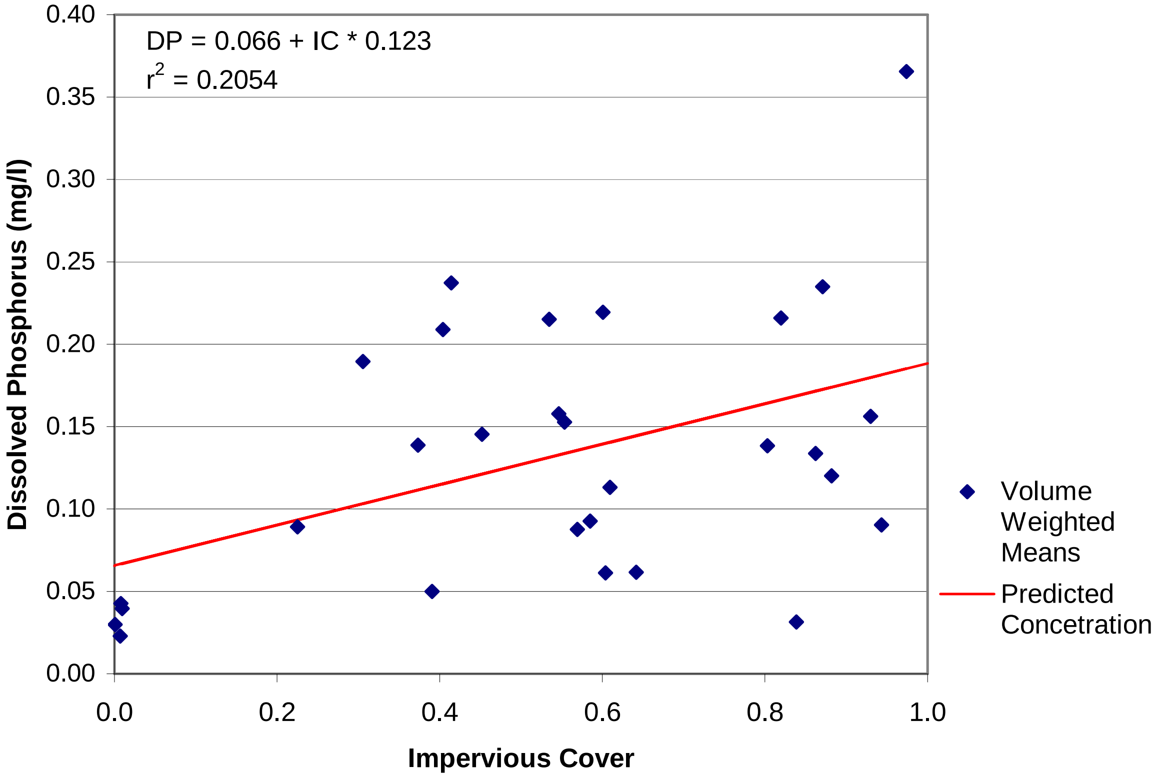

Figure 4.5: Dissolved phosphorus (DP) mean concentration versus impervious cover.

Table 4.8: Predicted dissolved phosphorus (DP) concentrations (mg/l).

Impervious Cover (%)	Predicted Concentration
0	0.066
1	0.067
5	0.072
10	0.078
15	0.084
20	0.090
30	0.103
40	0.115
50	0.127
60	0.139
70	0.152
80	0.164
90	0.176
100	0.188

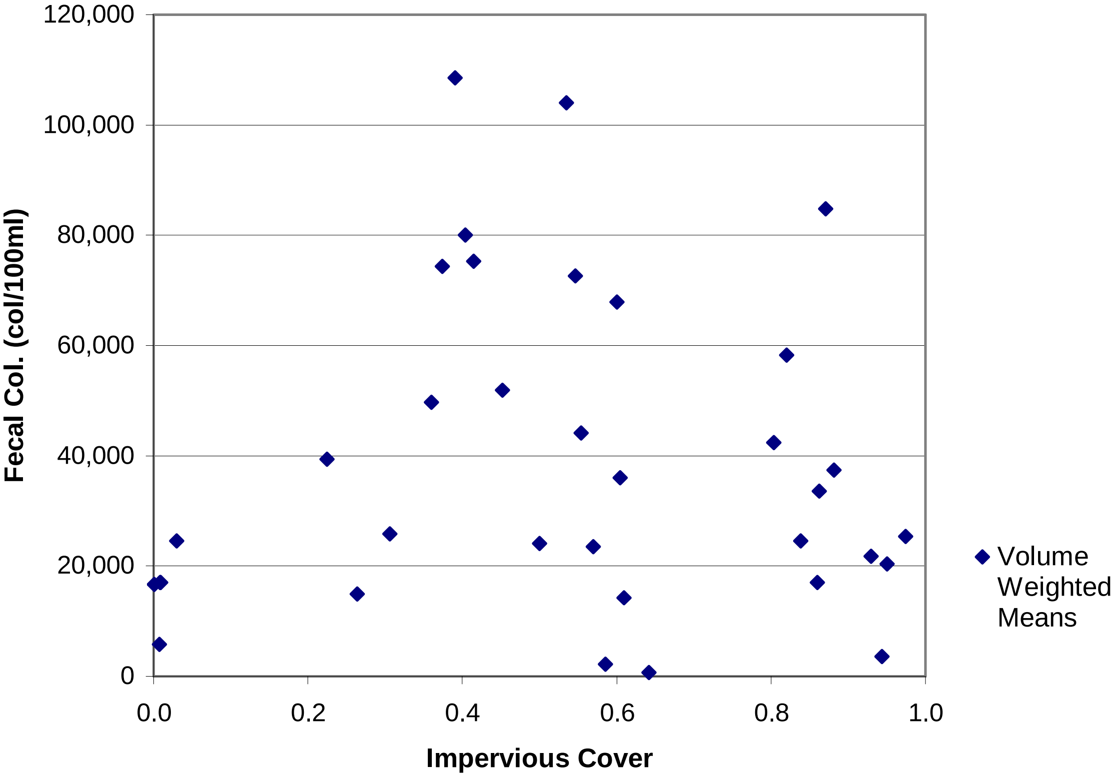

Figure 4.6: Fecal coliform (FCOL) mean concentration versus impervious cover.

Table 4.9: Predicted fecal coliform (FCOL) concentrations (col/100ml).

Impervious Cover (%)	Predicted Concentration
0	16,206
1	16,206
5	42,625
10	42,625
15	42,625
20	42,625
30	42,625
40	42,625
50	42,625
60	42,625
70	42,625
80	42,625
90	42,625
100	42,625

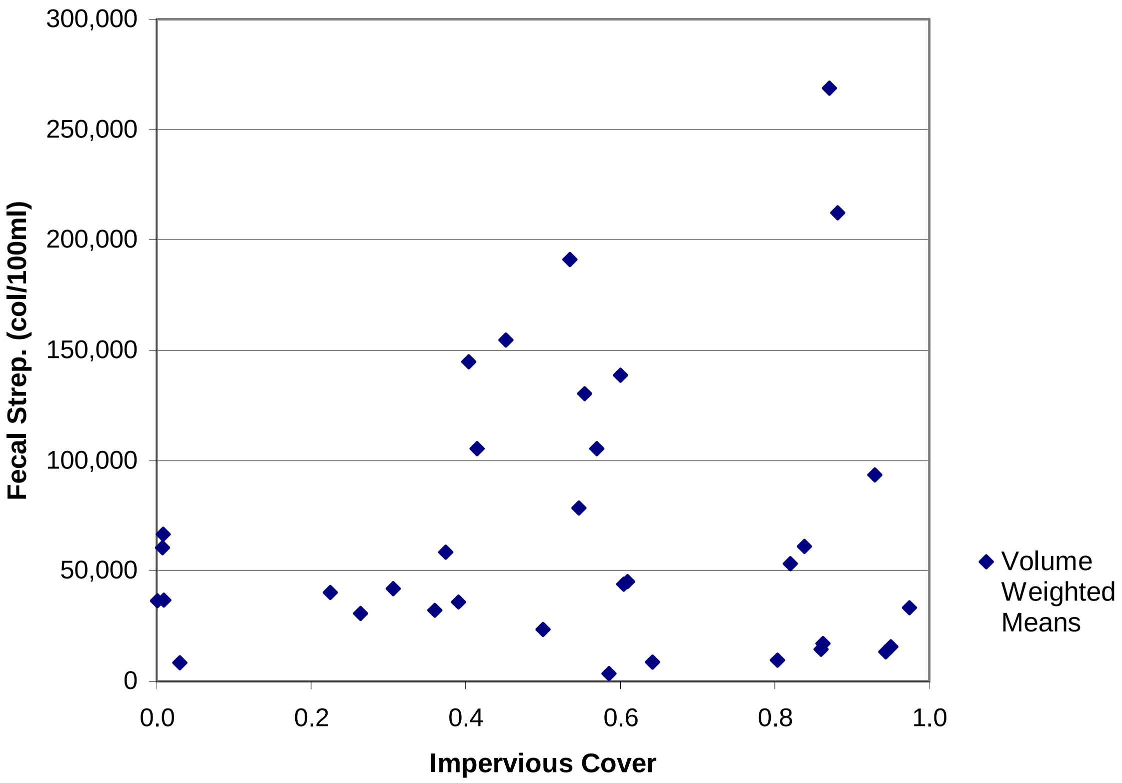

Figure 4.7: Fecal streptococci (FSTR) mean concentration versus impervious cover.

No significant relationship was found for fecal streptococci based on impervious cover or development condition. It is recommended that the average mean concentration of 69,004 col/100 ml be used to represent the mean watershed concentration regardless of impervious cover or development condition.

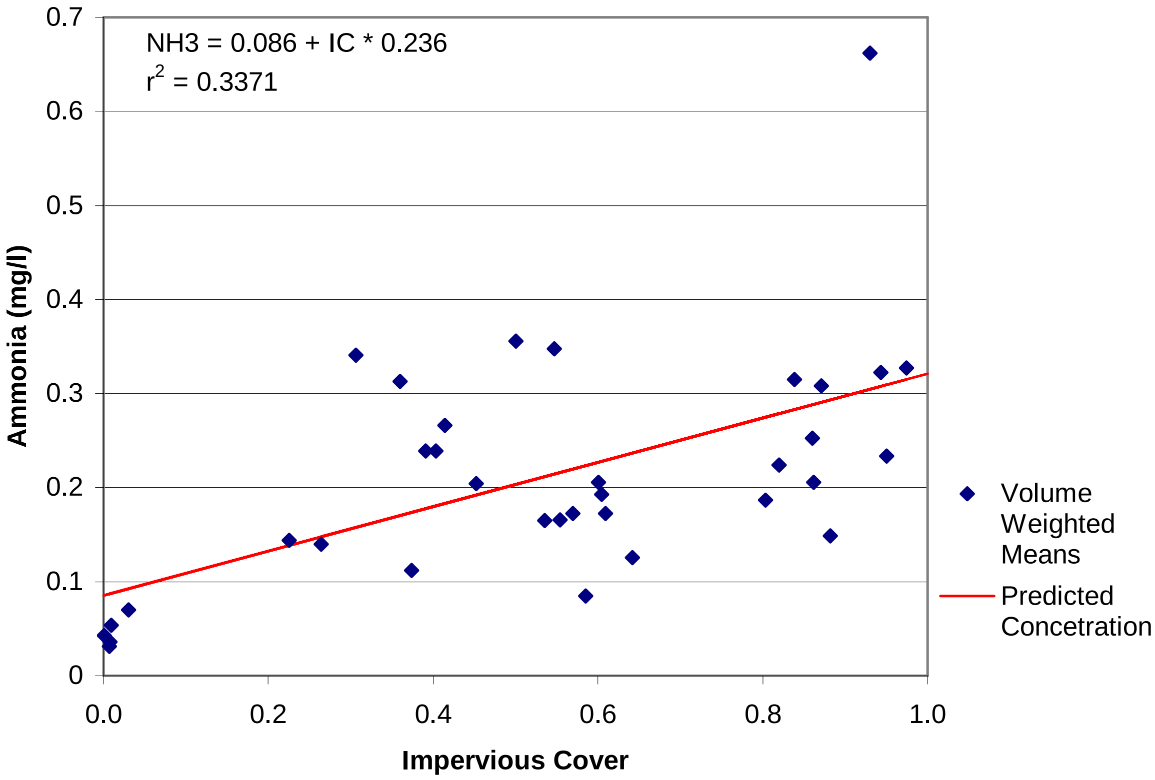

Figure 4.8: Ammonia (NH3) mean concentration versus impervious cover.

Table 4.10: Predicted ammonia (NH3) concentrations (mg/l).

Impervious Cover (%)	Predicted Concentration
0	0.086
1	0.088
5	0.097
10	0.109
15	0.121
20	0.133
30	0.156
40	0.180
50	0.203
60	0.227
70	0.250
80	0.274
90	0.298
100	0.321

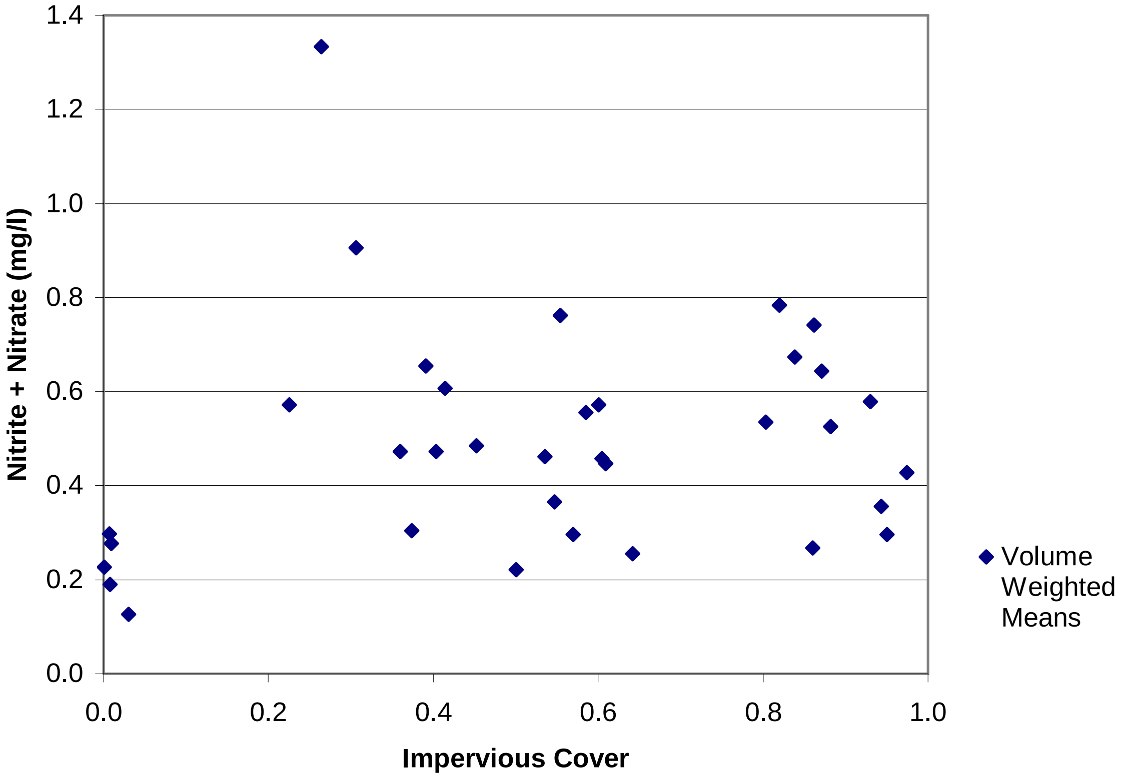

Figure 4.9: Nitrate + nitrite (NO23) mean concentration versus impervious cover.

Table 4.11: Predicted nitrate + nitrite (NO23) concentrations (mg/l).

Impervious Cover (%)	Predicted Concentration
0	0.224
1	0.224
5	0.541
10	0.541
15	0.541
20	0.541
30	0.541
40	0.541
50	0.541
60	0.541
70	0.541
80	0.541
90	0.541
100	0.541

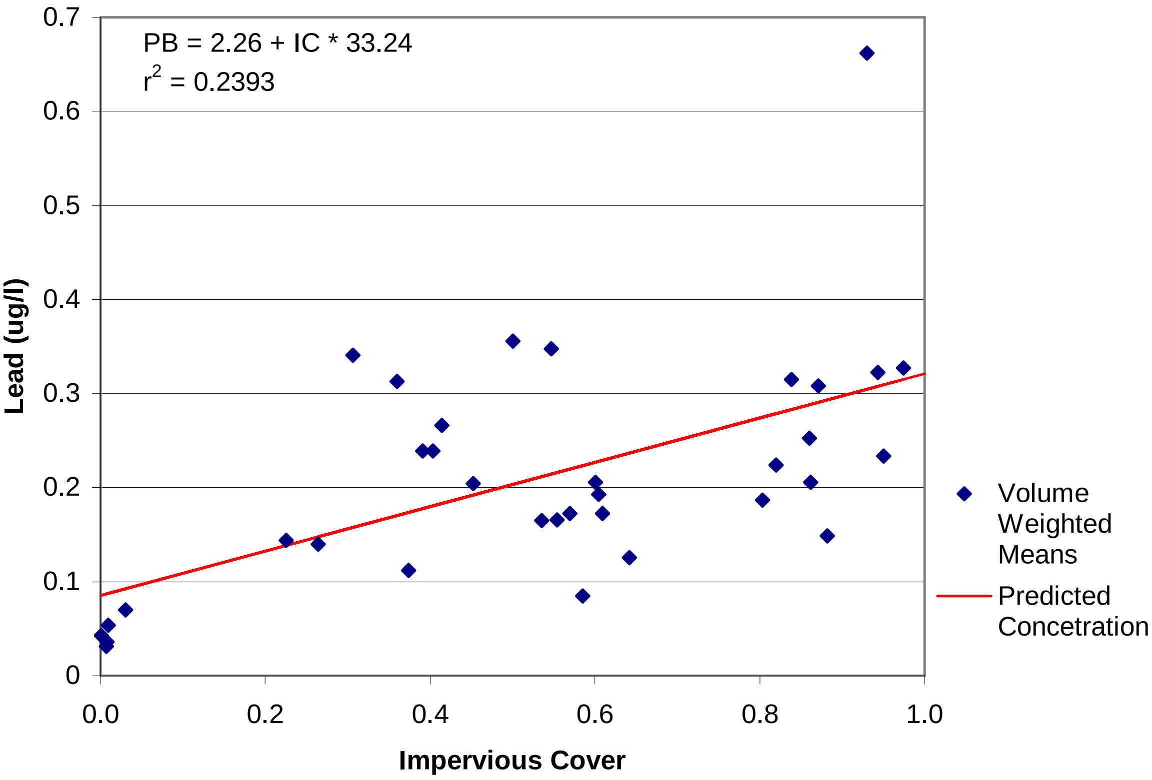

Figure 4.10: Lead (Pb) mean concentration versus impervious cover.

Table 4.12: Predicted lead (Pb) concentrations (ug/l).

Impervious Cover (%)	Predicted Concentration
0	2.26
1	2.59
5	3.92
10	5.58
15	7.24
20	8.90
30	12.23
40	15.55
50	18.88
60	22.20
70	25.53
80	28.85
90	32.17
100	35.50

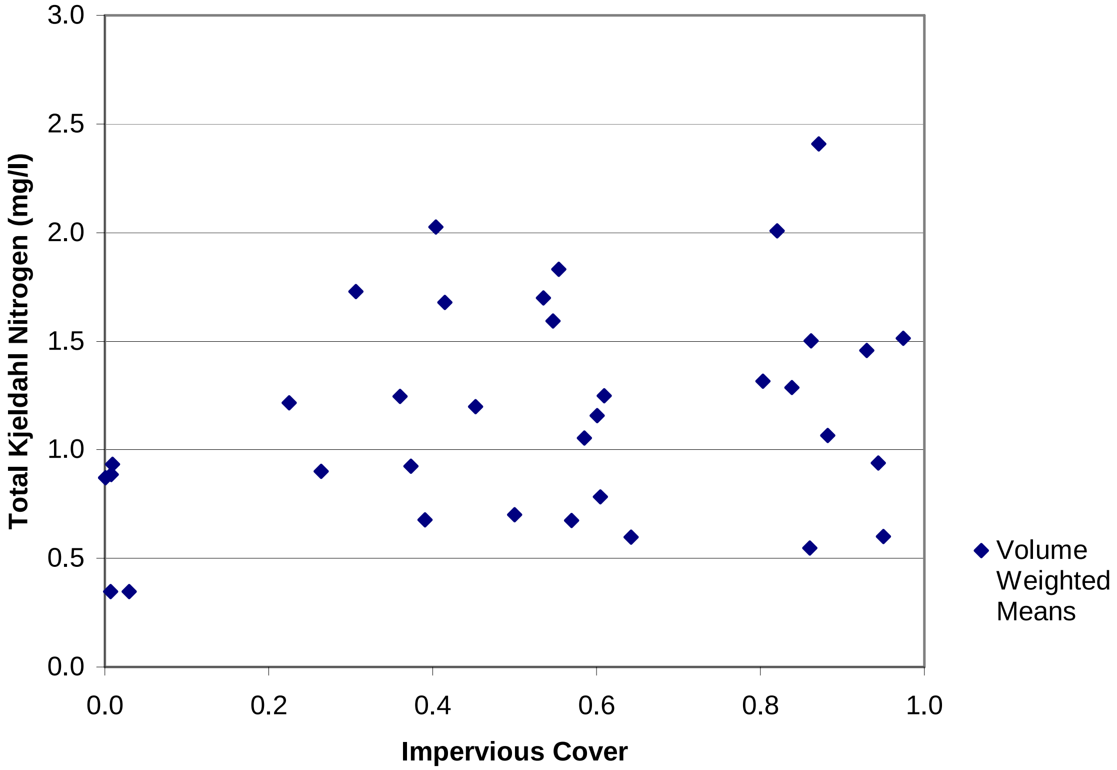

Figure 4.11: Total Kjeldahl nitrogen (TKN) mean concentration versus impervious cover.

Table 4.13: Predicted total Kjeldahl nitrogen (TKN) concentrations (mg/l).

Impervious Cover (%)	Predicted Concentration
0	0.68
1	0.68
5	1.24
10	1.24
15	1.24
20	1.24
30	1.24
40	1.24
50	1.24
60	1.24
70	1.24
80	1.24
90	1.24
100	1.24

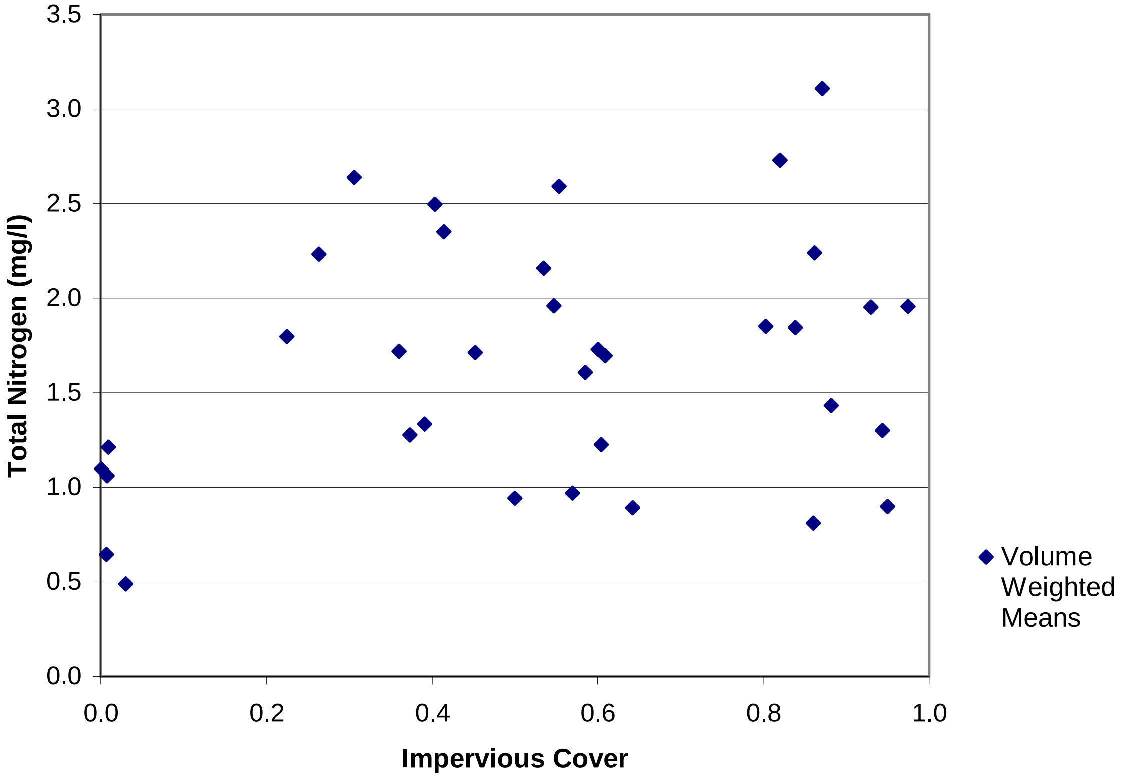

Figure 4.12: Total nitrogen mean concentration versus impervious cover.

Table 4.14: Predicted total nitrogen (TN) concentrations (mg/l).

Impervious Cover (%)	Predicted Concentration
0	0.90
1	0.90
5	1.78
10	1.78
15	1.78
20	1.78
30	1.78
40	1.78
50	1.78
60	1.78
70	1.78
80	1.78
90	1.78
100	1.78

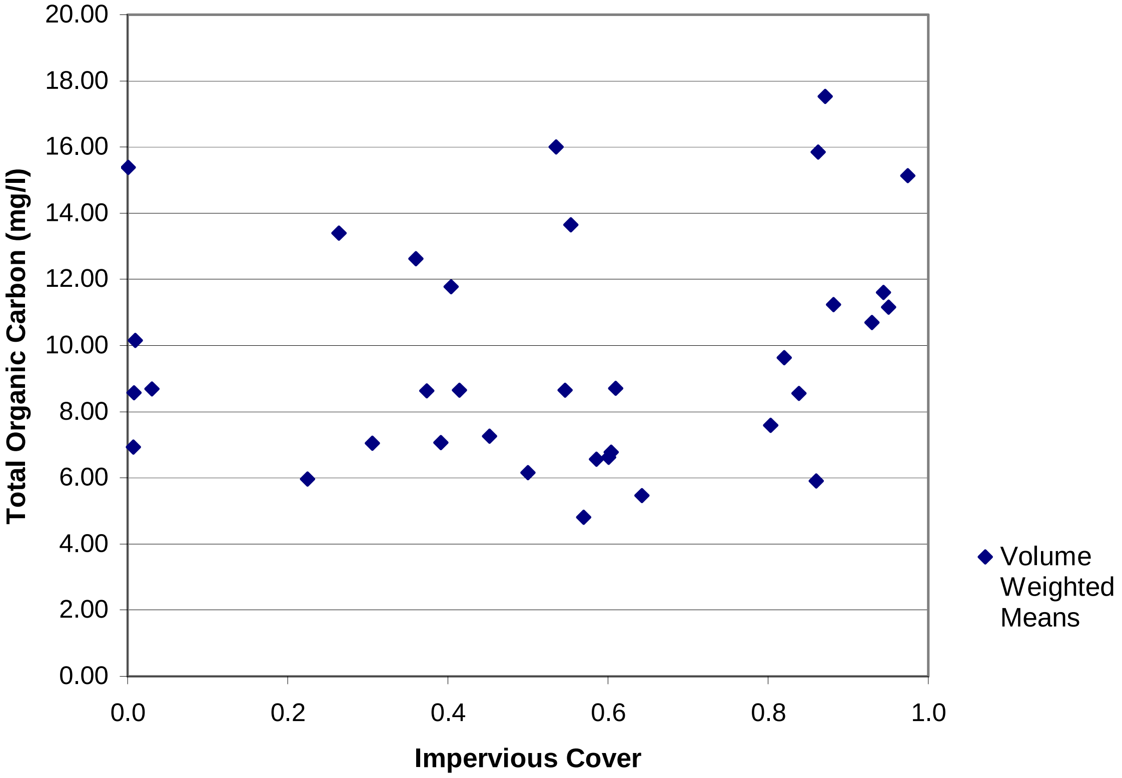

Figure 4.13: Total organic carbon (TOC) mean concentration versus impervious cover.

No significant relationship was found for total organic carbon based on impervious cover or development condition. It is recommended that the average mean concentration of 9.75 mg/l be used to represent the mean watershed concentration regardless of impervious cover or development condition.

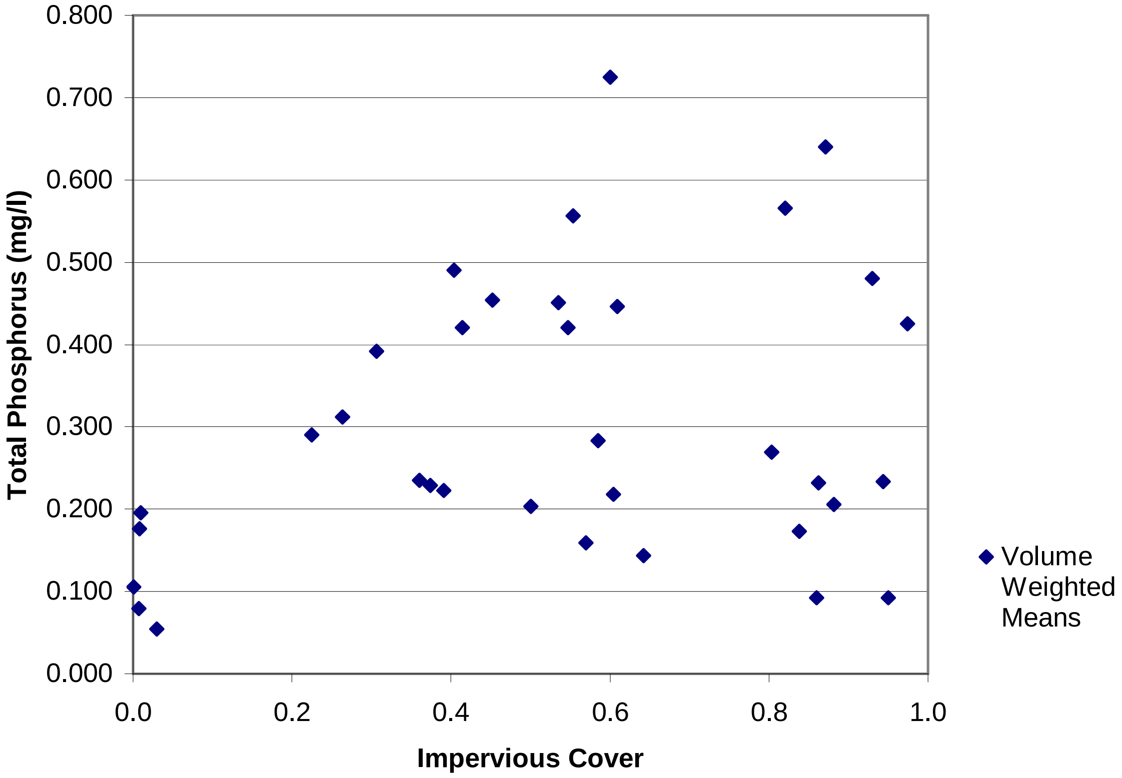

Figure 4.14: Total phosphorus mean concentration versus impervious cover.

Table 4.15: Predicted total phosphorus (TP) concentrations (mg/l).

Impervious Cover (%)	Predicted Concentration
0	0.122
1	0.122
5	0.337
10	0.337
15	0.337
20	0.337
30	0.337
40	0.337
50	0.337
60	0.337
70	0.337
80	0.337
90	0.337
100	0.337

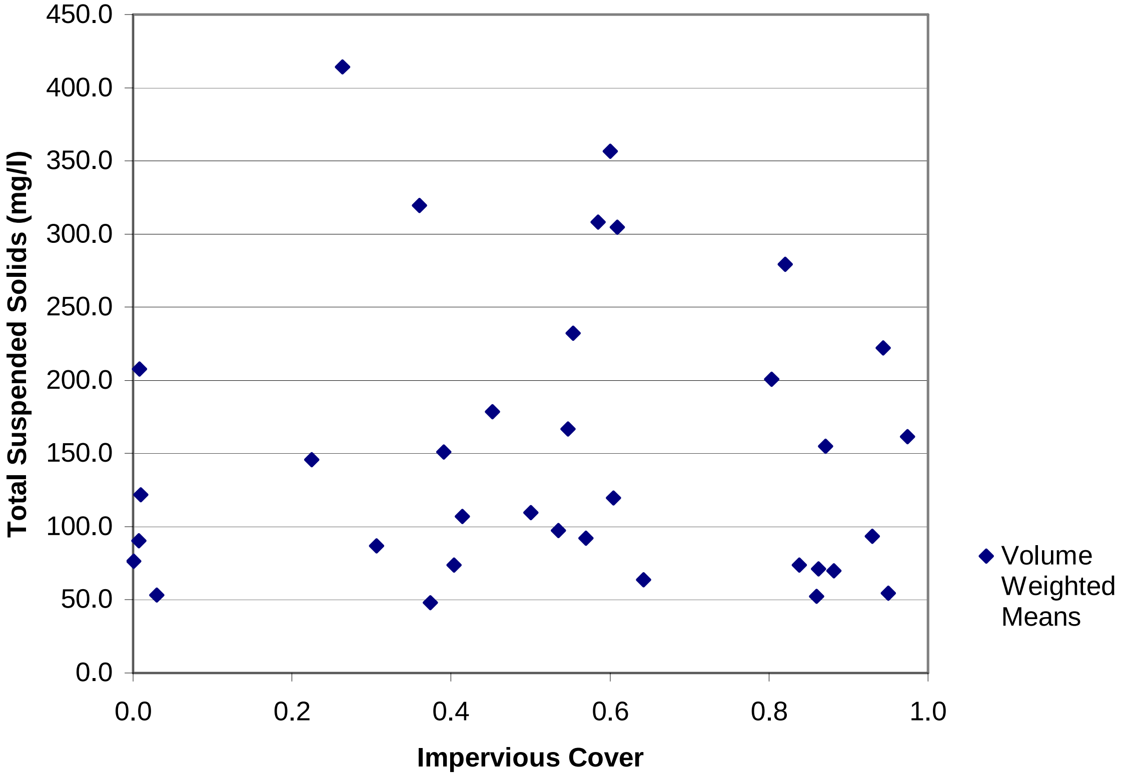

Figure 4.15: Total suspended solids (TSS) mean concentration versus impervious cover.

No significant relationship was found for total suspended sediment based on impervious cover or development condition. It is recommended that the average mean concentration of 153.7 mg/l be used to represent the mean watershed concentration regardless of impervious cover or development condition.

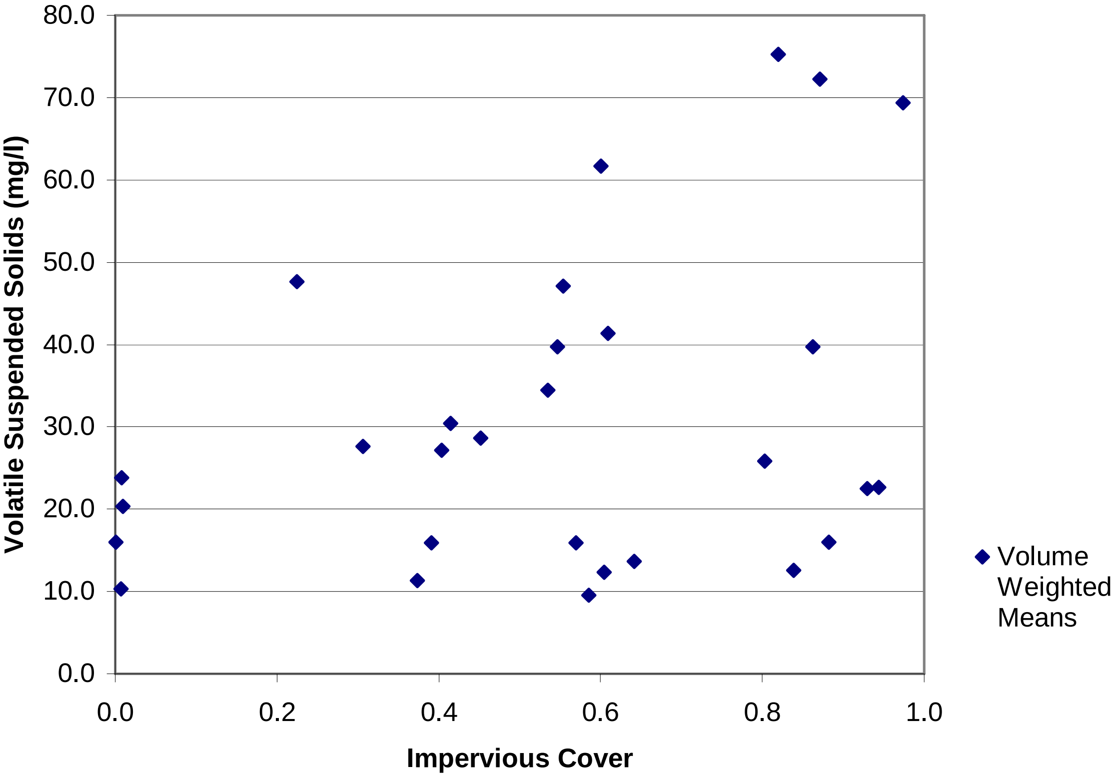

Figure 4.16: Volatile suspended solids (VSS) mean concentration versus impervious cover.

No significant relationship was found for volatile suspended sediment based on impervious cover or development condition. It is recommended that the average mean concentration of 30.4 mg/l be used to represent the mean watershed concentration regardless of impervious cover or development condition.

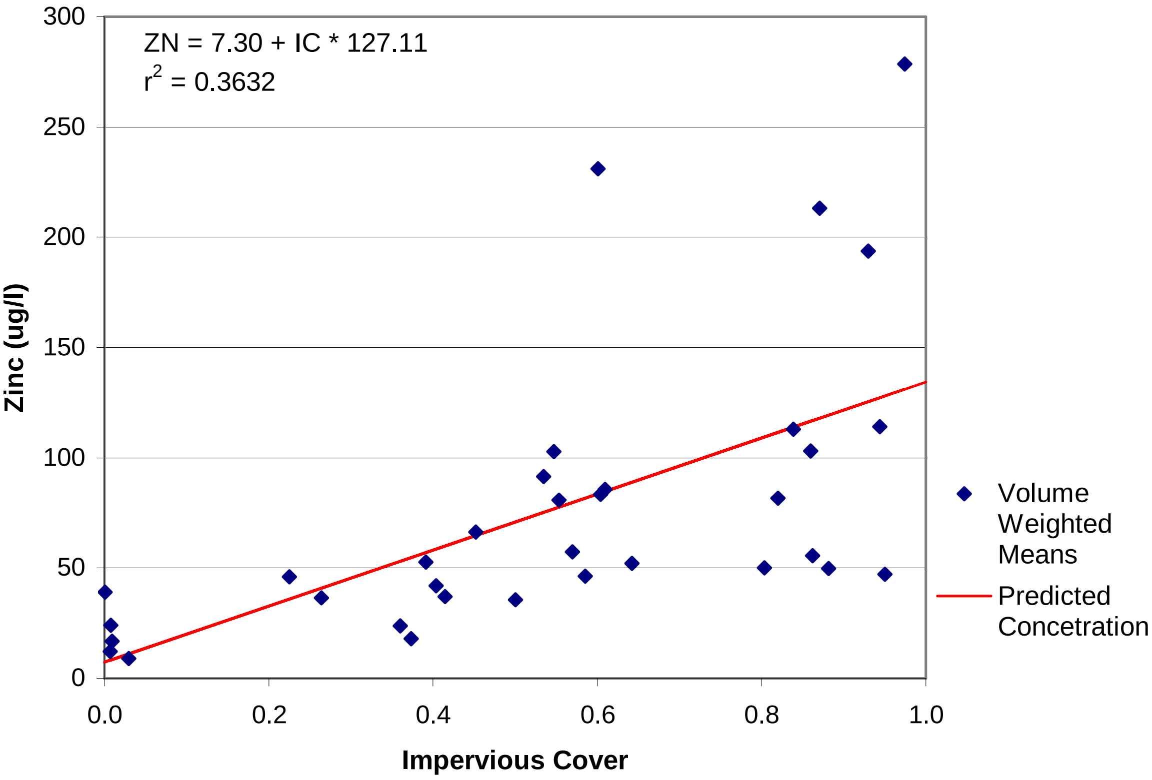

Figure 4.17: Zinc (Zn) mean concentration versus impervious cover.

Table 4.16: Predicted zinc (Zn) concentrations (ug/l).

Impervious Cover (%)	Predicted Concentration
0	7.30
1	8.57
5	13.66
10	20.01
15	26.37
20	32.72
30	45.44
40	58.15
50	70.86
60	83.57
70	96.28
80	108.99
90	121.70
100	134.41

5 REFERENCES

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Appendix A: Data Distribution

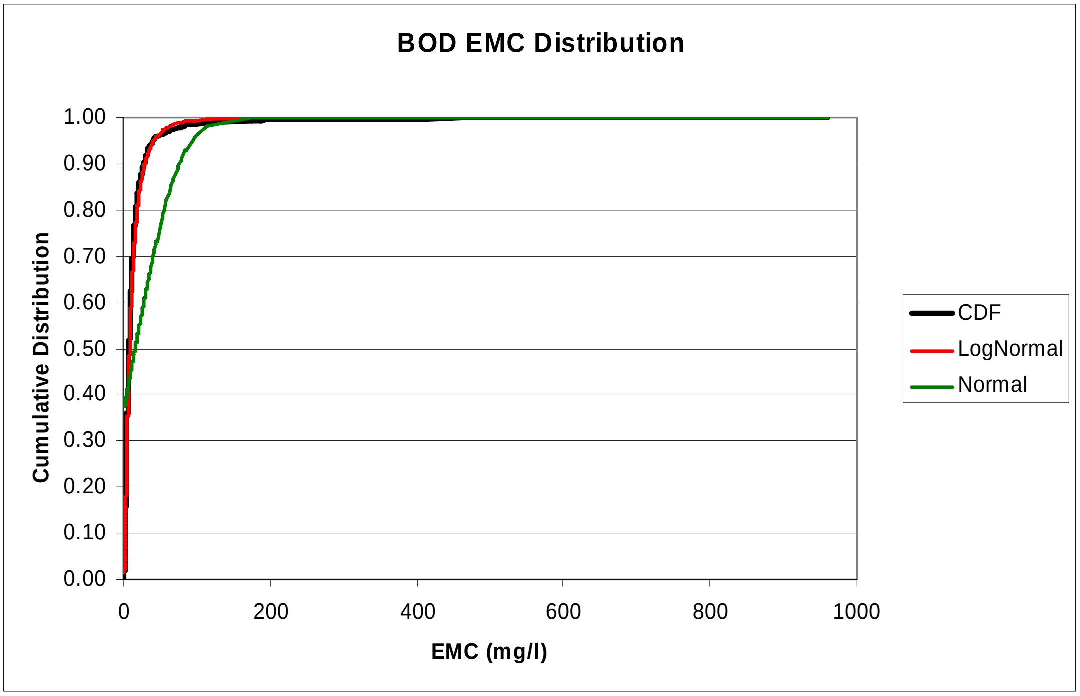

Figure A.1. Distribution of EMCs for bio-chemical oxygen demand.

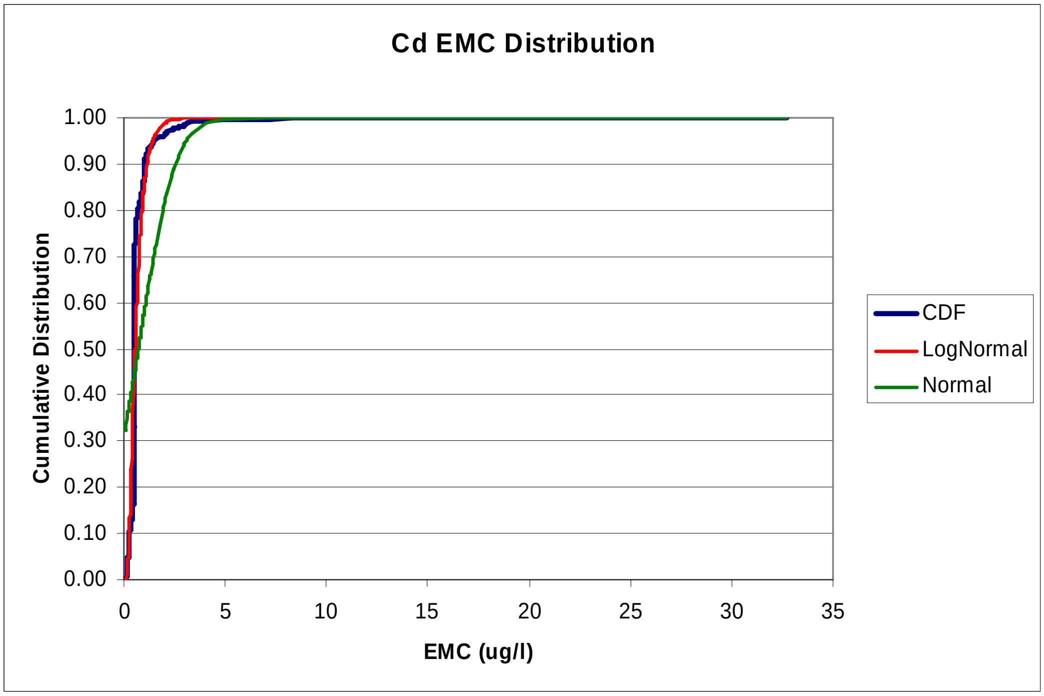

Figure A.2. Distribution of EMCs for cadmium.

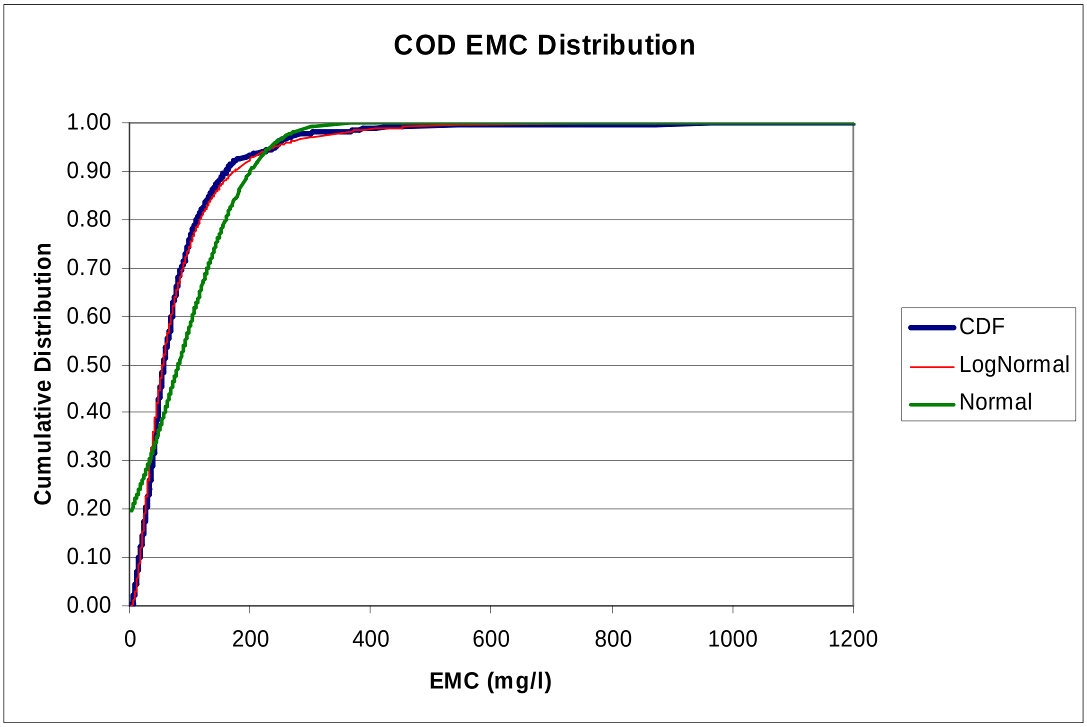

Figure A.3. Distribution of EMCs for chemical oxygen demand.

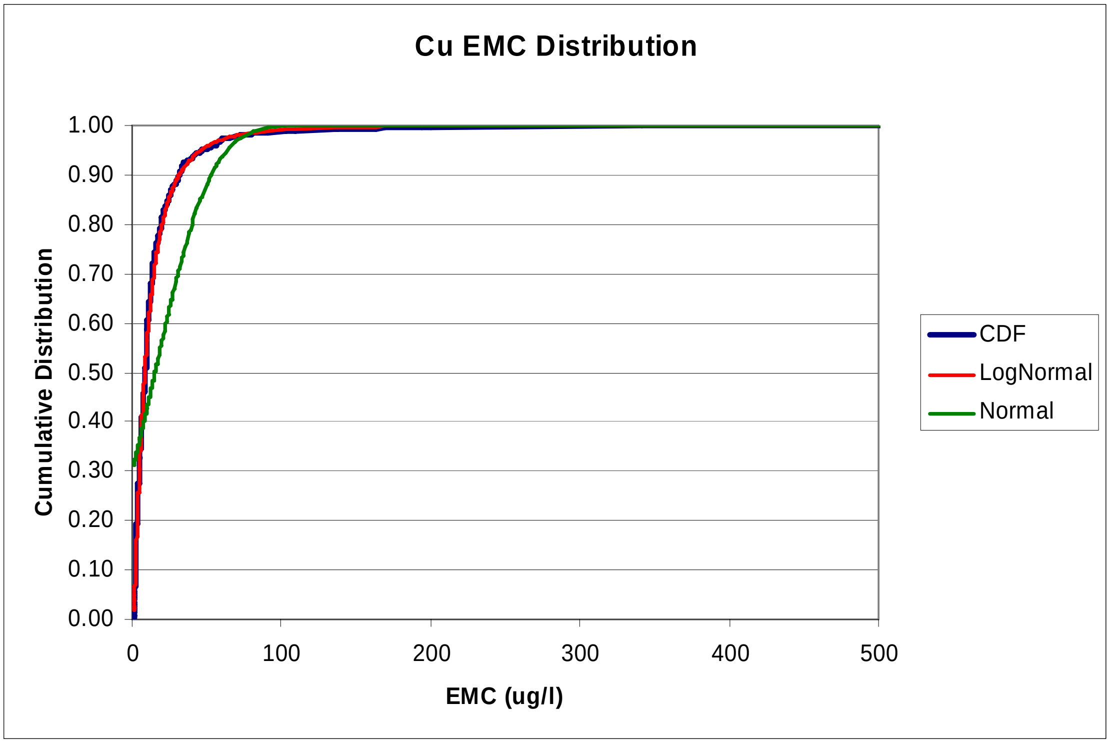

Figure A.4. Distribution of EMCs for copper.

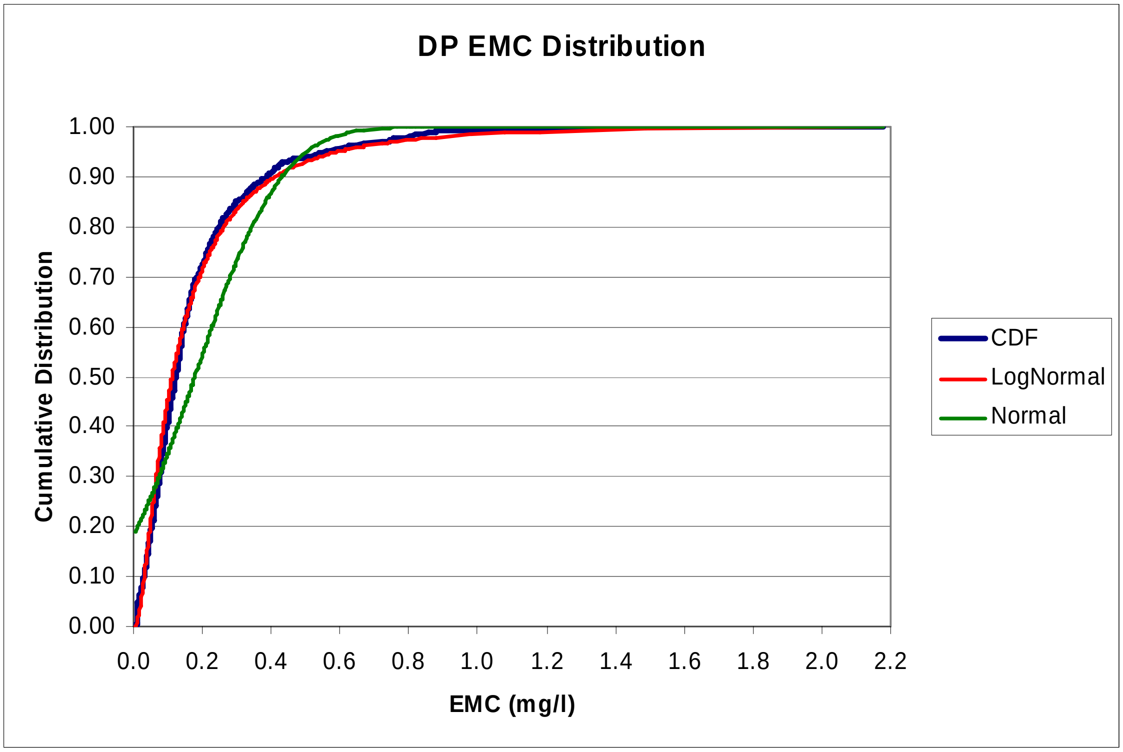

Figure A.5. Distribution of EMCs for dissolved phosphorous.

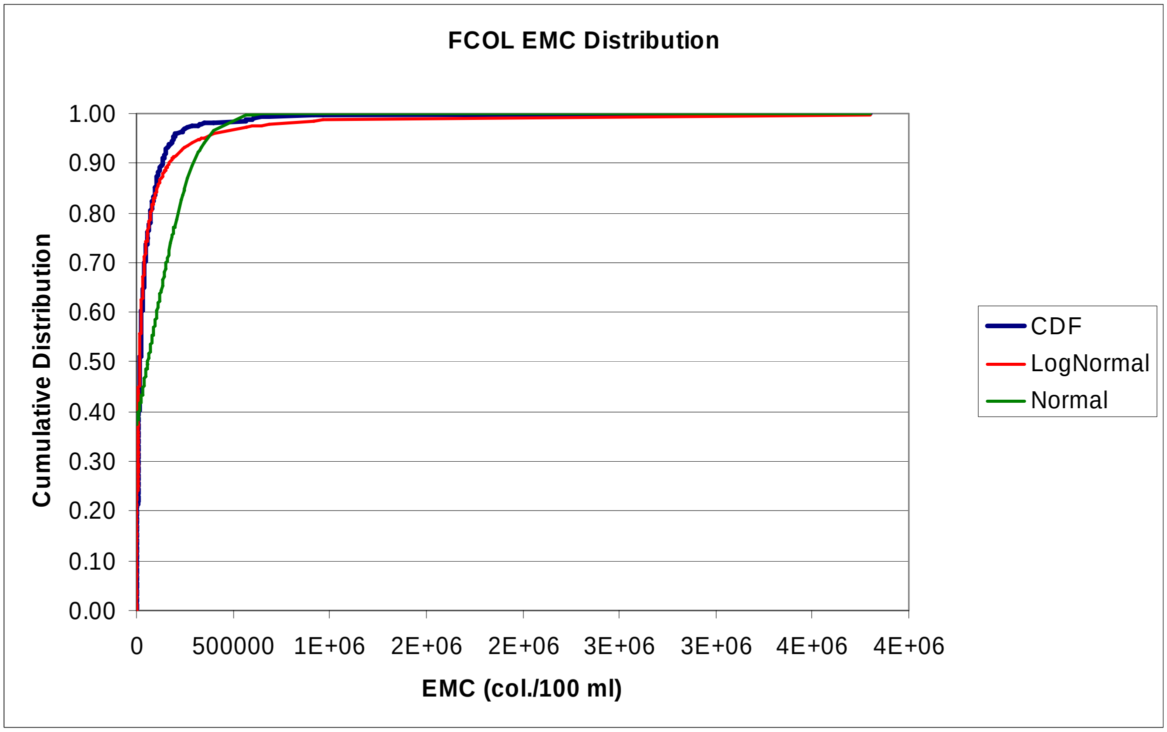

Figure A.6. Distribution of EMCs for fecal coliform.

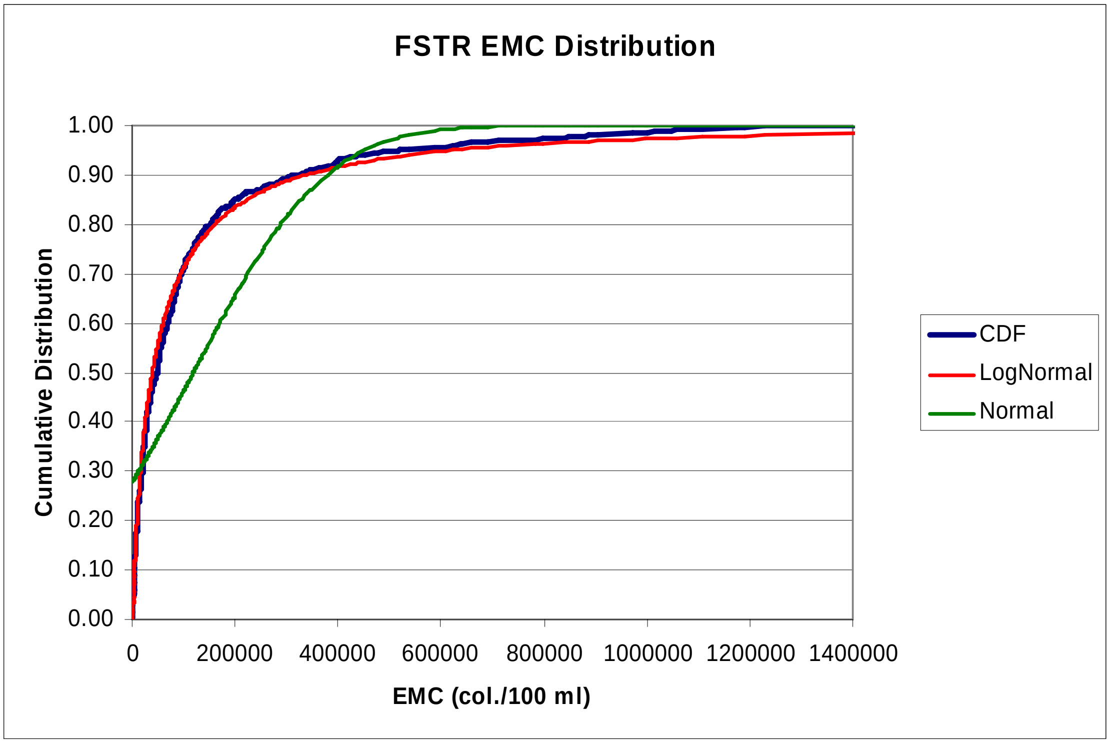

Figure A.7. Distribution of EMCs for fecal streptococci.

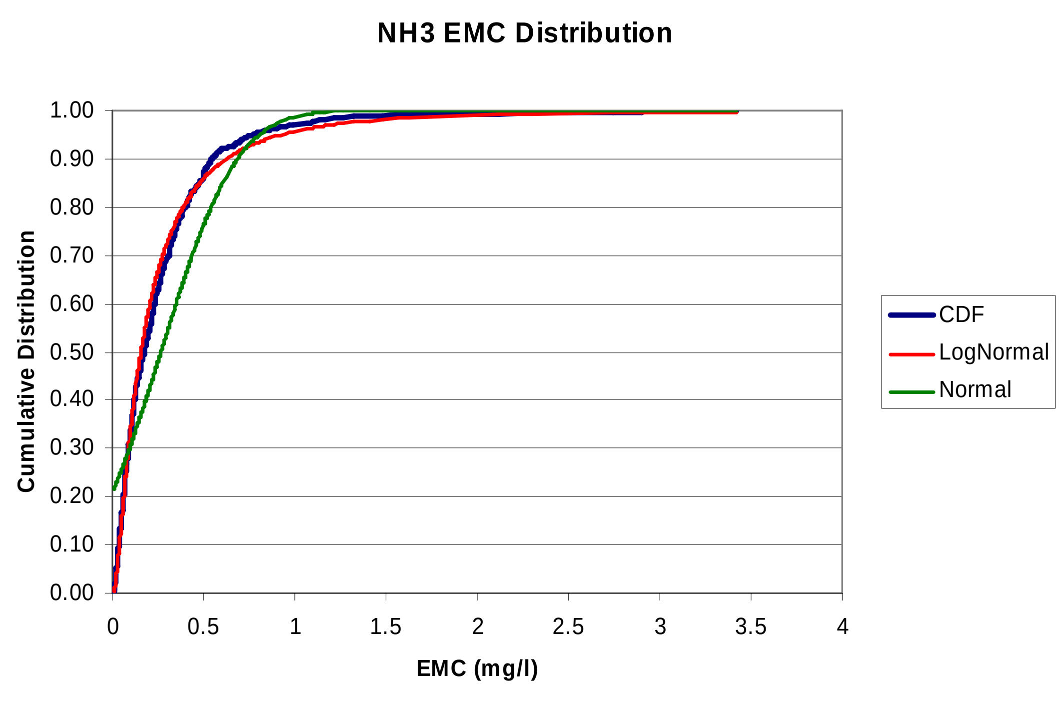

Figure A.8. Distribution of EMCs for ammonia.

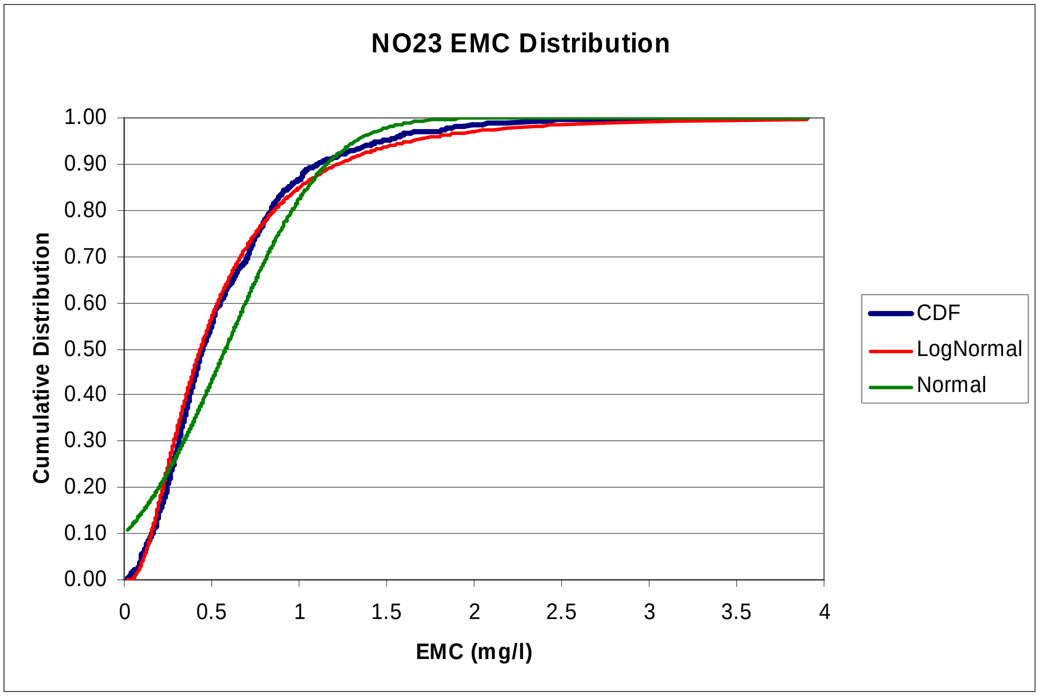

Figure A.9. Distribution of EMCs for nitrate plus nitrite.

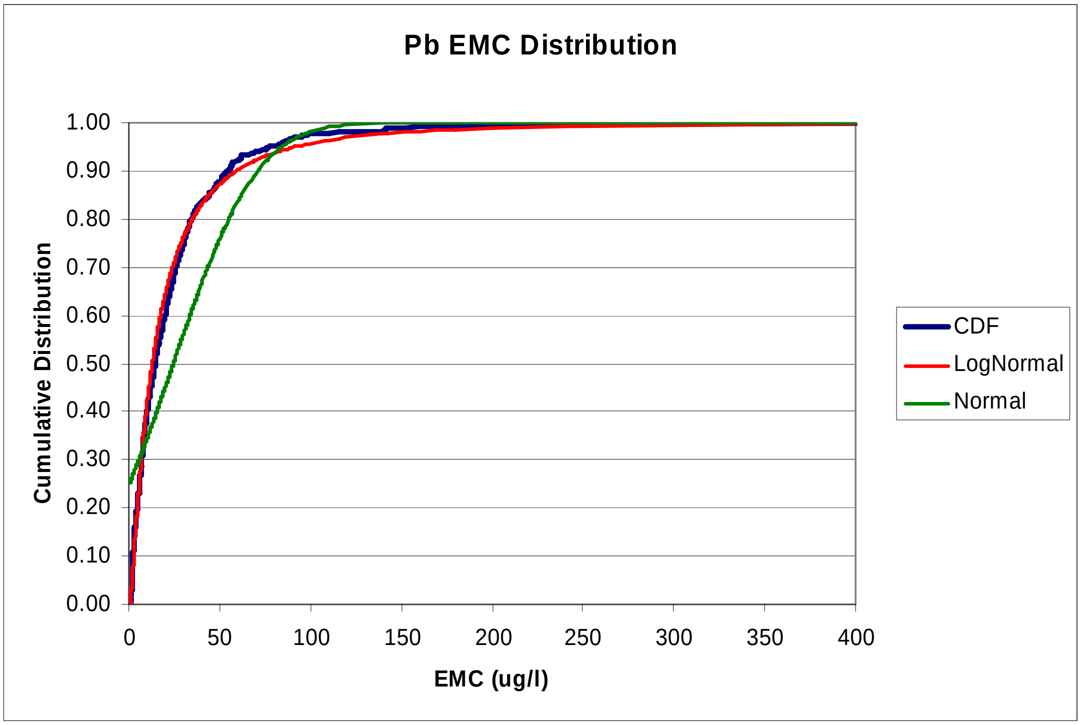

Figure A.10. Distribution of EMCs for lead.

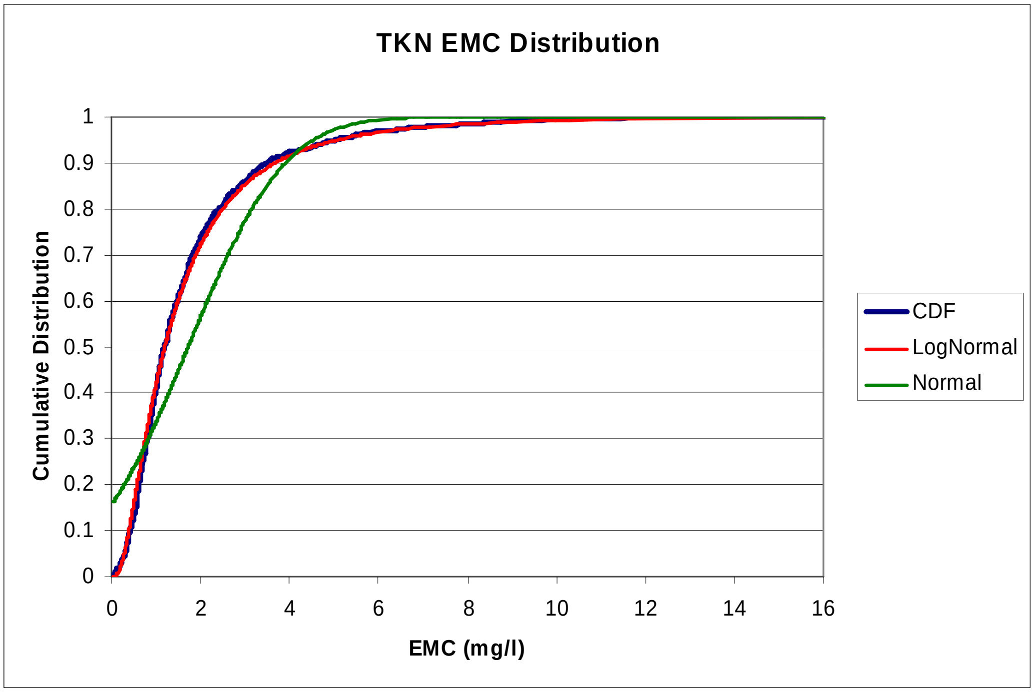

Figure A.11. Distribution of EMCs for total Kjeldahl nitrogen.

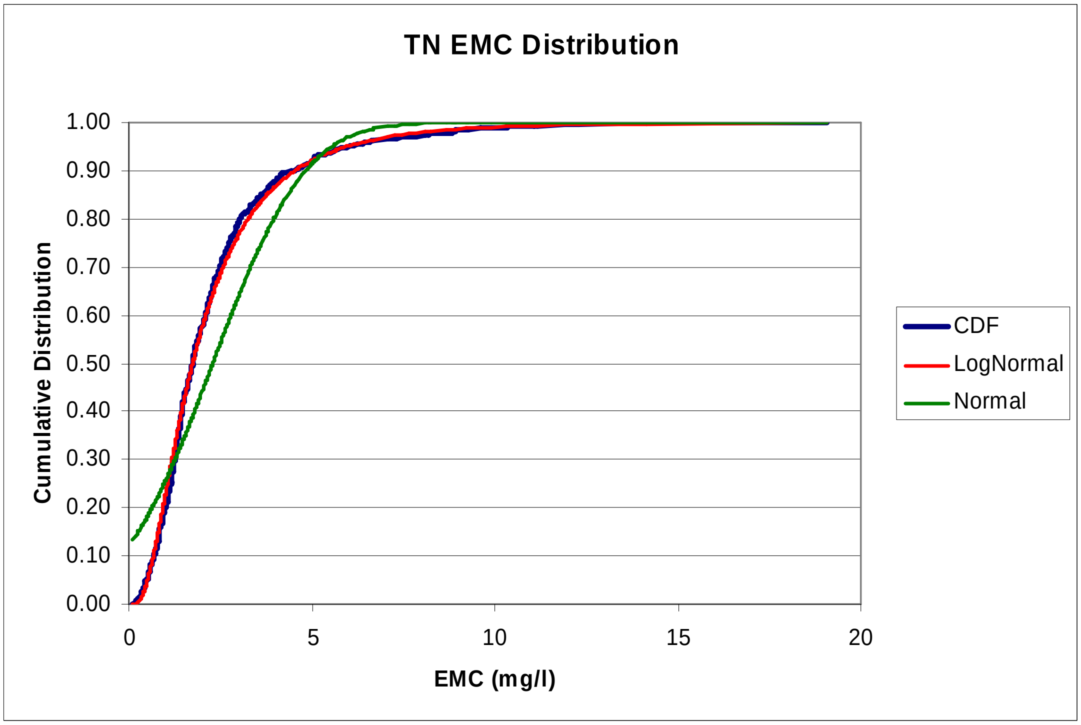

Figure A.12. Distribution of EMCs for total nitrogen.

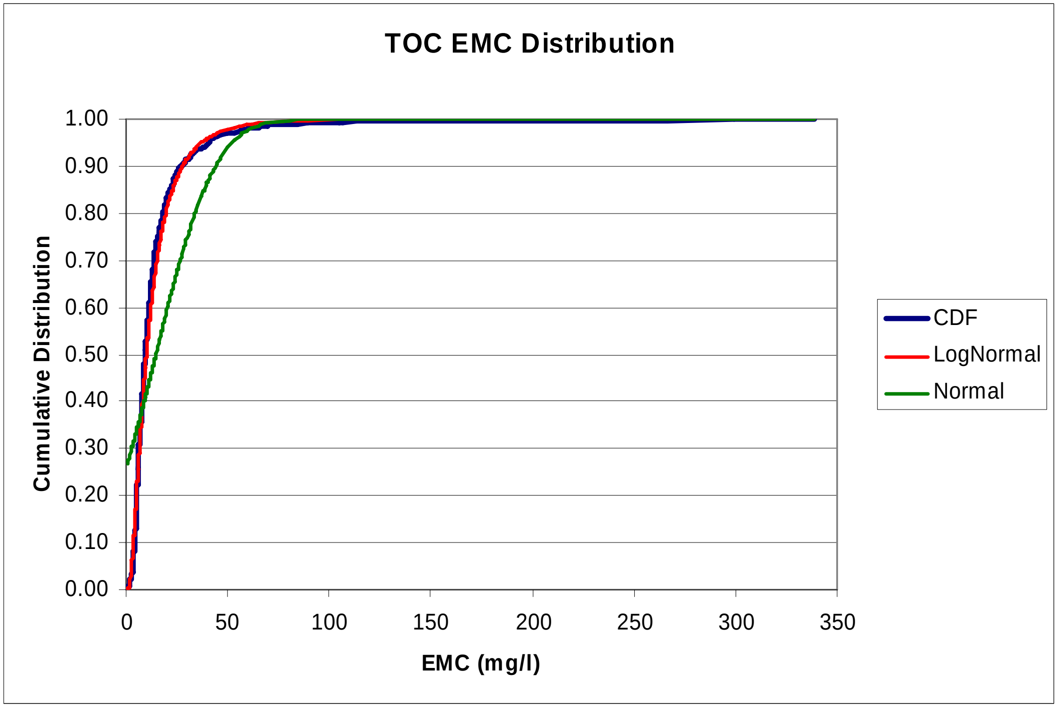

Figure A.13. Distribution of EMCs for total organic carbon.

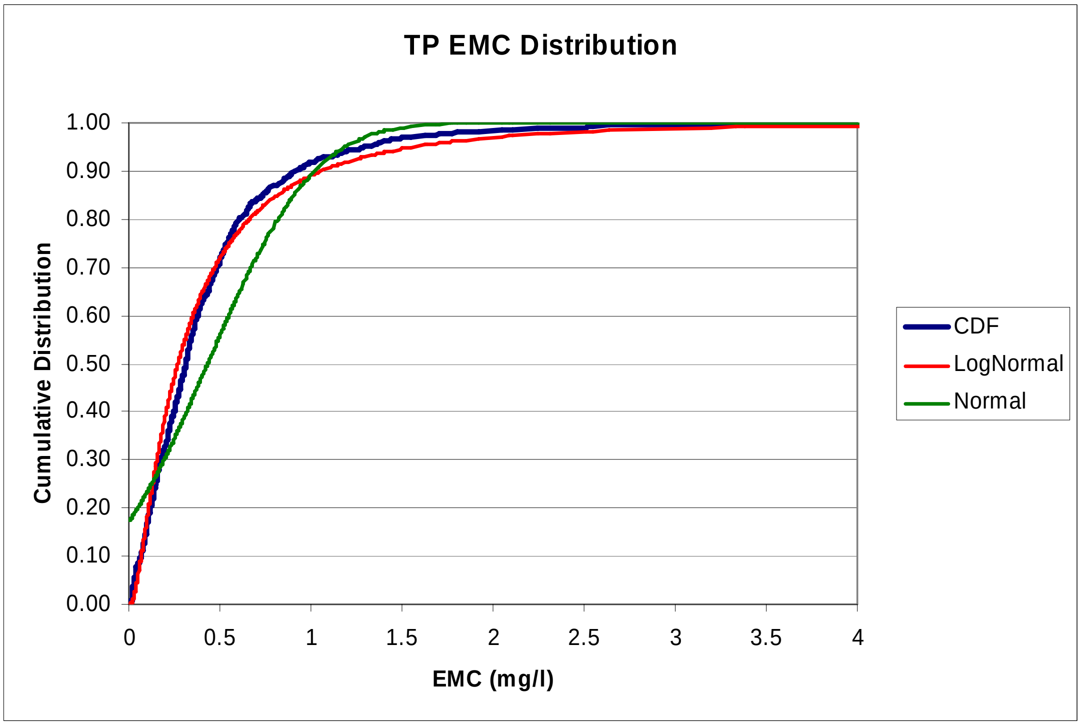

Figure A.14. Distribution of EMCs for total phosphorous.

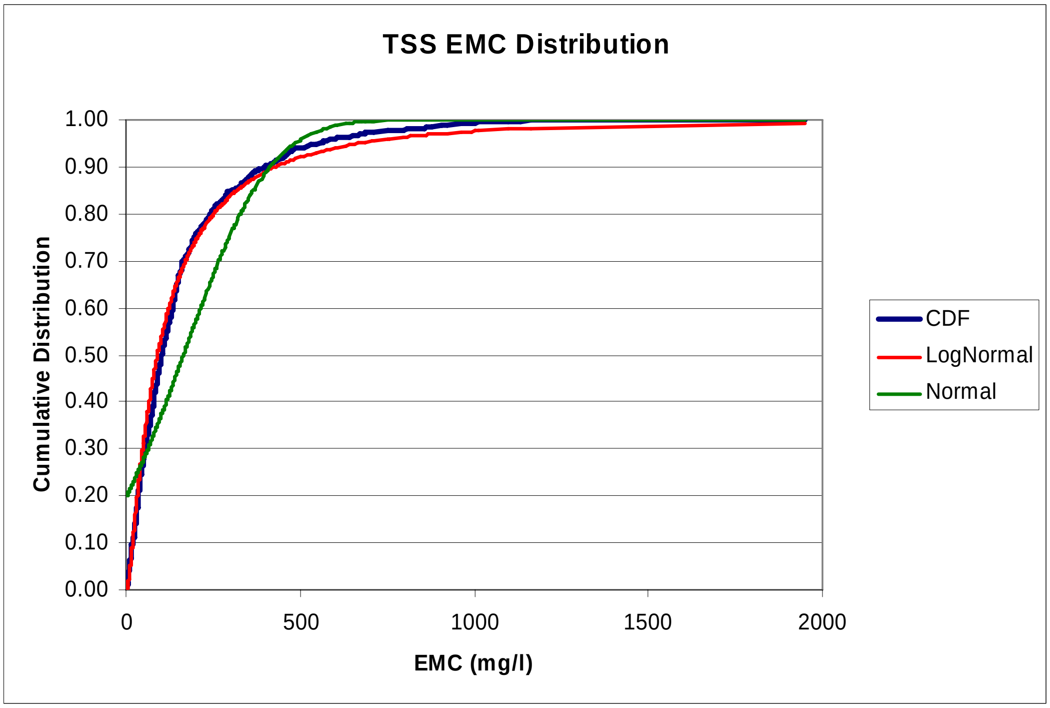

Figure A.15. Distribution of EMCs for total suspended solids.

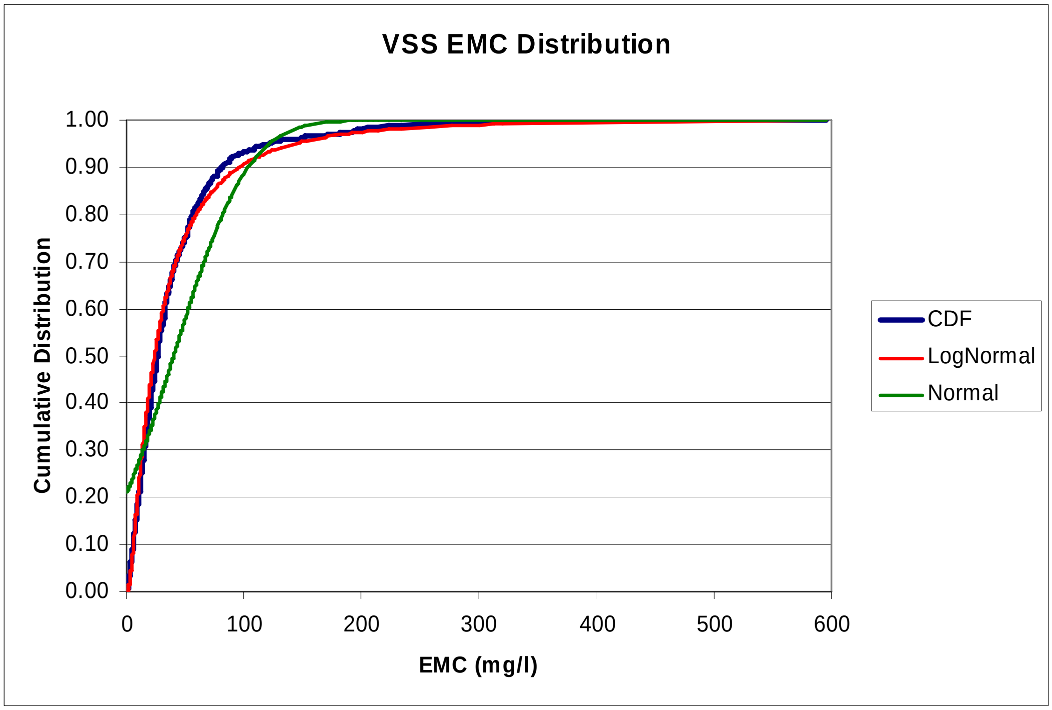

Figure A.16. Distribution of EMCs for volatile suspended solids.

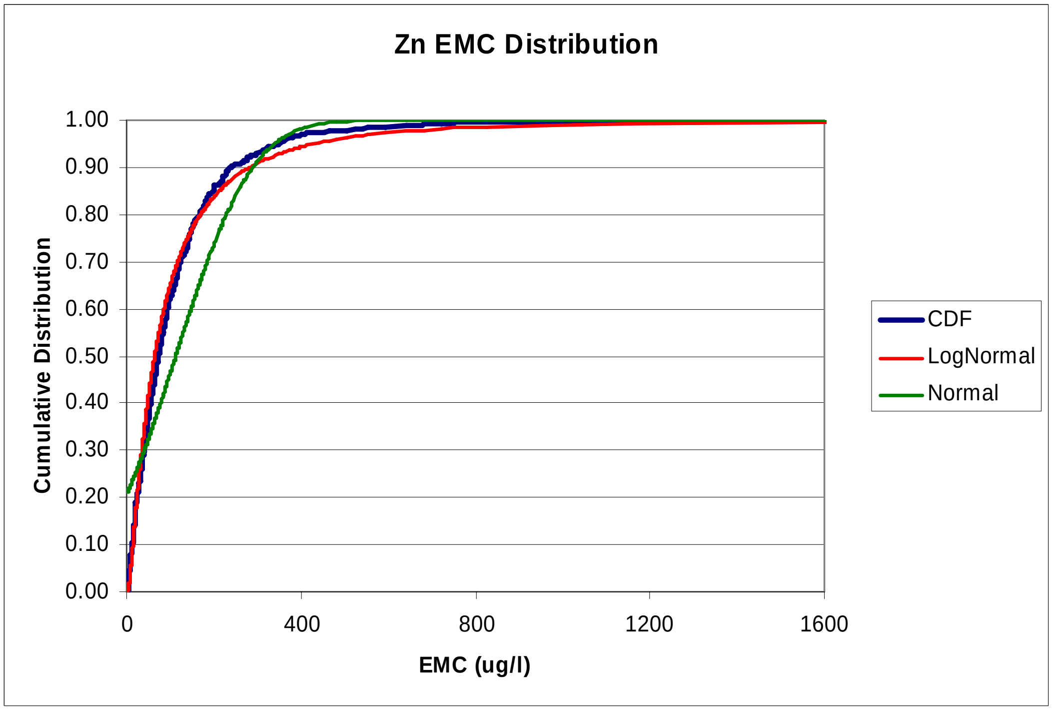

Figure A.17. Distribution of EMCs for zinc.

Appendix B: Runoff Data fit to Various Models

Table B.1: The results of model analyses for COA runoff Data

Model Name	Equation	Standard Error	Correlation Coefficient
Gaussian	y=a*exp(-((b-x)^2)/(2*c^2))	0.1297	0.8733
Rational Function	y=(a+bx)/(1+cx+dx^2)	0.1319	0.8742
Richards	y=a/((1+exp(b-cx))^(1/d))	0.1329	0.8722
Logistic	y=a/(1+b*exp(-cx))	0.1314	0.8697
Gompertz Relation	y=a*exp(-exp(b-cx))	0.1317	0.8690
Third Degree Poly.	y=a+bx+cx^2+dx^3	0.1330	0.8721
Linear	y=a+bx	0.1306	0.8659
Quadratic	y=a+bx+cx^2	0.1328	0.8666
Exponential Association	y=a(b-exp(-cx))	0.1328	0.8666
Shifted Power	y=a*(x-b)^c	0.1330	0.8662

Table B.2: Coefficients for various fitted models.

Model Name	Equation	Parameter Value			
		a	b	c	d
Gaussian	y=a*exp(-((b-x)^2)/(2*c^2))	0.6897	0.8958	0.3923	
Rational Function	y=(a+bx)/(1+cx+dx^2)	0.0666	0.1685	-1.877	1.241
Richards	y=a/((1+exp(b-cx))^(1/d))	0.6936	183.0	259.9	91.11
Logistic	y=a/(1+b*exp(-cx))	0.7599	12.09	5.345	
Gompertz Relation	y=a*exp(-exp(b-cx))	0.8829	1.124	2.817	
Third Degree Poly.	y=a+bx+cx^2+dx^3	0.04592	0.1381	1.941	-1.447
Linear	y=a+bx	0.03466	0.7411		
Quadratic	y=a+bx+cx^2	0.02130	0.8334	-0.0976	
Exponential Association	y=a(b-exp(-cx))	3.394	1.007	0.2445	
Shifted Power	y=a*(x-b)^c	0.7476	-0.0263	0.9356	

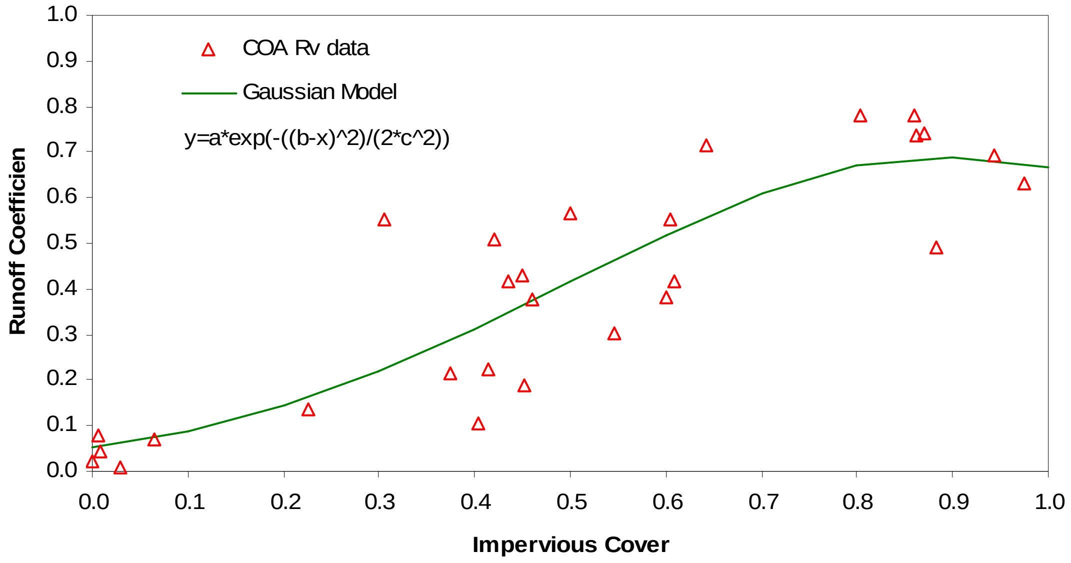

Figure B.1: Gaussian model fit to COA Rv data

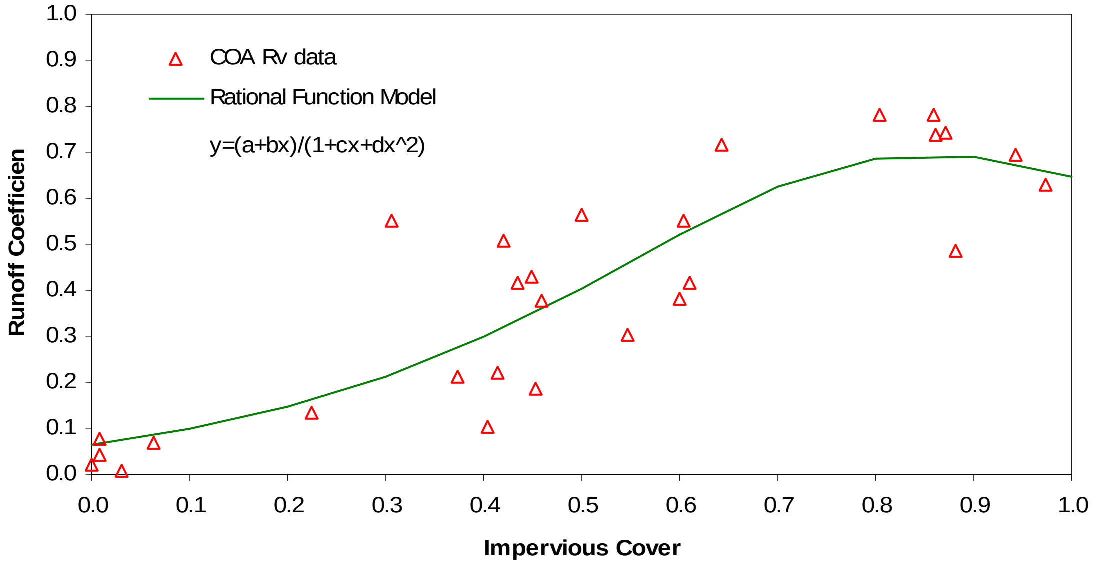

Figure B.2: Rational function model fit to COA Rv data

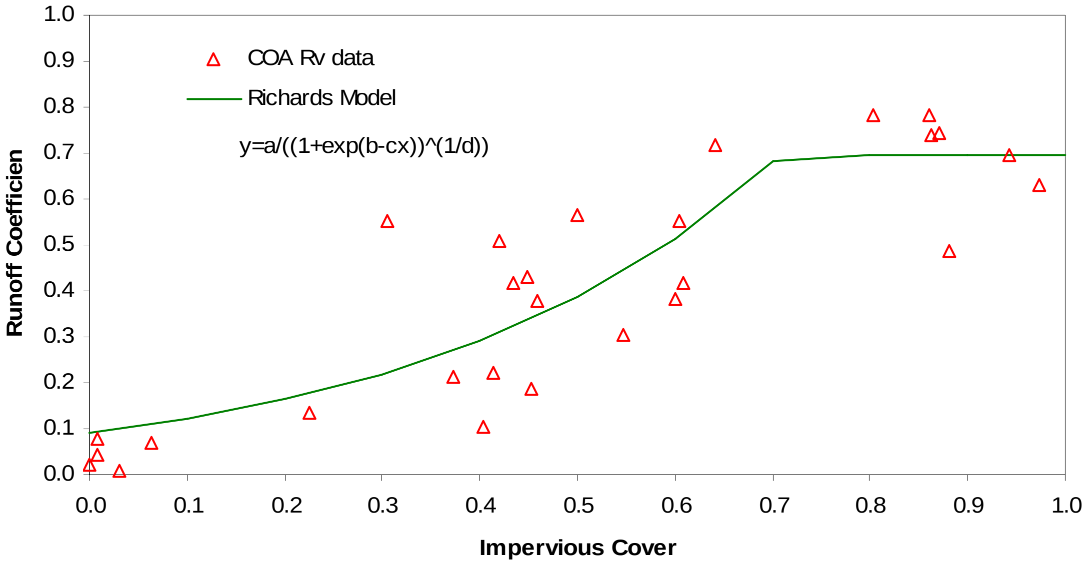

Figure B.3: Richards model fit to COA Rv data

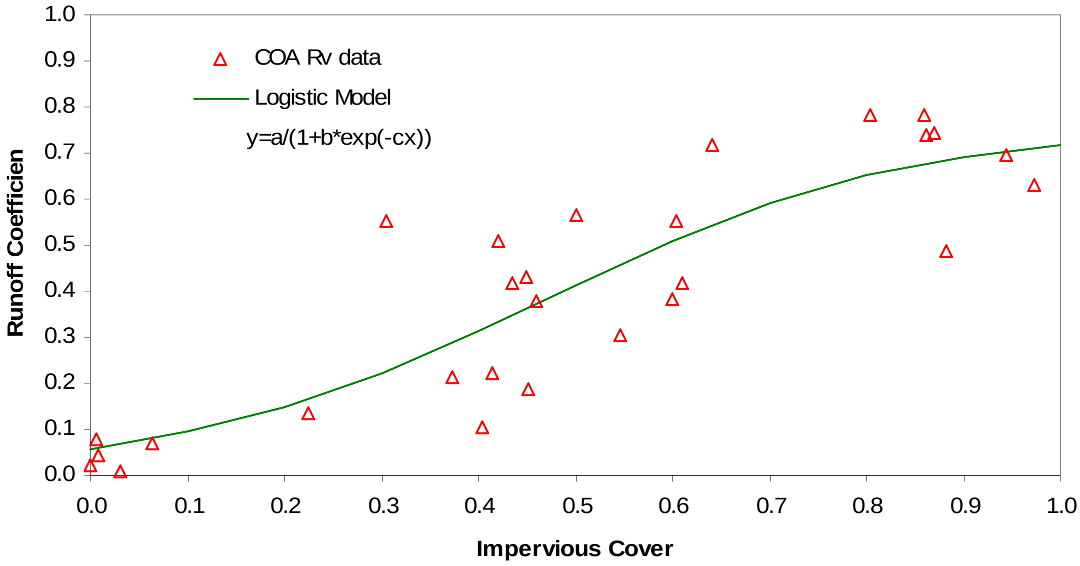

Figure B.4: Logistic model fit to COA Rv data

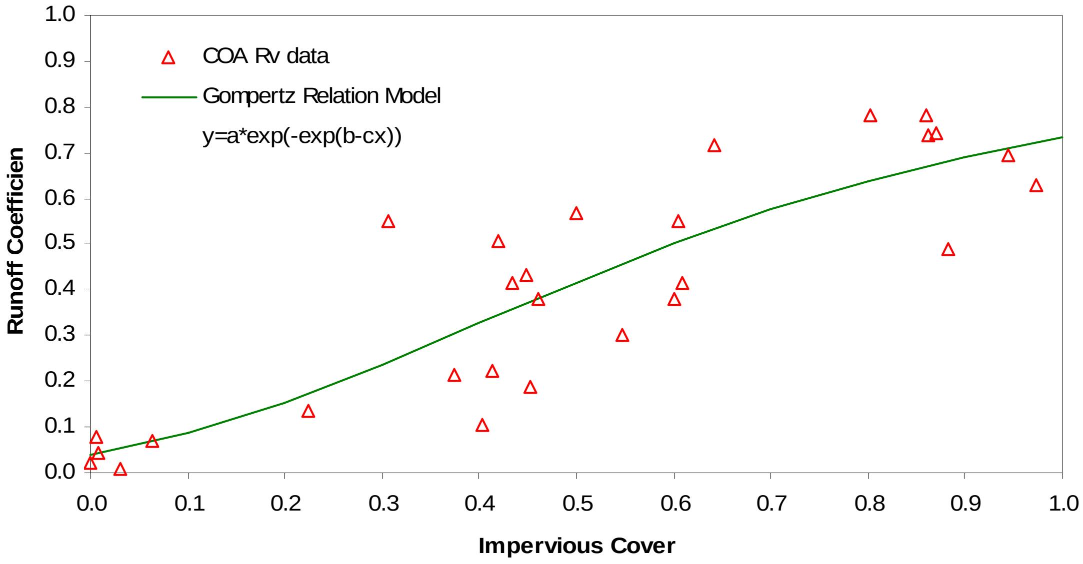

Figure B.5: Gompertz relation model fit to COA Rv data

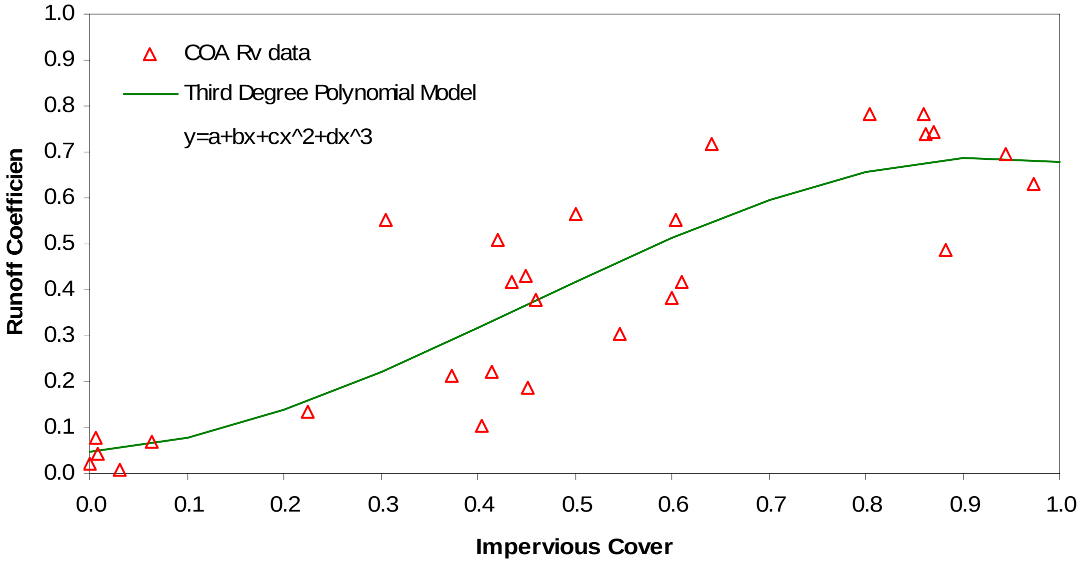

Figure B.6: Third degree polynomial model fit to COA Rv data

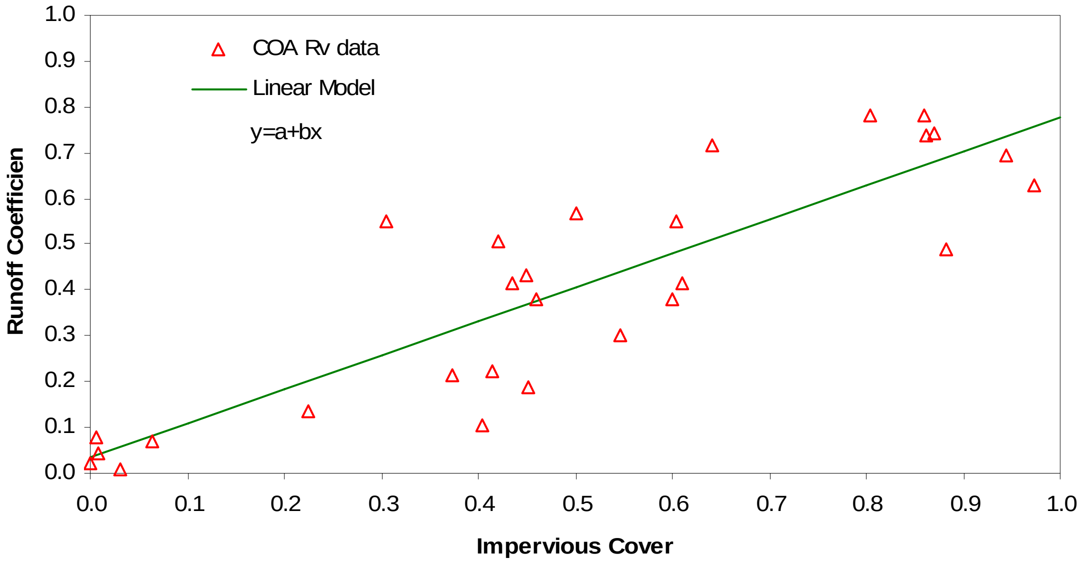

Figure B.7: Linear model fit to COA Rv data

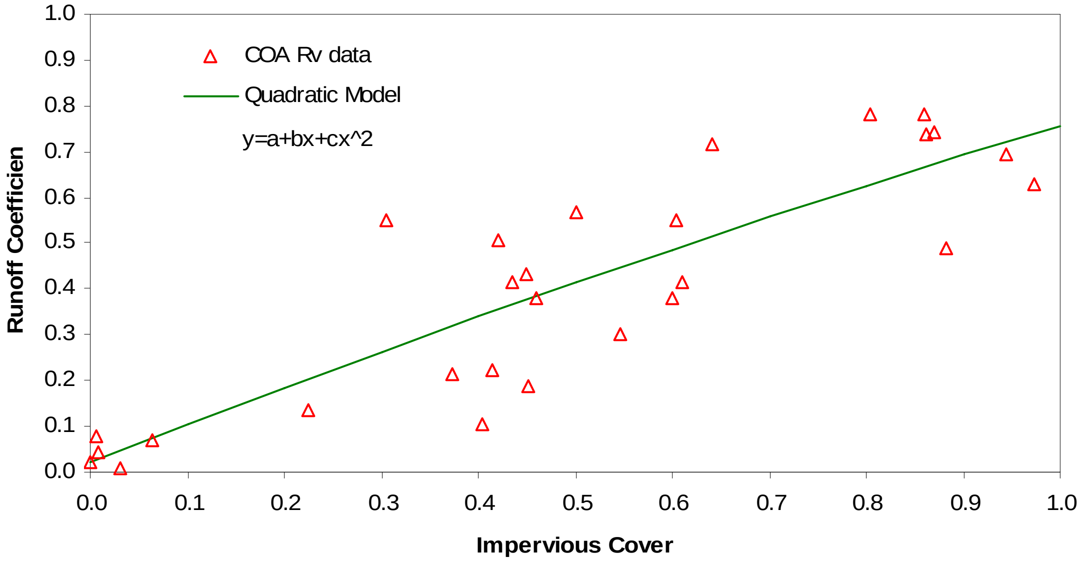

Figure B.8: Quadratic model fit to COA Rv data

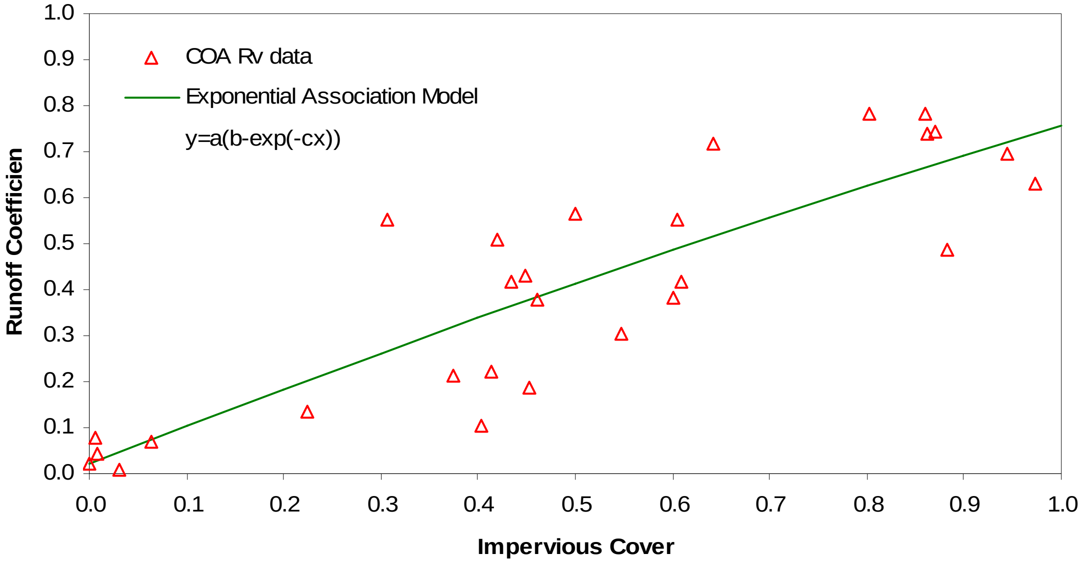

Figure B.9. Exponential association model fit to COA Rv data

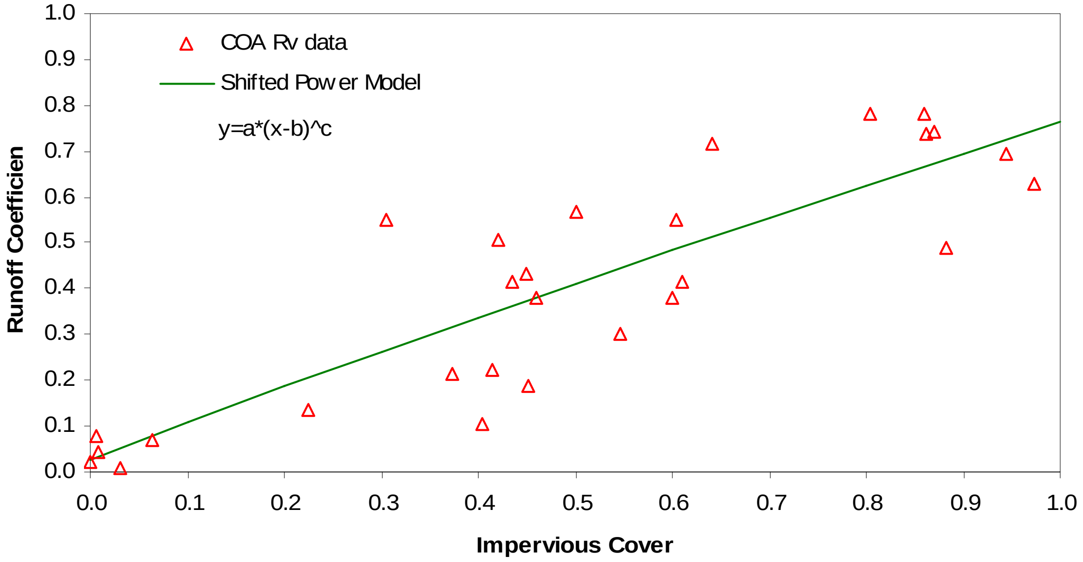

Figure B.10: Shifted power model fit to COA Rv data

Appendix C: SAS Output

BOD Analysis

```
P2060928.MCIMP, BOD REGRESSION ON IC
14:53 Thursday, October 5, 2006 191
11OCT2006:17:33:50 by Baolin Bai

The REG Procedure
Model: MODEL1
Dependent Variable: BOD

Number of Observations Read                         36
Number of Observations Used                         35
Number of Observations with Missing Values           1


                             Analysis of Variance

                            Sum of           Mean
Source            DF       Squares         Square    F Value    Pr > F

Model              1     131.93835      131.93835       7.21    0.0112
Error             33     603.77719       18.29628
Corrected Total   34     735.71554


Root MSE              4.27741    R-Square     0.1793
Dependent Mean        8.35827    Adj R-Sq     0.1545
Coeff Var            51.17584


                        Parameter Estimates

                     Parameter       Standard
Variable     DF       Estimate          Error    t Value    Pr > |t|

Intercept     1        4.87994        1.48341       3.29      0.0024
IC            1        6.50147        2.42107       2.69      0.0112
```

```
Duncan's Multiple Range Test for BOD

NOTE: This test controls the Type I comparisonwise error rate, not the
experimentwise error rate.


Alpha                               0.05
Error Degrees of Freedom              33
Error Mean Square               18.36408
Harmonic Mean of Cell Sizes 8.571429




NOTE: Cell sizes are not equal.


Number of Means          2
Critical Range       4.212


Means with the same letter are not significantly different.

          Mean      N    DEVELOP

A         9.144     30    1

B         3.643      5    0
```

Cd Analysis

```
P2060928.MCIMP, CD REGRESSION ON IC
14:53 Thursday, October 5, 2006 192
11OCT2006:17:33:52 by Baolin Bai

The REG Procedure
Model: MODEL1
Dependent Variable: CD

Number of Observations Read                         36
Number of Observations Used                         29
Number of Observations with Missing Values           7


                             Analysis of Variance

                                 Sum of           Mean
Source                   DF     Squares         Square    F Value    Pr > F

Model                     1     0.08769        0.08769       1.67    0.2067
Error                    27     1.41430        0.05238
Corrected Total          28     1.50199


Root MSE              0.22887    R-Square     0.0584
Dependent Mean        0.61533    Adj R-Sq     0.0235
Coeff Var            37.19464


                        Parameter Estimates

                     Parameter       Standard
Variable     DF       Estimate          Error    t Value    Pr > |t|

Intercept     1        0.51316        0.08968       5.72      <.0001
IC            1        0.18800        0.14530       1.29      0.2067
```

```
Duncan's Multiple Range Test for CD

NOTE: This test controls the Type I comparisonwise error rate, not the
experimentwise error rate.


Alpha                           0.05
Error Degrees of Freedom          28
Error Mean Square           0.052556
Harmonic Mean of Cell Sizes 6.933333





NOTE: Cell sizes are not equal.


Number of Means          2
Critical Range       .2522


Means with the same letter are not significantly different.


           Mean      N    DEVELOP

A        0.6291     26    1
A
A        0.5339      4    0
```

COD Analysis

```
P2060928.MCIMP, COD REGRESSION ON IC
14:53 Thursday, October 5, 2006 193
11OCT2006:17:33:53 by Baolin Bai

The REG Procedure
Model: MODEL1
Dependent Variable: COD

Number of Observations Read                         36
Number of Observations Used                         34
Number of Observations with Missing Values           2


                             Analysis of Variance

                                 Sum of           Mean
Source                DF        Squares         Square    F Value    Pr > F

Model                  1     3660.94291     3660.94291       7.05    0.0122
Error                 32          16615      519.21765
Corrected Total       33          20276


Root MSE             22.78635    R-Square     0.1806
Dependent Mean       52.58106    Adj R-Sq     0.1549
Coeff Var            43.33566


                        Parameter Estimates

                     Parameter       Standard
Variable     DF       Estimate          Error    t Value    Pr > |t|

Intercept     1       34.27648        7.92408       4.33      0.0001
IC            1       34.24899       12.89811       2.66      0.0122
```

```
Duncan's Multiple Range Test for COD

NOTE: This test controls the Type I comparisonwise error rate, not the
experimentwise error rate.


Alpha                             0.05
Error Degrees of Freedom            33
Error Mean Square             595.3781
Harmonic Mean of Cell Sizes 8.571429







NOTE: Cell sizes are not equal.


Number of Means          2
Critical Range       23.98


Means with the same letter are not significantly different.


           Mean      N    DEVELOP

A         54.36     30    1
A
A         42.23      5    0
```

Cu Analysis

```
P2060928.MCIMP, CU REGRESSION ON IC
14:53 Thursday, October 5, 2006 194
11OCT2006:17:33:54 by Baolin Bai

The REG Procedure
Model: MODEL1
Dependent Variable: CU

Number of Observations Read                         36
Number of Observations Used                         34
Number of Observations with Missing Values           2


                             Analysis of Variance

                                 Sum of           Mean
Source                   DF     Squares         Square    F Value    Pr > F

Model                     1   226.50411      226.50411       7.27    0.0111
Error                    32   997.03228       31.15726
Corrected Total          33  1223.53639


Root MSE              5.58187    R-Square     0.1851
Dependent Mean        9.70732    Adj R-Sq     0.1597
Coeff Var            57.50165


                        Parameter Estimates

                     Parameter       Standard
Variable     DF       Estimate          Error    t Value    Pr > |t|

Intercept     1        5.15428        1.94113       2.66      0.0122
IC            1        8.51901        3.15959       2.70      0.0111
```

```
Duncan's Multiple Range Test for CU

NOTE: This test controls the Type I comparisonwise error rate, not the
experimentwise error rate.


Alpha                              0.05
Error Degrees of Freedom             33
Error Mean Square              33.48642
Harmonic Mean of Cell Sizes    8.571429









NOTE: Cell sizes are not equal.


Number of Means          2
Critical Range       5.687


Means with the same letter are not significantly different.


           Mean      N    DEVELOP

A        10.409     30    1
A
A         5.039      5    0
```

DP Analysis

```
P2060928.MCIMP, DP REGRESSION ON IC
14:53 Thursday, October 5, 2006 195
11OCT2006:17:33:55 by Baolin Bai

The REG Procedure
Model: MODEL1
Dependent Variable: DP

Number of Observations Read                          36
Number of Observations Used                          29
Number of Observations with Missing Values            7


                             Analysis of Variance

                                 Sum of           Mean
Source                   DF     Squares         Square    F Value    Pr > F

Model                     1     0.03741        0.03741       6.98    0.0136
Error                    27     0.14474        0.00536
Corrected Total          28     0.18214


Root MSE              0.07322    R-Square     0.2054
Dependent Mean        0.13242    Adj R-Sq     0.1759
Coeff Var            55.29201


                        Parameter Estimates

                     Parameter       Standard
Variable     DF       Estimate          Error    t Value    Pr > |t|

Intercept     1        0.06568        0.02869       2.29      0.0301
IC            1        0.12279        0.04648       2.64      0.0136
```

```
Duncan's Multiple Range Test for DP

NOTE: This test controls the Type I comparisonwise error rate, not the
experimentwise error rate.


Alpha                               0.05
Error Degrees of Freedom              28
Error Mean Square               0.005058
Harmonic Mean of Cell Sizes     6.933333








NOTE: Cell sizes are not equal.


Number of Means            2
Critical Range        .07825


Means with the same letter are not significantly different.


           Mean      N    DEVELOP

A       0.15089     26    1

B       0.03373      4    0
```

F. Col. Analysis

```
P2060928.MCIMP, FCOL REGRESSION ON IC
14:53 Thursday, October 5, 2006 196
11OCT2006:17:33:56 by Baolin Bai

The REG Procedure
Model: MODEL1
Dependent Variable: FCOL

Number of Observations Read                         36
Number of Observations Used                         35
Number of Observations with Missing Values           1


                             Analysis of Variance

                                 Sum of           Mean
Source                   DF        Squares         Square    F Value    Pr > F

Model                     1       22059891       22059891       0.03    0.8735
Error                    33    28285009718      857121507
Corrected Total          34    28307069609


Root MSE                  29277    R-Square     0.0008
Dependent Mean            38851    Adj R-Sq    -0.0295
Coeff Var              75.35620


                        Parameter Estimates

                     Parameter       Standard
Variable     DF       Estimate          Error    t Value    Pr > |t|

Intercept     1          37429          10153       3.69      0.0008
IC            1     2658.44652          16571       0.16      0.8735
```

```
Duncan's Multiple Range Test for FCOL

NOTE: This test controls the Type I comparisonwise error rate, not the
experimentwise error rate.


Alpha                              0.05
Error Degrees of Freedom             33
Error Mean Square              7.6714E8
Harmonic Mean of Cell Sizes 8.571429








NOTE: Cell sizes are not equal.


Number of Means          2
Critical Range       27220


Means with the same letter are not significantly different.


           Mean      N    DEVELOP

A         42625     30    1
A
A         16206      5    0
```

F. Strep. Analysis

```
P2060928.MCIMP, FSTR REGRESSION ON IC
14:53 Thursday, October 5, 2006 197
11OCT2006:17:33:57 by Baolin Bai

The REG Procedure
Model: MODEL1
Dependent Variable: FSTR

Number of Observations Read                         36
Number of Observations Used                         35
Number of Observations with Missing Values           1


                             Analysis of Variance

                                 Sum of           Mean
Source                    DF        Squares         Square    F Value    Pr > F

Model                      1     2679995223     2679995223       0.65    0.4274
Error                     33    1.369366E11     4149594953
Corrected Total           34    1.396166E11


Root MSE                 64417    R-Square     0.0192
Dependent Mean           69004    Adj R-Sq    -0.0105
Coeff Var             93.35265


                        Parameter Estimates

                     Parameter       Standard
Variable     DF       Estimate          Error    t Value    Pr > |t|

Intercept     1          53328          22340       2.39      0.0229
IC            1          29302          36461       0.80      0.4274
```

```
The GLM Procedure

Duncan's Multiple Range Test for FSTR

NOTE: This test controls the Type I comparisonwise error rate, not the
experimentwise error rate.


Alpha                              0.05
Error Degrees of Freedom             33
Error Mean Square              4.0997E9
Harmonic Mean of Cell Sizes    8.571429





NOTE: Cell sizes are not equal.


Number of Means           2
Critical Range        62926


Means with the same letter are not significantly different.


           Mean      N    DEVELOP

A         73543     30    1
A
A         41772      5    0
```

NH3 Analysis

```
P2060928.MCIMP, NH3 REGRESSION ON IC
14:53 Thursday, October 5, 2006 198
11OCT2006:17:33:58 by Baolin Bai

The REG Procedure
Model: MODEL1
Dependent Variable: NH3

Number of Observations Read                         36
Number of Observations Used                         35
Number of Observations with Missing Values           1


                             Analysis of Variance

                                 Sum of           Mean
Source                DF         Squares         Square    F Value    Pr > F

Model                  1         0.17330        0.17330      16.78    0.0003
Error                 33         0.34084        0.01033
Corrected Total       34         0.51414


Root MSE              0.10163    R-Square     0.3371
Dependent Mean        0.21160    Adj R-Sq     0.3170
Coeff Var            48.02830


                        Parameter Estimates

                     Parameter       Standard
Variable     DF        Estimate         Error    t Value    Pr > |t|

Intercept     1         0.08554        0.03525       2.43      0.0208
IC            1         0.23563        0.05752       4.10      0.0003
```

```
Duncan's Multiple Range Test for NH3

NOTE: This test controls the Type I comparisonwise error rate, not the
experimentwise error rate.


Alpha                              0.05
Error Degrees of Freedom             34
Error Mean Square              0.010474
Harmonic Mean of Cell Sizes    8.611111







NOTE: Cell sizes are not equal.


Number of Means          2
Critical Range       .1002


Means with the same letter are not significantly different.


           Mean      N    DEVELOP

A       0.23828     31    1

B       0.04669      5    0
```

NO2+NO3 Analysis

```
P2060928.MCIMP, NO23 REGRESSION ON IC
14:53 Thursday, October 5, 2006 199
11OCT2006:17:33:58 by Baolin Bai

The REG Procedure
Model: MODEL1
Dependent Variable: NO23

Number of Observations Read                          36
Number of Observations Used                          35
Number of Observations with Missing Values            1


                             Analysis of Variance

                                 Sum of           Mean
Source                 DF       Squares         Square    F Value    Pr > F

Model                   1       0.05825        0.05825       1.02    0.3190
Error                  33       1.87784        0.05690
Corrected Total        34       1.93609


Root MSE              0.23855    R-Square     0.0301
Dependent Mean        0.48989    Adj R-Sq     0.0007
Coeff Var            48.69404


                        Parameter Estimates

                      Parameter       Standard
Variable     DF        Estimate          Error    t Value    Pr > |t|

Intercept     1         0.41680        0.08273       5.04      <.0001
IC            1         0.13660        0.13502       1.01      0.3190
```

```
Duncan's Multiple Range Test for NO23

NOTE: This test controls the Type I comparisonwise error rate, not the
experimentwise error rate.


Alpha                              0.05
Error Degrees of Freedom             34
Error Mean Square              0.045882
Harmonic Mean of Cell Sizes 8.611111








NOTE: Cell sizes are not equal.


Number of Means          2
Critical Range       .2098


Means with the same letter are not significantly different.


           Mean      N    DEVELOP

A        0.5406     31    1

B        0.2237      5    0
```

Pb Analysis

```
P2060928.MCIMP, PB REGRESSION ON IC
14:53 Thursday, October 5, 2006 200
11OCT2006:17:34:03 by Baolin Bai

The REG Procedure
Model: MODEL1
Dependent Variable: PB

Number of Observations Read                         36
Number of Observations Used                         35
Number of Observations with Missing Values           1


                             Analysis of Variance

                                 Sum of           Mean
Source                DF        Squares         Square    F Value    Pr > F

Model                  1     3449.23326     3449.23326      10.38    0.0029
Error                 33          10965      332.27668
Corrected Total       34          14414


Root MSE             18.22846    R-Square     0.2393
Dependent Mean       20.04111    Adj R-Sq     0.2162
Coeff Var            90.95535


                        Parameter Estimates

                     Parameter       Standard
Variable     DF       Estimate          Error    t Value    Pr > |t|

Intercept     1        2.25643        6.32166       0.36      0.7234
IC            1       33.24203       10.31754       3.22      0.0029
```

```
Duncan's Multiple Range Test for PB

NOTE: This test controls the Type I comparisonwise error rate, not the
experimentwise error rate.


Alpha                              0.05
Error Degrees of Freedom             34
Error Mean Square              388.4784
Harmonic Mean of Cell Sizes    8.611111


NOTE: Cell sizes are not equal.


Number of Means          2
Critical Range       19.30


Means with the same letter are not significantly different.


           Mean      N    DEVELOP

A        22.150     31    1
A
A         3.638      5    0
```

TKN Analysis

```
P2060928.MCIMP, TKN REGRESSION ON IC
14:53 Thursday, October 5, 2006 201
11OCT2006:17:34:06 by Baolin Bai

The REG Procedure
Model: MODEL1
Dependent Variable: TKN

Number of Observations Read                         36
Number of Observations Used                         35
Number of Observations with Missing Values           1


                             Analysis of Variance

                                 Sum of           Mean
Source                 DF       Squares         Square    F Value    Pr > F

Model                   1       0.81555        0.81555       3.51    0.0698
Error                  33       7.66099        0.23215
Corrected Total        34       8.47654


Root MSE              0.48182    R-Square     0.0962
Dependent Mean        1.17019    Adj R-Sq     0.0688
Coeff Var            41.17458


                        Parameter Estimates

                     Parameter       Standard
Variable     DF       Estimate          Error    t Value    Pr > |t|

Intercept     1        0.89672        0.16710       5.37      <.0001
IC            1        0.51115        0.27272       1.87      0.0698
```

```
Duncan's Multiple Range Test for TKN

NOTE: This test controls the Type I comparisonwise error rate, not the
experimentwise error rate.


Alpha                           0.05
Error Degrees of Freedom          34
Error Mean Square            0.21205
Harmonic Mean of Cell Sizes 8.611111




NOTE: Cell sizes are not equal.


Number of Means          2
Critical Range       .4510


Means with the same letter are not significantly different.


           Mean      N    DEVELOP

A        1.2397     31    1

B        0.6776      5    0
```

TN Analysis

```
P2060928.MCIMP, TN REGRESSION ON IC
14:53 Thursday, October 5, 2006 202
11OCT2006:17:34:10 by Baolin Bai

The REG Procedure
Model: MODEL1
Dependent Variable: TN

Number of Observations Read                         36
Number of Observations Used                         35
Number of Observations with Missing Values           1


                             Analysis of Variance

                                    Sum of           Mean
Source                 DF          Squares         Square    F Value    Pr > F

Model                   1          1.14274        1.14274       2.86    0.1001
Error                  33         13.17581        0.39927
Corrected Total        34         14.31855


Root MSE                0.63188    R-Square     0.0798
Dependent Mean          1.65612    Adj R-Sq     0.0519
Coeff Var              38.15396


                        Parameter Estimates

                     Parameter       Standard
Variable     DF       Estimate          Error    t Value    Pr > |t|

Intercept     1        1.33241        0.21914       6.08      <.0001
IC            1        0.60506        0.35765       1.69      0.1001
```

```
Duncan's Multiple Range Test for TN

NOTE: This test controls the Type I comparisonwise error rate, not the
experimentwise error rate.


Alpha                              0.05
Error Degrees of Freedom             34
Error Mean Square              0.324376
Harmonic Mean of Cell Sizes 8.611111







NOTE: Cell sizes are not equal.


Number of Means          2
Critical Range       .5578


Means with the same letter are not significantly different.


           Mean      N    DEVELOP

A        1.7758     31    1

B        0.9011      5    0
```

TOC Analysis

```
P2060928.MCIMP, TOC REGRESSION ON IC
14:53 Thursday, October 5, 2006 203
11OCT2006:17:34:14 by Baolin Bai

The REG Procedure
Model: MODEL1
Dependent Variable: TOC

Number of Observations Read                         36
Number of Observations Used                         35
Number of Observations with Missing Values           1


                             Analysis of Variance

                                 Sum of           Mean
Source                DF        Squares         Square    F Value    Pr > F

Model                  1       12.51046       12.51046       1.06    0.3112
Error                 33      390.24433       11.82559
Corrected Total       34      402.75479


Root MSE              3.43883    R-Square     0.0311
Dependent Mean        9.72742    Adj R-Sq     0.0017
Coeff Var            35.35196


                        Parameter Estimates

                     Parameter       Standard
Variable     DF       Estimate          Error    t Value    Pr > |t|

Intercept     1        8.65635        1.19259       7.26      <.0001
IC            1        2.00199        1.94642       1.03      0.3112
```

```
Duncan's Multiple Range Test for TOC

NOTE: This test controls the Type I comparisonwise error rate, not the
experimentwise error rate.


Alpha                              0.05
Error Degrees of Freedom             34
Error Mean Square              11.85104
Harmonic Mean of Cell Sizes    8.611111








NOTE: Cell sizes are not equal.


Number of Means          2
Critical Range       3.372


Means with the same letter are not significantly different.


           Mean      N    DEVELOP

A         9.947      5    0
A
A         9.713     31    1
```

TP Analysis

```
P2060928.MCIMP, TP REGRESSION ON IC
14:53 Thursday, October 5, 2006 204
11OCT2006:17:34:15 by Baolin Bai

The REG Procedure
Model: MODEL1
Dependent Variable: TP

Number of Observations Read                         36
Number of Observations Used                         35
Number of Observations with Missing Values           1


                             Analysis of Variance

                                 Sum of           Mean
Source                 DF        Squares         Square    F Value    Pr > F

Model                   1        0.07353        0.07353       2.64    0.1135
Error                  33        0.91800        0.02782
Corrected Total        34        0.99153


Root MSE              0.16679    R-Square     0.0742
Dependent Mean        0.30488    Adj R-Sq     0.0461
Coeff Var            54.70621


                        Parameter Estimates

                     Parameter       Standard
Variable     DF       Estimate          Error    t Value    Pr > |t|

Intercept     1        0.22276        0.05784       3.85      0.0005
IC            1        0.15349        0.09440       1.63      0.1135
```

```
Duncan's Multiple Range Test for TP

NOTE: This test controls the Type I comparisonwise error rate, not the
experimentwise error rate.


Alpha                              0.05
Error Degrees of Freedom             34
Error Mean Square              0.023546
Harmonic Mean of Cell Sizes 8.611111








NOTE: Cell sizes are not equal.


Number of Means          2
Critical Range       .1503


Means with the same letter are not significantly different.


           Mean      N    DEVELOP

A       0.33739     31    1

B       0.12210      5    0
```

TSS Analysis

```
P2060928.MCIMP, TSS REGRESSION ON IC
14:53 Thursday, October 5, 2006 205
11OCT2006:17:34:17 by Baolin Bai

The REG Procedure
Model: MODEL1
Dependent Variable: TSS

Number of Observations Read                         36
Number of Observations Used                         35
Number of Observations with Missing Values           1


                             Analysis of Variance

                                 Sum of           Mean
Source                DF        Squares         Square    F Value    Pr > F

Model                  1        4.39466        4.39466       0.00    0.9832
Error                 33         320808     9721.46103
Corrected Total       34         320813


Root MSE             98.59747    R-Square     0.0000
Dependent Mean      152.21809    Adj R-Sq    -0.0303
Coeff Var            64.77382


                        Parameter Estimates

                     Parameter       Standard
Variable     DF       Estimate          Error    t Value    Pr > |t|

Intercept     1      151.58328       34.19377       4.43      <.0001
IC            1        1.18656       55.80743       0.02      0.9832
```

```
Duncan's Multiple Range Test for TSS

NOTE: This test controls the Type I comparisonwise error rate, not the
experimentwise error rate.


Alpha                              0.05
Error Degrees of Freedom             34
Error Mean Square              9086.494
Harmonic Mean of Cell Sizes    8.611111








NOTE: Cell sizes are not equal.


Number of Means          2
Critical Range       93.36


Means with the same letter are not significantly different.


           Mean      N    DEVELOP

A        161.77     31    1
A
A        103.57      5    0
```

VSS Analysis

```
P2060928.MCIMP, VSS REGRESSION ON IC
14:53 Thursday, October 5, 2006 206
11OCT2006:17:34:18 by Baolin Bai

The REG Procedure
Model: MODEL1
Dependent Variable: VSS

Number of Observations Read                         36
Number of Observations Used                         29
Number of Observations with Missing Values           7


                             Analysis of Variance

                                 Sum of           Mean
Source                   DF     Squares         Square    F Value    Pr > F

Model                     1  1253.88058     1253.88058       3.69    0.0652
Error                    27  9162.65581      339.35762
Corrected Total          28       10417


Root MSE             18.42166    R-Square     0.1204
Dependent Mean       30.71987    Adj R-Sq     0.0878
Coeff Var            59.96661


                        Parameter Estimates

                     Parameter       Standard
Variable     DF       Estimate          Error    t Value    Pr > |t|

Intercept     1       18.50181        7.21833       2.56      0.0163
IC            1       22.48062       11.69523       1.92      0.0652
```

```
Duncan's Multiple Range Test for VSS

NOTE: This test controls the Type I comparisonwise error rate, not the
experimentwise error rate.


Alpha                             0.05
Error Degrees of Freedom            28
Error Mean Square             347.6939
Harmonic Mean of Cell Sizes 6.933333







NOTE: Cell sizes are not equal.


Number of Means          2
Critical Range       20.51


Means with the same letter are not significantly different.


           Mean      N    DEVELOP

A         32.39     26    1
A
A         17.62      4    0
```

Zn Analysis

```
P2060928.MCIMP, ZN REGRESSION ON IC
14:53 Thursday, October 5, 2006 207
11OCT2006:17:34:19 by Baolin Bai

The REG Procedure
Model: MODEL1
Dependent Variable: ZN

Number of Observations Read                        36
Number of Observations Used                        34
Number of Observations with Missing Values          2


                             Analysis of Variance

                                 Sum of           Mean
Source                 DF       Squares         Square    F Value    Pr > F

Model                   1         49559          49559      18.25    0.0002
Error                  32         86894     2715.44742
Corrected Total        33        136453


Root MSE             52.10996    R-Square     0.3632
Dependent Mean       76.16355    Adj R-Sq     0.3433
Coeff Var            68.41849


                        Parameter Estimates

                     Parameter       Standard
Variable     DF       Estimate          Error    t Value    Pr > |t|

Intercept     1        7.30281       18.43047       0.40      0.6946
IC            1      127.10935       29.75355       4.27      0.0002
```

```
Duncan's Multiple Range Test for ZN

NOTE: This test controls the Type I comparisonwise error rate, not the
experimentwise error rate.


Alpha                              0.05
Error Degrees of Freedom             33
Error Mean Square              3631.384
Harmonic Mean of Cell Sizes    8.571429








NOTE: Cell sizes are not equal.


Number of Means          2
Critical Range       59.22


Means with the same letter are not significantly different.


           Mean      N    DEVELOP

A         84.40     30    1

B         20.25      5    0
```