ASSESSMENT AND VERIFICATION OF URBAN NON-POINT POLLUTANT LOAD ESTIMATION TECHNIQUES

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INTERSTATE COMMISSION ON THE POTOMAC RIVER BASIN

This publication has been prepared for the Interstate Commission on the Potomac River Basin. Support was provided by the United States Government, the U.S. Environmental Protection Agency, and the signatory bodies to the ICPRB: Maryland, Pennsylvania, Virginia, West Virginia, and the District of Columbia.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

1. INTRODUCTION

1.1 Need for pollutant load estimation techniques

Today there is considerable concern over the effects of urban non-point source water pollution on receiving waters. Large amounts of money are being spent on determining the magnitude of the problem, on developing and implementing effective and inexpensive control measures, and on planning efforts to control or prevent the problem through prudent land use practices. One of the primary measures used to quantify pollutant levels and to measure the effectiveness of control measures is the seasonal or annual load. This is a measure of a pollutant (in units of mass or weight) delivered to a receiving body or transported past some measurement location during some unit of time. Seasonal or annual loads have been recommended for use in assessing the cumulative impacts of non-point source pollution on receiving water bodies (USEPA 1983).

There are a number of methods used to predict pollutant load levels in watersheds for which no monitoring data exist. They range in complexity from simple loading rates or export coefficients, which can be taken from the literature or easily calculated with minimal data requirements, to intricate process-oriented simulation models. Several simple load estimation techniques are available today. These techniques have the potential for widespread application, from large government agencies to small construction and engineering firms. The urban pollutant load estimates derived from these techniques can significantly affect both public-sector and private-sector policy development, from real estate development and zoning decisions to the selection and design of stormwater management programs. Because of the simplicity and availability of these techniques and the potential influence of their results, there is a need to characterize the uncertainty in the load estimates obtained through the use of these techniques.

This study compares and contrasts the behavior of three simple load estimation techniques over a range of watershed characteristics; evaluates the sensitivity of the three methods to input factors; and compares the pollutant load estimates from these techniques to observed pollutant loads.

1.2 Development of concern over effects of urban runoff

Urbanization can have drastic effects on a watershed's hydrological regime. Removal of the natural vegetation results in decreased evapotranspiration and increased stormflow and stream sedimentation (Savini and Kammerer 1961). The construction of buildings, streets, sidewalks, parking lots, etc., increases the imperviousness of the watershed. This results in greater flood flows, faster time to peak discharge during storm periods, and lesser groundwater recharge and base flow during dry periods (Leopold 1968, Savini and Kammerer 1961). Higher inputs of chemical contaminants and nutrients into receiving waters may be a consequence of urbanization (Leopold 1968). In addition, water temperature changes caused by urban runoff may adversely affect the biota in the receiving waters (Schueler 1987).

Prior to the late 1960s, regulatory and research attention on stormwater runoff was focused on protecting urban areas from floodwater (USEPA 1983, Delleur 1982). The phenomenal growth of urban areas sparked concerns over the effects of urban runoff on the quality of receiving waters, and by 1964 the U.S. Public Health Service began to get concerned about pollutants found in urban runoff (USEPA 1983). The Water Quality Act of 1965 authorized the Federal government to provide grants for the purpose of "assisting in the development of any project which will demonstrate a new or improved method of controlling the discharge into any water of untreated or inadequately treated sewage or other waste from sewerage which carry storm water or both storm water and sewage or other waste," (USEPA 1983).

Early research attention was focused on overflows from combined storm and sanitary sewers (American Public Works Association 1967, U.S. Public Health Service 1965). The American Public Works Association (APWA) published a comprehensive study of urban runoff pollution in 1969 (American Public Works Association 1969). The APWA study evaluated the pollution potential of a variety of sources, ranging from storm drainage, street litter, commercial and household chemical compounds, street de-icing chemicals, and air pollution and recommended actions to eliminate or reduce these pollution sources. Increasing Federal government interest in improving the quality of the nation's surface waters was demonstrated by passage of the Water Pollution Control Act of 1972. In 1973 the Council on Environmental Quality published "Total Urban Pollutant Loads: Sources and Abatement Strategies." The major findings of the report were: 1) urban runoff represented a substantial source of water pollution; and 2) unless the pollution from urban runoff was controlled or cleaned up the goals of the Water Pollution Control Act would not be met (USEPA 1983).

Although recognized as a significant source of water pollution, there remained a lack of accurate information on the nature and magnitude of urban runoff loads. The incomplete understanding of the nature and magnitude of urban runoff impacts downstream, as well as the cost and effectiveness of urban runoff controls, caused funding for the treatment of separate stormwater discharges to be deleted from the Clean Water Act of 1977. In response, The U.S. Environmental Protection Agency initiated the Nationwide Urban Runoff Program (NURP). NURP consisted of 28 projects which were concerned with one or more of the following: 1) characterizing pollutant types, loads, and impacts on receiving water quality; 2) determining the need for urban runoff control; and 3) evaluating various stormwater runoff control options (USEPA 1983).

1.3 Organization of this report

The problems caused by urbanization of watersheds are discussed in Section 1, along with the historical development of concern over the causes and effects of urban non-point source water pollution in the United States. In Section 2 the types of techniques used to estimate pollutant loads are then described, followed by a detailed discussion of the three methods evaluated in this study and of the procedures used to evaluate them. The results of the application of the three techniques to hypothetical watersheds are then discussed in Section 3, followed in Section 4 by a discussion of the application of these techniques to six actual watersheds in Austin, Texas. Finally, a summary of this report and the conclusions drawn from it are given in Section 5.

2. METHODS

2.1 Approach

This study consists of four phases: 1) selection of a representative set of simple urban load estimation techniques; 2) assembly of a data set of monitored sites in which both the sampling design and the knowledge of the upstream watershed is sufficient to allow unambiguous characterization of the observed and expected runoff characteristics; 3) application of the load estimation techniques to hypothetical watersheds in order to compare and contrast the behavior of these techniques over a range of watershed characteristics; and 4) application of the load estimation techniques to data from actual watersheds in order to compare the pollutant load estimates from these models to estimates based on observed pollutant concentrations.

2.2 Pollutants of concern

This study focuses on the following pollutants: total suspended solids (TSS), total nitrogen (TN), total phosphorus (TP), total copper (Cu), total lead (Pb) and total zinc (Zn). Nitrogen and phosphorus were chosen because they are two of the most important nutrients of concern in the Chesapeake Bay Program. The three metals, Cu, Pb, and Zn, are common components of urban runoff. Total suspended solids was included because the relationship between suspended solids and phosphorus and metal levels.

2.3 **Urban runoff load estimation** techniques

Numerous urban runoff load estimation techniques have been developed over the past two decades. Today the techniques span the range in complexity from simple loading rates or export coefficients, which can be taken from the literature or easily calculated with minimal data requirements, to continuous pollutant runoff simulation models (Reckhow et al 1985, Huber 1986). Huber (1986) described seven different load estimation methods:

1) constant concentration methods, in which the load is estimated as the product of runoff volume and concentration;
2) known frequency distribution methods, where knowledge of the statistical distribution of a pollutant's event mean concentration (EMC) is used to help estimate the pollutant load;
3) regression and loading function methods, where regression or other equations developed with data from actual monitored watersheds are used to estimate loads in unmonitored watersheds;
4) rating curve methods, in which pollutant concentration or load is regressed against flow rate or runoff volume, with no other predictor variables used;
5) simulation of pollutant buildup and washoff processes;
6) simulation of land surface erosion and sewer scour and deposition processes; and
7) miscellaneous modeling procedures incorporating factors such as precipitation patterns and quality, catchbasin characteristics, and baseflow quality.

The three methods evaluated in this study are: 1) a NURP EMC-based loading rate estimate (USEPA 1983); 2) the Metropolitan Council of Governments' Simple Method (Schueler 1987); and 3) the U.S. Geological Survey's national regression equations (Driver and Tasker 1988, Tasker and Driver 1988). The NURP EMC-based loading rate estimate and the Simple Method are constant concentration techniques, while the national regression equations (NREs) are a regression/loading function technique. The three methods are considered "simple" in that they can estimate loads for unmonitored watersheds using relatively easy calculations with minimal data requirements. Detailed descriptions of each of these three methods, as well as procedures for estimating confidence limits around these estimates are given below.

2.3.1 Load estimation using NURP EMC-based loading rates

Huber (1986) defines the event mean concentration (EMC) as the ratio of storm event mass loads to storm runoff volume. Published EMCs can, therefore, be used to calculate the annual pollutant load by multiplying the EMCs by the total annual storm runoff volume. The NURP study (USEPA 1983) found that EMC values were not significantly influenced either by geographic location of the sampled watershed or by the land use of the upstream catchment. While both the median and mean EMCs are given for the primary pollutants, the mean EMC was recommended for use in assessing cumulative (e.g., annual) effects stemming from urban runoff pollution (USEPA 1983). Since the site mean EMCs given in the NURP report (USEPA 1983, Table 6-25) are based on a large nationwide dataset collected and analyzed using similar methods, these data were judged to be suitable for estimating loading rates in this exercise. The NURP site mean EMCs used to estimate the loading rates are given in Appendix A (Table A-1).

The second quantity needed to estimate annual pollutant load from EMCs, runoff volume, was calculated by multiplying mean annual rainfall (MAR) by a runoff coefficient (Rv), as described in USEPA (1983). The formula for NURP EMC-based loading rate estimates is:

$$LR = EMC * Rv * MAR * 0.227 \tag{1}$$

where:

LR = annual loading rate (lbs/ac/yr);

EMC = NURP site mean EMC (mg/l);

Rv = runoff coefficient; and

MAR = mean annual rainfall (inches).

The value 0.227 is a unit conversion factor. Rv represents the fraction of rainfall which is converted into runoff over the desired time interval (in this case annually). It can be estimated from the percent impervious area of the watershed of concern, using the following equation (Schueler 1987):

$$Rv = 0.05 + (0.009 * IA) \tag{2}$$

where:

Rv = annual stormwater runoff coefficient; and

IA = percent impervious area.

Percent impervious area is most influenced by prevailing land use. For the purposes of this study, four primary land uses were assumed: 1) low density residential (IA = 20%); 2) medium density residential (IA = 40%); 3) high density residential (IA = 60%); and commercial (IA = 80%).

The loading rates just described are a function of mean annual precipitation. For this reason, two sets of loading rates were calculated, one set for hypothetical watersheds in the Washington, D.C., metropolitan area (MAR = 40.00 in), and one set for the actual watersheds in the Austin, Texas, metropolitan area (MAR = 32.49 in). The loading rates, with 10% and 90% confidence limits, used for the comparisons on hypothetical watersheds, are given in Appendix A (Table A-2). The loading rates used in the Austin watershed comparisons are also given in Appendix A (Table A-3). The calculation of confidence limits is discussed in Section 2.3.4.

2.3.2 Load estimation using the Simple Method

The Simple Method (Schueler 1987) is another constant concentration method used to estimates annual pollutant loads. The load is calculated by the following formula (Schueler 1987):

$$L = [(P)*(Pj)*(Rv)/12]*(C)*(A)*2.72 \qquad (3)$$

where:

L = stormwater pollutant load (pounds);

P = rainfall depth (inches) over the desired time interval;

Pj = precipitation correction factor;

Rv = runoff coefficient;

C = flow-weighted mean concentration (i.e., EMC) (mg/l); and

A = drainage basin area (acres).

The precipitation correction factor (Pj) adjusts the precipitation amount for the percentage of storms which produce no runoff. A value of 0.9 (Schueler 1987) was assumed as a constant in this study, though the Pj for a specific location can be determined empirically (Schueler 1987, Appendix A, Section 6). The values 12 and 2.72 are conversion factors. The C values used for the Simple Method estimates were taken from Schueler (1987, Table 1.1) are listed in Appendix B (Table B-1).

2.3.3 Load estimation using the NREs

The NREs are empirically-derived nonlinear regression equations based on pollutant monitoring data collected during the NURP project. In contrast with the NURP EMC-based estimates and the Simple Method, both of which provide estimates of the mean annual load, the NREs provide an estimate of the mean storm load. For the purposes of the NREs, a storm was defined as a rainfall event in which the total rainfall is at least 0.05 inches. Individual events were separated by at least 6 hours of zero recorded rainfall (Driver and Tasker 1988, Tasker and Driver 1988). The mean annual load is the product of the mean storm load and the mean number of storms per year.

Separate equations have been developed for chemical oxygen demand (COD), suspended solids (SS), dissolved solids (DS), total nitrogen (TN), total kjeldahl nitrogen (TKN in Driver and Tasker 1988 or AN as reported in Tasker and Driver 1988), total phosphorus (TP), dissolved phosphorus (DP), total copper (Cu), total lead (Pb) and total zinc (Zn). Depending on the constituent of concern, predictor variables used to estimate loads include drainage basin area (DA), impervious area (IA), mean annual rainfall (MAR), minimum January temperature (MJT), and a dummy variable which indicates whether or not the watershed is more than 75% commercial (X2). The basic form of the equation is:

$$W = 10^{[a + b\sqrt{DA} + cIA + dMAR + eMJT + fX2]} BCF \quad (4)$$

W is the event load in pounds, a is the regression constant, and b, c, d, e, and f are regression coefficients. BCF is a bias correction factor.

Only statistically significant predictors for a given pollutant are included in the load calculation. The regression constant, a, and the bias correction factor, BCF, are always included in the equations. For example, only DA, MAR and MJT are significant NRE predictors of TSS load. The formula to calculate TSS load would be:

$$W = 10^{[a + b\sqrt{DA} + dMAR + eMJT]}BCF \qquad (5)$$

Significant predictors of the pollutants studied in this report are given in Table 1.

Table 1. Significant predictors of pollutant load in the NREs. An "X" indicates whether the column variable is a significant predictor of the pollutant in question.

Pollutant	DA	IA	MAR	MJT	X2
TSS	X		X	X	
TN	X	X			X
TP	X		X	X	
Cu	X			X	
Pb	X	X	X		
Zn	X	X			

The mean event pollutant load estimates were obtained using a program provided by Gary Tasker of the U.S. Geological Survey in Reston, Virginia. In addition to the mean event load estimate, 90% and 10% confidence limits about that estimate are also given by this program. The mean event load and 90th and 10th percentile values were then multiplied by the mean number of storms to arrive at an estimated annual load (and estimated annual 90th and 10th percentile values). As with all regression-based estimation procedures, model predictions become unreliable for input values beyond the range of input values used to develop the equations. More detailed information about the NRE method and the equations used can be found in Driver and Tasker 1988, Tasker and Driver 1988, and Tasker et al 1991).

2.3.4 Uncertainty in load estimation

There are a number of sources of uncertainty in annual pollutant load estimates. In constant concentration load estimation methods, loads are determined as the product of a "mean" concentration and a "mean" runoff volume. The measured EMC may vary with monitoring protocol, such as whether the sample is a grab sample, flow-weighted sample, equal time increment sample, etc. Precipitation amount and duration influences pollution solution and mobilization, which also influences measured EMC. Measured EMCs may also be affected by antecedent conditions, seasonal variation in pollutant export processes, etc.

The estimated annual runoff value may also loading rate estimates. Runoff is a function of more than the "mean" depth of precipitation. Short, intense storms produce more runoff than longer, soaking events of the same depth. Soil and site conditions, such as infiltration capacity of the non-impervious areas, and treatment of baseflow also affect runoff volume estimates. The relationships among precipitation intensity, duration, and frequency affects estimates of both runoff volume and pollutant transport. For example, small, frequent storms may cumulatively result in high precipitation amounts, while producing little runoff. Likewise, large, infrequent storms may produce substantial runoff, while yielding relatively little pollutant transport (if most of the accumulated pollutants are washed off early in the storm).

Given the uncertainty in EMCs, runoff volume and number of storm events (when applicable), the annual load estimates may be viewed as random variables. Therefore, comparing and evaluating estimated loads may be more meaningful in the context of an expected range of variation, i.e., confidence limits about the mean. The only source of variation considered in this report was in EMCs. No attempt was made to quantify the uncertainty in runoff estimates; however, this issue is discussed further in a later section. The variability and statistical distribution of EMCs has been well characterized in the NURP study, and methods for estimating confidence limits for these data have been developed (USEPA 1983). Confidence limits were developed for all three load estimation techniques.

In keeping with the practice established in the NURP study (USEPA 1983) and in the development of the NREs (Driver and Tasker 1988, Tasker and Driver 1988, Tasker et al 1991), upper (90%) and lower (10%) confidence limits about the load estimate can be calculated by substituting the 90th percentile EMC and 10th percentile EMC, respectively, for the mean EMC, in (1). The 90th and 10th percentile EMCs can be calculated using the following formulas (USEPA 1983):

$$90\%\ C.L. = (median\ EMC) * \exp(1.2817 * \sqrt{\ln(1+CV^2)}) \tag{6}$$

$$10\%\ C.L. = (median\ EMC) * \exp(-1.2817 * \sqrt{\ln(1+CV^2)}) \tag{7}$$

Median EMC refers to the NURP site median EMC (USEPA 1983, Table 6-17). The values 1.2817 and -1.2817 are the standard normal probability values for the 90% and 10% percentiles, respectively. For each pollutant, the midpoint of the range of coefficient of variation, or CV (event-to-event variability in EMCs), values reported in the NURP study (USEPA 1983, Table 6-17) was used in equations (6) and (7). The CV values used were 1.5 for total suspended solids and 0.75 for the remaining pollutants.

For the Simple Method, 90% and 10% confidence limits can be calculated as described above with equations (6) and (7), respectively. Schueler (1987) does not report median EMC values. They can, however, be estimated from the mean values using the following formula:

$$median\ EMC = \frac{C}{\sqrt{1 + CV^2}} \qquad (8)$$

where:

C = flow-weighted mean concentration (i.e., EMC) (mg/l); and

CV = coefficient of variation.

Schueler (1987) also did not report CV values. The NURP CV values (described above) were used instead as a rough approximation. Since Schueler's urban site C values were either means for all NURP study sites or for NURP study sites within the Washington, D.C., or Baltimore, Maryland, metropolitan areas, these values were judged to be reasonable estimates.

Details on the calculation of confidence intervals about the NRE estimates can be found in Driver and Tasker (1988), Tasker and Driver (1988) and Tasker et al (1991).

2.4 Selection of watershed monitoring data

The data from six watersheds in the City of Austin (Texas) Stormwater Monitoring Program are used in the evaluation of the load estimation methods on actual watershed data. Description of the six watersheds and discussion of how observed loads were calculated is given in Section 4.

3. HYPOTHETICAL WATERSHED COMPARISONS

The three load estimation techniques were applied to hypothetical watersheds in order to compare and contrast the behavior of these techniques over a controlled range of watershed characteristics. A second goal was to evaluate the sensitivity of the results to variation in the values of some of the predictor variables. The range of watershed values chosen was determined by the range of data used in developing the NREs. Except for one special case, in which the sensitivity of the NRE TSS equation to mean minimum January temperature was evaluated, all climatic variables for the hypothetical watersheds were based on the climatic characteristics of Washington, D.C., watersheds. In order to simplify these comparisons across drainage areas, the annual loading rate, in lbs/ac/yr, was selected as the basis of comparison. For the NRE and Simple Methods the annual load was simply divided by the drainage basin area in order to derive the loading rate, whereas the NURP EMC-based load estimates were already in the proper form. Whenever possible, all load estimates, along with 90% and 10% confidence limits, for a particular set of watershed characteristics were plotted together for comparison. In other cases, the NRE estimates and the Simple Method estimates were individually plotted with the NURP EMC-based estimates. Comparisons focused on the range of the confidence limits and the relative magnitude of the mean estimates.

The results of the hypothetical watershed comparisons are shown in Figures 1-10. Figure 1 is a comparison of the NRE and NURP EMC-based estimates of TSS loading rates. The Simple Method was not used to estimate TSS load. Drainage basin size, mean annual rainfall, and mean minimum January temperature are significant predictors of TSS load in the NRE equation. For drainage areas of 50 to 500 acres, the NRE load estimates and the variability about those estimates are quite similar. For watersheds smaller than 50 acres (shown), or larger than 500 acres (not shown), the NRE equation is subject to a dramatic increase in the magnitude of the estimate and in the range of the confidence limits about that estimate. This pattern in NRE estimates is observed for all the pollutants studied. Therefore, for the remaining pollutants, only the NRE estimates for 100 acre watersheds are shown. The NRE 100 acre (approximately 0.2 mi^2) watershed values were chosen because of: 1) the relative similarity in NRE estimates and width of confidence limits for 50-500 acre watersheds; and 2) prediction errors are relatively small for watersheds near that size (Tasker et al 1991). In fact, when using the NREs to estimate pollutant loads for watersheds larger than 0.8 mi^2 (approximately 500 acres), Tasker et al (1991) actually recommend estimating loads using the 0.2 mi^2 watershed loading rate. They based this recommendation on the lesser prediction error for watersheds around that size.

It can be seen in Figure 1 that the confidence intervals about NRE estimates of TSS load for 50-500 acre watersheds are less than or approximately equal to the confidence intervals about the NURP EMC-based estimates. In addition, the NRE unit load estimates within this range of watershed sizes are consistently lower than the NURP EMC-based estimates. These patterns held for all pollutants studied. Figure 2 shows the sensitivity of the NRE TSS equation to mean minimum January temperature for 100 acre watersheds. The magnitude of the TSS load estimates, along with the confidence limits about the mean, increase markedly with a decrease in temperature. A similar pattern exists for all watershed sizes examined.

Comparisons of estimated TN loading rates are given in Figures 3 and 4. Drainage basin area, percent imperviousness, and land use (whether or not a watershed is greater that 75% commercial) are significant predictors of TN load in the NREs. Figure 3 shows the NRE estimates and the NURP EMC-based estimates. As with TSS, the NRE estimates are significantly less than the

NURP EMC-based estimates for a similar percent imperviousness, and the confidence intervals for the TN estimates are narrower than the confidence intervals around the corresponding NURP EMC-based estimates. Likewise, the NRE commercial watershed estimates are less than the NRE residential watershed estimates, and have even narrower confidence limits.

Figure 4 compares the Simple Method unit load estimates and NURP EMC-based estimates. The Simple Method estimates and confidence intervals are less than the NURP EMC-based estimates for all levels of imperviousness. This is due to two factors. The EMC (or C) values recommended for use in the Washington area by Schueler (1987) are lower than the site mean EMC reported in the NURP study. Also, no attempt was made to correct for the percentage of storms producing no runoff when calculating the NURP EMC-based estimates. The Simple Method residential and commercial watershed estimates are quite similar. That is because the C values recommended for the two land uses by Schueler (1987) are quite similar (2.00 mg/l for residential watersheds, 2.17 mg/l for commercial ones). Although land use may affect TN load estimates, Figures 3 and 4 show that the NRE estimates are significantly lower and with narrower confidence limits than the Simple Method estimates.

The results of all three load estimation methods for TP loading rates are shown in Figure 5. Drainage basin area, mean annual rainfall, and mean minimum January temperature are significant predictors of TP load in the NREs. The significance of minimum January temperature, as in the NRE TSS equation, reflects the close association of phosphorus transport with suspended solids transport. The Simple Method gave no C value for TP from commercial watersheds in the Washington, D.C., metropolitan area, therefore only residential estimates are shown. A comparison of NRE and NURP EMC-based estimates of Cu unit load are shown in Figure 6. Drainage area and mean minimum January temperature are significant predictors of Cu load in the NREs. The Simple Method gave no C values for Cu in the Washington Metropolitan area, therefore no Simple Method estimates were calculated. The same patterns discussed previously hold for TP and Cu load estimates.

Comparisons of estimated Pb loads are shown in Figures 7 and 8, while comparisons of estimated Zn loads are given in Figures 9 and 10. As the relationships among load estimation techniques are similar for both pollutants, they will be discussed together. In the NREs, drainage area, percent imperviousness, and mean annual rainfall are significant predictors of Pb loads, while only drainage area and percent imperviousness are significant predictors of Zn load.

A comparison of NRE and NURP EMC-based estimates is given in Figure 7, for Pb, and in Figure 9, for Zn. A similar relationship between NRE estimates and NURP EMC-based estimates as discussed previously exists for the two pollutants. Simple Method estimates of Pb (Figure 8) and Zn (Figure 10) loads from residential watersheds are likewise smaller in magnitude and have narrower confidence intervals in relation to their corresponding loading rate estimates. For commercial watersheds, however, the opposite is true. This is caused by the great disparity in Schueler's (1987) recommended C values for Pb and Zn between the two land use types (0.018 mg/l for Pb in residential watersheds, 0.370 mg/l in commercial ones; 0.037 mg/l for Zn in residential watersheds, 0.250 in commercial ones). The NRE estimates fall between the Simple Method residential and commercial watershed estimates, and have intermediate-width confidence limits.

In the Washington, D.C., metropolitan area, land use significantly affects some mean pollutant concentrations. This effect is most strongly demonstrated with the metals Pb and Zn. Therefore Schueler (1987) recommended using, whenever possible, different C values for residential and commercial watersheds in the Washington, D.C., metropolitan area (for watersheds outside of the Washington metropolitan area, however, only one value is given, regardless of land use). These findings contrasts with the results of the NURP study, which determined that land use had no overall significant effect on EMCs. This results given here indicate that loads and related confidence limits estimated by constant concentration techniques are highly sensitive to the choice of EMC used. This suggests that EMCs, particularly for metals, must be chosen carefully and should, if possible, be site specific.

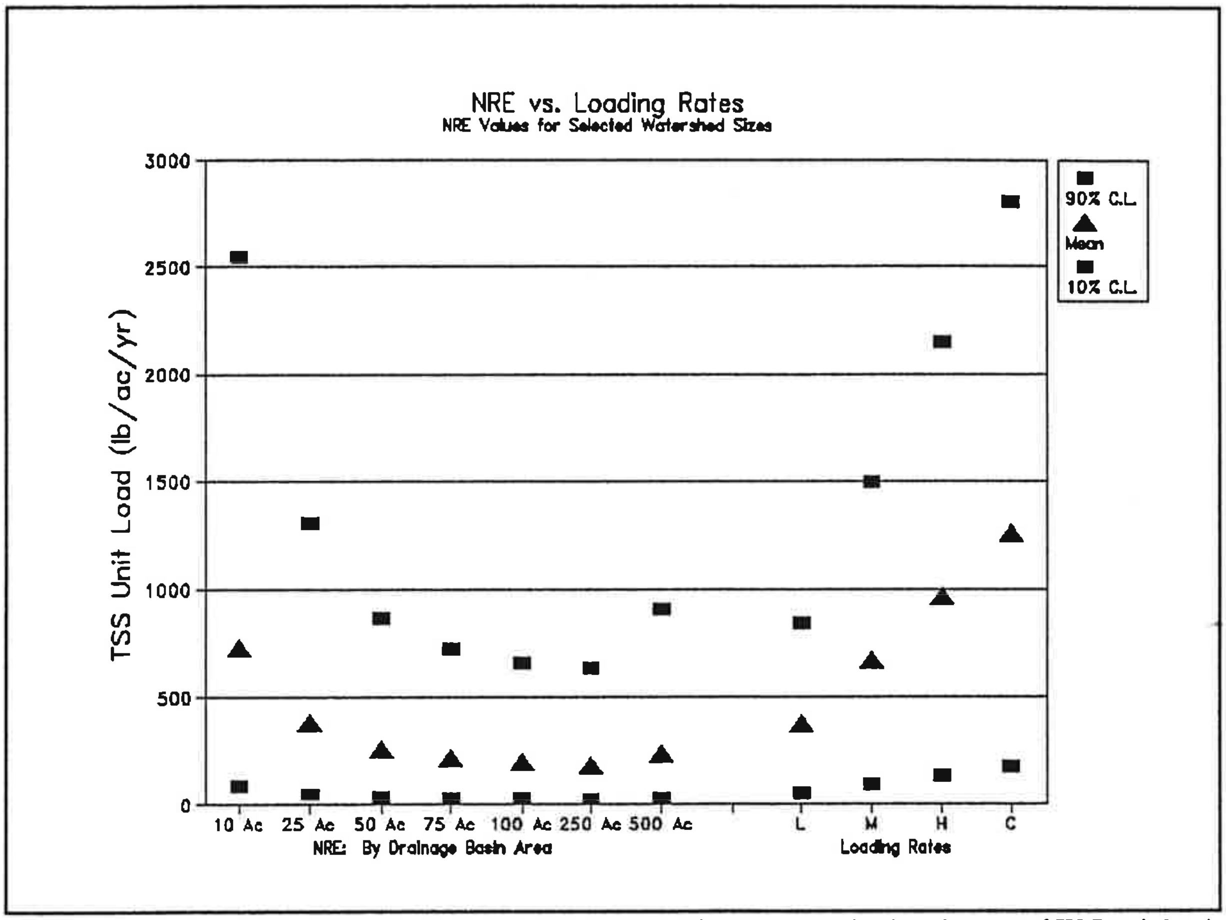

Figure 1. Comparison of NRE and loading rate (derived from NURP data) estimates of TSS unit load. The NRE results are plotted as a function of watershed size, while the loading rates are a function of impervious area (i.e., land use).

NURP EMC-Based Estimate Key:

L = Low Density Residential Land Use

M = Medium Density Residential Land Use

H = High Density Residential Land Use

C = Commercial Land Use

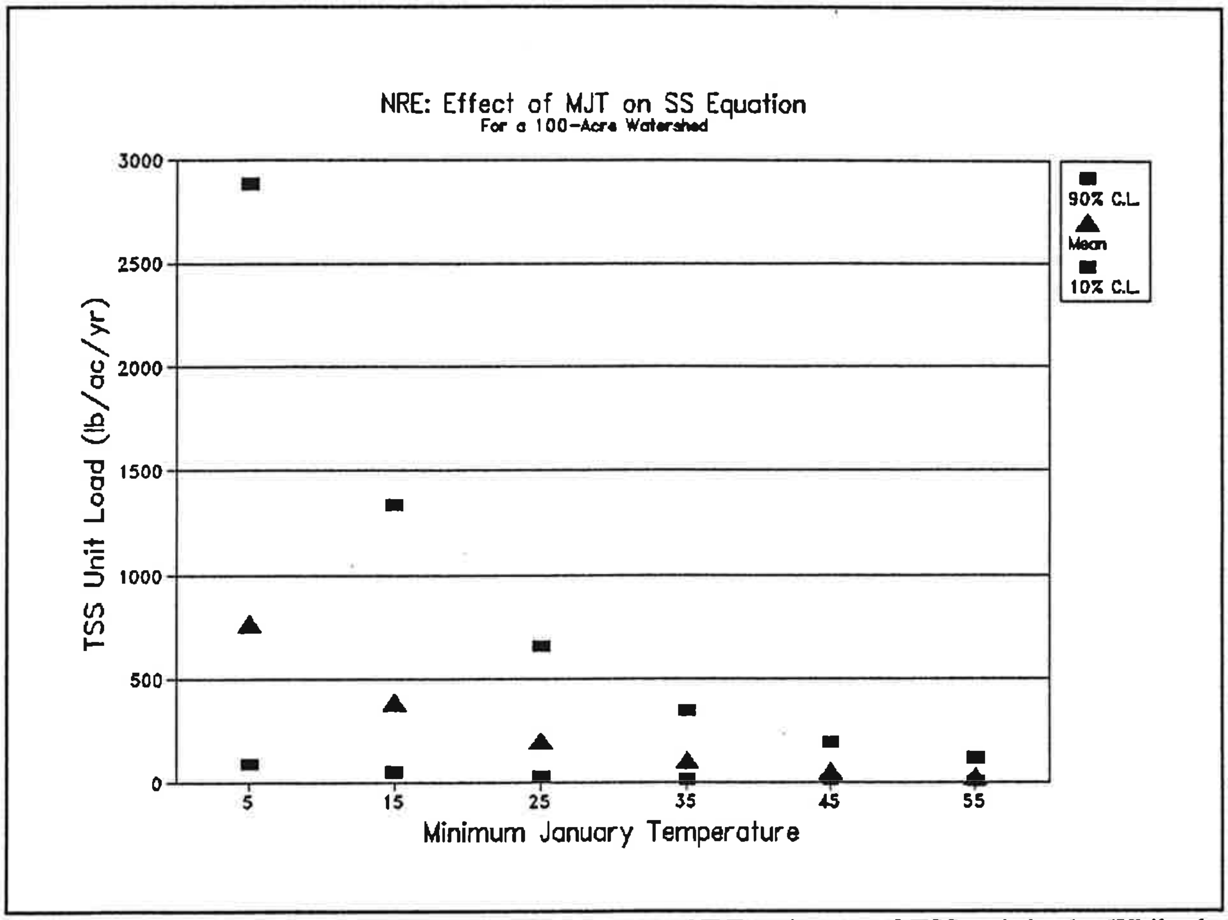

Figure 2. Effect of minimum January temperature on NRE estimates of TSS unit load. While the magnitude of variability in the estimates changes with changes in drainage basin size, the pattern of variability remains similar across temperatures.

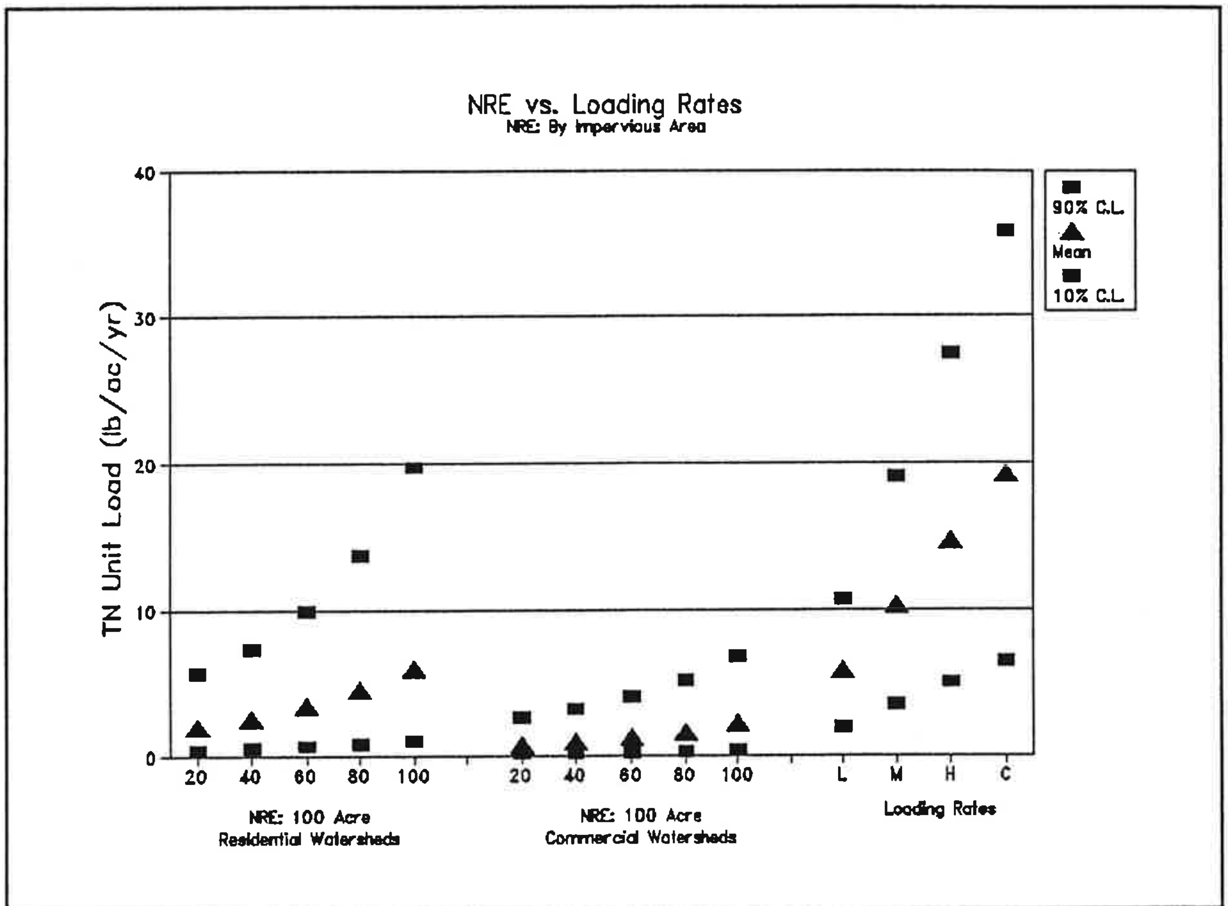

Figure 3. Comparison of NRE and loading rate (derived from NURP data) estimates of TN unit load. The NRE estimates are plotted as a function of impervious area, as are the loading rates.

NURP EMC-Based Estimate Key:

L = Low Density Residential Land Use

M = Medium Density Residential Land Use

H = High Density Residential Land Use

C = Commercial Land Use

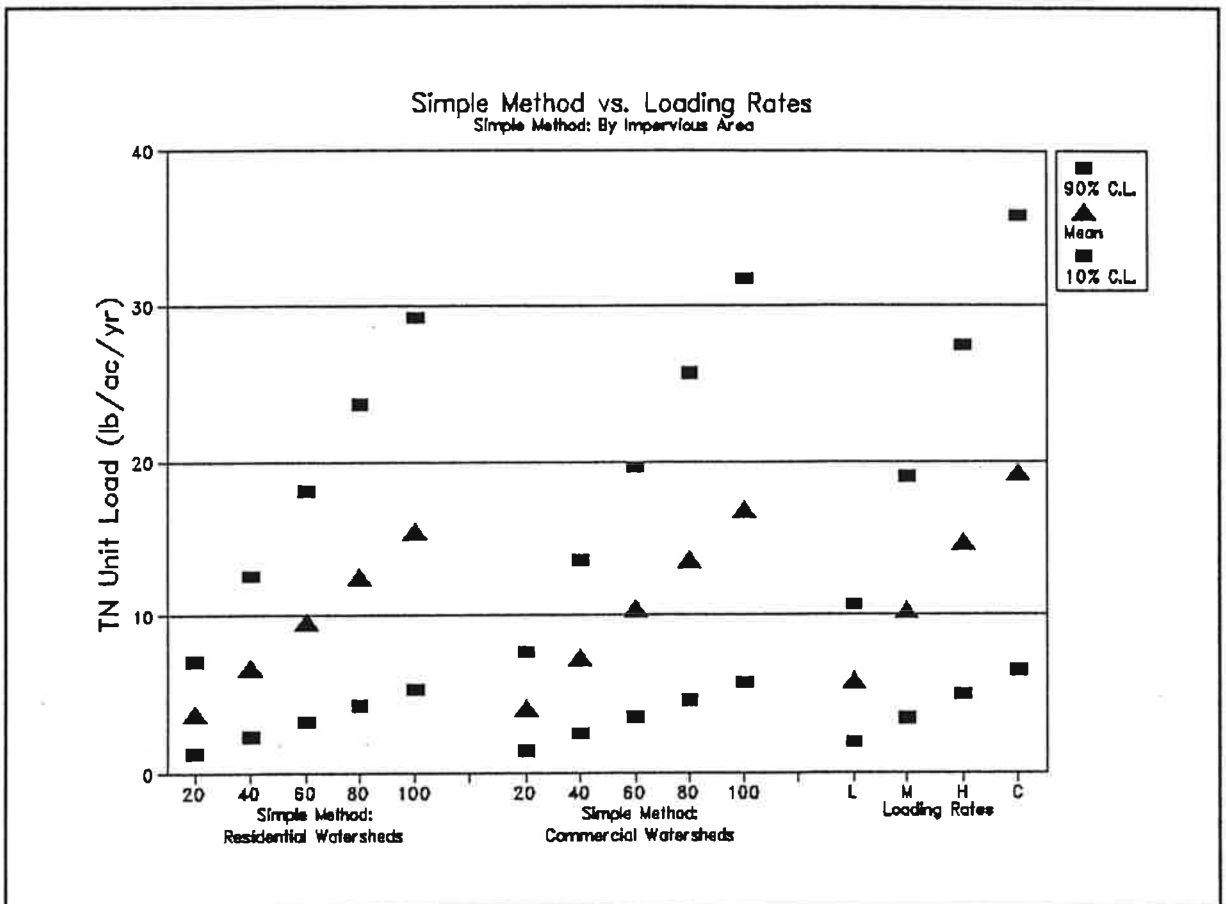

Figure 4. Comparison of Simple Method and loading rate (derived from the NURP data) estimates of TN unit load. The Simple Method estimates are plotted as a function of impervious area, as are the loading rates.

NURP EMC-Based Estimate Key:

L = Low Density Residential Land Use

M = Medium Density Residential Land Use

H = High Density Residential Land Use

C = Commercial Land Use

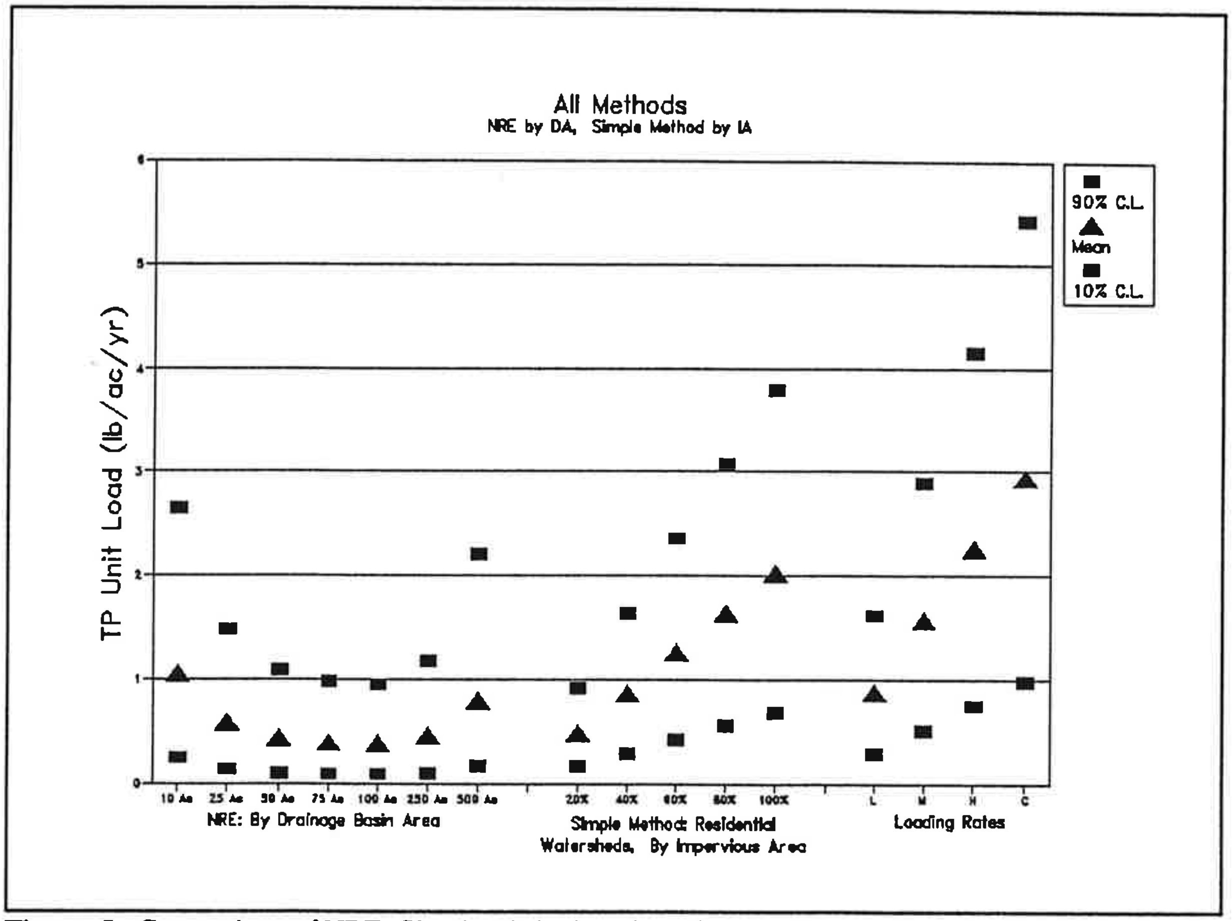

Figure 5. Comparison of NRE, Simple Method, and loading rate (derived from NURP data) estimates of TP unit load. NRE estimates are a function of drainage area, while Simple Method and loading rate estimates are a function of imperviousness.

NURP EMC-Based Estimate Key:

L = Low Density Residential Land Use

M = Medium Density Residential Land Use

H = High Density Residential Land Use

C = Commercial Land Use

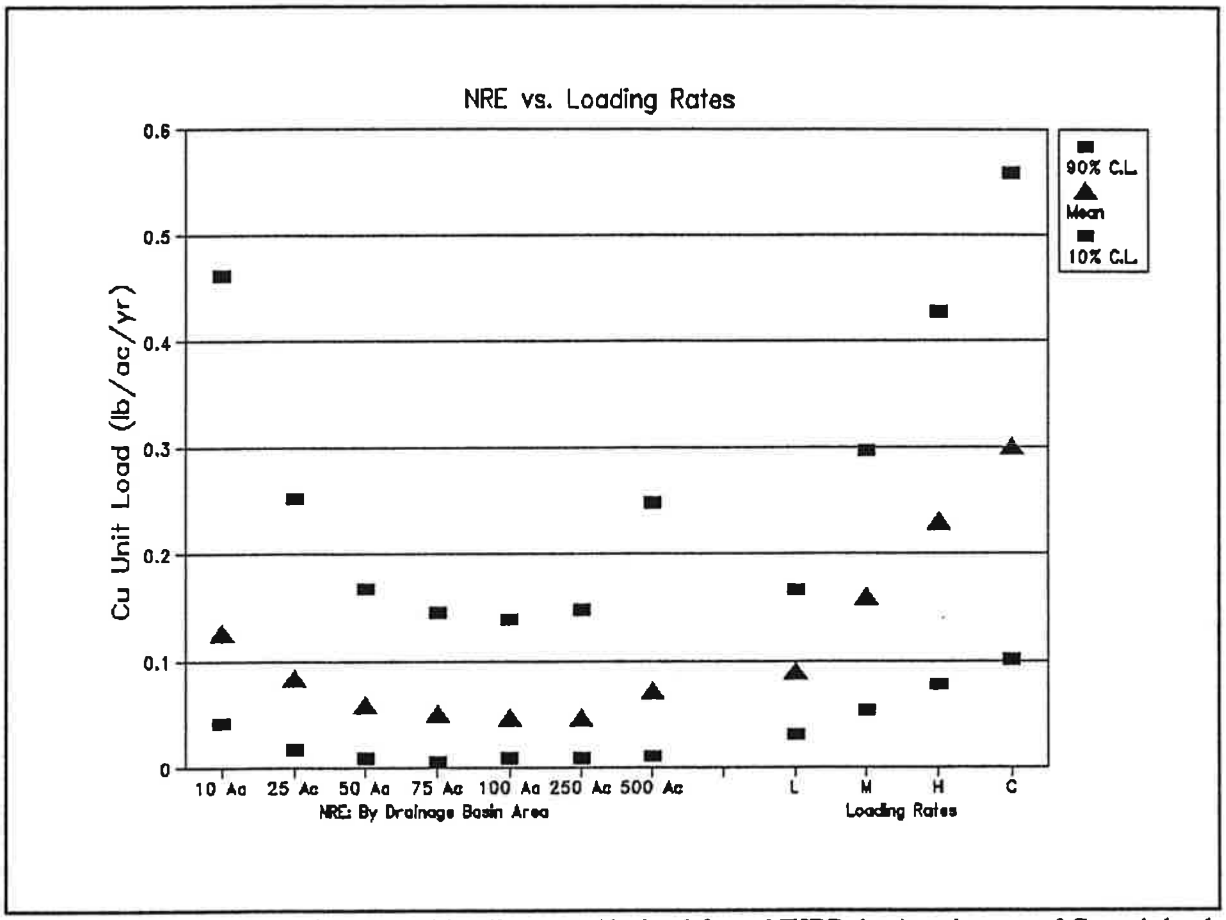

Figure 6. Comparison of NRE and loading rate (derived from NURP data) estimates of Cu unit load. NRE estimates are a function of drainage area, while loading rate estimates are a function of imperviousness.

NURP EMC-Based Estimate Key:

L = Low Density Residential Land Use

M = Medium Density Residential Land Use

H = High Density Residential Land Use

C = Commercial Land Use

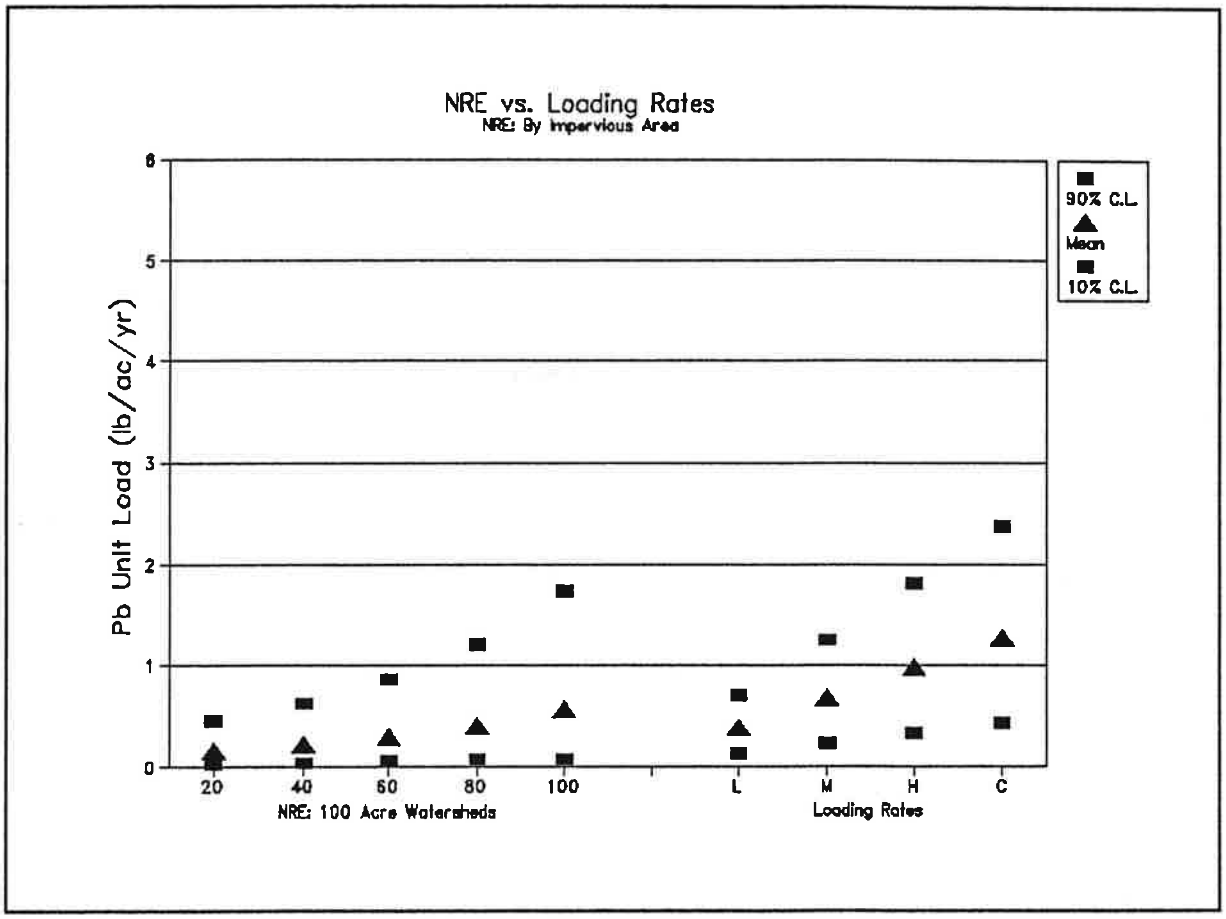

Figure 7. Comparison of NRE and loading rate (derived from NURP data) estimates of Pb unit load. Both NRE and loading rate estimates are a function of imperviousness.

NURP EMC-Based Estimate Key:

L = Low Density Residential Land Use

M = Medium Density Residential Land Use

H = High Density Residential Land Use

C = Commercial Land Use

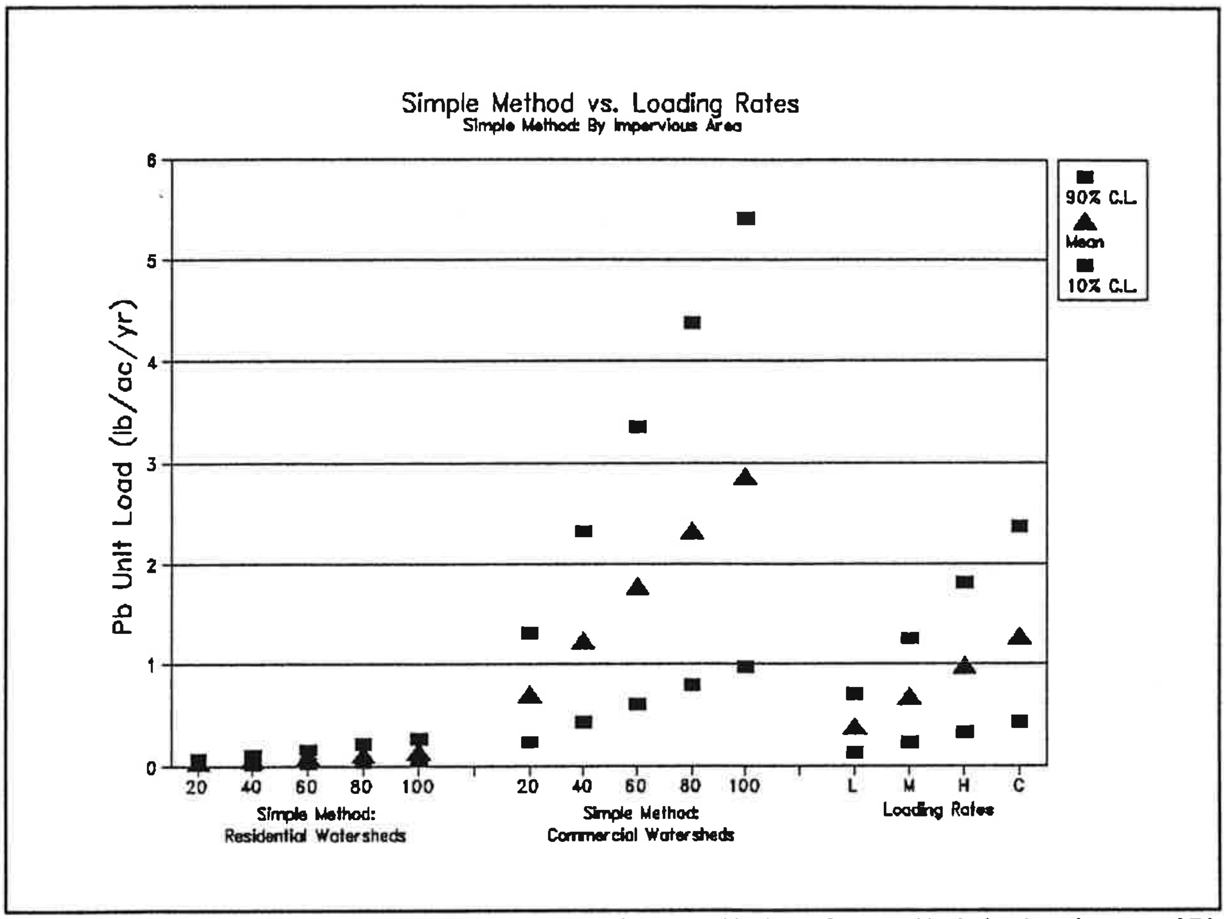

Figure 8. Comparison of Simple Method and loading rate (derived from NURP data) estimates of Pb unit load. Both Simple Method and loading rate estimates are a function of imperviousness.

NURP EMC-Based Estimate Key:

L = Low Density Residential Land Use

M = Medium Density Residential Land Use

H = High Density Residential Land Use

C = Commercial Land Use

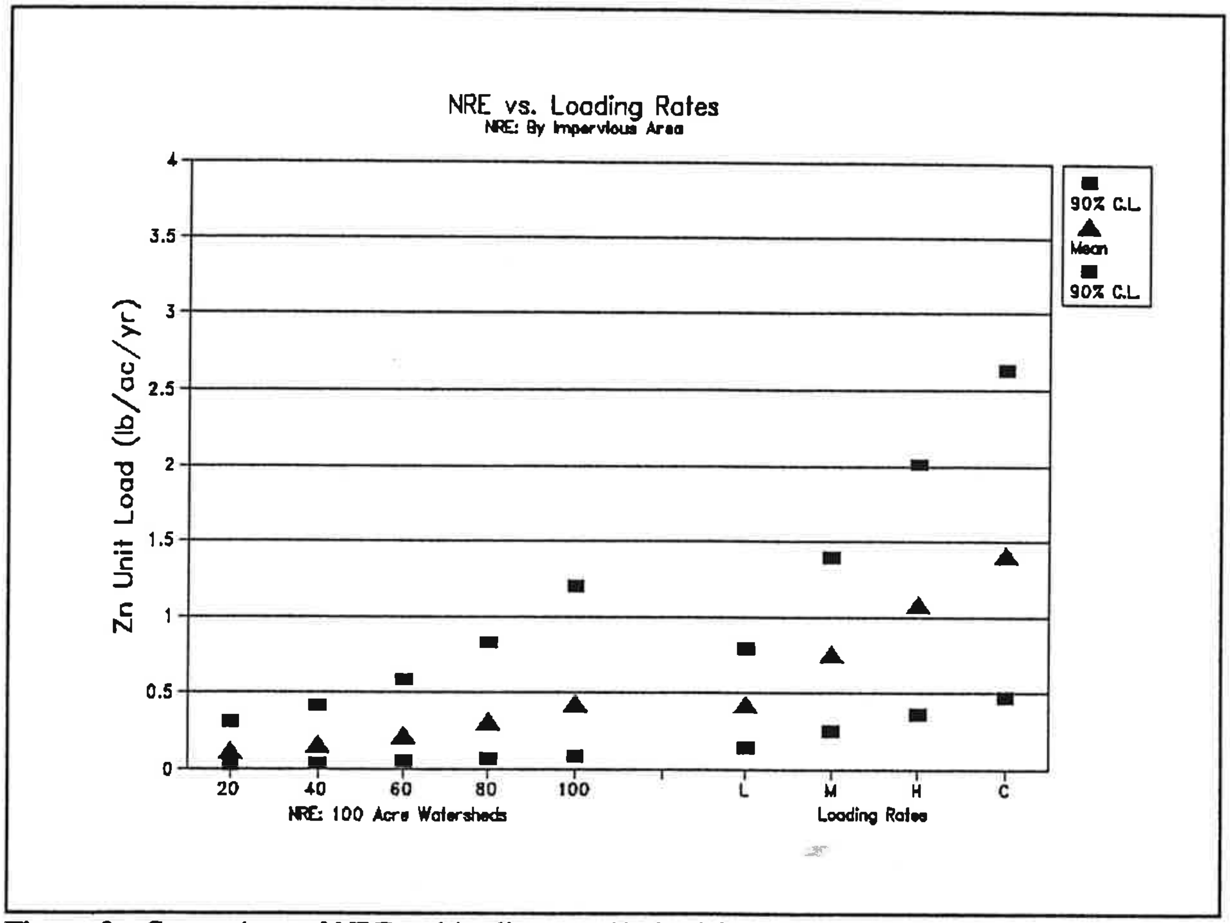

Figure 9. Comparison of NRE and loading rate (derived from NURP data) estimates of Zn unit load. Both NRE and loading rate estimates are a function of imperviousness.

NURP EMC-Based Estimate Key:

L = Low Density Residential Land Use

M = Medium Density Residential Land Use

H = High Density Residential Land Use

C = Commercial Land Use

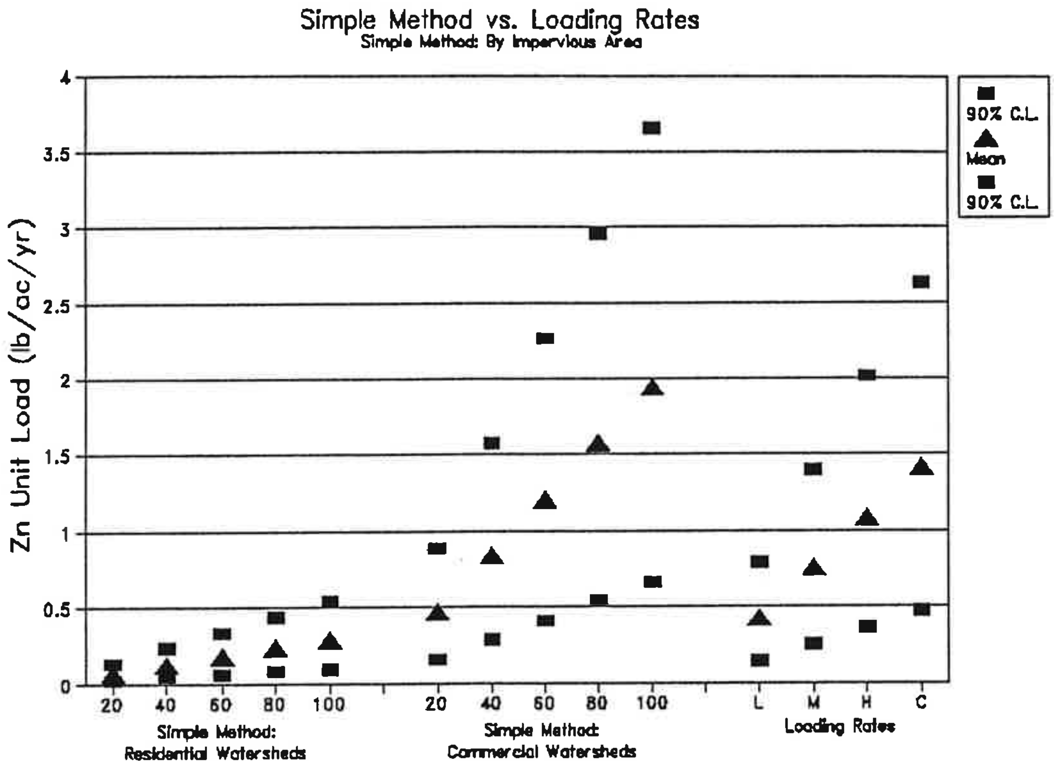

Figure 10. Comparison of Simple Method and loading rate (derived from NURP data) estimates of Zn unit load. Both Simple Method and loading rate estimates are a function of imperviousness.

NURP EMC-Based Estimate Key:

L = Low Density Residential Land Use

M = Medium Density Residential Land Use

H = High Density Residential Land Use

C = Commercial Land Use

4. ACTUAL WATERSHED COMPARISONS

The set of load estimation techniques were applied to six small, single land use, watersheds in Austin, Texas, in order to compare the pollutant load estimates from these models to estimates based on observed pollutant concentrations. The watersheds were Rollingwood (RO), Maple Run III (MI), Hart Lane (HL), Highwood Apartments (HI), Barton Creek Square Mall (BCSM or BC in this study), and Brodie Oaks Plaza (BI). Again, the annual loading rate (including 90% and 10% confidence limits for the estimated loads) was selected as the basis for comparison. The observed loading rate was plotted with the estimated loading rates for each of the six watersheds (in this case the NURP EMC-based estimate was chosen based on land use). Comparisons were based on whether the observed load fell within the confidence limits of the estimated loads, indicating no significant difference between the observed and estimated loads, and on whether the observed load was greater or less than the mean estimated load. The characteristics of the six watersheds are given in Table 2.

4.1 Calculation of observed loads for Austin watersheds

The observed annual pollutant loads were calculated by multiplying the observed mean EMC for the pollutant in question by the annual stormwater runoff volume calculated using the rainfall-runoff regression procedure described in City of Austin (1990a, 1990b, 1990c). Mean EMCs, by land use, for the six pollutants of concern are given in Table 3.

The annual runoff volume was calculated with a storm rainfall-runoff regression procedure developed from a frequency distribution of storm events (by rainfall depth) in the Shoal Creek drainage basin, a centrally-located watershed in the City of Austin. The frequency data are given in Table 4. The form of the regression equation is:

Table 2. Characteristics of the six small, single-use watersheds in Austin, Texas. Data from City of Austin (1990b, Table 1).

Watershed Name	Drainage Area (ac)	Impervious Area (%)	Land Use	a_0	a_1
Rollingwood (RO)	63	21	Single Family	0.0224	1.22
Maple Run III (MI)	28	36	Single Family	0.20	1.00
Hart Lane (HL)	371	39	Single Family	0.1450	1.1058
Highwood Apts. (HI)	3	50	Multi-Family	0.385	1.119
Barton Creek Square Mall (BCSM)	47	86	Commercial	0.741	1.1168
Brodie Oaks (BI)	31	95	Commercial	0.900	1.0

$$Q = a_0 P^{a_1} \tag{9}$$

where:

Q = Storm runoff depth (inches)

P = Storm rainfall depth (inches)

The variables a_0 and a_1 are regression coefficients. The coefficients for each watershed are also listed in Table 2. The midpoint value for each rainfall depth interval was multiplied by the appropriate regression coefficients (for storms greater than 2.5 inches the midpoint was estimated as 2.6). A weighted sum of each of the runoff depths obtained (weighting by number of days of rainfall per year) was obtained to arrive at the annual runoff volume.

4.2 Results

The comparisons of the results of the three load estimation techniques to observed loads in the six Austin watersheds are given in Figures 11-16. A comparison of observed TSS loads to NRE and

Table 3. EMC values (mg/l) used to calculate observed loads for Austin watersheds (data from City of Austin 1990b, Table 14).

Pollutant	New Suburban Single Family	New Suburban Multi-Family	New Suburban Commercial
TSS	170	170	170
TN	2.20	1.40	2.20
TP	0.20	0.20	0.20
Cu	0.01	0.01	0.01
Pb	0.02	0.02	0.03
Zn	0.04	0.04	0.05

NURP EMC-based estimates is shown in Figure 11. For sites with greater than 30% imperviousness (all except RO), the observed loads do not significantly differ from NURP EMC-based estimates, and the observed load just barely lies outside the loading rate 10% confidence limit for RO. Except for the highly impervious watersheds (BC and BI), observed TSS loads do not differ significantly from NRE estimates. The NRE TSS equation underestimates TSS load levels for BC and BI. It is interesting to note the variability about the NRE load estimate for HI. This watershed is only 3 acres in size, which is below the lower limit (of approximately 50 acres) at which the NRE equations maintain a reasonable level of consistency in load and confidence interval estimates (i.e., the size effect described in the hypothetical watershed comparisons). This effect holds for all the pollutants studied.

The TN estimated and observed loads are shown in Figure 12. All three load estimation techniques were used. The Simple Method and NURP EMC-based methods produce similar estimates with similar confidence intervals, a pattern consistently observed for all of the remaining pollutants. The two methods produce similar estimates here because both methods use national average EMC or

Table 4. Frequency distribution of rainfall events (by size) for the Shoal Creek watershed, 1976-1985 (data from City of Austin 1990c, Table 2).

RANGE OF RAINFALL (INCH)	FREQ. OF OCCURRENCE (%)	NO. OF DAYS OF RAINFALL (PER YEAR)	RAINFALL DEPTH (INCH)	CUMULATIVE DEPTH (INCH)
0.05-0.10	14	9	0.7	0.7
0.11-0.20	15	10	1.4	2.1
0.21-0.30	18	13	3.3	5.1
0.31-0.40	10	7	2.3	7.4
0.41-0.50	10	7	3.0	10.4
0.51-0.75	15	11	6.9	17.2
0.76-1.00	5	3	2.3	19.6
1.01-1.25	3	2	2.1	21.7
1.26-1.50	2	1	1.3	23.0
1.51-2.00	3	2	3.1	26.2
2.01-2.50	2	1	2.1	28.4
>2.50	3	2	5.2	33.7

C values. The Simple Method did not give land use specific C values for areas outside the Washington, D.C., metropolitan area. All three load estimation techniques overestimate the TN load at RO. For the watersheds between 30% and 50% imperviousness (MI, HL, and HI) the Simple Method and NURP EMC-based method either overestimate the TN load, or the observed load just falls within the lower confidence limit. The TN load is overestimated by the NRE at HI (the size effect). For the two highly impervious watersheds (BC and BI), both the Simple Method and NURP EMC-based estimates reasonably agree with the observed TN load. The NRE TN equation underestimates the TN load for BC and BI, as it underestimated TSS loads for these two watersheds.

NRE estimates for TP load (Figure 13) follow the pattern for TN, except that the observed TP load for HI falls within the NRE confidence limits. The relationship of observed TP loads to the Simple Method and NURP EMC-based estimates is similar to that for TN loads. For the metals Cu (Figure 14), Pb (Figure 15), and Zn (Figure 16), the Simple Method and NURP EMC-based method consistently overestimate the loading rate when compared to observed loads. So do the NREs, except for the two highly impervious watersheds, where the NREs consistently perform better.

4.3 Hydrological considerations

Some of the disparity between the observed and estimated loads may be a function of the hydrology of the Austin watersheds. The dataset on which the impervious area/runoff coefficient regression was based was an extension of earlier work with NURP data. However, Austin NURP watersheds were part of a group that was excluded from the regression (Schueler 1987). This group, as a whole, has a lower runoff coefficient/impervious area ratio than the NURP sites that were used to develop the regression equation (USEPA 1983). The Austin area occurs in a region primarily underlain by limestone, with higher infiltration rates and lower runoff than most areas around the nation (Steve Stecher, personal communication). As shown in Figure 17, runoff coefficients predicted by equation (2) are higher than observed runoff coefficients calculated for the Austin watersheds, except for the 95% impervious site. The difference is most marked for less impervious sites. This results in higher runoff estimates using the runoff-imperviousness relationship in (2). Higher runoff estimates translate into higher load estimates in constant concentration techniques, such as the NURP EMC-based method and Simple Method evaluated in this study. This indicates that other factors, such as the infiltration capacity of the soil, etc., are of relatively greater importance in determining runoff volume than just percent impervious area.

More accurate estimates might be achieved using constant concentration methods that can more adequately model local hydrological conditions. One must, however, weigh the value and intended purpose of the load estimate against the potential increase in complexity and difficulty in the use of more detailed hydrologic modelling procedures.

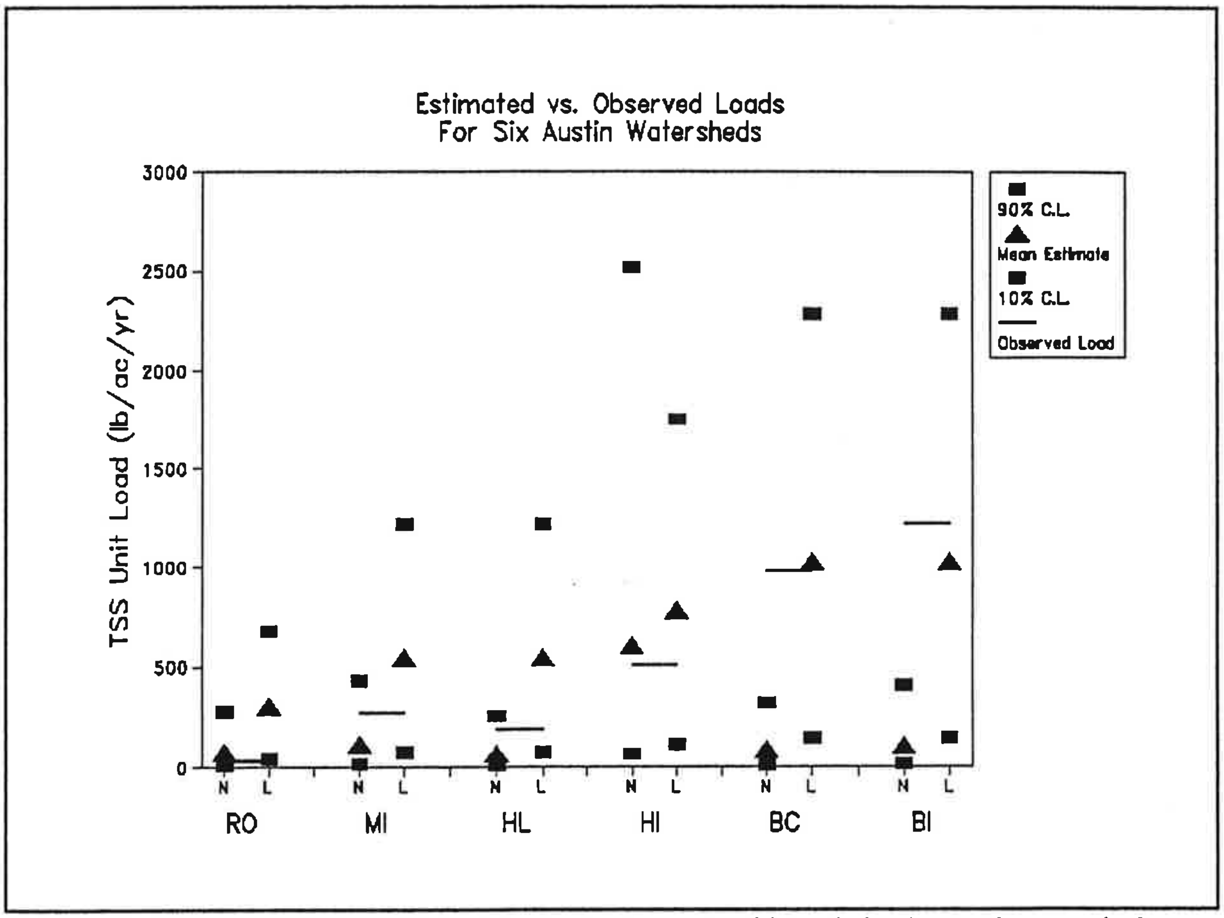

Figure 11. Comparison of TSS load estimates to observed TSS loads in six Austin watersheds.

Estimate Type Key:

N = National Regression Equation

L = Loading Rate

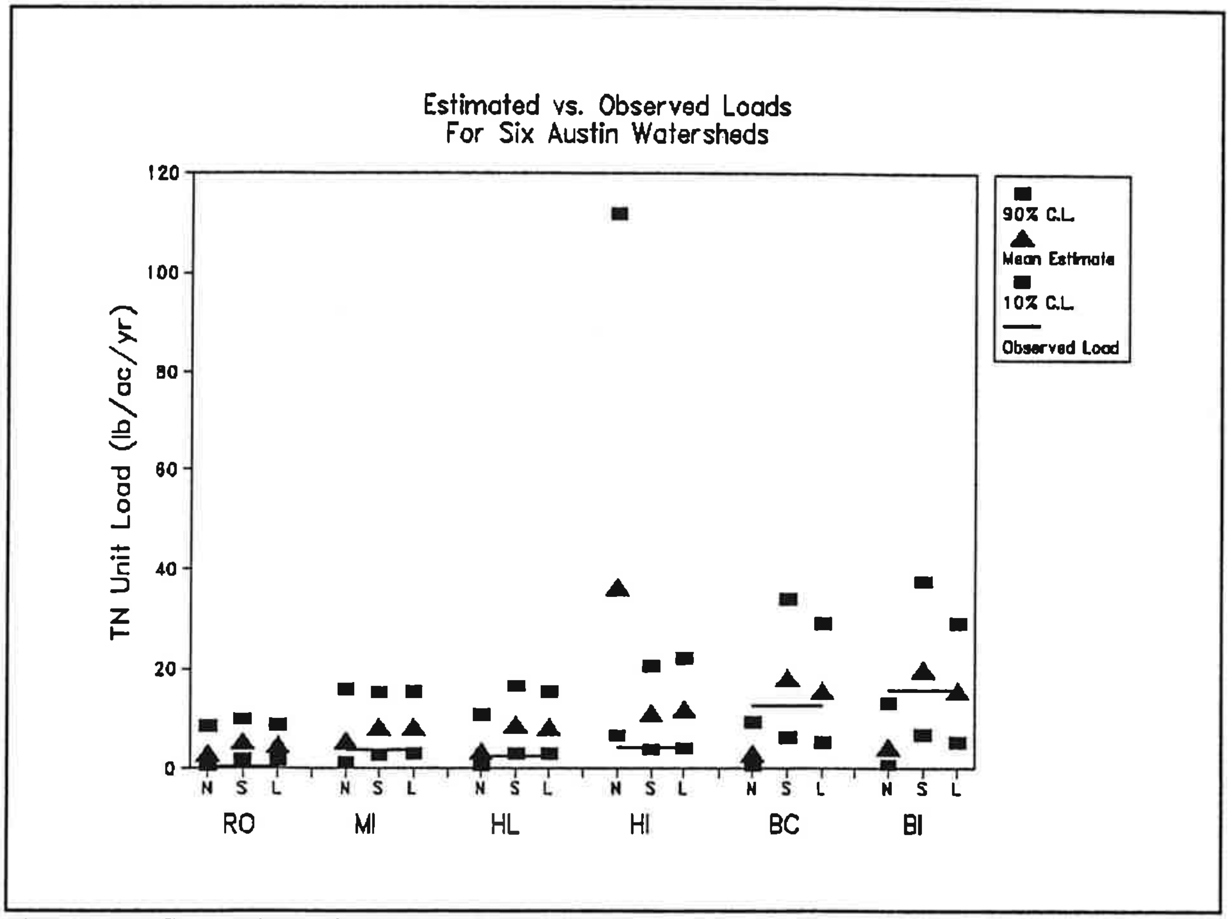

Figure 12. Comparison of TN load estimates to observed TSS loads in six Austin watersheds.

Estimate Type Key:

N = National Regression Equation

S = Simple Method

L = Loading Rate

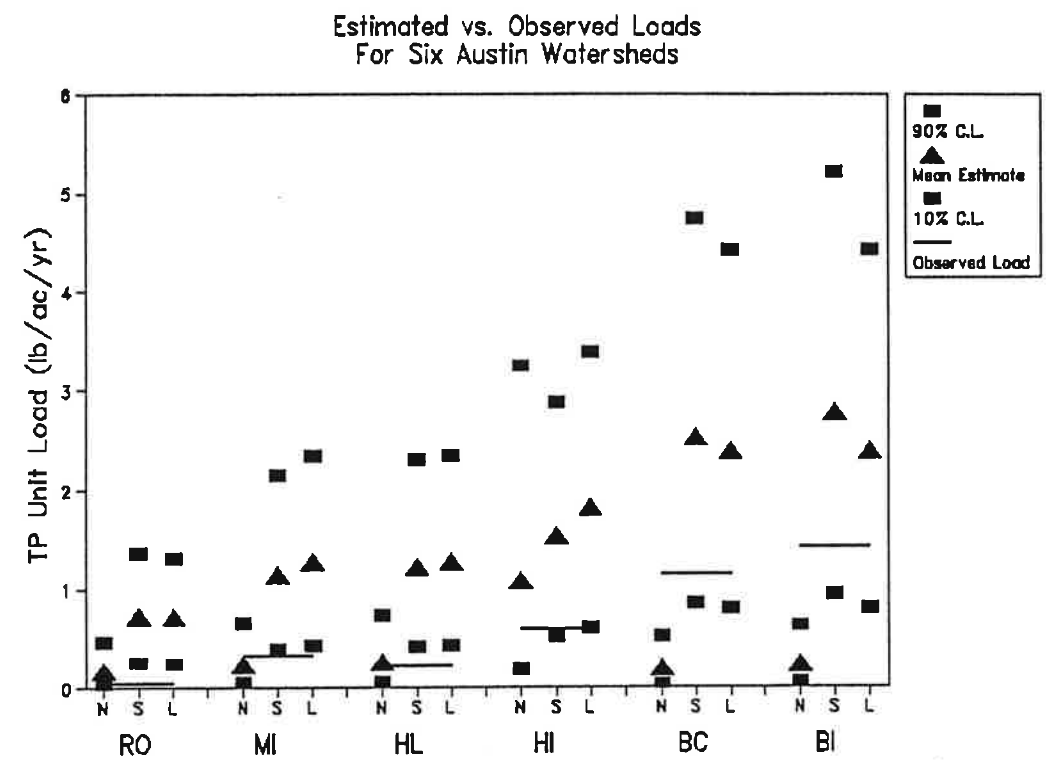

Figure 13. Comparison of TP load estimates to observed TSS loads in six Austin watersheds.

Estimate Type Key:

N = National Regression Equation

S = Simple Method

L = Loading Rate

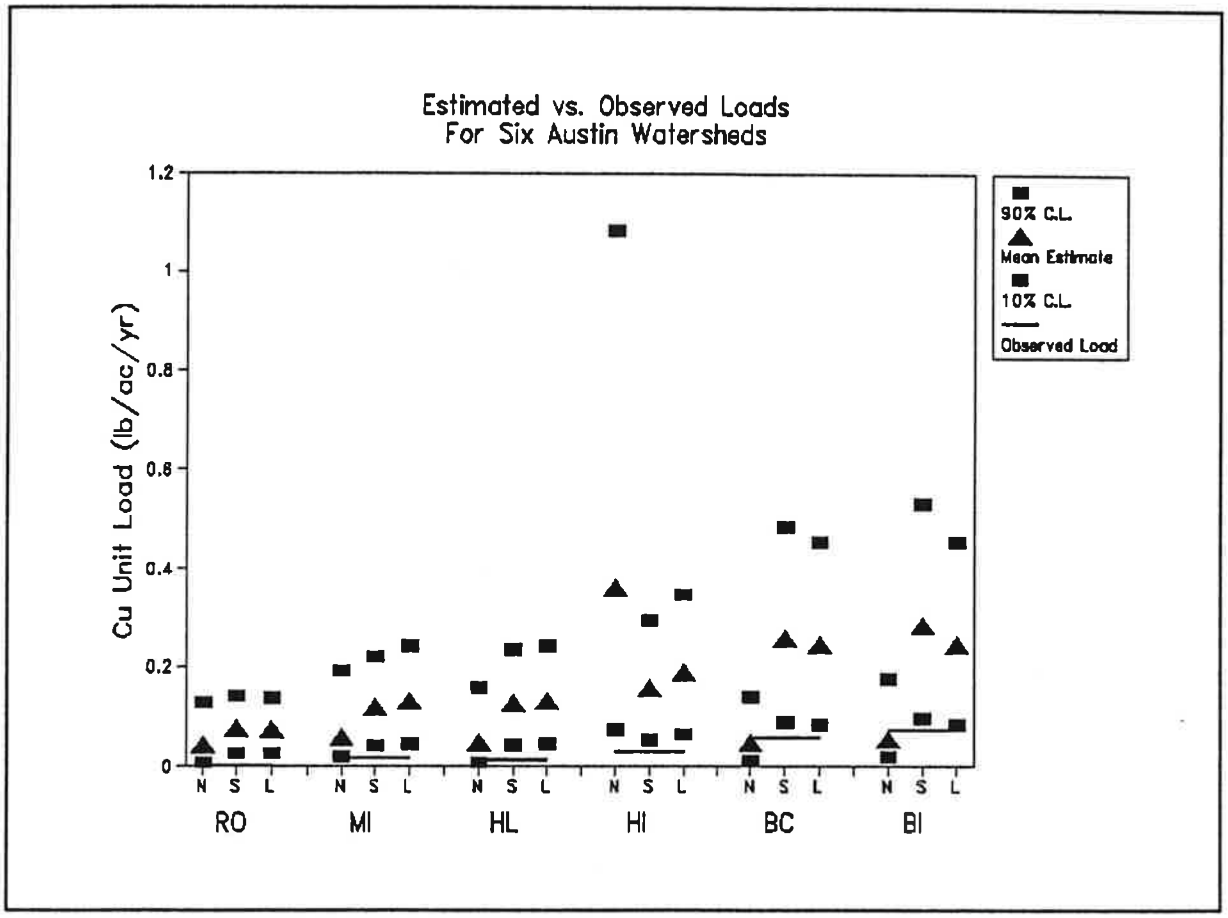

Figure 14. Comparison of Cu load estimates to observed TSS loads in six Austin watersheds.

Estimate Type Key:

N = National Regression Equation

S = Simple Method

L = Loading Rate

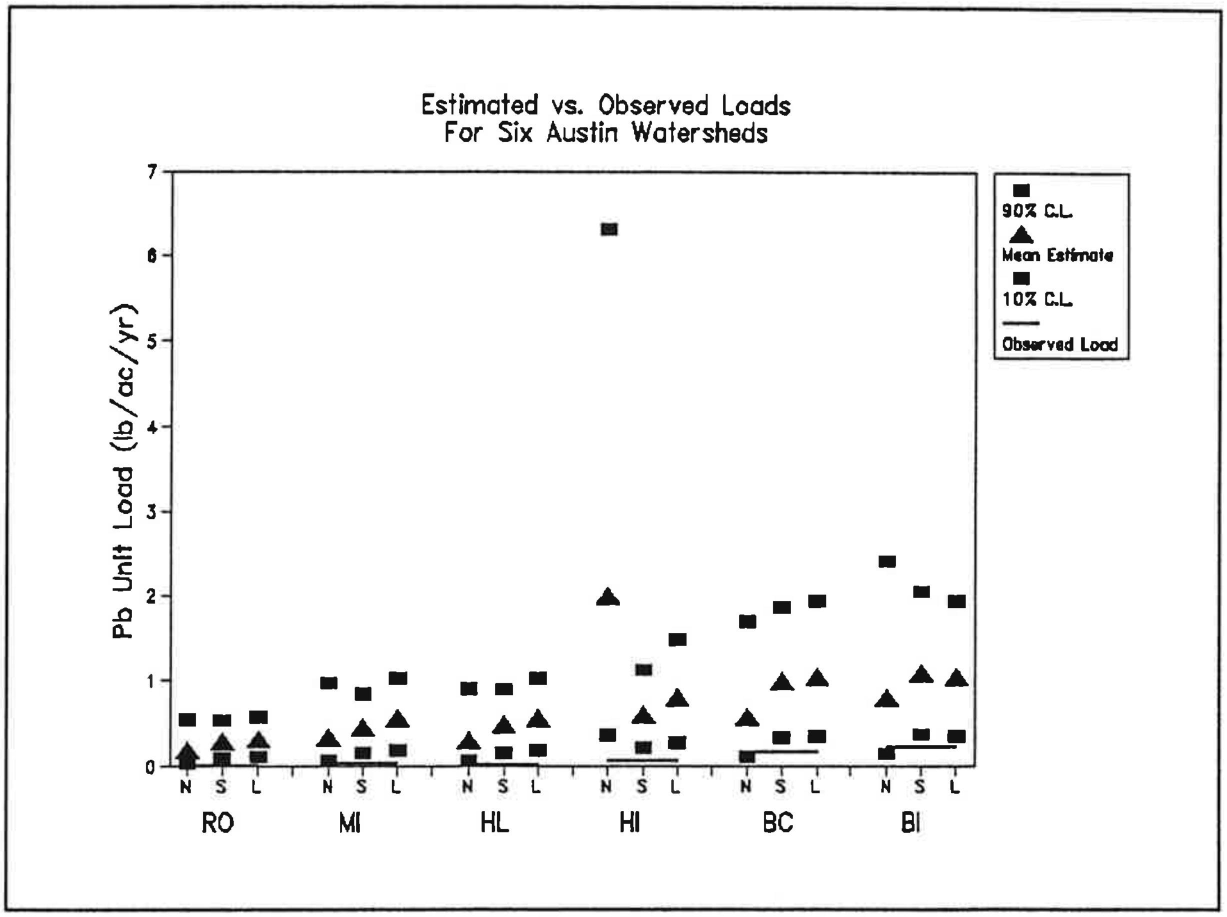

Figure 15. Comparison of Pb load estimates to observed TSS loads in six Austin watersheds.

Estimate Type Key:

N = National Regression Equation

S = Simple Method

L = Loading Rate

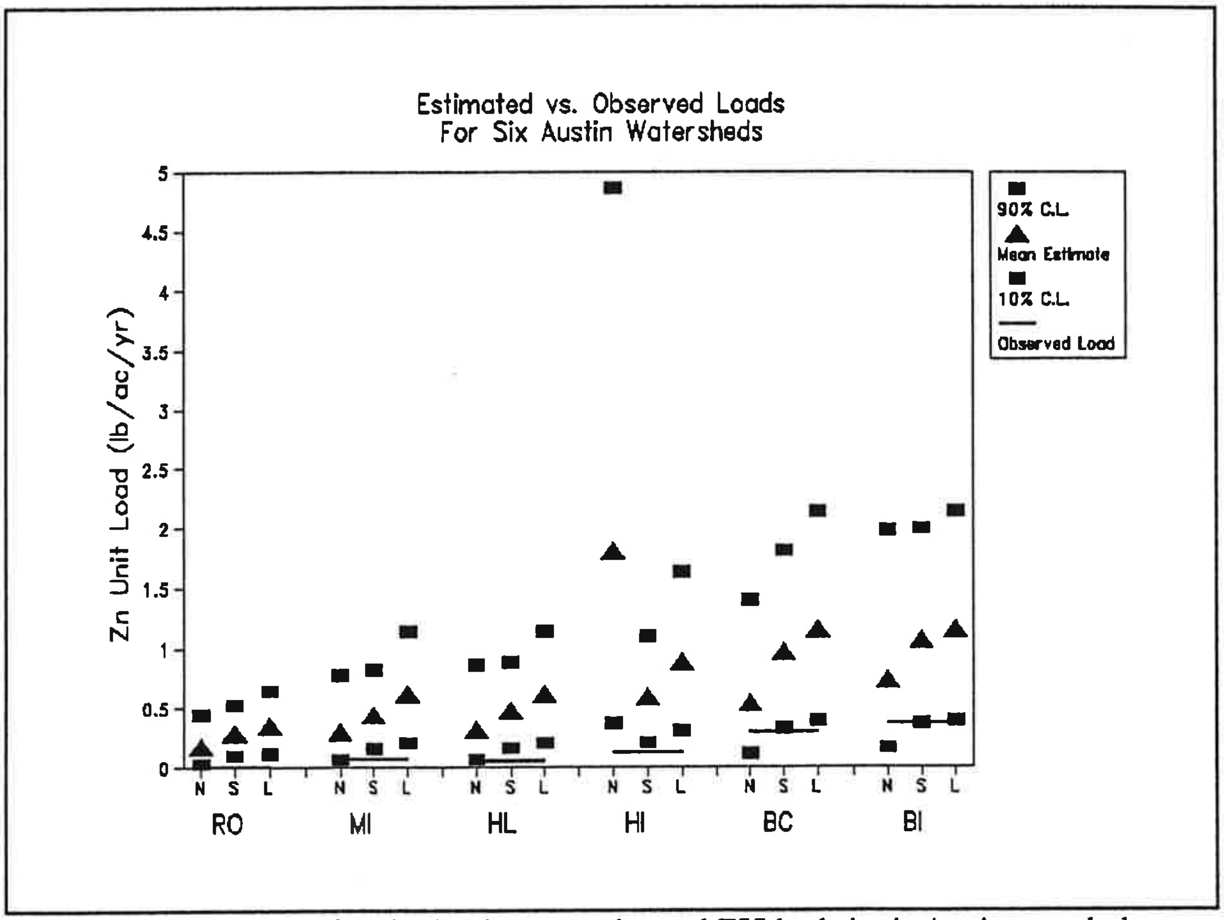

Figure 16. Comparison of Zn load estimates to observed TSS loads in six Austin watersheds.

Estimate Type Key:

N = National Regression Equation

S = Simple Method

L = Loading Rate

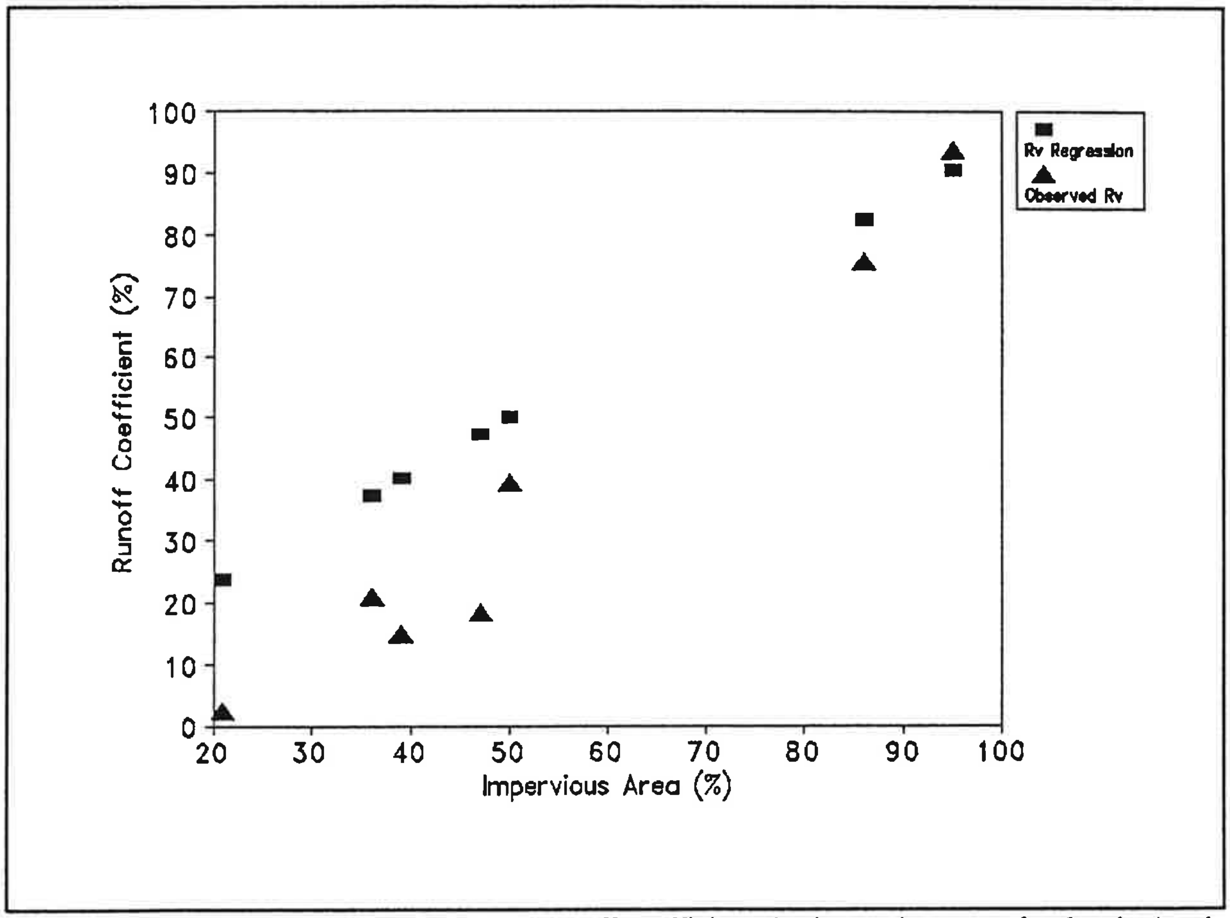

Figure 17. Plot of estimated and observed runoff coefficients by impervious area for the six Austin watersheds.

5. SUMMARY AND CONCLUSIONS

Water pollution from urban runoff has, over the last 25 years, been recognized as a potentially serious environmental problem. In the United States, several laws have been enacted that mandate cleanup of our surface waters, and that require control or elimination of pollutant-bearing runoff. In addition, several studies, most notably the Nationwide Urban Runoff Program, have been undertaken to characterize the extent of and problems caused by urban runoff.

Pollutant mass loads are quantitative measures which can be used to assess the cumulative impacts of urban runoff pollution on receiving waters. There is quite a range of load estimation techniques, from simple loading rates and export coefficients to complex process-oriented simulation models. This study compared the performance of three load estimation techniques: 1) NURP EMC-based loading rates; 2) the Metropolitan Washington Council of Governments' Simple Method; and 3) the U.S.G.S. national regression equations. First, all three techniques were applied to hypothetical watersheds in order to find out how the methods perform over a controlled range of watershed characteristics. Then the techniques were applied to six watersheds in Austin, Texas, in order to compare the estimates from these methods to observed loads.

For watersheds ranging in size from 50 to 500 acres, the NRE method consistently produces more lower load estimates with narrower confidence limits, whereas the NURP EMC-based method and Simple Method produce higher estimates with wider confidence limits. The magnitude and width of the confidence limits of the NURP EMC-based method and Simple Method are strongly influenced by the choice of EMC value used. Another finding is that the runoff volumes calculated by the two constant concentration methods are less accurate for watersheds with lower impervious areas.

Based on the results of this study, the following conclusions may be drawn:

1) due to the variability of the data, confidence limits around the load estimate should be reported along with the estimate;

2) that site specific, or at least regional, EMCs should be used to improve the accuracy of constant concentration methods. This appears to be especially true for metals; and

3) the accuracy of the two constant concentration methods would be improved with more realistic hydrological parameters, particularly for watersheds with low impervious areas.

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APPENDIX A. LISTING OF NURP EMCs AND EMC-BASED LOAD ESTIMATES

Table A-1. NURP site mean EMCs (mg/l) used to estimate NURP EMC-based loading rates (data from USEPA 1983, Table 6-25).

Constituent	Site Mean Concentration (mg/l)
TSS	180
TN	0.42
TP[1]	2.76
Cu	0.043
Pb	0.182
Zn	0.202

[1]This value is the sum of the site mean EMCs for total kjeldahl nitrogen (TKN) and nitrate plus nitrite (NO_{2+3}-N).

Table A-2. NURP EMC-based loading rate estimates (lb/ac/yr) for hypothetical watersheds in the Washington, D.C., metropolitan area. Mean annual rainfall = 40.00 in.

Land Use	TSS Loading Rate (lb/ac/yr)	10% - 90% Confidence Limits
Low Density Residential	375	52 - 838
Medium Density Residential	669	92 - 1494
High Density Residential	963	133 - 2150
Commercial	1256	174 - 2806

Land Use	TN Loading Rate (lb/ac/yr)	10% - 90% Confidence Limits
Low Density Residential	5.8	1.9 - 10.7
Medium Density Residential	10.3	3.4 - 19.1
High Density Residential	14.8	5.0 - 27.4
Commercial	19.3	6.5 - 35.8

Land Use	TP Loading Rate (lb/ac/yr)	10% - 90% Confidence Limits
Low Density Residential	0.9	0.3 - 1.6
Medium Density Residential	1.6	0.5 - 2.9
High Density Residential	2.2	0.7 - 4.2
Commercial	2.9	1.0 - 5.4

Table A-2 (continued). NURP EMC-based loading rate estimates (lb/ac/yr) for hypothetical watersheds in the Washington, D.C., metropolitan area. Mean annual rainfall = 40.00 in.

Land Use	Cu Loading Rate (lb/ac/yr)	10% - 90% Confidence Limits
Low Density Residential	0.09	0.03 - 0.17
Medium Density Residential	0.16	0.05 - 0.30
High Density Residential	0.23	0.08 - 0.43
Commercial	0.30	0.10 - 0.56

Land Use	Pb Loading Rate (lb/ac/yr)	10% - 90% Confidence Limits
Low Density Residential	0.38	0.13 - 0.71
Medium Density Residential	0.68	0.23 - 1.26
High Density Residential	0.98	0.33 - 1.81
Commercial	1.28	0.43 - 2.37

Land Use	Zn Loading Rate (lb/ac/yr)	10% - 90% Confidence Limits
Low Density Residential	0.42	0.14 - 0.79
Medium Density Residential	0.75	0.25 - 1.40
High Density Residential	1.08	0.36 - 2.01
Commercial	1.41	0.47 - 2.63

Table A-3. NURP EMC-based loading rate estimates (lb/ac/yr) for watersheds in the Austin, Texas, metropolitan area. Mean annual rainfall = 32.49 in.

Land Use	TSS Loading Rate (lb/ac/yr)	10% - 90% Confidence Limits
Low Density Residential	305	42 - 681
Medium Density Residential	543	75 - 1214
High Density Residential	782	108 - 1747
Commercial	1020	141 - 2280

Land Use	TN Loading Rate (lb/ac/yr)	10% - 90% Confidence Limits
Low Density Residential	4.7	1.6 - 8.7
Medium Density Residential	8.3	2.8 - 15.5
High Density Residential	12.0	4.0 - 22.3
Commercial	15.6	5.2 - 29.1

Land Use	TP Loading Rate (lb/ac/yr)	10% - 90% Confidence Limits
Low Density Residential	0.7	0.2 - 1.3
Medium Density Residential	1.3	0.4 - 2.3
High Density Residential	1.8	0.6 - 3.4
Commercial	2.4	0.8 - 4.4

Table A-3 (continued). NURP EMC-based loading rate estimates (lb/ac/yr) for watersheds in the Austin, Texas, metropolitan area. Mean annual rainfall = 32.49 in.

Land Use	Cu Loading Rate (lb/ac/yr)	10% - 90% Confidence Limits
Low Density Residential	0.07	0.02 - 0.14
Medium Density Residential	0.13	0.04 - 0.24
High Density Residential	0.19	0.06 - 0.35
Commercial	0.24	0.08 - 0.45

Land Use	Pb Loading Rate (lb/ac/yr)	10% - 90% Confidence Limits
Low Density Residential	0.31	0.10 - 0.57
Medium Density Residential	0.55	0.18 - 1.02
High Density Residential	0.79	0.27 - 1.47
Commercial	1.04	0.35 - 1.92

Land Use	Zn Loading Rate (lb/ac/yr)	10% - 90% Confidence Limits
Low Density Residential	0.34	0.12 - 0.64
Medium Density Residential	0.61	0.21 - 1.14
High Density Residential	0.88	0.30 - 1.64
Commercial	1.15	0.39 - 2.14

APPENDIX B. LISTING OF SIMPLE METHOD "C" VALUES AND LOAD ESTIMATES

Table B-1. Urban "C" values (mg/l) used to estimate annual loading rates with the Simple Method (Schueler 1987, Table 1.1).

Constituent	Washington, D.C., watersheds		National NURP Study Average
	New Suburban NURP Sites	Central Business District Sites	
TN	2.00	2.17	3.31
TP	0.26		0.46
Cu			0.047
Pb	0.018	0.370	0.180
Zn	0.037	0.250	0.176