The AMSA 2000/2001 Survey of Dioxin-like Compounds in Biosolids: Statistical Analyses

Prepared for:
Association of Metropolitan Sewerage Agencies (AMSA)

by:
Matthew J. Alvarado, B.S., Sarah Armstrong, M.S., M.S., and Edmund Crouch, Ph.D.
Cambridge Environmental, Inc.
58 Charles St.
Cambridge, MA 02141
(617)225-0810

October 30, 2001

Contents

Cambridge Environmental Inc

58 Charles Street Cambridge, Massachusetts 02141
617-225-0810 FAX: 617-225-0813 E-mail: info@CambridgeEnvironmental.com

58 Charles Street Cambridge, Massachusetts 02141
617-225-0810 FAX: 617-225-0813 E-mail: info@CambridgeEnvironmental.com

Table of tables

58 Charles Street Cambridge, Massachusetts 02141
617-225-0810 FAX: 617-225-0813 E-mail: info@CambridgeEnvironmental.com

Table of Figures

58 Charles Street Cambridge, Massachusetts 02141
617-225-0810 FAX: 617-225-0813 E-mail: info@CambridgeEnvironmental.com

58 Charles Street Cambridge, Massachusetts 02141
617-225-0810 FAX: 617-225-0813 E-mail: info@CambridgeEnvironmental.com

1 Executive Summary

In October 2000, the Association of Metropolitan Sewerage Agencies (AMSA) began a voluntary survey to determine current levels of dioxin-like compounds (*i.e.*, polychlorinated dibenzo-p-dioxins, polychlorinated dibenzofurans and dioxin-like coplanar PCBs) in biosolids (sewage sludge). These data were collected, first, to assist U.S. EPA in developing an environmentally sound and technically correct dioxin limit for land-applied biosolids, and second, to determine whether dioxin concentrations in biosolids have decreased since the 1994/1995 AMSA survey. The survey was open to all publicly owned treatment works (POTWs) in the U.S.

A total of 201 samples were received from 171 POTWs located in 31 states. The participating POTWs also submitted questionnaires containing site-specific influent, process, and biosolids related information. The mass fraction of dioxin-like compounds in these samples was then analyzed by Midwest Research Institute (MRI). The survey methods are described in Chapter 2.

The dioxin-like compound mass fractions and questionnaire data were provided to Cambridge Environmental Inc. for statistical analysis. One sample (10761200b), described as "incinerator ash," was omitted from analysis, leaving 200 samples from 171 POTWs. The statistical analysis had three goals. The first goal was to characterize the distributions of dioxin-like compounds in biosolids from these various POTWs. The second goal was to determine whether the results of AMSA's 2000/2001 survey were significantly different from the results of AMSA's 1994/1995 Survey of Dioxin-like Compounds in Biosolids (Green *et al.*, 1995b). The final goal was to determine whether there were any correlations between regional, influent, process, or biosolids related information and TEQ mass fractions of dioxin-like compounds in the biosolids (using the toxic equivalency factor (TEF) system of Van den Berg *et al.*, 1998).

Chapter 3 addresses the first goal by compiling the means, medians, standard deviations, and percentiles of the mass fraction and toxicity equivalent (TEQ) mass fraction distributions of dioxin-like compounds. Congener mass fractions were reported by MRI on a dry-weight basis. Non-detected congeners were assumed to be either absent, present at one-half of the detection limit, or present at the detection limit of the congener.[1] Congener mass fractions were converted to toxicity equivalent (TEQ) mass fractions using the TEF system of Van den Berg *et al.* (1998). Table 1.1 presents the means and percentiles for the TEQ distributions. Further details of the distributions can be found in Chapter 3,

[1] U.S. EPA has indicated that all non-detected congeners will be assumed to be present at one-half of detection limits (Dominak, personal communication, 2001).

along with the prevalence and relative contribution to the total TEQ mass fraction of each dioxin, furan, and PCB congener.

The TEQ mass fraction distributions appear to be approximately lognormal, so logarithmically transformed TEQ data were used in subsequent analyses that compare and correlate distributions. These analyses were conducted with the assumption that non-detected congeners were absent, or that non-detected congeners were present at the detection limits. These assumptions do not alter the conclusions.

Table 1.1 Statistics for TEQ data[A] (pg TEQ/g)

	Non-detects set to detection limits			Non-detects set to one half of detection limits[B]			Non-detects set to zero		
	Total	Dioxins and Furans	PCBs	Total	Dioxins and Furans	PCBs	Total	Dioxins and Furans	PCBs
Mean	54.2	42.4	11.7	48.5	38.4	10.0	42.8	34.5	8.3
Minimum	13.72	11.06	1.08	7.10	5.94	0.54	0.15	0.08	0.00
10^{th} Percentile	16.40	13.45	2.49	9.65	7.55	1.75	2.71	1.48	0.52
25^{th} Percentile	19.86	14.91	3.85	13.09	9.55	2.99	6.17	3.66	1.59
Median	27.41	19.14	7.29	21.67	15.15	5.70	15.85	11.79	3.37
75^{th} Percentile	38.91	27.37	11.62	36.00	24.81	10.06	31.61	21.49	9.06
90^{th} Percentile	67.69	39.46	17.55	54.00	37.36	16.98	49.53	36.60	14.59
95^{th} Percentile	89.93	58.99	37.34	88.07	53.24	28.14	86.52	49.08	18.77
99^{th} Percentile	228.51	118.29	81.07	226.12	118.28	81.04	223.72	118.28	81.01
Maximum	3590.05	3578.61	228.65	3590.05	3578.61	228.65	3590.05	3578.61	228.64

[A] U.S. EPA has proposed a 300 pg TEQ/g limit for land applied biosolids, using the International TEF scheme (described in U.S. EPA, 1989) for the 17 2,3,7,8-substituted polychlorinated dibenzo-p-dioxins and polychlorinated dibenzofurans, and the World Health Organization's TEF scheme (Van den Berg *et al*., 1998) for the 12 coplanar PCBs (Federal Register, 1999). EPA now intends to use the Van den Berg *et al*. (1998) scheme for all dioxin-like compounds, and this scheme is used in the analysis.

[B] U.S. EPA has indicated that all non-detected congeners will be assumed to be present at one-half of the detection limit (Dominak, 2001).

Chapter 4 compares the results of the 1994/1995 AMSA survey to the results of the 2000/2001 survey. The 1994/1995 and 2000/2001 data sets were modified as described in Chapter 4 in order to allow the most robust comparison possible. Table 1.2 gives the means and medians for the modified, facility-averaged data sets. The means of the logarithmically transformed data sets appear to be significantly different, and the 2000/2001 data show lower average TEQ mass fractions than the 1994/1995 data. When non-detected congeners are assumed to be absent, the median dioxin/furan TEQ mass fraction declined by 56%, the median PCB subset TEQ mass fraction (containing only those PCB congeners analyzed in the 1994/1995 survey) declined by 83%, and the median adjusted total TEQ mass fraction declined by 64%. The corresponding means declined by 0.5%, 79%, and 32%, respectively. Thus, the decrease in mean total TEQ appears to be driven by declining PCB concentrations.

Table 1.2 Comparison of modified 1994/1995 and 2000/2001 data sets[A]

	Non-detects set to detection limits.						Non-detects set to zero					
	Adjusted Total[B]		Dioxins & Furans		PCB subset[C]		Adjusted Total[B]		Dioxins & Furans		PCB subset[C]	
	1994 1995	2000 2001	1994 1995	2000 2001	1994 1995	2000 2001	1994 1995	2000 2001	1994 1995	2000 2001	1994 1995	2000 2001
Number of Facilities[A]	74	182	74	182	74	182	74	182	74	182	74	182
Mean	81.7	52.5	57.3	44.1	24.4	8.4	60.5	41.1	36.3	36.1	24.2	5.04
Median	55.7	25.0	44.6	19.2	9.3	4.8	37.0	13.3	25.5	11.3	9.2	1.5

[A] Samples averaged by facility as described in Chapter 4, in order to obtain comparable data. 74 POTWs participated in the 1994/1995 survey, while 171 POTWs and 9 post-processing facilities participated in the 2000/2001 survey.
[B] Total of dioxin/furan TEQ and PCB subset TEQ only.
[C] Only 4 PCB congeners with non-zero TEF values (using the system of Van den Berg, *et al*., 1998) were analyzed in the 1994/1995 survey (PCB-77, PCB-81, PCB-126, PCB-169). Thus, only these four congeners are used to determine the PCB subset TEQ for the 2000/2001 samples in this comparison.

Finally, Chapter 5 evaluates whether the characteristics of the facilities from which the samples were taken are correlated with the TEQ mass fraction found, the degree of such correlation, and the usefulness of such correlations as predictors of TEQ mass fraction, assuming the observed correlations are not accidental. First, the U.S. EPA Region of the facility, the average daily flow to a facility, and the percent solids in the sample were all analyzed independently to determine whether they were correlated with the TEQ mass fractions of the samples. Next, numeric characteristics of the facility (*e.g.*, average daily flow, percent industrial load) were combined with binary variables coding for U.S. EPA Region, process characteristics, and sample descriptions in a stepwise multiple linear regression to determine whether these characteristics might provide useful predictors of TEQ mass fraction. This analysis must be considered a "data-dredging" exercise, since the study design strictly allows no causal inferences or generalizations — any correlations found cannot be considered causal or even predictive without further evaluation.

The analysis of the samples by U.S. EPA Region suggests that the total and PCB TEQ mass fractions may vary between regions, although the evidence is weak considering the assumptions required and the number of statistical tests performed. While the median total TEQ mass fraction in Region 1 is well below the 10th percentile of total TEQ mass fraction for Regions 2 and 7, this may be an artifact of the sampling method or simply random variation, particularly since only two samples from Region 1 are available. Thus, while there may be regional differences in total and PCB TEQ mass fractions, further sampling designed to tests such a hypothesis would be required to confirm it.

Single variable regressions of the average daily flow to POTWs, percent solids in sample, percent industrial loading of a POTW, and percent of service area with combined sewers, with TEQ mass fractions show that while the correlations are potentially significant, the uncertainty in the predicted values is so large that these variables, when used independently, cannot predict the TEQ mass fraction of biosolids from a given POTW to within an order of magnitude. Similarly, a multiple linear regression of the numeric questionnaire variables (*i.e.*, percent industrial flow, percent service area with Combined sewers, *etc*.) suggests that these variables are not useful in predicting the TEQ mass fraction of a sample.

The results of the stepwise multiple linear regression presented in Chapter 5 suggest that five variables are potentially useful in predicting the TEQ mass fraction of a sample: whether the sample is in Region 2 (positive coefficient), whether the sample was anaerobically digested (positive coefficient), whether the sample was centrifuged (negative coefficient), whether the sample was air dried (positive coefficient), and whether the sample was filter pressed (negative coefficient). In the regression of the logarithm of total TEQ mass fraction, these five variables account for 21% of the variation between samples. For PCB TEQs, these five variables account for 28% of the variation, the highest of any of the regressions evaluated; however, that leaves approximately three-fourths of the variation between samples unaccounted for. Thus, this correlation, even if it is applicable in general, is unlikely to have any significant predictive power, at least on a POTW by POTW basis: the 90% prediction interval of the total TEQ regression is 3.89 on a logarithmic scale, or a 50-fold variation in the untransformed values, too large for useful predictions. The same argument holds for the regressions versus total and dioxin/furan TEQ mass fraction. Given the limitations of the data used here, further experimentation and analysis would be needed to confirm any of the trends observed in the regression of the AMSA 2000/2001 survey samples, and changes in a POTW's process may not result in the increases and decreases of TEQ mass fraction predicted by the regression.

2 Survey Method

In October, 2000, the Association of Metropolitan Sewerage Agencies (AMSA), began a voluntary survey to determine current levels of dioxin-like compounds (*i.e.*, polychlorinated dibenzo-p-dioxins, polychlorinated dibenzofurans, and dioxin-like coplanar PCBs) in biosolids. The survey was open to both AMSA and non-AMSA wastewater treatment agencies, and was publicized by AMSA, U.S. EPA's Regional Sludge Coordinators, the fifty State Biosolids Coordinators, several environmental engineering consulting firms (*i.e.*, Camp, Dresser & McKee), the National Small Flows Clearinghouse at West Virginia University, and several other wastewater associations. Overall, 111 separate agencies participated in the survey, providing 201 samples from 180 facilities. Participants were asked to provide a biosolids sample to Midwest Research Institute (MRI) for chemical analysis, and to provide process information for their POTWs (*e.g.*, average daily flow, percent industrial loading, *etc*.). The process information questionnaire is provided in Appendix A.

Chemical analyses of biosolids samples were performed by MRI; MRI's report is attached as Appendix B. The dioxin, furan, and PCB congeners analyzed are listed in Table 2.1, and correspond to the list cited by U.S. EPA (Federal Register, 1999). Where our text refers to "PCB congeners" or "dioxin/furan congeners," it refers only to those compounds listed in Table 2.1. All mass fractions (concentrations) presented in the text are on a dry-weight basis.

Questionnaire data for the biosolids samples were compiled by AMSA into electronic spreadsheet format that provided cross-references to sample IDs, but no sewerage agency identification information. Dioxin-like compound concentration data associated with sample IDs were provided by MRI in electronic spreadsheet format. Both sets of spreadsheets were then provided to Cambridge Environmental Inc. for statistical analysis. These spreadsheet data are provided in Appendices C and D.[2]

[2] In Appendix D, average daily flow is only reported as a range, and percent industrial loading and percent service area with combined sewers are presented as binary yes/no answers. Exact numerical data was reported to Cambridge Environmental, Inc., but is not presented so as to maintain the confidentiality of the survey.

Table 2.1 Congeners analyzed by MRI

Congener
2,3,7,8-TCDF
2,3,7,8-TCDD
1,2,3,7,8-PeCDF
2,3,4,7,8-PeCDF
1,2,3,7,8-PeCDD
1,2,3,4,7,8-HxCDF
1,2,3,6,7,8-HxCDF
2,3,4,6,7,8-HxCDF
1,2,3,7,8,9-HxCDF
1,2,3,4,7,8-HxCDD
1,2,3,6,7,8-HxCDD
1,2,3,7,8,9-HxCDD
1,2,3,4,6,7,8-HpCDF
1,2,3,4,7,8,9-HpCDF
1,2,3,4,6,7,8-HpCDD
OCDF
OCDD
PCB-81
PCB-77
PCB-123
PCB-118
PCB-114
PCB-105
PCB-126
PCB-167
PCB-156
PCB-157
PCB-169
PCB-189

3 Data Distributions

This chapter summarizes the analytical results of the dioxin/furan and dioxin-like PCB testing of the biosolids samples collected in the 2000/2001 AMSA survey. Biosolids samples were analyzed by MRI, Inc; MRI's report is attached as Appendix B. Complete analytical results for each of the 201 samples are presented in Appendix C.

3.1 Independence of samples

A total of 201 samples from 171 POTWs located in a total of 31 states were analyzed by MRI. However, sample 10761200b, described as "incinerator ash," is not representative of dioxin/furan and PCB mass fraction in biosolids, as most of the organic material in the sample was destroyed during incineration. Thus, this sample was omitted from further analysis, leaving 200 biosolids samples.

In this chapter, each biosolids sample is treated as an independent sample of some population of biosolids products, except where noted in the text. Some samples are of biosolids from the same municipal region, but from different POTWs, while 29 POTWs sent in two samples. Samples from the same POTW or from different POTWs within the same municipal region share the first four digits of their Sample ID number. It is possible that these samples may be more similar to each other than to the rest of the biosolids samples, as they share either a POTW or a municipality, and thus may not be completely independent of each other. However, most of the samples from the same POTW are of widely different final products (such as dried biosolids cake versus non-dewatered biosolids), and the biosolids samples from the same municipality were treated by separate POTWs. Simply averaging such results together would potentially lose information on differences between the two products from the same POTW and differences between POTWs in the same municipality.

In addition, no distinctions are made in this chapter according to the type of sample (*i.e.*, compost, vacuum filter cake, *etc*.) or any other POTW characteristic.

3.2 Treatment of non-detects

Three assumptions were applied to non-detected congeners, to test the effect of making such assumptions. In the first, non-detected congeners were assumed to be absent (*i.e.*, present at a mass fraction of zero). In the second, non-detected congeners were assumed to be present at half the detection limit. In the third, non-detected congeners were assumed to be present at the detection limit. The tables and figures for Chapter 3 present all three sets of results, as do the analytical results in Appendices E and F. However, for simplicity, all discussions in this chapter assume that non-detected congeners are present at one-half detection limits, unless otherwise noted. There are no essential differences in results evaluated using any of the assumptions.

3.3 Mass fraction distributions

Table 3.1 lists the total dioxin/furan and PCB mass fraction for each sample on a dry-weight basis. Three mass fraction totals are listed for each sample: the total mass fraction of dioxin/furan congeners, total mass fraction of PCB congeners, and the total mass fraction of all dioxin/furan and PCB congeners. The summary statistics for the mass fraction distributions are presented in Table 3.2, while the percentiles of the mass fraction distribution are presented in Table 3.3. Figures 3.1 through 3.9 present histograms of the mass fraction distributions.

When non-detected congeners are assumed to be present at one-half detection limits, the mean mass fraction of PCB congeners is approximately 22.0 ng/g (ppb), while the mean mass fraction of dioxin/furan congeners is 7.50 ng/g. The median mass fraction of the PCB congeners is 14.7 ng/g, the range being 0.06 ng/g to 261 ng/g, while the median mass fraction of dioxin/furan congeners is approximately 3.48 ng/g, the range being 0.10 ng/g to 291 ng/g. Thus, while on average the mass fraction of PCB congeners is larger than the mass fraction of dioxin/furan congeners, the ranges are similar. In addition the maxima occur in different samples, so the maximum total mass fraction is less than the sum of the maximum PCB congener mass fraction and the maximum dioxin/furan mass fraction.

3.4 Toxicity equivalency factors

In order to obtain an estimate of the aggregate human toxicity of the dioxin/furan and PCB congeners, toxicity equivalency factors (TEFs) were used to estimate the "toxicity equivalent" (TEQ) mass fraction of dioxin/furan and PCB congeners in each sample. The TEF values used are those for humans from Van den Berg *et al*. (1998), and are listed in Table 3.4. To determine the TEQ mass fraction of each congener in a sample, the mass fraction of that congener (in units of pg/g, or ppt) was multiplied by the TEF for that congener, providing a 2,3,7,8-TCDD toxicity equivalent mass fraction for each congener in units of pg TEQ/g. The TEQ mass fraction for each congener was then summed in each biosolids sample, providing the summary TEQ results for each sample presented in Table 3.5. TEQ data for each individual congener in a sample is provided in Appendix F.

3.5 TEQ distribution — characteristics and lognormality tests

The total mass fraction of dioxin-like compounds in each sample, on a TEQ basis, are listed in Table 3.5. Summary statistics for these results are presented in Table 3.6, and percentiles of the TEQ distributions are presented in Table 3.8. Figures 3.10 through 3.18 present histograms of the summarized TEQ data.

When non-detected congeners are assumed to be present at one-half detection limits, the mean TEQ mass fraction of PCB congeners is 10.0 pg TEQ/g (ppt TEQ), with a median value of 5.7 pg TEQ/g and a range from 0.54 pg TEQ/g to 228.7 pg TEQ/g. The mean TEQ value of dioxin/furan congeners is 38.4 pg TEQ/g (ppt TEQ), with a median value of 15.2 pg TEQ/g and a range from 5.94 pg TEQ/g to 3579 pg TEQ/g. The total TEQ values for the samples have a mean value of 48.5 pg TEQ/g, with a median of 21.7 pg TEQ/g and a range from 7.10 pg TEQ/g to 3590 pg TEQ/g. Only 0.5% of samples contain total TEQ greater than 300 ppt TEQ, the limiting concentration for land-applied biosolids proposed by EPA (Federal Register, 1999).

Sample 10781200c, with the maximum recorded total TEQ mass fraction of 3590 pg TEQ/g, the majority from dioxin/furans, may be exceptional. The next highest sample (10441100t) has a total TEQ mass fraction of 256.4 pg TEQ/g, less than one-tenth that of 10781200c. The POTW submitting this sample has an average flow of between 1 to 10 million gallons per day, and approximately 20% of its daily flow comes from industrial sources (R. Dominak, personal communication, 2001). In addition, biosolids from this facility generally only contain 2%–3% solids. This sample has been retested, with TEQ values ranging from 2,720 ppt TEQ to 4,840 ppt TEQ. A second sample from this source gave a TEQ mass fraction of approximately 2,800 ppt. This analysis uses the original value of 3590 ppt TEQ in all calculations.

Table 3.9 shows the distribution of total TEQ values (when non-detected congeners are assumed to be absent) binned into ranges suggested by U.S. EPA. As shown, 67 samples (33.5 %) are in the range of 0 to 10 pg TEQ/g, while 64 (32.0 %) and 49 (24.5 %) are in the ranges 10-25 pg TEQ/g and 25-50 pg TEQ/g, respectively. Only the outlier (10781200c) is above a total TEQ level of 300 pg TEQ/g. Thus, one third of all samples are below 10 pg TEQ/g, and 90% of samples are below 50 pg TEQ/g.

An inspection of Table 3.6 shows that the standard deviations for all of the analyzed congener categories are much larger than the mean values, and Figures 3.10 through 3.18 show that the distributions have long right tails.[3] Both characteristics suggest that a transformation of the data may lead to a distribution that is closer to normal, with statistics that allow more robust comparisons. Following Green *et al.* (1995), who found approximately lognormal distributions in the 1994/1995 AMSA survey data, a logarithmic transformation of the data was performed. Summary statistics for the transformed data are presented in Table 3.7 (natural logarithms are used throughout). In order to assess the log-normality of the data sets, the logarithmically transformed data were plotted in Figures 3.19 through 3.24 in a form for which a perfect lognormal distribution would give an approximate straight line. What are plotted are the points:

$$\left\{\ln\left(x_i\right),\Phi^{-1}\left(\left(i-3/8\right)/\left(n+1/4\right)\right)\right\} \qquad (3.1)$$

for $i = 1,2,...,n$, where Ö$^{-1}$ is the inverse normal distribution, n is the number of samples, and x_i are the sample mass fraction placed in order of increasing value. The ordinate here is an approximation to the expected value of the i^{th} normal statistic (Cunane, 1978). The transformed distributions are all more normal than the untransformed distributions. The distributions obtained when the non-detected congeners are assumed to be absent approximate lognormality more closely than those obtained when non-detected congeners are assumed present at detection limits. Thus, the statistics of the logarithmically transformed data given in Table 3.7 will be used for subsequent characterization and comparison of distributions.

---

[3] The same is true for the distributions of mass fraction data; however, the mass fraction data sets were neither transformed nor tested for lognormality.

3.6 Relative contributions of dioxin-like compounds to total TEQ mass fraction

In order to assess the relative contributions of each dioxin-like compound to the total TEQ mass fraction for that sample, the TEQ mass fraction for each congener in a sample was divided by the total TEQ mass fraction for the sample, giving the fraction of the total TEQ value represented by the congener. Then, the 200 results for each congener were assessed by calculating the minimum, median, maximum, and other percentiles for the distribution of fractions for each congener. The results are displayed in the box-and-whisker plots shown in Figures 3.26 through 3.28, where non-detected congeners assumed to be absent, present at one half of their detection limits, or present at detection limits. The x-axis of each of the figures lists a numeric code for the congeners, the code for which is presented in Table 3.10. The midline of each box shows the median value of the relative contribution for that congener to the total TEQ of the sample. The X marker represents the mean value of the relative contribution for that congener to the total TEQ of the sample. The ends of the box represent the 75th and 25th percentiles, the ends of the whiskers represent the 90th and 10th percentiles, and the triangles represent the minimum and maximum values. A large box size or whisker length means that the relative contribution of the given congener varies widely from samples to sample; a high position for the box means that, on average, this congener contributes more to the total TEQ value than the others.

As can be seen from Figure 3.27, most congeners show a tight spread of relative contributions close to 0, except for their maximum values. Congeners 5 (1,2,3,7,8-PeCDF), 15 (1,2,3,4,6,7,8-HpCDD), and 24 (PCB-126) have both higher and larger boxes and whiskers, suggesting that while on average these congeners contribute greatly to the total TEQ value of a sample, their fractional contributions in any specific sample may vary widely. The median relative contributions for these congeners are 22.0%, 10.3%, and 15.0%, respectively. Congeners 2 (2,3,7,8-TCDF), 4 (2,3,4,7,8-PeCDF), 6 (1,2,3,4,7,8-HxCDF), 7 (1,2,3,6,7,8-HxCDF), 8 (2,3,4,6,7,8-HxCDF), 9 (1,2,3,7,8,9-HxCDF), 10 (1,2,3,4,7,8-HxCDD), 11 (1,2,3,6,7,8-HxCDD), 12 (1,2,3,7,8,9-HxCDD), 13 (1,2,3,4,6,7,8-HpCDF), 21 (PCB-118), 23 (PCB-105), and 26 (PCB-156) have median relative contributions between 1.2% and 6.5%. The remaining congeners have median relative contributions between 0% and 1.2%. The mean relative contributions for Congeners 5, 15, and 24 are 23.3%, 12.3%, and 16.4%, respectively, while the mean relative contributions for the remaining congeners are between 7.5% and 0%

In addition to the relative contributions of individual congeners to TEQ values, the relative contributions of dioxin congeners, furan congeners, and PCB congeners to the total TEQ values were assessed. The percentile results are shown in Table 3.11. Dioxins made the largest median relative contribution, 51%, with a mean of 51% and a range from 8% to 92%. Furans made the smallest median relative contribution, 19%, with a mean of 22% and a range from 3% to 87%. PCBs had a median relative contribution of 27%, with a mean of 28% and a range from 0% to 89%. Thus, while on average the relative contribution of PCBs to the total TEQ value may be over one quarter of the total TEQ value, the relative contribution varies widely from sample to sample, and may be as large as 89%.

Finally, we assessed the prevalence of each congener in the samples, *i.e.*, the fraction of samples in which a particular congener was detected. The results are shown in Figure 3.29. 2,3,7,8-TCDD (congener 2) was detected in 26% of samples. Ten congeners, 13 (1,2,3,4,6,7,8-HpCDF), 15 (1,2,3,4,6,7,8-HpCDD), 16 (OCDF), 17 (OCDD), 19 (PCB-77), 21 (PCB-118), 22 (PCB-114), 23 (PCB-105), 25 (PCB-167), 26 (PCB-156), and 29 (PCB-189), were detected in over 80% of samples. Three congeners, 3 (1,2,3,7,8-PeCDF), 9 (1,2,3,7,8,9-HxCDF), and 28 (PCB-169), were detected in less than 10% of samples.

Table 3.1 Summary of mass fraction totals for the 200 biosolids samples. (pg/g)

Sample ID #	Non-detects set to detection limits.			Non-detects set to one-half of detection limits			Non-detects set to zero.		
	Total	Dioxins & Furans	PCB	Total	Dioxins & Furans	PCB	Total	Dioxins & Furans	PCB
10040101a	3.01e+04	6.80e+03	2.33e+04	3.01e+04	6.79e+03	2.33e+04	3.00e+04	6.77e+03	2.33e+04
10040101b	2.18e+04	2.11e+03	1.97e+04	2.16e+04	2.10e+03	1.95e+04	2.14e+04	2.08e+03	1.94e+04
10040101c	4.11e+04	2.89e+03	3.82e+04	4.09e+04	2.87e+03	3.80e+04	4.06e+04	2.85e+03	3.77e+04
10040101d	3.67e+04	3.02e+03	3.36e+04	3.65e+04	2.99e+03	3.35e+04	3.63e+04	2.97e+03	3.33e+04
10051000a	1.55e+04	2.54e+03	1.30e+04	1.53e+04	2.51e+03	1.28e+04	1.52e+04	2.49e+03	1.27e+04
10051000b	3.95e+04	3.78e+03	3.57e+04	3.94e+04	3.75e+03	3.57e+04	3.94e+04	3.71e+03	3.57e+04
10061000a	1.49e+04	2.39e+03	1.25e+04	1.49e+04	2.37e+03	1.25e+04	1.48e+04	2.35e+03	1.25e+04
10071000a	1.20e+04	1.65e+03	1.04e+04	1.19e+04	1.63e+03	1.03e+04	1.19e+04	1.62e+03	1.03e+04
10081000a	9.10e+03	1.49e+03	7.61e+03	9.06e+03	1.46e+03	7.60e+03	9.02e+03	1.43e+03	7.59e+03
10091000a-RA	8.73e+03	2.01e+03	6.72e+03	8.44e+03	1.99e+03	6.46e+03	8.15e+03	1.96e+03	6.20e+03
10101000a	2.13e+04	3.01e+03	1.83e+04	2.12e+04	2.99e+03	1.83e+04	2.12e+04	2.98e+03	1.82e+04
10111000a	9.60e+04	7.55e+03	8.85e+04	9.58e+04	7.53e+03	8.83e+04	9.56e+04	7.51e+03	8.81e+04
10121000a	4.25e+04	2.29e+03	4.02e+04	4.22e+04	2.26e+03	3.99e+04	4.20e+04	2.23e+03	3.97e+04
10131000a	1.96e+04	2.56e+03	1.71e+04	1.94e+04	2.54e+03	1.68e+04	1.91e+04	2.51e+03	1.66e+04
10141000a	7.65e+04	1.45e+04	6.20e+04	7.62e+04	1.45e+04	6.17e+04	7.60e+04	1.45e+04	6.15e+04
10141000b	5.42e+04	6.12e+03	4.80e+04	5.38e+04	6.11e+03	4.77e+04	5.34e+04	6.11e+03	4.73e+04
10141000c	3.51e+04	7.52e+03	2.76e+04	3.47e+04	7.50e+03	2.72e+04	3.43e+04	7.49e+03	2.69e+04
10141000d	1.08e+05	2.46e+04	8.33e+04	1.07e+05	2.46e+04	8.21e+04	1.05e+05	2.46e+04	8.09e+04
10141000e	4.72e+04	7.08e+03	4.01e+04	4.71e+04	7.07e+03	4.00e+04	4.70e+04	7.06e+03	4.00e+04
10141000f	1.54e+04	2.82e+03	1.26e+04	1.53e+04	2.79e+03	1.25e+04	1.53e+04	2.77e+03	1.25e+04
10151000a	1.86e+04	5.45e+03	1.31e+04	1.84e+04	5.43e+03	1.30e+04	1.83e+04	5.41e+03	1.29e+04
10151000b	2.46e+04	6.84e+03	1.78e+04	2.45e+04	6.82e+03	1.77e+04	2.45e+04	6.81e+03	1.77e+04
10151000c	1.80e+04	4.88e+03	1.31e+04	1.80e+04	4.86e+03	1.31e+04	1.79e+04	4.84e+03	1.31e+04
10151000d	1.47e+04	1.95e+03	1.27e+04	1.46e+04	1.92e+03	1.26e+04	1.45e+04	1.89e+03	1.26e+04
10151000e	4.33e+04	2.94e+03	4.03e+04	4.21e+04	2.92e+03	3.92e+04	4.09e+04	2.90e+03	3.80e+04
10151000f	4.81e+04	1.08e+04	3.73e+04	4.81e+04	1.08e+04	3.73e+04	4.80e+04	1.08e+04	3.72e+04
10151000g	3.60e+04	7.41e+03	2.86e+04	3.59e+04	7.39e+03	2.85e+04	3.58e+04	7.37e+03	2.84e+04
10151000h	7.42e+04	6.05e+04	1.38e+04	7.41e+04	6.05e+04	1.36e+04	7.39e+04	6.05e+04	1.35e+04
10161000a	1.15e+04	1.54e+03	9.94e+03	1.14e+04	1.52e+03	9.93e+03	1.14e+04	1.49e+03	9.92e+03
10171000a	2.31e+04	4.81e+03	1.83e+04	2.30e+04	4.79e+03	1.82e+04	2.29e+04	4.77e+03	1.82e+04
10181000a	6.87e+03	1.93e+03	4.95e+03	6.68e+03	1.90e+03	4.78e+03	6.49e+03	1.88e+03	4.61e+03
10191000a	3.07e+04	1.02e+04	2.05e+04	3.03e+04	1.02e+04	2.01e+04	3.00e+04	1.02e+04	1.98e+04

Table 3.1 Summary of mass fraction totals for the 200 biosolids samples. (pg/g)

Sample ID #	Non-detects set to detection limits.			Non-detects set to one-half of detection limits			Non-detects set to zero.		
	Total	Dioxins & Furans	PCB	Total	Dioxins & Furans	PCB	Total	Dioxins & Furans	PCB
10201000a-RA	2.46e+04	2.11e+03	2.25e+04	2.41e+04	2.09e+03	2.20e+04	2.36e+04	2.07e+03	2.15e+04
10211000a	1.65e+04	9.08e+03	7.44e+03	1.65e+04	9.08e+03	7.43e+03	1.65e+04	9.08e+03	7.42e+03
10221000b	2.00e+03	2.99e+02	1.70e+03	1.94e+03	2.69e+02	1.67e+03	1.88e+03	2.39e+02	1.64e+03
10221000c	2.82e+04	2.90e+03	2.53e+04	2.81e+04	2.88e+03	2.52e+04	2.80e+04	2.86e+03	2.51e+04
10221000e	1.52e+04	1.93e+03	1.32e+04	1.51e+04	1.91e+03	1.32e+04	1.50e+04	1.88e+03	1.32e+04
10221000f	2.92e+04	5.82e+03	2.34e+04	2.91e+04	5.80e+03	2.33e+04	2.90e+04	5.78e+03	2.33e+04
10231000a	3.43e+03	5.41e+02	2.89e+03	3.35e+03	5.12e+02	2.84e+03	3.27e+03	4.84e+02	2.78e+03
10241000a	1.85e+03	4.35e+02	1.41e+03	1.77e+03	4.06e+02	1.37e+03	1.70e+03	3.77e+02	1.32e+03
10241000b	1.18e+04	1.63e+03	1.02e+04	1.17e+04	1.61e+03	1.01e+04	1.15e+04	1.58e+03	9.96e+03
10251000a	2.09e+04	5.74e+03	1.51e+04	2.05e+04	5.72e+03	1.47e+04	2.01e+04	5.69e+03	1.44e+04
10251200a	1.71e+04	3.53e+03	1.36e+04	1.69e+04	3.50e+03	1.34e+04	1.67e+04	3.48e+03	1.33e+04
10261000a	2.67e+04	9.35e+03	1.73e+04	2.62e+04	9.33e+03	1.69e+04	2.58e+04	9.31e+03	1.65e+04
10271100a	1.20e+04	2.18e+03	9.84e+03	1.20e+04	2.16e+03	9.83e+03	1.20e+04	2.13e+03	9.82e+03
10271100b	8.37e+03	1.86e+03	6.52e+03	7.99e+03	1.83e+03	6.16e+03	7.61e+03	1.81e+03	5.80e+03
10281100a	3.73e+04	8.93e+03	2.83e+04	3.72e+04	8.92e+03	2.83e+04	3.71e+04	8.90e+03	2.82e+04
10281100b	2.31e+04	3.15e+03	1.99e+04	2.30e+04	3.13e+03	1.98e+04	2.28e+04	3.11e+03	1.97e+04
10291100a-RA	1.90e+03	1.76e+03	1.35e+02	1.81e+03	1.74e+03	6.74e+01	1.72e+03	1.72e+03	0.00e+00
10301100a	3.59e+03	6.73e+02	2.92e+03	3.49e+03	6.45e+02	2.85e+03	3.39e+03	6.17e+02	2.78e+03
10311100a	4.06e+04	1.01e+04	3.05e+04	4.05e+04	1.01e+04	3.04e+04	4.03e+04	1.01e+04	3.03e+04
10311100b	4.92e+04	1.38e+04	3.54e+04	4.91e+04	1.38e+04	3.53e+04	4.90e+04	1.38e+04	3.52e+04
10321100a	3.72e+04	4.27e+03	3.29e+04	3.71e+04	4.25e+03	3.29e+04	3.71e+04	4.23e+03	3.28e+04
10331100a	1.97e+04	2.08e+03	1.76e+04	1.77e+04	2.06e+03	1.57e+04	1.57e+04	2.04e+03	1.37e+04
10341100a	5.10e+03	9.83e+02	4.12e+03	4.99e+03	9.55e+02	4.04e+03	4.88e+03	9.28e+02	3.96e+03
10351100a	3.44e+04	1.26e+04	2.18e+04	3.39e+04	1.26e+04	2.13e+04	3.34e+04	1.26e+04	2.08e+04
10351100b	2.35e+04	6.31e+03	1.72e+04	2.32e+04	6.29e+03	1.69e+04	2.30e+04	6.27e+03	1.67e+04
10361100a	3.34e+04	5.81e+03	2.75e+04	3.32e+04	5.80e+03	2.74e+04	3.30e+04	5.79e+03	2.73e+04
10371100a	3.42e+04	4.98e+03	2.92e+04	3.42e+04	4.96e+03	2.92e+04	3.41e+04	4.94e+03	2.92e+04
10381100a	2.14e+04	2.03e+03	1.93e+04	2.10e+04	2.00e+03	1.90e+04	2.06e+04	1.98e+03	1.86e+04
10381100b	3.63e+04	4.65e+03	3.16e+04	3.63e+04	4.62e+03	3.16e+04	3.62e+04	4.60e+03	3.16e+04
10391100a	9.90e+03	1.47e+03	8.43e+03	9.77e+03	1.45e+03	8.33e+03	9.64e+03	1.43e+03	8.22e+03
10391100b	6.51e+03	1.08e+03	5.43e+03	6.39e+03	1.06e+03	5.34e+03	6.28e+03	1.03e+03	5.24e+03
10391100c	8.32e+02	1.33e+02	6.99e+02	7.11e+02	9.79e+01	6.13e+02	5.90e+02	6.26e+01	5.27e+02

Table 3.1 Summary of mass fraction totals for the 200 biosolids samples. (pg/g)

Sample ID #	Non-detects set to detection limits.			Non-detects set to one-half of detection limits			Non-detects set to zero.		
	Total	Dioxins & Furans	PCB	Total	Dioxins & Furans	PCB	Total	Dioxins & Furans	PCB
10391100d	1.66e+04	3.70e+03	1.29e+04	1.65e+04	3.68e+03	1.29e+04	1.64e+04	3.65e+03	1.28e+04
10391100e	1.46e+04	1.13e+03	1.34e+04	1.45e+04	1.10e+03	1.34e+04	1.45e+04	1.08e+03	1.34e+04
10391100f	1.18e+04	1.42e+03	1.04e+04	1.17e+04	1.40e+03	1.03e+04	1.15e+04	1.37e+03	1.01e+04
10401100a	2.40e+04	1.17e+04	1.23e+04	2.38e+04	1.17e+04	1.21e+04	2.36e+04	1.17e+04	1.18e+04
10401100b	7.66e+03	5.38e+03	2.28e+03	7.56e+03	5.36e+03	2.21e+03	7.46e+03	5.33e+03	2.13e+03
10401100c	1.55e+04	9.96e+03	5.59e+03	1.55e+04	9.93e+03	5.52e+03	1.54e+04	9.91e+03	5.45e+03
10411100a	1.01e+04	2.52e+03	7.59e+03	9.90e+03	2.51e+03	7.39e+03	9.69e+03	2.50e+03	7.19e+03
10411100b	3.89e+03	8.20e+02	3.07e+03	3.78e+03	7.96e+02	2.99e+03	3.68e+03	7.72e+02	2.91e+03
10421100a	7.40e+03	1.38e+03	6.02e+03	7.36e+03	1.36e+03	6.00e+03	7.32e+03	1.34e+03	5.97e+03
10431100a	5.94e+03	1.32e+03	4.62e+03	5.81e+03	1.29e+03	4.52e+03	5.68e+03	1.26e+03	4.41e+03
10441100a	3.53e+04	6.73e+03	2.86e+04	3.52e+04	6.71e+03	2.85e+04	3.51e+04	6.69e+03	2.84e+04
10441100b	1.42e+04	2.53e+03	1.17e+04	1.42e+04	2.52e+03	1.16e+04	1.41e+04	2.50e+03	1.16e+04
10441100c	4.75e+04	5.72e+03	4.18e+04	4.70e+04	5.70e+03	4.13e+04	4.65e+04	5.69e+03	4.09e+04
10441100d	6.27e+04	1.28e+04	4.98e+04	6.26e+04	1.28e+04	4.98e+04	6.25e+04	1.28e+04	4.97e+04
10441100e	2.33e+04	3.00e+03	2.03e+04	2.32e+04	2.98e+03	2.03e+04	2.32e+04	2.95e+03	2.02e+04
10441100f	5.02e+04	7.68e+03	4.25e+04	5.00e+04	7.66e+03	4.24e+04	4.99e+04	7.63e+03	4.23e+04
10441100g	3.66e+04	7.63e+03	2.90e+04	3.65e+04	7.61e+03	2.89e+04	3.63e+04	7.60e+03	2.87e+04
10441100h	1.94e+04	1.88e+03	1.75e+04	1.93e+04	1.85e+03	1.75e+04	1.92e+04	1.83e+03	1.74e+04
10441100i	5.17e+04	3.42e+03	4.83e+04	5.16e+04	3.39e+03	4.82e+04	5.15e+04	3.37e+03	4.81e+04
10441100j	1.36e+05	1.52e+04	1.21e+05	1.35e+05	1.52e+04	1.20e+05	1.35e+05	1.52e+04	1.19e+05
10441100k	4.10e+04	7.89e+03	3.31e+04	4.08e+04	7.87e+03	3.29e+04	4.06e+04	7.85e+03	3.28e+04
10441100l	4.74e+04	7.61e+03	3.97e+04	4.72e+04	7.60e+03	3.96e+04	4.71e+04	7.60e+03	3.95e+04
10441100m	6.30e+04	2.87e+04	3.42e+04	6.28e+04	2.87e+04	3.42e+04	6.27e+04	2.87e+04	3.41e+04
10441100n	3.56e+04	6.10e+03	2.95e+04	3.55e+04	6.08e+03	2.94e+04	3.53e+04	6.06e+03	2.92e+04
10441100o	9.82e+04	8.23e+03	9.00e+04	9.76e+04	8.22e+03	8.94e+04	9.69e+04	8.20e+03	8.87e+04
10441100p	3.98e+04	1.77e+04	2.21e+04	3.97e+04	1.77e+04	2.21e+04	3.97e+04	1.77e+04	2.20e+04
10441100q	5.84e+04	9.67e+03	4.87e+04	5.81e+04	9.66e+03	4.84e+04	5.77e+04	9.64e+03	4.81e+04
10441100r	4.50e+04	1.09e+04	3.41e+04	4.49e+04	1.09e+04	3.40e+04	4.49e+04	1.09e+04	3.40e+04
10441100s	2.73e+04	3.48e+03	2.38e+04	2.72e+04	3.45e+03	2.37e+04	2.71e+04	3.43e+03	2.36e+04
10441100t	1.68e+05	1.20e+04	1.56e+05	1.68e+05	1.19e+04	1.56e+05	1.68e+05	1.19e+04	1.56e+05
10441100u-RA	1.49e+04	5.10e+03	9.80e+03	1.48e+04	5.08e+03	9.71e+03	1.47e+04	5.07e+03	9.62e+03
10441100v	5.47e+04	8.93e+03	4.58e+04	5.46e+04	8.91e+03	4.57e+04	5.45e+04	8.90e+03	4.56e+04

Table 3.1 Summary of mass fraction totals for the 200 biosolids samples. (pg/g)

Sample ID #	Non-detects set to detection limits.			Non-detects set to one-half of detection limits			Non-detects set to zero.		
	Total	Dioxins & Furans	PCB	Total	Dioxins & Furans	PCB	Total	Dioxins & Furans	PCB
10441100w	2.50e+04	4.37e+03	2.07e+04	2.46e+04	4.34e+03	2.02e+04	2.41e+04	4.32e+03	1.98e+04
10441100x	5.57e+04	1.16e+04	4.41e+04	5.55e+04	1.16e+04	4.39e+04	5.54e+04	1.16e+04	4.38e+04
10441100y	5.31e+04	1.93e+04	3.38e+04	5.30e+04	1.93e+04	3.37e+04	5.29e+04	1.92e+04	3.37e+04
10451100a	2.99e+03	3.77e+02	2.62e+03	2.83e+03	3.48e+02	2.48e+03	2.67e+03	3.20e+02	2.35e+03
10461100a	4.67e+04	8.07e+03	3.87e+04	4.67e+04	8.06e+03	3.86e+04	4.67e+04	8.05e+03	3.86e+04
10471100a	5.15e+03	1.51e+03	3.64e+03	5.03e+03	1.48e+03	3.55e+03	4.91e+03	1.45e+03	3.45e+03
10481100a	3.35e+03	6.57e+02	2.70e+03	3.27e+03	6.30e+02	2.64e+03	3.19e+03	6.03e+02	2.59e+03
10491100a	2.37e+04	5.11e+03	1.86e+04	2.33e+04	5.09e+03	1.82e+04	2.29e+04	5.07e+03	1.78e+04
10501100a	1.75e+04	3.15e+03	1.43e+04	1.75e+04	3.13e+03	1.43e+04	1.74e+04	3.10e+03	1.43e+04
10501100b	9.87e+03	1.33e+03	8.54e+03	9.74e+03	1.30e+03	8.44e+03	9.60e+03	1.27e+03	8.33e+03
10511100a	8.59e+03	1.47e+03	7.11e+03	8.55e+03	1.45e+03	7.10e+03	8.50e+03	1.42e+03	7.08e+03
10521100a	6.09e+03	2.77e+03	3.33e+03	6.00e+03	2.74e+03	3.26e+03	5.90e+03	2.71e+03	3.19e+03
10531100a	1.27e+04	6.16e+03	6.52e+03	1.27e+04	6.15e+03	6.50e+03	1.26e+04	6.13e+03	6.48e+03
10541100a	2.08e+04	8.12e+03	1.27e+04	2.04e+04	8.10e+03	1.23e+04	2.00e+04	8.07e+03	1.20e+04
10541100b	5.53e+04	2.48e+04	3.05e+04	5.52e+04	2.48e+04	3.04e+04	5.50e+04	2.47e+04	3.03e+04
10551100a	5.35e+04	1.19e+04	4.16e+04	5.30e+04	1.19e+04	4.12e+04	5.26e+04	1.19e+04	4.07e+04
10561100a	4.32e+03	1.08e+03	3.24e+03	4.26e+03	1.06e+03	3.20e+03	4.20e+03	1.04e+03	3.16e+03
10571100a	1.65e+04	3.86e+03	1.27e+04	1.65e+04	3.86e+03	1.26e+04	1.65e+04	3.85e+03	1.26e+04
10571100b	2.43e+04	2.95e+03	2.14e+04	2.42e+04	2.93e+03	2.13e+04	2.42e+04	2.90e+03	2.13e+04
10581100a	2.02e+04	3.31e+03	1.69e+04	1.99e+04	3.28e+03	1.66e+04	1.96e+04	3.26e+03	1.63e+04
10591100a	1.33e+04	2.22e+03	1.10e+04	1.32e+04	2.20e+03	1.10e+04	1.31e+04	2.18e+03	1.09e+04
10601100a	7.88e+03	1.36e+03	6.52e+03	7.76e+03	1.33e+03	6.43e+03	7.64e+03	1.31e+03	6.34e+03
10611100a	2.37e+04	2.21e+03	2.15e+04	2.37e+04	2.18e+03	2.15e+04	2.37e+04	2.16e+03	2.15e+04
10621100a	2.05e+04	3.26e+03	1.72e+04	1.99e+04	3.24e+03	1.67e+04	1.93e+04	3.22e+03	1.61e+04
10621100b	5.73e+03	8.69e+02	4.86e+03	5.65e+03	8.41e+02	4.81e+03	5.58e+03	8.14e+02	4.76e+03
10621100c	1.08e+03	2.44e+02	8.31e+02	9.39e+02	2.18e+02	7.21e+02	8.03e+02	1.93e+02	6.11e+02
10631100a	3.62e+03	5.42e+02	3.08e+03	3.50e+03	5.13e+02	2.99e+03	3.38e+03	4.84e+02	2.90e+03
10641100a	2.76e+04	1.39e+04	1.37e+04	2.75e+04	1.38e+04	1.36e+04	2.74e+04	1.38e+04	1.36e+04
10641100b	2.74e+04	7.41e+03	1.99e+04	2.73e+04	7.39e+03	1.99e+04	2.73e+04	7.38e+03	1.99e+04
10641100c	3.25e+04	2.72e+04	5.30e+03	3.24e+04	2.71e+04	5.24e+03	3.23e+04	2.71e+04	5.18e+03
10641100d	2.88e+04	7.43e+03	2.13e+04	2.86e+04	7.42e+03	2.12e+04	2.85e+04	7.40e+03	2.11e+04
10641100e	4.99e+03	1.41e+03	3.58e+03	4.93e+03	1.38e+03	3.55e+03	4.87e+03	1.36e+03	3.52e+03

Table 3.1 Summary of mass fraction totals for the 200 biosolids samples. (pg/g)

Sample ID #	Non-detects set to detection limits.			Non-detects set to one-half of detection limits			Non-detects set to zero.		
	Total	Dioxins & Furans	PCB	Total	Dioxins & Furans	PCB	Total	Dioxins & Furans	PCB
10651100a	3.66e+04	1.14e+04	2.52e+04	3.66e+04	1.14e+04	2.51e+04	3.65e+04	1.14e+04	2.51e+04
10651100b	7.80e+04	1.36e+04	6.43e+04	7.78e+04	1.36e+04	6.42e+04	7.77e+04	1.36e+04	6.41e+04
10651100c	6.88e+04	1.37e+04	5.51e+04	6.85e+04	1.37e+04	5.48e+04	6.82e+04	1.37e+04	5.45e+04
10661100a	1.02e+05	5.00e+03	9.67e+04	1.01e+05	4.98e+03	9.64e+04	1.01e+05	4.96e+03	9.62e+04
10681100a	2.98e+04	4.72e+03	2.51e+04	2.98e+04	4.71e+03	2.51e+04	2.97e+04	4.69e+03	2.50e+04
10691200a	3.73e+04	4.56e+03	3.27e+04	3.72e+04	4.54e+03	3.26e+04	3.71e+04	4.52e+03	3.26e+04
10701200a	2.88e+03	5.93e+02	2.29e+03	2.65e+03	5.65e+02	2.09e+03	2.43e+03	5.37e+02	1.89e+03
10711200a	5.97e+03	1.46e+03	4.51e+03	5.88e+03	1.43e+03	4.45e+03	5.79e+03	1.40e+03	4.38e+03
10711200b	1.61e+04	2.29e+03	1.38e+04	1.60e+04	2.27e+03	1.37e+04	1.58e+04	2.25e+03	1.36e+04
10721200a	7.23e+03	1.88e+03	5.35e+03	7.01e+03	1.86e+03	5.14e+03	6.78e+03	1.84e+03	4.94e+03
10731200a	1.01e+04	5.68e+03	4.46e+03	1.01e+04	5.65e+03	4.40e+03	9.97e+03	5.62e+03	4.35e+03
10731200b	1.00e+04	2.17e+03	7.88e+03	9.87e+03	2.15e+03	7.73e+03	9.70e+03	2.12e+03	7.58e+03
10741200a	2.65e+04	3.96e+03	2.25e+04	2.63e+04	3.94e+03	2.24e+04	2.62e+04	3.91e+03	2.23e+04
10741200b	2.70e+04	3.30e+03	2.37e+04	2.67e+04	3.28e+03	2.34e+04	2.63e+04	3.25e+03	2.31e+04
10751200a	3.63e+03	7.01e+02	2.93e+03	3.51e+03	6.73e+02	2.84e+03	3.40e+03	6.44e+02	2.75e+03
10751200b	2.57e+04	4.98e+03	2.07e+04	2.53e+04	4.96e+03	2.03e+04	2.49e+04	4.94e+03	2.00e+04
10761200a	2.19e+04	7.75e+03	1.42e+04	2.17e+04	7.73e+03	1.39e+04	2.14e+04	7.71e+03	1.37e+04
10761200d	8.88e+03	7.95e+02	8.08e+03	8.52e+03	7.72e+02	7.74e+03	8.15e+03	7.49e+02	7.41e+03
10761200e	1.38e+04	5.52e+03	8.32e+03	1.35e+04	5.51e+03	8.03e+03	1.32e+04	5.50e+03	7.75e+03
10771200a	2.38e+03	3.43e+02	2.04e+03	2.31e+03	3.23e+02	1.99e+03	2.23e+03	3.02e+02	1.93e+03
10781200a	4.48e+04	1.79e+04	2.69e+04	4.36e+04	1.79e+04	2.57e+04	4.24e+04	1.79e+04	2.46e+04
10781200b	1.71e+04	3.00e+03	1.41e+04	1.69e+04	2.98e+03	1.39e+04	1.67e+04	2.95e+03	1.37e+04
10781200c	3.06e+05	2.91e+05	1.44e+04	3.06e+05	2.91e+05	1.43e+04	3.06e+05	2.91e+05	1.43e+04
10791200a	8.53e+03	1.38e+03	7.16e+03	8.41e+03	1.35e+03	7.06e+03	8.28e+03	1.32e+03	6.96e+03\
10791200b	1.48e+04	1.73e+03	1.30e+04	1.45e+04	1.70e+03	1.28e+04	1.42e+04	1.68e+03	1.25e+04
10791200c	7.99e+03	1.07e+03	6.91e+03	7.93e+03	1.04e+03	6.89e+03	7.88e+03	1.02e+03	6.86e+03
10791200d	1.34e+04	2.74e+03	1.07e+04	1.33e+04	2.72e+03	1.06e+04	1.31e+04	2.70e+03	1.04e+04
10791200e	8.97e+03	2.52e+03	6.45e+03	8.86e+03	2.49e+03	6.36e+03	8.74e+03	2.47e+03	6.27e+03
10791200f	2.67e+05	5.05e+03	2.62e+05	2.66e+05	5.04e+03	2.61e+05	2.65e+05	5.04e+03	2.60e+05
10791200g	2.03e+04	4.08e+03	1.62e+04	2.02e+04	4.06e+03	1.62e+04	2.01e+04	4.04e+03	1.61e+04
10801200a	3.19e+04	1.68e+04	1.51e+04	3.19e+04	1.68e+04	1.51e+04	3.18e+04	1.68e+04	1.50e+04
10811200a	7.97e+03	2.35e+03	5.62e+03	7.93e+03	2.33e+03	5.60e+03	7.88e+03	2.30e+03	5.58e+03

Table 3.1 Summary of mass fraction totals for the 200 biosolids samples. (pg/g)

Sample ID #	Non-detects set to detection limits.			Non-detects set to one-half of detection limits			Non-detects set to zero.		
	Total	Dioxins & Furans	PCB	Total	Dioxins & Furans	PCB	Total	Dioxins & Furans	PCB
10811200b	1.61e+03	6.08e+02	9.99e+02	1.53e+03	5.73e+02	9.59e+02	1.46e+03	5.38e+02	9.19e+02
10821200a	2.59e+04	3.57e+03	2.23e+04	2.58e+04	3.56e+03	2.22e+04	2.57e+04	3.54e+03	2.22e+04
10831200a	1.72e+04	8.83e+02	1.64e+04	1.72e+04	8.55e+02	1.63e+04	1.71e+04	8.27e+02	1.63e+04
10841200a	5.95e+04	1.68e+04	4.27e+04	5.85e+04	1.68e+04	4.18e+04	5.76e+04	1.68e+04	4.08e+04
10851200a	4.01e+04	1.03e+04	2.98e+04	4.01e+04	1.03e+04	2.97e+04	4.00e+04	1.03e+04	2.97e+04
10861200a	2.64e+04	5.43e+03	2.10e+04	2.63e+04	5.41e+03	2.09e+04	2.63e+04	5.39e+03	2.09e+04
10870101a	1.53e+04	6.62e+03	8.69e+03	1.52e+04	6.60e+03	8.57e+03	1.50e+04	6.58e+03	8.44e+03
10871200a	6.19e+04	1.76e+04	4.43e+04	6.18e+04	1.76e+04	4.42e+04	6.17e+04	1.76e+04	4.42e+04
10871200b	1.02e+04	2.80e+03	7.38e+03	9.93e+03	2.78e+03	7.15e+03	9.67e+03	2.75e+03	6.92e+03
10881200a	1.69e+04	3.15e+03	1.37e+04	1.67e+04	3.14e+03	1.35e+04	1.65e+04	3.12e+03	1.34e+04
10891200a	8.71e+03	2.04e+03	6.67e+03	8.57e+03	2.03e+03	6.54e+03	8.43e+03	2.01e+03	6.42e+03
10901200a	9.50e+03	2.15e+03	7.35e+03	9.15e+03	2.13e+03	7.03e+03	8.81e+03	2.10e+03	6.70e+03
10911200a	9.05e+03	1.34e+03	7.71e+03	9.02e+03	1.32e+03	7.70e+03	8.98e+03	1.29e+03	7.69e+03
10921200a	1.84e+04	3.55e+03	1.48e+04	1.83e+04	3.52e+03	1.47e+04	1.81e+04	3.49e+03	1.46e+04
10931200b	1.53e+04	2.30e+03	1.30e+04	1.52e+04	2.28e+03	1.29e+04	1.51e+04	2.26e+03	1.29e+04
10941200a	2.24e+04	8.34e+03	1.41e+04	2.22e+04	8.33e+03	1.39e+04	2.20e+04	8.31e+03	1.37e+04
10951200a	8.14e+03	1.44e+03	6.70e+03	7.79e+03	1.41e+03	6.38e+03	7.45e+03	1.39e+03	6.06e+03
10961200a	6.09e+03	1.89e+03	4.20e+03	5.93e+03	1.86e+03	4.07e+03	5.78e+03	1.84e+03	3.94e+03
10961200b	1.39e+04	5.33e+03	8.57e+03	1.38e+04	5.30e+03	8.46e+03	1.36e+04	5.27e+03	8.36e+03
10971200a	3.90e+04	9.90e+03	2.91e+04	3.87e+04	9.90e+03	2.88e+04	3.83e+04	9.90e+03	2.84e+04
10981200a	9.80e+03	9.55e+02	8.84e+03	9.75e+03	9.32e+02	8.82e+03	9.70e+03	9.10e+02	8.79e+03
10991200a	2.70e+04	4.17e+03	2.28e+04	2.69e+04	4.15e+03	2.27e+04	2.68e+04	4.13e+03	2.27e+04
11001200a	3.32e+04	7.47e+03	2.57e+04	3.30e+04	7.46e+03	2.55e+04	3.27e+04	7.45e+03	2.53e+04
11010101a	8.51e+03	1.05e+03	7.46e+03	8.46e+03	1.03e+03	7.43e+03	8.41e+03	1.00e+03	7.40e+03
11020101a	7.91e+04	5.11e+03	7.40e+04	7.83e+04	5.09e+03	7.33e+04	7.76e+04	5.07e+03	7.26e+04
11030101a	5.06e+04	2.69e+04	2.37e+04	4.99e+04	2.69e+04	2.30e+04	4.92e+04	2.69e+04	2.23e+04
11040101a	3.23e+04	3.18e+03	2.91e+04	3.21e+04	3.16e+03	2.89e+04	3.18e+04	3.13e+03	2.87e+04
11050101a	2.42e+04	3.31e+03	2.09e+04	2.39e+04	3.29e+03	2.06e+04	2.36e+04	3.26e+03	2.04e+04
11060101a	2.18e+04	4.76e+03	1.70e+04	2.16e+04	4.75e+03	1.68e+04	2.14e+04	4.74e+03	1.66e+04
11070101a	4.50e+03	8.99e+02	3.60e+03	4.39e+03	8.78e+02	3.52e+03	4.29e+03	8.56e+02	3.43e+03
11080101a	2.16e+04	1.63e+04	5.23e+03	2.14e+04	1.63e+04	5.10e+03	2.13e+04	1.63e+04	4.96e+03
11090101a	5.60e+03	6.88e+02	4.91e+03	5.51e+03	6.60e+02	4.85e+03	5.41e+03	6.32e+02	4.78e+03

Table 3.1 Summary of mass fraction totals for the 200 biosolids samples. (pg/g)

Sample ID #	Non-detects set to detection limits.			Non-detects set to one-half of detection limits			Non-detects set to zero.		
	Total	Dioxins & Furans	PCB	Total	Dioxins & Furans	PCB	Total	Dioxins & Furans	PCB
11100101a	2.16e+04	1.82e+03	1.98e+04	2.14e+04	1.79e+03	1.97e+04	2.13e+04	1.76e+03	1.95e+04
11100101b	1.42e+04	1.46e+03	1.27e+04	1.40e+04	1.43e+03	1.26e+04	1.39e+04	1.40e+03	1.25e+04
11110101a	1.08e+05	7.76e+04	3.05e+04	1.08e+05	7.76e+04	3.05e+04	1.08e+05	7.75e+04	3.05e+04
11120101a	1.37e+04	1.42e+03	1.23e+04	1.36e+04	1.40e+03	1.22e+04	1.34e+04	1.38e+03	1.20e+04
11130101a	1.71e+04	6.64e+03	1.05e+04	1.71e+04	6.63e+03	1.04e+04	1.70e+04	6.62e+03	1.04e+04
11140101a	1.06e+04	2.35e+03	8.26e+03	1.04e+04	2.33e+03	8.07e+03	1.02e+04	2.31e+03	7.88e+03
11150501a	3.49e+04	4.73e+03	3.01e+04	3.48e+04	4.72e+03	3.01e+04	3.48e+04	4.70e+03	3.01e+04
11150501b	1.71e+04	2.66e+03	1.45e+04	1.71e+04	2.64e+03	1.44e+04	1.70e+04	2.61e+03	1.44e+04

Table 3.2 Characteristics of mass fraction data

Treatment of non-detects	Data subset	Number of samples (N)	Mean mass fraction (pg/g)	Standard deviation (pg/g)	Standard error of the mean (pg/g)	Median (pg/g)
Detection limits	Total	200	2.97e+04	3.57e+04	2.52e+03	2.11e+04
	Dioxins and Furans	200	7.52e+03	2.18e+04	1.54e+03	3.50e+03
	PCBs	200	2.22e+04	2.68e+04	1.89e+03	1.50e+04
One half detection limits	Total	200	2.95e+04	3.56e+04	2.52e+03	2.07e+04
	Dioxins and Furans	200	7.50e+03	2.18e+04	1.54e+03	3.48e+03
	PCBs	200	2.20e+04	2.67e+04	1.89e+03	1.47e+04
Zero	Total	200	2.93e+04	3.56e+04	2.52e+03	2.04e+04
	Dioxins and Furans	200	7.48e+03	2.18e+04	1.54e+03	3.45e+03
	PCBs	200	2.18e+04	2.66e+04	1.88e+03	1.44e+04

Table 3.3 Percentiles of mass fraction data

	Non-detects set to detection limits			Non-detects set to one half of detection limits			Non-detects set to zero		
	Total (pg/g)	Dioxins and Furans (pg/g)	PCBs (pg/g)	Total (pg/g)	Dioxins and Furans (pg/g)	PCBs (pg/g)	Total (pg/g)	Dioxins and Furans (pg/g)	PCBs (pg/g)
Minimum	8.32e+02	1.33e+02	1.35e+02	7.11e+02	9.79e+01	6.74e+01	5.90e+02	6.26e+01	0.00e+00
10th Percentile	5.55e+03	9.80e+02	3.64e+03	5.46e+03	9.53e+02	3.55e+03	5.36e+03	9.26e+02	3.51e+03
25th Percentile	1.01e+04	1.88e+03	7.56e+03	9.89e+03	1.86e+03	7.43e+03	9.69e+03	1.83e+03	7.41e+03
Median	2.11e+04	3.50e+03	1.50e+04	2.07e+04	3.48e+03	1.47e+04	2.04e+04	3.45e+03	1.44e+04
75th Percentile	3.66e+04	7.53e+03	2.86e+04	3.65e+04	7.51e+03	2.85e+04	3.63e+04	7.49e+03	2.84e+04
90th Percentile	5.54e+04	1.36e+04	4.18e+04	5.52e+04	1.36e+04	4.14e+04	5.51e+04	1.36e+04	4.08e+04
95th Percentile	7.80e+04	1.77e+04	5.54e+04	7.79e+04	1.77e+04	5.51e+04	7.76e+04	1.77e+04	5.49e+04
99th Percentile	1.69e+05	6.06e+04	1.21e+05	1.69e+05	6.06e+04	1.20e+05	1.69e+05	6.06e+04	1.20e+05
Maximum	3.06e+05	2.91e+05	2.62e+05	3.06e+05	2.91e+05	2.61e+05	3.06e+05	2.91e+05	2.60e+05

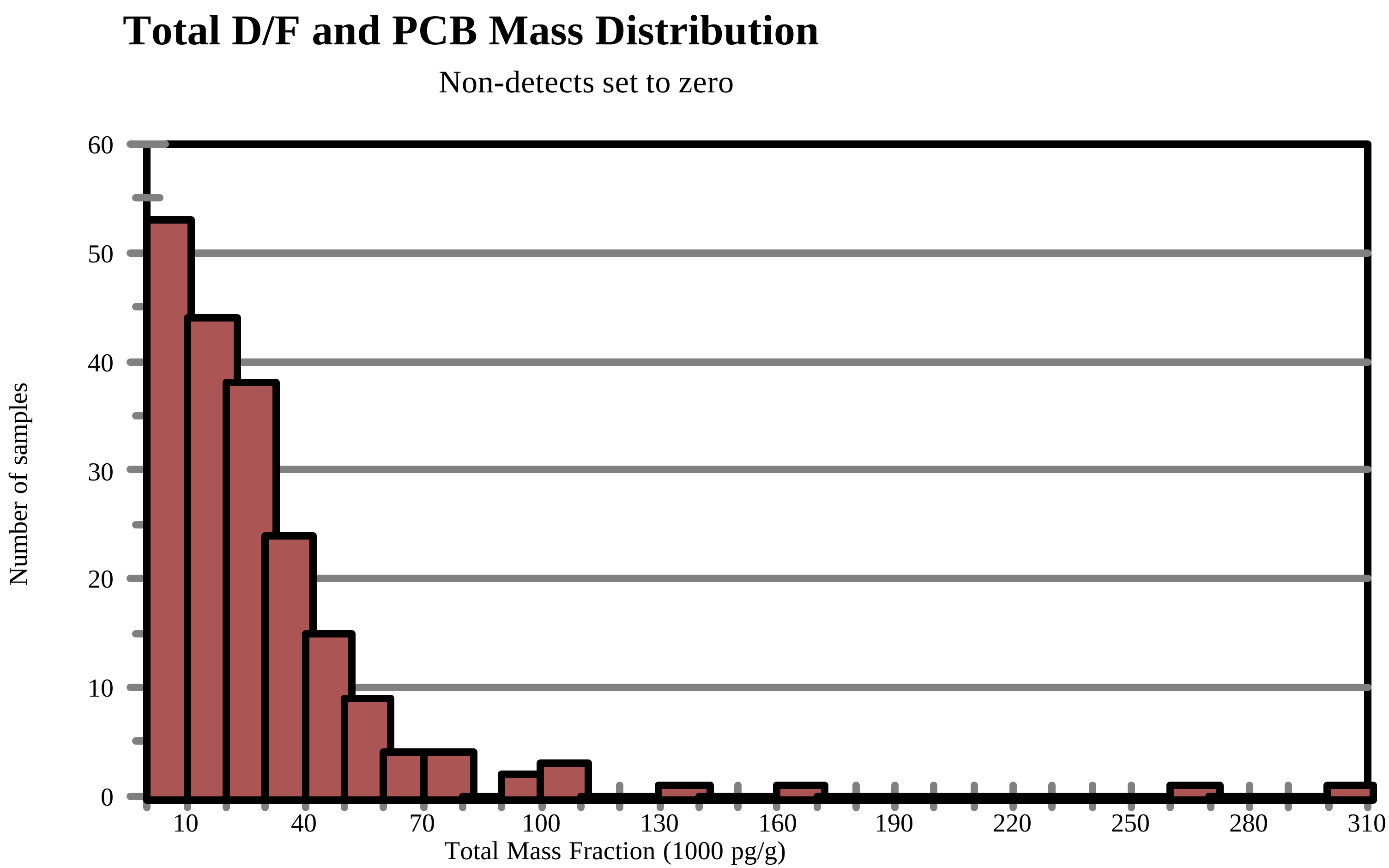

Figure 3.1 Histogram of the total mass fraction of dioxin/furan and PCB congeners. Non-detects set to zero.

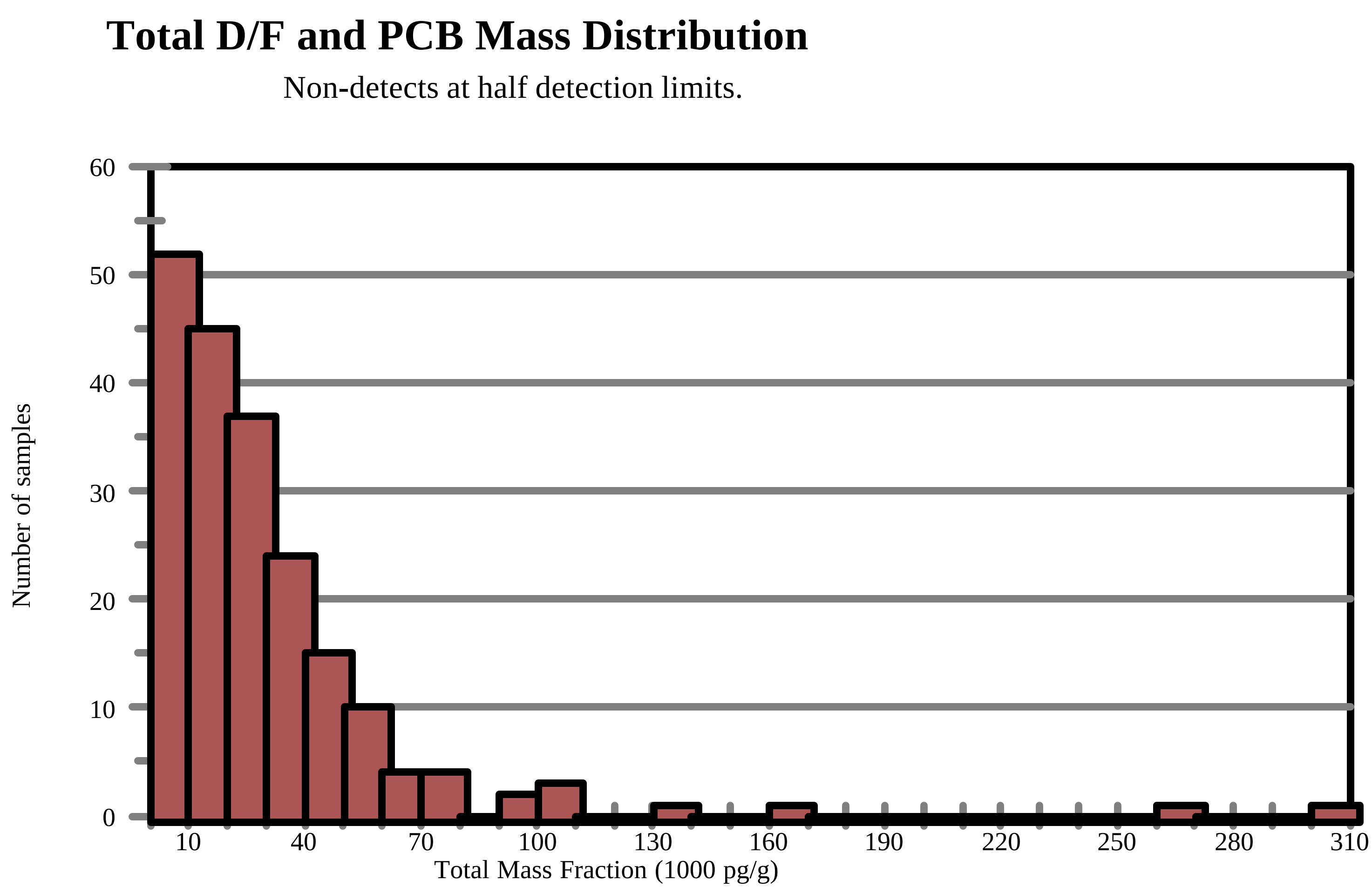

Figure 3.2 Histogram of the total mass fraction of dioxin/furan and PCB congeners. Non-detects set to one-half detection limits.

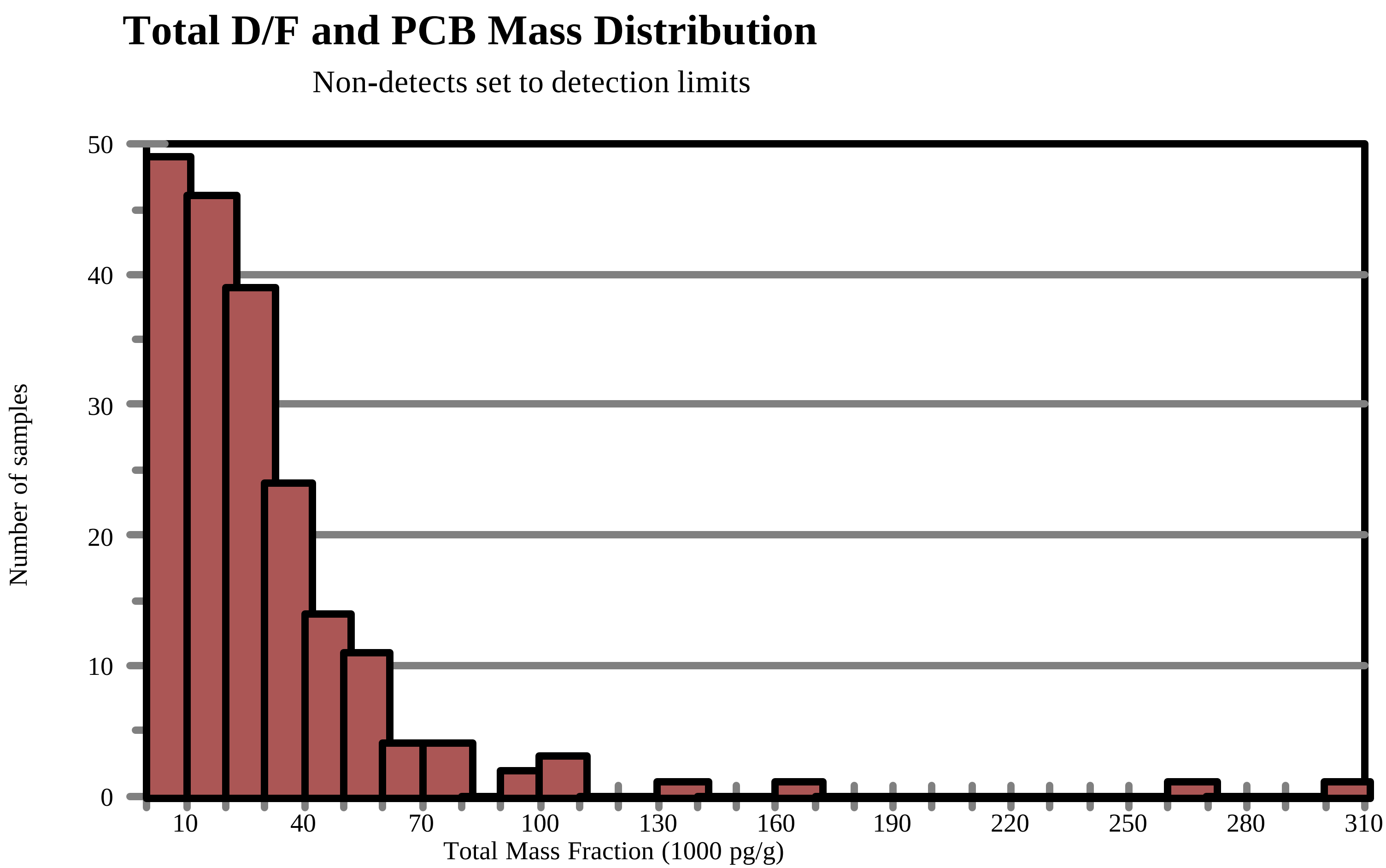

Figure 3.3 Histogram of the total mass fraction of dioxin/furan and PCB congeners. Non-detects set to detection limits.

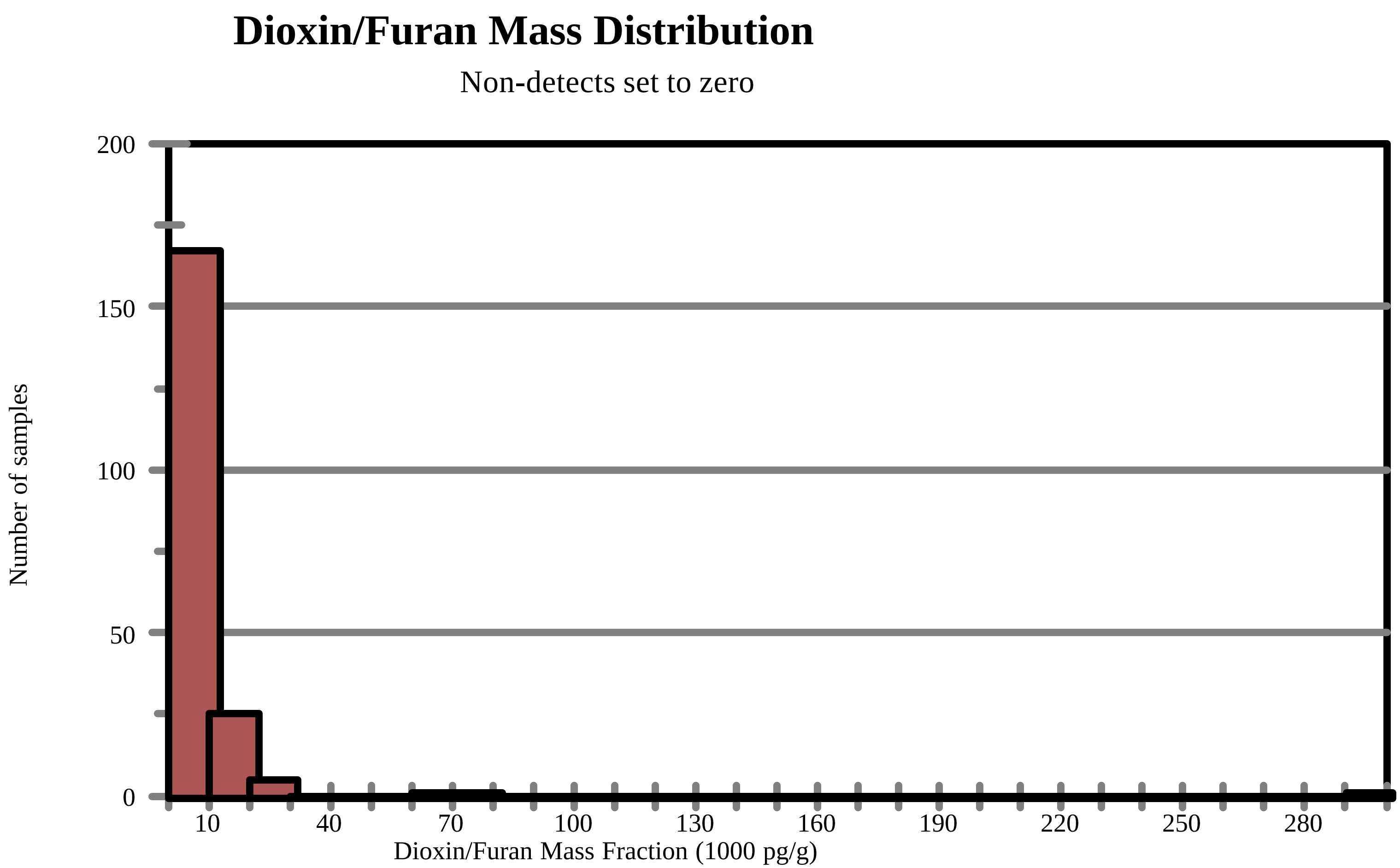

Figure 3.4 Histogram of the mass fraction of dioxin/furan congeners. Non-detects set to zero.

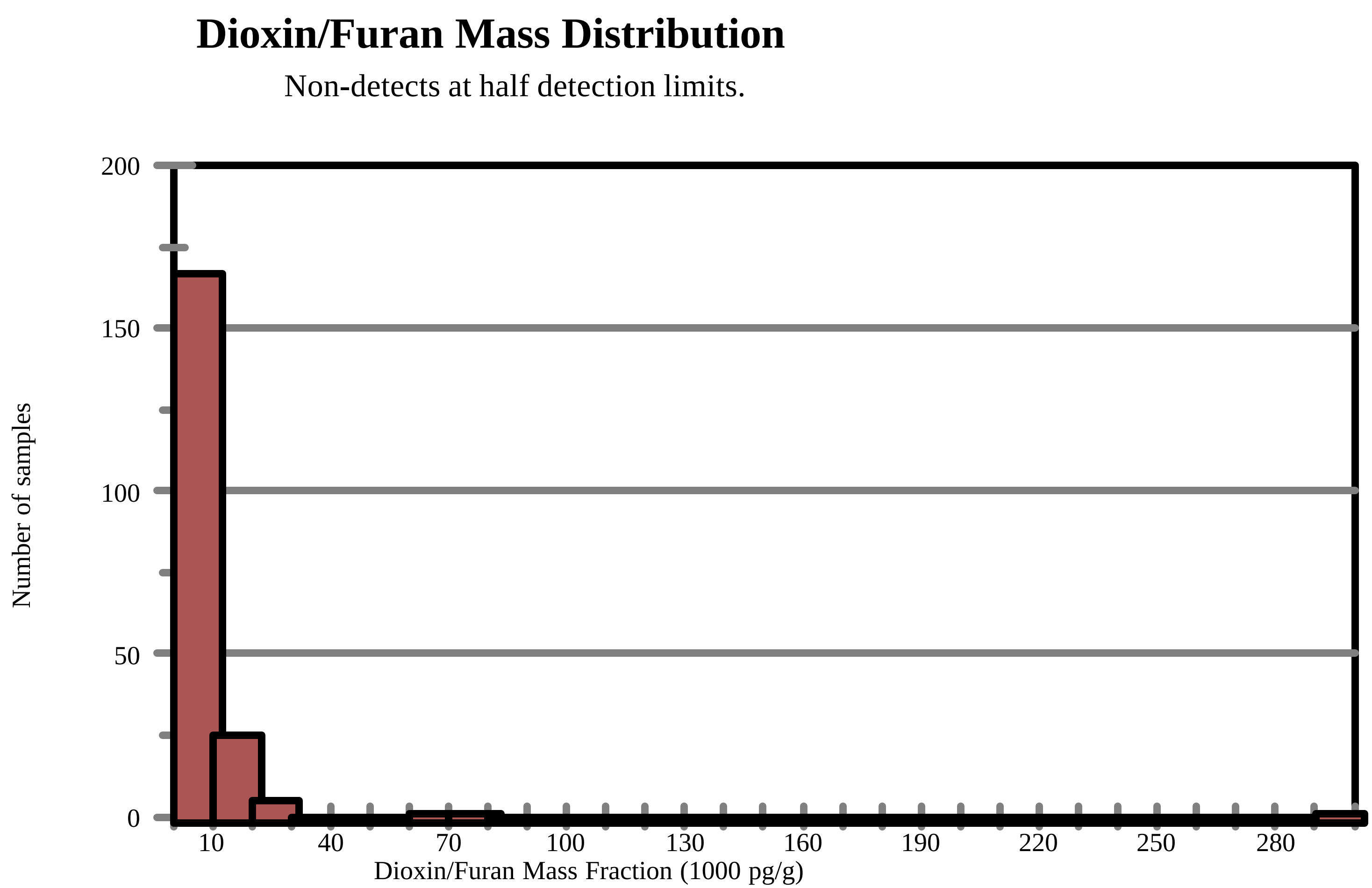

Figure 3.5 Histogram of the mass fraction of dioxin/furan congeners. Non-detects set to one-half detection limits.

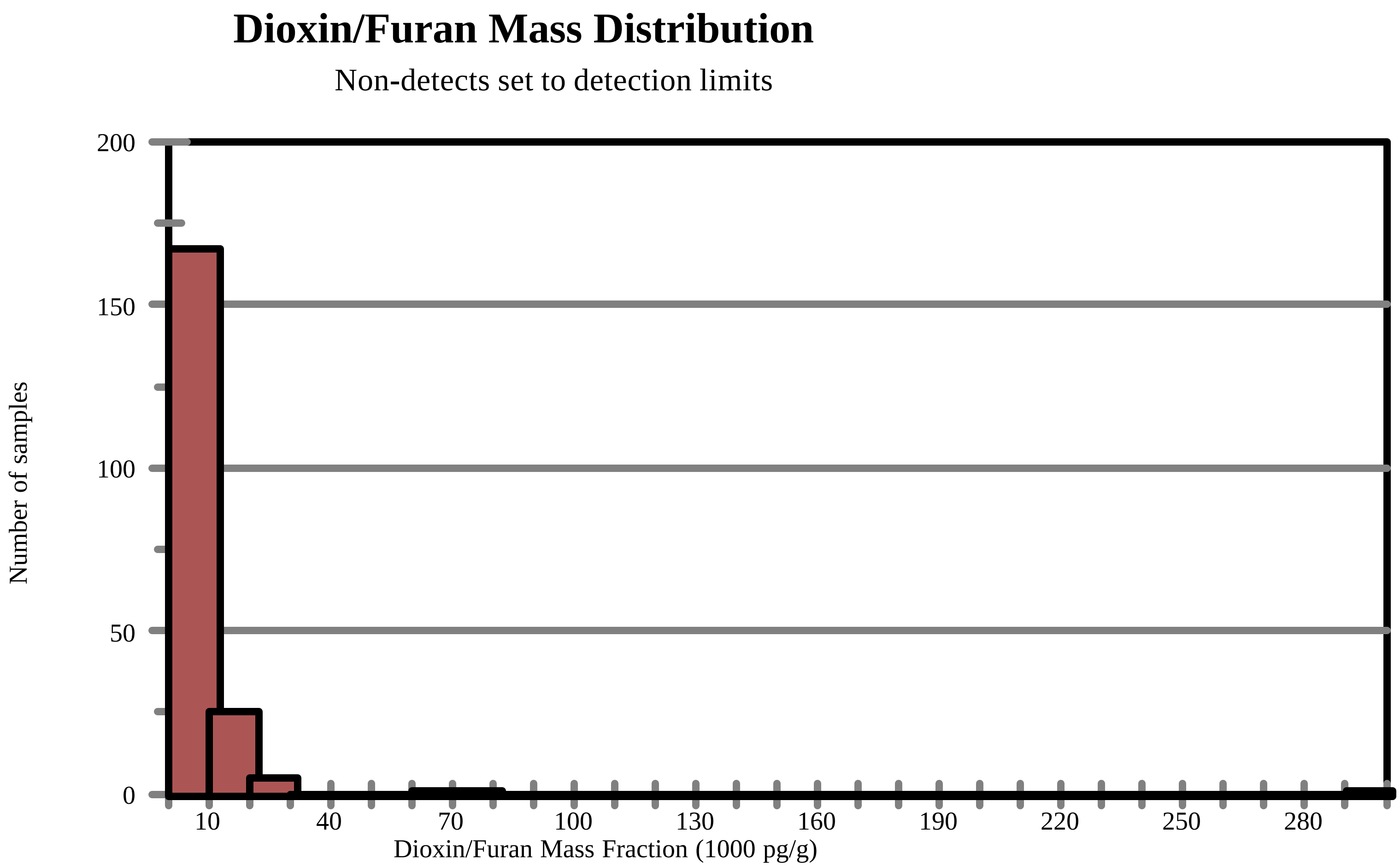

Figure 3.6 Histogram of the mass fraction of dioxin/furan congeners. Non-detects set to detection limits.

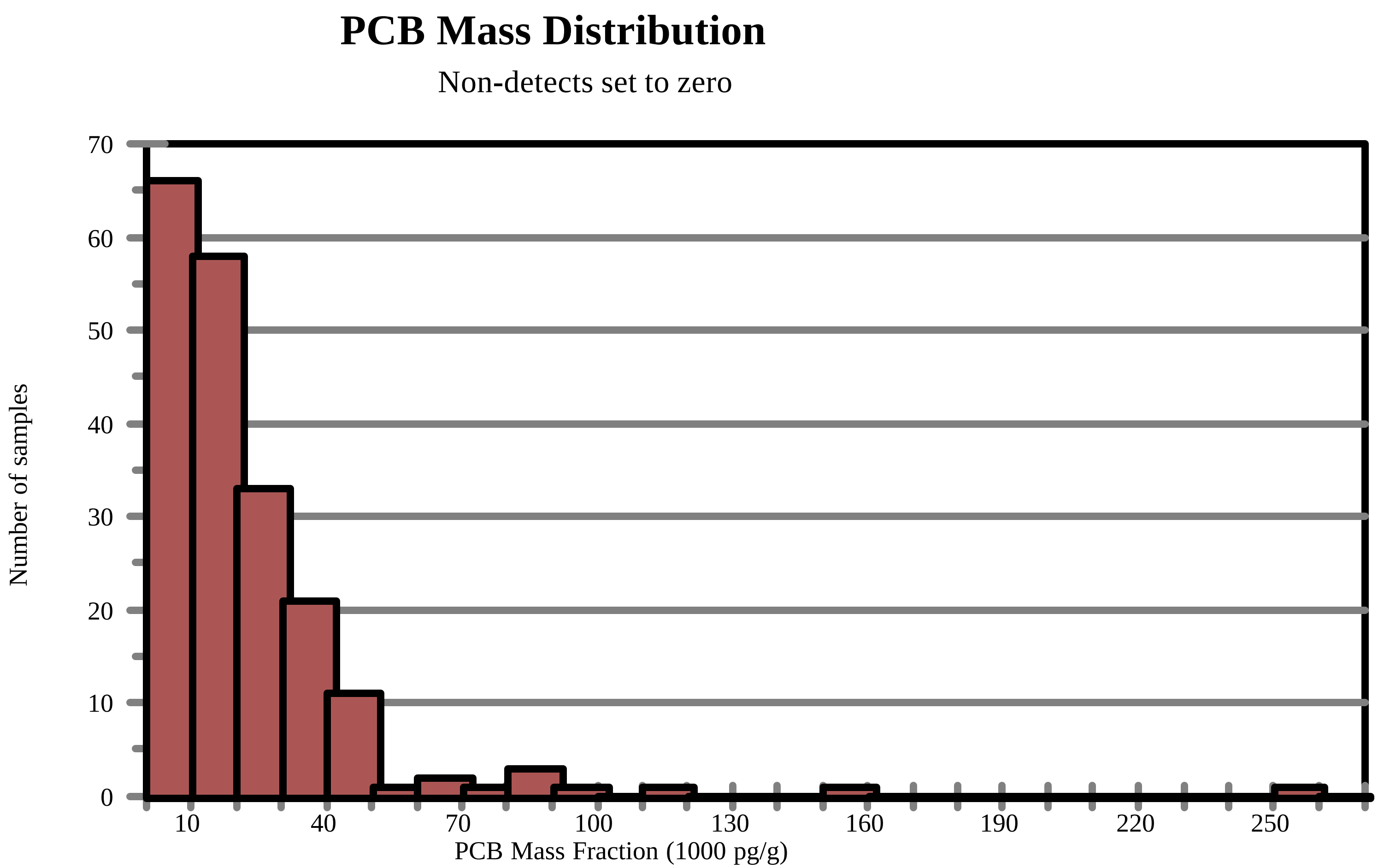

Figure 3.7 Histogram of mass fraction of PCB congeners. Non-detects set to zero.

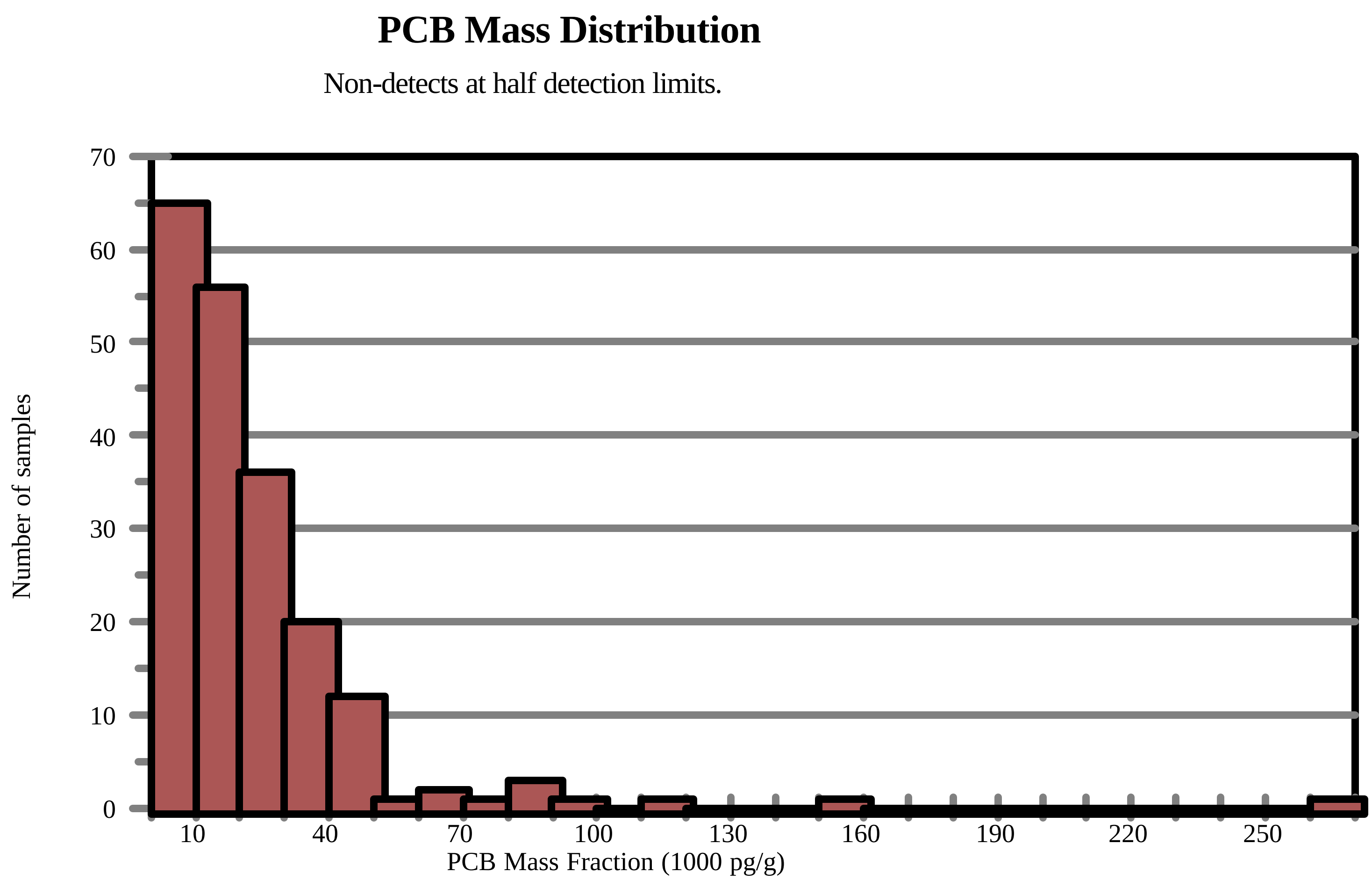

Figure 3.8 Histogram of the mass fraction of PCB congeners. Non-detects set to one-half detection limits.

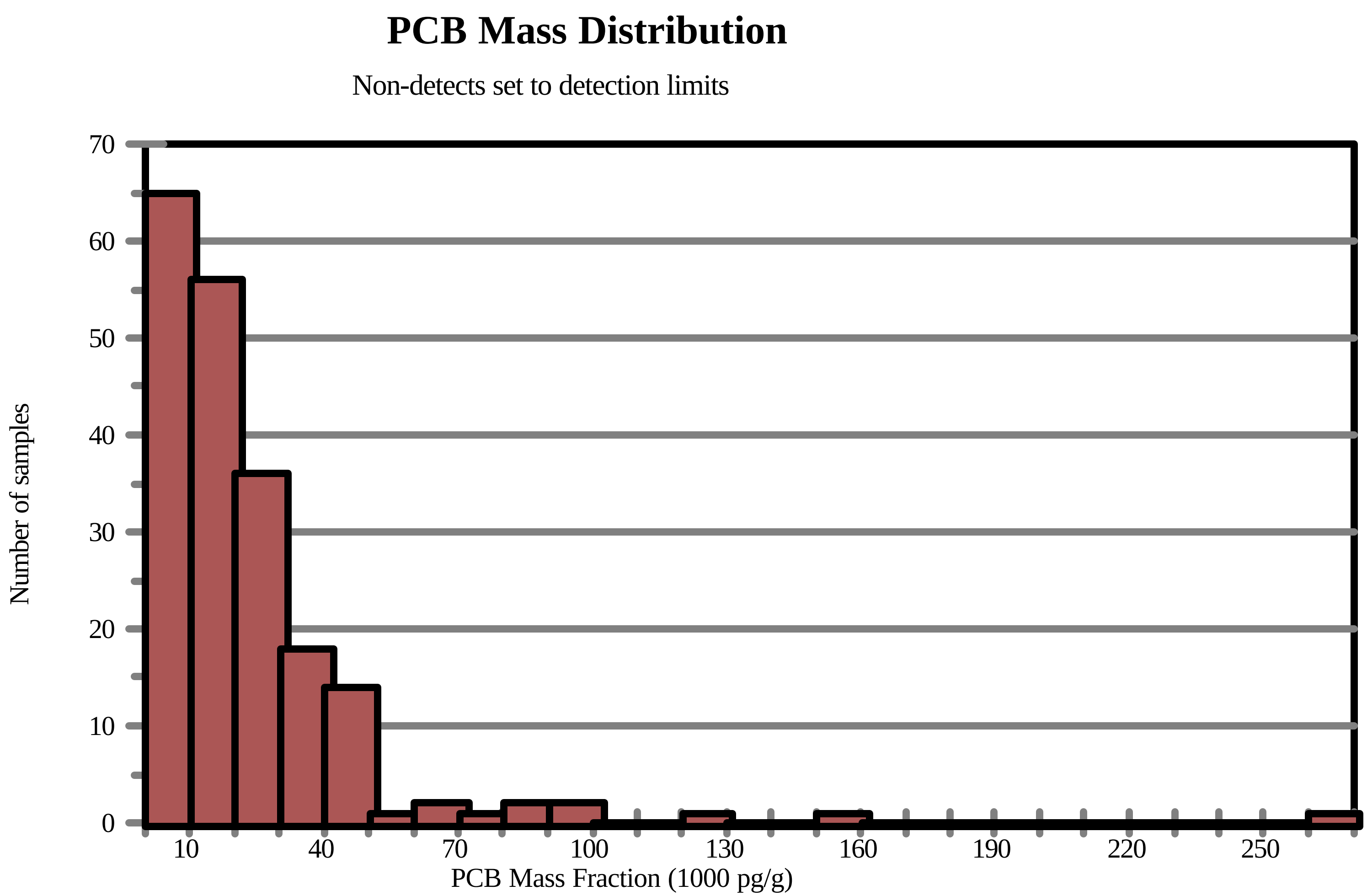

Figure 3.9 Histogram of the mass fraction of PCB congeners. Non-detects set to detection limits.

Table 3.4 Toxicity equivalency factors for dioxin/furans and dioxin-like PCBs (Van den Berg *et al.*, 1998)

Congener	TEF
2,3,7,8-TCDF	0.1
2,3,7,8-TCDD	1
1,2,3,7,8-PeCDF	0.05
2,3,4,7,8-PeCDF	0.5
1,2,3,7,8-PeCDD	1
1,2,3,4,7,8-HxCDF	0.1
1,2,3,6,7,8-HxCDF	0.1
2,3,4,6,7,8-HxCDF	0.1
1,2,3,7,8,9-HxCDF	0.1
1,2,3,4,7,8-HxCDD	0.1
1,2,3,6,7,8-HxCDD	0.1
1,2,3,7,8,9-HxCDD	0.1
1,2,3,4,6,7,8-HpCDF	0.01
1,2,3,4,7,8,9-HpCDF	0.01
1,2,3,4,6,7,8-HpCDD	0.01
OCDF	0.0001
OCDD	0.0001
PCB-81	0.0001
PCB-77	0.0001
PCB-123	0.0001
PCB-118	0.0001
PCB-114	0.0005
PCB-105	0.0001
PCB-126	0.1
PCB-167	1E-05
PCB-156	0.0005
PCB-157	0.0005
PCB-169	0.01
PCB-189	0.0001

Table 3.5 Summary of TEQ totals for the 200 biosolids samples (pg TEQ/g)

Sample ID #	Non-detects set to detection limits.			Non-detects set to one half detection limits.			Non-detects set to zero.		
	Total	Dioxins & Furans	PCB	Total	Dioxins & Furans	PCB	Total	Dioxins & Furans	PCB
10040101a	30.63	22.04	8.60	28.41	19.91	8.49	26.18	17.79	8.39
10040101b	25.80	19.17	6.64	22.78	16.30	6.47	19.75	13.44	6.31
10040101c	30.44	16.98	13.46	23.59	14.45	9.13	16.73	11.93	4.80
10040101d	26.92	16.33	10.59	23.36	12.94	10.42	19.80	9.54	10.25
10051000a	19.62	14.14	5.48	11.88	8.26	3.62	4.14	2.38	1.76
10051000b	33.50	23.12	10.37	30.39	20.11	10.28	27.29	17.11	10.18
10061000a	24.16	20.06	4.10	19.63	16.69	2.94	15.10	13.33	1.78
10071000a	22.48	17.63	4.86	18.16	14.85	3.31	13.84	12.08	1.77
10081000a	16.95	13.42	3.53	10.89	7.45	3.44	4.83	1.49	3.34
10091000a-RA	18.27	14.46	3.81	10.86	8.53	2.33	3.44	2.60	0.84
10101000a	23.35	17.19	6.17	18.37	12.31	6.06	13.40	7.44	5.96
10111000a	72.14	40.30	31.84	69.94	38.57	31.37	67.74	36.84	30.90
10121000a	29.00	14.10	14.90	21.05	7.91	13.13	13.09	1.73	11.37
10131000a	23.36	17.07	6.29	19.85	13.76	6.09	16.34	10.44	5.90
10141000a	104.54	76.34	28.19	102.73	74.64	28.09	100.92	72.93	27.99
10141000b	50.91	28.99	21.92	41.96	27.49	14.47	33.02	25.99	7.03
10141000c	54.56	41.23	13.33	52.00	39.02	12.98	49.44	36.82	12.62
10141000d	116.02	66.32	49.70	106.11	66.09	40.02	96.20	65.85	30.34
10141000e	38.81	24.46	14.35	37.60	23.36	14.24	36.40	22.26	14.14
10141000f	19.94	15.45	4.49	13.95	9.57	4.38	7.96	3.68	4.28
10151000a	25.09	19.49	5.61	19.83	16.15	3.69	14.57	12.81	1.76
10151000b	27.36	21.41	5.95	22.53	18.30	4.23	17.69	15.18	2.51
10151000c	21.21	17.68	3.54	17.05	14.32	2.73	12.89	10.97	1.93
10151000d	17.90	13.97	3.94	11.65	7.82	3.83	5.40	1.67	3.73
10151000e	89.53	16.58	72.95	52.56	13.24	39.32	15.58	9.90	5.68
10151000f	35.68	21.04	14.64	33.51	18.95	14.56	31.33	16.85	14.48
10151000g	27.25	17.09	10.16	23.87	13.88	9.99	20.49	10.67	9.82
10151000h	89.21	84.52	4.69	87.62	84.38	3.24	86.03	84.23	1.80
10161000a	18.08	14.66	3.42	12.17	8.84	3.32	6.26	3.03	3.23
10171000a	34.71	25.21	9.50	28.09	22.02	6.06	21.47	18.84	2.63
10181000a	20.31	14.90	5.41	12.97	9.98	3.00	5.63	5.06	0.58
10191000a	39.52	31.30	8.23	37.44	29.42	8.02	35.37	27.55	7.82

Table 3.5 Summary of TEQ totals for the 200 biosolids samples (pg TEQ/g)

Sample ID #	Non-detects set to detection limits.			Non-detects set to one half detection limits.			Non-detects set to zero.		
	Total	Dioxins & Furans	PCB	Total	Dioxins & Furans	PCB	Total	Dioxins & Furans	PCB
10201000a-RA	30.52	15.82	14.70	21.68	12.80	8.88	12.85	9.77	3.07
10211000a	123.17	118.00	5.17	123.08	118.00	5.08	122.98	118.00	4.99
10221000b	13.96	12.54	1.42	7.29	6.46	0.83	0.62	0.39	0.23
10221000c	27.77	18.24	9.53	25.06	15.63	9.43	22.35	13.03	9.33
10221000e	18.14	13.84	4.31	11.89	7.69	4.21	5.64	1.54	4.10
10221000f	29.74	21.24	8.50	27.01	18.67	8.35	24.28	16.09	8.19
10231000a	15.11	12.85	2.26	8.04	6.70	1.34	0.98	0.55	0.43
10241000a	14.26	12.86	1.40	7.42	6.63	0.79	0.59	0.41	0.18
10241000b	32.14	26.23	5.91	27.83	22.06	5.77	23.52	17.89	5.62
10251000a	21.64	16.16	5.48	18.06	12.66	5.40	14.47	9.16	5.31
10251200a	24.22	14.79	9.43	14.58	8.92	5.66	4.94	3.04	1.90
10261000a	31.53	24.37	7.16	25.99	21.26	4.73	20.46	18.15	2.31
10271100a	18.64	14.90	3.74	12.82	9.17	3.65	7.00	3.45	3.55
10271100b	27.71	22.71	4.99	20.04	17.19	2.85	12.37	11.66	0.70
10281100a	33.22	24.63	8.59	30.37	21.85	8.52	27.53	19.08	8.46
10281100b	26.95	15.63	11.32	19.38	12.35	7.03	11.80	9.07	2.73
10291100a-RA	13.89	12.81	1.08	8.11	7.57	0.54	2.34	2.34	0.00
10301100a	16.94	12.79	4.15	8.93	6.65	2.28	0.92	0.51	0.41
10311100a	41.58	30.53	11.05	36.55	28.93	7.62	31.51	27.33	4.18
10311100b	48.74	37.29	11.45	48.28	36.93	11.35	47.82	36.57	11.24
10321100a	30.54	19.85	10.69	25.07	17.37	7.69	19.60	14.90	4.70
10331100a	68.11	30.78	37.33	48.72	27.77	20.95	29.34	24.77	4.57
10341100a	14.72	12.94	1.78	8.58	6.93	1.65	2.44	0.91	1.53
10351100a	35.11	26.97	8.14	33.05	25.11	7.94	30.98	23.25	7.73
10351100b	25.49	18.35	7.14	19.71	12.79	6.92	13.94	7.23	6.71
10361100a	37.66	25.87	11.79	36.40	24.71	11.68	35.14	23.56	11.58
10371100a	33.47	21.34	12.12	30.62	18.79	11.83	27.78	16.24	11.54
10381100a	30.40	22.12	8.28	24.10	18.66	5.44	17.81	15.20	2.61
10381100b	33.89	23.21	10.67	30.41	19.83	10.57	26.93	16.46	10.47
10391100a	23.58	20.59	3.00	17.22	15.14	2.08	10.86	9.70	1.16
10391100b	19.47	17.30	2.16	13.89	11.85	2.03	8.30	6.40	1.90

Table 3.5 Summary of TEQ totals for the 200 biosolids samples (pg TEQ/g)

Sample ID #	Non-detects set to detection limits.			Non-detects set to one half detection limits.			Non-detects set to zero.		
	Total	Dioxins & Furans	PCB	Total	Dioxins & Furans	PCB	Total	Dioxins & Furans	PCB
10391100c	16.33	12.28	4.05	8.24	6.18	2.06	0.15	0.08	0.07
10391100d	25.26	20.81	4.45	18.28	15.09	3.19	11.31	9.38	1.92
10391100e	17.38	13.96	3.41	11.37	8.06	3.31	5.37	2.16	3.21
10391100f	17.96	14.74	3.22	11.87	8.79	3.08	5.78	2.84	2.94
10401100a	50.26	42.69	7.57	49.80	42.44	7.36	49.35	42.19	7.15
10401100b	21.64	19.36	2.27	15.32	14.05	1.27	9.00	8.74	0.26
10401100c	21.68	18.90	2.78	15.59	12.93	2.65	9.49	6.96	2.52
10411100a	34.72	30.65	4.07	30.73	28.24	2.50	26.75	25.83	0.92
10411100b	14.67	13.12	1.55	10.66	9.71	0.96	6.66	6.29	0.37
10421100a	19.28	17.03	2.25	13.93	12.37	1.56	8.57	7.72	0.86
10431100a	15.86	13.48	2.38	9.73	7.49	2.23	3.59	1.50	2.09
10441100a	36.45	24.26	12.18	33.15	21.11	12.03	29.85	17.96	11.89
10441100b	31.51	23.57	7.94	25.51	20.72	4.79	19.50	17.87	1.64
10441100c	37.04	21.26	15.78	34.64	19.11	15.53	32.24	16.97	15.27
10441100d	116.39	35.91	80.48	112.51	32.03	80.48	108.62	28.15	80.47
10441100e	21.25	15.40	5.85	17.70	11.95	5.75	14.16	8.51	5.65
10441100f	38.86	23.18	15.68	35.38	19.93	15.44	31.89	16.68	15.21
10441100g	46.83	36.14	10.68	45.50	34.99	10.51	44.16	33.83	10.33
10441100h	20.09	14.28	5.81	13.84	8.14	5.70	7.58	1.99	5.60
10441100i	67.67	15.63	52.04	61.84	9.81	52.03	56.02	4.00	52.02
10441100j	97.55	49.66	47.89	96.74	49.29	47.45	95.93	48.91	47.02
10441100k	38.65	25.82	12.83	34.62	22.38	12.24	30.59	18.94	11.65
10441100l	45.38	27.98	17.41	44.58	27.60	16.98	43.79	27.23	16.56
10441100m	69.91	56.34	13.57	65.69	52.59	13.10	61.48	48.85	12.63
10441100n	34.70	22.50	12.19	31.19	19.24	11.95	27.68	15.98	11.70
10441100o	59.75	27.83	31.92	50.26	25.14	25.12	40.77	22.45	18.32
10441100p	47.88	38.84	9.04	46.14	37.23	8.91	44.41	35.62	8.79
10441100q	47.15	27.72	19.42	45.72	26.83	18.89	44.28	25.93	18.35
10441100r	46.06	34.49	11.57	44.42	32.95	11.47	42.78	31.41	11.37
10441100s	24.68	15.98	8.70	18.42	10.10	8.31	12.15	4.23	7.93
10441100t	268.02	39.37	228.65	256.35	27.71	228.65	244.69	16.05	228.64
10441100u-RA	25.40	20.52	4.88	21.11	18.03	3.09	16.83	15.53	1.30

Table 3.5 Summary of TEQ totals for the 200 biosolids samples (pg TEQ/g)

Sample ID #	Non-detects set to detection limits.			Non-detects set to one half detection limits.			Non-detects set to zero.		
	Total	Dioxins & Furans	PCB	Total	Dioxins & Furans	PCB	Total	Dioxins & Furans	PCB
10441100v	41.83	27.90	13.93	39.08	25.59	13.49	36.32	23.27	13.05
10441100w	29.16	16.05	13.10	25.59	12.76	12.83	22.03	9.47	12.56
10441100x	51.28	37.35	13.93	48.27	34.47	13.79	45.25	31.59	13.66
10441100y	68.91	54.82	14.10	65.71	51.80	13.91	62.51	48.79	13.72
10451100a	24.25	12.80	11.45	12.50	6.61	5.88	0.74	0.43	0.32
10461100a	48.24	34.55	13.69	46.08	32.58	13.50	43.92	30.61	13.31
10471100a	16.92	14.14	2.79	9.66	8.03	1.63	2.40	1.93	0.46
10481100a	13.91	12.38	1.53	7.46	6.52	0.94	1.01	0.65	0.36
10491100a	29.75	23.67	6.08	24.69	20.45	4.24	19.63	17.23	2.39
10501100a	22.24	16.64	5.60	16.52	11.02	5.50	10.81	5.41	5.40
10501100b	16.57	13.46	3.11	10.45	7.48	2.97	4.34	1.50	2.84
10511100a	17.23	14.53	2.70	11.44	8.84	2.60	5.66	3.16	2.50
10521100a	16.87	13.97	2.90	10.08	8.41	1.67	3.30	2.85	0.45
10531100a	62.32	59.84	2.48	59.92	57.54	2.39	57.53	55.23	2.29
10541100a	27.52	18.98	8.54	17.53	12.46	5.07	7.53	5.93	1.60
10541100b	39.04	28.65	10.39	35.19	25.49	9.69	31.34	22.34	9.00
10551100a	54.50	37.21	17.29	53.82	36.84	16.99	53.15	36.46	16.68
10561100a	16.51	14.92	1.59	10.53	9.52	1.01	4.54	4.12	0.43
10571100a	40.89	37.04	3.84	37.83	34.08	3.75	34.78	31.12	3.66
10571100b	22.88	15.92	6.96	17.62	12.57	5.06	12.36	9.21	3.15
10581100a	25.73	17.14	8.58	21.69	13.75	7.94	17.65	10.36	7.29
10591100a	22.37	15.71	6.66	14.17	10.09	4.08	5.98	4.48	1.50
10601100a	39.14	30.05	9.09	26.54	21.53	5.01	13.95	13.02	0.93
10611100a	26.19	18.63	7.56	23.19	15.79	7.40	20.19	12.95	7.24
10621100a	28.58	18.99	9.59	22.06	16.17	5.89	15.55	13.36	2.19
10621100b	16.89	13.05	3.85	9.28	7.01	2.27	1.66	0.97	0.69
10621100c	19.72	13.68	6.04	10.85	7.79	3.06	1.98	1.90	0.08
10631100a	14.68	13.01	1.66	7.84	6.82	1.02	1.01	0.63	0.38
10641100a	27.43	23.74	3.69	20.99	18.18	2.81	14.54	12.62	1.92
10641100b	30.20	22.39	7.80	24.95	17.25	7.70	19.71	12.11	7.60
10641100c	63.30	58.95	4.35	55.63	53.08	2.55	47.95	47.21	0.75
10641100d	30.21	20.77	9.44	21.67	15.43	6.24	13.12	10.08	3.04

Table 3.5 Summary of TEQ totals for the 200 biosolids samples (pg TEQ/g)

Sample ID #	Non-detects set to detection limits.			Non-detects set to one half detection limits.			Non-detects set to zero.		
	Total	Dioxins & Furans	PCB	Total	Dioxins & Furans	PCB	Total	Dioxins & Furans	PCB
10641100e	16.41	14.58	1.83	9.67	8.49	1.17	2.93	2.41	0.52
10651100a	36.79	27.26	9.53	35.09	25.66	9.43	33.39	24.06	9.33
10651100b	52.57	33.28	19.29	51.43	32.40	19.03	50.29	31.52	18.76
10651100c	71.49	34.06	37.43	55.99	33.19	22.80	40.49	32.32	8.17
10661100a	52.58	23.28	29.30	49.27	20.21	29.06	45.96	17.15	28.82
10681100a	41.56	29.48	12.08	38.32	26.35	11.97	35.09	23.23	11.86
10691200a	39.19	29.45	9.74	36.30	26.66	9.64	33.41	23.88	9.53
10701200a	25.32	13.04	12.28	13.13	6.86	6.27	0.95	0.69	0.26
10711200a	15.58	13.74	1.84	8.77	7.55	1.22	1.96	1.37	0.60
10711200b	28.32	22.37	5.94	25.27	19.48	5.79	22.23	16.60	5.63
10721200a	19.91	17.03	2.87	15.43	13.63	1.80	10.96	10.23	0.72
10731200a	25.30	19.69	5.62	16.94	13.82	3.12	8.57	7.96	0.62
10731200b	22.52	15.19	7.33	15.73	11.54	4.19	8.93	7.89	1.04
10741200a	25.04	17.52	7.52	19.28	11.90	7.38	13.52	6.28	7.24
10741200b	23.58	15.71	7.88	19.96	12.38	7.59	16.34	9.05	7.30
10751200a	16.07	12.99	3.08	8.52	6.80	1.72	0.97	0.62	0.35
10751200b	31.04	23.00	8.04	28.17	20.35	7.82	25.30	17.70	7.60
10761200a	38.68	21.70	16.97	28.76	19.30	9.46	18.85	16.90	1.94
10761200d	14.71	11.06	3.64	9.46	5.94	3.52	4.21	0.81	3.41
10761200e	63.65	20.00	43.66	38.60	16.25	22.35	13.54	12.50	1.05
10771200a	14.91	12.86	2.05	9.00	7.86	1.15	3.10	2.85	0.24
10781200a	48.53	36.24	12.30	40.41	28.73	11.68	32.28	21.23	11.06
10781200b	26.98	16.08	10.90	17.03	10.70	6.34	7.09	5.32	1.77
10781200c	3590.05	3578.61	11.44	3590.05	3578.61	11.44	3590.05	3578.61	11.44
10791200a	16.42	13.84	2.58	9.38	7.62	1.76	2.33	1.40	0.93
10791200b	19.51	14.36	5.16	12.94	8.21	4.74	6.38	2.06	4.32
10791200c	16.21	13.47	2.74	9.14	7.29	1.86	2.08	1.10	0.97
10791200d	19.10	15.91	3.19	12.56	10.26	2.31	6.03	4.61	1.42
10791200e	19.38	15.34	4.04	12.05	9.61	2.45	4.73	3.87	0.86
10791200f	228.12	89.00	139.12	225.81	88.95	136.86	223.51	88.90	134.61
10791200g	25.03	17.78	7.25	19.95	15.17	4.78	14.87	12.56	2.32
10801200a	34.37	28.62	5.75	29.38	23.73	5.65	24.39	18.83	5.56

Table 3.5 Summary of TEQ totals for the 200 biosolids samples (pg TEQ/g)

Sample ID #	Non-detects set to detection limits.			Non-detects set to one half detection limits.			Non-detects set to zero.		
	Total	Dioxins & Furans	PCB	Total	Dioxins & Furans	PCB	Total	Dioxins & Furans	PCB
10811200a	16.21	13.67	2.54	9.47	7.81	1.66	2.72	1.94	0.78
10811200b	13.72	12.42	1.30	7.10	6.39	0.71	0.49	0.36	0.12
10821200a	27.38	19.12	8.27	22.51	16.81	5.69	17.63	14.51	3.12
10831200a	18.51	12.94	5.58	12.36	6.88	5.48	6.21	0.83	5.38
10841200a	68.01	45.88	22.12	64.38	44.42	19.96	60.76	42.97	17.80
10851200a	35.63	26.49	9.14	30.09	21.09	9.01	24.56	15.68	8.88
10861200a	27.87	18.41	9.46	22.29	12.92	9.36	16.70	7.44	9.26
10870101a	23.02	19.33	3.69	17.40	13.86	3.54	11.78	8.39	3.39
10871200a	77.30	60.49	16.81	73.08	56.38	16.71	68.87	52.27	16.60
10871200b	19.38	15.22	4.16	11.84	9.32	2.52	4.31	3.42	0.88
10881200a	23.27	18.49	4.78	18.68	15.37	3.30	14.08	12.26	1.82
10891200a	22.61	19.27	3.34	19.64	16.49	3.15	16.67	13.71	2.96
10901200a	21.59	15.73	5.86	16.01	12.59	3.42	10.42	9.45	0.97
10911200a	16.38	13.80	2.58	10.10	8.26	1.84	3.83	2.72	1.10
10921200a	30.33	19.43	10.90	17.89	11.52	6.36	5.45	3.62	1.83
10931200b	22.47	17.03	5.43	19.29	13.96	5.33	16.11	10.88	5.23
10941200a	32.35	26.03	6.31	29.40	23.44	5.96	26.45	20.84	5.61
10951200a	17.17	14.01	3.16	11.08	8.15	2.93	4.98	2.28	2.71
10961200a	15.75	13.87	1.88	9.57	7.78	1.79	3.39	1.69	1.70
10961200b	21.09	16.92	4.17	13.33	10.68	2.66	5.58	4.43	1.15
10971200a	156.94	147.03	9.91	153.83	146.79	7.04	150.73	146.55	4.18
10981200a	18.47	15.66	2.82	12.91	10.19	2.72	7.34	4.72	2.62
10991200a	25.33	19.29	6.05	18.50	13.94	4.56	11.67	8.60	3.07
11001200a	37.03	29.26	7.77	34.15	26.54	7.61	31.27	23.82	7.45
11010101a	17.10	14.16	2.94	10.27	8.27	1.99	3.43	2.38	1.04
11020101a	67.92	25.63	42.30	53.62	23.04	30.58	39.31	20.45	18.86
11030101a	54.80	47.12	7.67	50.50	45.11	5.38	46.20	43.10	3.09
11040101a	24.58	15.99	8.60	20.83	12.57	8.26	17.07	9.15	7.92
11050101a	28.40	19.78	8.62	22.61	16.94	5.66	16.82	14.11	2.71
11060101a	61.62	47.26	14.37	53.58	45.23	8.35	45.53	43.20	2.33
11070101a	19.14	16.64	2.50	12.90	11.42	1.47	6.66	6.20	0.45
11080101a	37.47	34.02	3.45	32.28	28.99	3.29	27.08	23.95	3.14

Table 3.5 Summary of TEQ totals for the 200 biosolids samples (pg TEQ/g)

Sample ID #	Non-detects set to detection limits.			Non-detects set to one half detection limits.			Non-detects set to zero.		
	Total	Dioxins & Furans	PCB	Total	Dioxins & Furans	PCB	Total	Dioxins & Furans	PCB
11090101a	14.90	12.65	2.25	8.74	6.61	2.13	2.58	0.57	2.01
11100101a	28.10	13.80	14.30	16.14	7.61	8.53	4.18	1.43	2.76
11100101b	23.36	13.85	9.51	13.30	7.70	5.61	3.25	1.54	1.70
11110101a	122.77	103.89	18.88	121.61	102.82	18.80	120.45	101.74	18.71
11120101a	33.18	18.37	14.80	23.99	15.72	8.27	14.81	13.07	1.74
11130101a	36.60	30.45	6.16	32.96	29.10	3.86	29.32	27.76	1.56
11140101a	22.81	16.55	6.26	16.87	13.20	3.67	10.93	9.85	1.08
11150501a	37.05	22.52	14.53	35.90	21.38	14.52	34.76	20.24	14.52
11150501b	22.42	15.68	6.73	16.55	9.91	6.63	10.68	4.14	6.54

Table 3.6 Characteristics of TEQ data

Treatment of non-detects	Data subset	Number of samples (N)	Mean mass fraction (pg TEQ/g)	Standard deviation (pg TEQ/g)	Standard error of the mean (pg TEQ/g)	Median (pg TEQ/g)
Detection limits	Total	200	54.2	253.2	17.9	27.4
	Dioxins and Furans	200	42.4	251.9	17.8	19.1
	PCBs	200	11.7	21.0	1.49	7.29
One half of detection limits	Total	200	48.5	253.6	17.9	21.7
	Dioxins and Furans	200	38.4	252.3	17.8	15.2
	PCBs	200	10.0	20.3	1.44	5.70
Zero	Total	200	42.8	254.1	18.0	15.8
	Dioxins and Furans	200	34.5	252.7	17.9	11.8
	PCBs	200	8.31	20.2	1.43	3.37

Table 3.7 Characteristics of logarithmically transformed TEQ data

Treatment of non-detects	Data subset	Number of samples (N)	Mean	Standard deviation	Standard error of the mean
Detection limits	Total	200	3.41	0.69	0.05
	Dioxins and Furans	200	3.07	0.63	0.04
	PCBs	200	1.96	0.89	0.06
One half of detection limits	Total	200	3.15	0.82	0.06
	Dioxins and Furans	200	2.80	0.78	0.06
	PCBs	200	1.73	0.97	0.07
Zero	Total	200	2.62	1.30	0.09
	Dioxins and Furans	200	2.18	1.38	0.10
	PCBs [A]	199	1.23	1.35	0.10

[A] As one sample had no PCBs detected, the PCB mass fraction for this sample could not be transformed using the natural logarithm, and were ignored.

Table 3.8 Percentiles of TEQ data (pg TEQ/g)

	Non-detects set at detection limits			Non-detects set at one half of detection limits			Non-detects set to zero		
	Total	Dioxins and Furans	PCBs	Total	Dioxins and Furans	PCBs	Total	Dioxins and Furans	PCBs
Minimum	13.72	11.06	1.08	7.10	5.94	0.54	0.15	0.08	0.00
10th Percentile	16.40	13.45	2.49	9.65	7.55	1.75	2.71	1.48	0.52
25th Percentile	19.86	14.91	3.85	13.09	9.55	2.99	6.17	3.66	1.59
Median	27.41	19.14	7.29	21.67	15.15	5.70	15.85	11.79	3.37
75th Percentile	38.91	27.37	11.62	36.00	24.81	10.06	31.61	21.49	9.06
90th Percentile	67.69	39.46	17.55	54.00	37.36	16.98	49.53	36.60	14.59
95th Percentile	89.93	58.99	37.34	88.07	53.24	28.14	86.52	49.08	18.77
99th Percentile	228.51	118.29	81.07	226.12	118.28	81.04	223.72	118.28	81.01
Maximum	3590.05	3578.61	228.65	3590.05	3578.61	228.65	3590.05	3578.61	228.64

Table 3.9 Number of samples with total TEQ values within specified ranges. (Non-detects set to zero.)

Range (ppt = pg/g)	Number of samples	Percentage of samples
0-<10 ppt	67	33.50%
>10-<25 ppt	64	32.00%
>25-<50 ppt	49	24.50%
>50-<100 ppt	12	6.00%
>100-<300 ppt	7	3.50%
> 300 ppt	1	0.50%

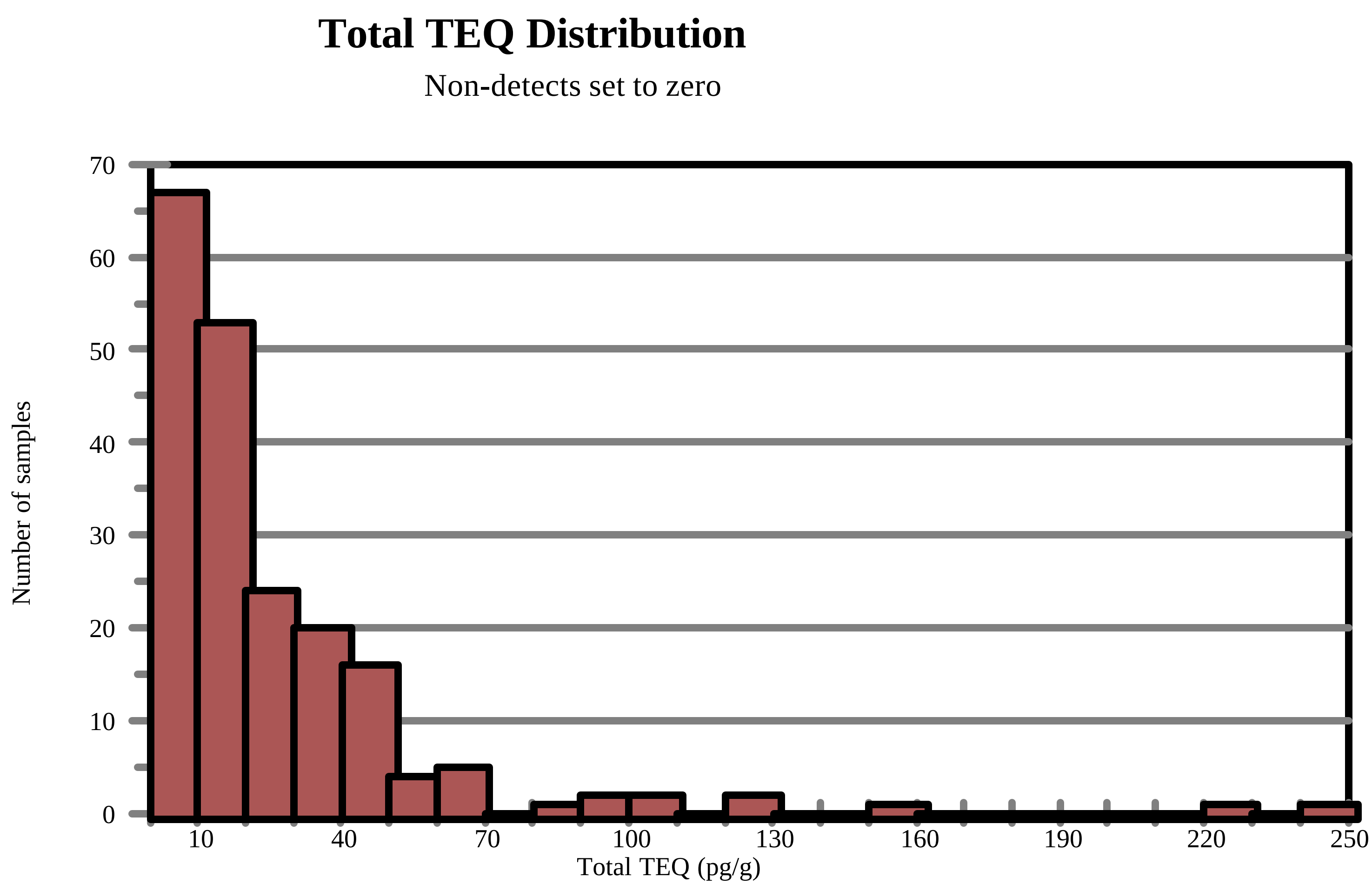

Figure 3.10 Histogram of the total TEQ mass fraction for each sample. Non-detects set to zero. Sample at 3590 pg TEQ/g not shown.

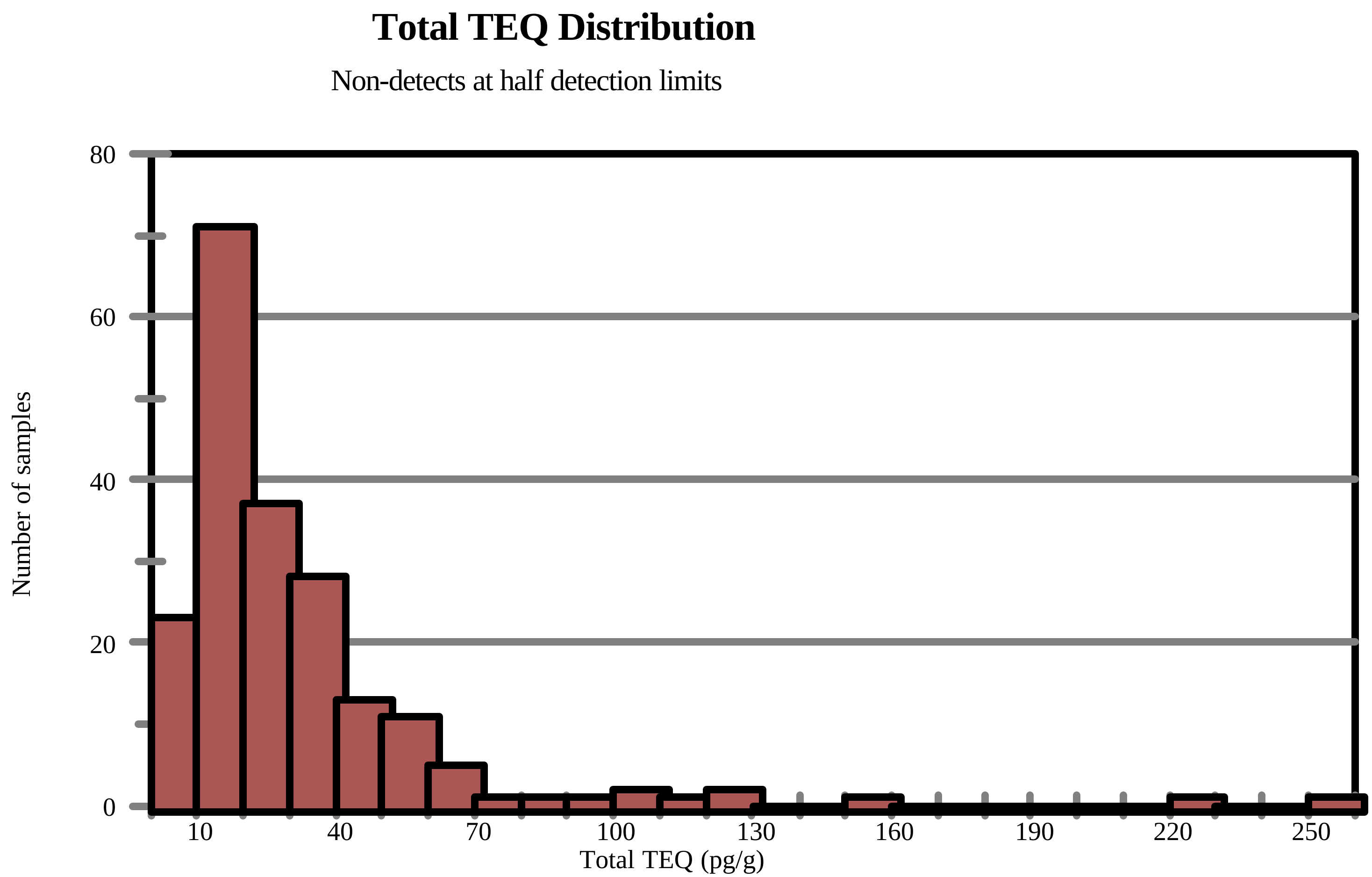

Figure 3.11 Histogram of the total TEQ mass fractions for each sample. Non-detects set to one-half detection limits. Sample at 3590 pg TEQ/g not shown.

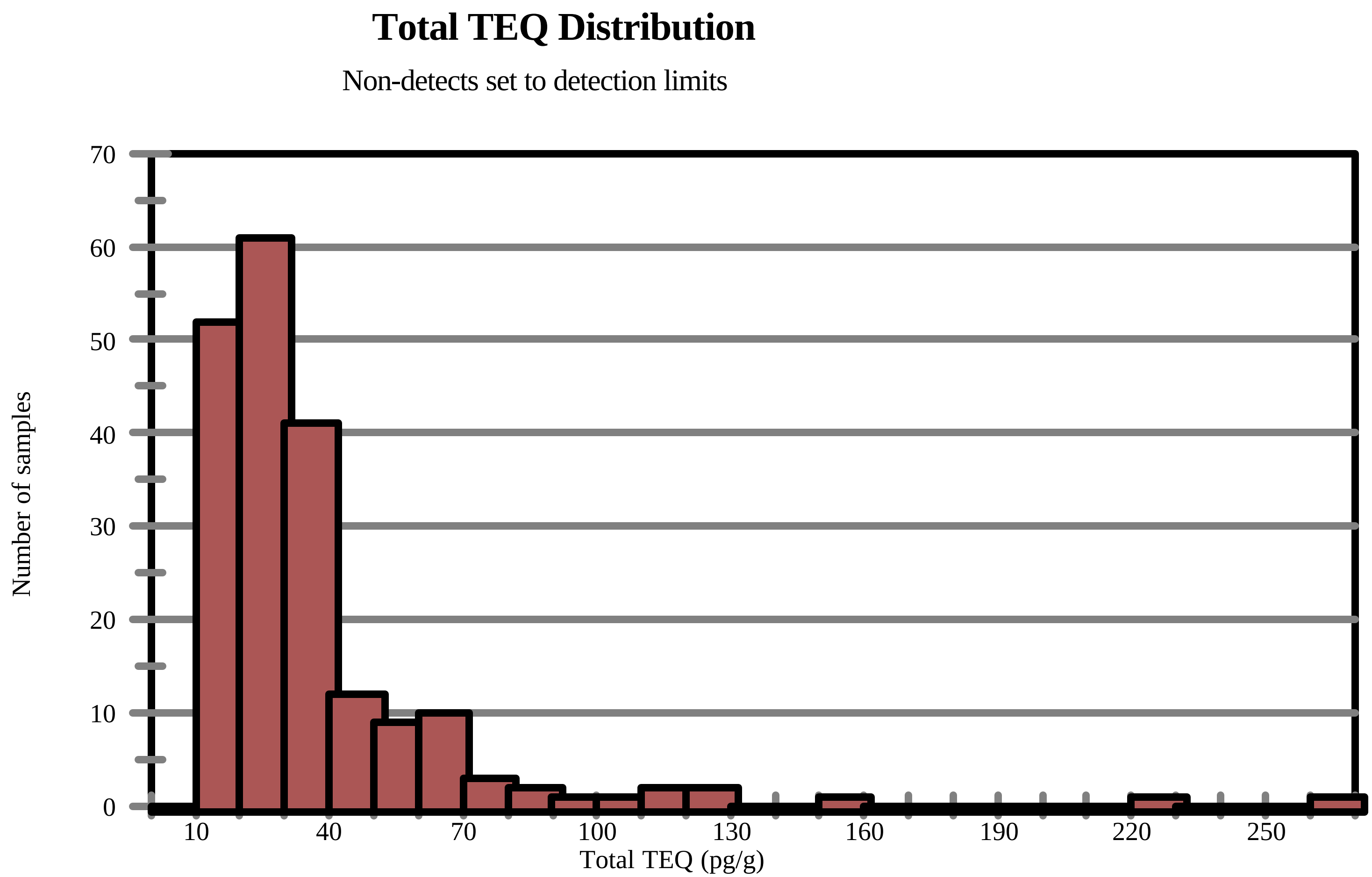

Figure 3.12 Histogram of the total TEQ mass fractions for each sample. Non-detects set to detection limits. Sample at 3590 pg TEQ/g not shown.

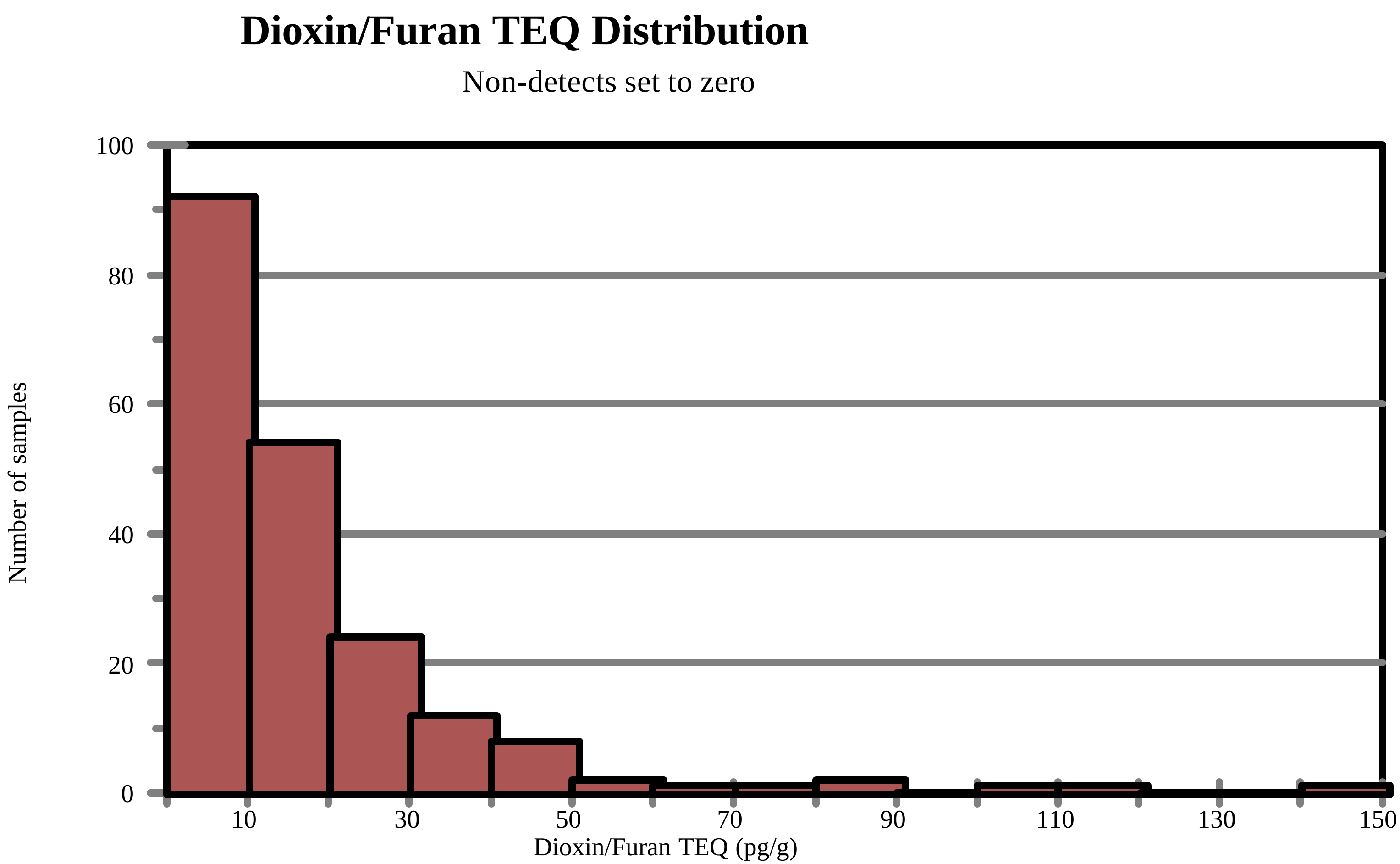

Figure 3.13 Histogram of the dioxin/furan TEQ mass fractions for each sample. Non-detects set to zero. Sample at 3579 pg TEQ/g not shown.

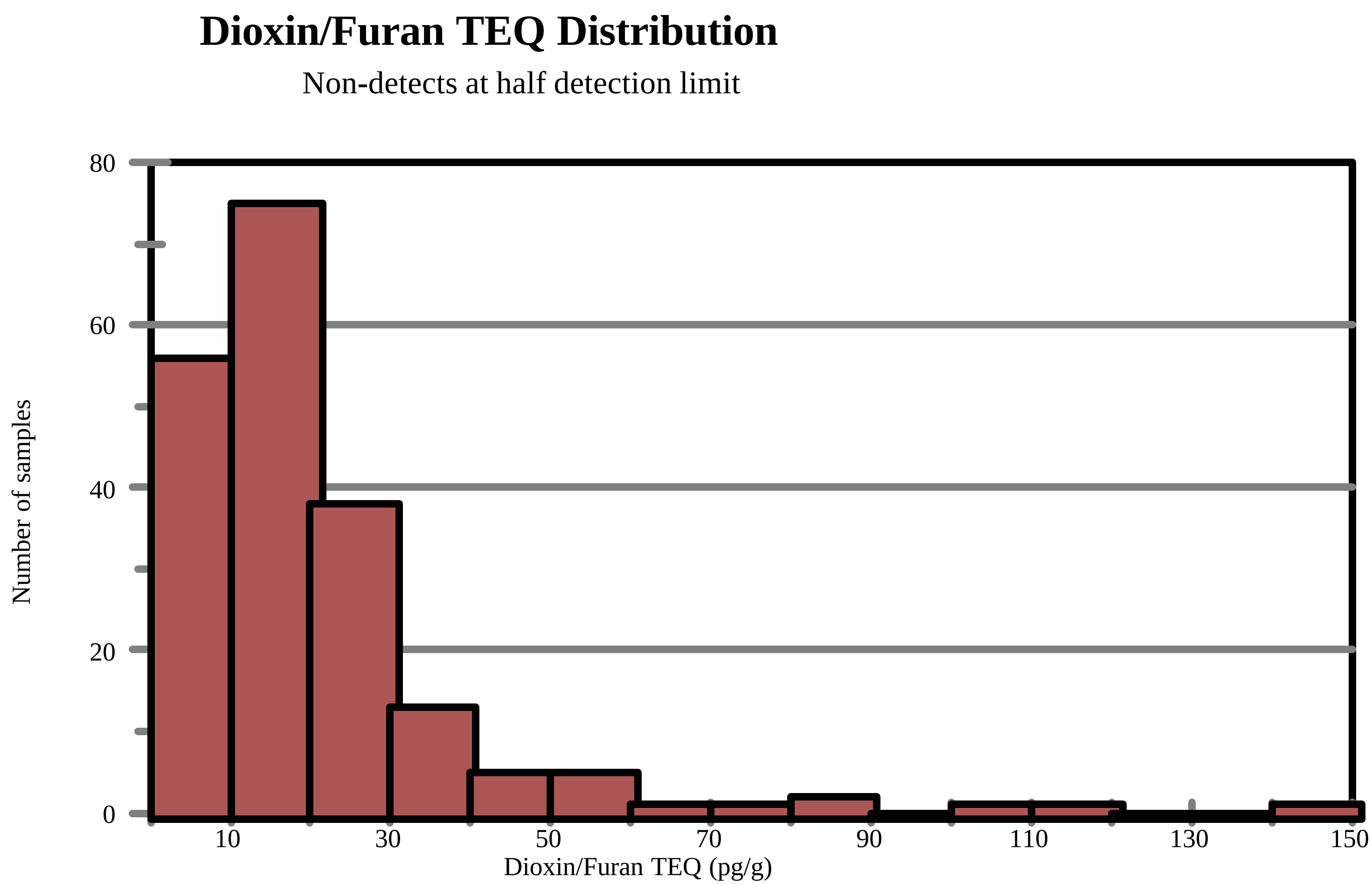

Figure 3.14 Histogram of the dioxin/furan TEQ mass fractions for each sample. Non-detects set to one-half detection limits. Sample at 3579 pg TEQ/g not shown.

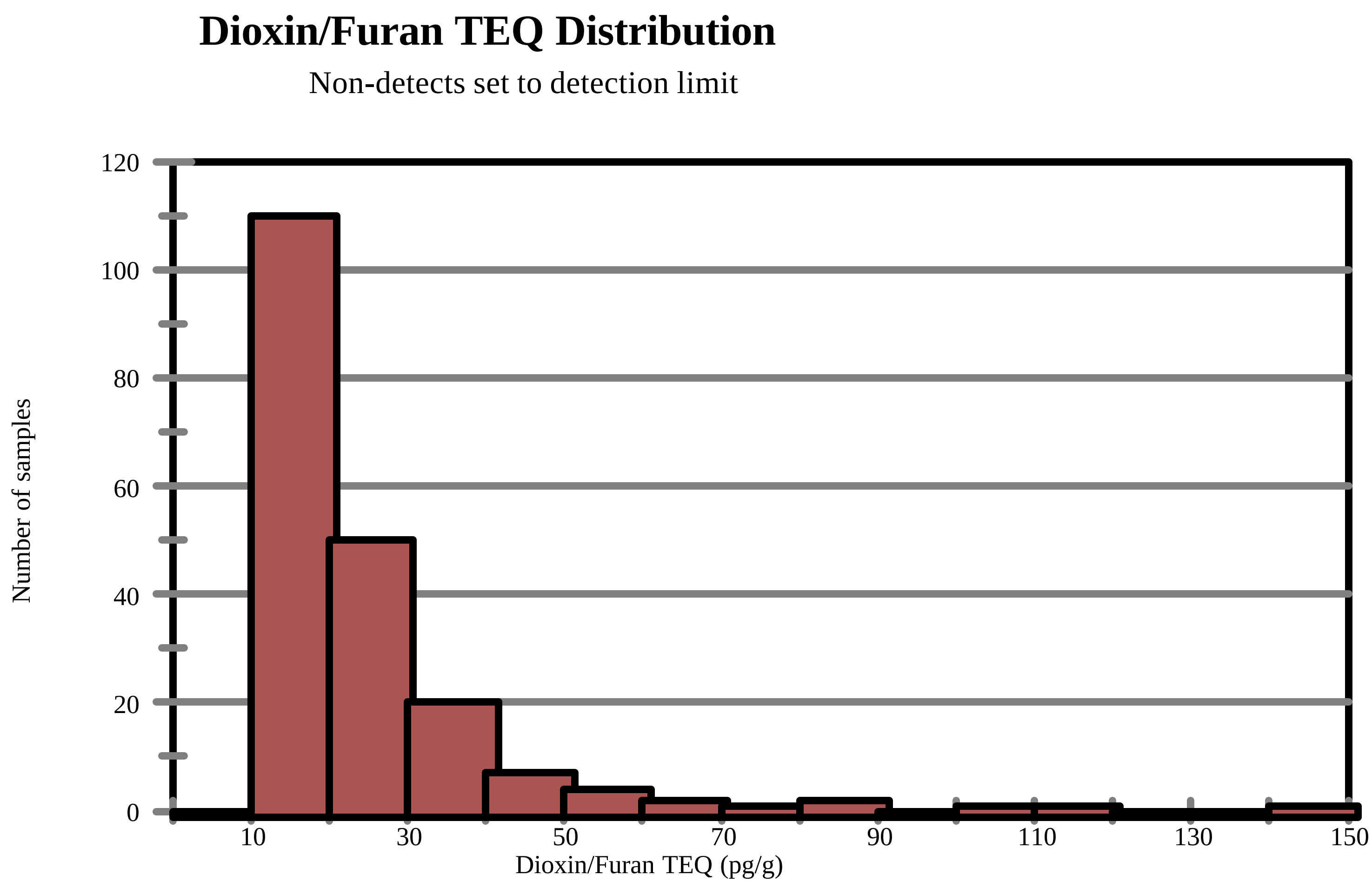

Figure 3.15 Histogram of the dioxin/furan TEQ mass fractions for each sample. Non-detects set to detection limits. Sample at 3579 pg TEQ/g not shown.

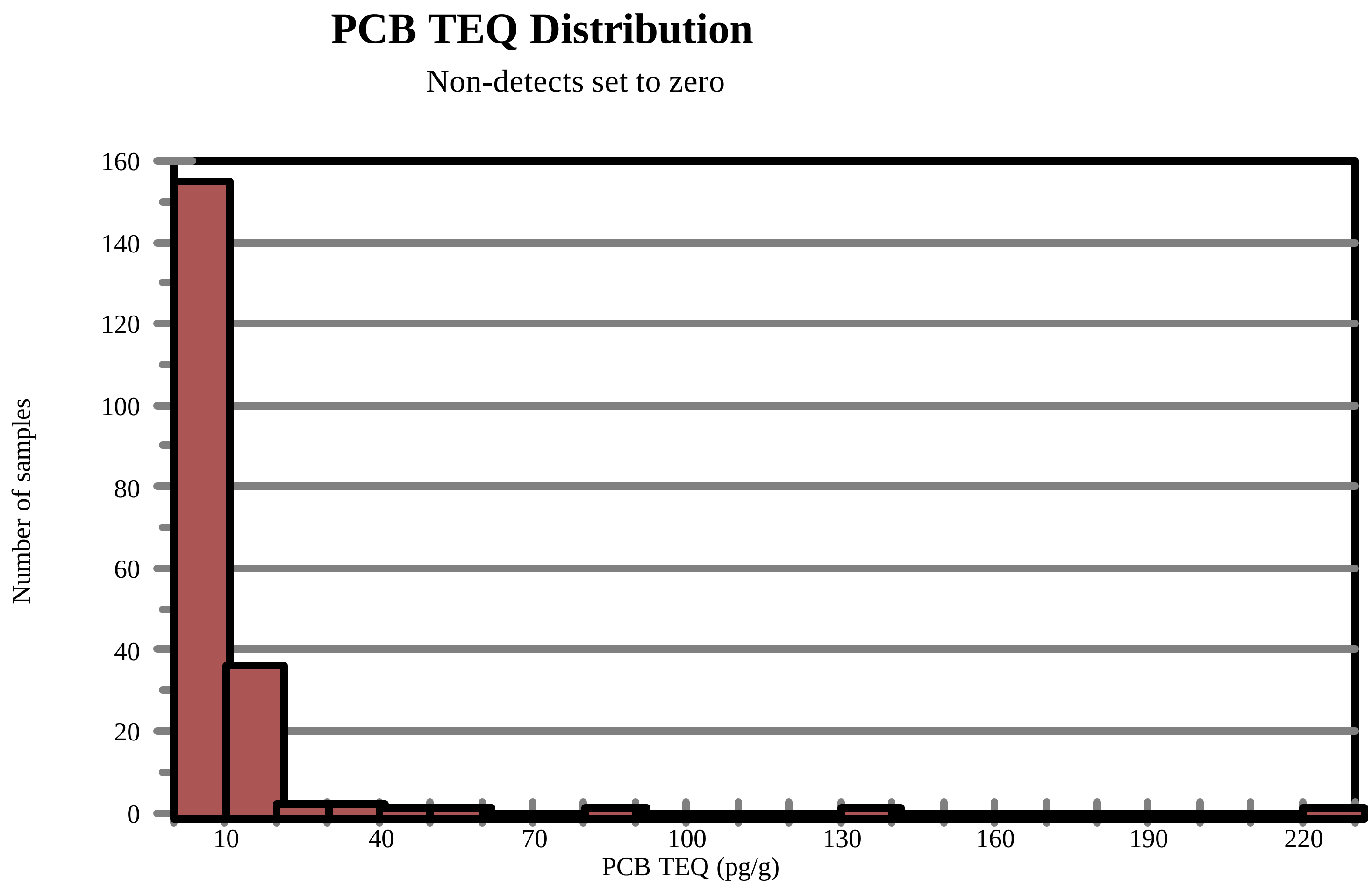

Figure 3.16 Histogram of the PCB TEQ mass fractions for each sample. Non-detects set to zero.

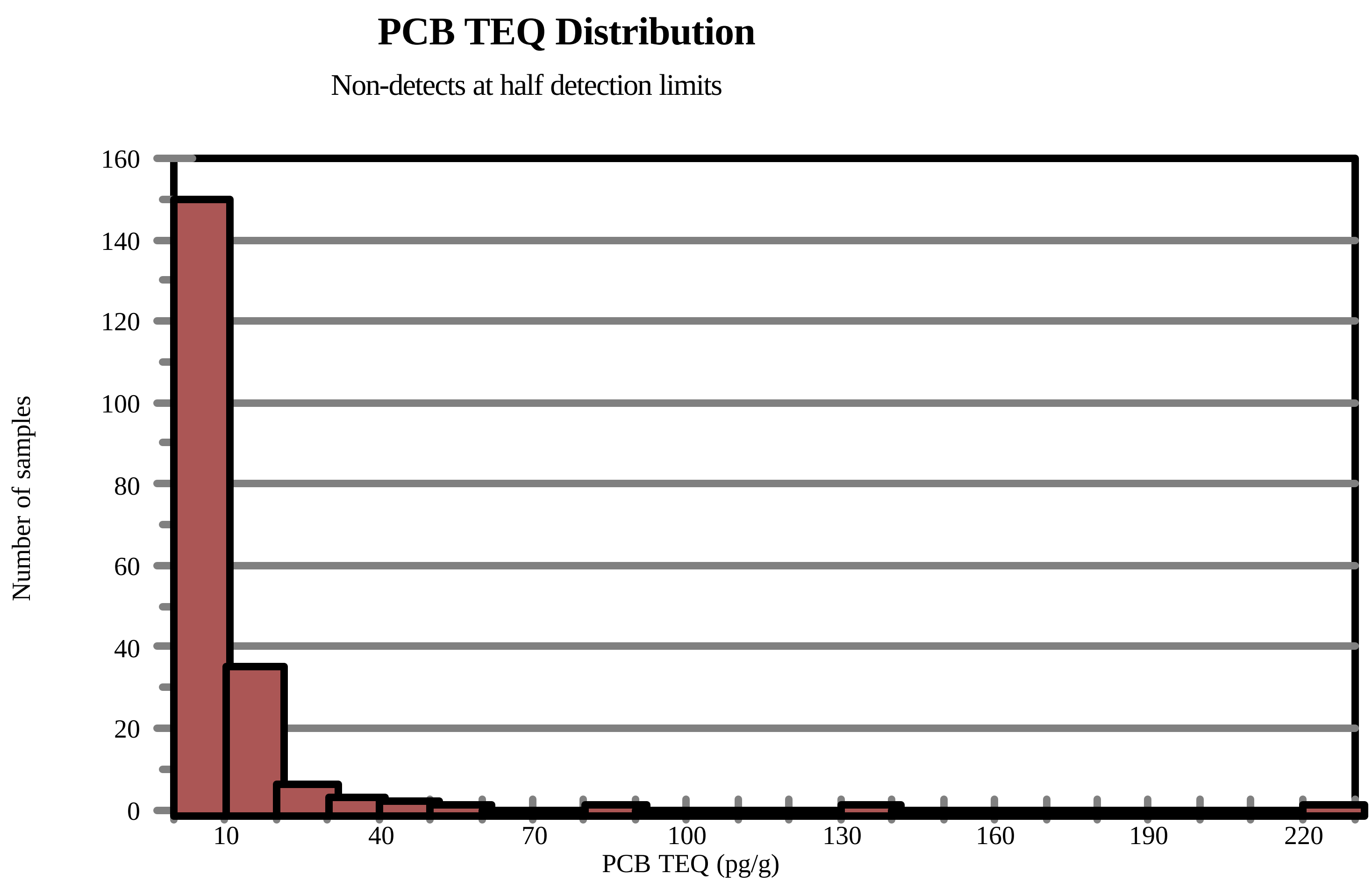

Figure 3.17 Histogram of the PCB TEQ mass fractions for each sample. Non-detects set to one-half detection limits.

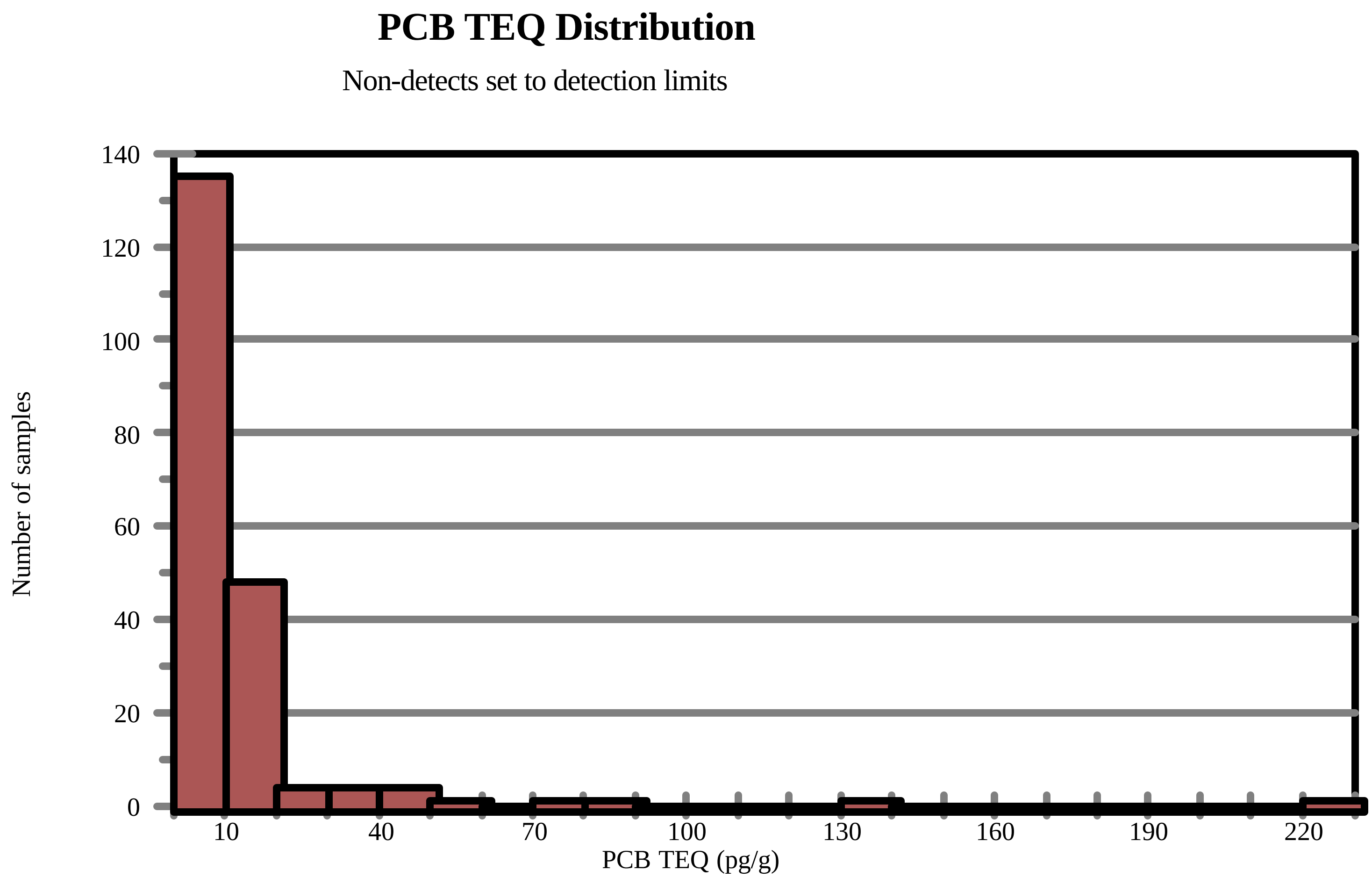

Figure 3.18 Histogram of the PCB TEQ mass fractions for each sample. Non-detects set to detection limits.

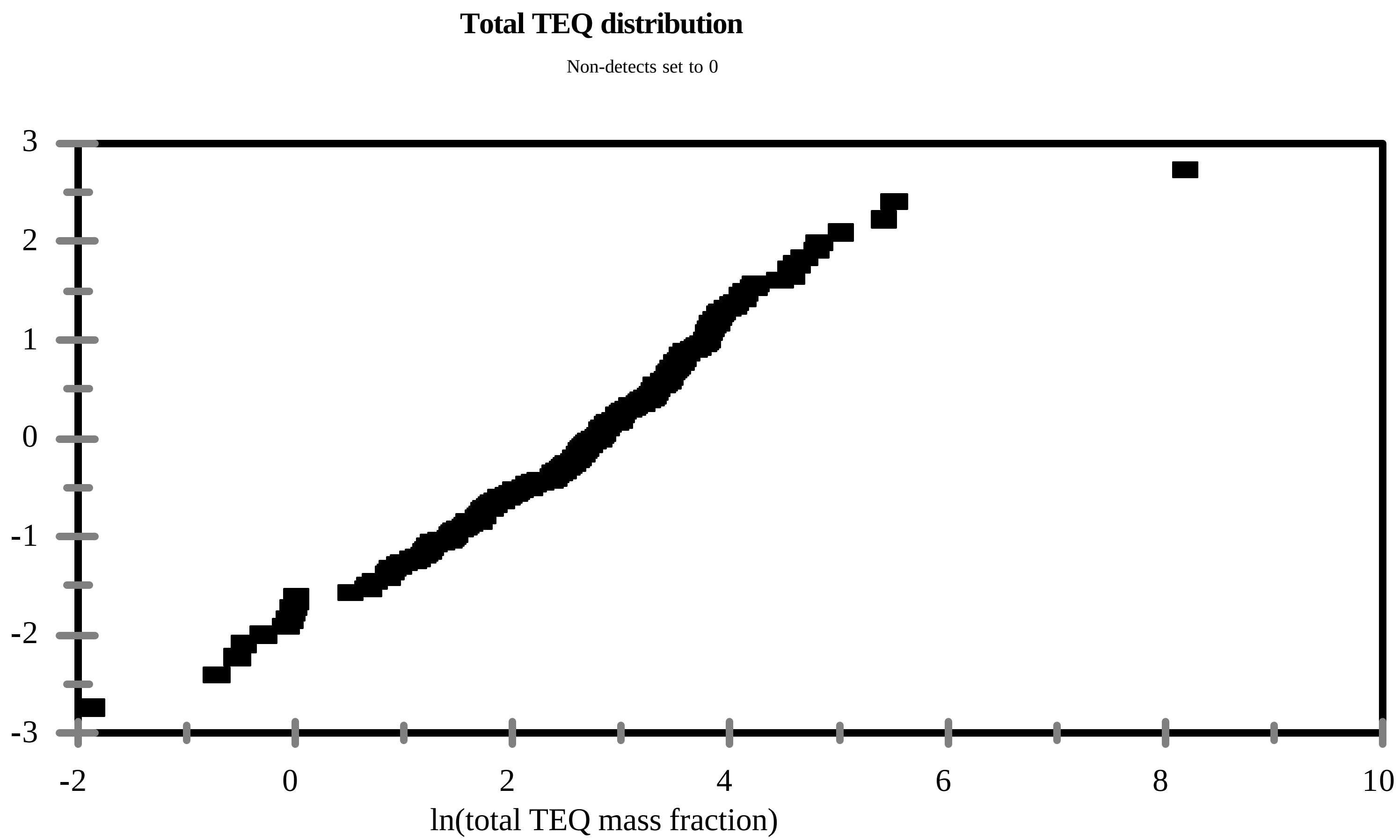

Figure 3.19 Distribution of ln(total TEQ mass fraction). Non-detects set to zero.

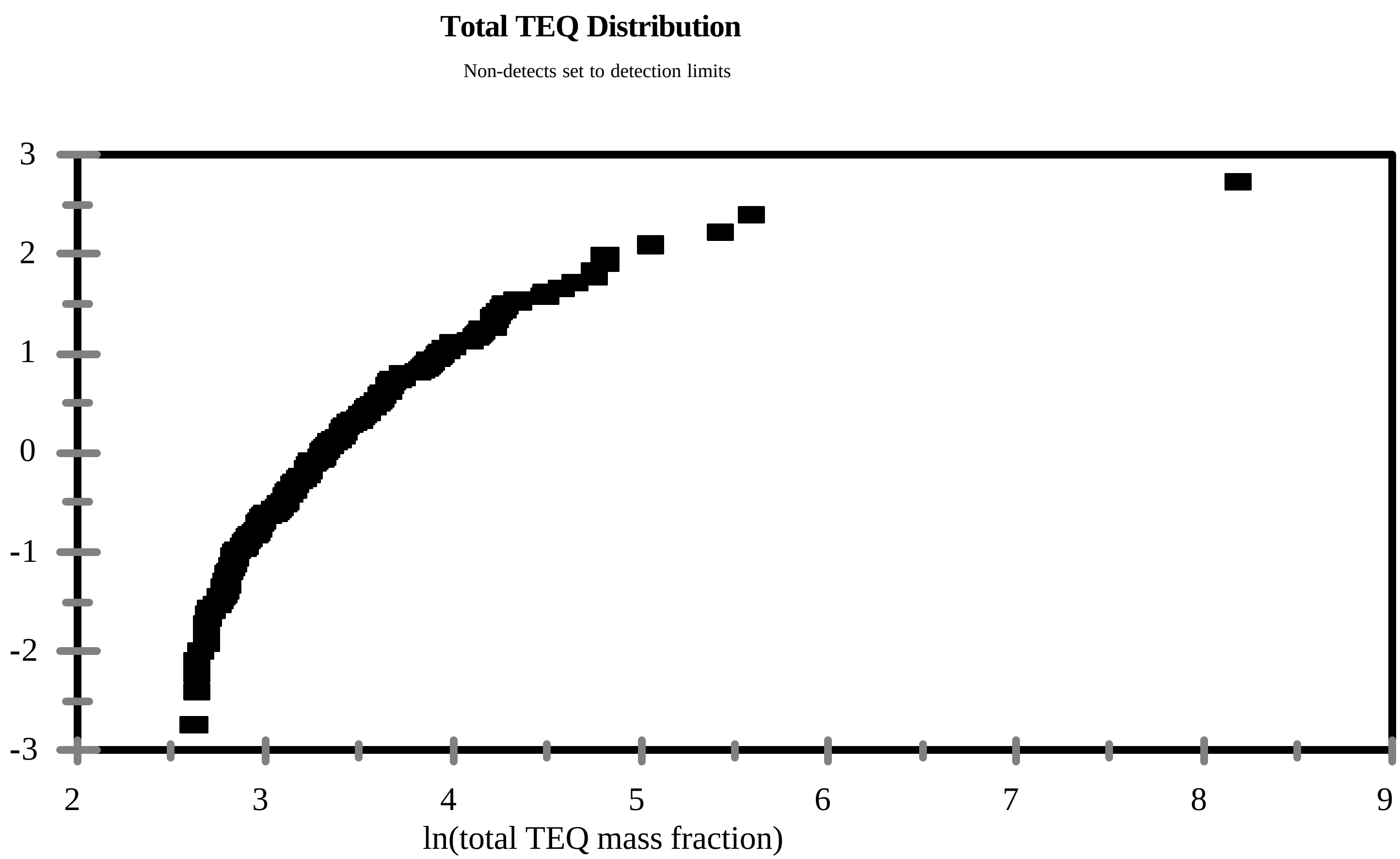

Figure 3.20 Distribution of ln(total TEQ mass fraction). Non-detects set to detection limits.

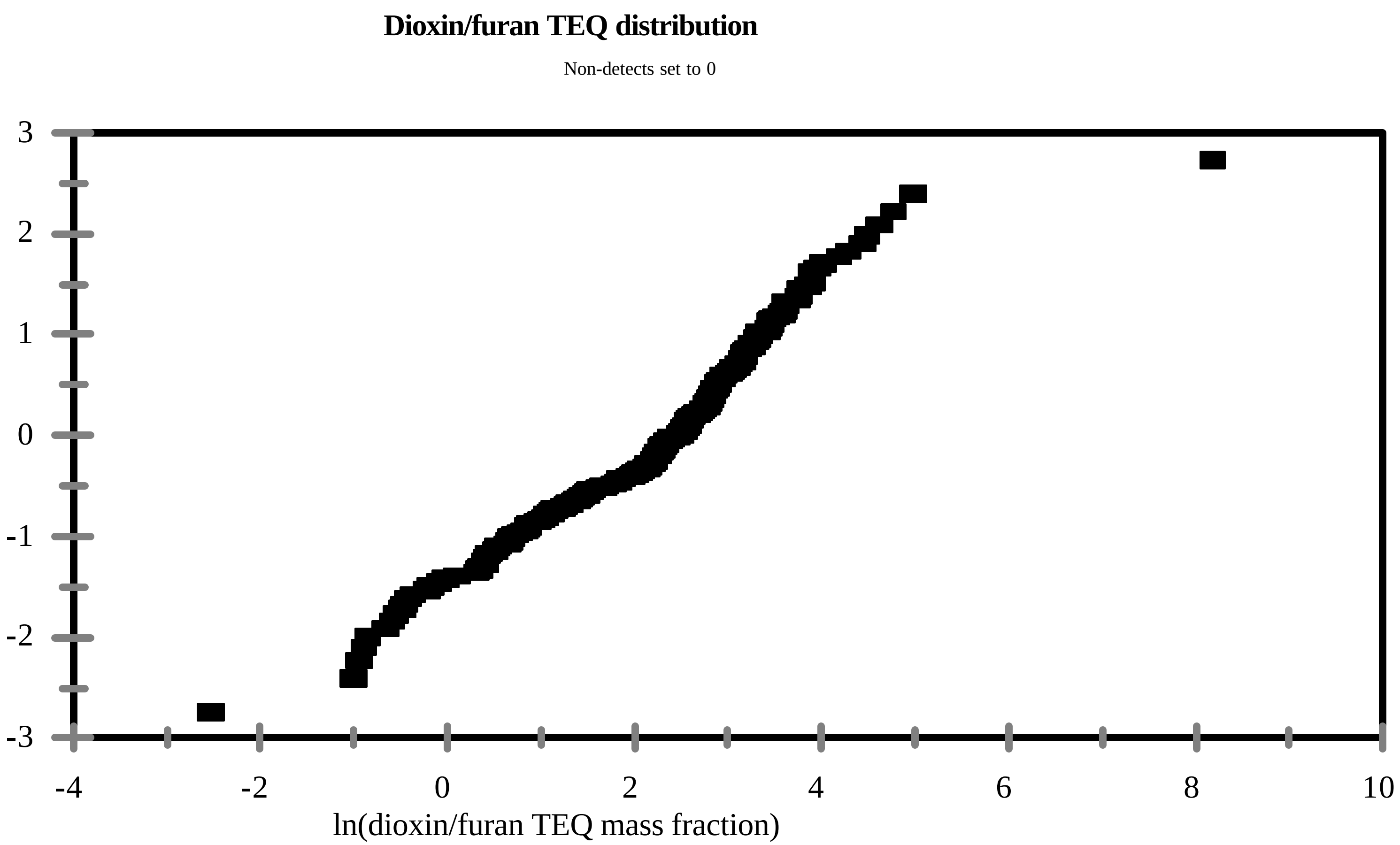

Figure 3.21 Distribution of ln(dioxin/furan TEQ mass fraction). Non-detects set to zero.

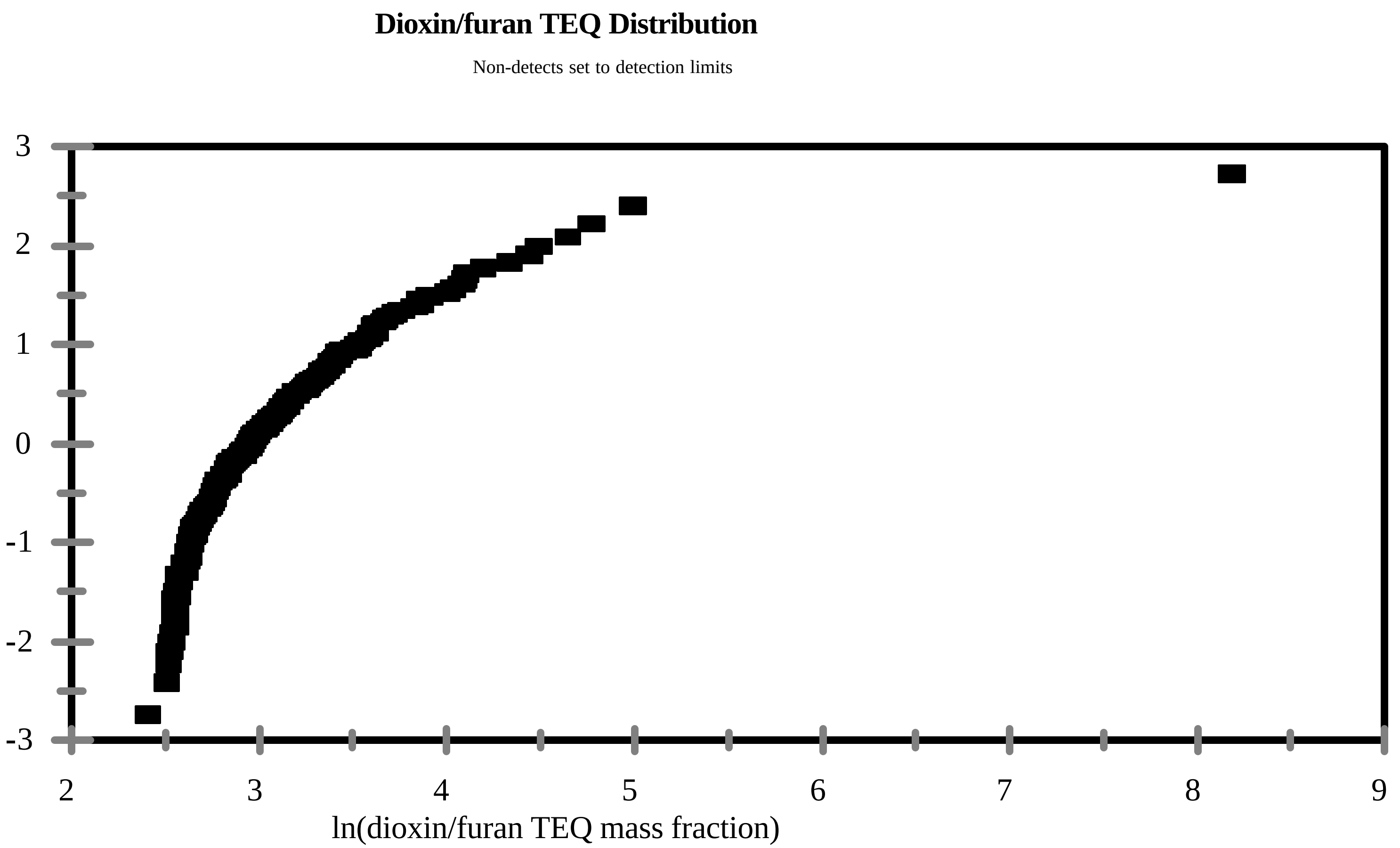

Figure 3.22 Distribution of ln(dioxin/furan TEQ mass fraction). Non-detects set to detection limits.

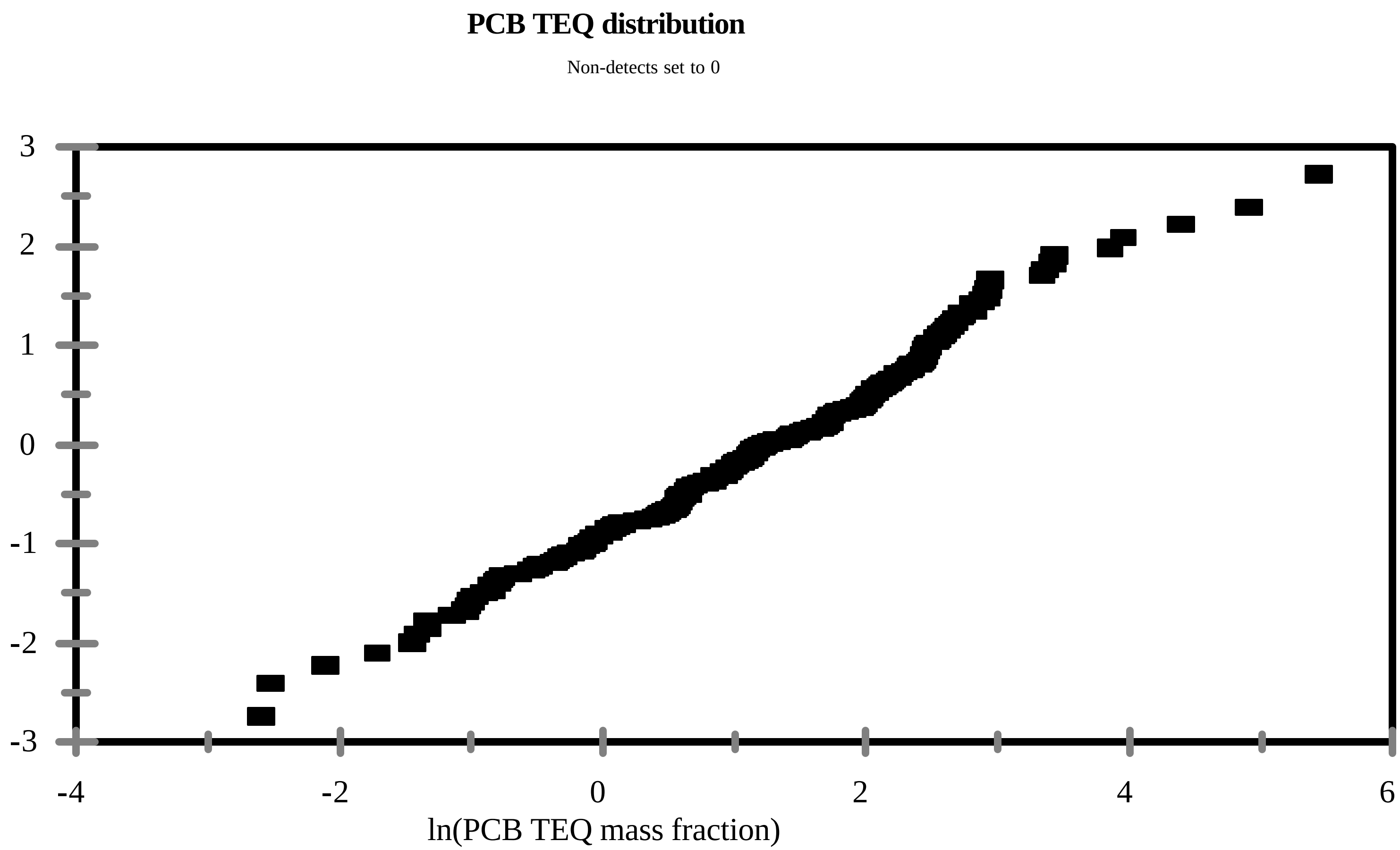

Figure 3.23 Distribution of ln(PCB TEQ mass fraction). Non-detects set to zero.

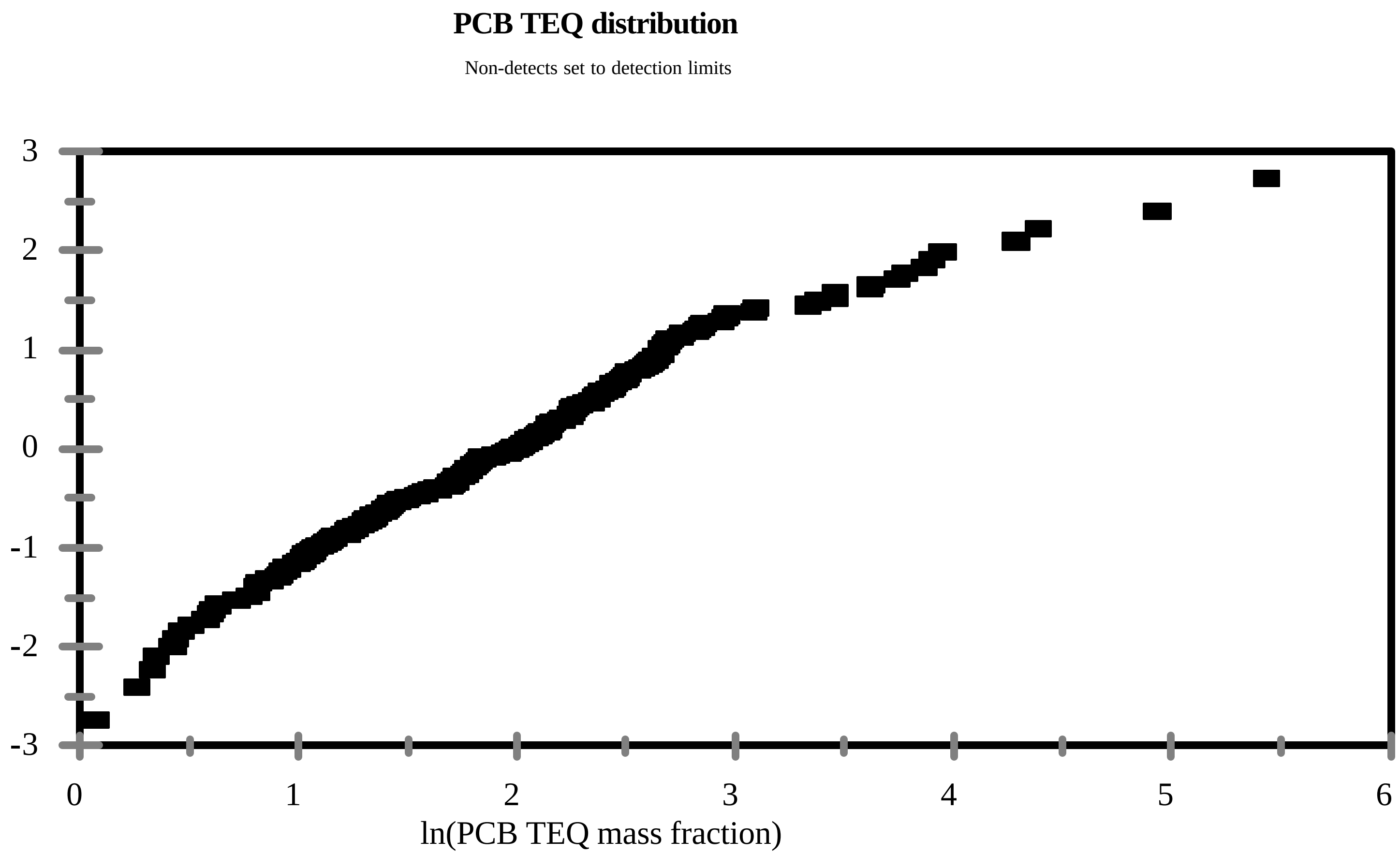

Figure 3.24 Distribution of ln(PCB TEQ mass fraction). Non-detects set to detection limits.

Table 3.10 Congener number for following charts.

Congener	Number
2,3,7,8-TCDF	1
2,3,7,8-TCDD	2
1,2,3,7,8-PeCDF	3
2,3,4,7,8-PeCDF	4
1,2,3,7,8-PeCDD	5
1,2,3,4,7,8-HxCDF	6
1,2,3,6,7,8-HxCDF	7
2,3,4,6,7,8-HxCDF	8
1,2,3,7,8,9-HxCDF	9
1,2,3,4,7,8-HxCDD	10
1,2,3,6,7,8-HxCDD	11
1,2,3,7,8,9-HxCDD	12
1,2,3,4,6,7,8-HpCDF	13
1,2,3,4,7,8,9-HpCDF	14
1,2,3,4,6,7,8-HpCDD	15
OCDF	16
OCDD	17
PCB-81	18
PCB-77	19
PCB-123	20
PCB-118	21
PCB-114	22
PCB-105	23
PCB-126	24
PCB-167	25
PCB-156	26
PCB-157	27
PCB-169	28
PCB-189	29

Legend for Box and Whisker Plots

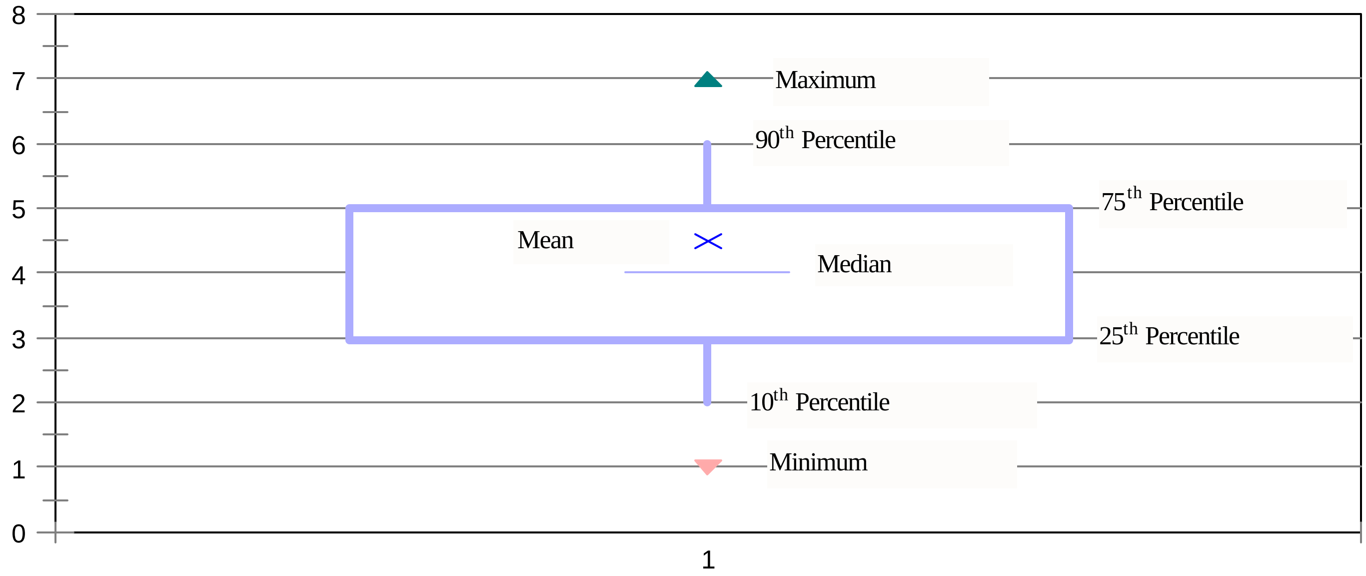

Figure 3.25 Legend for Box and Whisker Plots

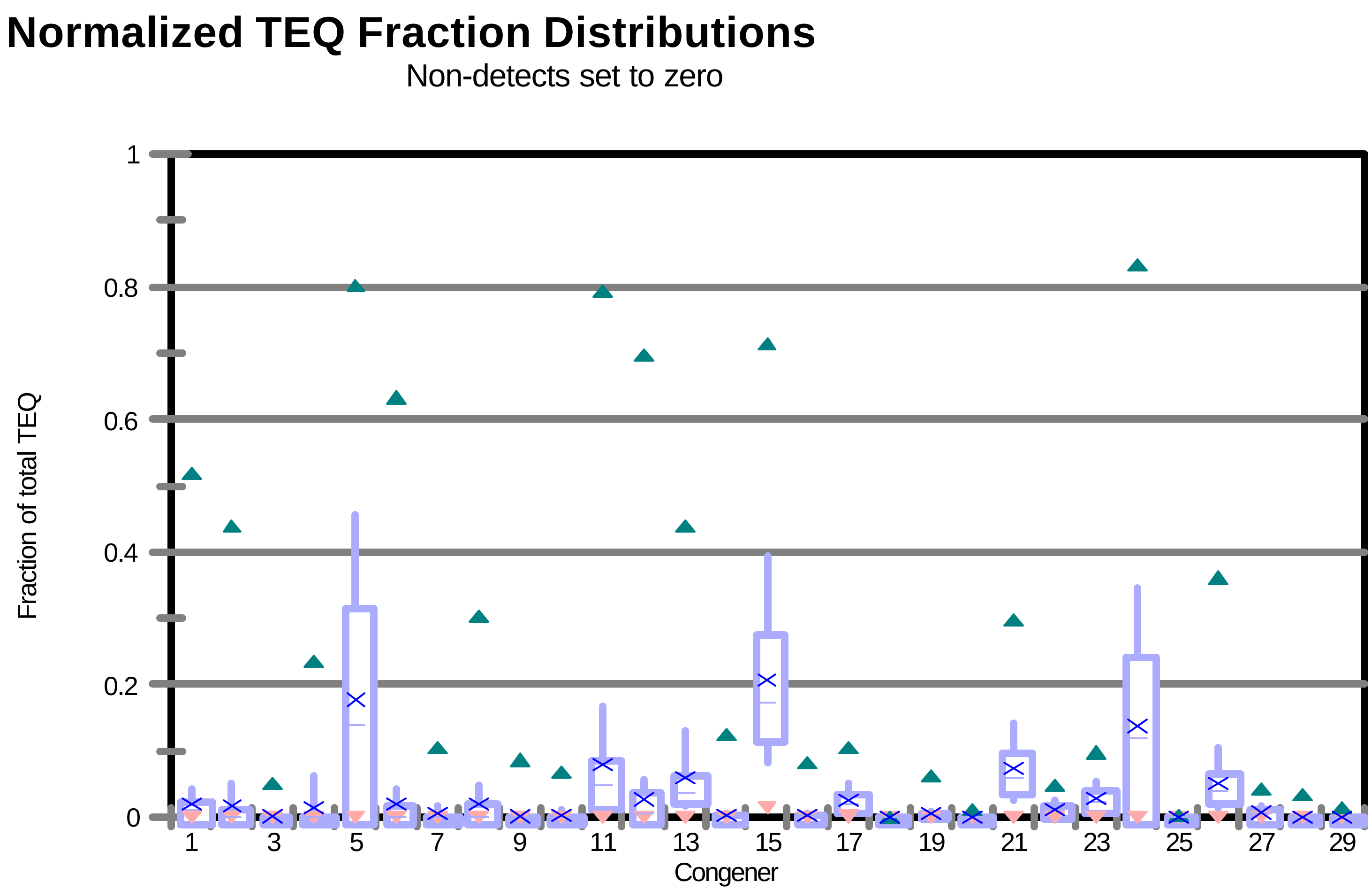

Figure 3.26 Distribution of fraction of total TEQ contributed by each congener. Non-detects set to zero.

Normalized TEQ Fraction Distributions

Non-detects at half detection limits.

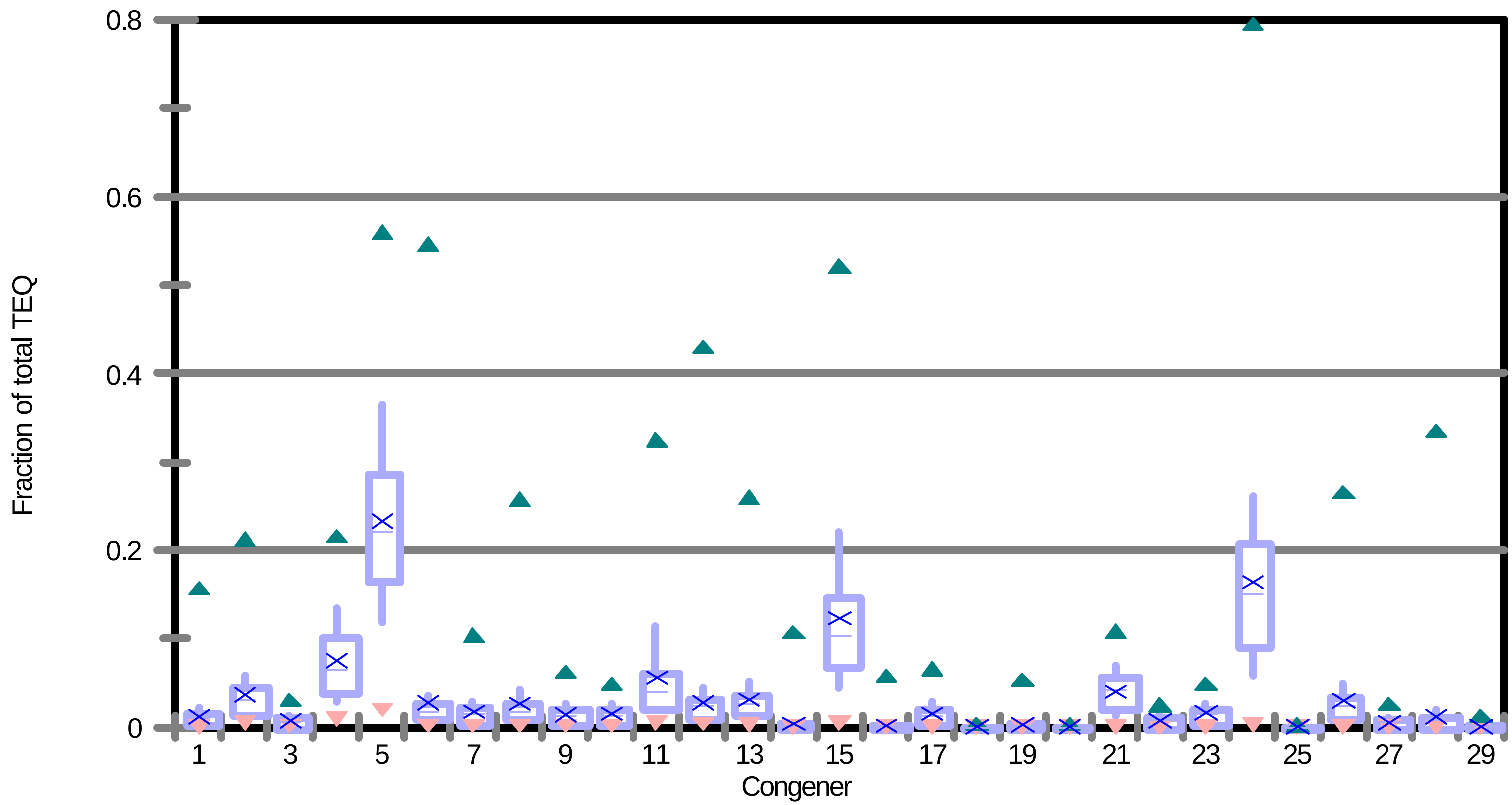

Figure 3.27 Distribution of fraction of total TEQ contributed by each congener. Non-detects set to detection limits.

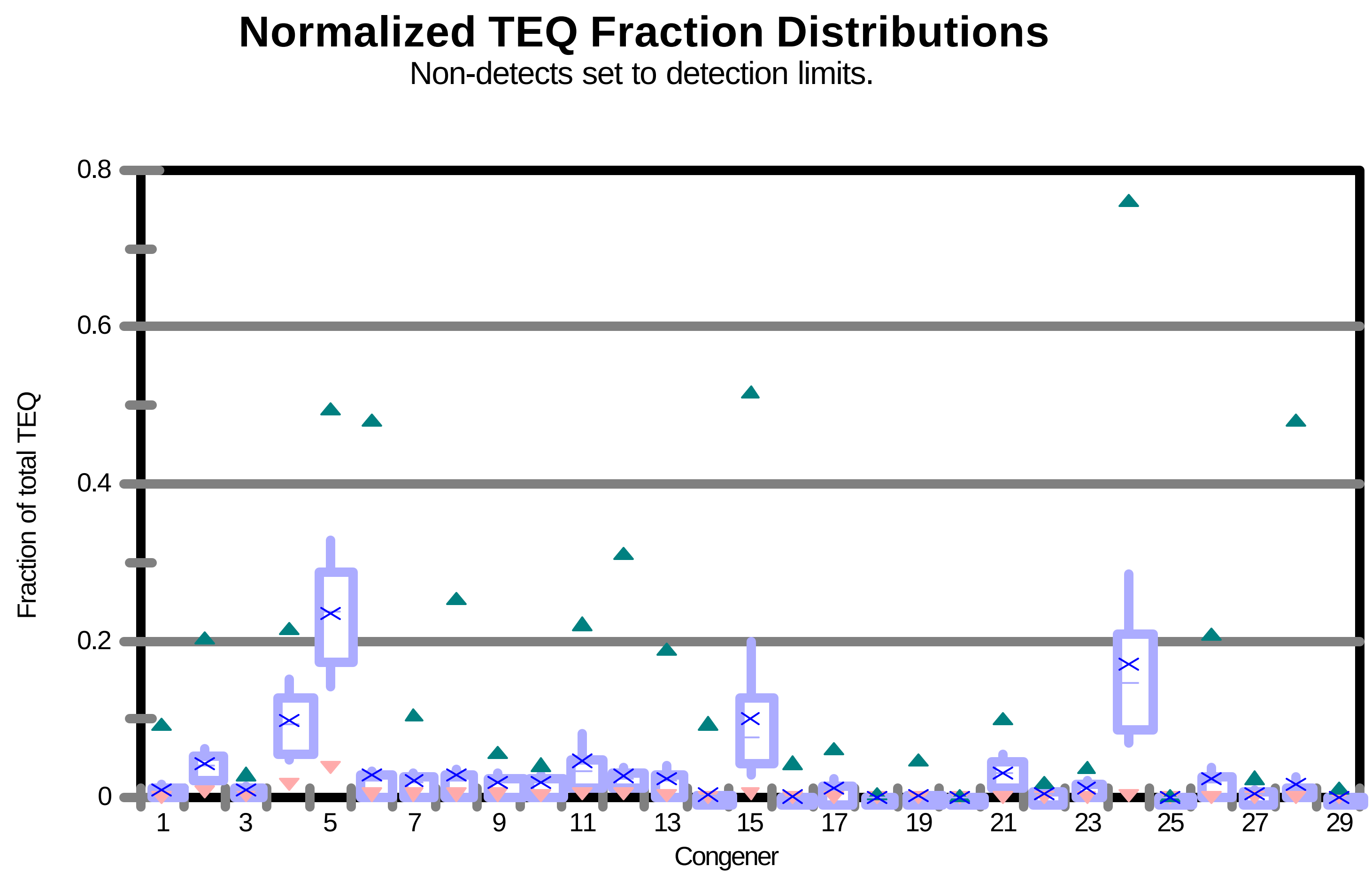

Figure 3.28 Distribution of fraction of total TEQ contributed by each congener. Non-detects set to detection limits.

Cambridge Environmental Inc

58 Charles Street Cambridge, Massachusetts 02141
617-225-0810 FAX: 617-225-0813 E-mail: info@CambridgeEnvironmental.com

Table 3.11 Contribution of PCBs, Dioxins, and Furans to total TEQ mass fractions.

	Fraction of total TEQ value for sample								
	Non-detects set to detection limit			Non-detects set to half detection limits			Non-detects set to zero		
	Dioxins	Furans	PCBs	Dioxins	Furans	PCBs	Dioxins	Furans	PCBs
Mean	0.49	0.24	0.27	0.51	0.22	0.28	0.54	0.15	0.32
Minimum	0.10	0.04	0.00	0.08	0.03	0.00	0.02	0.00	0.00
10^{th} percentile	0.35	0.14	0.12	0.35	0.11	0.12	0.22	0.03	0.08
25^{th} percentile	0.43	0.17	0.17	0.44	0.13	0.19	0.41	0.05	0.16
Median	0.49	0.23	0.25	0.51	0.19	0.27	0.54	0.09	0.29
75^{th} percentile	0.56	0.29	0.33	0.60	0.26	0.35	0.70	0.18	0.43
90^{th} percentile	0.62	0.34	0.44	0.67	0.34	0.44	0.81	0.30	0.58
Maximum	0.88	0.82	0.85	0.92	0.87	0.89	0.96	0.96	0.93

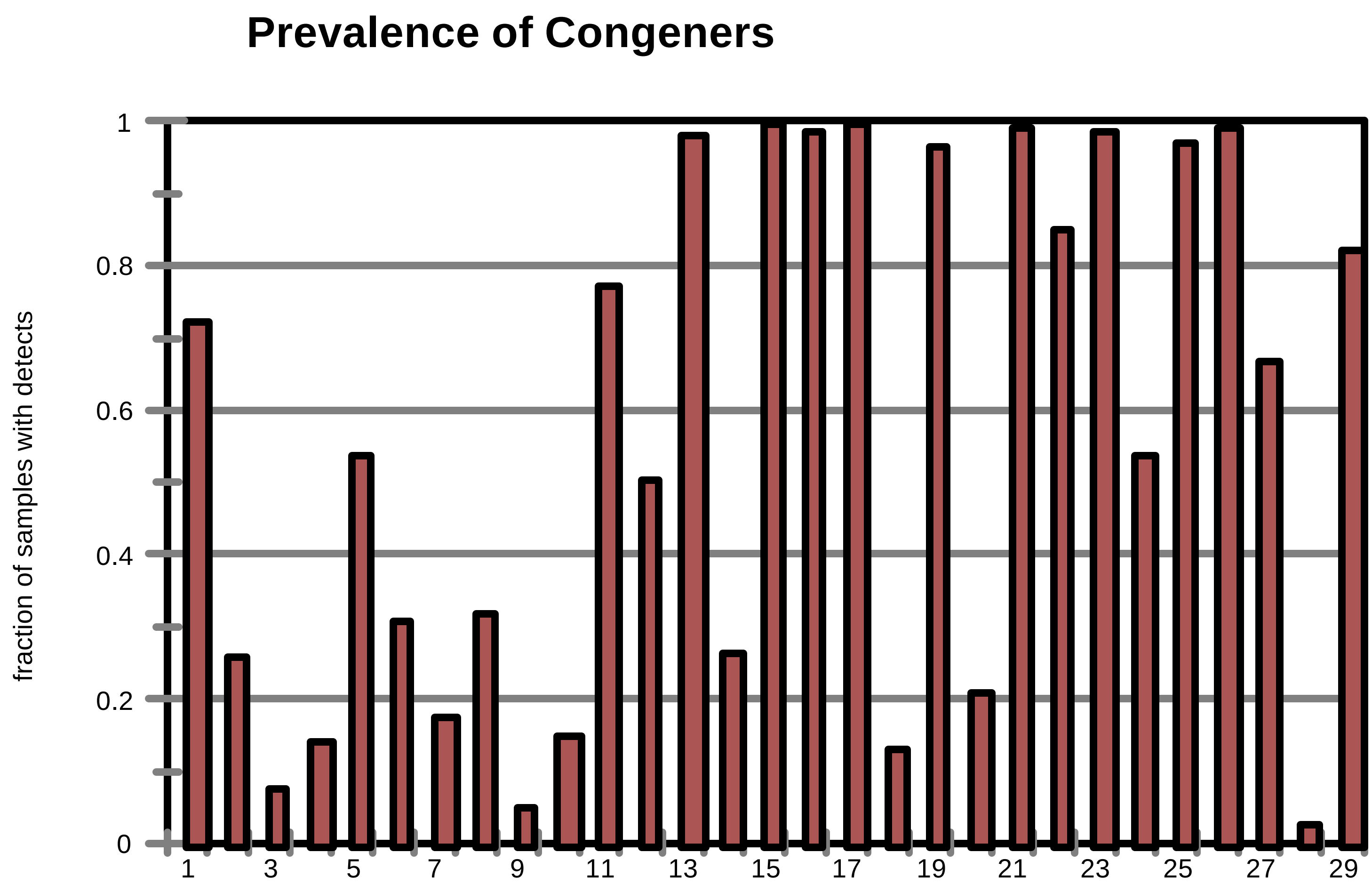

Figure 3.29 Prevalence of each congener in individual samples.

4 Comparison of the 2000/2001 and 1994/1995 data sets

The 2000/2001 AMSA data were compared with 1994/1995 data reported by Green *et al.* (1995a) and Green *et al.* (1995b). Those reports described mass fractions of dioxins, furans, and three dioxin-like PCBs in biosolids samples collected by AMSA in 1994 and analyzed by MRI in 1994 and 1995. The purpose of the comparison was first, to see if there has been any statistically significant change in the dioxin levels reported by POTWs since the 1994/1995 survey and second, to see if the data sets were sufficiently similar that they could be combined for further analysis.

The characteristics of the 1994/1995 data set, as reported in Green *et al.* (1995b), are presented in Table 4.1. There were available a total of 104 sample analyses from 75 separate facilities. Five of the samples had biosolids concentrations less than 0.1%; these were omitted from further consideration as not being representative of biosolids, leaving 99 sample analyses from 74 separate facilities. It was not known whether multiple samples from a single facility corresponded to different biosolids streams, or were multiple samples from the same biosolids stream, so samples from identical facilities were averaged together prior to analysis (Green *et al.*, 1995b).

The facility-identification coding scheme for the 1994/1995 samples was no longer available, and the 1994/1995 questionnaires did not allow identification of the individual biosolids streams sampled within a facility, so that individual matching of facilities or samples between 1994/1995 and 2000/2001 was not possible. To generate as similar a population comparison as possible, the facility-averaging method used for the 1994/1995 samples was applied to the 2000/2001 samples. Multiple samples from within the same facility were averaged. For the 2000/2001 samples, individual samples were identified as being from the same facility if they had the same

- first four digits of their code number,
- average daily flow,
- percent industrial loading,
- percent Combined sewers service area, and
- annual biosolids production.

The last four variables correspond to similar items on the questionnaires in 1994/1995 and 2000/2001. As a result of this averaging, the 2000/2001 comparison sample set contains 200 samples from 182 facilities.[1] As Green *et al.* (1995b) considered two assumptions for non-detected congeners (absent or present at detection limits), these same assumptions were used for the 2000/2001 comparison sample set.

Several further modifications must be made to the two data sets before they can be compared. First, the 1994/1995 TEQ mass fractions were originally calculated using a different TEF system than the Van den Berg *et al.* (1998) system applied to the 2000/2001 data. Table 4.2 shows the differences between the two sets of TEQ values. The characteristics of the 1994/1995 data set were recalculated using the Van den Berg *et al.* (1998) TEF values. The results for the 1994/1995 data with the new TEF values are presented in Table 4.3 (for the untransformed data) and Table 4.4 (for the logarithmically transformed data).

The second modification involves the PCB TEQ totals for the different data sets. Only four PCB congeners with non-zero TEFs in the Van den Berg *et al.* (1998) system were analyzed in both the 1994/1995 and 2000/2001 survey — PCB-77, PCB-81, PCB-126, and PCB-169.[2] The total TEQ values for these four congeners for each 2000/2001 sample are presented in Table 4.5. The sum of the TEQ mass fractions of the dioxin/furan congeners with the TEQ mass fractions of these four PCB congeners is referred to as the "adjusted total."

Table 4.6 shows the facility-averaged 2000/2001 results, listing the dioxin/furan, PCB subset, and adjusted total TEQ mass fraction for each facility. The characteristics of this adjusted 2000/2001 data set are given in Table 4.7 (for the untransformed data) and Table 4.8 (for the logarithmically transformed data).

As can be seen from comparing the results of Table 4.3 with Table 4.7, and Table 4.4 with Table 4.8, the means and medians of the untransformed and logarithmically transformed data are lower for the 2000/2001 data set than for the 1994/1995 data set. In addition, Figure 4.1 shows that the histograms for the two untransformed data sets are dissimilar.

Further quantitative comparisons of the 1994/1995 and 2000/2001 data transformed as described were performed using an F-test to test for equal variance, and subsequently the appropriate t-test (for equal or unequal variances, the latter using Satterthwaite's approximation for the degrees of freedom) to

---

[1] As there are 180 facilities (171 POTWs and 9 post-processing plants) participating in the survey, this suggests that two facilities have two separate process streams within their facility. These separate process streams are treated as separate facilities in this chapter.

[2] In the 1995 analyses, only three of the six PCB congeners measured in biosolids samples had non-zero TEFs. In the Van den Berg *et al.* (1998) system, four of the six have non-zero TEFs. The 1994/1995 data have been reanalyzed to include the additional PCB congener (PCB-81) in Table 4.3 and 4.4.

compare test for similar means (Snedecor and Cochran, 1989; the degrees of freedom for Satterthwaite's approximation were not rounded). Table 4.9 lists *F*- and *t*-statistics and associated probabilities for random samples.

Table 4.9 shows that when non-detected congeners are assumed to be present at their detection limits, the variance for the 1994/1995 data set is larger than that of the 2000/2001 data set, resulting in *F* statistics greater than 1. However, when non-detected congener are assumed to be absent, the variance for the 2000/2001 data set is larger than that of the 1994/1995 data set, resulting in *F* statistics less than 1. Assuming non-detected congeners to be present at half detection limits (not shown in Table 4.9) results in *F* statistics slightly larger than 1, in between the two previous values. As the *F* statistics appear to be a function of the assumption made for the treatment of non-detected congeners, the null hypothesis that the variances for the two data sets are the same cannot be rejected. Thus, the *t*-test for equal variances is used for all data set pairs.

However, the differences between the means of the 1994/1995 logarithmically transformed data and the 2000/2001 logarithmically transformed data would be highly significant for random samples, with the 2000/2001 data showing lower average TEQ mass fractions. While the samples were not obtained by random processes (for example, as random samples of all facilities producing biosolids), the differences indicated in Table 4.9 almost certainly indicate a real decrease between 1994/1995 and 2000/2001 in the concentrations of dioxin/furan and PCB TEQs in biosolids produced in similar facilities. If non-detected congeners are assumed to be absent, the mean TEQ-based mass fractions of dioxins/furans declined by 0.5%, the mean TEQ-based mass fraction of the PCB subset declined by 79%, and the adjusted total by 32%. The corresponding medians declined by 56%, 83%, and 64%, respectively.

Since these differences are almost certainly the result of a real change in concentrations of TEQs in biosolids, the 1994/1995 and 2000/2001 data sets should not be combined for comparison with POTW questionnaire data. Thus, in Chapter 5, we only use the 2000/2001 data set for comparisons with POTW variables.

Table 4.1 Characteristics of 1994/1995 TEQ mass fraction data using 1989 and 1995 TEF values: Green *et al*. (1995b)

Treatment of non-detects	Data subset	Average (pg TEQ/g)	Standard deviation (pg TEQ/g)	Standard error of the mean (pg TEQ/g)	Median (pg TEQ/g)
Detection limits	Total	112.7	114.3	13.3	77.9
	Dioxins and Furans	64.6	50.6	5.89	49.1
	PCBs 77, 126, and 169	48.1	89.2	10.4	23.9
Zero	Total	95.2	110.2	12.8	56.9
	Dioxins and Furans	47.7	45.0	5.23	30.0
	PCBs 77, 126, and 169	47.5	89.4	10.4	22.6

Table 4.2 Differences between TEF values used in Green *et al.* (1995b), and TEF values used in this report (Van den Berg *et al.*, 1998)

Congener	1994 TEF (Green, et al., 1995)	2000 TEF (Van den Berg, 1998)
2,3,7,8-TCDF	0.1	0.1
2,3,7,8-TCDD	1	1
1,2,3,7,8-PeCDF	0.05	0.05
2,3,4,7,8-PeCDF	0.5	0.5
1,2,3,7,8-PeCDD	0.5	1
1,2,3,4,7,8-HxCDF	0.1	0.1
1,2,3,6,7,8-HxCDF	0.1	0.1
2,3,4,6,7,8-HxCDF	0.1	0.1
1,2,3,7,8,9-HxCDF	0.1	0.1
1,2,3,4,7,8-HxCDD	0.1	0.1
1,2,3,6,7,8-HxCDD	0.1	0.1
1,2,3,7,8,9-HxCDD	0.1	0.1
1,2,3,4,6,7,8-HpCDF	0.01	0.01
1,2,3,4,7,8,9-HpCDF	0.01	0.01
1,2,3,4,6,7,8-HpCDD	0.01	0.01
OCDF	0.001	0.0001
OCDD	0.001	0.0001
PCB-81	0	0.0001
PCB-77	0.01	0.0001
PCB-123	NA	0.0001
PCB-118	NA	0.0001
PCB-114	NA	0.0005
PCB-105	NA	0.0001
PCB-126	0.1	0.1
PCB-167	NA	1E-05
PCB-156	NA	0.0005
PCB-157	NA	0.0005
PCB-169	0.05	0.01
PCB-189	NA	0.0001
NA - Congener was not analyzed in 1994 AMSA survey.		

Table 4.3 Characteristics of 1994/1995 TEQ mass fraction data using Van den Berg *et al*. (1998) TEF values

Treatment of non-detects	Data subset	Number of samples (N)	Mean (pg TEQ/g)	Standard deviation (pg TEQ/g)	Standard error of the mean (pg TEQ/g)	Median (pg TEQ/g)
Detection limits	Adjusted Total	74	81.7	75.1	8.7	55.7
	Dioxins and Furans	74	57.3	45.0	5.23	44.6
	4 PCBs	74	24.4	47.7	5.5	9.34
Zero	Adjusted Total	74	60.5	69.0	8.0	37.0
	Dioxins and Furans	74	36.3	38.9	4.52	25.5
	4 PCBs	74	24.2	47.7	5.5	9.2

Table 4.4 Characteristics of logarithmically transformed 1994/1995 TEQ mass fraction data using Van den Berg *et al*. (1998) TEF values

Treatment of non-detects	Data subset	Number of samples (N)	Mean	Standard deviation	Standard error of the mean
Detection limits	Adjusted Total	74	4.09	0.77	0.09
	Dioxins and Furans	74	3.80	0.70	0.081
	4 PCBs	74	2.50	1.03	0.12
Zero	Adjusted Total	74	3.57	1.07	0.12
	Dioxins and Furans	74	3.05	1.12	0.13
	4 PCBs	74	2.42	1.28	0.15

Table 4.5 TEQ contributions to each 2000/2001 sample from 77-PCB, 81-PCB, 126-PCB, and 169-PCB.

Sample ID #	PCB subset (pg TEQ/g)	
	Non-detects set to detection limits.	Non-detects set to zero.
10040101a	5.90	5.70
10040101b	4.10	3.90
10040101c	8.93	0.29
10040101d	6.55	6.35
10051000a	3.62	0.03
10051000b	4.83	4.63
10061000a	2.36	0.03
10071000a	3.10	0.02
10081000a	2.51	2.32
10091000a-RA	2.82	0.04
10101000a	3.66	3.46
10111000a	20.25	19.34
10121000a	9.14	5.62
10131000a	3.90	3.69
10141000a	19.99	19.79
10141000b	15.17	0.31
10141000c	9.47	9.06
10141000d	38.49	19.16
10141000e	8.97	8.77
10141000f	2.67	2.47
10151000a	3.77	0.04
10151000b	3.48	0.04
10151000c	1.63	0.03
10151000d	2.11	1.91
10151000e	67.30	0.03
10151000f	9.27	9.11
10151000g	5.76	5.42
10151000h	2.85	0.08
10161000a	2.05	1.86
10171000a	6.91	0.04
10181000a	4.74	0.02
10191000a	5.45	5.22
10201000a-RA	11.62	0.01
10211000a	4.15	3.97

Table 4.5 TEQ contributions to each 2000/2001 sample from 77-PCB, 81-PCB, 126-PCB, and 169-PCB.

Sample ID #	PCB subset (pg TEQ/g)	
	Non-detects set to detection limits.	Non-detects set to zero.
10221000b	1.19	0.01
10221000c	6.30	6.10
10221000e	2.49	2.29
10221000f	5.21	4.91
10231000a	1.81	0.01
10241000a	1.21	0.01
10241000b	4.50	4.30
10251000a	3.60	3.42
10251200a	7.57	0.04
10261000a	4.74	0.04
10271100a	2.40	2.20
10271100b	4.18	0.02
10281100a	4.50	4.37
10281100b	8.62	0.03
10291100a-RA	1.05	0.00
10301100a	3.75	0.01
10311100a	6.96	0.10
10311100b	6.80	6.60
10321100a	6.04	0.06
10331100a	35.13	2.38
10341100a	1.23	1.04
10351100a	5.29	4.88
10351100b	5.28	4.86
10361100a	8.14	7.95
10371100a	7.99	7.41
10381100a	5.51	0.03
10381100b	5.99	5.79
10391100a	1.77	0.02
10391100b	1.46	1.26
10391100c	3.95	0.00
10391100d	2.54	0.02
10391100e	1.54	1.34
10391100f	1.73	1.53
10401100a	5.68	5.48

Table 4.5 TEQ contributions to each 2000/2001 sample from 77-PCB, 81-PCB, 126-PCB, and 169-PCB.

Sample ID #	PCB subset (pg TEQ/g)	
	Non-detects set to detection limits.	Non-detects set to zero.
10401100b	1.98	0.01
10401100c	2.04	1.84
10411100a	3.04	0.03
10411100b	1.13	0.01
10421100a	1.41	0.01
10431100a	1.74	1.54
10441100a	8.23	7.95
10441100b	6.32	0.02
10441100c	9.79	9.29
10441100d	75.35	75.35
10441100e	2.93	2.73
10441100f	9.85	9.38
10441100g	6.87	6.59
10441100h	3.28	3.08
10441100i	49.73	49.73
10441100j	24.02	23.20
10441100k	8.12	6.95
10441100l	11.57	10.73
10441100m	8.80	7.87
10441100n	8.10	7.61
10441100o	13.26	0.05
10441100p	5.81	5.56
10441100q	12.46	11.40
10441100r	6.61	6.42
10441100s	5.26	4.50
10441100t	224.67	224.67
10441100u-RA	3.56	0.00
10441100v	7.29	6.42
10441100w	10.76	10.43
10441100x	7.95	7.71
10441100y	9.48	9.11
10451100a	11.11	0.01
10461100a	8.15	7.78
10471100a	2.27	0.01

Table 4.5 TEQ contributions to each 2000/2001 sample from 77-PCB, 81-PCB, 126-PCB, and 169-PCB.

Sample ID #	PCB subset (pg TEQ/g)	
	Non-detects set to detection limits.	Non-detects set to zero.
10481100a	1.14	0.01
10491100a	3.59	0.05
10501100a	3.65	3.45
10501100b	1.94	1.74
10511100a	1.76	1.57
10521100a	2.43	0.01
10531100a	1.56	1.37
10541100a	6.75	0.03
10541100b	6.21	4.83
10551100a	11.42	11.22
10561100a	1.16	0.01
10571100a	1.97	1.79
10571100b	3.84	0.03
10581100a	6.28	5.15
10591100a	5.17	0.01
10601100a	8.17	0.01
10611100a	4.49	4.17
10621100a	7.29	0.06
10621100b	3.16	0.01
10621100c	5.92	0.00
10631100a	1.24	0.01
10641100a	1.78	0.02
10641100b	4.99	4.79
10641100c	3.61	0.01
10641100d	6.44	0.05
10641100e	1.31	0.01
10651100a	5.92	5.72
10651100b	9.63	9.12
10651100c	29.33	0.09
10661100a	13.64	13.19
10681100a	8.63	8.41
10691200a	5.61	5.42
10701200a	11.99	0.00
10711200a	1.21	0.01

Table 4.5 TEQ contributions to each 2000/2001 sample from 77-PCB, 81-PCB, 126-PCB, and 169-PCB.

Sample ID #	PCB subset (pg TEQ/g)	
	Non-detects set to detection limits.	Non-detects set to zero.
10711200b	4.05	3.85
10721200a	2.10	0.02
10731200a	5.01	0.01
10731200b	6.22	0.02
10741200a	4.25	3.98
10741200b	4.46	4.12
10751200a	2.69	0.01
10751200b	5.14	4.92
10761200a	15.06	0.05
10761200d	2.61	2.38
10761200e	42.63	0.02
10771200a	1.78	0.01
10781200a	8.70	7.85
10781200b	9.07	0.05
10781200c	9.46	9.46
10791200a	1.59	0.02
10791200b	3.28	2.45
10791200c	1.79	0.02
10791200d	1.70	0.04
10791200e	3.14	0.02
10791200f	77.85	73.48
10791200g	4.96	0.03
10801200a	3.72	3.53
10811200a	1.77	0.02
10811200b	1.17	0.00
10821200a	5.22	0.08
10831200a	3.44	3.25
10841200a	16.38	12.08
10851200a	5.13	4.87
10861200a	6.56	6.37
10870101a	2.42	2.23
10871200a	10.31	10.10
10871200b	3.09	0.00
10881200a	2.87	0.04

Table 4.5 TEQ contributions to each 2000/2001 sample from 77-PCB, 81-PCB, 126-PCB, and 169-PCB.

Sample ID #	PCB subset (pg TEQ/g)	
	Non-detects set to detection limits.	Non-detects set to zero.
10891200a	2.46	2.17
10901200a	4.84	0.03
10911200a	1.49	0.01
10921200a	9.12	0.06
10931200b	3.68	3.47
10941200a	4.35	3.79
10951200a	2.33	1.89
10961200a	1.34	1.19
10961200b	2.99	0.05
10971200a	5.77	0.06
10981200a	1.53	1.34
10991200a	3.01	0.03
11001200a	4.09	3.79
11010101a	1.93	0.03
11020101a	23.09	0.08
11030101a	4.64	0.06
11040101a	4.33	3.65
11050101a	5.79	0.05
11060101a	12.08	0.05
11070101a	2.01	0.02
11080101a	2.67	2.48
11090101a	1.58	1.38
11100101a	11.55	0.02
11100101b	7.85	0.05
11110101a	14.58	14.40
11120101a	13.08	0.02
11130101a	4.61	0.02
11140101a	5.11	0.04
11150501a	12.50	12.50
11150501b	5.60	5.41

Table 4.6 2000/2001 facility averaged TEQ totals used for comparison to 1994/1995 data

Facility ID #	Non-detects set to detection limits			Non-detects set to zero.		
	Adjusted Total (pg TEQ/g)	Dioxins and Furans (pg TEQ/g)	PCB subset (pg TEQ/g)	Adjusted Total (pg TEQ/g)	Dioxins and Furans (pg TEQ/g)	PCB subset (pg TEQ/g)
10040101a+b	25.60	20.60	5.00	20.41	15.61	4.80
10040101c+d	24.40	16.66	7.74	14.05	10.73	3.32
10051000a	17.76	14.14	3.62	2.41	2.38	0.03
10051000b	27.95	23.12	4.83	21.74	17.11	4.63
10061000a	22.42	20.06	2.36	13.36	13.33	0.03
10071000a	20.73	17.63	3.10	12.10	12.08	0.02
10081000a	15.93	13.42	2.51	3.80	1.49	2.32
10091000a	17.28	14.46	2.82	2.64	2.60	0.04
10101000a	20.85	17.19	3.66	10.90	7.44	3.46
10111000a	60.55	40.30	20.25	56.18	36.84	19.34
10121000a	23.24	14.10	9.14	7.34	1.73	5.62
10131000a	20.97	17.07	3.90	14.13	10.44	3.69
10141000a+b	70.24	52.67	17.58	59.51	49.46	10.05
10141000c	50.70	41.23	9.47	45.88	36.82	9.06
10141000d+e	69.12	45.39	23.73	58.02	44.06	13.97
10141000f	18.12	15.45	2.67	6.15	3.68	2.47
10151000a	23.26	19.49	3.77	12.85	12.81	0.04
10151000b	24.89	21.41	3.48	15.22	15.18	0.04
10151000c	19.31	17.68	1.63	10.99	10.97	0.03
10151000d	16.08	13.97	2.11	3.58	1.67	1.91
10151000e	83.88	16.58	67.30	9.93	9.90	0.03
10151000f	30.31	21.04	9.27	25.96	16.85	9.11
10151000g	22.85	17.09	5.76	16.09	10.67	5.42
10151000h	87.37	84.52	2.85	84.31	84.23	0.08
10161000a	16.71	14.66	2.05	4.89	3.03	1.86
10171000a	32.12	25.21	6.91	18.89	18.84	0.04
10181000a	19.64	14.90	4.74	5.07	5.06	0.02
10191000a	36.74	31.30	5.45	32.77	27.55	5.22
10201000a	27.43	15.82	11.62	9.78	9.77	0.01
10211000a	122.15	118.00	4.15	121.96	118.00	3.97
10221000b	13.73	12.54	1.19	0.39	0.39	0.01
10221000c+e	20.44	16.04	4.40	11.48	7.28	4.20

Table 4.6 2000/2001 facility averaged TEQ totals used for comparison to 1994/1995 data

Facility ID #	Non-detects set to detection limits			Non-detects set to zero.		
	Adjusted Total (pg TEQ/g)	Dioxins and Furans (pg TEQ/g)	PCB subset (pg TEQ/g)	Adjusted Total (pg TEQ/g)	Dioxins and Furans (pg TEQ/g)	PCB subset (pg TEQ/g)
10221000f	26.45	21.24	5.21	21.00	16.09	4.91
10231000a	14.66	12.85	1.81	0.56	0.55	0.01
10241000a	14.07	12.86	1.21	0.41	0.41	0.01
10241000b	30.73	26.23	4.50	22.19	17.89	4.30
10251000a	19.76	16.16	3.60	12.59	9.16	3.42
10251200a	22.36	14.79	7.57	3.08	3.04	0.04
10261000a	29.11	24.37	4.74	18.19	18.15	0.04
10271100a	17.29	14.90	2.40	5.65	3.45	2.20
10271100b	26.89	22.71	4.18	11.68	11.66	0.02
10281100a+b	26.69	20.13	6.56	16.28	14.07	2.20
10291100a	13.86	12.81	1.05	2.34	2.34	0.00
10301100a	16.54	12.79	3.75	0.52	0.51	0.01
10311100a	37.49	30.53	6.96	27.43	27.33	0.10
10311100b	44.09	37.29	6.80	43.17	36.57	6.60
10321100a	25.89	19.85	6.04	14.95	14.90	0.06
10331100a	65.90	30.78	35.13	27.15	24.77	2.38
10341100a	14.17	12.94	1.23	1.95	0.91	1.04
10351100a	32.25	26.97	5.29	28.14	23.25	4.88
10351100b	23.63	18.35	5.28	12.09	7.23	4.86
10361100a	34.01	25.87	8.14	31.51	23.56	7.95
10371100a	29.34	21.34	7.99	23.65	16.24	7.41
10381100a	27.64	22.12	5.51	15.23	15.20	0.03
10381100b	29.20	23.21	5.99	22.24	16.46	5.79
10391100a	22.36	20.59	1.77	9.72	9.70	0.02
10391100b	18.76	17.30	1.46	7.66	6.40	1.26
10391100c	16.23	12.28	3.95	0.08	0.08	0.00
10391100d	23.35	20.81	2.54	9.40	9.38	0.02
10391100e	15.50	13.96	1.54	3.50	2.16	1.34
10391100f	16.47	14.74	1.73	4.37	2.84	1.53
10401100a	48.37	42.69	5.68	47.67	42.19	5.48
10401100b	21.35	19.36	1.98	8.75	8.74	0.01
10401100c	20.94	18.90	2.04	8.81	6.96	1.84

Table 4.6 2000/2001 facility averaged TEQ totals used for comparison to 1994/1995 data

Facility ID #	Non-detects set to detection limits			Non-detects set to zero.		
	Adjusted Total (pg TEQ/g)	Dioxins and Furans (pg TEQ/g)	PCB subset (pg TEQ/g)	Adjusted Total (pg TEQ/g)	Dioxins and Furans (pg TEQ/g)	PCB subset (pg TEQ/g)
10411100a+b	23.97	21.89	2.09	16.08	16.06	0.02
10421100a	18.44	17.03	1.41	7.73	7.72	0.01
10431100a	15.22	13.48	1.74	3.05	1.50	1.54
10441100a+h	25.03	19.27	5.75	15.49	9.98	5.51
10441100b	29.89	23.57	6.32	17.89	17.87	0.02
10441100c	31.05	21.26	9.79	26.26	16.97	9.29
10441100d	111.26	35.91	75.35	103.50	28.15	75.35
10441100e+x	31.81	26.37	5.44	25.27	20.05	5.22
10441100f	33.04	23.18	9.85	26.07	16.68	9.38
10441100g	43.02	36.14	6.87	40.42	33.83	6.59
10441100i+w	46.09	15.84	30.25	36.82	6.73	30.08
10441100j+o	57.38	38.74	18.64	47.31	35.68	11.63
10441100k+s	27.59	20.90	6.69	17.30	11.58	5.72
10441100l	39.55	27.98	11.57	37.96	27.23	10.73
10441100m	65.14	56.34	8.80	56.72	48.85	7.87
10441100n	30.61	22.50	8.10	23.59	15.98	7.61
10441100p	44.65	38.84	5.81	41.18	35.62	5.56
10441100q	40.18	27.72	12.46	37.33	25.93	11.40
10441100r	41.10	34.49	6.61	37.82	31.41	6.42
10441100t	264.04	39.37	224.67	240.72	16.05	224.67
10441100u+v	29.64	24.21	5.43	22.61	19.40	3.21
10441100y	64.30	54.82	9.48	57.91	48.79	9.11
10451100a	23.91	12.80	11.11	0.43	0.43	0.01
10461100a	42.71	34.55	8.15	38.39	30.61	7.78
10471100a	16.41	14.14	2.27	1.95	1.93	0.01
10481100a	13.53	12.38	1.14	0.66	0.65	0.01
10491100a	27.26	23.67	3.59	17.28	17.23	0.05
10501100a	20.28	16.64	3.65	8.85	5.41	3.45
10501100b	15.39	13.46	1.94	3.24	1.50	1.74
10511100a	16.29	14.53	1.76	4.72	3.16	1.57
10521100a	16.40	13.97	2.43	2.86	2.85	0.01
10531100a	61.40	59.84	1.56	56.61	55.23	1.37

Table 4.6 2000/2001 facility averaged TEQ totals used for comparison to 1994/1995 data

Facility ID #	Non-detects set to detection limits			Non-detects set to zero.		
	Adjusted Total (pg TEQ/g)	Dioxins and Furans (pg TEQ/g)	PCB subset (pg TEQ/g)	Adjusted Total (pg TEQ/g)	Dioxins and Furans (pg TEQ/g)	PCB subset (pg TEQ/g)
10541100a	25.73	18.98	6.75	5.97	5.93	0.03
10541100b	34.86	28.65	6.21	27.17	22.34	4.83
10551100a	48.64	37.21	11.42	47.68	36.46	11.22
10561100a	16.08	14.92	1.16	4.13	4.12	0.01
10571100a	39.01	37.04	1.97	32.91	31.12	1.79
10571100b	19.76	15.92	3.84	9.24	9.21	0.03
10581100a	23.43	17.14	6.28	15.51	10.36	5.15
10591100a	20.88	15.71	5.17	4.49	4.48	0.01
10601100a	38.21	30.05	8.17	13.03	13.02	0.01
10611100a	23.12	18.63	4.49	17.12	12.95	4.17
10621100a	26.27	18.99	7.29	13.42	13.36	0.06
10621100b	16.21	13.05	3.16	0.98	0.97	0.01
10621100c	19.60	13.68	5.92	1.90	1.90	0.00
10631100a	14.25	13.01	1.24	0.64	0.63	0.01
10641100a	25.52	23.74	1.78	12.64	12.62	0.02
10641100b	27.39	22.39	4.99	16.90	12.11	4.79
10641100c	62.56	58.95	3.61	47.22	47.21	0.01
10641100d	27.21	20.77	6.44	10.13	10.08	0.05
10641100e	15.89	14.58	1.31	2.42	2.41	0.01
10651100a	33.18	27.26	5.92	29.78	24.06	5.72
10651100b	42.91	33.28	9.63	40.64	31.52	9.12
10651100c	63.39	34.06	29.33	32.41	32.32	0.09
10661100a	36.91	23.28	13.64	30.34	17.15	13.19
10681100a	38.10	29.48	8.63	31.64	23.23	8.41
10691200a	35.06	29.45	5.61	29.29	23.88	5.42
10701200a	25.03	13.04	11.99	0.69	0.69	0.00
10711200a	14.95	13.74	1.21	1.38	1.37	0.01
10711200b	26.42	22.37	4.05	20.44	16.60	3.85
10721200a	19.13	17.03	2.10	10.25	10.23	0.02
10731200a	24.70	19.69	5.01	7.97	7.96	0.01
10731200b	21.41	15.19	6.22	7.91	7.89	0.02
10741200a	21.78	17.52	4.25	10.26	6.28	3.98

Table 4.6 2000/2001 facility averaged TEQ totals used for comparison to 1994/1995 data

Facility ID #	Non-detects set to detection limits			Non-detects set to zero.		
	Adjusted Total (pg TEQ/g)	Dioxins and Furans (pg TEQ/g)	PCB subset (pg TEQ/g)	Adjusted Total (pg TEQ/g)	Dioxins and Furans (pg TEQ/g)	PCB subset (pg TEQ/g)
10741200b	20.17	15.71	4.46	13.17	9.05	4.12
10751200a+b	21.91	18.00	3.92	11.62	9.16	2.46
10761200a+e	49.70	20.85	28.85	14.73	14.70	0.03
10761200d	13.68	11.06	2.61	3.19	0.81	2.38
10771200a	14.64	12.86	1.78	2.86	2.85	0.01
10781200a	44.94	36.24	8.70	29.08	21.23	7.85
10781200b	25.15	16.08	9.07	5.37	5.32	0.05
10781200c	3588.07	3578.61	9.46	3588.07	3578.61	9.46
10791200a	15.43	13.84	1.59	1.42	1.40	0.02
10791200b	17.64	14.36	3.28	4.51	2.06	2.45
10791200c	15.26	13.47	1.79	1.12	1.10	0.02
10791200d	17.61	15.91	1.70	4.65	4.61	0.04
10791200e	18.48	15.34	3.14	3.89	3.87	0.02
10791200f	166.85	89.00	77.85	162.39	88.90	73.48
10791200g	22.74	17.78	4.96	12.59	12.56	0.03
10801200a	32.34	28.62	3.72	22.37	18.83	3.53
10811200a	14.51	13.04	1.47	1.16	1.15	0.01
10821200a	24.34	19.12	5.22	14.59	14.51	0.08
10831200a	16.38	12.94	3.44	4.08	0.83	3.25
10841200a	62.26	45.88	16.38	55.04	42.97	12.08
10851200a	31.62	26.49	5.13	20.56	15.68	4.87
10861200a	24.97	18.41	6.56	13.81	7.44	6.37
10870101a+ 10871200a	46.27	39.91	6.37	36.49	30.33	6.16
10871200b	18.32	15.22	3.09	3.42	3.42	0.00
10881200a	21.35	18.49	2.87	12.29	12.26	0.04
10891200a	21.73	19.27	2.46	15.88	13.71	2.17
10901200a	20.57	15.73	4.84	9.48	9.45	0.03
10911200a	15.29	13.80	1.49	2.74	2.72	0.01
10921200a	28.56	19.43	9.12	3.68	3.62	0.06
10931200b	20.71	17.03	3.68	14.36	10.88	3.47
10941200a	30.39	26.03	4.35	24.64	20.84	3.79
10951200a	16.34	14.01	2.33	4.17	2.28	1.89

Table 4.6 2000/2001 facility averaged TEQ totals used for comparison to 1994/1995 data

Facility ID #	Non-detects set to detection limits			Non-detects set to zero.		
	Adjusted Total (pg TEQ/g)	Dioxins and Furans (pg TEQ/g)	PCB subset (pg TEQ/g)	Adjusted Total (pg TEQ/g)	Dioxins and Furans (pg TEQ/g)	PCB subset (pg TEQ/g)
10961200a	15.21	13.87	1.34	2.88	1.69	1.19
10961200b	19.92	16.92	2.99	4.48	4.43	0.05
10971200a	152.80	147.03	5.77	146.61	146.55	0.06
10981200a	17.19	15.66	1.53	6.06	4.72	1.34
10991200a	22.29	19.29	3.01	8.63	8.60	0.03
11001200a	33.35	29.26	4.09	27.60	23.82	3.79
11010101a	16.09	14.16	1.93	2.41	2.38	0.03
11020101a	48.71	25.63	23.09	20.53	20.45	0.08
11030101a	51.76	47.12	4.64	43.17	43.10	0.06
11040101a	20.31	15.99	4.33	12.81	9.15	3.65
11050101a	25.57	19.78	5.79	14.15	14.11	0.05
11060101a	59.34	47.26	12.08	43.25	43.20	0.05
11070101a	18.66	16.64	2.01	6.22	6.20	0.02
11080101a	36.69	34.02	2.67	26.43	23.95	2.48
11090101a	14.23	12.65	1.58	1.95	0.57	1.38
11100101a	25.36	13.80	11.55	1.45	1.43	0.02
11100101b	21.70	13.85	7.85	1.60	1.54	0.05
11110101a	118.46	103.89	14.58	116.15	101.74	14.40
11120101a	31.45	18.37	13.08	13.09	13.07	0.02
11130101a	35.06	30.45	4.61	27.78	27.76	0.02
11140101a	21.66	16.55	5.11	9.88	9.85	0.04
11150501a+b	28.15	19.10	9.05	21.14	12.19	8.95

Table 4.7 Characteristics of 2000/2001facility averaged TEQ mass fraction data

Treatment of non-detects	Data subset	Number of samples (N)	Mean (pg TEQ/g)	Standard deviation (pg TEQ/g)	Standard error of the mean (pg TEQ/g)	Median (pg TEQ/g)
Detection limits	Adjusted Total	182	52.5	265.1	19.6	25.0
	Dioxins and Furans	182	44.1	264.0	19.6	19.2
	PCB subset	182	8.35	19.1	1.42	4.79
Zero	Adjusted Total	182	41.1	266.0	19.7	13.3
	Dioxins and Furans	182	36.1	264.8	19.6	11.3
	PCB subset	182	5.04	18.5	1.37	1.54

Table 4.8 Characteristics of logarithmically transformed 2000/2001 facility averaged TEQ mass fraction data

Treatment of non-detects	Data subset	Number of samples (N)	Mean	Standard deviation	Standard error of the mean
Detection limits	Adjusted Total	182	3.34	0.64	0.05
	Dioxins and Furans	182	3.09	0.60	0.04
	PCB subset	182	1.57	0.88	0.07
Zero	Adjusted Total	182	2.42	1.38	0.10
	Dioxins and Furans	182	2.19	1.37	0.10
	PCB subset	179	-0.82	2.82	0.21

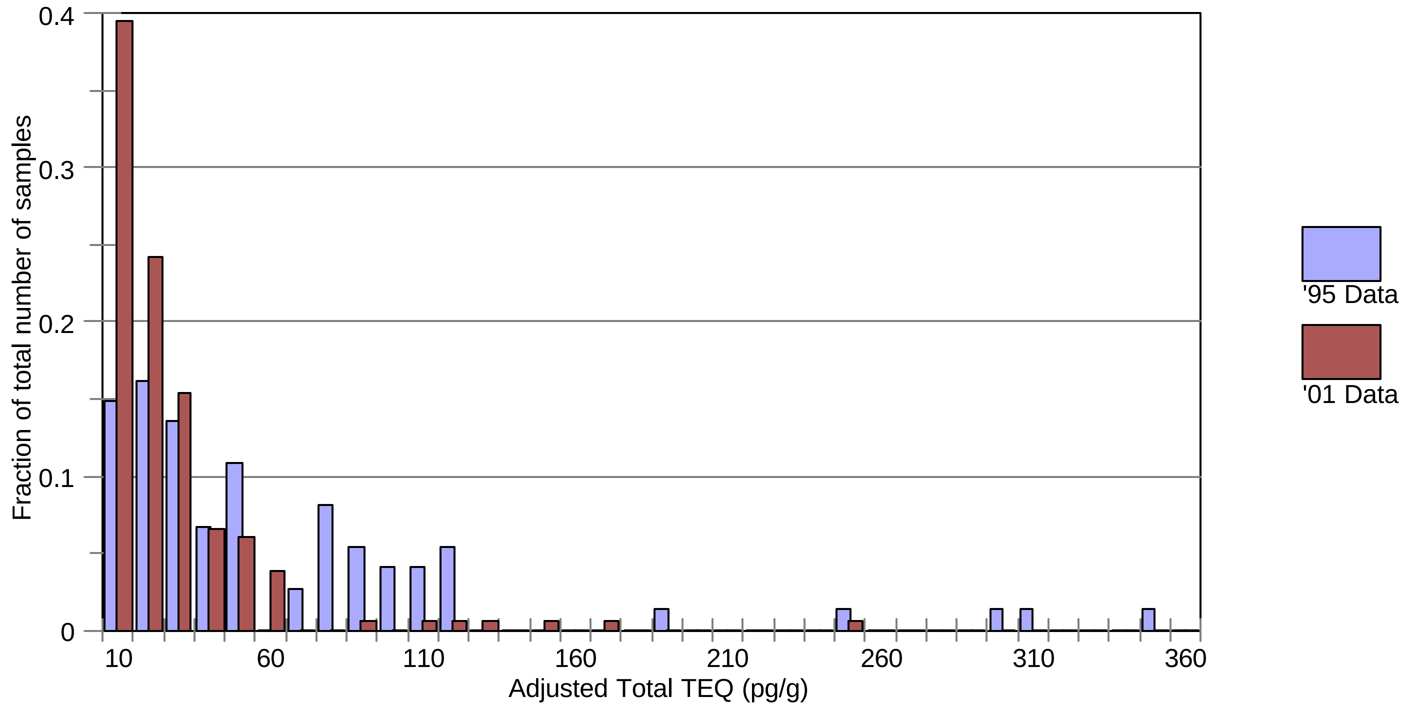

Figure 4.1 Histogram comparing adjusted TEQ distribution totals for both 1994/1995 and 2000/2001 facility-averaged data. Non-detected congeners are assumed to have a mass fraction of zero.

Table 4.9 *F* and *t* test results for comparison of 1994/1995 and 2000/2001 facility averaged data

Treatment of non-detects	Data subset	Numerator Degrees of freedom	Denominator Degrees of freedom	*F* score	*t* test degrees of freedom	*t* statistic	*t* probability (2-tailed test)
Detection limits	Adjusted Total	73	181	1.45	254	**7.99**	**4.60e-14**
	Dioxins and Furans	73	181	1.34	254	**8.14**	**1.76e-14**
	PCB subset	73	181	1.38	254	**7.33**	**3.05e-12**
Zero	Adjusted Total	73	181	0.60	254	**6.48**	**4.69e-10**
	Dioxins and Furans	73	181	0.20	254	**4.81**	**2.61e-06**
	PCB subset	73	178	0.20	251	**9.47**	**2.17e-18**
Statistically significant (to 95% level of confidence) *t* scores are in boldface.							

58 Charles Street Cambridge, Massachusetts 02141
617-225-0810 FAX: 617-225-0813 E-mail: info@CambridgeEnvironmental.com

5 Multiple Linear Regression Analyses

5.1 Introduction

In this chapter, we evaluate whether the characteristics of the facilities from which the samples were taken in 2000/2001 are correlated with the TEQ mass fractions found, the degree of such correlation, and the usefulness of such correlations as predictors of TEQ mass fraction, assuming that the observed correlations are not just accidental. For this analysis, non-detected congeners were treated under two assumptions. In the first, non-detected congeners were assumed to be absent. In the second, non-detected congeners were assumed to be present at detection limits. Unless otherwise stated, statements in the text of this chapter assume non-detected congeners are absent.

Finding a strong correlation might suggest follow-up study to determine the reason for the correlation, and might subsequently lead to corrective or ameliorative action to reduce TEQ mass fractions in particular circumstances. In view of the lack of any prior hypotheses, the analysis is limited to evaluation of linear models relating reported or inferred characteristics of the facilities (or transforms of their numerical values) with the logarithm of TEQ mass fraction. The entire set of analyses must be considered a "data-dredging" exercise, since the study design strictly allows no causal inferences or generalizations — any correlations found cannot be considered causal or even predictive without further evaluation. The questionnaire completed by survey participants can be found in Appendix A.

Several responses to questions requesting a numeric response were provided as ranges or qualitatively. Where a range was given (*i.e.*, for average daily flow, percent industrial loading, percent service area with combined sewers, or average percent solids in final biosolids), the mid-point of the range was coded. Where only an upper bound was provided (*i.e.*, for percent industrial loading and percent service area with combined sewers) that upper bound was coded. When only a lower bound was provided (*i.e.*, for percent service area with combined sewers), that lower bound was coded. For total annual biosolids, if values for two separate products were given, the values were added together to get the total for the facility. For average percent solids in final biosolids, if two values were given for two separate products, the larger of the two was coded. The responses of "insignificant" and "minimal" were coded as zero. Other qualitative responses to questions requesting a numeric response, such as "not indicated" or "undefined," were coded as missing data.

5.2 Regional Statistics

Tables 5.1 through 5.6 list the summary statistics for logarithmically transformed TEQ data when samples are sorted by U.S. EPA region. Figures 5.1 through 5.6 display the box-and-whisker plots of the data for each region.

Tables 5.7 through 5.12 present analysis of variance tables for the logarithmically transformed TEQ data. These tables are used to compare the means of multiple samples (Box, *et al.*, 1978). The analysis assumes that within each region there is some normally distributed population (in this case, some population of biosolids with lognormally distributed TEQ mass fraction), that we have a random sample from each such population, and that the population in each region has the same within-region variance. The purpose of the analysis of variance table is then to determine if the variance between regional means is explicable by the variance within regions, assuming that the means within each region are identical. It is important to note that the underlying assumptions of this analysis may not be satisfied for the logarithmically transformed TEQ data. The population of biosolids is not well-defined. As the survey was voluntary, the samples obtained within each region do not represent a random sample of POTWs or biosolids within each region. Furthermore, there is no *a priori* reason for each region to have the same variance. Nevertheless, the analysis of variance table may still be used to see how the variance between regions compares with the pooled variance within regions to give a rough estimate of the importance of the variation of means between regions.

Box *et al.* (1978) describe the procedure for calculating the terms of the analysis of variance table. The calculation results in a within-region variance (mean square) estimate and a between-region variance (mean square) estimate. These variances are then compared using an F test to assess significance. For logarithmically transformed regional total TEQ and PCB TEQ, the means in different regions are apparently different (we chose to test at what would be a 95% confidence level for random samples). This suggests that total TEQ and PCB TEQ values might vary between U.S. EPA Regions, although the evidence is weak considering the assumptions required and the number of statistical tests performed. Figures 5.1 and 5.2 show the median total TEQ mass fractions for Region 1 to be well below the 10^{th} percentile for Regions 2 and 7, while Figures 5.5 and 5.6 show the same for PCB TEQ. However, it is possible that these regional variations are artifacts of the sampling method or simply random variation. Thus, while there may be regional differences in total TEQ or PCB TEQ mass fractions, further sampling designed to test such a hypothesis would be required to confirm it.

5.3 *TEQ mass fractions versus single numeric variables*

Several simple linear regressions were used to test whether a single numeric variable, such as average daily flow to a POTW, might be used to predict the TEQ mass fractions of biosolids from that facility. Four numeric variables were evaluated in this manner: average daily flow to a POTW, percent solids in the sample, percent industrial loading of a POTW, and percent of service area with combined sewers. For each regression, two standard significance tests were performed as indicators of potentially useful correlations, using the 95th percentile as an initial demarcation of such a potentially useful indicator.[1] The first tested for a non-zero correlation coefficient (*r*), and the second for a non-zero slope in the regression.[2]

The results of the regression of the average daily flow values for POTWs versus the logarithmically transformed TEQ data from those POTWs. The results of the simple linear regression are presented in Table 5.13. Figures 5.7 through 5.12 present the logarithmically transformed TEQ and average daily flow data, along with the calculated regression lines and 90% prediction intervals of the regression. The correlation coefficient for total and PCB logarithmically transformed TEQ mass fractions with average daily flow were apparently non-zero, as were the coefficients in the correlation for total, dioxin/furan, and PCB logarithmically transformed TEQ.

However, the fraction of variance accounted for by the regression (estimated as r^2) is 6% or less for these correlations, suggesting that, while the correlation coefficients may not be zero, they are far to small to usefully predict the TEQ mass fraction of biosolids leaving a given POTW. This is further illustrated by the large prediction intervals calculated for each regression, as shown in Figures 5.7 through 5.12. For example, for POTWs where the average daily flow is 100 million gallons a day (MGD), 90% are predicted to have logarithmically transformed total TEQ values that vary from approximately 0.3 to 4.7, giving untransformed TEQ mass fractions of 1.3 pg TEQ./g to 130 pg TEQ/g, a range of approximately two orders of magnitude. Thus, the average daily flow to a POTW cannot predict the TEQ mass fraction of biosolids leaving that POTW.

Identical conclusions are obtained if the independent variable in the correlation is taken to be the logarithm of average daily flow, rather than the average daily flow itself, although we do not show these analyses.

---

[1] As stated before, as the survey may not be a random sample, no precise probabilistic confidence-level statements can be made. The 95th percentile used here is simply used as a cutoff value, and does not imply a 95% confidence level in the results.

[2] In a linear regression of the form $y = mx+b$, the slope of x in the regression is m. The corellation coefficient is r, calculated as bs_x/s_y, where s_x and s_y are the standard deviations of the x and y variables, respectively.

In addition to the regressions just described, samples were segregated into two groups, one for POTWs with average daily flows below 1 MGD and one for POTWs with average daily flows above 1 MGD, in order to determine whether there is a significant difference between the TEQ distributions of these two groups. Summary statistics for these samples are presented in Tables 5.14 and 5.15. Table 5.16 presents the results of F and t tests comparing these groups. The F-tests on standard deviations suggest that the POTWs with average daily flows less than 1 MGD may be more homogeneous than larger POTWs for dioxin/furan TEQ. However, the t-tests do not suggest any significant difference between the mean TEQ mass fractions of these groups.

Simple linear regressions and standard statistical tests were performed for the percent solids in a sample as received by MRI, just as for average daily flow, and with the same caveat. The results are presented in Table 5.17. Figures 5.13 through 5.18 present the logarithmically transformed TEQ and percent solids, along with the calculated regression lines and 90% prediction intervals of the regression. None of the correlations coefficients or slopes of correlation test as significantly different from zero. Furthermore, these regressions account for no more than 0.3% of the variance between the samples, and Figures 5.13 through 5.18 show that the prediction intervals for these simple regressions are almost as large as those for the regressions of average daily flow to a POTW. Thus, the percent solids in a biosolids sample does not appear to be a useful predictor of the TEQ mass fraction of that sample.

The results of the simple linear regression of percent industrial loading versus TEQ mass fraction are presented in Table 5.18, and the regression lines and 90% prediction intervals are shown in Figures 5.19 through 5.24. Only three of the regressions show significant correlations: PCB TEQ mass fraction when non-detected congeners are set to detection limits, and total and dioxin/furan TEQ when non-detects are set to zero. The fact that the importance of the correlations depends on the treatments of the non-detected congeners suggests an artifact. In addition, these regressions account for no more than 3% of the variance between samples, and also give unreasonably large prediction intervals. Thus, the percent industrial loading of a POTW does not appear to be a useful predictor of the TEQ mass fraction of a sample.

Finally, the results of the simple linear regression of percent service area with combined sewers with TEQ mass fraction are presented in Table 5.19, and the regression lines and prediction intervals are shown in Figures 5.25 through 5.30. Both the correlation coefficients and slopes of all six of these regressions test as potentially significant, and the regressions account for 9% of the total TEQ variance and 18% of the PCB TEQ variance. However, even for this regression the 90% prediction interval is too large for this variable to provide a useful prediction of the TEQ mass fraction of a sample: the prediction interval at 0% service area with combined sewers is approximately 4.1, leaving an over 50-fold variation in the prediction of untransformed TEQ values. Thus, neither percent of service area with combined sewers, nor any of the other three numeric variables analyzed, appears to be a useful predictor of the TEQ mass fraction of a sample.

5.4 Multiple linear regression of questionnaire variables

Several multiple linear regression analyses were performed in order to determine if any of the responses to the questionnaire in Appendix A were correlated with TEQ mass fractions, or whether a linear combination of these variables might provide a useful predictor of TEQ mass fraction. The analysis assumes that samples were random from some relevant population; but the previous cautions (see Section 5.3) apply. All probability values cited herein must be considered simply as relative indicators of potential importance, and they cannot be used for any probabilistic confidence statements. The sample data matrix of questionnaire responses is presented in Appendix G, with each row corresponding to a single sample and each column corresponding to a questionnaire response. The variables initially included in the regressions are shown in Table 5.20.

Numeric variables were entered into the matrix using the value given for each sample. Qualitative descriptive variables (*i.e.*, regional variables, process variables, and sample description variables) were entered with a 1 denoting a positive response or a 0 denoting a negative response.

Responses to the questionnaire queries were incomplete for some samples. Samples with incomplete numeric responses (that is, any numeric response not provided or not interpretable) were excluded from analysis when numeric variables were being analyzed. In addition, several of the qualitative variables had very few positive responses. In accordance with the usual guideline, variables with fewer than three positive responses were omitted from the analyses reported here. In addition, if two variables were themselves highly correlated (*e.g.*, average daily flow and total annual biosolids), only one was used, as analyzing both simultaneously would result in arbitrary values for their regression coefficients. The list of excluded variables is given in Table 5.19.

A stepwise approach was adopted to simplify the analysis. Variables were analyzed in groups according to variable type: numeric, regional, process, or sample description. Each group was then regressed against the total TEQ mass fractions for each sample, first with non-detected congeners treated as zero and then with non-detected congeners taken at the detection limit (Sections 5.4.1 to 5.4.4). Standard significance tests were then applied to examine whether the coefficients differed from zero, using a cutoff value of 90% confidence level as an indicator of potential importance (see the statements above about interpretation of such statements). Variables for which the coefficients were different from zero at a 90% confidence level in the group analyses for both treatments of non-detected congeners were then combined into an overall regression, with certain omissions to prevent the use of highly correlated variables (Section 5.4.5).

5.4.1 Numeric variables

The regression results for the six numeric variables are presented in Tables 5.22 through 5.25. Samples for which any numeric data were unavailable (*i.e.*, the value "ERR" is present in the matrix in Appendix G) were excluded form this regression, leaving 129 samples. The regression of the six numeric variables versus the logarithmically transformed total TEQ only accounts for approximately 11% of the variance of the samples ($r^2 = 0.11$). Thus, the correlation of total TEQ mass fractions with the numeric variables is unlikely to provide a precise prediction of the TEQ mass fractions of biosolids leaving a POTW.

Of the six numeric variables, none appear to be potentially important: that is, none of the coefficients are different from zero when a 90% confidence level is used as the cutoff value. Thus no numeric variables are included in the overall regression performed in Section 5.4.5.

5.4.2 Regional variables

The regression results for the regional variables are presented in Tables 5.26 through 5.29. The regression of the nine regional variables versus the logarithmically transformed total TEQ only accounts for approximately 11% of the variance of the samples ($r^2 = 0.11$). Thus, the correlation of total TEQ mass fractions with region is unlikely to provide a precise prediction of the TEQ mass fractions of biosolids leaving a POTW.

Of the nine regional variables, only one appears to be potentially important: the variable coding for Region 2. The variable coding for Region 4 also passes the 90% confidence test when non-detected are assumed to be present at detection limits, but not when non-detected congeners are assumed to be absent, suggesting that the suggested importance of the Region 4 variable is an artifact of the sampling method. Thus, only the variable coding for Region 2 is included in the overall regression performed in Section 5.4.5.

5.4.3 Process variables

The results of the regression of logarithmically transformed total TEQ mass fractions versus process variables (defined as responses related to the processing of biosolids) are presented in Tables 5.30 through 5.33. The process variable regression accounted for 21% of the variation between samples, and thus these variables do not strongly predict the TEQ mass fraction of biosolids leaving a specific POTW.

Four process variables were found to be potentially important: anaerobic digestion, centrifuge, air drying, and filter press. These process variables were thus included in the overall regression in Section 5.4.5.

5.4.4 Sample description variables

Regressions of sample description variables on logarithmically transformed total TEQ mass fractions were performed (Tables 5.34 through 5.37), simply to ensure that no possible clue to high TEQ mass fractions (among the descriptors of these samples) was overlooked. These variables are not suitable for inclusion in any overall regression, since the descriptors are not well-defined, several correspond to process variables evaluated elsewhere, there is no guarantee that similar descriptors would be applied to similarly handled biosolids in different POTWs, and several descriptors could equally be applied to some biosolids (although the questionnaire limited the response to just one descriptor).

The regression accounted for 21% of the variation between samples. Although one process description variable, anaerobically digested biosolids, was potentially useful according to the criteria selected, this corresponds to the process variable anaerobic digestion which was already evaluated. Thus, sample descriptors do not apparently add any further predictive information with respect to TEQ mass fractions in the samples, and are not included in the overall regression in Section 5.4.5.

5.4.5 Combined regressions

The selected variables from Sections 5.4.1 through 5.4.4, shown in Table 5.38, were combined and regressed against the total TEQ, dioxin/furan TEQ, and PCB TEQ mass fraction in each sample using both treatments of non-detected congeners, giving six regressions in total. The results of these regressions are presented in Tables 5.39 through 5.50.

Tests of the five selected variables suggest that they may have useful predictive power. The regression of total TEQ mass fraction versus the five variables given in Table 5.38 accounts for 21% of the variation between samples. The regression of the logarithm of PCB TEQ mass fraction versus the five variables in Table 5.38 accounts for 28% of the variation, the highest of any of the regressions evaluated; however, that leaves approximately three-fourths of the variation between samples unaccounted for. Thus this correlation, even if it is applicable in general, is unlikely to have any significant predictive power, at least on a POTW by POTW basis: the 90% prediction interval of the total TEQ regression is 3.89 on a logarithmic scale, or a 50-fold variation in the untransformed values, too large for useful predictions. The same argument holds for the regressions versus dioxin/furan and PCB TEQ mass fractions.

In addition, it cannot be shown from the analyses given here that a particular process change will increase or decrease the TEQ mass fractions from a given POTW. First, several variables may be hiding other, unmeasured variables, which are the true causes of the observed effects. Second, the data used in the regression are not from a random sample of the population as assumed by the regression. Rather, the data are contributed by facilities that chose to participate in the AMSA survey. Thus, variables that are determined to be potentially important by the regression modeling may only be so because of the method of sample collection. For example, the coefficient for the use of a filter press is negative. However, this may simply be because facilities with filter presses and high TEQ mass fractions declined to participate in the survey. Therefore, further experimentation and analysis is needed to confirm any of the trends observed in the regression of the AMSA 2000/2001 survey samples, and changes in a POTW's process may not result in the increases and decreases of TEQ mass fractions predicted by the regression.

We now examine the results for each variable in turn:

"Region 2" is suggested to be predictive by all six regressions. The coefficients for "Region 2" are all positive, suggesting that TEQ mass fractions are higher in Region 2 than in other regions. This is roughly consistent with the results of Section 5.2, which suggested differences in the mean TEQ values between regions. However, the apparent importance of this variable may be an artifact of sampling: it is possible that POTWs in Region 2 with lower TEQ mass fractions chose not to participate in the survey. The maximum size of the coefficient for Region 2 is 0.87 (for PCB TEQ when non-detected congeners are assumed to be absent). The maximum variation suggested by this variable can be estimated as the difference between the product of the estimated coefficient and the maximum value of the variable (1) and the product of the estimated coefficient and the minimum value of the variable (0). Thus, the maximum variation suggested by "Region 2" is 0.87 on a logarithmic scale, or a variation of 2.4-fold in untransformed TEQ mass fractions.

"Anaerobic digestion" is suggested to be predictive by all six regressions. The coefficients for "anaerobic digestion" are all positive, suggesting that TEQ mass fractions are generally higher in biosolids dried with drying beds. However, the maximum variation suggested is only a factor of 2.0.

"Centrifuge" is suggested to be predictive in four regressions: dioxin/furan TEQ when non-detects are set to zero, PCB congeners when non-detected congeners are set to detection limits, and total TEQ for both treatments of non-detected congeners. The fact that the treatments of the non-detected congeners affect the significance of the coefficients suggests an artifact of sampling or process data collection. It is possible that "centrifuge" is accounting for some of the variation due to the different detection limits used for the various samples. The coefficients are negative, suggesting that centrifugation is associated with lower TEQ values. However, it is unclear how centrifugation could decrease the TEQ level of a sample. The maximum size of the coefficient is approximately -0.43, corresponding to a maximum variation of 0.43 on a natural logarithmic scale, or about a factor of 1.5-fold.

"Air drying" is suggested to be predictive in all regressions except PCB TEQ when non-detects are set to detection limits. The fact that the treatments of the non-detected congeners affect the significance of the coefficients suggests an artifact of sampling. The coefficients are positive, suggesting that air drying is associated with higher TEQ values. However, it is unclear how air drying could increase the TEQ level of a sample. The maximum size of the coefficient is approximately 1.81, corresponding to a maximum variation of 1.81 on a natural logarithmic scale, or about a factor of 6.1-fold.

“Filter press” is suggested to be predictive in all six regressions. The coefficients are negative, suggesting that filter pressing is associated with lower TEQ values. However, it is unclear how filter pressing could decrease the TEQ level of a sample. The maximum size of the coefficient is approximately -0.98 corresponding to a maximum variation of 0.98 on a natural logarithmic scale, or about a factor of 2.7-fold.

In summary, the results of the final overall regression using the variables from Table 5.38 suggest some predictive power, but the collective ability to predict the TEQ level of a given sample from a POTW would be relatively small, as the regression only explains approximately 21% of the variance between samples. Furthermore, the combined maximum variations of these five variables account for an approximate 100-fold variation in TEQ, where the observed maximum variation is over 10,000-fold. The listed five variables may be causally linked to TEQ mass fractions, correlated with causal variables, or the results found here may be an artifact of the sample or data collection procedures.

Table 5.1 Logarithmically transformed total TEQ statistics by U.S. EPA region (non-detects set to zero)

Region	1	2	3	4	5	6	7	8	9	10
Number of Samples	2	33	32	26	43	12	9	11	16	16
Mean	1.56	3.32	2.55	2.92	2.47	2.04	2.82	2.62	1.84	2.57
Standard Deviation	0.07	0.91	1.15	1.51	1.45	1.02	0.62	1.38	1.31	1.20
Standard Error of the mean	0.05	0.16	0.20	0.30	0.22	0.29	0.21	0.42	0.33	0.30
Median	1.56	3.47	2.72	2.98	2.57	2.41	2.87	2.47	1.84	2.93

Table 5.2 Logarithmically transformed total TEQ statistics by U.S. EPA region (non-detects set to detection limits)

Region	1	2	3	4	5	6	7	8	9	10
Number of Samples	2	33	32	26	43	12	9	11	16	16
Mean	2.82	3.70	3.37	3.60	3.41	3.04	3.48	3.49	3.08	3.37
Standard Deviation	0.03	0.58	0.51	1.03	0.69	0.30	0.43	0.59	0.37	0.31
Standard Error of the mean	0.02	0.10	0.09	0.20	0.11	0.09	0.14	0.18	0.09	0.08
Median	2.82	3.66	3.27	3.32	3.22	3.03	3.39	3.19	3.00	3.43

Table 5.3 Logarithmically transformed total dioxin/furan TEQ statistics by U.S. EPA region (non-detects set to zero)

Region	1	2	3	4	5	6	7	8	9	10
Number of Samples	2	33	32	26	43	12	9	11	16	16
Mean	1.12	2.72	2.11	2.58	1.94	1.62	2.48	2.35	1.53	2.15
Standard Deviation	0.42	0.90	1.30	1.59	1.57	1.27	1.09	1.45	1.39	1.27
Standard Error of the mean	0.30	0.16	0.23	0.31	0.24	0.37	0.36	0.44	0.35	0.32
Median	1.12	2.83	2.33	2.58	2.21	2.13	2.67	2.13	1.55	2.62

Table 5.4 Logarithmically transformed total dioxin/furan TEQ statistics by U.S. EPA region (non-detects set to detection limits)

Region	1	2	3	4	5	6	7	8	9	10
Number of Samples	2	33	32	26	43	12	9	11	16	16
Mean	2.67	3.25	3.02	3.30	3.07	2.82	3.06	3.20	2.86	3.03
Standard Deviation	0.04	0.43	0.41	1.09	0.62	0.28	0.38	0.66	0.32	0.31
Standard Error of the mean	0.03	0.07	0.07	0.21	0.10	0.08	0.13	0.20	0.08	0.08
Median	2.67	3.17	2.87	2.97	2.84	2.81	3.00	2.96	2.73	3.09

Table 5.5 Logarithmically transformed total PCB TEQ statistics by U.S. EPA region (non-detects set to zero)

Region	1	2	3	4	5	6	7	8	9	10
Number of Samples	2	33	32	26	42	12	9	11	16	16
Mean	0.07	2.10	1.21	1.22	1.29	0.47	1.00	0.98	0.26	1.33
Standard Deviation	1.30	1.32	1.10	1.24	1.44	1.30	0.51	1.40	1.23	1.27
Standard Error of the mean	0.92	0.23	0.20	0.24	0.22	0.38	0.17	0.42	0.31	0.32
Median	0.07	2.43	1.17	1.02	1.44	0.74	1.00	1.14	0.06	1.81

Table 5.6 Logarithmically transformed total PCB TEQ statistics by U.S. EPA region (non-detects set to detection limits)

Region	1	2	3	4	5	6	7	8	9	10
Number of Samples	2	33	32	26	43	12	9	11	16	16
Mean	1.12	2.72	2.11	2.58	1.94	1.62	2.48	2.35	1.53	2.15
Standard Deviation	0.42	0.90	1.30	1.59	1.57	1.27	1.09	1.45	1.39	1.27
Standard Error of the mean	0.30	0.16	0.23	0.31	0.24	0.37	0.36	0.44	0.35	0.32
Median	1.12	2.83	2.33	2.58	2.21	2.13	2.67	2.13	1.55	2.62

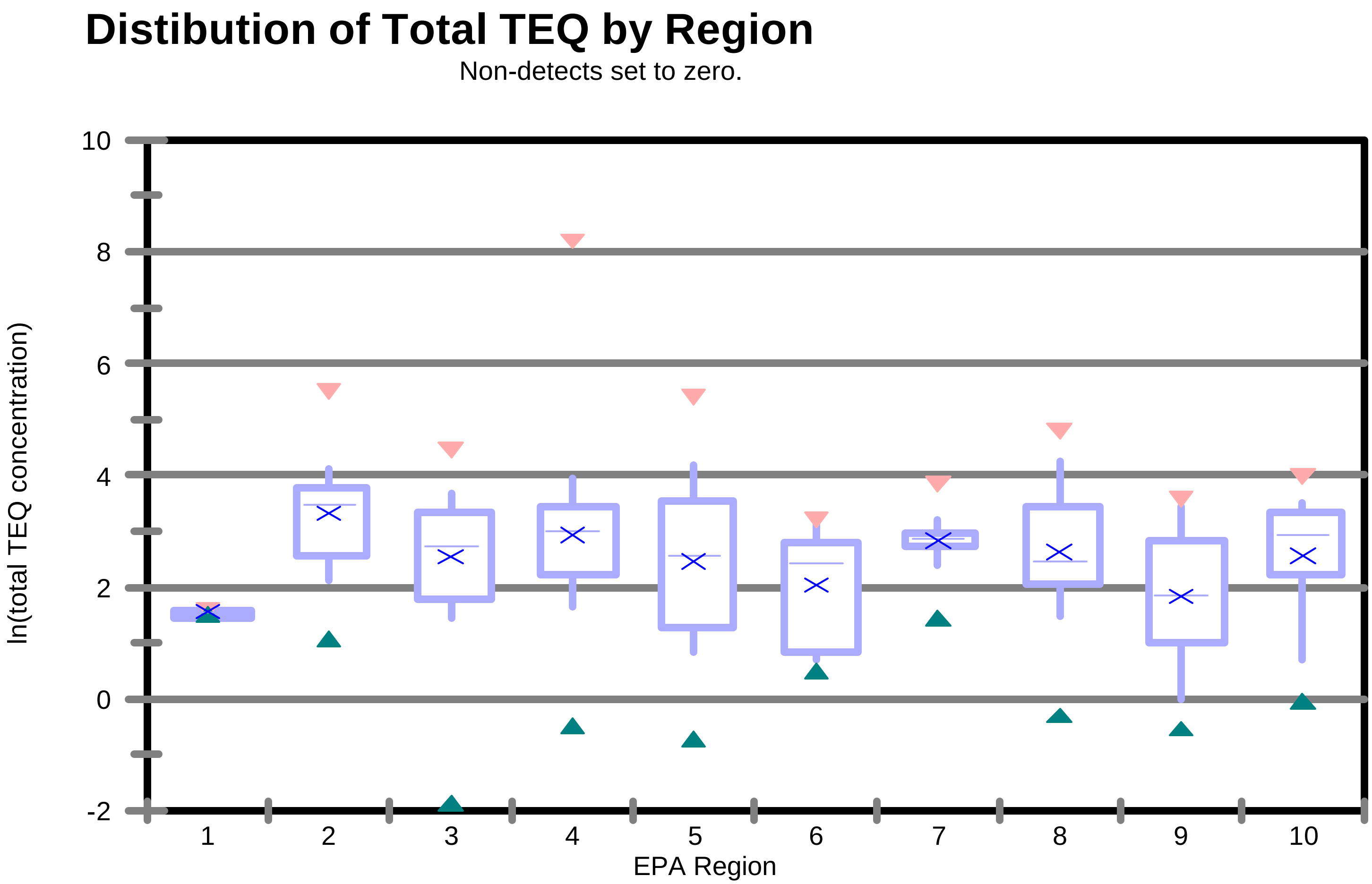

Figure 5.1 Distribution of total TEQ mass fractions by U.S. EPA region. Non-detects set to zero.

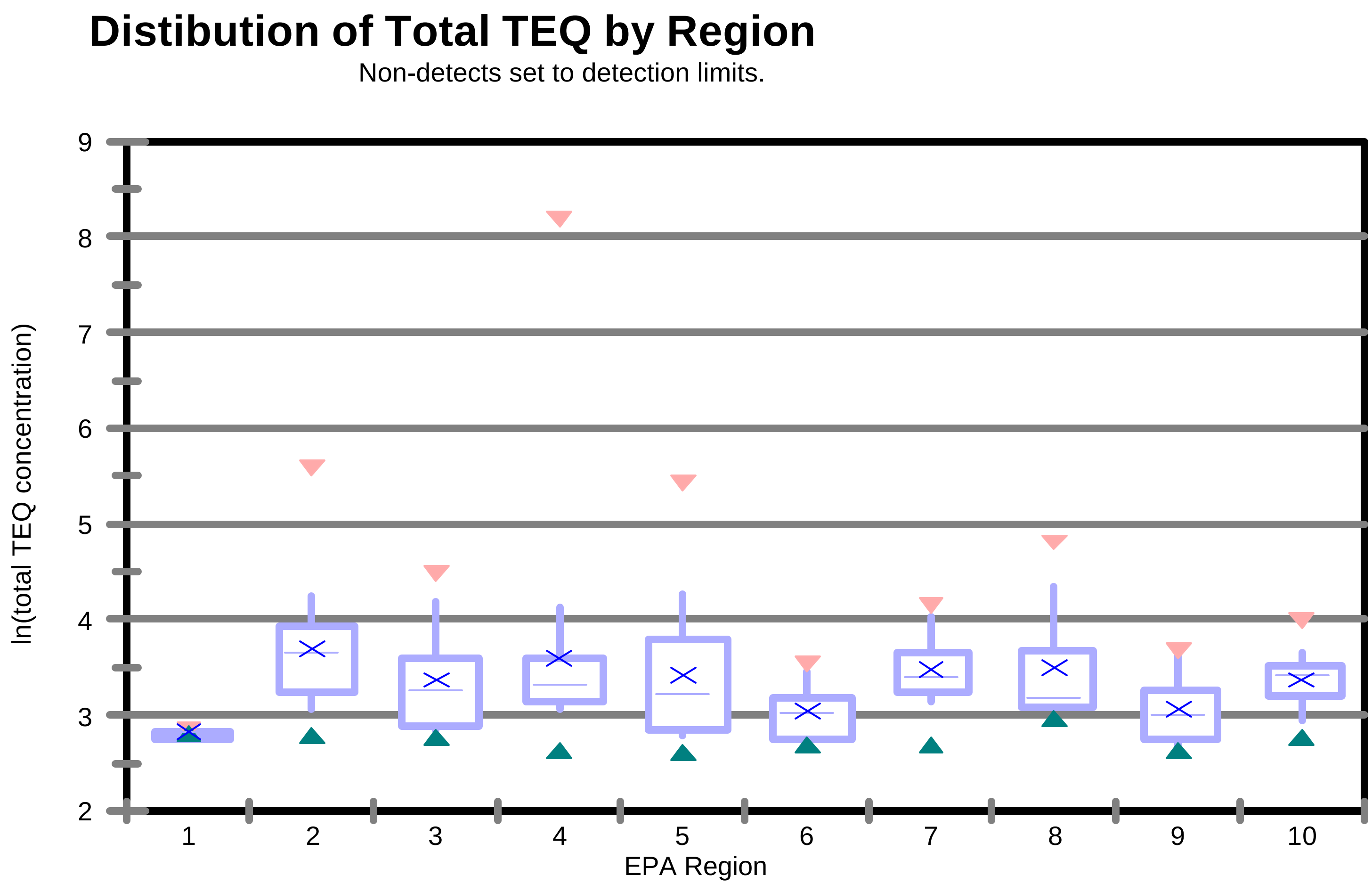

Figure 5.2 Distribution of total TEQ mass fractions by U.S. EPA region. Non-detects set to detection limits.

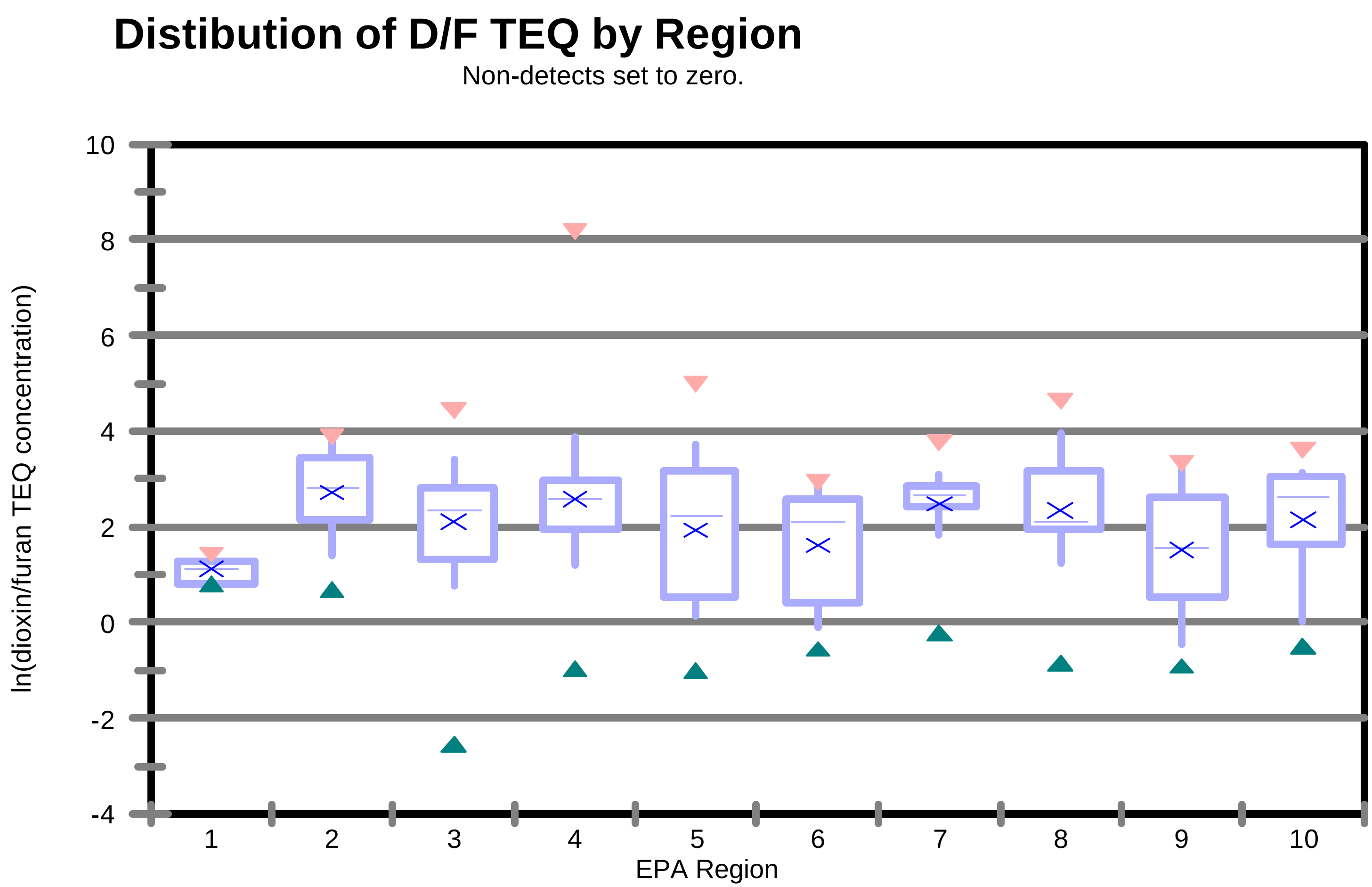

Figure 5.3 Distribution of dioxin/furan TEQ mass fractions by U.S. EPA region. Non-detects set to zero.

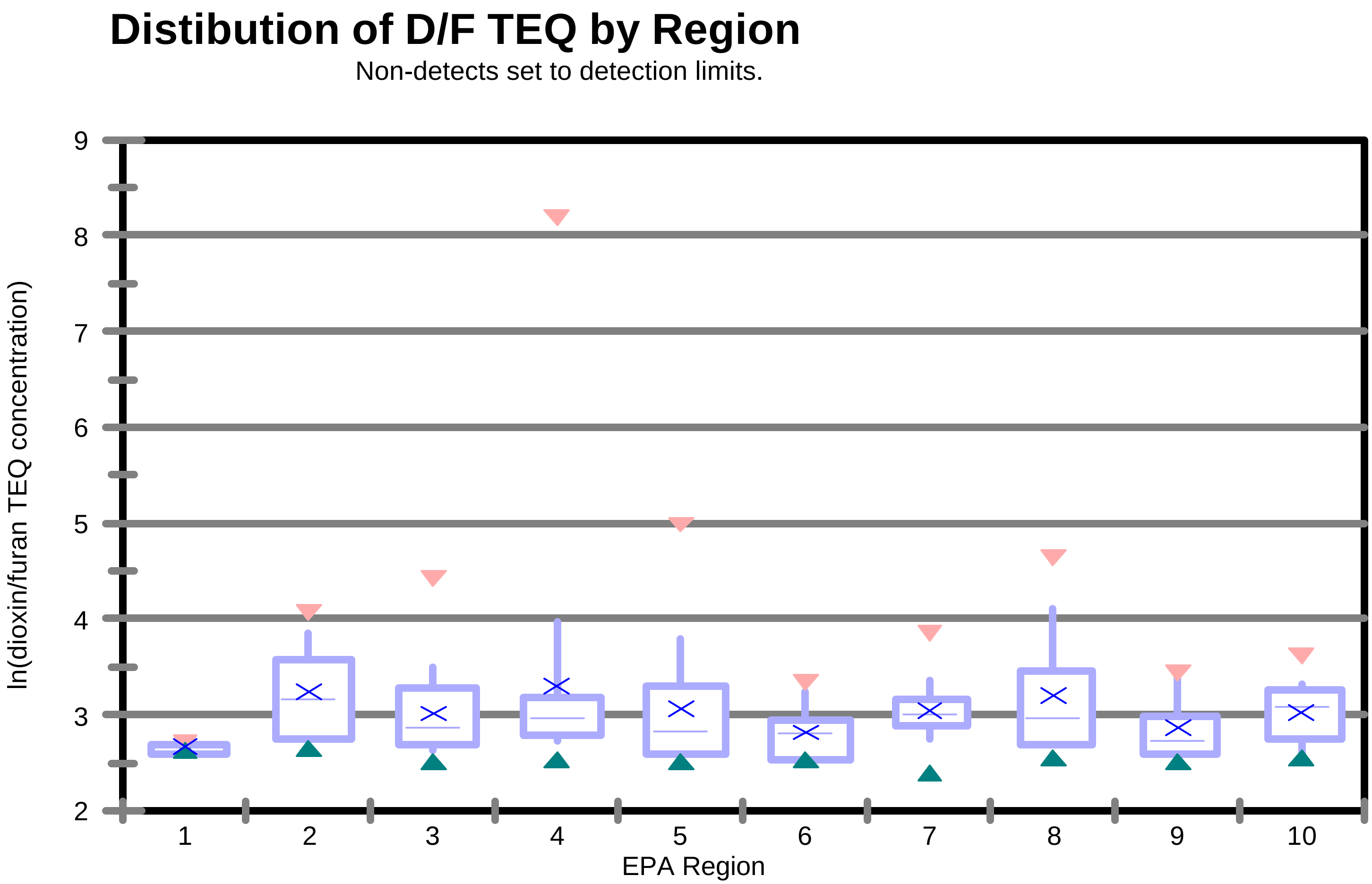

Figure 5.4 Distribution of dioxin/furan TEQ mass fractions by U.S. EPA region. Non-detects set to detection limits.

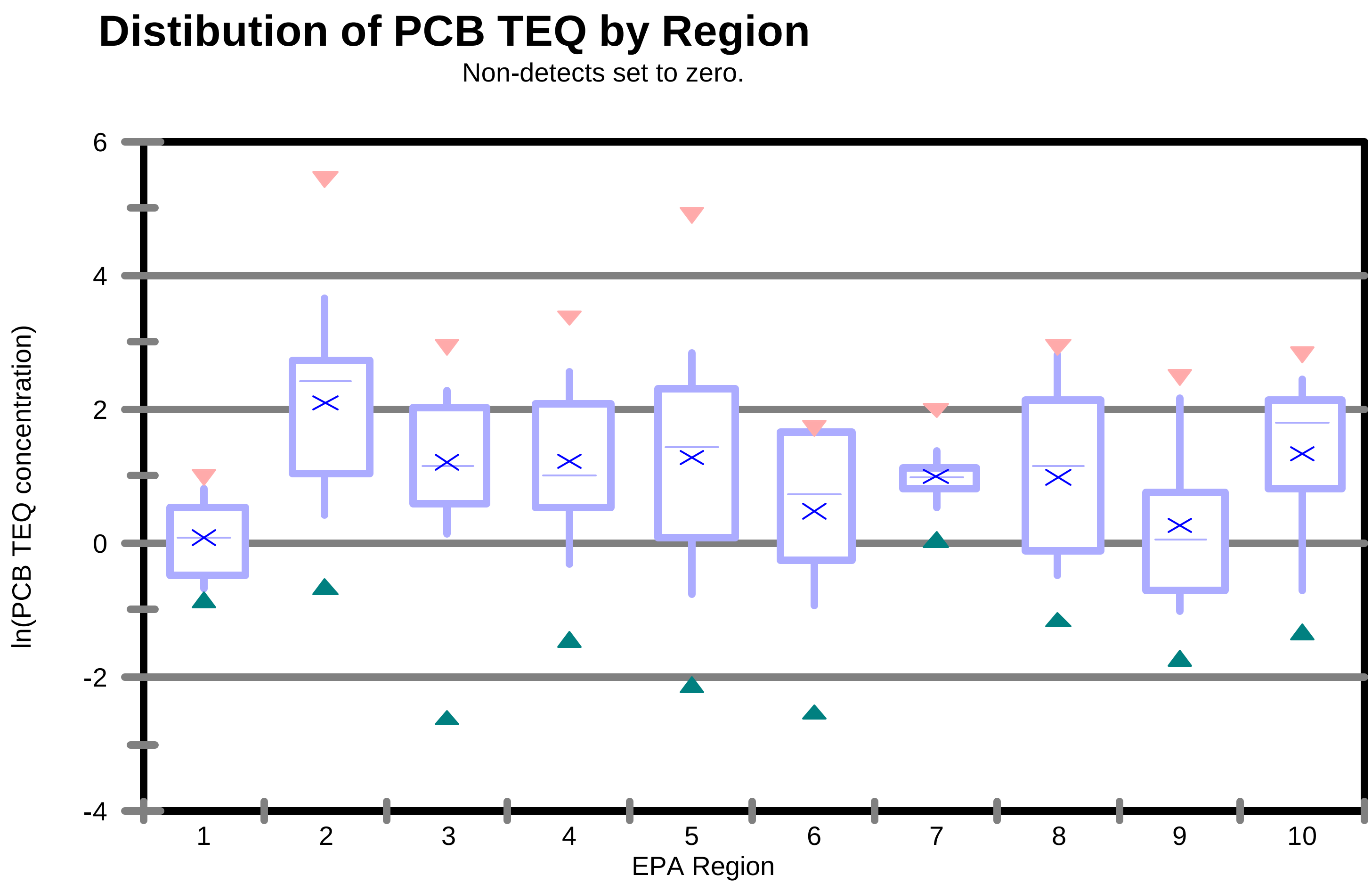

Figure 5.5 Distribution of PCB TEQ mass fractions by U.S. EPA region. Non-detects set to zero.

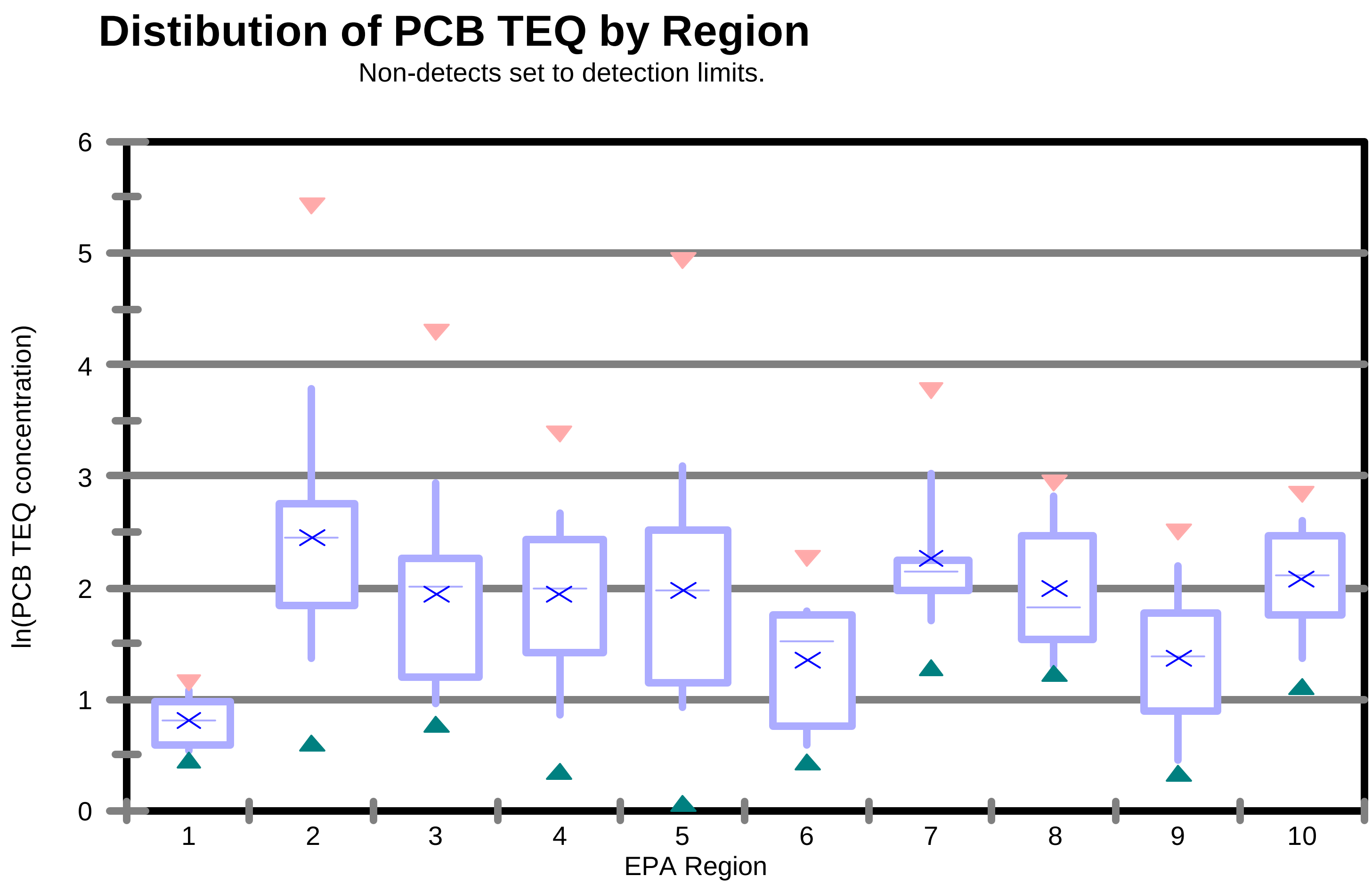

Figure 5.6 Distribution of PCB TEQ mass fractions by U.S. EPA region. Non-detects set to detection limits.

Table 5.7 Analysis of variance table for logarithmically transformed total TEQ (non-detects set to zero).

Source of variation	Sum of squares	Degrees of freedom	Mean square	*F* score	*F* probability
Between regions	36.26	9	4.03	2.61	0.01
Within regions	293.65	190	1.55		

Table 5.8 Analysis of variance table for logarithmically transformed total TEQ (non-detects set to detection limits).

Source of variation	Sum of squares	Degrees of freedom	Mean square	*F* score	*F* probability
Between regions	8.02	9	0.89	2.26	0.02
Within regions	75.10	190	0.40		

Table 5.9 Analysis of variance table for logarithmically transformed total dioxin/furan TEQ (non-detects set to zero).

Source of variation	Sum of squares	Degrees of freedom	Mean square	*F* score	*F* probability
Between regions	30.41	9	3.38	1.85	0.06
Within regions	346.97	190	1.83		

Table 5.10 Analysis of variance table for logarithmically transformed total dioxin/furan TEQ (non-detects set to detection limits).

Source of variation	Sum of squares	Degrees of freedom	Mean square	*F* score	*F* probability
Between regions	4.41	9	0.49	1.40	0.19
Within regions	66.44	190	0.35		

Table 5.11 Analysis of variance table for logarithmically transformed total PCB TEQ (non-detects set to zero).

Source of variation	Sum of squares	Degrees of freedom	Mean square	*F* score	*F* probability
Between regions	50.97	9	5.66	3.49	5.15e-04
Within regions	306.67	189	1.62		

Table 5.12 Analysis of variance table for logarithmically transformed total PCB TEQ (non-detects set to detection limits).

Source of variation	Sum of squares	Degrees of freedom	Mean square	*F* score	*F* probability
Between regions	21.86	9	2.43	3.52	4.70e-04
Within regions	131.14	190	0.69		

Table 5.13 Correlation results for logarithmically transformed TEQ mass fractions (pg/g TEQ) vs. average daily flow (MGD)

	Non-detects set to detection limits.			Non-detects set to zero.		
	Total	Dioxin/furan	PCB	Total	Dioxin/furan	PCB
Number of samples	194.00	194.00	194.00	194.00	194.00	193.00
Degrees of freedom	192.00	192.00	192.00	192.00	192.00	191.00
Correlation coefficient (*r*)	**0.16**	0.12	**0.24**	**0.16**	0.12	**0.23**
Fraction of variance accounted for by regression (r^2)	0.02	0.01	0.06	0.02	0.02	0.05
Constant of correlation (*b*) (pg/g TEQ)	3.37	3.05	1.84	2.49	2.07	1.03
Slope of correlation (*m*) (pg/g TEQ per MGD)	**0.0011**	**0.0008**	**0.0022**	**0.0021**	**0.0018**	**0.0032**
Standard error of the slope (s_m)	0.0005	0.0005	0.0006	0.0010	0.0011	0.0010
Standard error of the estimate ($s_{y/x}$)	0.64	0.60	0.84	1.28	1.38	1.30
t statistic for slope	2.21	1.65	3.45	2.18	1.73	3.25

Average of average daily flow values: 49.36 MGD.
Standard deviation of annual daily flow values: 94.36 MGD.
[A] *r* values in boldface are significant at 95%.
[B] Slopes in boldface are significant at 95% (2-tailed test).

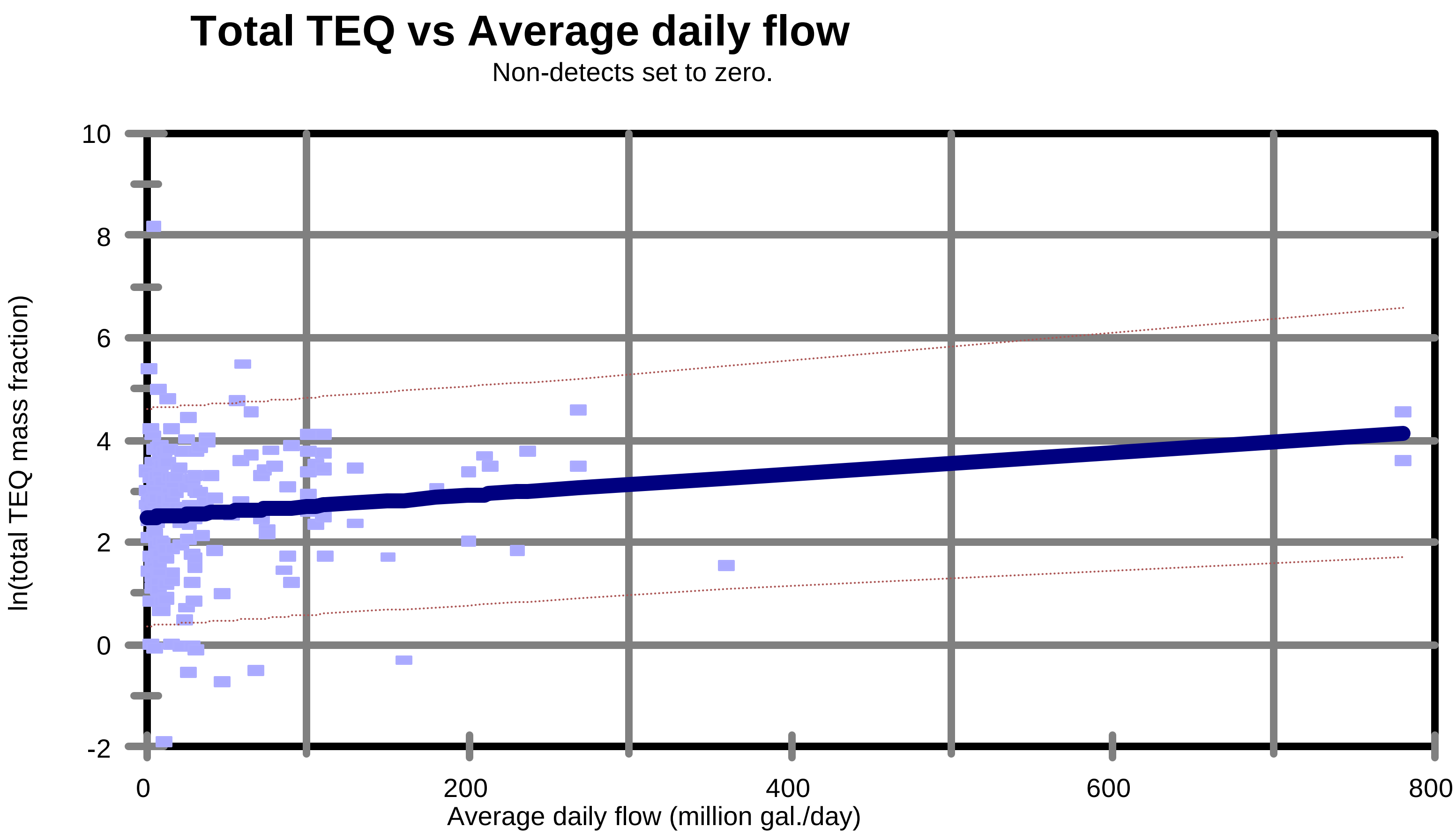

Figure 5.7 Regression line and 90 % prediction interval for total TEQ mass fraction versus average daily flow. Non-detects set to zero.

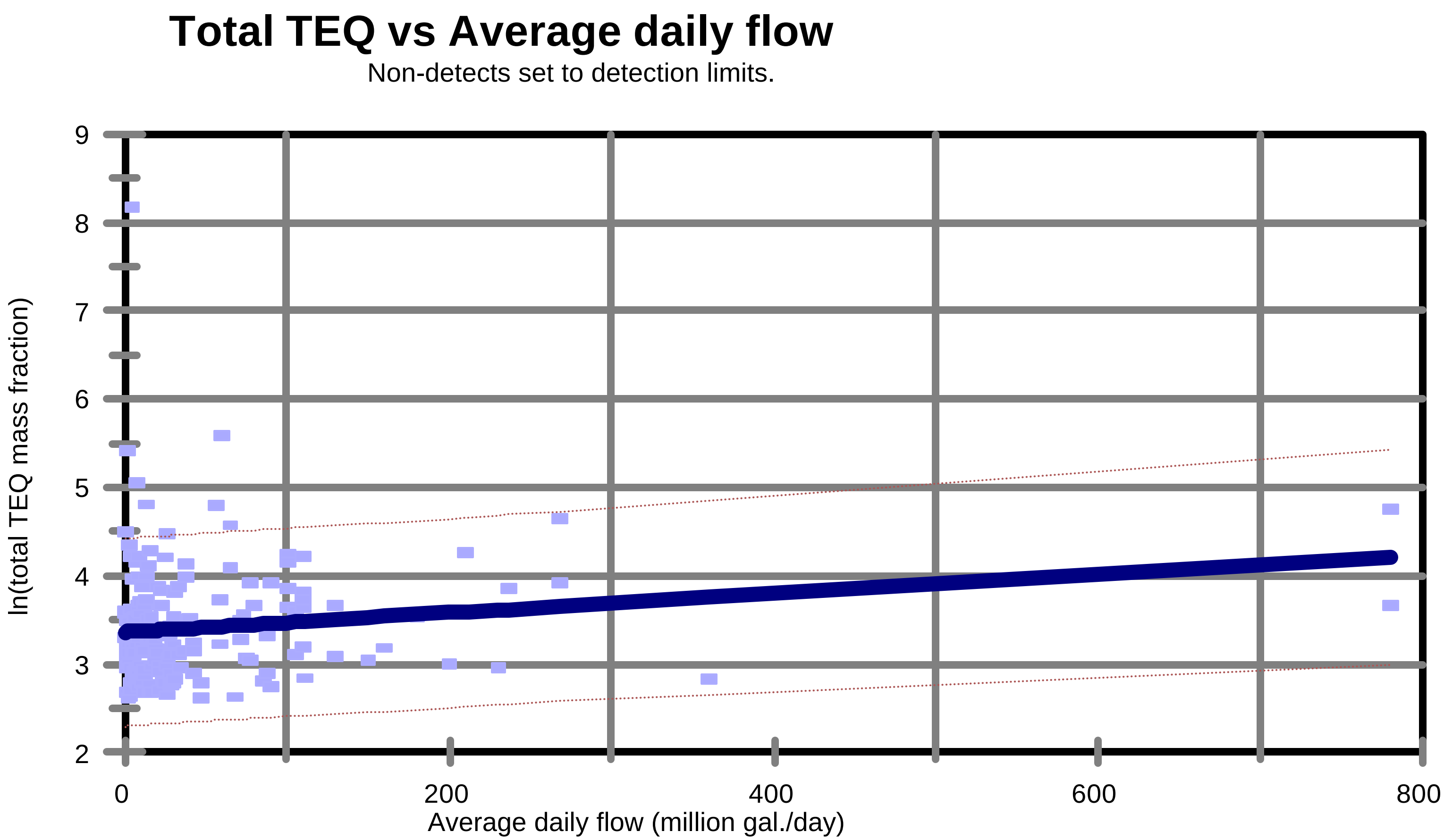

Figure 5.8 Regression line and 90 % prediction interval for total TEQ mass fraction versus average daily flow. Non-detects set to detection limits.

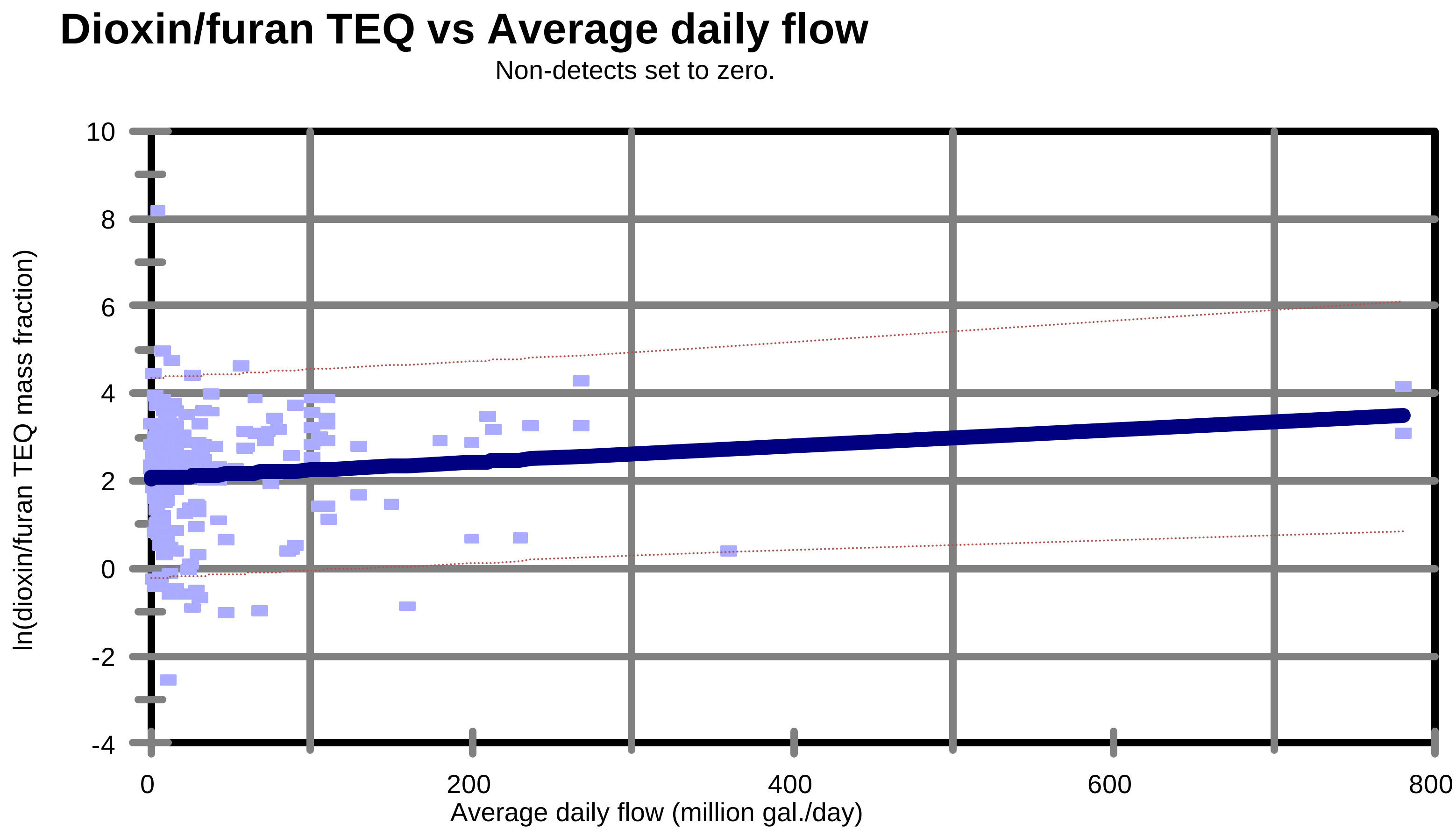

Figure 5.9 Regression line and 90 % prediction interval for dioxin/furan TEQ mass fraction versus average daily flow. Non-detects set to zero.

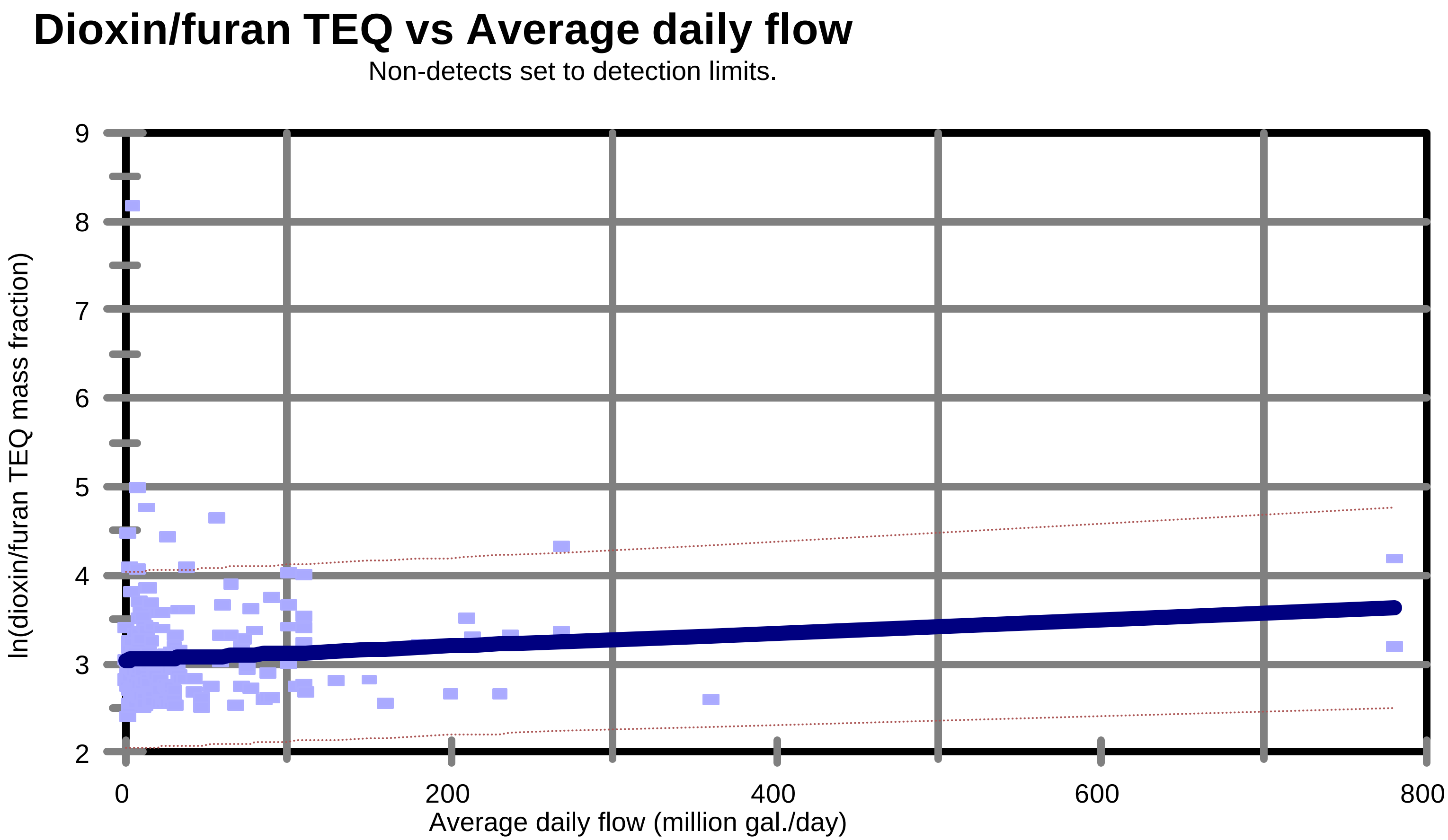

Figure 5.10 Regression line and 90 % prediction interval for dioxin/furan TEQ mass fraction versus average daily flow. Non-detects set to detection limits.

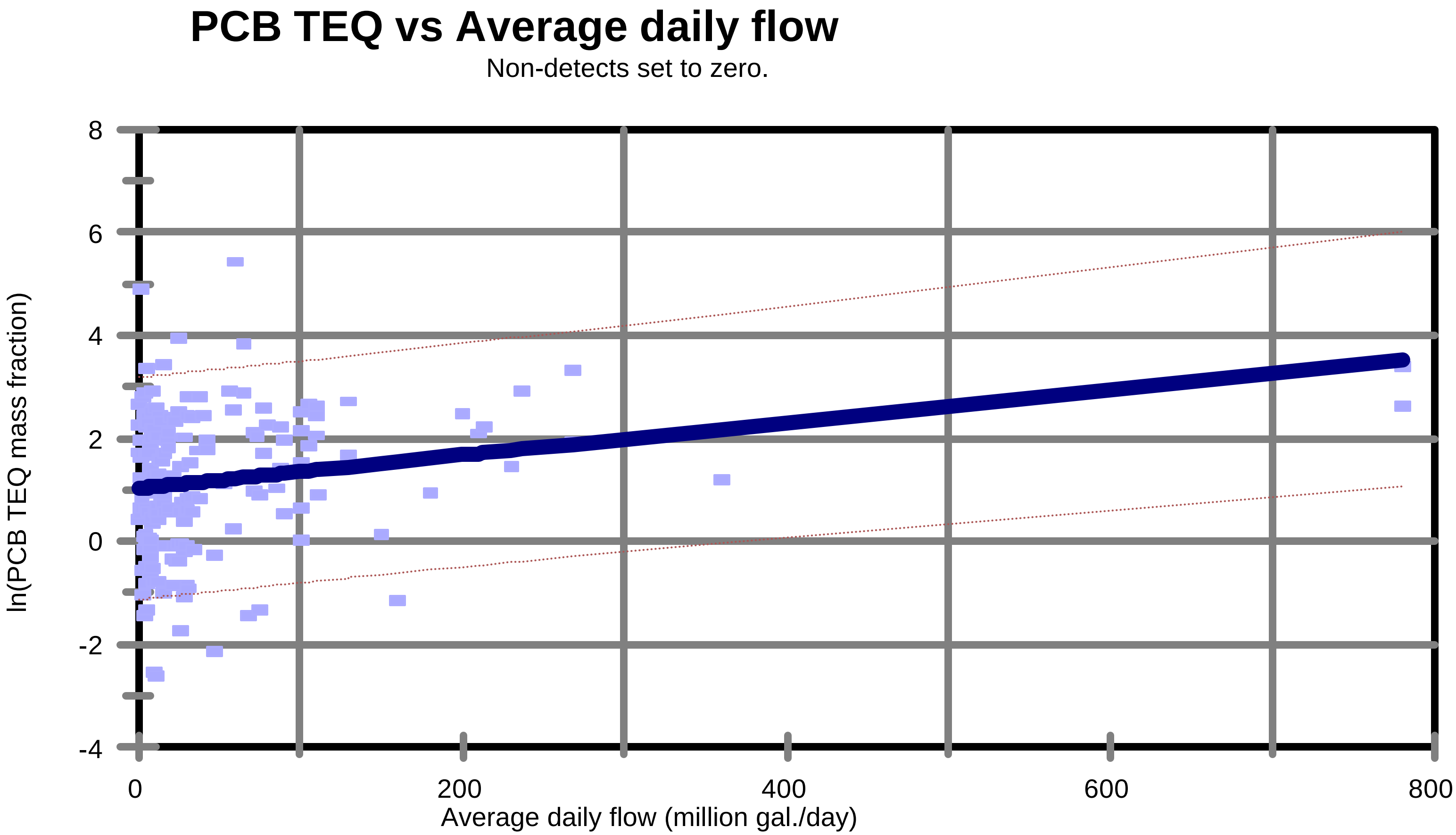

Figure 5.11 Regression line and 90 % prediction interval for PCB TEQ mass fraction versus average daily flow. Non-detects set to zero.

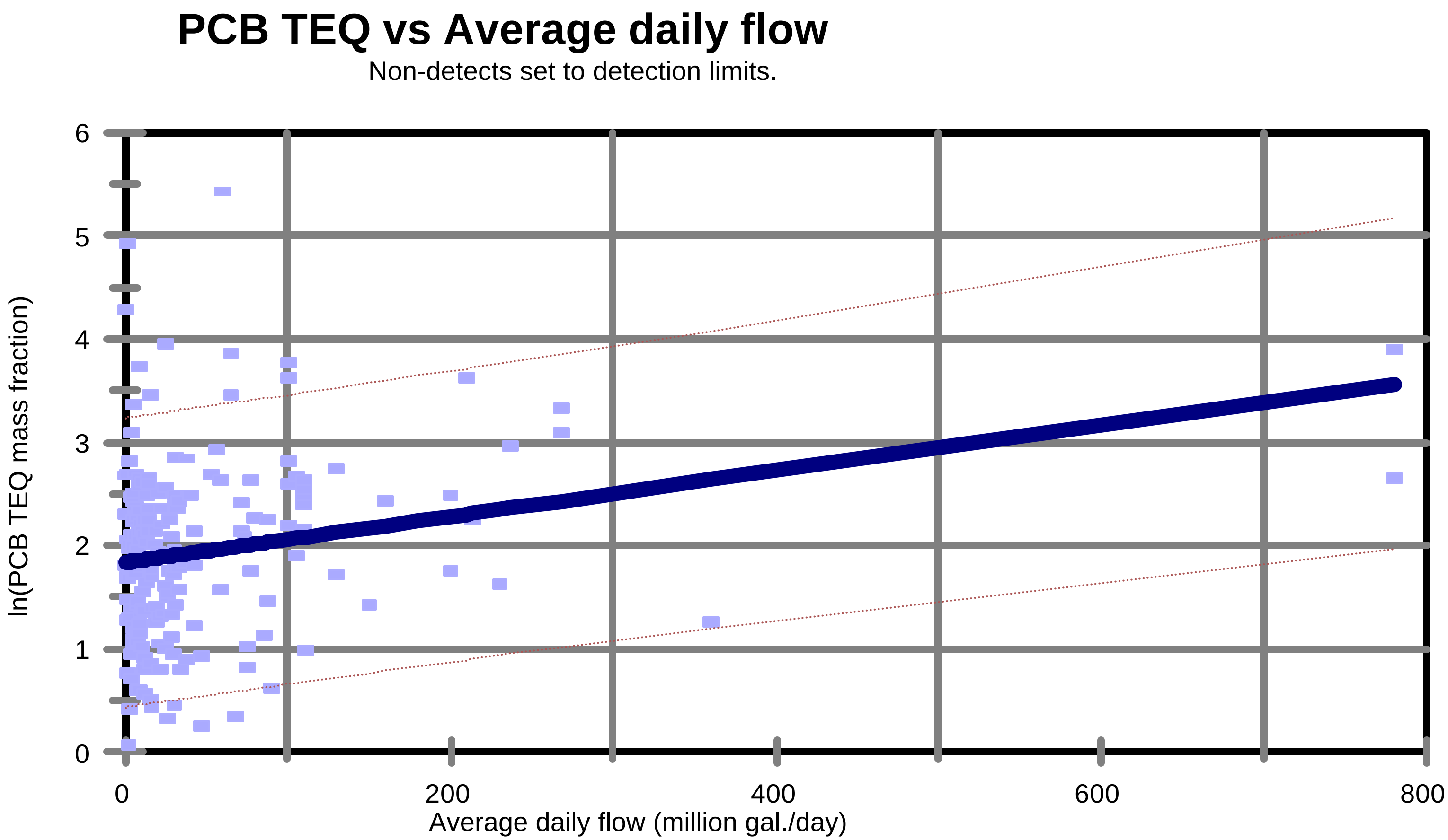

Figure 5.12 Regression line and 90 % prediction interval for PCB TEQ mass fraction versus average daily flow. Non-detects set to detection limits.

Table 5.14 Characteristics of logarithmically transformed TEQ mass fraction data for facilities with # 1 MGD average daily flow

Treatment of non-detects	Data subset	Number of samples (N)	Mean	Standard deviation	Standard error of the mean
Detection limits	Total	7	3.51	0.50	0.19
	Dioxins and Furans	7	2.96	0.22	0.08
	PCBs	7	2.32	1.10	0.41
Zero	Total	7	2.88	0.45	0.17
	Dioxins and Furans	7	2.52	0.46	0.17
	PCBs	7	1.43	0.89	0.34

Table 5.15 Characteristics of logarithmically transformed TEQ mass fraction data for facilities with > 1 MGD average daily flow

Treatment of non-detects	Data subset	Number of samples (N)	Mean	Standard deviation	Standard error of the mean
Detection limits	Total	187	3.42	0.65	0.05
	Dioxins and Furans	187	3.09	0.61	0.04
	PCBs	187	1.93	0.86	0.06
Zero	Total	187	2.59	1.31	0.10
	Dioxins and Furans	187	2.15	1.41	0.10
	PCBs	186	1.18	1.35	0.10

Table 5.16 *F* and *t* test results for comparison of facilities with # 1 MGD average daily flow versus > 1 MGD average daily flow

Treatment of non-detects	Data subset	Numerator Degrees of freedom	Denominator Degrees of freedom	*F* score	*F* probability	*t* test degrees of freedom	*t* statistic	*t* probability (2-tailed test)
Detection limits	Total	186	6	1.74	0.25	192	0.37	0.71
	Dioxins and Furans	186	6	**7.98**	**0.01**	10.09	-1.39	0.19
	PCB	186	6	0.62	0.86	192	1.18	0.24
Zero	Total	186	6	**8.40**	**0.01**	10.33	1.50	0.16
	Dioxins and Furans	186	6	**9.39**	**0.00**	10.92	1.84	0.09
	PCB	185	6	2.27	0.15	191	0.47	0.64
Statistically significant (to 95% level of confidence) *F* and *t* scores are in boldface.								

Table 5.17 Correlation results for logarithmically transformed TEQ mass fractions (pg/g TEQ) vs. percent solids in sample

	Non-detects set to detection limits.			Non-detects set to zero.		
	Total	Dioxin/furan	PCB	Total	Dioxin/furan	PCB
Number of samples	200	200	200	200	200	199
Degrees of freedom	198	198	198	198	198	197
Correlation coefficient *(r)*	0.03	0.06	0.04	0.03	0.03	0.02
Fraction of variance accounted for by regression (r^2)	0.0010	0.0031	0.0017	0.00095	0.0010	0.0005
Constant of correlation (*b*) (pg/g TEQ)	3.41	3.05	2.01	2.58	2.14	1.26
Slope of correlation (*m*) (pg/g TEQ per MGD)	0.0010	0.0016	-0.0017	0.00193	0.0021	-0.0015
Standard error of the slope (s_m)	0.0022	0.0021	0.0030	0.0045	0.0048	0.0047
Standard error of the estimate $(s_{y/x})$	0.65	0.60	0.88	1.29	1.38	1.35
t statistic for slope	0.45	0.79	-0.57	0.43	0.45	-0.33

Average of percent solids in sample: 21.87%.
Standard deviation of percent solids in sample: 20.56%
[A] *r* values in boldface are significant at 95%.
[B] Slopes in boldface are significant at 95% (2-tailed test).

Cambridge Environmental Inc
58 Charles Street Cambridge, Massachusetts 02141
617-225-0810 FAX: 617-225-0813 E-mail: info@CambridgeEnvironmental.com

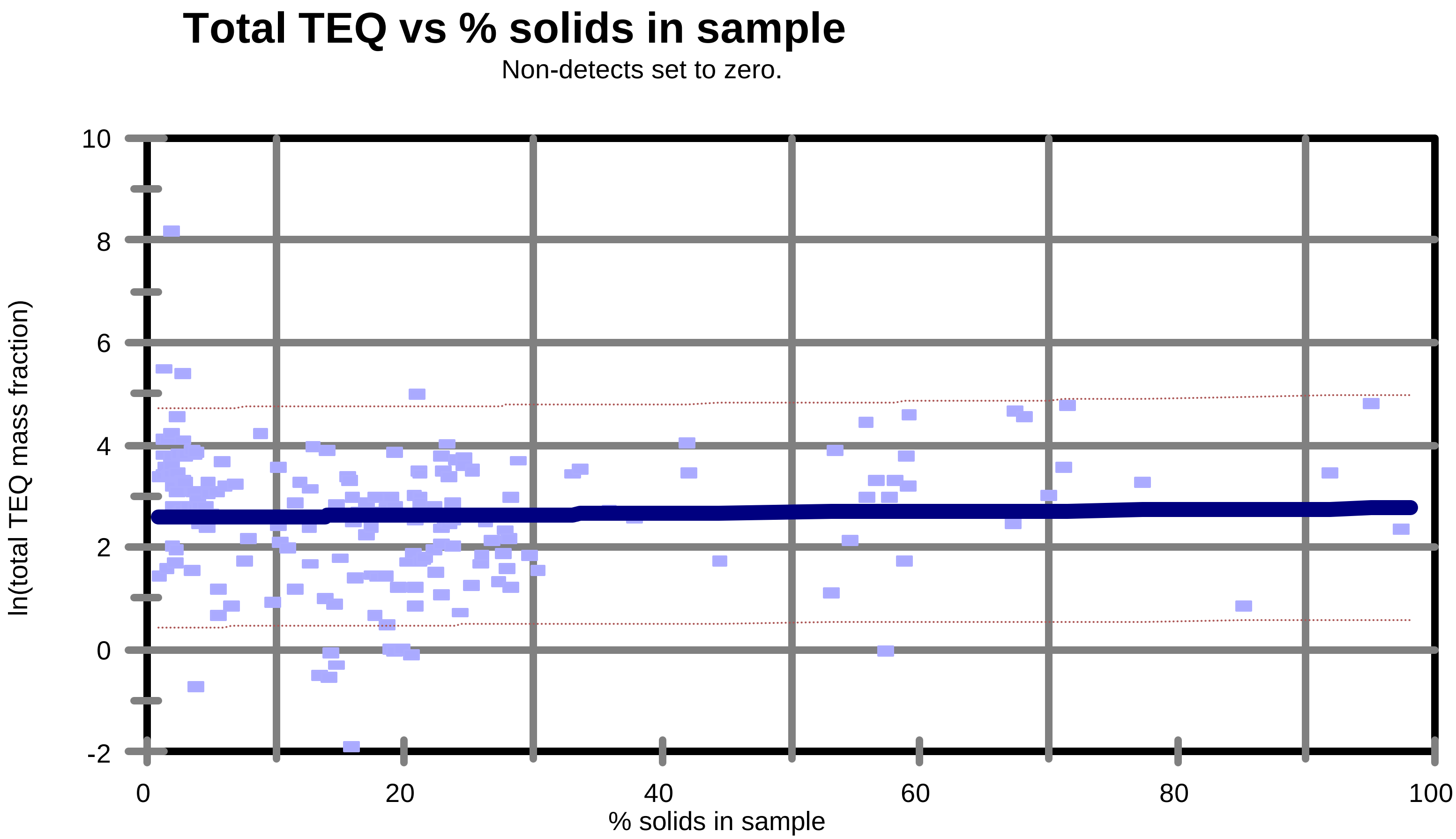

Figure 5.13 Regression line and 90 % prediction interval for total TEQ mass fraction versus percent solids in sample. Non-detects set to zero.

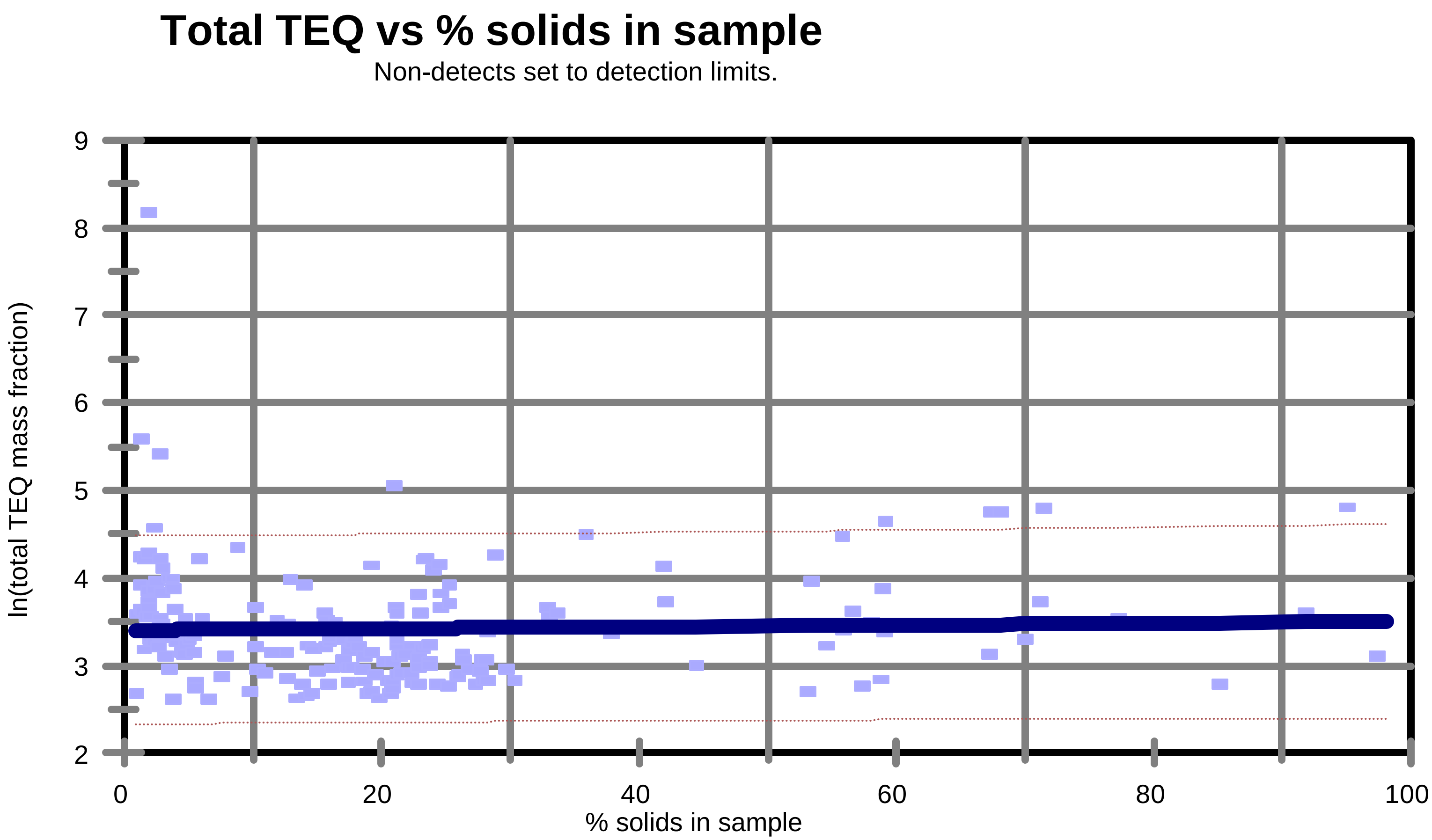

Figure 5.14 Regression line and 90 % prediction interval for total TEQ mass fraction versus percent solids in sample. Non-detects set to detection limits.

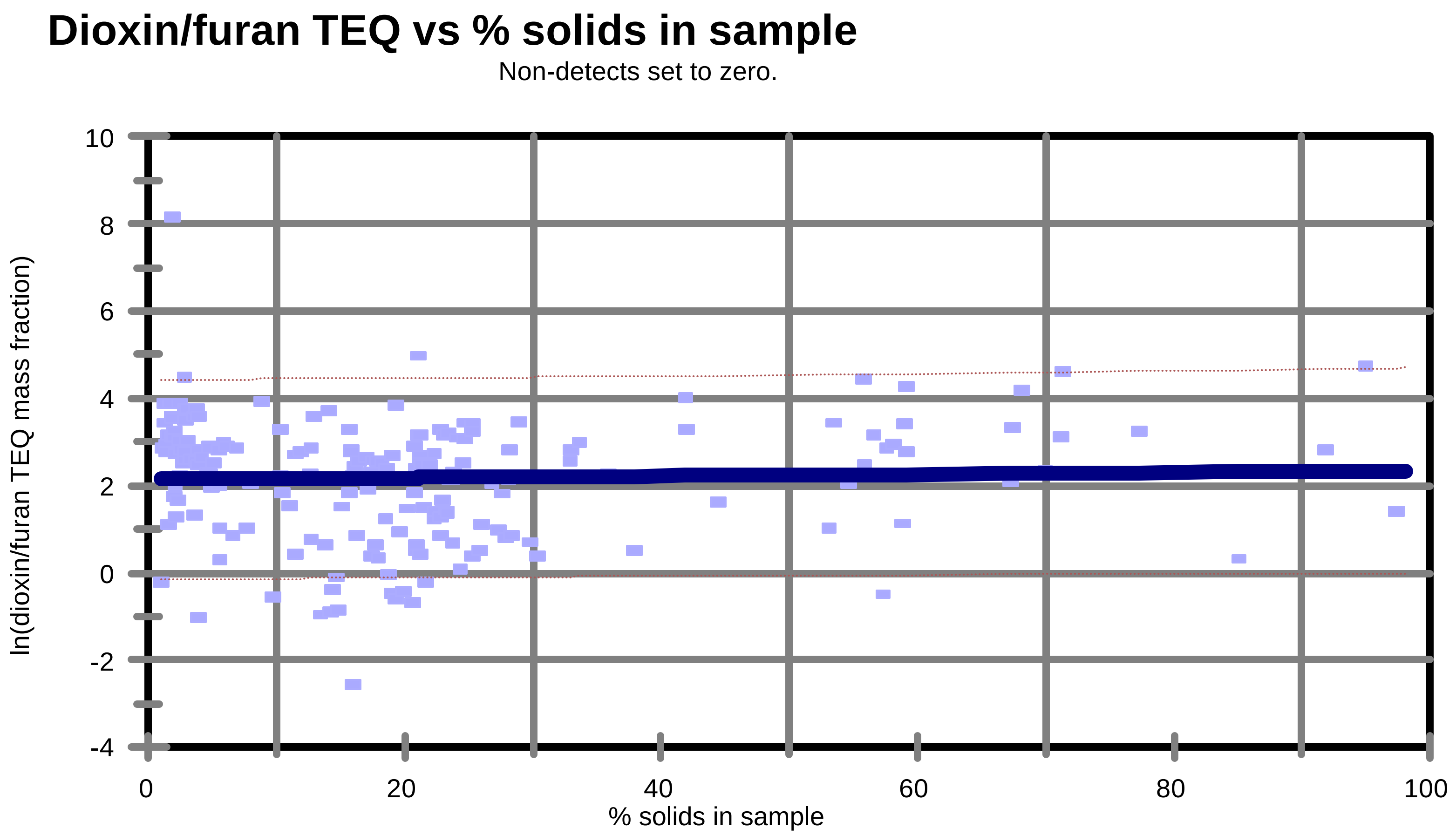

Figure 5.15 Regression line and 90 % prediction interval for dioxin/furan TEQ mass fraction versus percent solids in sample. Non-detects set to zero.

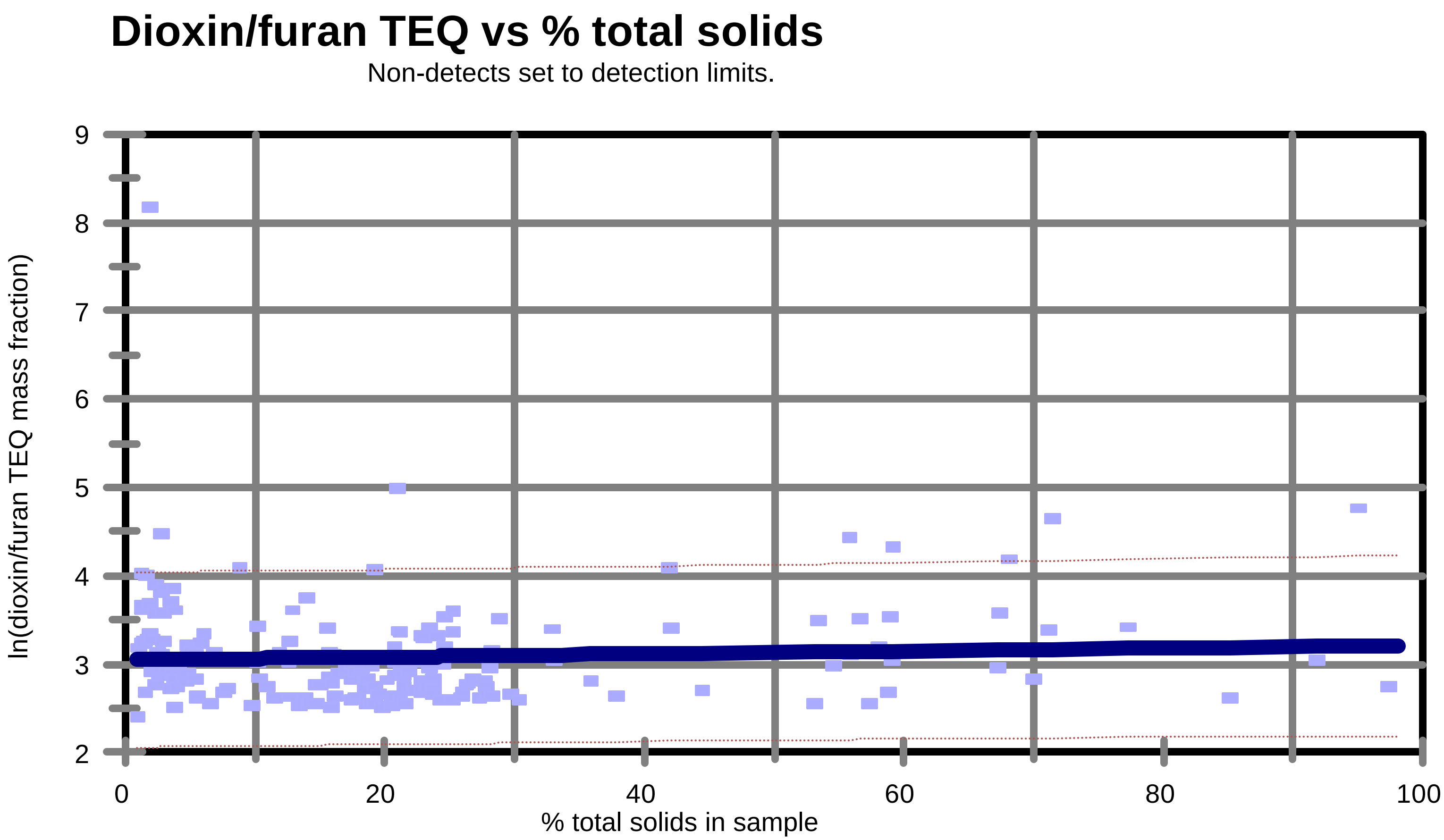

Figure 5.16 Regression line and 90 % prediction interval for dioxin/furan TEQ mass fraction versus percent solids in sample. Non-detects set to detection limits.

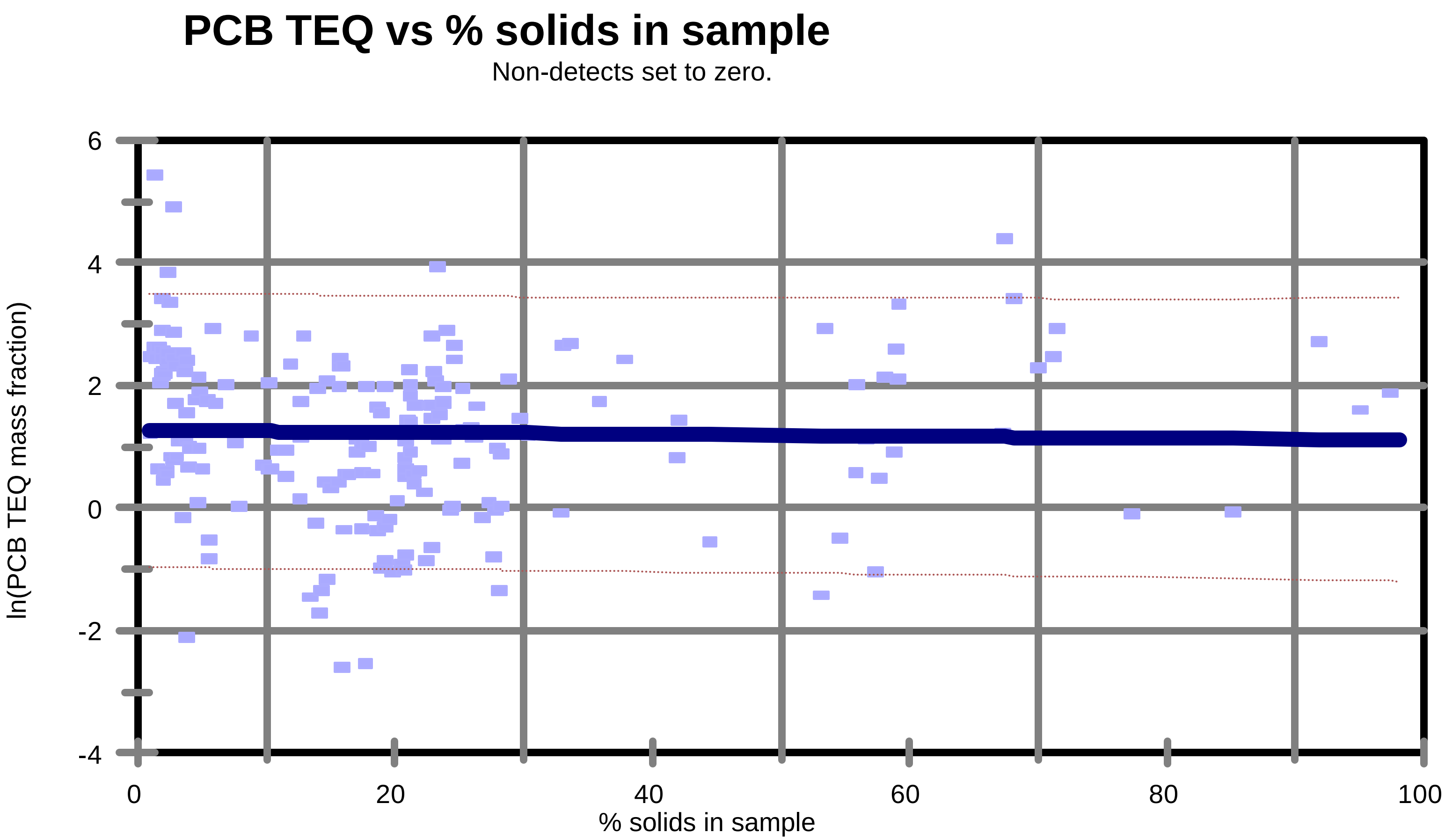

Figure 5.17 Regression line and 90 % prediction interval for PCB TEQ mass fraction versus percent solids in sample. Non-detects set to zero.

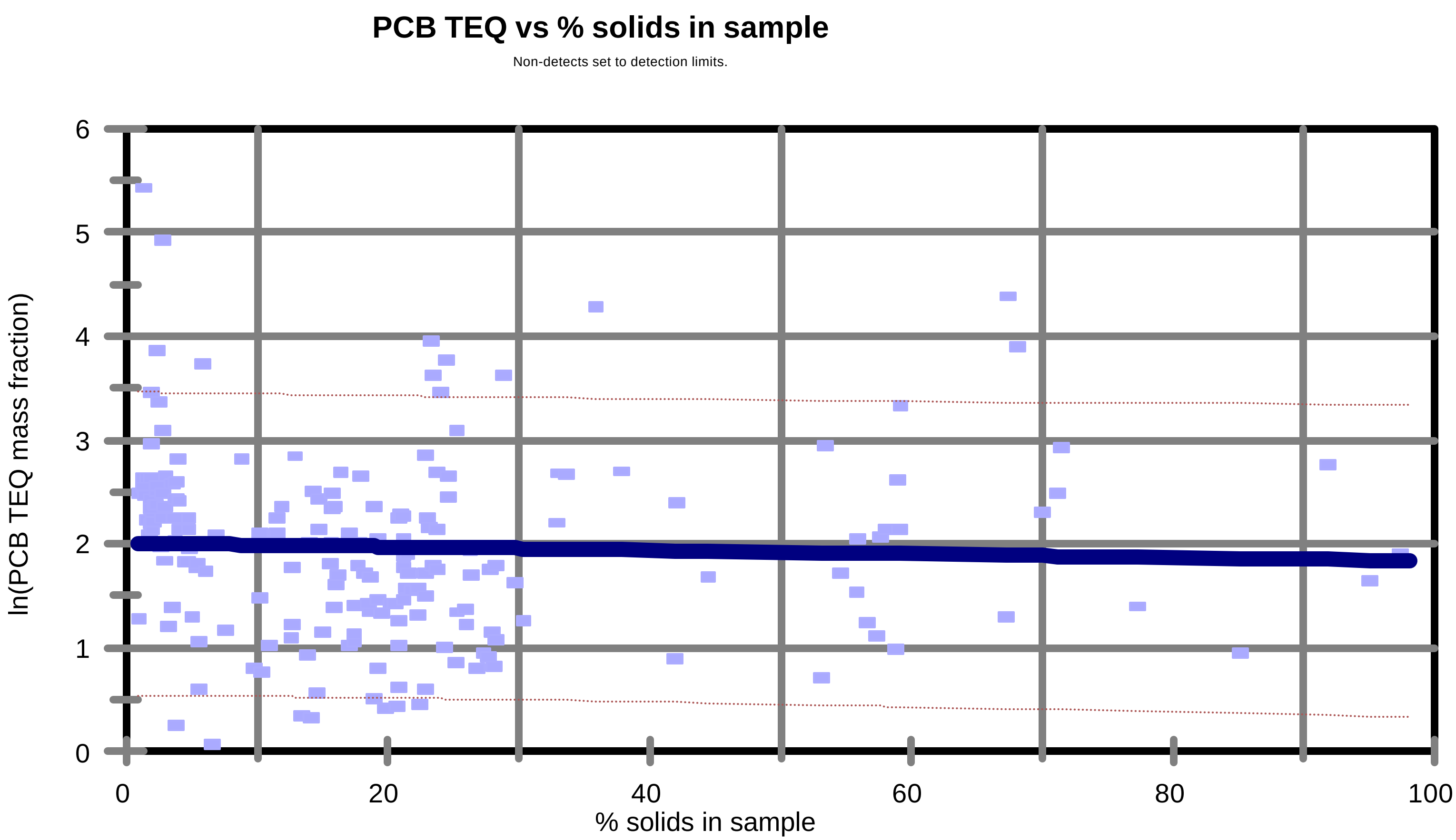

Figure 5.18 Regression line and 90 % prediction interval for PCB TEQ mass fraction versus percent solids in sample. Non-detects set to detection limits.

Table 5.18 Correlation results for logarithmically transformed TEQ mass fractions (pg/g TEQ) vs. percent industrial loading

	Non-detects set to detection limits.			Non-detects set to zero.		
	Total	Dioxin/furan	PCB	Total	Dioxin/furan	PCB
Number of samples	189	189	189	189	189	189
Degrees of freedom	187	187	187	187	187	187
Correlation coefficient *(r)*	0.11	0.06	**0.16**	**0.15**	**0.17**	0.07
Fraction of variance accounted for by regression (r^2)	0.0117	0.0042	0.0245	0.0213	0.0288	0.0052
Constant of correlation (*b*) (pg/g TEQ)	3.47	3.11	2.05	2.73	2.34	1.24
Slope of correlation (*m*) (pg/g TEQ per MGD)	-0.0046	-0.0026	**-0.0089**	**-0.0124**	**-0.0155**	-0.0062
Standard error of the slope (s_m)	0.0031	0.0029	0.0041	0.0062	0.0066	0.0063
Standard error of the estimate $(s_{y/x})$	0.65	0.61	0.86	1.29	1.39	1.33
t statistic for slope	-1.49	-0.88	**-2.17**	**-2.02**	**-2.35**	-0.99

Average of percent industrial loading: 12.1%.
Standard deviation of percent industrial loading: 15.3%
[A] *r* values in boldface are significant at 95%.
[B] Slopes in boldface are significant at 95% (2-tailed test).

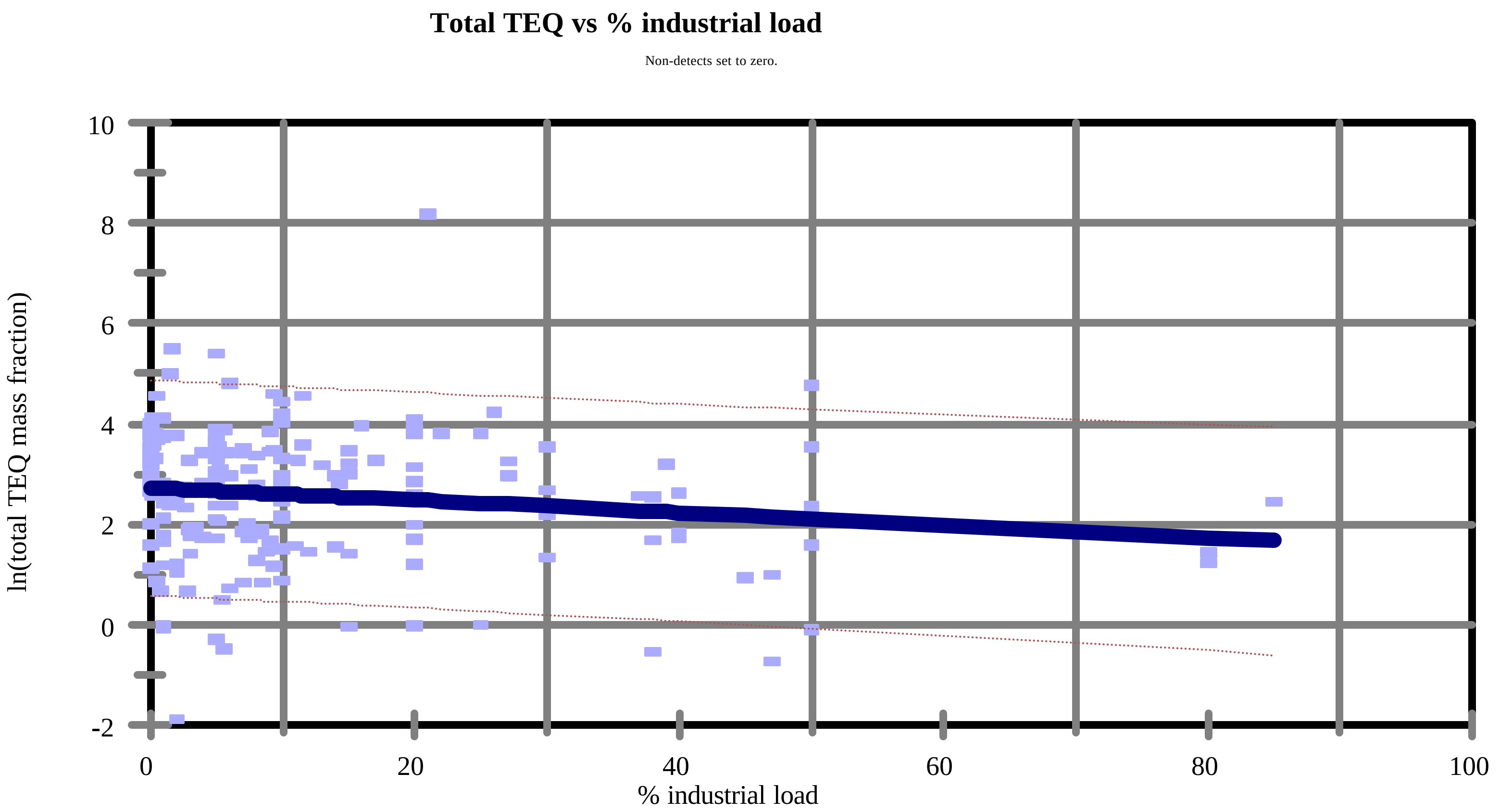

Figure 5.19 Regression line and 90% confidence interval for total TEQ mass fraction versus percent industrial loading. Non-detects set to zero.

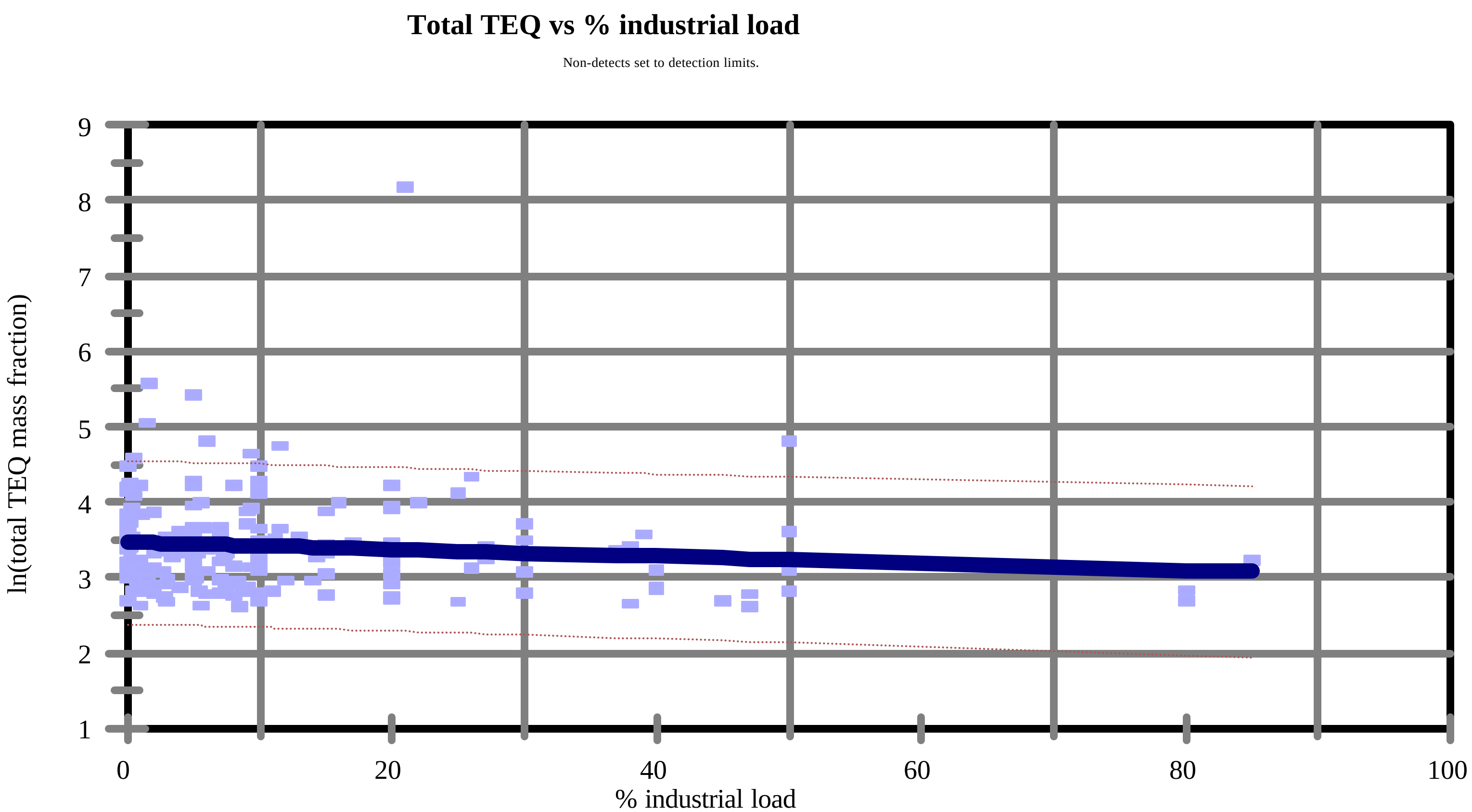

Figure 5.20 Regression line and 90% prediction interval for total TEQ mass fraction versus percent industrial loading. Non-detects set to detection limits.

Cambridge Environmental Inc
58 Charles Street Cambridge, Massachusetts 02141
617-225-0810 FAX: 617-225-0813 E-mail: info@CambridgeEnvironmental.com

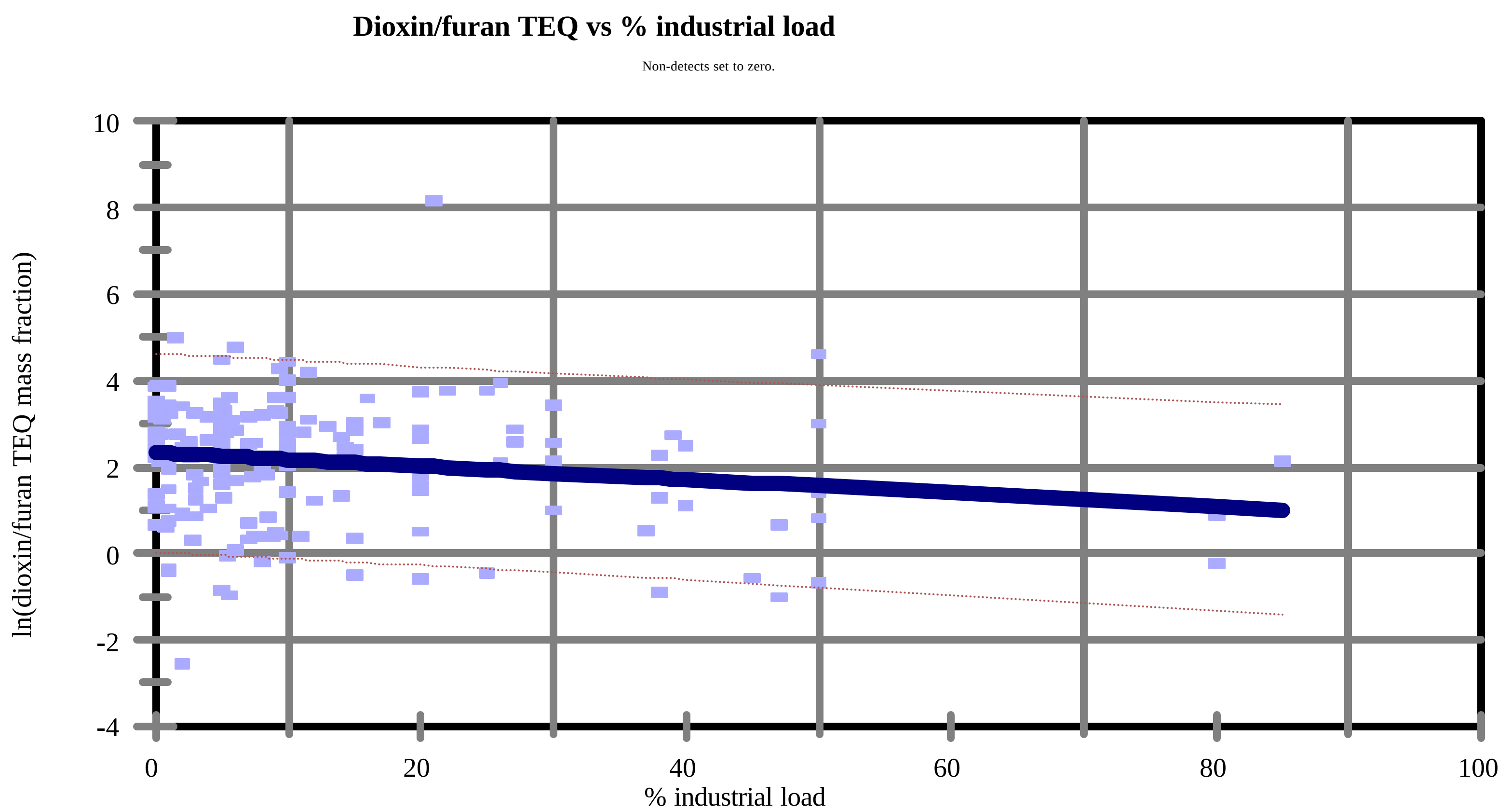

Figure 5.21 Regression line and 90% prediction interval for dioxin/furan TEQ mass fraction versus percent industrial loading. Non-detects set to zero.

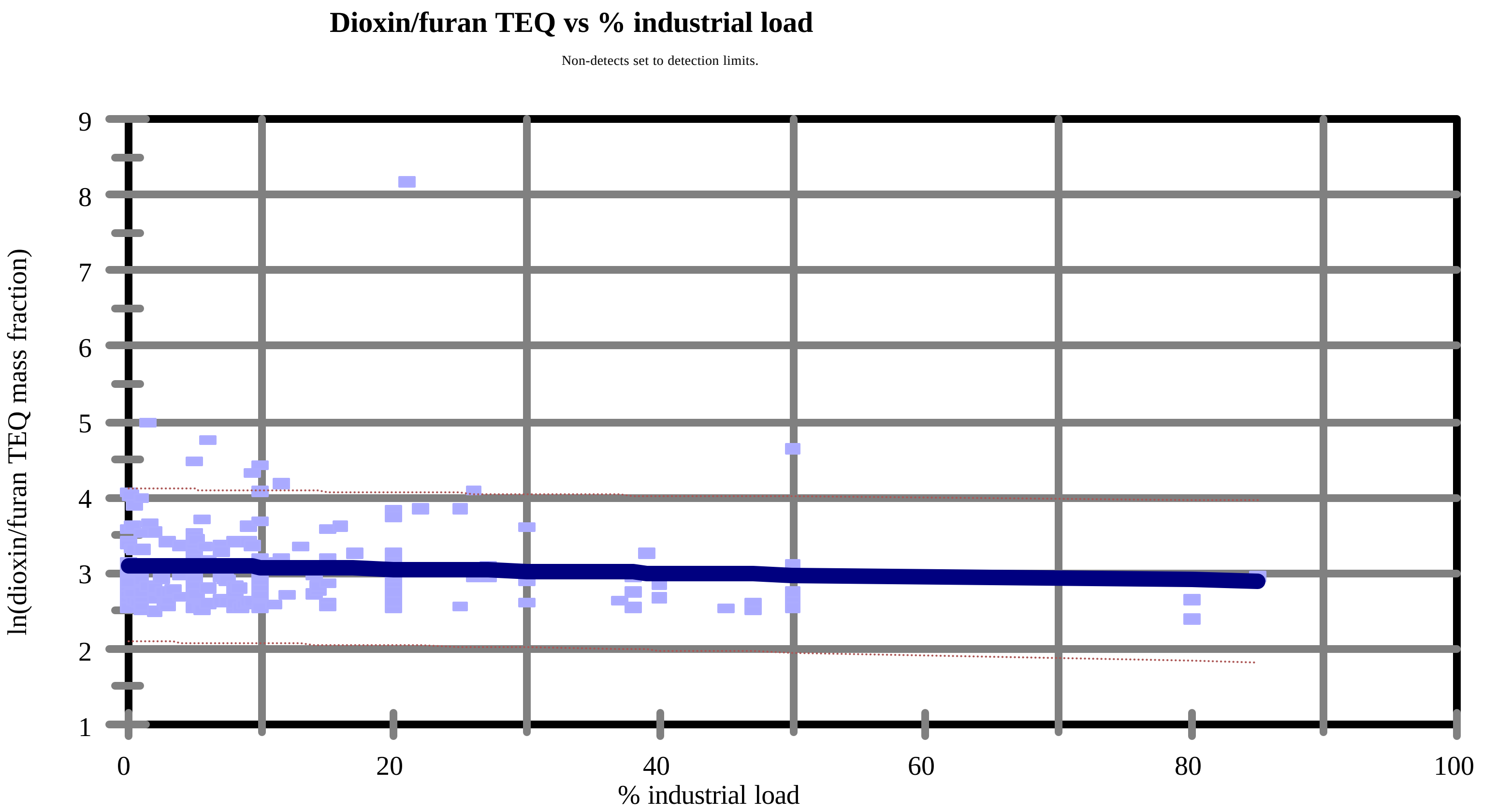

Figure 5.22 Regression line and 90% prediction interval for dioxin/furan mass fraction versus percent industrial loading. Non-detects set to detection limits.

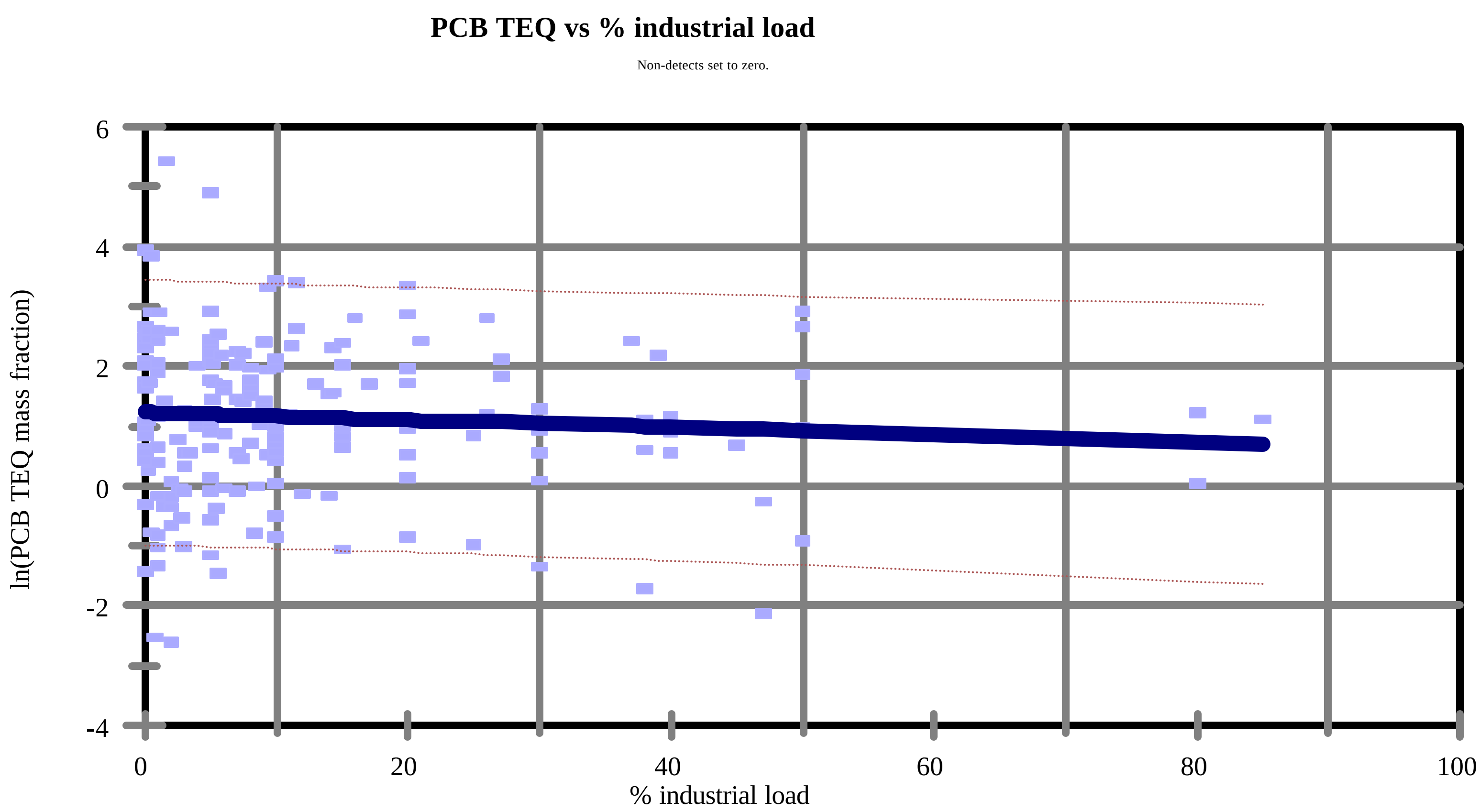

Figure 5.23 Regression line and 90% prediction interval for PCB TEQ mass fraction versus percent industrial loading. Non-detects set to zero.

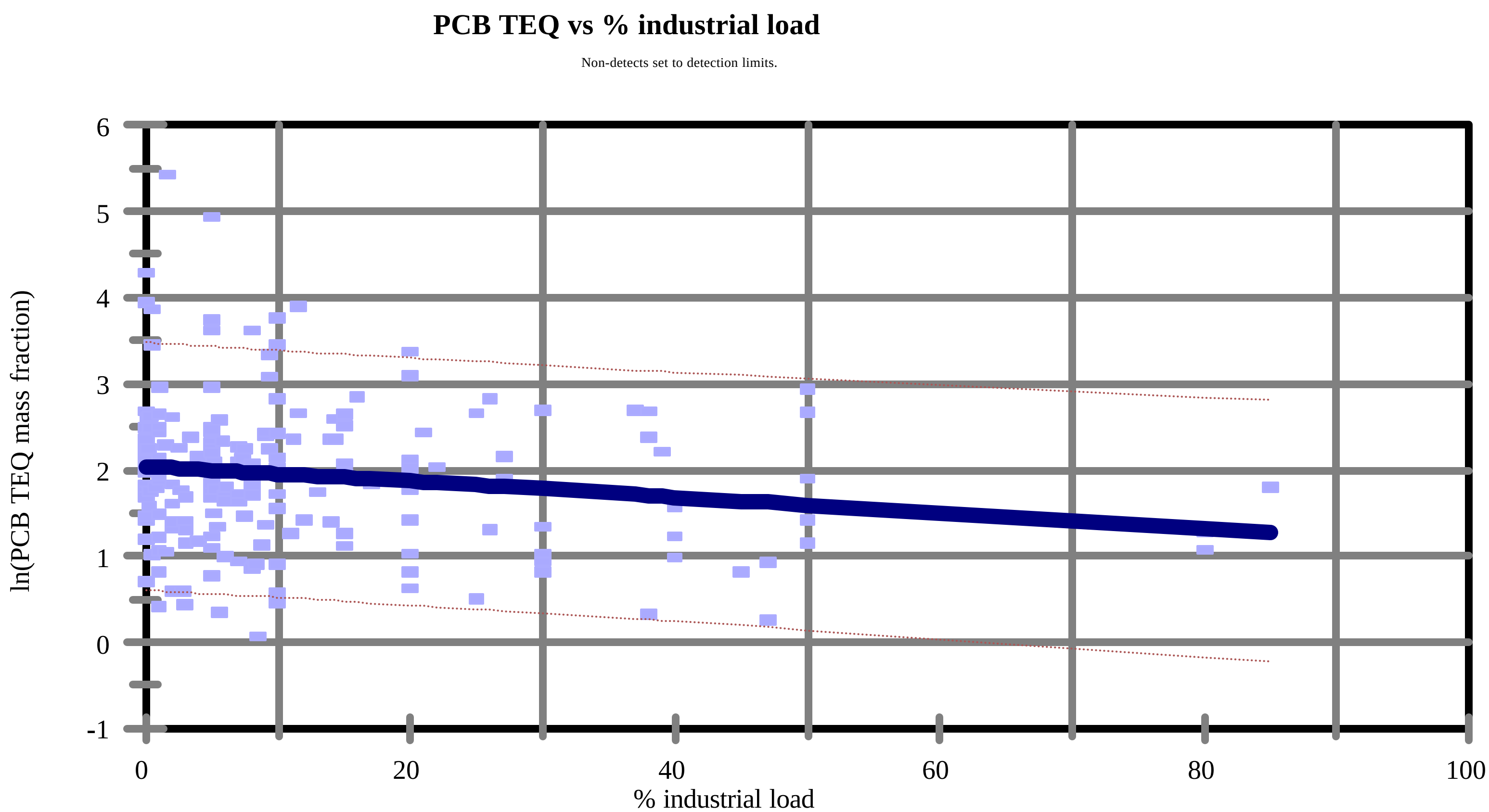

Figure 5.24 Regression line and 90% prediction interval for PCB TEQ mass fraction versus percent industrial loading. Non-detects set to detection limits.

58 Charles Street Cambridge, Massachusetts 02141
617-225-0810 FAX: 617-225-0813 E-mail: info@CambridgeEnvironmental.com

Table 5.19 Correlation results for logarithmically transformed TEQ mass fractions (pg/g TEQ) vs. percent service area with combined sewers

	Non-detects set to detection limits.			Non-detects set to zero.		
	Total	Dioxin/furan	PCB	Total	Dioxin/furan	PCB
Number of samples	179	179	179	179	179	179
Degrees of freedom	177	177	177	177	177	177
Correlation coefficient (*r*)	**0.27**	**0.18**	**0.38**	**0.30**	**0.23**	**0.42**
Fraction of variance accounted for by regression (r^2)	0.07	0.03	0.14	0.09	0.05	0.18
Constant of correlation (*b*) (pg/g TEQ)	3.35	3.05	1.82	2.47	2.05	0.99
Slope of correlation (*m*) (pg/g TEQ per MGD)	**0.0059**	**0.0038**	**0.0108**	**0.0131**	**0.0110**	**0.0182**
Standard error of the slope (s_m)	0.0016	0.0015	0.0020	0.0031	0.0034	0.0029
Standard error of the estimate ($s_{y/x}$)	0.62	0.60	0.79	1.22	1.35	1.16
t statistic for slope	**3.73**	**2.50**	**5.42**	**4.26**	**3.21**	**6.20**

Average of percent service area with combined sewers: 13.7%.
Standard deviation of percent service area with combined sewers: 29.7%
[A] *r* values in boldface are significant at 95%.
[B] Slopes in boldface are significant at 95% (2-tailed test).

58 Charles Street Cambridge, Massachusetts 02141
617-225-0810 FAX: 617-225-0813 E-mail: info@CambridgeEnvironmental.com

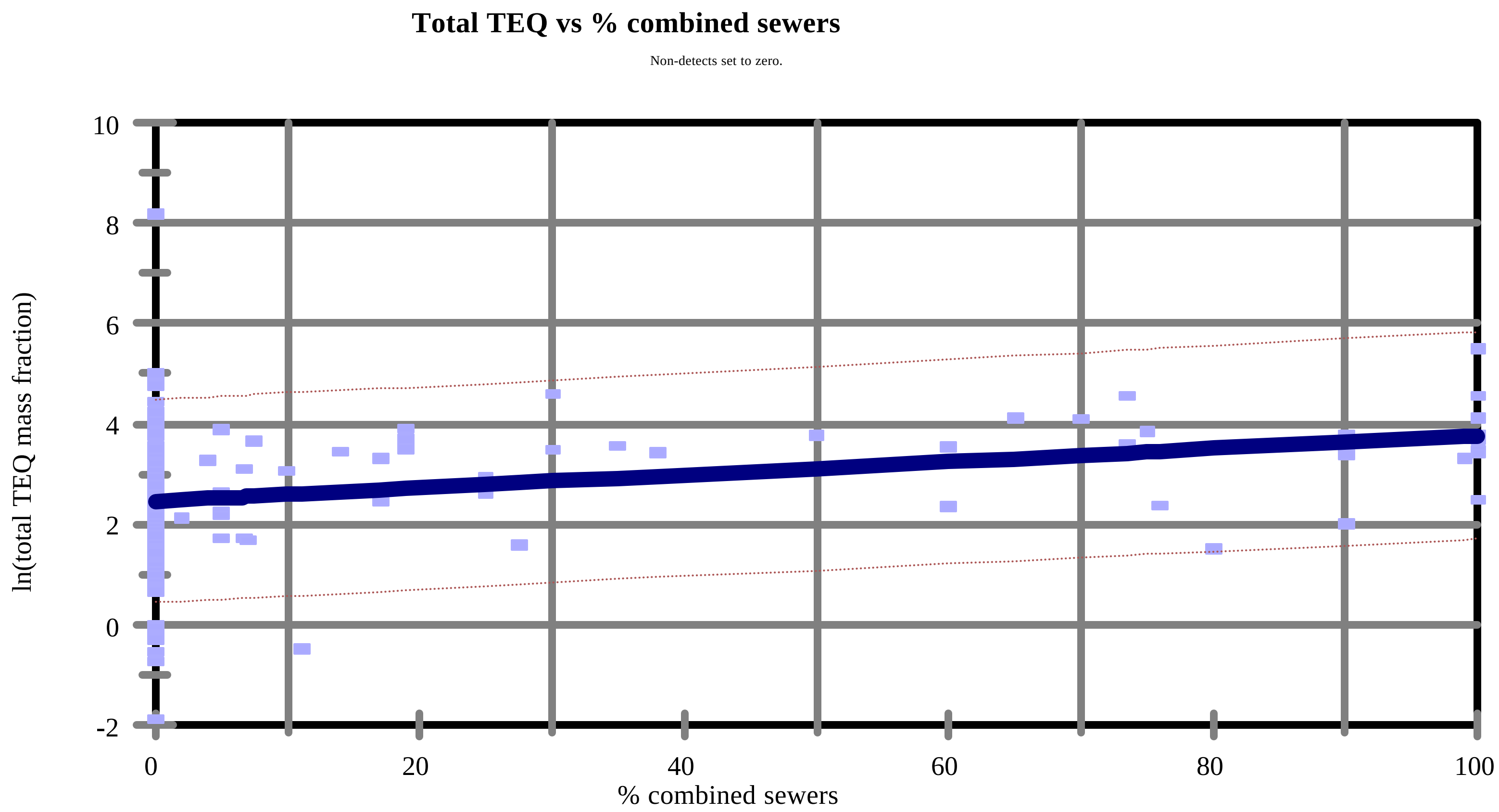

Figure 5.25 Regression line and 90% prediction interval for total TEQ mass fraction versus percentage of service area with combined sewers. Non-detects set to zero.

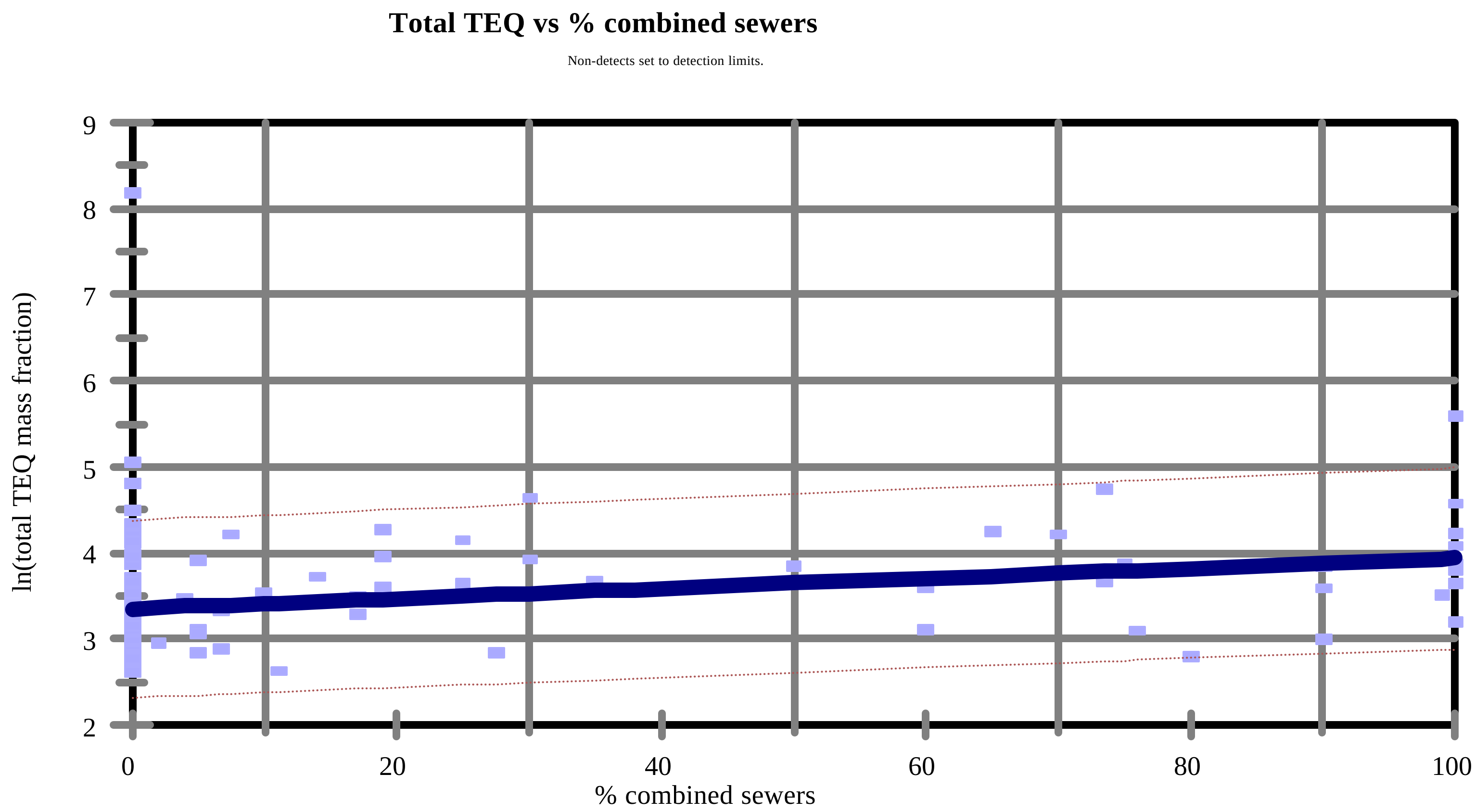

Figure 5.26 Regression line and 90% prediction interval for total TEQ mass fraction versus percent of service area with combined sewers. Non-detects set to detection limits.

Cambridge Environmental Inc
58 Charles Street Cambridge, Massachusetts 02141
617-225-0810 FAX: 617-225-0813 E-mail: info@CambridgeEnvironmental.com

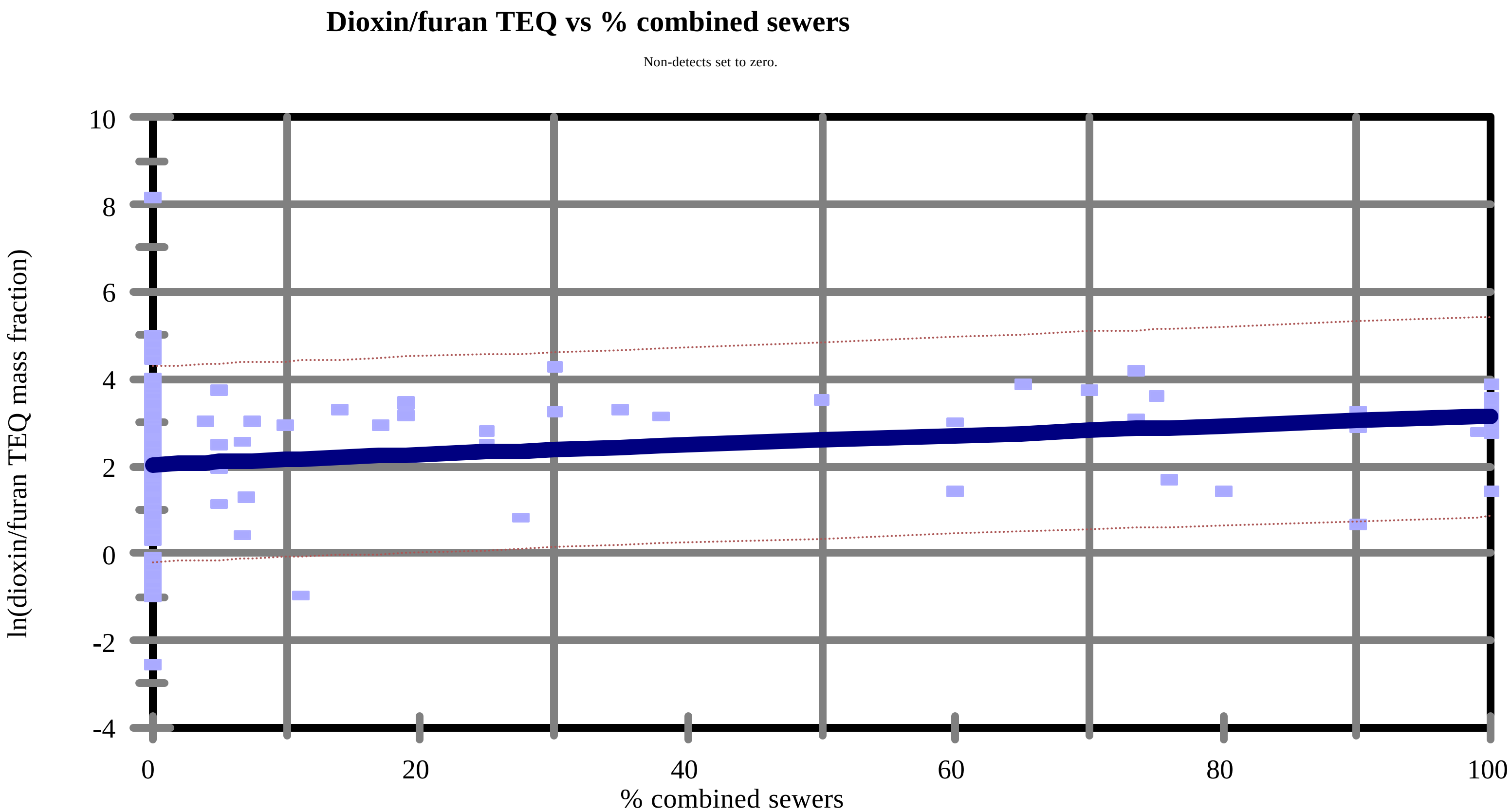

Figure 5.27 Regression line and 90% prediction interval for dioxin/furan TEQ mass fraction versus percent of service area with combined sewers. Non-detects set to zero.

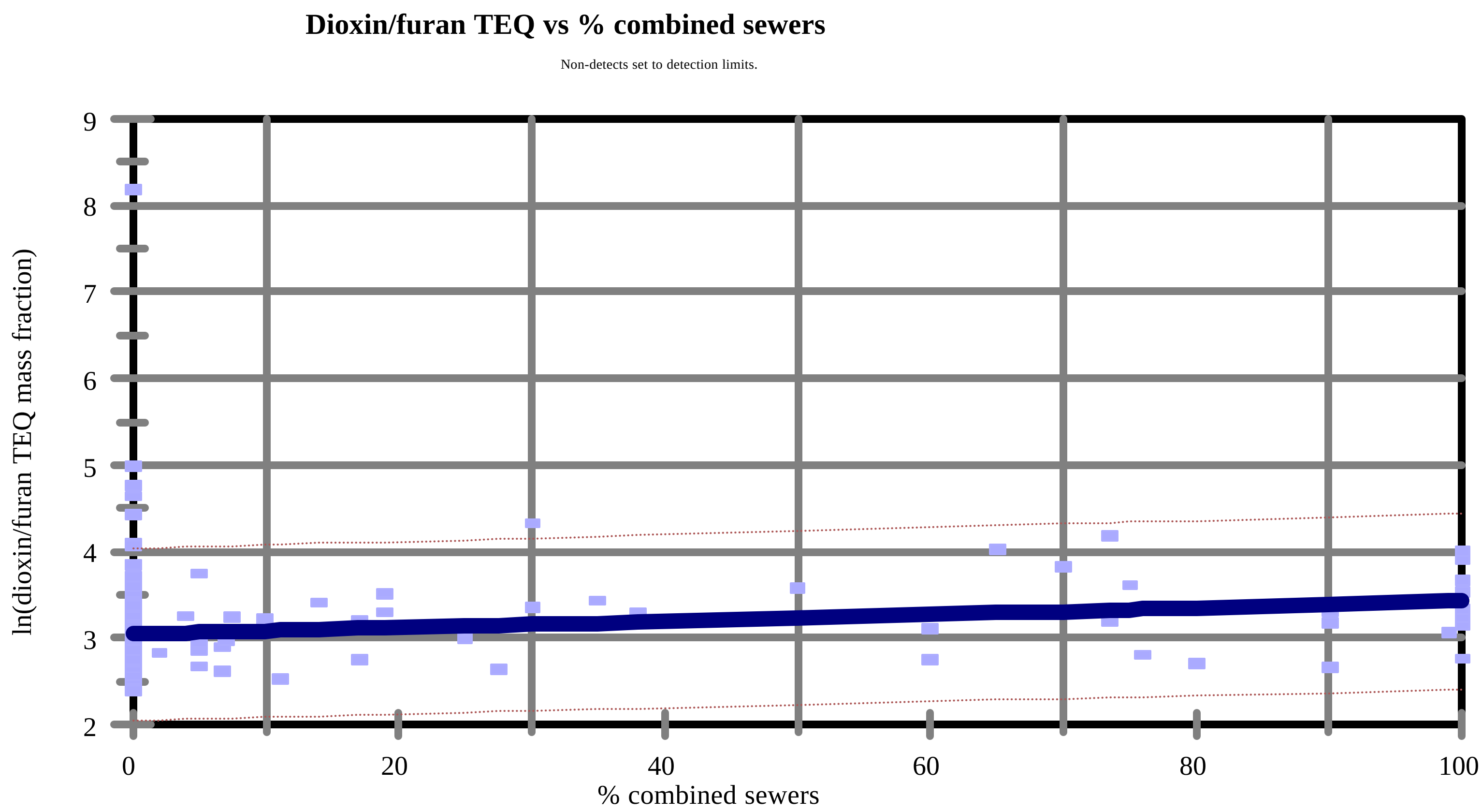

Figure 5.28 Regression line and 90% prediction interval for dioxin/furan mass fraction versus percent of service area with combined sewers. Non-detects set to detection limits.

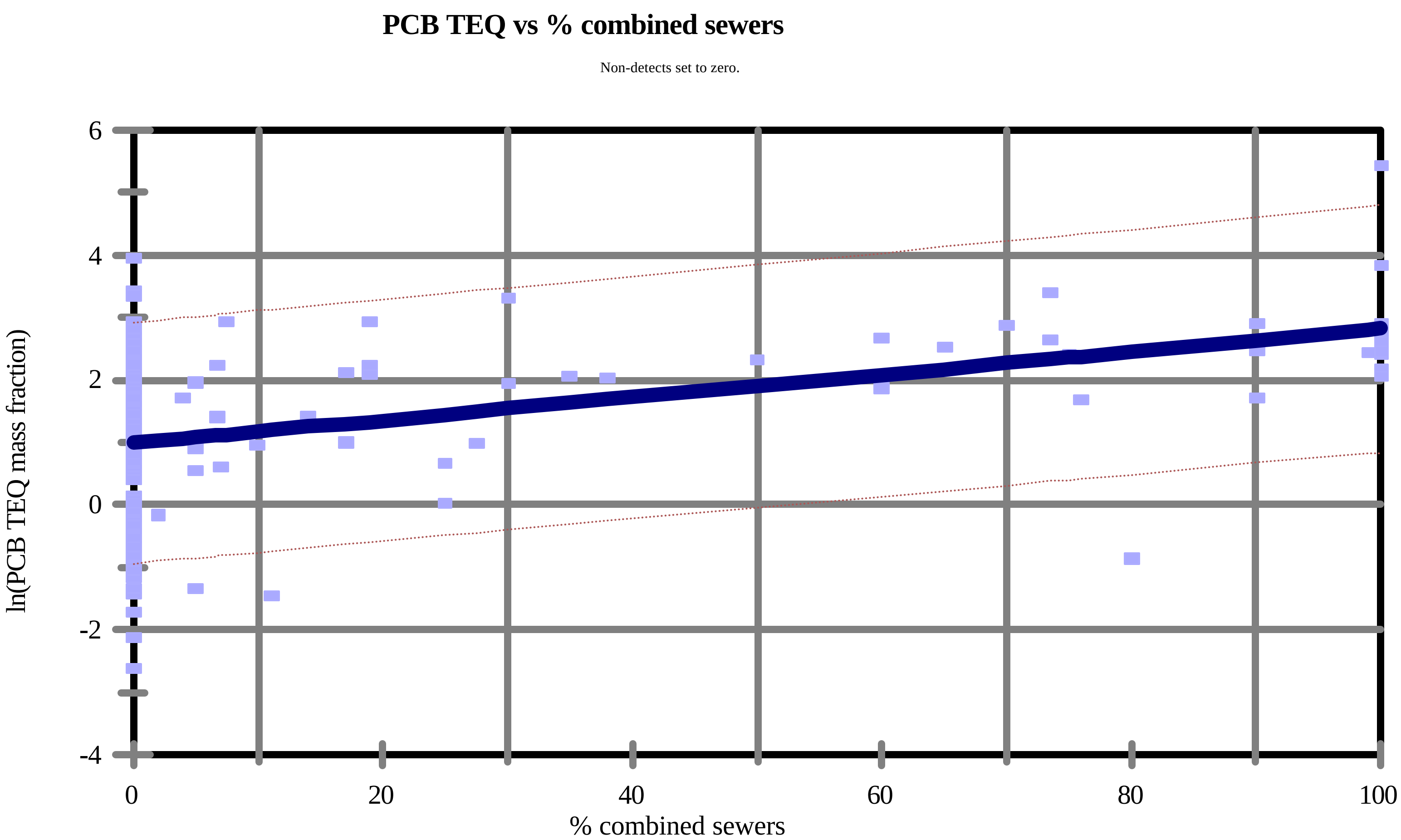

Figure 5.29 Regression line and 90% prediction interval for PCB TEQ mass fraction versus percent of service area with combined sewers. Non-detects set to zero.

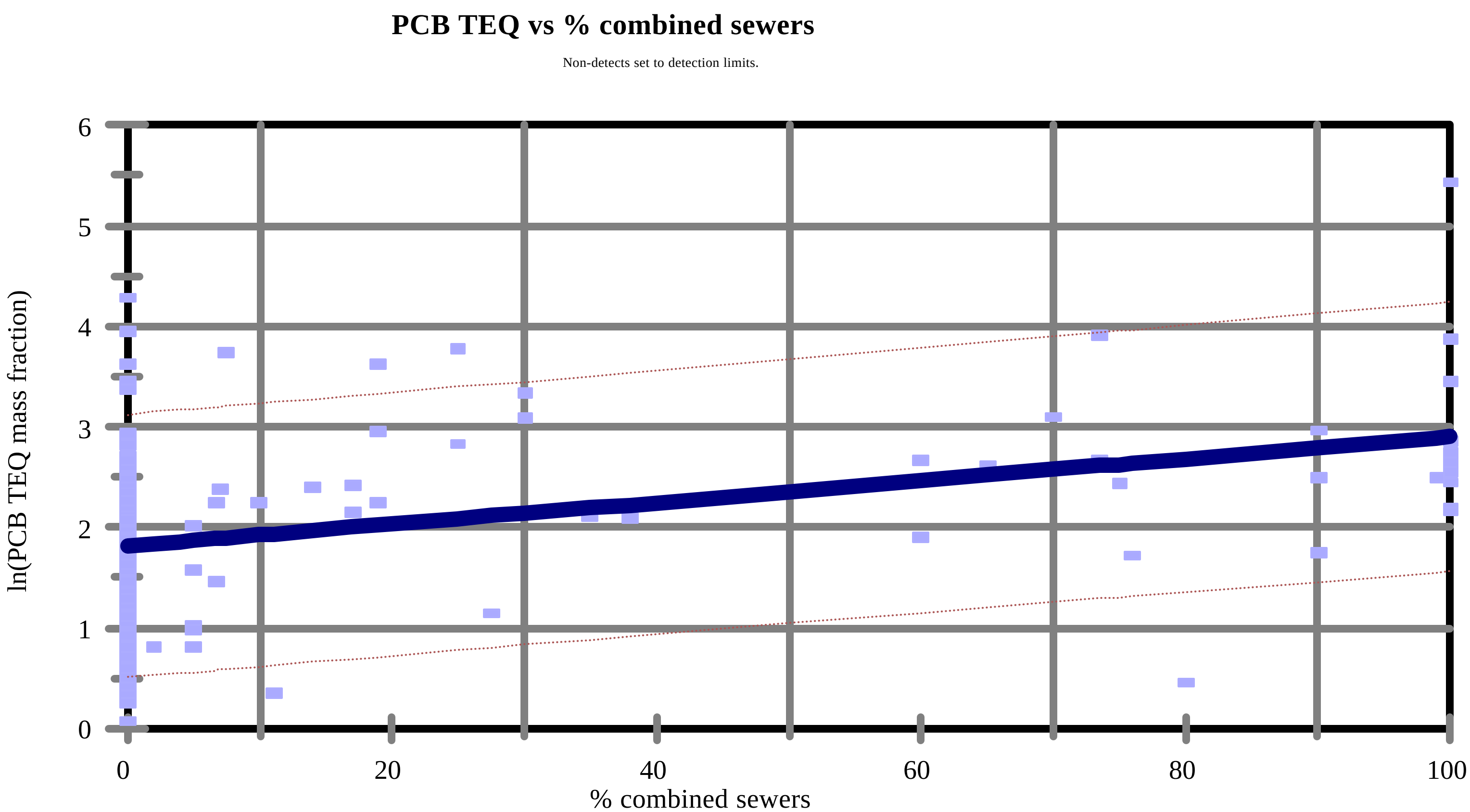

Figure 5.30 Regression line and 90% prediction interval for PCB TEQ mass fraction versus percent of service area with combined sewers. Non-detects set to detection limits.

Table 5.20 Variables initially included in multiple linear regression

Numeric Variables (7)	
	Percent solids in sample
	Total annual biosolids
	Average daily flow
	Average percent total solids
	Percent industrial loading
	Percent service area with Combined sewerss
	Percent from other POTWs

Regional Variables (by U.S. EPA Region) (10)	
	Region 1
	Region 2
	Region 3
	Region 4
	Region 5
	Region 6
	Region 7
	Region 8
	Region 9
	Region 10

Process variables (26)	
	Gravity thickening (lagooning)
	Gravity belt thickening

Table 5.20 Variables initially included in multiple linear regression

Process variables (cont.) (26)	
	Aerobic digestion
	Anaerobic digestion
	Polymer
	$FeCl_3$
	$FeCl_2$
	H_2O_2
	Thermal conditioning
	Alum
	Lime stabilization
	DAFT
	Carbonaceous activated sludge
	$KMnO_4$
	WAS (waste activated sludge)
	Centrifuge
	Aerated mixing w/out digestion
	Decanting
	ATAD
	Filter press
	Drying beds
	Vacuum filters
	AASSD process
	N-Viro
	Air drying

Table 5.20 Variables initially included in multiple linear regression

	Heat drying

Sample description variables (16)	
	Vacuum filter cake
	Filter press cake
	Centrifuge cake
	Aerobically digested biosolids
	Anaerobically digested biosolids
	Lagooned biosolids
	Lime stabilized biosolids
	Non-dewatered biosolids
	Dewatered biosolids
	Heat dried biosolids
	Air dried biosolids
	AASSD (N-Viro)
	TAGRO
	ATAD biosolids
	GBT cake
	Compost

Table 5.21 Variables excluded from multiple linear regression

Variable	Type
Total annual biosolids	Numeric
Region 1	Regional
H_2O_2	Process
Alum	Process
Carbonaceous activated sludge	Process
$KMnO_4$	Process
Aerated mixing without digestion	Process
Vacuum filters	Process
N-Viro	Process
Vacuum filter cake	Sample Description
Non-dewatered biosolids	Sample Description
TAGRO	Sample Description
ATAD biosolids	Sample Description
GBT cake	Sample Description

Table 5.22 Regression coefficients for logarithmically transformed total TEQ versus six numeric variables. Non-detects set to zero.

Variable	Coefficient	Standard Error of Coefficient	t statistic of coefficient
Percent solids in sample (%)	-0.0052	0.0098	0.53
Average daily flow (MGD)	1.14e-06	0.0012	0.001
Average percent total solids (%)	0.0146	0.0099	1.48
Percent industrial loading (%)	-0.0109	0.0077	1.42
Percentage of service area with combined sewers (%)	0.0088	0.0059	1.50
Percent of flow from other POTWs (%)	0.0162	0.0133	1.21
Coefficients that pass a 90% confidence test are in boldface.			

Table 5.23 Correlation results for logarithmically transformed total TEQ versus the six numeric variables in Table 5.22. Non-detects set to zero.

Parameter	Value
Number of samples	129
Degrees of freedom	122
Correlation coefficient (*r*)	0.33
Fraction of variance accounted for by regression (r^2)	0.11
Constant of correlation (*b*)	2.34
Standard error of the estimate	1.30

Table 5.24 Regression coefficients for logarithmically transformed total TEQ versus six numeric variables. Non-detects set to detection limits.

Variable	Coefficient	Standard Error of Coefficient	t statistic of coefficient
Percent solids in sample (%)	-0.0025	0.0051	0.49
Average daily flow (MGD)	1.83e-04	0.0006	0.29
Average percent total solids (%)	0.0064	0.0051	1.26
Percent industrial loading (%)	-0.0038	0.0040	0.96
Percentage of service area with combined sewers (%)	0.0029	0.0030	0.97
Percent of flow from other POTWs (%)	0.0087	0.0069	1.27
Coefficients that are significant with 90% confidence are in boldface.			

Table 5.25 Correlation results for logarithmically transformed total TEQ versus the six numeric variables in Table 5.22. Non-detects set to detection limits.

Parameter	Value
Number of samples	129
Degrees of freedom	122
Correlation coefficient *(r*)	0.28
Fraction of variance accounted for by regression (r^2)	0.08
Constant of correlation (*b*)	3.29
Standard error of the estimate	0.67

Table 5.26 Regression coefficients for logarithmically transformed total TEQ versus U.S. EPA Region. Non-detects set to zero.

Region	Coefficient	Standard Error of Coefficient	t statistic of coefficient
2	**1.76**	0.91	**1.94**
3	0.99	0.91	1.09
4	1.36	0.91	1.50
5	0.91	0.90	1.01
6	0.48	0.95	0.50
7	1.26	0.97	1.30
8	1.06	0.96	1.11
9	0.28	0.93	0.30
10	1.01	0.93	1.08
Coefficients that pass a 90% confidence test are in boldface.			

Table 5.27 Correlation results for logarithmically transformed total TEQ versus the nine regional variables in Table 5.26. Non-detects set to zero.

Parameter	Value
Number of samples	200
Degrees of freedom	190
Correlation coefficient (*r*)	0.33
Fraction of variance accounted for by regression (r^2)	0.11
Constant of correlation (*b*)	1.56
Standard error of the estimate	1.24

Table 5.28 Regression coefficients for logarithmically transformed total TEQ versus U.S. EPA Region. Non-detects set to detection limits.

Region	Coefficient	Standard Error of Coefficient	t statistic of coefficient
2	**0.88**	**0.46**	**1.92**
3	0.55	0.46	1.20
4	**0.78**	**0.46**	**1.68**
5	0.59	0.45	1.30
6	0.22	0.48	0.46
7	0.66	0.49	1.34
8	0.67	0.48	1.38
9	0.25	0.47	0.53
10	0.55	0.47	1.17
Coefficients that pass a 90% confidence test are in boldface.			

Table 5.29 Correlation results for logarithmically transformed total TEQ versus the nine regional variables in Table 5.26. Non-detects set to detection limits.

Parameter	Value
Number of samples	200
Degrees of freedom	190
Correlation coefficient (r)	0.31
Fraction of variance accounted for by regression (r^2)	0.10
Constant of correlation (b)	2.82
Standard error of the estimate	0.63

Table 5.30 Regression coefficients for logarithmically transformed total TEQ versus process variables. Non-detects set to zero.

Variable	Coefficient	Standard Error of Coefficient	t statistic of coefficient
Gravity thickening (lagooning)	0.13	0.23	0.56
Gravity belt thickening	-0.29	0.40	0.72
Aerobic digestion	0.20	0.29	0.67
Anaerobic digestion	**0.69**	**0.23**	**2.95**
Polymer	-0.06	0.30	0.21
$FeCl_3$	0.05	0.28	0.19
$FeCl_2$	-0.56	0.58	0.96
Thermal conditioning	0.46	0.50	0.91
Lime stabilization	0.10	0.29	0.36
DAFT	-0.17	0.55	0.32
WAS (waste activated sludge)	-0.71	0.60	1.19
Centrifuge	**-0.44**	**0.26**	**1.69**
Decanting	-0.38	0.73	0.52
ATAD	0.70	0.76	0.92
Filter press	**-0.82**	**0.26**	**3.20**
Drying beds	0.10	0.32	0.33
AASSD process	0.10	0.71	0.14
Air drying	**1.35**	**0.65**	**2.08**
Heat drying	**0.63**	**0.37**	**1.70**
Coefficients that pass a 90% confidence test are in boldface.			

Table 5.31 Correlation results for logarithmically transformed total TEQ versus the nineteen process variables in Table 5.30. Non-detects set to zero.

Parameter	Value
Number of samples	200
Degrees of freedom	180
Correlation coefficient *(r)*	0.45
Fraction of variance accounted for by regression (r^2)	0.21
Constant of correlation (*b*)	2.59
Standard error of the estimate	1.21

Table 5.32 Regression coefficients for logarithmically transformed total TEQ versus process variables. Non-detects set to detection limits.

Variable	Coefficient	Standard Error of Coefficient	t statistic of coefficient
Gravity thickening (lagooning)	0.005	0.12	0.04
Gravity belt thickening	-0.30	0.20	1.45
Aerobic digestion	0.07	0.15	0.46
Anaerobic digestion	**0.30**	**0.12**	**2.50**
Polymer	0.02	0.15	0.12
$FeCl_3$	0.04	0.14	0.26
$FeCl_2$	-0.22	0.30	0.72
Thermal conditioning	0.13	0.26	0.49
Lime stabilization	0.05	0.15	0.36
DAFT	-0.28	0.28	0.99
WAS (waste activated sludge)	-0.29	0.30	0.94
Centrifuge	**-0.29**	**0.13**	**2.16**
Decanting	-0.13	0.37	0.36
ATAD	-0.02	0.39	0.05
Filter press	**-0.38**	**0.13**	**2.88**
Drying beds	0.10	0.16	0.60
AASSD process	-0.13	0.36	0.37
Air drying	**0.68**	**0.33**	**2.04**
Heat drying	0.25	0.19	1.32
Coefficients that pass a 90% confidence test are in boldface.			

58 Charles Street Cambridge, Massachusetts 02141
617-225-0810 FAX: 617-225-0813 E-mail: info@CambridgeEnvironmental.com

Table 5.33 Correlation results for logarithmically transformed total TEQ versus the nineteen process variables in Table 5.30. Non-detects set to detection limits.

Parameter	Value
Number of samples	200
Degrees of freedom	180
Correlation coefficient *(r)*	0.42
Fraction of variance accounted for by regression (r^2)	0.18
Constant of correlation (*b*)	3.48
Standard error of the estimate	0.62

Table 5.34 Regression coefficients for logarithmically transformed total TEQ versus sample description variables. Non-detects set to zero.

Variable	Coefficient	Standard Error of Coefficient	t statistic of coefficient
Filter press cake	-0.11	0.43	0.25
Centrifuge cake	0.09	0.45	0.20
Aerobically digested biosolids	-0.08	0.55	0.14
Anaerobically digested biosolids	**1.22**	**0.46**	**2.65**
Lagooned biosolids	0.92	0.67	1.37
Lime stabilized biosolids	-0.68	0.49	1.40
Dewatered biosolids	0.27	0.56	0.48
Heat dried biosolids	0.60	0.67	0.90
Air dried biosolids	0.72	0.59	1.22
AASSD (N-Viro)	-0.41	0.80	0.51
Compost	0.89	0.55	1.63
Coefficients that pass a 90% confidence test are in boldface.			

Table 5.35 Correlation results for logarithmically transformed total TEQ versus the eleven sample description variables in Table 5.34. Non-detects set to zero.

Parameter	Value
Number of samples	200
Degrees of freedom	188
Correlation coefficient (r)	0.46
Fraction of variance accounted for by regression (r^2)	0.21
Constant of correlation (b)	2.35
Standard error of the estimate	1.18

Table 5.36 Regression coefficients for logarithmically transformed total TEQ versus sample description variables. Non-detects set to detection limits.

Variable	Coefficient	Standard Error of Coefficient	t statistic of coefficient
Filter press cake	0.05	0.22	0.24
Centrifuge cake	0.10	0.22	0.47
Aerobically digested biosolids	0.07	0.27	0.26
Anaerobically digested biosolids	**0.75**	**0.23**	**3.28**
Lagooned biosolids	0.39	0.34	1.15
Lime stabilized biosolids	-0.13	0.24	0.54
Dewatered biosolids	0.16	0.28	0.55
Heat dried biosolids	0.39	0.34	1.16
Air dried biosolids	**0.68**	**0.29**	**2.31**
AASSD (N-Viro)	-0.19	0.40	0.47
Compost	**0.47**	**0.27**	**1.73**
Coefficients that pass a 90% confidence test are in boldface.			

Table 5.37 Correlation results for logarithmically transformed total TEQ versus the eleven sample description variables in Table 5.34. Non-detects set to detection limits.

Parameter	Value
Number of samples	200
Degrees of freedom	188
Correlation coefficient (*r*)	0.47
Fraction of variance accounted for by regression (r^2)	0.22
Constant of correlation (*b*)	3.19
Standard error of the estimate	0.59

58 Charles Street Cambridge, Massachusetts 02141
617-225-0810 FAX: 617-225-0813 E-mail: info@CambridgeEnvironmental.com

Table 5.38 Variables used in combined regression

Variable	Type
Region 2	Regional
Anaerobic Digestion	Process
Centrifuge	Process
Air drying	Process
Filter press	Process

Table 5.39 Regression coefficients for logarithmically transformed total TEQ versus variables from Table 5.38. Non-detects set to zero.

Variable	Coefficient	Standard Error of Coefficient	t statistic of coefficient
Region 2	**0.75**	**0.23**	**3.30**
Anaerobic Digestion	**0.58**	**0.17**	**3.35**
Centrifuge	**-0.38**	**0.22**	**1.76**
Air drying	**1.63**	**0.59**	**2.74**
Filter press	**-0.77**	**0.21**	**3.76**
Coefficients that pass a 90% confidence test are in boldface.			

Table 5.40 Correlation results for logarithmically transformed total TEQ versus the five variables in Table 5.38. Non-detects set to zero.

Parameter	Value
Number of samples	200
Degrees of freedom	194
Correlation coefficient (*r*)	0.46
Fraction of variance accounted for by regression (r^2)	0.21
Constant of correlation (*b*)	2.58
Standard error of the estimate	1.16

Table 5.41 Regression coefficients for logarithmically transformed total TEQ versus variables from Table 5.38. Non-detects set to detection limits.

Variable	Coefficient	Standard Error of Coefficient	t statistic of coefficient
Region 2	**0.32**	**0.12**	**2.70**
Anaerobic Digestion	**0.29**	**0.09**	**3.18**
Centrifuge	**-0.25**	**0.11**	**2.18**
Air drying	**0.79**	**0.31**	**2.59**
Filter press	**-0.34**	**0.11**	**3.23**
Coefficients that pass a 90% confidence test are in boldface.			

Table 5.42 Correlation results for logarithmically transformed total TEQ versus the five variables in Table 5.38. Non-detects set to detection limits.

Parameter	Value
Number of samples	200
Degrees of freedom	194
Correlation coefficient (*r*)	0.41
Fraction of variance accounted for by regression (r^2)	0.17
Constant of correlation (*b*)	3.42
Standard error of the estimate	0.60

Table 5.43 Regression coefficients for logarithmically transformed dioxin/furan TEQ versus variables from Table 5.38. Non-detects set to zero.

Variable	Coefficient	Standard Error of Coefficient	t statistic of coefficient
Region 2	**0.59**	**0.25**	**2.36**
Anaerobic Digestion	**0.54**	**0.19**	**2.78**
Centrifuge	**-0.43**	**0.24**	**1.76**
Air drying	**1.81**	**0.66**	**2.76**
Filter press	**-0.74**	**0.23**	**3.25**
Coefficients that pass a 90% confidence test are in boldface.			

Table 5.44 Correlation results for logarithmically transformed dioxin/furan TEQ versus the five variables in Table 5.38. Non-detects set to zero.

Parameter	Value
Number of samples	200
Degrees of freedom	194
Correlation coefficient (r)	0.40
Fraction of variance accounted for by regression (r^2)	0.16
Constant of correlation (b)	2.18
Standard error of the estimate	1.28

Table 5.45 Regression coefficients for logarithmically transformed dioxin/furan TEQ versus variables from Table 5.38. Non-detects set to detection limits.

Variable	Coefficient	Standard Error of Coefficient	t statistic of coefficient
Region 2	**0.19**	**0.11**	**1.69**
Anaerobic Digestion	**0.21**	**0.09**	**2.52**
Centrifuge	-0.15	0.11	1.41
Air drying	**0.87**	**0.29**	**3.00**
Filter press	**-0.22**	**0.10**	**2.18**
Coefficients that pass a 90% confidence test are in boldface.			

Table 5.46 Correlation results for logarithmically transformed dioxin/furan TEQ versus the five variables in Table 5.38. Non-detects set to detection limits.

Parameter	Value
Number of samples	200
Degrees of freedom	194
Correlation coefficient (r)	0.34
Fraction of variance accounted for by regression (r^2)	0.12
Constant of correlation (b)	3.05
Standard error of the estimate	0.57

Table 5.47 Regression coefficients for logarithmically transformed PCB TEQ versus variables from Table 5.38. Non-detects set to zero.

Variable	Coefficient	Standard Error of Coefficient	t statistic of coefficient
Region 2	**0.87**	**0.23**	**3.86**
Anaerobic Digestion	**0.69**	**0.17**	**3.98**
Centrifuge	-0.28	0.22	1.30
Air drying	**1.13**	**0.59**	**1.91**
Filter press	**-0.98**	**0.20**	**4.77**
Coefficients that pass a 90% confidence test are in boldface.			

Table 5.48 Correlation results for logarithmically transformed PCB TEQ versus the five variables in Table 5.38. Non-detects set to zero.

Parameter	Value
Number of samples	200
Degrees of freedom	194
Correlation coefficient (*r*)	0.53
Fraction of variance accounted for by regression (r^2)	0.28
Constant of correlation (*b*)	1.16
Standard error of the estimate	1.15

Table 5.49 Regression coefficients for logarithmically transformed PCB TEQ versus variables from Table 5.38. Non-detects set to detection limits.

Variable	Coefficient	Standard Error of Coefficient	t statistic of coefficient
Region 2	**0.50**	**0.15**	**3.25**
Anaerobic Digestion	**0.42**	**0.12**	**3.60**
Centrifuge	**-0.34**	**0.15**	**2.30**
Air drying	0.54	0.40	1.34
Filter press	**-0.62**	**0.14**	**4.43**
Coefficients that pass a 90% confidence test are in boldface.			

Table 5.50 Correlation results for logarithmically transformed PCB TEQ versus the five variables in Table 5.38. Non-detects set to detection limits.

Parameter	Value
Number of samples	200
Degrees of freedom	194
Correlation coefficient *(r)*	0.47
Fraction of variance accounted for by regression (r^2)	0.22
Constant of correlation (*b*)	2.00
Standard error of the estimate	0.79

58 Charles Street Cambridge, Massachusetts 02141
617-225-0810 FAX: 617-225-0813 E-mail: info@CambridgeEnvironmental.com

6 Conclusions

Statistical analyses were performed on the data sets gathered during the AMSA 2000/2001 Survey of Dioxin-like Compounds in Biosolids. Chemical composition data was provided by MRI, while questionnaire responses for each sample were provided by AMSA. The statistical analyses had three goals: to characterize the distributions of dioxin-like compounds in biosolids from these various POTWs, to determine whether the results of AMSA's 2000/2001 survey were significantly different from the results of AMSA's 1994/1995 Survey of Dioxin-like Compounds in Biosolids and to determine whether there were any correlations between a POTW's regional, influent, process and biosolids related information and its TEQ mass fractions of dioxin-like compounds in the biosolids (using the TEF system of Van den Berg *et al.*, 1998). The conclusions of the statistical analyses are as follows:

The distributions of total, dioxin/furan, and PCB TEQ mass fraction appear to be approximately lognormal. When non-detected congeners are assumed to be present at one-half of their detection limits, the mean TEQ mass fraction of PCB congeners is 10.0 pg TEQ/g (ppt TEQ), with a median value of 5.7 pg TEQ/g and a range from 0.54 pg TEQ/g to 228.7 pg TEQ/g. The mean TEQ value of dioxin/furan congeners is 38.4 pg TEQ/g (ppt TEQ), with a median value of 15.2 pg TEQ/g and a range from 5.94 pg TEQ/g to 3579 pg TEQ/g. The total TEQ values for the samples have a mean value of 48.5 pg TEQ/g, with a median of 21.7 pg TEQ/g and a range from 7.10 pg TEQ/g to 3590 pg TEQ/g.

The means of the logarithmically transformed 2000/2001 and 1994/1995 AMSA survey data sets appear to be significantly different, and the 2000/2001 data show lower average TEQ mass fractions than the 1994/1995 data. When non-detected congeners are assumed to be absent, the median dioxin/furan TEQ mass fraction declined by 56%, the median PCB subset TEQ mass fraction (containing only those PCB congeners analyzed in the 1994/1995 survey) declined by 83%, and the median adjusted total TEQ mass fraction declined by 64%. The corresponding means declined by 0.5%, 79%, and 32%, respectively. Thus, the decrease in mean total TEQ appears to be driven by declining PCB concentrations.

The analysis of the samples by U.S. EPA Region suggests that the total and PCB TEQ mass fractions might vary between regions, although the evidence is weak considering the assumptions required and the number of statistical tests performed. While the median total TEQ mass fraction Region 1 is well below the 10^{th} percentile of total TEQ mass fraction for Regions 2 and 7, this may be an artifact of the sampling method or simply random variation, particularly since only two samples from Region 1 are available. Thus, while there may be regional differences in total and

PCB TEQ mass fractions, further sampling designed to tests such a hypothesis would be required to confirm it.

Single variable regressions of the average daily flow to POTWs, percent solids in sample, percent industrial loading of a POTW, and percent of service area with combined sewers, with TEQ mass fractions show that while the correlations are potentially significant, the uncertainty in the predicted values is so large that these variables, when used independently, cannot predict the TEQ mass fraction of biosolids from a given POTW to within an order of magnitude. Similarly, a multiple linear regression of the numeric questionnaire variables (*i.e.*, percent industrial flow, percent service area with Combined sewerss, *etc*.) suggests that these variables are not useful in predicting the TEQ mass fraction of a sample.

The results of the stepwise multiple linear regression presented in Chapter 5 suggest that five variables are potentially useful in predicting the TEQ mass fraction of a sample: whether the sample is in Region 2 (positive coefficient), whether the sample was anaerobically digested (positive coefficient), whether the sample was centrifuged (negative coefficient), whether the sample was air dried (positive coefficient), and whether the sample was filter pressed (negative coefficient). In the regression of the logarithm of total TEQ mass fraction, these five variables account for 21% of the variation between samples. For PCB TEQ the five variables account for 28% of the variation, the highest of any of the regressions evaluated; however, that leaves approximately three-fourths of the variation between samples unaccounted for. Thus this correlation, even if it is applicable in general, is unlikely to have any significant predictive power, at least on a POTW by POTW basis:the 90% prediction interval of the total TEQ regression is 3.89 on a logarithmic scale, or a 50-fold variation in the untransformed values, too large for useful predictions. The same argument holds for the regressions versus total and dioxin/furan TEQ mass fraction. Given the limitations of the data used here, further experimentation and analysis would be needed to confirm any of the trends observed in the regression of the AMSA 2000/2001 survey samples, and changes in a POTW's process may not result in the increases and decreases of TEQ mass fraction predicted by the regression.

58 Charles Street Cambridge, Massachusetts 02141
617-225-0810 FAX: 617-225-0813 E-mail: info@CambridgeEnvironmental.com

7 References

Box, G.E.P., Hunter, W.G., and Hunter, J.S. (1978). *Statistics for experimenters: An Introduction to Design, Data Analysis, and Model Building.* John Wiley & Sons, New York.

Dominak, R. (2001). Residuals Manager, Northeast Ohio Regional Sewer District. Personal communication, September 4, 2001.

Federal Register (1999). *Standards for the Use or Disposal of Sewage Sludge:Proposed Rule.* Federal Register, Thursday, December 23, 1999, Vol. 64, No. 246, pp. 72045-72062.

Green, L.C., Crouch, E.A.C., Armstrong, S.R., Lash, T.L., and Lester, R.L. (1995a). *Comments on: Estimating Exposure to Dioxin-like Compounds: Review Draft.* Cambridge Environmental Inc., Cambridge, MA, January 12, 1995.

Green, L.C., Lester, R.L., and Armstrong, S.R. (1995b). *Addendum to "Comments on: Estimating Exposure to Dioxin-like Compounds: Review Draft".* Cambirdge Environmental Inc., Cambridge, MA, May 11, 1995.

Snedecor, G.W., and Cochran,W.G. (1989). *Statistical Methods.* 8th ed. Iowa University Press, Ames, IA.

U.S. EPA. (1989). *Interim Procedures for Estimating Risks Associated with Exposures to Mixtures of Chlorinated Dibenzo-p-Dioxins and Dibenzofurans (CDDS and CDFs): 1989 Update.* EPA/625/3-89/016. Risk Assessment Forum, U.S. EPA,Washington, DC.

Van den Berg, M., Birnbaum, L., Bosveld, A.T.C., Brunstrom, B., Cook, P., *et al.* (1998). *Toxic Equivalency Factors (TEFs) for PCBs, PCDDs, PCDFs for Humans and Wildlife.* Environmental Health Perspectives, 106(12):775-792.

58 Charles Street Cambridge, Massachusetts 02141
617-225-0810 FAX: 617-225-0813 E-mail: info@CambridgeEnvironmental.com