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SEASONAL TRENDS IN BLOOD LEAD LEVELS IN MILWAUKEE: STATISTICAL METHODOLOGY

Technical Programs Branch
Chemical Management Division (7404)
Office of Pollution Prevention and Toxics
U.S. Environmental Protection Agency
401 M Street, S.W.
Washington, D.C. 20460

DISCLAIMER

CONTRIBUTING ORGANIZATIONS

The study described in this report was conducted by the U.S. Environmental Protection Agency (EPA) and its contractor QuanTech and the Milwaukee Health Department. The Milwaukee Health Department provided the data and consultation, and EPA and its contractor entered the data into a database, analyzed the data, and produced the report.

QuanTech

Quantech (formerly David C. Cox & Associates) provided technical assistance regarding the data management, and was responsible for the statistical analysis, and for the overall production of the report.

U.S. Environmental Protection Agency

The U.S. Environmental Protection Agency (EPA) funded the analysis of the data and was responsible for managing the study, for reviewing study documents, and for arranging for the peer review of the final report. The EPA Project Leader was Bradley Schultz. The EPA Work Assignment Manager and Project Officer was Samuel Brown. Cindy Stroup and Barbara Leczynski provided valuable guidance. Janet Remmers, Dan Reinhart and Phil Robinson also provided useful comments.

Milwaukee Health Department

The study could not have been done without the assistance and cooperation of the Milwaukee Health Department. Major contributors included Amy Murphy, Thomas Schlenker, Mary Jo Gerlach, Kris White, and Sue Shepeard.

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EXECUTIVE SUMMARY

Most studies on the effectiveness of interventions for reducing children's blood lead levels (PbB) have not distinguished declines in PbB due to program effectiveness from seasonal and age-related fluctuations in PbB. In this report, seasonal fluctuations and age effects in 1990-94 blood lead levels for a northern urban environment are studied, using data from 13,476 children screened for blood lead in Milwaukee, Wisconsin. The purpose was to determine whether there were seasonal and age trends, and if so, to estimate the magnitude of the trends. These estimates can then be used to help interpret studies with blood lead monitoring data, especially studies on the effectiveness of interventions to reduce blood lead levels.

The Milwaukee data showed sizeable seasonal and age trends in Milwaukee children's PbB levels. Blood lead levels were about 40% higher in the summer than the winter, and about 15-20% higher at ages two to three years than at ages less than one year or ages five to seven years. Statistical methodology was developed to account for these fluctuations, so that the effectiveness of intervention programs may be quantified. These estimates are being used in studies of the effectiveness of lead interventions in Milwaukee. The methodology was described in considerable technical detail to facilitate analyses of seasonal and age effects in PbB in other environments.

A tentative result suggests the magnitude of seasonal PbB fluctuations may be greatest for children less than four years old. Better understanding of the reasons for the trends might help to better determine mechanisms for reducing childhood lead exposure. Seasonal fluctuations in PbB are probably greater in cooler environments such as Milwaukee's, where seasonal changes in exposure to outdoor lead sources and sunlight are more extreme. At least in the northern U.S., the magnitude of the seasonal and age trends are large enough so that they must be considered in the design and interpretation of any blood lead monitoring results.

1 INTRODUCTION

Many Federal, State, and local programs have been implemented to reduce lead exposure in children. However, most of the studies of the effectiveness of the interventions for reducing blood lead (PbB) levels (see Burgoon, et al, 1994 and U.S.EPA, 1995a) have ignored effects of seasonal fluctuations in PbB levels and dependencies of PbB levels on age. A few studies on abatement effects eliminated the confounding of seasonal effects but not age effects, by spacing PbB measurements one year apart. For retrospective studies, the requirement of many repeat measurements one year apart is not feasible. Thus, quantification of the effects of abatements and other promising intervention strategies has often not been possible. For example, a study on the effect of educational and counselling interventions for reducing PbB levels in children (Kimbrough, et al, 1994) reported that "educating parents proved a very effective tool" for reducing PbB levels, but did not estimate the decline in PbB levels due to the intervention. Instead, declines in the Granite City, Illinois children's PbB levels following interventions were simply reported as being too large to be attributed entirely to seasonal and age effects.

In this report seasonal fluctuations and age effects in 1990-93 PbB levels for a northern urban environment are studied using data from 13,476 children screened for blood lead in Milwaukee, Wisconsin. The purpose is to determine whether seasonal and age effects exist, and if so, to develop simple adjustments to allow for quantification of the effects of education and abatement programs. Some previous analyses of data from the 1970's and early 1980's, such as U.S.EPA(1995b), indicated seasonal trends; this analysis sought to verify and estimate the current trend. Statistical methodology is described in detail to facilitate analyses of seasonal and age effects in PbB for other environments. Tables with adjustment factors specific to the 1990-93 Milwaukee PbB data are also included. The adjustment factors are necessary for planned analyses of the effectiveness of abatement and lead educational programs in Milwaukee from 1990-93.

1.1 PEER REVIEW COMMENTS

This study was reviewed independently by members of a peer review panel. Comments which are important for interpreting the study results or which had an important impact on the report are discussed below.

Some reviewers wanted a clearer description of the Milwaukee Health Department screening program expansion, and how the expansion may have affected results of the analysis and validity of the seasonal adjustment factors. In response, portions of the text were rewritten. Table 1 was added; it delineates the changes and shows how the available data was used. Also Figure 1 now includes a needle plot showing the number of children screened for blood lead from 1983-1993. Geographical information was requested, so the appendices now include Table C1 which shows blood lead level results by zip code.

One of the reviewers was concerned about correlations among residuals from different time periods. In response, greater emphasis was placed on Figure 12, a residual plot for 90th percentile results which indicated the residuals were not correlated. The analysis of 90th percentiles better describe blood lead levels of children at high risk for lead poisoning than the analysis of mean blood lead levels which indicated correlation among residuals. More discussion about this correlation was added to the text.

One of the reviewers thought that the use of the Beta model was not well justified. In response, figures were added to show that the fit to the model was very good for the 90th percentiles. The beta model, with a minimum of parameters fit the data as well as sinusoidal models. The Beta model also allowed for direct assessment of features such as the potential for abrupt or asymmetric seasonal changes in PbB between winter and summer. A test for symmetry is now detailed in Section 4.2.1.

Some of the reviewers were concerned about limitations inherent in making adjustments for removal of seasonal trends. Comments were made that well-designed randomized trials would likely be a better approach for studies of intervention effectiveness. In response, text in the Discussion section now more completely discusses these limitations, and mentions that some seasonal effects might be controlled for in some well-designed studies. However, formulating well-designed studies for evaluating effectiveness of interventions is problematic. Furthermore, retrospective studies, which by definition can not control for seasonality, have certain advantages. First, retrospective studies usually would include a larger number of children. Second, retrospective studies would not create artificial circumstances which could lead to invalid conclusions. Finally, they would not arbitrarily deprive control group children of benefits from interventions being evaluated.

One of the reviewers was concerned about inferences about the interaction between age and other effects since the participation in the screening program may be different for older children (ages greater than three years). Although these are valid concerns, older children were usually screened for the same reasons as younger children, and only rarely because of clinical indications. Also, Figure 4 indicates that the relationship between age and PbB seems consistent from ages 2 to 7.

2 DATA DESCRIPTION

2.1 DATA COLLECTION

The PbB data is a result of widespread blood lead screening of Milwaukee children, generally less than seven years old. The screening, occurring in many locations, attempts to identify children with elevated blood lead levels, so steps can be taken to reduce lead exposure and lead-related health impacts. The program began in the 1980's with a few health providers and laboratories reporting blood lead measurements to the Milwaukee Health Department (MHD). In late 1989, the MHD improved its computerization of its records. The screening program expanded dramatically in late 1991. From 1992 through 1993 baseline measurements on 10136 children (about 5000 per year) were sent to the MHD. This corresponds to a coverage of about 50%, since about 10,000 children are born in Milwaukee per year.

At some of the blood screening locations, all of the results are reported to the local health department. Although by law all lead screening data is being reported to the local health department, some sites only reported elevated blood lead levels in the past. Samples for the sites reporting only elevated blood lead levels have been excluded, since this might bias the estimates of seasonality of results. Biases in estimates of average blood lead levels in the population of children in Milwaukee may also result from a procedural change in October, 1991, after which all blood analyses directly measured the lead levels. Prior to October, 1991, some children were screened using FEP (free erythrocyte protoporphyrin) blood analyses (instead of blood lead). Follow-up blood lead measurements were made for these children having an elevated FEP level. FEP measurements were not used for any of the analyses.

Available data for the analyses includes PbB measurements on 25,665 children from 1986 to March, 1994. All PbB measurements in the data set are the baseline measurements which were made before any intervention by the MHD. For children with multiple PbB measurements, the data for this seasonality analysis only includes the first measurement. Blood lead levels from children with prior FEP measurements were also excluded. The next three paragraphs detail the other exclusion criteria.

By 1990, some sites reported all measurements to the MHD. However, other sites tended to report only elevated blood lead measurements to the MHD, and data on 9581 children from these sites was excluded (see Appendix for further details). This exclusion was made to reduce the effect on estimates that would be due to changes in the reporting of measurements to the MHD.

The analysis, tables, and figures (except Figure 1) excluded pre-1990 data on 2,051 children and 1994 data on 557 children. The pre-1990 data was excluded because it represented blood lead levels for a small vaguely defined set of children who tended to have abnormally high blood lead levels. Data from 1994 was excluded because of concerns that it may not have been complete.

Table 1 identifies the MHD measurements on 13,746 children that had been used for this report. Tables 2 and 3 are frequency distributions of these children by year of measurement and age.

Table 1. Use of Blood Lead Measurements from the Milwaukee Health Department

Description	Use	Number of PbB measurements
All recorded baseline measurements from 1986 to 3/94		25,665
Providers report all measurements	Figure 1	25,665 - 9,581 = 16084
Measurements from 1990 through 1993	All analyses, tables, and figures except figure 1, and exceptions below.	16084 - 2051(pre90) - 557 (early 94) = 13,476.
Recorded ages from 6 months to 7 years	Table 3, Figure 4, Section 4.3	13,476-572 = 12,904.

Table 2. First Time Participants in the Milwaukee Blood Lead Screening Program from 1990-1993 by Year of Measurement

Year	Number of Observations	Percent
1990	1,431	10.6
1991	2,466	18.3
1992	5,260	39.0
1993	4,319	32.1
Total	13,476	100.0

Table 3. First Time Participants in the Milwaukee Blood Screening Program from 1990-1993 by Age

Age Category	Number of Observations	Percent
0.5 - 1 Year	2,601	20.2
1 - 1.5 Years	4,378	33.9
1.5 - 2.0 Years	969	7.5
2.0 - 2.5 Years	690	5.3
2.5 - 3.0 Years	616	4.8
3.0 - 3.5 Years	626	4.8
3.5 - 4.0 Years	720	5.6
4.0 - 4.5 Years	772	6.0
4.5 - 5.0 Years	636	4.9
5.0 - 5.5 Years	461	3.6
5.5 - 6.0 Years	214	1.7
6.0 - 6.5 Years	120	0.9
6.5 - 7.0 Years	101	0.8
Total	12,904	100.0

Note: 123 children had a missing value for age category due to the date of birth being missing, the ages of 343 children were greater than 7 years, and the ages of 106 children were less than 6 months.

2.2 SUMMARY STATISTICS

Semi-monthly means (aggregated twice a month) and 90th percentiles of untransformed PbB measurements were used for graphing the data and as inputs for the formal analyses. The 90th percentiles were generally preferred for the purpose of quantifying effects of interventions for reducing lead exposure of children with higher blood lead levels. This is because the blood lead levels at the 90th percentile are more similar to those of children receiving lead interventions than those at the mean, median, or other measures of central tendancy. Since there are 24 semi-monthly periods per year, and four years of data, 96 values of means and 90th percentiles for time periods from 1990 through 1993 were statistically analyzed for most analyses. For analyzing effects of age on seasonality results (described in sections 3.2.4 and 4.3), semi-monthly values were calculated for each of four age groups from 1990 through 1993 for a total of 4*96=384 means and 90th percentiles.

The measurements used for calculating the semi-monthly statistics may be thought of as samples from populations of baseline blood lead levels that would be reported to the MHD. The populations change as actual blood lead levels change, and as the screening program coverage becomes more complete. For a semi-monthly period, the actual sample of measurements depends on a number of factors that include which children are tested at clinics that report all measurements to the MHD, the timing of the measurements, measurement errors, and so on.

From 1990 through 1993, the only obvious systematic change in the number of measurements reported to MHD occurred in late 1991 (see Figure 1). Nevertheless, subtle changes associated with the expansion of the screening program may have resulted in gradual systematic changes in the blood lead level summary statistics. These changes may have had a non-negligible effect on estimates of long term declines in blood lead levels. In contrast, the gradual changes would have had less effect on estimates characterizing the seasonality of blood lead levels, because seasonal levels differ substantially (by about 40%) within a relatively short period of time (between winter and summer).

2.3 DESCRIPTIVE STATISTICS AND FIGURES

As described in section 2.1, the analyses were based on PbB measurements made after 1989. Figure 1, shows a striking difference in the characteristics of the 1986 through 1989 versus the post-1989 time series of mean PbB measurements. The excess variation in mean pre-1990 PbB levels is primarily due to the much smaller number of children screened before the 1990's. The large drop in observed PbB levels in late 1989 may partially be a consequence of the expansion of the screening program. It is likely that before 1990 when there was an even greater need to target children with the highest blood lead levels, the relatively few participating health care providers may have served children primarily in areas of the city where blood lead levels tended to be higher. By 1990, participating primary health providers were more numerous, and areas of the city with differing blood lead level characteristics may have been more evenly represented among the children being screened. Although useful for estimating seasonal and age-related trends, the data here, especially through 1991, is limited in its ability to determine long-term trends in blood lead levels. The most reliable source for determination of long-term trends is NHANES II and NHANES III (Pirkle, et al, 1994) which provided data from 1975-1978 and 1988-1991. These surveys found that blood lead levels had decreased substantially during the 1980's, but that a significant number of children still had blood lead contents at levels widely considered as unhealthy.

Figure 2 is a plot of summary PbB levels from 1990-93 aggregated by semi-monthly period. Open circles and diamonds denote raw means and distribution-free 90th percentiles for each semi-monthly period. Solid boxes and triangles denote smoothed means and 90th percentiles. Smoothing reduces short-term fluctuations caused in part by variation due to the small number of children sampled each period. The smoothed values were weighted moving averages over time. For time period t, the smoothed value was equal to 30% of the raw value at time period t, plus 20% of the sum of the raw values at time period t-1 (preceding) and t+1 (following), plus 10% of the sum of raw values at time periods t-2 and t+2, plus 5% of the sum of the raw values at time periods t-3 and t+3.

The smoothed curves in Figure 2 clearly show seasonal fluctuations in PbB measurements with a peak around July or August and minimum values occurring in the winter. In the summer, the peaks are easily identified, but for some winters, the PbB measurements seem almost constant. Especially for 1993, the plot indicates seasonal fluctuations may be asymmetric. That is, the rise to peak levels may be more gradual and over a longer period of time than the decline to the lowest winter levels. However, a long-term decline in lead levels would accentuate the steepness of the seasonal declines in the fall and winter. Apparent seasonal fluctuations could have also been confounded with changes associated with the expansion of the screening program. From late September to early October, 1991, the number of PbB measurements rose from 112 to 235. The simultaneous sharp drop in PbB levels may have been partially due to the inclusion of lower risk children into the screening population eligible for the study.

Figure 3 illustrates results from functional form fits for both means and 90th percentiles. The functional forms were used to clarify issues such as the possible asymmetry of the data. Details about the functional form fit are provided in section 3.2.2 and Appendix A. From the fit, peak PbB levels most likely occur in August.

Figure 4 presents plots of mean and 90th percentile PbB levels by age. PbB levels increased rapidly before the age of 2 years, and then declined gradually thereafter. Similar results were indicated in at least two other studies. In the Sydney Lead Study (Cooney, et al, 1989), blood lead levels increased from birth to 18 months and then declined for ages 18 to 48 months. In the Port Pirie Study (Baghurst, et al, 1992), PbB levels peaked at age two years. Figure 5, a plot of mean PbB by gender of child, shows no detectable difference in PbB between males and females.

Figure 6 shows smoothed plots of 90th percentile PbB levels for two different age groups. The plots suggest substantial seasonality from 1990 to 1993 for children less than 3 years old, but only in 1992 for the older children. The extent to which seasonality depends on age is uncertain, because of the substantial seasonality shown for all age groups in 1992. Plots in Figure 7 suggest similar seasonality in PbB for ages 6 months to 1 year, 1-1.5 years, and 1.5-3 years in 1990, 1992, and 1993. In 1991, PbB measurements had an observed peak in late summer only for children less than one year old. In 1991, the early peak in PbB measurements for ages 1-3 years may be due in part to procedural changes that may have occurred in the blood lead screening program.

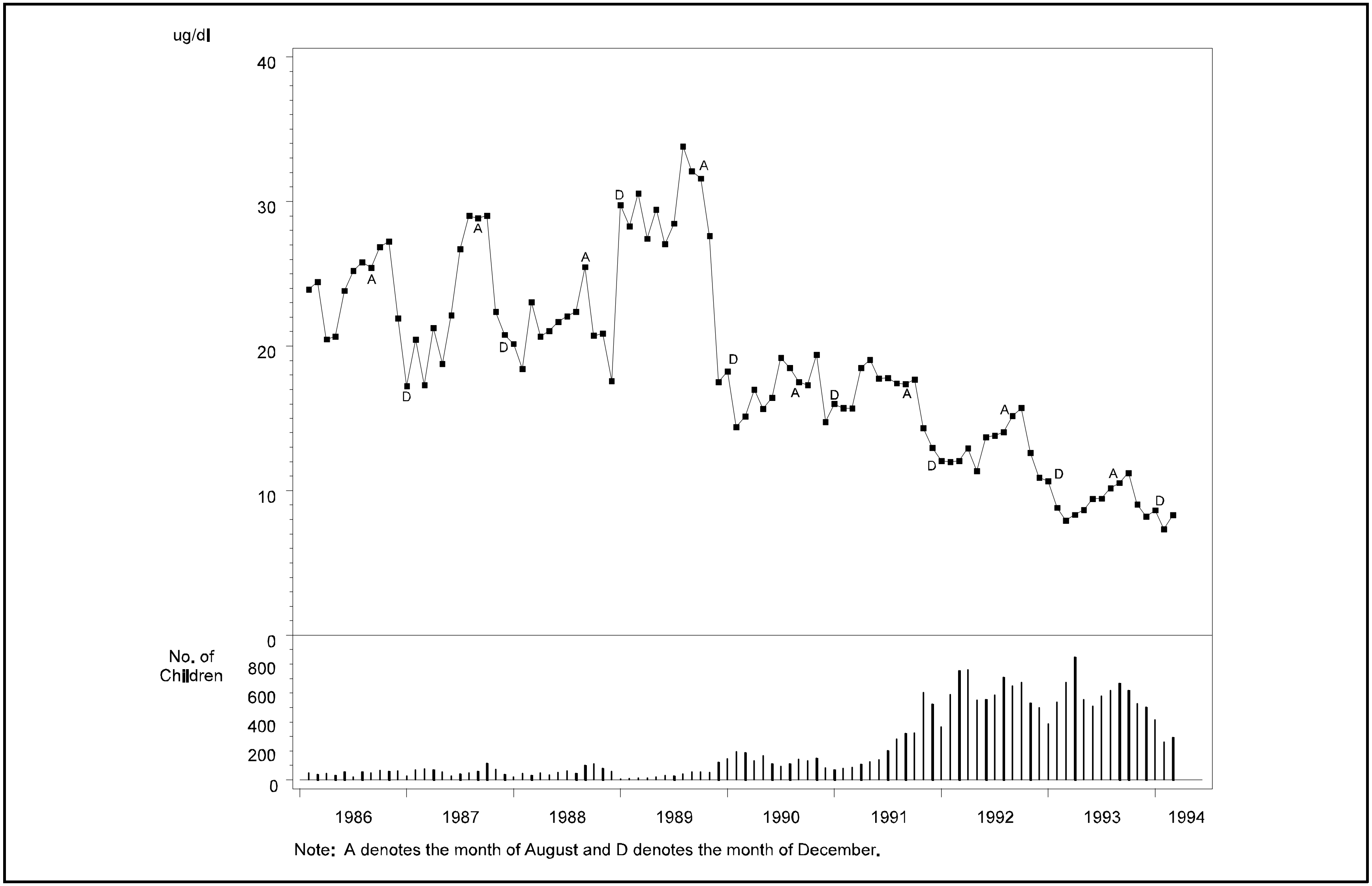

Figure 1 Mean Monthly Blood Lead Levels and Number of Children Screened Based on Milwaukee Health Department Data from Sites that Report All Measurements.

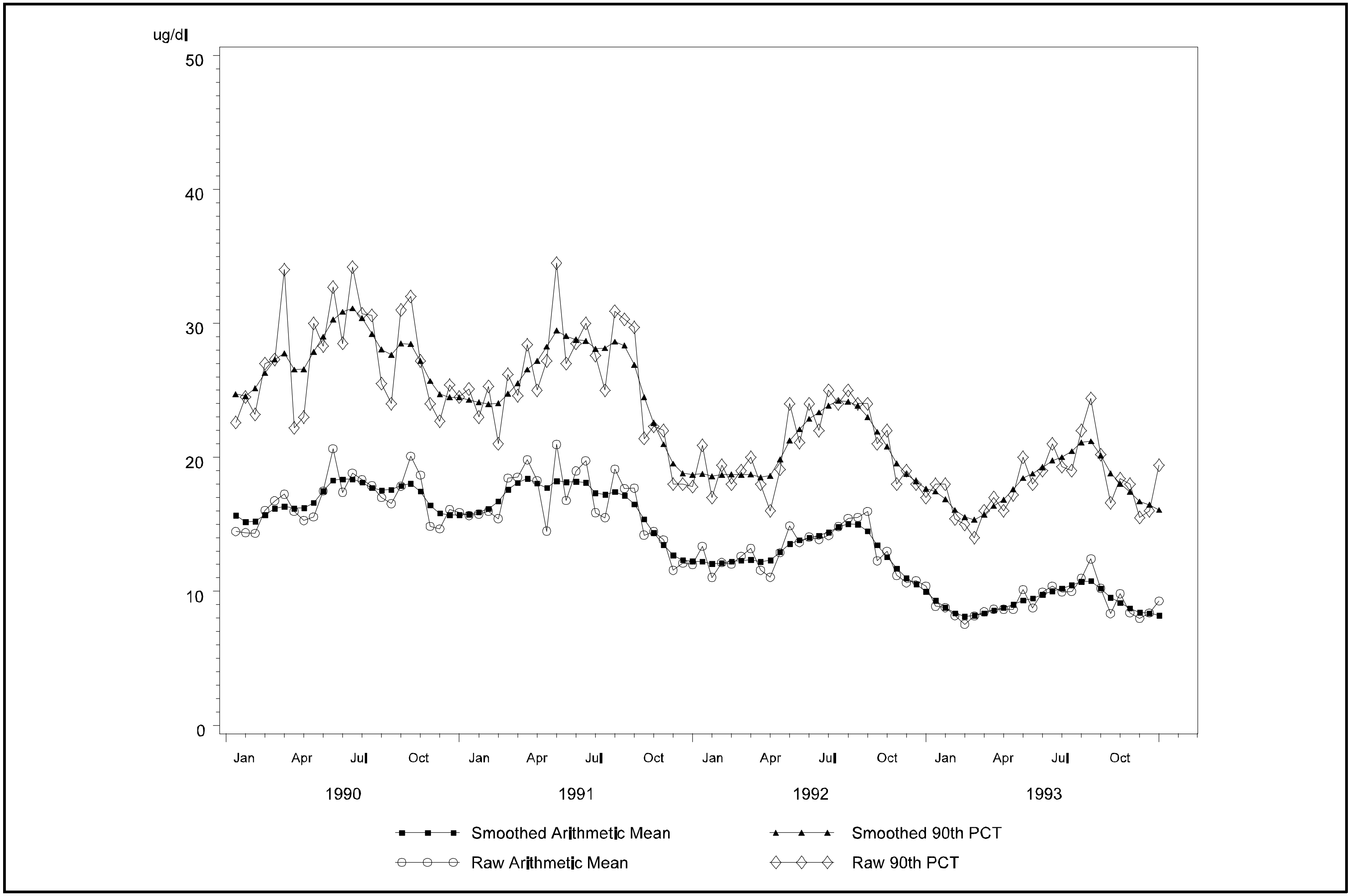

Figure 2 Semi-monthly Arithmetic Mean and 90th Percentile Blood Lead Levels with Smoothed Estimates 1990-1993.

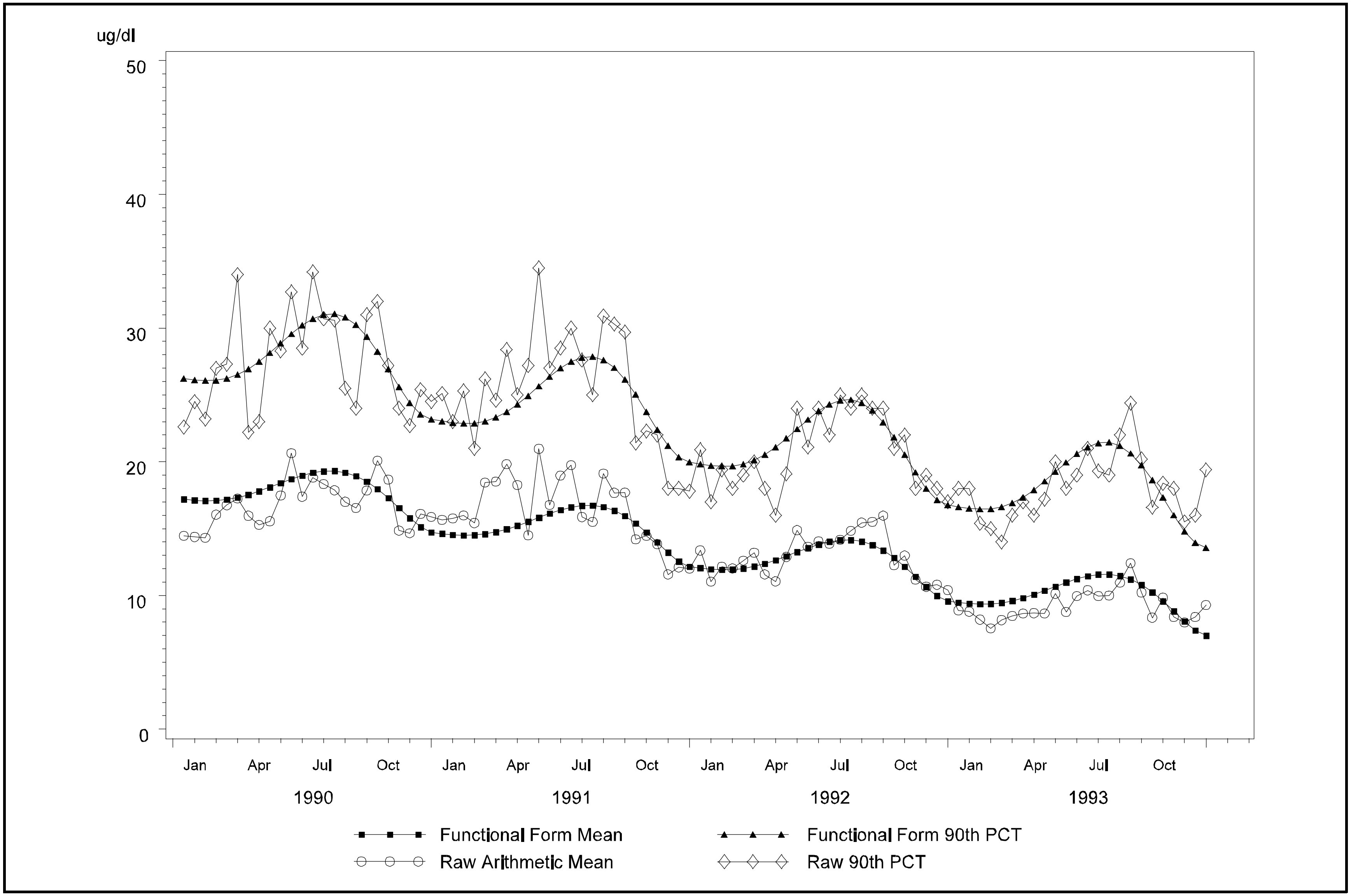

Figure 3 Semi-monthly Arithmetic Mean and 90th Percentile Blood Lead Levels with Functional Form Fit 1990-1993.

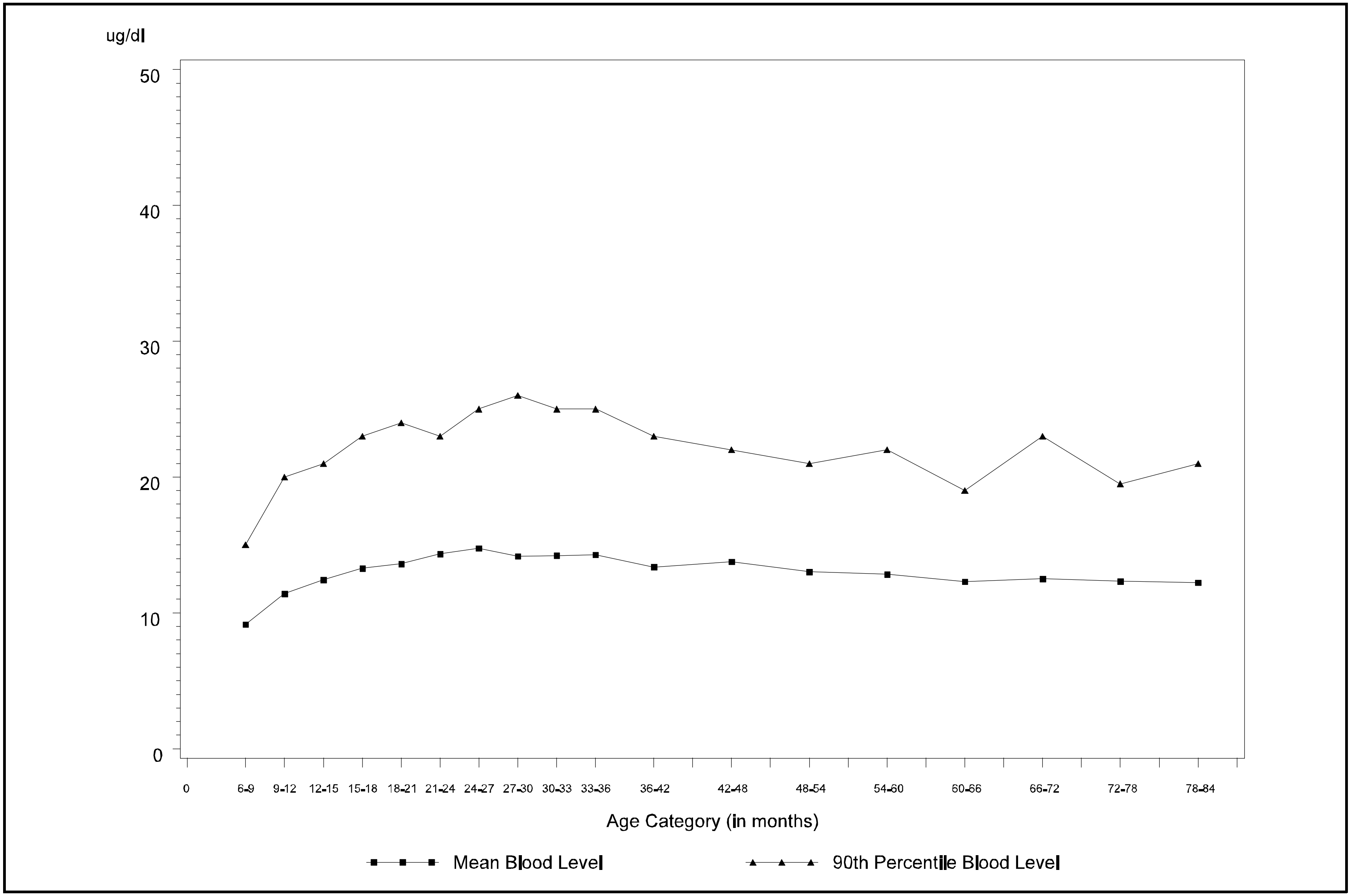

Figure 4 Arithmetic Mean and 90th Percentile Blood Lead Levels for 1990-1993 by Age Category (n=12,904).

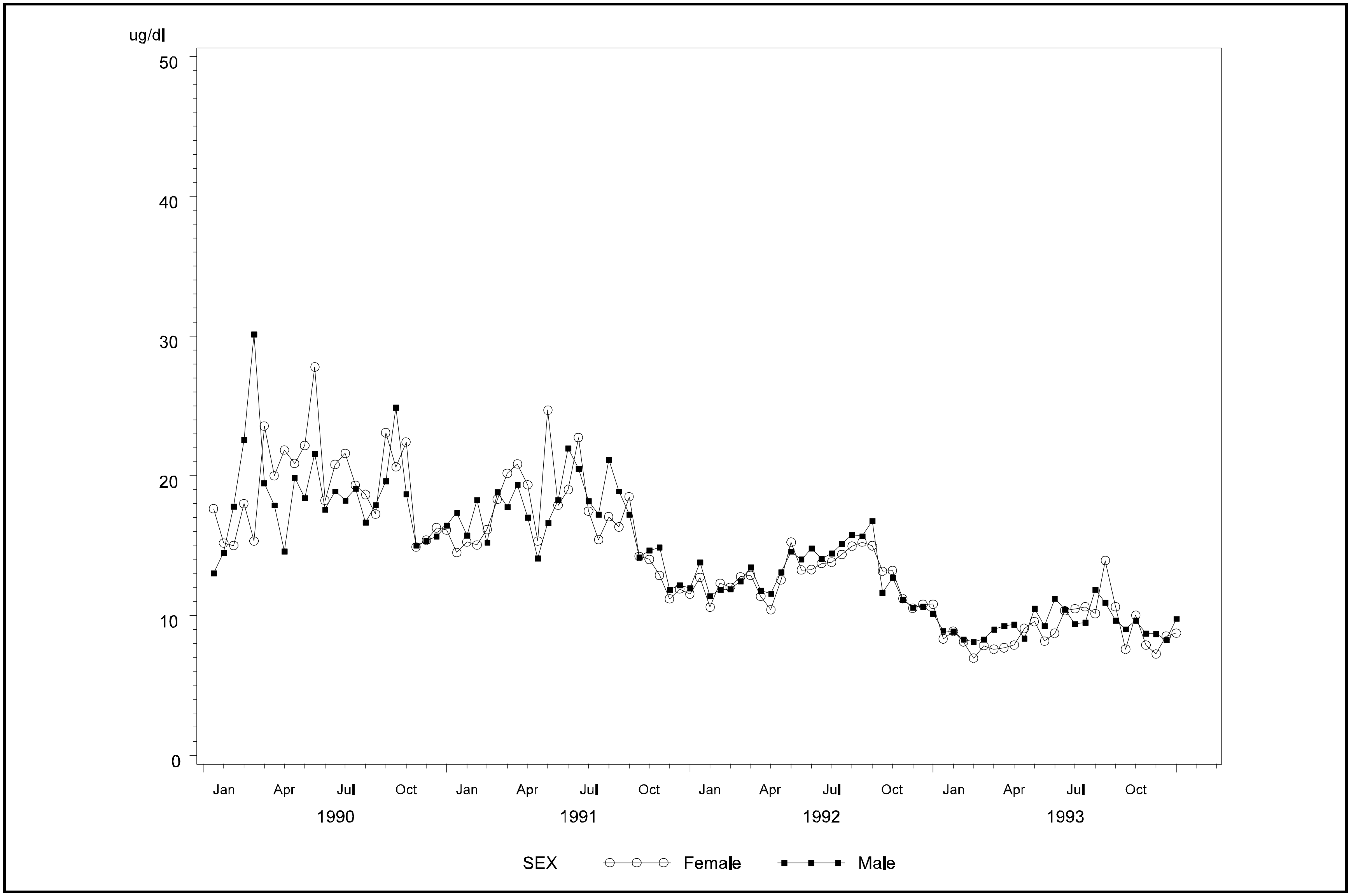

Figure 5 Semi-monthly Arithmetic Mean Blood Lead Levels for Males and Females.

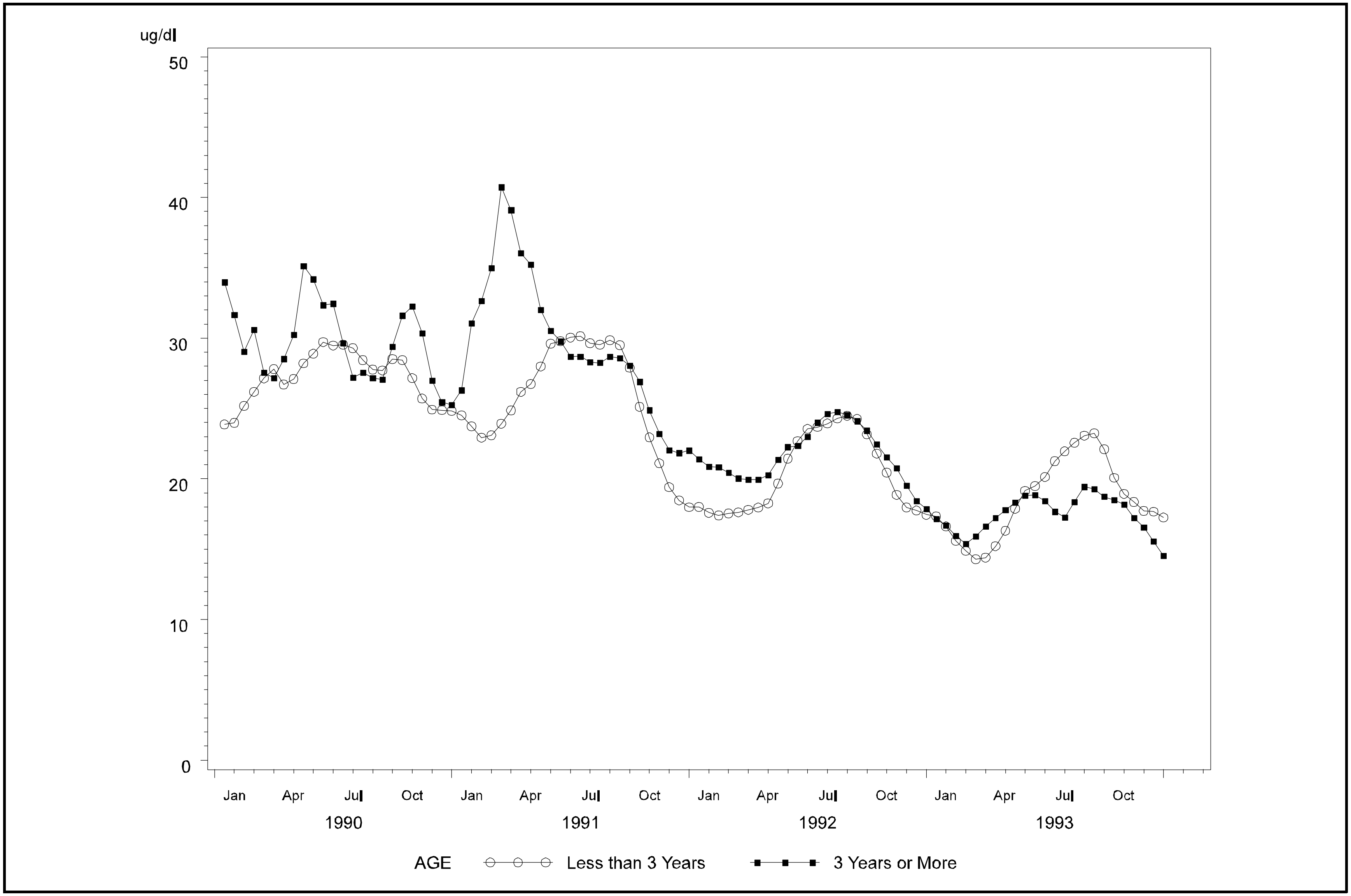

Figure 6 Semi-monthly Smoothed 90th Percentile Blood Lead Levels for Two Age Groups.

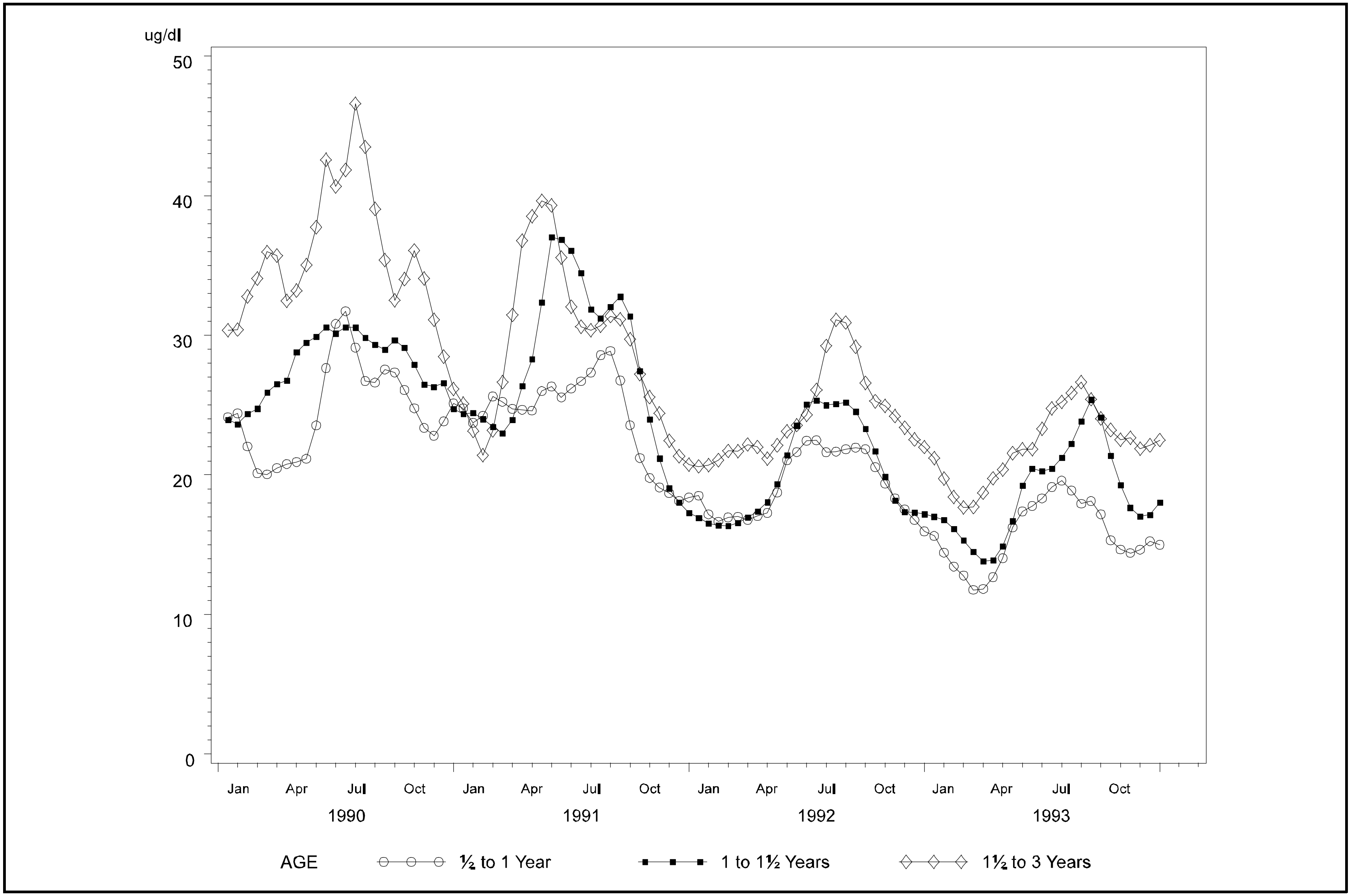

Figure 7. Semi-monthly Smoothed 90th percentile Blood Lead Levels for Children Under Three Years of Age.

3 METHODOLOGY

Empirical smoothing and model fitting approaches were used to characterize seasonal and long-term trends in the data.

3.1 EMPIRICAL SMOOTHING APPROACH

The empirical smoothing approach included 1) calculating arithmetic means and empirical percentiles ("raw means and percentiles") of PbB measurements for each half-month period, 2) smoothing the raw means and percentiles using weighted moving averages, and 3) plotting both the raw and smoothed statistics against time.

Plots of the raw means and percentiles over time are often sufficient to depict seasonal and long-term trends of time series. Differences in raw means and percentiles of the PbB levels are approximately unbiased estimates of differences in baseline blood lead levels of children covered by the MHD screening program. Thus, the January, 1993 minus the January, 1992 90th percentile (sample) PbB measurements would on average be equal to the actual drop from January, 1992 to January, 1993 in the 90th percentile PbB levels of children covered by the program. Nevertheless, moving averages were calculated, because sampling variation and random short-term fluctuations can mask trends. In general, the moving average of a time series y_t, is given by:

(1) $s_t = \Sigma_{j=[-p,p]} w_j y_{t+j}$; $t = p+1, ..., n-p$.

Here, the weights w_j, $j=-p, -p+1, ..., p$, add to 1, and p is the order of the moving average. The greater the order and the more similar the weights, the greater the degree of smoothing, and the greater the reduction in sampling variation and short-term fluctuations. The weights used here were $w_0=.3$, $w_1=.2$, $w_2=.1$, $w_3=.05$, and $w_{-j} = w_j$. Assuming independence, the sampling variance for the smoothed statistics would be only about 19.5% (or 100% * $.3^2+2*(.2^2+.1^2+.05^2)$) of the sampling variance of the raw statistics. The moving average of order 3 helped discern trends occurring over time intervals of a few months or longer. Graphs of the raw means and percentiles showed that PbB is higher in the summer than the winter, but may reach a peak in some years as early as April. Graphs of the smoothed means clearly showed that peak PbB's probably occur sometime in the summer, perhaps in July or August.

In theory, the moving average may have also obscured observation of interesting sudden rises in blood lead levels occurring within a couple of months. In Figure 2, the moving averages rounded the observed rise in PbB from June to August, 1993, so that the August measurement appears as part of a more gradual rise in PbB from January to August. Although a sudden two-month 20% rise in PbB seems unlikely, the moving average would have obscured observation of the rise, if it did occur. In general, weights are chosen to balance the opposing objectives of 1) minimizing deviations between the smoothed and raw data so that important shorter-term fluctuations are not obscured, and 2) reducing unwanted short-term fluctuations to facilitate better discovery of long-term trends. Appendix A demonstrates, through a more mathematical description of the problem, how the chosen weights achieved this balance rather well.

3.2 MODELLING

The graphs of the smoothed statistics led to many questions about the size and timing of the seasonal fluctuations. Modelling was needed for testing hypotheses (such as whether the seasonality is symmetric), and to construct meaningful parameter estimates. Modelling was also used, almost as an exploratory tool as described in section 3.2.3, to investigate the complicated relationship between age and seasonality in PbB. The analyses used a novel nonlinear regression approach based on the beta function. As a check, the data was also fit using a more common sinusoidal function model. Both the beta and sinusoidal functions models assumed that non-age related patterns in PbB could be reasonably expressed as the sum of an overall (downward) linear trend and a function for seasonality.

3.2.1 Sinusoidal Functions

The sinusoidal function model is given in equation 2, where summary PbB levels for the ith time period, Y_i, are expressed as a linear function of sine and cosine functions:

(2) $$Y_i = \alpha + \beta_0 t_i + \Sigma_{j=[1,p]}(\beta_{1j}\sin(2\pi j x_i) + \beta_{2j}\cos(2\pi j x_i)) + e_i$$

Here, t is time in years ranging from t=0 on January 1, 1990 to t=4 on January 1, 1994, and x = the fractional portion of t so that x ranges from 0 on January 1 to 1 on December 31; e_i represents the random error term. The e_i would be independent if the e_i represent differences between sampled summary PbB levels and "true" means or percentiles for populations of PbB levels of Milwaukee children. However, the random errors could be correlated if the e_i also reflected the unpredictability of changing climatic conditions. For example, June and July PbB levels could be correlated if a hotter-than-normal July often follows a hotter-than-normal June, and PbB levels rise with temperature.

The random errors might also be correlated if the model (in equation 2) is misspecified. For example, for the interval from 1990 through 1993, the long-term trend might be concave (turning downward). Then the random error terms as defined through equation 2 would tend to be positive somewhere in the middle of the time interval, negative elsewhere, and the correlation would likely be positive.

SAS's PROC REG (SAS, 1990) was used to fit the data to the sinusoidal model, and higher frequency terms were eliminated using the appropriate F-statistic. The e_i were assumed to be asymptotically normal, and the first-order correlation was calculated to test the assumption of independence of the successive e_i.

3.2.2 <u>Beta Function</u>

The beta function was preferred for modelling fluctuations in PbB levels, because with a minimum of parameters, it allowed for features suggested by our empirical analysis. The seasonal component may not be symmetric, and it was noted that during winter months, lead levels seemed relatively constant. The beta function allows for this relatively constant low period with a minimum of parameters whereas the sinusoidal function does not. Unlike the sinusoidal form, the beta function assumes that the peak and minimum PbB level are reached once each year, and that between the times of peak and minimum PbB levels, (mean or 90th percentile) PbB levels change monotonically. The beta functional form for semi-monthly summary lead levels Y_i, shown in equation 3 with subscripts omitted, includes components for both linear trend (L) and seasonality (S).

(3) $Y = L+S(\phi)+e$ where,
$L = \alpha + \beta t$, and
$S(\phi) = A(z/R)^{TR}\ ((1-z)/(1-R))^{T(1-R)}$.

Here α, β, A, R, ϕ, and T are parameters, t=time in years, and z=the fractional portion of $(t-\phi)$, i.e. $\|(t-\phi) - \mathrm{int}(t-\phi)\|$, so that if $\phi=0$, z ranges from 0 on January 1 to 1 on December 31. e is the random error component. ϕ is the phase parameter ranging from -0.5 to 0.5 ($-0.5 < \phi \leq 0.5$). The phase parameter is included to allow the model to fit the seasonal maximum at the appropriate time of year. The seasonal component equals 0 when z = 0, and reaches its maximum, A, when z = R. Thus A, ($A \geq 0$), is the difference between maximum and minimum values of the seasonal component. Note that when A=0, the model suggests there is no seasonal variation. Maximum lead levels occur on the $365(R+\phi)$th day of the year. R, ($0 \leq R \leq 1$), determines whether the seasonal component is symmetric. If R=.5, the time between maximum and minimum lead levels is one-half year. If R > .5, the rise to maximum lead levels is more gradual than the decline to minimum levels. T (T > 0) determines the abruptness of changes in the seasonal component around the seasonal peak, the $365(R+\phi)$ day of the year. Assuming that maximum lead levels occur during the summer, a large value of T indicates almost constant lead levels in the winter and most of the spring, a rapid rise to their peak in the summer, and then a rapid decline to the winter levels. A small value of T indicates less abrupt changes between peak and minimum lead levels.

Parameters α, β, A, R, and T were estimated through nonlinear regression. The model was first fit assuming $\phi=0$ and the e_i were independent. The model was then fit using a range of values for ϕ to test whether ϕ=0 and to evaluate the sensitivity of inferences to changes in ϕ. The independence assumption was checked by calculating a version of a correlogram from the studentized residuals. The correlogram is a plot of sample correlations $g_1, \ldots, g_{24}$ where

(4) $g_k = (\Sigma r_t r_{t+k})/(n-k) \qquad t = 1, 2, \ldots 96-k+1,$

and the r_t are the studentized residuals. Under the assumption of independence, the absolute value of the sample correlations would generally be less than $2/n^{.5}$ (Diggle, 1990).

3.2.3 Accounting for the Expansion of the Program

Two more nonlinear regressions were also considered to account for the greater coverage of the screening program in 1992 and 1993. First, weights were set equal to the semi-monthly sample sizes, to account for the possibility that the $Var(e_i)$ are approximately proportional to the sample sizes. The data was also reanalyzed after adding a term to the model to account for the effect of the program expansion in October, 1991. The term, denoted by P, is P = 0 if t < 1.79 (corresponding to October 1, 1991); = Δ otherwise.

The sinusoidal model with the term for the program expansion was thus (omitting subscript i):

(5) $Y = \alpha + \beta_0 t + \Sigma_{j=[1,p]}(\beta_{1j}\sin(2\pi jx) + \beta_{2j}\cos(2\pi jx)) + P + e$

The beta model with term P is:

(6) $Y = \alpha + \beta t + P + S + e$

Weighted analyses (with weights equal to the sample sizes) based on the generalized models of equation 5 and 6 will be referred to as "weighted + P" analyses.

3.2.4 Accounting for the Effect of Age

As shown in Figure 6, both overall PbB levels and seasonality may depend on age. Equation 7 incorporates age effects into the model, so that

(7) $Y = \gamma_k(L+S_k+P)+e$ where

$$L = \alpha + \beta t, \text{ and } S_k = A_k(x/R)^{TR} ((1-x)/(1-R))^{T(1-R)}$$

and γ_k and A_k are parameters defined for age categories,
k=0: (0.5,1], k=1: (1,1.5], k=2: (1.5,3], and k=3: (3,7) years. The age categories were chosen so that the age categories are similar with respect to: 1) the number of children within each category, and 2) the range of mean PbB levels associated with the ages within age category. From Figure 4, the range of mean PbB levels are about 2.5 µg/dL = (11.5-9) µg/dl for the ages (0.5,1] years, 2 µg/dL = (13.5-11.5) µg/dL for ages (1,1.5], 1.25 µg/dL = (14.75-13.5) µg/dL for ages (1.5,3] years, and about 1.5 µg/dL = (14.5-13) µg/dL for ages (3,7] years.

The γ_k are multiplicative age-related factors for overall PbB levels. For example, if γ_0=1 and γ_1=1.3, children between 1 and 1.5 years would have average PbB levels 30% higher on January 1 than children up to 1 years old. After adjusting for overall lead levels, the A_k, which represent seasonal differences between high and low PbB levels, are also allowed to depend on the same age categories. Results from this model (equation 7) are presented in Section 4.3.

4 RESULTS

4.1 BETA FUNCTION MODELLING RESULTS

4.1.1 Unweighted Nonlinear Regression Analysis

The minimum PbB occurred sometime between late October and early March, because the basic model of Equation 3 fit the data well (for details see Appendix A, Section A2) for ϕ between -1/6 and 1/6. The date of maximum PbB, sometime between late July and mid-September, could be more precisely estimated, because lead levels apparently changed abruptly during the summer and early fall. For a minimum PbB occurring on January 1, the estimated maximum detrended PbB date (or the date of maximum PbB if the long-term time trend were removed) was August 13 with a 95% confidence interval (July 25, September 2). For values of ϕ between -1/6 and 1/6, estimated maximum PbB dates ranged from August 4 to September 4. A, the difference in maximum and minimum lead levels, was also insensitive to choice of ϕ. For ϕ=0, the estimate of A from monthly mean PbB values was 3.66 with a 95% confidence interval (2.65, 4.67). For 90th percentile PbB values, the estimate was 6.70 with a confidence interval (5.22, 8.19). In 1993, the seasonal component would account for a 38% rise in mean PbB and a 40% rise in 90th percentile PbB levels from January to August. However, for some ϕ, the seasonal component was symmetric whereas for other ϕ it was not. Assuming a minimum PbB on January 1, the 95% confidence interval for R would be .56 to .67, so that the seasonal component would be asymmetric. Results for other values of ϕ are shown in Table 4. Estimates of R ranged from .425 for a minimum PbB on March 1 to .88 for the minimum occurring on November 1.

Residuals for the unweighted analysis of means and 90th percentiles for ϕ=0, are shown in Figures 8 and 9. Both figures suggest the residuals are generally larger for time periods before October, 1991 when sample sizes were smaller. Figure 8 also suggests a positive correlation in residuals for the semi-monthly means. Correlograms are shown in Figures 10 and 11. Correlations with absolute values above $2/(96)^2 = 0.204$ are generally considered significant (see section 3.2.2). From Figure 10, the absolute correlations for semi-monthly means less than four months apart are significantly greater than zero. In contrast, it is not clear from Figure 11 whether the 90th percentiles are correlated. In Figure 11, one sample correlation of 0.23 at 3.5 months was (barely) significant (exceeded 0.204) and other sample correlations for short time lags (0.5 and 2 months) were nearly significant.

Table 4. Summary of PROC NLIN Results by Phase (ϕ)

MEANS DATA				
Phase	Date of Minimum PbB	R[1]	Residual SS	Fit[2]
-5/24	Oct. 16	(.82,.94)	287.4	
-4/24	Nov. 1	(.78,.91)	269.4	Acceptable
-3/24	Nov. 16	(.73,.84)	264.9	Acceptable
-2/24	Dec. 1	(.67,.78)	265.7	Acceptable
-1/24	Dec. 16	(.62,.72)	266.9	Acceptable
0	Jan. 1	(.56,.67)	267.1	Acceptable
1/24	Jan. 16	(.51,.63)	267.0	Acceptable
2/24	Feb. 1	(.46,.57)	268.3	Acceptable
3/24	Feb. 16	(.41,.53)	271.3	Acceptable
4/24	Mar. 1	(.37,.48)	274.8	Acceptable
5/24	Mar. 16		277.9	
MSE = 2.94 (for phase = -3/24)				
90th PERCENTILE DATA				
Phase	Date of Minimum PbB	R	Residual SS	Fit[3]
-5/24	Oct. 16	(.82,.94)	695.90	
-4/24	Nov. 1	(.77,.87)	661.60	Acceptable
-3/24	Nov. 16	(.72,.81)	644.66	Acceptable
-2/24	Dec. 1	(.67,.75)	639.61	Acceptable
-1/24	Dec. 16	(.61,.70)	639.21	Acceptable
0	Jan. 1	(.56,.65)	639.08	Acceptable
1/24	Jan. 16	(.52,.60)	638.98	Acceptable
2/24	Feb. 1	(.47,.55)	639.78	Acceptable
3/24	Feb. 16	(.42,.50)	642.13	Acceptable
4/24	Mar. 1	(.37,.45)	646.03	Acceptable
5/24	Mar. 16	(.32,.41)	650.17	Acceptable
MSE = 7.10 (for phase = 1/24)				

[1] Maximum PbB occurs 365*R days after minimum PbB. R=0.5 implies seasonality is symmetric.

[2] For means data, fit is acceptable (see Appendix A) if Residual SS < 276.1 = 264.9 + 3.81*2.92.
[3] For 90th percentile data, fit is acceptable if Residual SS < 666.1 = 639.0 + 3.81*7.10

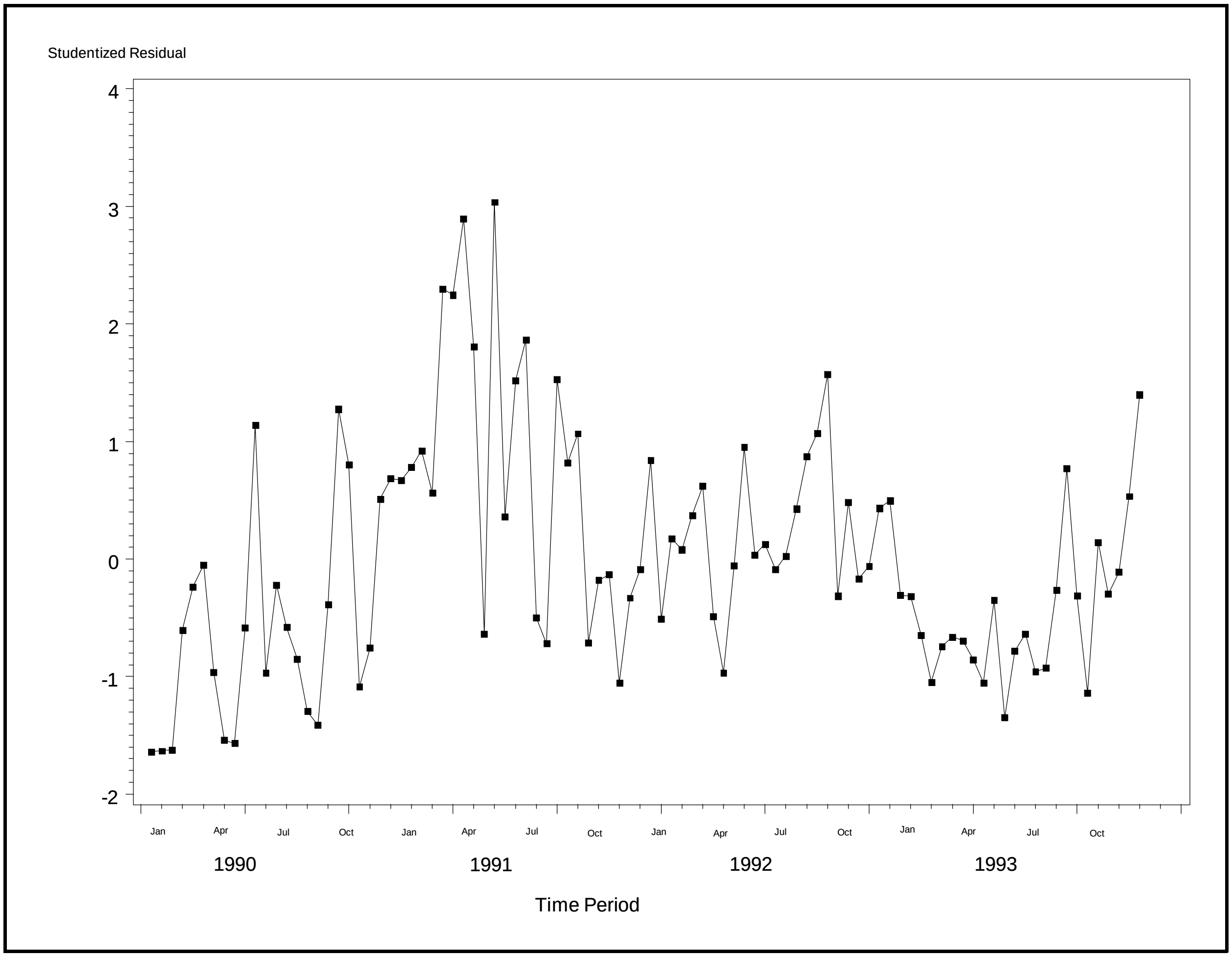

Figure 8. Studentized Residuals from Unweighted Analyses of Means.

Figure 9. Studentized Residuals from Unweighted Analyses of 90th Percentiles.

Figure 10. Correlogram from Unweighted Analyses of Means.

Figure 11. Correlogram from Unweighted Analyses of 90th Percentiles.

Correlation in residuals for means and 90th percentiles could be a result of correlations in short-term non-seasonal PbB fluctuations, and/or model misspecification. Short term non-seasonal fluctuations may include three components. The first component, sampling variation, would be approximately independent for different time periods. The second component is generated by unpredictable changes in climate and other factors that affect exposure and physiology and may cause short-term unpredictable changes in overall levels of PbB. Most of these unpredictable changes are short-lived, but some could last for several months, resulting in correlated means and 90th percentile PbB levels. The third component would include effects of short-term changes linked to the expansion of the PbB screening program; these changes may affect the types of children whose PbB measurements are reported to the MHD. Enough children would have to be sampled each month over a sufficiently extensive time period to be able to detect these correlations; otherwise the sampling variation would overwhelm the variation from the last two components.

Model misspecification might have resulted in correlated residuals. This may have occurred if from 1990-93 the long term trend was not strictly linear (see section 3.2.1). Nonlinearity in observed trends could be due to either nonlinear trends in summary values of PbB levels of all Milwaukee children, or nonlinear effects linked to the screening program's expansion. As discussed in the next section, the observed correlations seem partially attributable to the effects of an abrupt expansion of the MHD screening program in October, 1991.

4.1.2 <u>Weights and the 1991 Procedural Change</u>

The results described in the previous section suggested that a weighted regression analysis would be appropriate, since the residuals tended to be larger before the program expanded in October, 1991. Weights were set equal to semi-monthly sample sizes, a proper choice if sampling error accounted for almost all of the random fluctuations. A weighted+P regression analysis was also performed to account for a possible October, 1991 shift in the types of children included in the screening program. Residuals from the weighted+P fit to the 90th percentile data are shown in Figure 12. The plot shows no obvious pattern, indicating that under the model with the expansion term (see equation 6), the random error components for the 90th percentiles may be independent. Thus, the weighted+P analysis apparently yields valid confidence intervals for parameters R and A characterizing the seasonal variation of 90th percentile blood lead levels.

Residuals for the weighted+P fit to the means data, shown in Figure 13, show a slight quadratic trend. The trend in the means residuals may be due to a nonlinear trend in mean PbB values of all Milwaukee children. Alternatively, nonlinear changes in the observed mean PbB values may be partially attributable to changes in the types of children covered by the program. It is not clear why the long-term trend seems linear for 90th percentiles, but may be nonlinear for the means data. It is possible that the difference in trends may be partially attributable to MHD interventions which target children at high risk of lead poisoning.

Parameter estimates resulting from the unweighted regression, the weighted (without the expansion term), and the weighted + P regression analyses are shown in Table 5 under the assumption that $\phi=0$. The first two columns of Table 5 compare parameter estimates from weighted and unweighted regression analyses. The choice of weights causes negligible to about 10% changes in estimates of slope, A (the difference between seasonal maximum and minimum PbB), and R (defines time of maximum PbB). The last column shows confidence intervals from weighted + P analyses. The estimate of Δ was substantially and significantly different from 0 only for the 90th percentile data. The similarity between the three sets of confidence intervals for A and R shows that the uncertainty about proper weighting of the data and treatment of the effects of 1991 procedural changes may have had only a minimal effect on the results.

Table 5. Comparison of Nonlinear Regression Results for $\phi=0$

MEANS DATA

Parameter	Confidence Interval		
	Unweighted	Weighted	Weighted + P[1]
Intercept[2]	(16.2,18.3)	(16.4,18.2)	(16.5,18.3)
Slope[3]	(-.120,-.095)	(-.124,-.100)	(-.125,-.086)
Amplitude[2]	(2.65,4.67)	(3.26,4.80)	(3.13,4.74)
R	(.564,.671)	(.601,.671)	(.601,.674)
T	(0.80,8.62)	(2.36,9.73)	(2.24,9.71)
Δ[2]			(-1.63,.665)
90th PERCENTILE DATA			
Parameter	Confidence Interval		
	Unweighted	Weighted	Weighted + P[1]
Intercept	(24.9,27.8)	(24.3,27.0)	(24.8,27.2)
Slope	(-.153,-.114)	(-.146,-.109)	(-.105,-.050)
Amplitude	(5.21,8.19)	(5.95,8.31)	(5.25,7.49)
R	(.564,.646)	(.596,.654)	(.602,.661)
T	(2.65,9.64)	(4.18,10.9)	(4.06,10.4)
Δ			(-5.34,-2.11)

[1]Weighted analysis using model with procedural term.
[2]µg/dL
[3]µg/dL per semi-monthly time period
[4]Point estimate of slope for 90th % from weighted + P = -.0777
[5]Point estimate of procedural discontinuity in 90th % = -3.727

Figure 12. Studentized Residuals of 90th Percentiles from Weighted Analyses Using the Program Expansion Term.

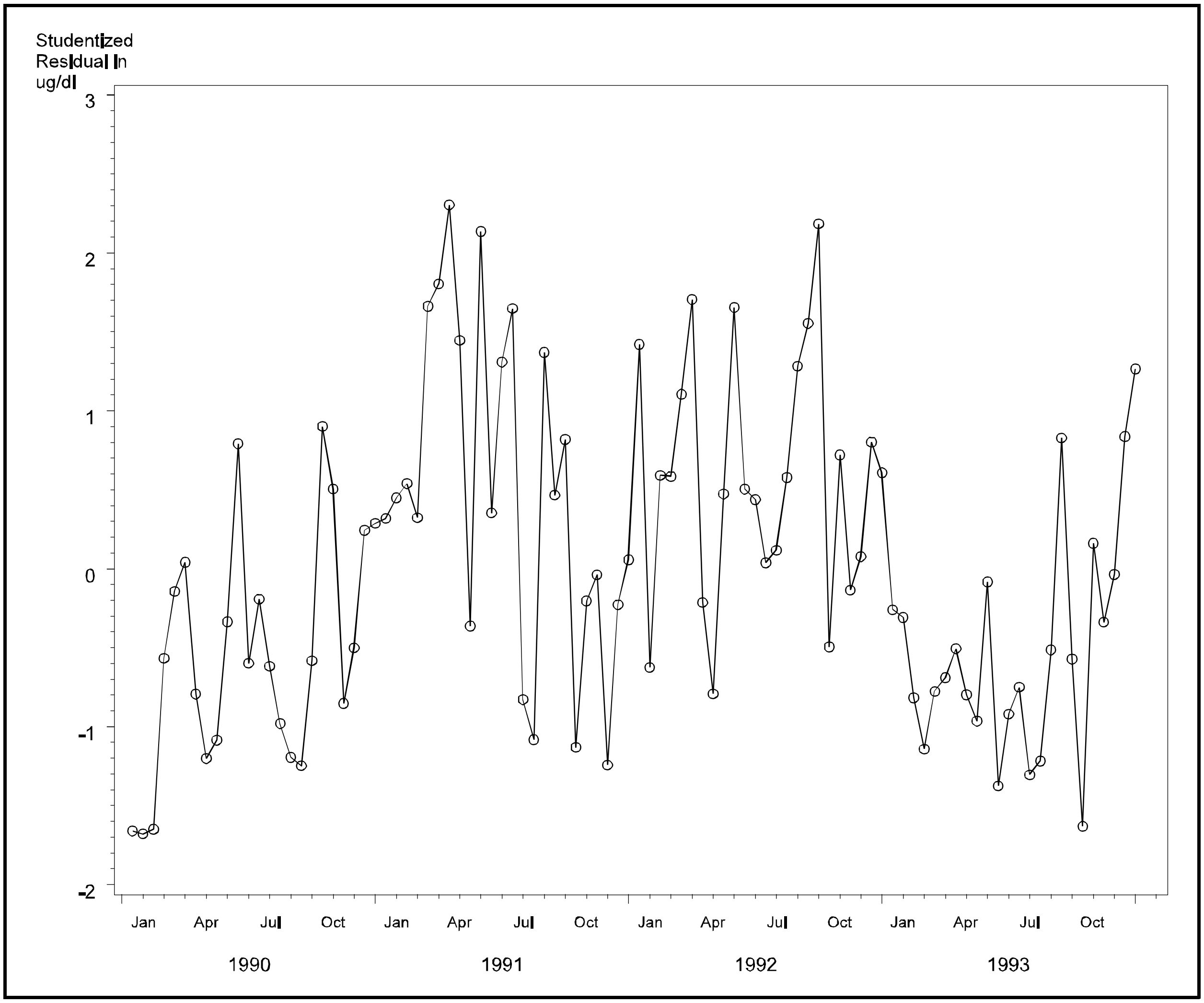

Figure 13. Studentized Residuals of Means from Weighted Analysis Using the Program Expansion Term

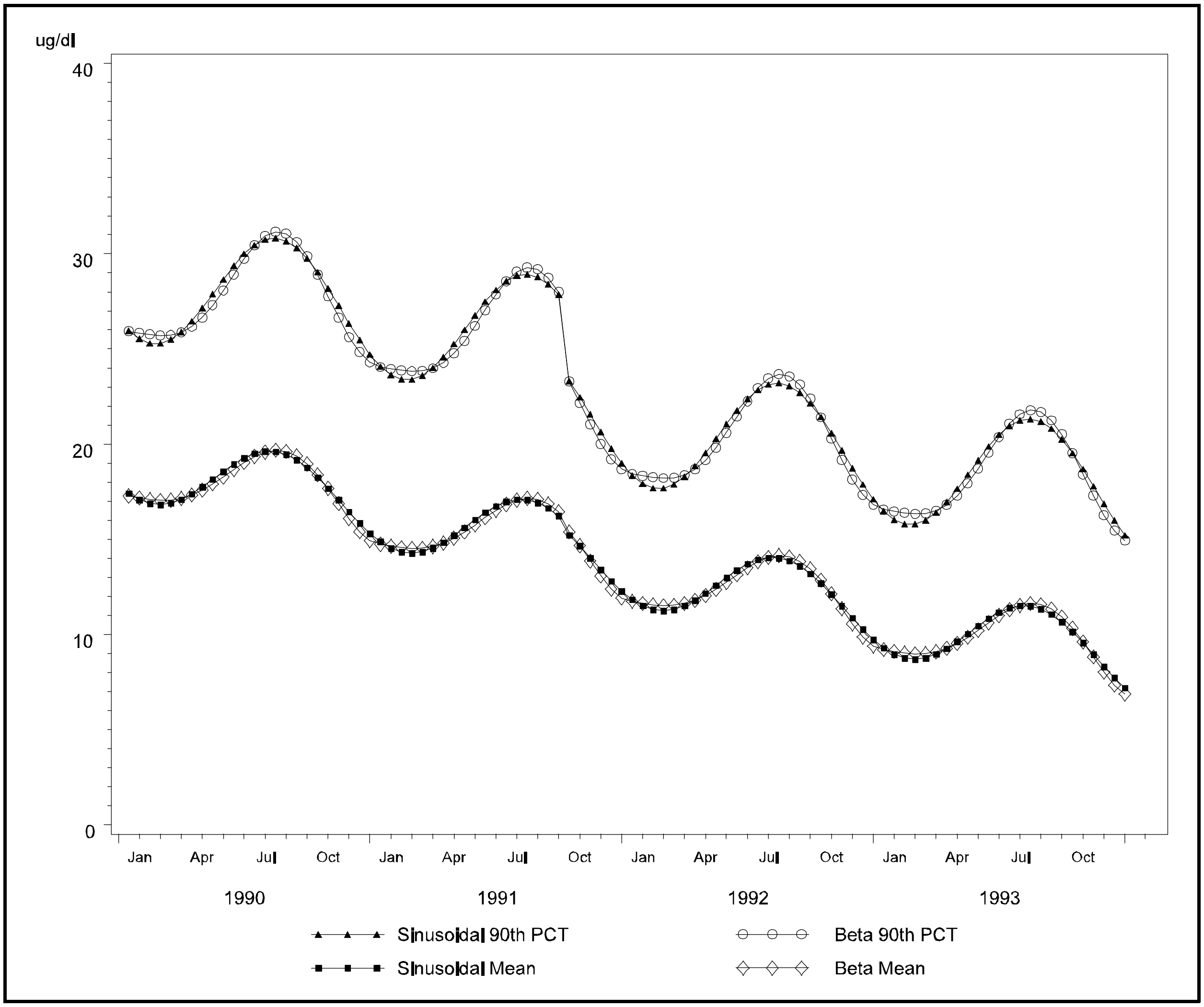

Figure 14. Predicted Values Derived from Fitting 90th Percentiles and Means to the Sinusoidal and Beta Models

4.2 SINUSOIDAL FUNCTION MODELLING RESULTS

The model of equation 8 provided an adequate fit to the 90th percentile data. As was the case with the beta function, residuals resulting from the sinusoidal fit to the means data were somewhat correlated.

(8) $$y_i = \alpha + \beta_0 t_i + \beta_1 \sin(2\pi x_i) + \beta_2 \cos(2\pi x_i) + P_i + e_i$$

Higher frequency sine and cosine terms (see equation 2) contributed little to the overall fit. Parameter estimates from a weighted analysis are shown in Table 6.

Table 6. Parameter Estimates and First Order Correlation of Residuals for Weighted Sinusoidal Model Fit.

Parameter	Means	90th Percentiles
Intercept[1] (α)	19.2	28.7
Slope[2] (β_0)	-.106	-.0786
Sine[1] (β_1)	-1.53	-2.46
Cosine[1] (β_2)	-1.29	-2.10
Δ[1]	-0.50	-3.83
First order correlation	0.07	0.34

[1]µg/dL
[2]µg/dL per semi-monthly time period

4.2.1 Comparison with Beta Function Modelling Results

Table 7 compares sinusoidal and beta function modelling estimates of the 1) slope, 2) the difference between seasonal maximum and minimum PbB, 3) the date corresponding to 365*R, the date of maximum (detrended) PbB. The weighted (weights equal to the number of children) mean square errors (MSE), a statistic that indicates how closely the model fit the data, are also given. Plots of the predicted mean and 90th percentile blood lead values are shown in Figure 14. Both Table 7 and Figure 14 show similar results from the Beta and sinusoidal models. This may be an indication that the two models will yield reasonable results if 1) PbB levels change monotonically between peak and minimum levels, 2) seasonal fluctuations are not highly asymmetrical, and 3) changes in PbB around the peak level are not too abrupt.

Although the choice of model (sinusoidal or beta) had only a minimal impact on these estimates, the beta functional model is a recommended tool for other PbB analyses because it can: 1) more directly assess asymmetry, and 2) more flexibly account for abrupt seasonal changes. Table 8 illustrates how the beta model can be used to test whether the seasonal effect is symmetric, or if R=0.5. Parameter estimates and a weighted version (weights equal to the sample sizes) of the residual sum of squares (RSS) for R constrained to equal 0.5 (using the weighted+P approach for 90th percentiles) is given in the first column. The same are then shown for R unconstrained in the second column. Results of an F test, shown at the bottom of the table, indicate that there is insufficient evidence to reject the hypothesis that the seasonality is symmetric. Note that the parameter estimates in both columns of the table are virtually identical.

Abruptness and asymmetry of seasonal fluctuations could depend on climate and other factors. It would be much more difficult to test the symmetry of the seasonality using the sinusoidal model.

Table 7. Comparison of Sinusoidal and Beta Function Modelling Results[1]

MEANS DATA		
Parameter	Sinusoidal Model Estimate	Beta Function Model Estimate
Slope[2]	-0.106	-0.101
A[3]	4.00	3.94
Date of Maximum PbB	8/21	8/21
Weighted[4] MSE	265	266
90th PERCENTILE DATA		
Slope	-0.078	-0.078
A	6.47	6.37
Date of Maximum PbB	8/21	8/18
Weighted MSE	532	525

[1]Weighted+P analysis
[2]µg/dL per semi-monthly period
[3]Absolute difference between maximum and minimum seasonal PbB levels (µg/dL)
[4]Weights equal to number of children; denominator equals 96-6=90 for sinusoidal model, 96-7=89 for Beta model

Table 8. Testing Symmetry (R=0.5) through the Beta Model

Results for 90th Percentiles		
	Estimate	
Parameter	R=0.5	R unconstrained
Intercept	26.0	26.0
Slope	-0.775	-0.775
A	6.36	6.37
Δ	-3.75	-3.73
R	0.5	0.56
T	7.42	7.43
ϕ	0.11	0.06
Weighted RSS	46830	46760
F-statistic = (46830-46760)/(46760/89) = 0.14		

4.3 AGE'S EFFECT ON SEASONALITY

Results from this section will show that the seasonality and overall level of PbB may depend on age in a fairly complicated way. Parameter estimates for the model of equation 6 (section 3.2.3) are shown in Table 9. Note from the intercept estimates that winter PbB levels increase with age, but the seasonal difference between highest and lowest PbB levels is greatest between ages 1 to 3 years. For children aged 1.5 to 3 years in 1993, there was an estimated 38% increase in PbB levels from January 1 to peak levels in August. This compares to a 30% increase for the youngest, a 41% increase for 1 to 1.5 year olds, and only a 15% increase for children over 3. Estimated percent increases in the 90th percentile PbB's were (from youngest to oldest) 30%, 48%, 37%, and 3%. The difference in the size of the overall seasonal trend from 1990 to 1993 by age group is striking. In fact, the observed seasonal trend for children over 3 years old was not significant. Summer PbB levels were actually higher for the 1 to 3 year olds than for older children.

However, as Figures 15 and 16 show, conclusions about the dependency of the seasonality on age require caution. Only PbB measurements for ages 1.25 to 2.5 were consistently higher in the summer than the winter from 1990 through 1993. Similar "seasonal" patterns can be observed in 1991 to 1993 PbB measurements for ages 0.75 to 1.25 years, and 1992-1993 PbB measurements for ages 0.5 to 0.75 years. For ages 2.5

to 4 years, "seasonal" patterns can be observed in 1992 to 1993, but not in 1990 or 1991. For ages 4 to 7 years, PbB was higher in the summer than the winter in 1992, perhaps in 1993, but not in 1990 or 1991.

The lack of any discernable pattern in PbB measurements for some age groups in 1990 and 1991 may be largely due to sampling variation. (For children less than 9 months data was so limited the graph was omitted.) Conversely, observed patterns in the empirical data that suggest seasonality may be the result of short-term random fluctuations in PbB, sampling variation, or aberrations due to pre-1992 procedural changes affecting the reporting of PbB measurements. The inconsistent patterns in the PbB data for older children only demonstrate the need for analyses of data beyond 1993. The additional data would be helpful to determine whether patterns observed in older children in 1992 are evidence of real seasonality in PbB levels, or merely an aberration caused by random fluctuations and sampling variation. If the additional data would show substantially less seasonality for older children, adjustments described later in Section 4.4.1 could then be modified to account for the dependency of seasonality on age.

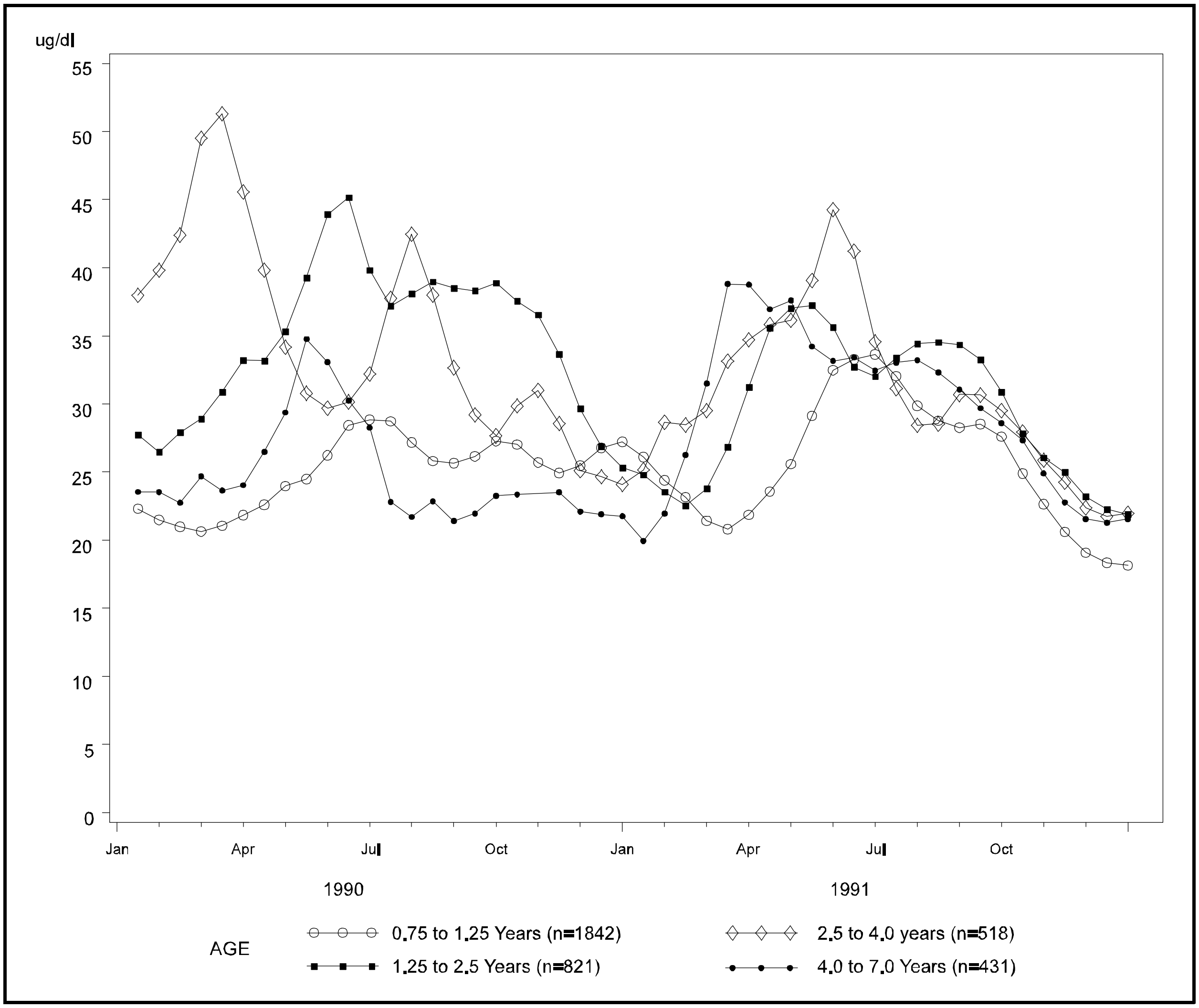

Figure 15. Semi-monthly Smoothed 90th Percentile Blood Lead Levels by Age Group (1990 to 1991)

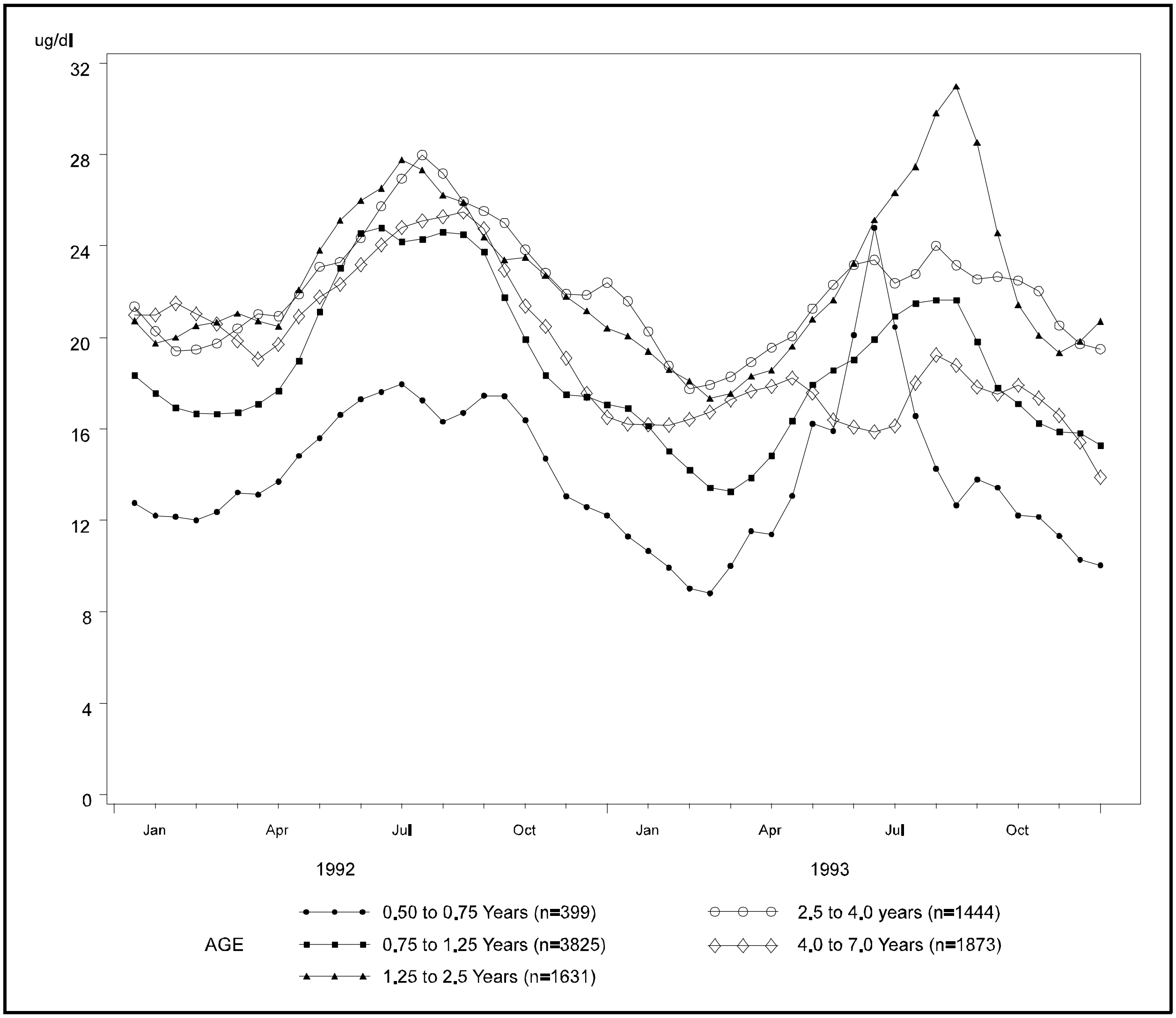

Figure 16. Semi-monthly Smoothed 90th Percentile Blood Lead Levels by Age Group (1992 to 1993)

Table 9. Estimates from Model Incorporating Age

MEANS DATA				
Parameter	Age Group (in Years)			
	(.5, 1]	(1, 1.5]	(1.5, 3]	>3
Intercept (PbB on 1/1/90)	15.2	16.5[1]	19.1	19.8
Slope[2]	-.073	-.079[3]	-.092	-.096
Seasonal Difference[4]	3.0	4.4[5]	4.8[6]	1.9
R	.623			
T	5.0			
P[4]	-1.8			
γ	1.00[7]	1.09	1.26	1.31

90th PERCENTILE DATA				
Parameter	Age Group (in Years)			
	(.5, 1]	(1, 1.5]	(1.5, 3]	>3
Intercept	23.8	25.0	30.9	31.9
Slope	-.061	-.064	-.079	-.082
Seasonal Difference	5.9	8.9	8.9	0.7
R	.605			
T	5.2			
P	-5.0			
γ	1.00[5]	1.05	1.30	1.34

[1]Equals $\alpha\gamma_1$ = 15.2*1.09
[2]µg/dL per semi-monthly period
[3]Equals $\beta\gamma_1$ = -.073*1.09
[4]µg/dL
[5]Equals $A_1*\gamma_1$ = 4.04*1.09
[6]38% increase from January, 1993 levels
[7]Fixed

4.4 ADJUSTMENT FACTORS

Several methods for seasonal adjustment of data were considered for analyses of abatement and educational outreach programs. Adjustments were based on results for 90th percentiles (instead of means), because the 90th percentiles better describe the PbB levels of children targeted by the intervention programs. Adjustments could be additive or multiplicative. For example, by defining additive seasonal adjustments s_i for each of 24 bimonthly time periods, the adjusted PbB, Y^*, of a measurement Y taken during time period i would be $Y^* = Y + s_i$. For multiplicative adjustments, $Y^* = Y*s_i$. For our data, "average" PbB levels were only about twice as large during the summer of 1990 as compared to the winter of 1993, so either type of seasonal adjustment would yield similar results. Our model fitting procedures assumed that the effects of seasonality were additive.

Multiplicative adjustments would have been indicated if the studentized residuals had been larger for higher predicted PbB measurements. The graph of the studentized residuals from the weighted + P analysis of 90th percentiles, shown in Figure 11, indicates no change in the size of residuals from 1990 to 1993, despite the decline in PbB. Thus, additive adjustments seem adequate.

Adjustments could be calculated as simple differences in raw statistics, or based on model fitting results. Advantages of adjustments based on raw differences are their simplicity and "unbiasedness", but "raw" adjustments are often unstable. For 90th percentiles denoted by z_0 for the reference period and z_i for period i, the simple adjustment would be $s_i = z_0 - z_i$.

Adjustments based on model fitting results would be $s_i = \hat{Y}_0 - \hat{Y}_i$, where perhaps

$$\hat{Y}_i = \hat{\alpha} + \hat{\beta} t_i + \hat{P}_i + \hat{S}_i(\phi).$$

Model-based adjustments would tend to be more stable, because the models are calibrated using all available data, as opposed to data from only the ith and reference periods. Model-based adjustments are recommended when data is limited, and the variance of raw estimates is very large. However, model fitting introduces an additional potential source of bias caused by model misspecification. Although for our data, results were almost identical for the beta and the sinusoidal models, adjustments would sometimes be highly dependent on the choice of model.

Moving averages often offer a reasonable compromise between adjustment strategies based on model fitting and raw statistics. Seasonal adjustments shown in Appendix D are based on the moving average of order 3 described earlier in Section 3.1. Data used for the adjustment are within 3 periods of the adjusted period, yet the sampling variance may be less than 20% of the sampling variance for the raw summary statistics. Adjustments based on higher order moving averages would have been recommended if there had been more sampling variation. Moving averages require the assumption that second derivatives (which describe the rates at which the slope of a function changes) of "true" seasonal and time trends are sufficiently small.

4.4.1 Age and Seasonal Adjustments for Use in Studies of Intervention Effectiveness in Milwaukee

Multiplicative age and additive seasonal adjustments used in a study of intervention effectiveness (U.S. EPA, 1996) in Milwaukee are given in Appendix D. For that study, the adjusted PbB values were "equivalent" PbB values for ages 1.75 to 2 years for measurements made in January, 1993.

The adjusted PbB measurement, y^*, for a child in age group k during time period i with PbB measurement y was calculated using the formula:

(9) $y^*=(y+A_i)*M_k$.

Here, M_k is the multiplicative age adjustment factors (for the kth age group); A_i is the additive seasonality adjustment factor (for the ith time period). The age and seasonal adjustment factors are shown in the last columns of Tables D.1 and Table D.2 respectively. For example, to calculate the adjusted measurement corresponding to a March 7, 1992 measurement of 20µg/dL for a 1.4 year old child, note that the age adjustment factor (from Table D.1) is 1.083, and the seasonality adjustment factor (from Table D.2) is 1.42. The adjusted PbB would be (20+1.42)*1.083 = 23.2.

Note that the seasonality adjustment precedes the age adjustment, and that the final adjustments depend to a small extent on the ordering. For the age adjustment to precede the seasonality adjustment, the seasonality adjustments would have had to be modified to represent the seasonal fluctuations for ages 1.75 to 2 years. The absolute difference in summer and winter PbB levels between ages 1.75 and 2 years might be greater than for other age groups. This is because seasonal differences seem proportional to average PbB levels, and PbB levels tend to peak around age 2 years.

The multiplicative age adjustment factors are inversely proportional to the arithmetic mean PbB's based on data from 1990-1993. The additive seasonality adjustment factors are based upon moving averages of the "detrended" 90th percentile PbB's. Here, detrended means that the linear long-term trend had been removed from the semi-monthly 90th percentiles before the moving averages had been calculated. The reason for this was to assure that the adjustments would only reflect changes in PbB due to seasonality. The "detrending" was designed to filter out other effects (such as effects related to the screening program expansion). The long-term trend was removed by first fitting the 1990-93 90th percentiles to the Beta function model, equation 3, with ϕ=0. From the model fit, the estimate of the downward trend was 0.1335µg/dL per semi-monthly time period. Thus, the time series was detrended by adding 0.1335*i to the 90th percentile PbB measurements for time periods i = 1 ... 99. The time series was then smoothed using the moving average with weights .3, .2, .1, and .05. The additive seasonality adjustment factors, A_i, were then set equal to the smoothed values minus the smoothed value for i=73 (for the first half of January, 1993).

It is difficult to determine a "best" method for filtering out all of the long-term (non-seasonal) effects on PbB from the seasonal adjustment factors. A control group should be used in studies of intervention effectiveness for reducing lead exposure, so that changes in adjusted blood lead levels due to the non-seasonal factors (that can not be filtered out) would affect both study and control groups. An alternative set of seasonal adjustment factors are given in Table D.3. A desirable feature of these adjustment factors is the lack of any discontinuity due to the effect of procedural changes in October, 1991. For these adjustment factors, the time series of semi-monthly PbB values was detrended using the results from the weighted+P analysis given in the third column of table 3. The detrending was accomplished by first adding .0777*i to the 90th percentiles to remove the long-term trend. Then 3.727 was added for time periods after September, 1991 to remove the effect of procedural changes in October, 1991. Smoothing and the A_i were then calculated as described in the previous paragraph.

5 DISCUSSION

The Milwaukee data showed sizeable seasonal and age trends in Milwaukee children's PbB levels. Blood lead levels were about 40% higher in the summer than the winter, and about 15-20% higher at ages two years than at ages one year and five years. The seasonal fluctuations have been attributed to complex physiological changes linked to increased exposure to lead or increased sunlight in the summer. Exposure may increase in the summer because of factors that include increased outdoor playing time, more opening and closing of windows, increased hand-to-mouth activity, and drier leaded dust that more easily enters homes. In Milwaukee, the age effect, related to factors such as increased hand-to-mouth activity of two year olds, was similar to the age effect observed in at least two other studies, the Sydney Lead Study (Cooney, et al, 1989), and the Port Pirie Study (Baghurst, et al, 1992).

Inconsistent results on seasonality in PbB from many small studies (see McCusker, 1979) suggest that seasonal patterns in PbB differ by location and/or climate. The Milwaukee data shows substantial seasonal fluctuation in PbB, so these trends must be recognized in similar northern urban environments. Seasonal fluctuations in PbB are probably largest in cooler environments such as Milwaukee's where seasonal differences in outdoor play and exposure to sunlight are more extreme. The Milwaukee results contrast with suggestions of some researchers that early evidence of seasonal trends (Blanksma et al, 1969; Guinee, 1972) are no longer relevant because of the phaseout of leaded gasoline (see U.S.EPA, 1995a).

The MHD data set has limitations that must be noted. The MHD data is routinely collected health department data, and was not subject to the types of data quality checks had the data been collected for other purposes. Also, the data is not reliable for estimating long-term trends before 1992, since blood lead screening was much more limited before 1992. Thus, evaluating long-term trends in PbB was beyond the scope of this study (see NHANES III, Pirkle, et al, 1994). Nevertheless, the changes in PbB associated with the expansion of the screening program would have had less effect on estimates characterizing the seasonality of blood lead levels, because seasonal levels differ substantially within a short period of time (between summer and winter).

Other studies should help refine our understanding of the factors that may cause complex seasonal and age-related patterns. Further study is suggested by a tentative result suggesting that the magnitude of seasonal PbB fluctuations may depend on age. For 1990, 1991, and 1993, the seasonal fluctuations in PbB levels, although substantial for ages 1-3 years, were limited for ages 4 to 7.

A model based on the beta function, developed to analyze the complex seasonal patterns in PbB levels (see U.S.EPA, 1995b), should have broad application. Unlike traditional methods, the beta function model allows for direct assessment of features such as the potential for abrupt or asymmetric seasonal changes in PbB between winter and summer levels. Statistical literature includes discussion of other time series with possible asymmetric rises and falls such as the Canadian Lynx data (Campbell and Walker, 1977) and sunspots data (Morris, 1977). Although evidence for asymmetry was limited in the Milwaukee data, it is necessary to be able to test for such features in PbB data from other environments, where seasonal characteristics in PbB levels may differ.

Both empirical and model-based results indicated that seasonal and age related trends could influence results from studies of the effectiveness of interventions for lowering PbB in children. Although these trends might sometimes be controlled for in well-designed prospective studies, adjustment factors would be needed for trend removal in retrospective studies. However, retrospective studies have several advantages. First, they allow for adequate sample sizes, a major consideration because of the large variability in PbB levels. Second, they do not create artificial circumstances which could lead to invalid conclusions. They also do not arbitrarily deprive control group children of benefits from the interventions being evaluated.

Seasonal and age-related adjustment factors were calculated through a four-stage process. First, 90th percentiles were calculated to summarize PbB levels for each of the 96 semimonthly periods between 1990 and 1993. Second, the 90th percentile PbB values were fit to a model so that long-term trends in PbB could be removed. The seasonal adjustments were then based on the moving averages of the detrended 90th percentile PbB values. Finally, age adjustments were calculated as simple ratios of arithmetic means using predefined age categories. 90th percentiles were chosen as the summary statistics for the semi-monthly periods, because of their applicability to populations of children subject to PbB interventions. Since age and seasonal trends likely depend on many factors related to geographic location, type of environment (urban or rural), and time period, the adjustment factors shown in Appendix D are specific to Milwaukee from 1990 to 1993. Nevertheless, the four-step procedure, with appropriate modifications, should be applicable to many other PbB data sets, so that the effects of abatement and educational interventions in other locations may also be quantified.

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APPENDIX A. TECHNICAL DETAILS

A1. Inputs to PROC NLIN and Properties of Estimates

SAS's PROC NLIN and the Newton-Raphson option were used for most[1] of the nonlinear regression beta function model fits. Details about the algorithm are provided in the SAS/STAT User's Guide, Volume 2.

If the random errors e_i are independent and identically distributed with finite variance σ^2, then the resulting parameter estimates of α, β, A, R, and T are consistent with asymptotic normal distributions. If in addition, the e_i are also normally distributed, then upon satisfaction of certain regularity conditions, the estimates are maximum likelihood estimates. Details are provided in Seber and Wild (1989).

Inputs into PROC NLIN include starting values for the parameter estimates, a model statement, bounds for some of the parameters, and first and second partial derivatives of E(Y) with respect to the parameters. The model, without a phase component, is:

$$E(Y) = \alpha + \beta t + A(x/R)^{TR} \left((1-x)/(1-R)\right)^{T(1-R)}.$$

The first derivative with respect to A is:

$$d(E(Y))/dA = (x/R)^{TR} \left((1-x)/(1-R)\right)^{T(1-R)}.$$

Let $F = \exp((\ln x - \ln R)TR + (\ln(1-x)-\ln(1-R))T(1-R))$. Then the first derivative with respect to T is:

$$d(E(Y)/dT) = AF(R \ln(x/R) + (1-R)\ln((1-x)/(1-R))).$$

[1] A MATLAB program was written to generate the results shown in Table 8.

The other first and second derivatives can be gleaned from the programming code for the unweighted fit:

```
proc nlin method=newton data=avlead;
parms a0=17.3 a1=-.11 a2=5 a3=.6 a4=5;
temp = (x/a3)**(a3*a4)*((1-x)/(1-a3))**(a4*(1-a3));
model y=a0 + (a1*t) + a2*temp;
bounds a3>=0, a4>=0, a3<=1;
der.a0 = 1;
der.a1 = t;
der.a2 = temp;
temp2= log(x/(1-x))+log((1-a3)/a3);
der.a3 = a2*temp*a4*temp2;
temp3=a3*log(x/a3)+(1-a3)*log((1-x)/(1-a3));
der.a4 = a2*temp*temp3;
der.a0.a0 = 0;
der.a0.a1 = 0;
der.a0.a2 = 0;
der.a0.a3 = 0;
der.a0.a4 = 0;
der.a1.a1 = 0;
der.a1.a2 = 0;
der.a1.a3 = 0;
der.a1.a4 = 0;
der.a2.a2 = 0;
der.a2.a3 = temp*a4*temp2;
der.a2.a4 = temp*temp3;
dfda3=temp*a4*temp2;
der.a3.a3 = a2*a4*(temp/(a3*(a3-1))+dfda3*temp2);
dfdt=temp*temp3;
der.a3.a4 = a2*temp2*(temp+a4*dfdt);
der.a4.a4 = a2*temp3*dfdt;
output out=preds p=yhat r=yresid;
```

A2. Incorporating Phase

The model

$$Y = \alpha + \beta(t) + S(\phi) + e$$

was fit by comparing the residual sums of squares of repeated fits using a range of values for ϕ. An approximate 95% confidence interval for ϕ would include all values of ϕ for which the residual sum of squares is no greater than $RSS^* + 3.81*MSE^*$. Here, RSS^* and MSE^* are the residual sums of squares and mean square error values minimized with respect to ϕ, and 3.81 is the critical value corresponding to α=.05 for the chi-square distribution with 1 df.

Referring to table 5, RSS^* for 90th percentiles $\approx$ 639.0 and $MSE^* \approx 7.1 = 639/90$, so the 95% confidence interval for ϕ would include all values for which RSS < 666.1 = 639.0 + 3.81*7.1. This approach allowed observation of how assumptions about ϕ affected estimates of other parameters.

A3. Properties of the Nonlinear Regression Estimates

If the random errors e_i are independent and identically distributed with finite variance σ^2, then the parameter estimates of α, β, A, R, T, P, are, upon satisfaction of regularity conditions (see Seber and Wild), consistent with asymptotic normal distributions. If in addition, the e_i are also normally distributed, then the nonlinear regression estimates are maximum likelihood estimates.

A4. Mathematical Justification for Moving Average Weights

The theoretical material in this section is from Diggle, 1990. Let $\hat{\mu}(t_i)$ be a moving average for the time series $y(t_i)$. Weights for a moving average might be chosen to minimize the quantity $Q(\alpha)$, where

$$Q(\alpha) = \Sigma\,(y_i - \hat{\mu}(t_i))^2 + \alpha \int (\hat{\mu}''(t))^2\,dt.$$

The summation term, "the residual sum of squares", measures the closeness of the fit between the moving average and the original time series. The integral term measures the smoothness of the moving average. α determines the tradeoff between goals of obtaining a very smooth fit and minimizing the residual sum of squares.

If data are equally spaced at unit time intervals (as ours is), then $Q(\alpha)$ would be approximately minimized when

(8) $w_i = .5*h^{-1}(K((i+.5)/h)+K((i-.5)/h))$, where $h=\alpha^{.25}$, and

$$K(u) = .5 \exp(-|u|/2^{-1}) \sin(.25\pi + |u|/2^{-1}).$$

The weights of the 3-order moving average are within .05 of the weights given in (8) for α=1. For larger values of α, $Q(\alpha)$ would be minimized by a higher order moving average.

APPENDIX B. DATABASE DEVELOPMENT

The Milwaukee Health Department (MHD) provided the data described in this report from the health department's lead case tracking system called "STELLAR". One of STELLAR's data files, LAB.BAS, contains records for each blood lead level reported to the health department. Each time a child's blood lead level was reported, all the children's blood lead levels in LAB.BAS were reviewed by MHD staff, and additional entries to the STELLAR data files were made when necessary. LAB.BAS also includes the corresponding date of measurement, the sample type, the child's name and date of birth, the child identifier, the address identifier, and the medical provider. As of July 1994, there were 75,084 records in this file.

Medical providers and laboratories send data on children's blood lead levels to the MHD. Providers include primary care physicians, public health clinics, HEADSTART centers, and Women Infant and Children centers (WICs). Some providers reported all measurements and some only reported elevated levels. A list of all possible providers was created from the LAB file and each was called to verify the procedure used. All HEADSTART and WICs but only half of the clinics and physicians reported all measurements. Therefore, a final list of providers that reported all measurements was created and used in the creation of the database. The data analyzed for this report only includes measurements from providers who reported all measurements regardless of level.

The database used for the analysis was created by first sorting the LAB file by the child identifier and sampling date. The first measurement in chronological order for each child was maintained in the database. Measurements were deleted if the corresponding provider name was not among those listed as reporting all measurements. The final database has 16,084 observations: 2,051 measurements occurring before January 1, 1990, 13,476 measurements occurring between January 1, 1990 and December 31, 1993, and 557 measurements after December 31, 1993.

APPENDIX C. GEOGRAPHIC SUMMARY OF HEALTH DEPARTMENT DATA

Table C.1 summarizes blood lead data for each Milwaukee zip code which according to the 1990 U.S. Census had at least 2500 children less than 7 years old. U.S. Census population figures for each zip code are given in the first column. The table compares the Census data to the number of children who had blood lead measurements taken for first time (the number of children screeened).

Estimates of coverage of the MHD screening program are given in the last column. The coverage of the MHD (screening) program for 1992-93 can be defined as the proportion of children who were are born in Milwaukee from 1992 through 1993 who have or will be tested for blood lead before their seventh birthday. The number of children born during 1992-93 would have been about 2/7 times the number of children less than seven years old in 1990. The number of children born in 1992-93 who would be screened by their seventh birthday would be approximately equal to the number of children tested for blood lead for the first time from 1992-93 under the following two assumptions. First, the number of children screened reached equilibrium by 1992. Second, the age distribution of the children screened was about the same for each year by 1992. A crude estimate of coverage for each zip code was calculated as the ratio of the the number of children screened during 1992-93 divided by 2/3 * (1990 Census population for ages up to 7 years).

Table C1. Census Counts and Summary of Milwaukee Health Department Blood Lead Data by Zipcode[1]

Zipcode	1990 U.S Census Population Ages 0-7 Years	Mean PbB (µg/dL)	Number Screened		Coverage[2]
		1990-93	1990-91	1992-93	1992-93
53204	6558	11.5	459	1406	75%
53205	2611	14.0	176	371	50%
53206	7092	15.0	504	1180	58%
53207	4504	9.3	73	343	27%
53208	6925	14.7	414	825	42%
53209	5506	10.6	237	540	34%
53210	4806	15.4	514	742	54%
53212	5736	14.9	489	1198	73%
53215	5709	10.6	207	713	44%
53216	4332	11.5	225	533	43%
53218	4775	9.1	160	470	34%
53221	3066	8.2	53	183	21%
53225	2837	7.5	38	177	22%
Total[3]	74739				

[1] Includes only zipcodes with >2500 children less than 7 years old.
[2] Equals number screened during 1992-93 divided by (2/7)*population
[3] Over all zipcodes

APPENDIX D. 1990-93 MILWAUKEE PbB MEASUREMENT ADJUSTMENT FACTORS

(These factors are not appropriate for other PbB data sets).

Table D1. Multiplicative Age Adjustment Factors for 1990-1993 Milwaukee PbB Data

Age Category (Years)	Number	Arithmetic Mean(µg/dL)	Adjustment Factor
.5-.75	519	9.14	1.568
.75-1	2082	11.41	1.256
1-1.25	3585	12.43	1.154
1.25-1.5	793	13.28	1.080
1.5-1.75	605	13.60	1.054
1.75-2.0	364	14.34	1.000
2.0-2.25	408	14.75	0.972
2.25-2.5	282	14.17	1.012
2.5-2.75	318	14.21	1.009
2.75-3.0	298	14.29	1.004
3.0-3.5	626	13.38	1.072
3.5-4.0	720	13.76	1.042
4.0-4.5	772	13.02	1.101
4.5-5.0	636	12.84	1.117
5.0-5.5	461	12.30	1.165
5.5-6.0	214	12.51	1.146
6.0-6.5	120	12.33	1.163
6.5-7.0	101	12.23	1.173
Other[1]	466	10.75	1.334

[1]Includes 123 without any recorded birthdate, 106 with ages less than 6 months, and 237 with ages greater than 7 years.

Table D2. Seasonal Additive Adjustment Factors Without Procedural Correction for 1990-March, 1994 Milwaukee PbB Data

Year 1990					
Time Period Starting Date	90th Percentile PbB	Detrended 90th Percentiles[1]	Smoothed Detrended Series[2]	Adjustment Factors Without Detrending[3]	Adjustment Factors[4]
Jan 1, 90	22.6	12.987	14.116	-6.175	3.324
Jan 16	24.5	15.021	14.782	-6.766	2.658
Feb 1	23.2	13.854	15.886	-7.771	1.554
Feb 16	27.0	17.788	17.078	-8.850	0.362
Mar 1	27.3	18.221	18.226	-9.865	-0.786
Mar 16	34.0	25.055	18.815	-10.320	-1.375
Apr 1	22.2	13.388	17.743	-9.115	-0.303
Apr 16	23.0	14.322	17.892	-9.130	-0.452
May 1	30.0	21.455	19.330	-10.435	-1.890
May 16	28.3	19.889	20.589	-11.560	-3.149
Jun 1	32.7	24.422	21.997	-12.835	-4.557
Jun 16	28.5	20.356	22.716	-13.420	-5.276
Jul 1	34.2	26.189	23.109	-13.680	-5.669
Jul 16	30.7	22.823	22.528	-12.965	-5.088
Aug 1	30.6	22.856	21.471	-11.775	-4.031
Aug 16	25.5	17.890	20.440	-10.610	-3.000
Sep 1	24.0	16.523	20.178	-10.215	-2.738
Sep 16	31.0	23.657	21.157	-11.060	-3.717
Oct 1	32.0	24.791	21.241	-11.010	-3.801
Oct 16	27.2	20.124	20.124	-9.760	-2.684
Nov 1	24.0	17.058	18.753	-8.255	-1.313
Nov 16	22.7	15.891	17.906	-7.275	-0.466
Dec 1	25.4	18.725	17.805	-7.040	-0.365
Dec 16	24.5	17.958	17.943	-7.045	-0.503

Table D2 (continued) - Year 1991					
Time Period Starting Date	90th Percentile PbB	Detrended 90th Percentiles[1]	Smoothed Detrended Series[2]	Adjustment Factors Without Detrending[3]	Adjustment Factors[4]
Jan 1, 91	25.1	18.692	17.877	-6.845	-0.437
Jan 16	23.0	16.725	17.835	-6.670	-0.395
Feb 1	25.3	19.159	17.834	-6.535	-0.394
Feb 16	21.0	14.992	18.027	-6.595	-0.587
Mar 1	26.2	20.326	18.876	-7.310	-1.436
Mar 16	24.6	18.859	19.784	-8.085	-2.344
Apr 1	28.4	22.793	20.948	-9.115	-3.508
Apr 16	25.0	19.526	21.716	-9.750	-4.276
May 1	27.2	21.860	22.915	-10.815	-5.475
May 16	34.5	29.293	24.253	-12.020	-6.813
Jun 1	27.0	21.927	23.977	-11.610	-6.537
Jun 16	28.5	23.560	23.830	-11.330	-6.390
Jul 1	30.0	25.194	23.884	-11.250	-6.444
Jul 16	27.6	22.927	23.412	-10.645	-5.972
Aug 1	25.0	20.461	23.601	-10.700	-6.161
Aug 16	30.9	26.494	24.224	-11.190	-6.784
Sep 1	30.3	26.028	24.073	-10.905	-6.633
Sep 16	29.7	25.561	22.781	-9.480	-5.341
Oct 1	21.4	17.395	20.490	-7.055	-3.050
Oct 16	22.3	18.428	18.683	-5.115	-1.243
Nov 1	22.0	18.262	17.237	-3.535	0.203
Nov 16	18.0	14.395	15.920	-2.085	1.520
Dec 1	18.0	14.529	15.344	-1.375	2.096
Dec 16	17.8	14.462	15.352	-1.250	2.088

Table D2 (continued) - Year 1992					
Time Period Starting Date	90th Percentile PbB	Detrended 90th Percentiles[1]	Smoothed Detrended Series[2]	Adjustment Factors Without Detrending[3]	Adjustment Factors[4]
Jan 1, 92	20.9	17.696	15.566	-1.330	1.874
Jan 16	17.0	13.929	15.519	-1.150	1.921
Feb 1	19.4	16.463	15.763	-1.260	1.677
Feb 16	18.0	15.196	15.921	-1.285	1.519
Mar 1	19.0	16.330	16.020	-1.250	1.420
Mar 16	20.0	17.463	16.188	-1.285	1.252
Apr 1	18.0	15.597	16.107	-1.070	1.333
Apr 16	16.0	13.730	16.355	-1.185	1.085
May 1	19.1	16.964	17.704	-2.400	-0.264
May 16	24.0	21.997	19.237	-3.800	-1.797
Jun 1	21.1	19.231	20.221	-4.650	-2.781
Jun 16	24.0	22.264	21.139	-5.435	-3.699
Jul 1	22.0	20.398	21.758	-5.920	-4.318
Jul 16	25.0	23.531	22.386	-6.415	-4.946
Aug 1	24.0	22.665	22.865	-6.760	-5.425
Aug 16	25.0	23.798	22.948	-6.710	-5.508
Sep 1	24.0	22.932	22.782	-6.410	-5.342
Sep 16	24.0	23.065	22.065	-5.560	-4.625
Oct 1	21.0	20.199	21.099	-4.460	-3.659
Oct 16	22.0	21.332	20.132	-3.360	-2.692
Nov 1	18.0	17.466	19.016	-2.110	-1.576
Nov 16	19.0	18.599	18.349	-1.310	-0.909
Dec 1	18.0	17.733	17.933	-0.760	-0.493
Dec 16	17.0	16.866	17.536	-0.230	-0.096

Table D2 (continued) - Year 1993					
Time Period Starting Date	90th Percentile PbB	Detrended 90th Percentiles[1]	Smoothed Detrended Series[2]	Adjustment Factors Without Detrending[3]	Adjustment Factors[4]
Jan 1, 93	18.0	18.000	17.440	0.000	0.000
Jan 16	18.0	18.134	17.014	0.560	0.426
Feb 1	15.4	15.667	16.337	1.370	1.103
Feb 16	15.0	15.401	15.931	1.910	1.509
Mar 1	14.0	14.534	15.874	2.100	1.566
Mar 16	16.0	16.668	16.398	1.710	1.042
Apr 1	17.0	17.801	17.171	1.070	0.269
Apr 16	16.0	16.935	17.775	0.600	-0.335
May 1	17.2	18.268	18.678	-0.170	-1.238
May 16	20.0	21.202	19.642	-1.000	-2.202
Jun 1	18.0	19.335	20.120	-1.345	-2.680
Jun 16	19.0	20.469	20.709	-1.800	-3.269
Jul 1	21.0	22.602	21.362	-2.320	-3.922
Jul 16	19.3	21.036	21.746	-2.570	-4.306
Aug 1	19.0	20.869	22.329	-3.020	-4.889
Aug 16	22.0	24.003	23.113	-3.670	-5.673
Sep 1	24.4	26.536	23.341	-3.765	-5.901
Sep 16	20.2	22.470	22.420	-2.710	-4.980
Oct 1	16.6	19.003	21.218	-1.375	-3.778
Oct 16	18.4	20.937	20.567	-0.590	-3.127
Nov 1	18.0	20.670	20.090	0.020	-2.650
Nov 16	15.5	18.304	19.514	0.730	-2.074
Dec 1	16.0	18.937	19.387	0.990	-1.947
Dec 16	19.4	22.471	19.141	1.370	-1.701

Table D2 (continued) - Year 1994					
Time Period Starting Date	90th Percentile PbB	Detrended 90th Percentiles[1]	Smoothed Detrended Series[2]	Adjustment Factors Without Detrending[3]	Adjustment Factors[4]
Jan 1, 94	13.0	16.204	18.209	2.435	-0.769
Jan 16	13.0	16.338	18.828	1.950	-1.388
Feb 1	14.0	17.471	20.261	0.630	-2.821
Feb 16	17.0	20.605	23.373	-2.384	-5.933
Mar 1	35.0	38.738	28.164	-7.098	-10.724

[1]Detrended by subtracting .1335*(73-i) from 90th percentiles.
[2]Smoothed values of column 3 using weights .3, .2, .1, .05.
[3]Adjustment factors if 90th percentiles had not been detrended.
[4]Equals 17.44 (smoothed value at t=73) - column 3 values.
[5]Uses 1994 90th percentile semi-monthly PbB values.

Table D3. Seasonal Adjustment Factors with Procedural Correction for 1990 - March, 1994 Milwaukee PbB Data

Year 1990				
Time Period Starting Date	90th Percentile PbB	Detrended 90th Percentiles[1]	Smoothed Detrended Series[2]	Adjustment Factors[3]
Jan 1, 90	22.6	17.006	18.087	3.080
Jan 16	24.5	18.983	18.721	2.446
Feb 1	23.2	17.761	19.784	1.383
Feb 16	27.0	21.639	20.929	0.238
Mar 1	27.3	22.016	22.021	-0.854
Mar 16	34.0	28.794	22.554	-1.387
Apr 1	22.2	17.072	21.427	-0.260
Apr 16	23.0	17.950	21.520	-0.352
May 1	30.0	25.027	22.902	-1.735
May 16	28.3	23.405	24.105	-2.938
Jun 1	32.7	27.883	25.458	-4.291
Jun 16	28.5	23.760	26.120	-4.953
Jul 1	34.2	29.538	26.458	-5.291
Jul 16	30.7	26.116	25.821	-4.654
Aug 1	30.6	26.093	24.708	-3.541
Aug 16	25.5	21.071	23.621	-2.454
Sep 1	24.0	19.649	23.304	-2.137
Sep 16	31.0	26.726	24.226	-3.060
Oct 1	32.0	27.804	24.254	-3.087
Oct 16	27.2	23.082	23.082	-1.915
Nov 1	24.0	19.960	21.655	-0.488
Nov 16	22.7	18.737	20.752	0.415
Dec 1	25.4	21.515	20.595	0.572
Dec 16	24.5	20.693	20.678	0.489

Table D3 (continued) - Year 1991				
Time Period Starting Date	90th Percentile PbB	Detrended 90th Percentiles[1]	Smoothed Detrended Series[2]	Adjustment Factors[3]
Jan 1, 91	25.1	21.370	20.555	0.612
Jan 16	23.0	19.348	20.458	0.709
Feb 1	25.3	21.726	20.401	0.766
Feb 16	21.0	17.504	20.538	0.629
Mar 1	26.2	22.781	21.331	-0.164
Mar 16	24.6	21.259	22.184	-1.017
Apr 1	28.4	25.137	23.292	-2.125
Apr 16	25.0	21.814	24.004	-2.837
May 1	27.2	24.092	25.147	-3.980
May 16	34.5	31.470	26.430	-5.263
Jun 1	27.0	24.047	26.097	-4.930
Jun 16	28.5	25.625	25.895	-4.728
Jul 1	30.0	27.203	25.893	-4.726
Jul 16	27.6	24.880	25.366	-4.199
Aug 1	25.0	22.358	25.498	-4.331
Aug 16	30.9	28.336	26.252	-5.085
Sep 1	30.3	27.814	26.418	-5.251
Sep 16	29.7	27.291	25.816	-4.649
Oct 1	21.4	22.796	24.587	-3.420
Oct 16	22.3	23.774	23.470	-2.303
Nov 1	22.0	23.551	22.340	-1.173
Nov 16	18.0	19.629	21.154	0.013
Dec 1	18.0	19.707	20.522	0.645
Dec 16	17.8	19.584	20.474	0.693

Table D3 (continued) - Year 1992				
Time Period Starting Date	90th Percentile PbB	Detrended 90th Percentiles[1]	Smoothed Detrended Series[2]	Adjustment Factors[3]
Jan 1, 92	20.9	22.762	20.632	0.535
Jan 16	17.0	18.940	20.530	0.637
Feb 1	19.4	21.418	20.718	0.449
Feb 16	18.0	20.095	20.820	0.347
Mar 1	19.0	21.173	20.863	0.304
Mar 16	20.0	22.251	20.976	0.191
Apr 1	18.0	20.328	20.838	0.329
Apr 16	16.0	18.406	21.031	0.136
May 1	19.1	21.584	22.324	-1.157
May 16	24.0	26.562	23.801	-2.634
Jun 1	21.1	23.739	24.729	-3.562
Jun 16	24.0	26.717	25.592	-4.425
Jul 1	22.0	24.795	26.155	-4.988
Jul 16	25.0	27.872	26.727	-5.560
Aug 1	24.0	26.950	27.150	-5.983
Aug 16	25.0	28.028	27.178	-6.011
Sep 1	24.0	27.105	26.955	-5.788
Sep 16	24.0	27.183	26.183	-5.016
Oct 1	21.0	24.261	25.161	-3.994
Oct 16	22.0	25.338	24.138	-2.971
Nov 1	18.0	21.416	22.966	-1.799
Nov 16	19.0	22.494	22.244	-1.077
Dec 1	18.0	21.572	21.772	-0.605
Dec 16	17.0	20.649	21.319	-0.152

Table D3 (continued) - Year 1993				
Time Period Starting Date	90th Percentile PbB	Detrended 90th Percentiles[1]	Smoothed Detrended Series[2]	Adjustment Factors[3]
Jan 1, 93	18.0	21.727	21.167	0.000
Jan 16	18.0	21.805	20.685	0.482
Feb 1	15.4	19.282	19.952	1.215
Feb 16	15.0	18.960	19.490	1.677
Mar 1	14.0	18.038	19.378	1.789
Mar 16	16.0	20.116	19.846	1.322
Apr 1	17.0	21.193	20.563	0.604
Apr 16	16.0	20.271	21.111	0.056
May 1	17.2	21.549	21.959	-0.792
May 16	20.0	24.426	22.866	-1.699
Jun 1	18.0	22.504	23.289	-2.122
Jun 16	19.0	23.582	23.822	-2.655
Jul 1	21.0	25.659	24.419	-3.252
Jul 16	19.3	24.037	24.747	-3.580
Aug 1	19.0	23.815	25.275	-4.108
Aug 16	22.0	26.893	26.002	-4.836
Sep 1	24.4	29.370	26.175	-5.008
Sep 16	20.2	25.248	25.198	-4.031
Oct 1	16.6	21.726	23.941	-2.774
Oct 16	18.4	23.603	23.233	-2.066
Nov 1	18.0	23.281	22.701	-1.534
Nov 16	15.5	20.859	22.069	-0.902
Dec 1	16.0	21.436	21.886	-0.719
Dec 16	19.4	24.914	21.584	-0.417

Table D3 (continued) - Year 1994				
Time Period Starting Date	90th Percentile PbB	Detrended 90th Percentiles[1]	Smoothed Detrended Series[2]	Adjustment Factors[3]
Jan 1	13.0	18.592	20.569	0.598
Jan 16	13.0	18.670	21.160	0.007
Feb 1	14.0	19.747	22.546	-1.379
Feb 16	17.0	22.825	25.616	-4.449
Mar 1	35.0	40.901	30.375	-9.208

[1]Detrended by adding .0777*(i-73) and 3.727 for t>42.
[2]Smoothed values of column 3 using weights .3, .2, .1, .05.
[3]Equals 21.167 (smoothed value at i=73) - column 3 values.
sizes (n=120).

APPENDIX E. 1990-96 MILWAUKEE PbB MEASUREMENT ADJUSTMENT FACTORS

(These factors are not appropriate for other PbB data sets).

In response to one of the peer reviewer's comments a set of seasonality adjustments was calculated for log(PbB) values, and zipcode information for the screened children was incorporated into the trend analysis. During peer review, additional Milwaukee Health Department blood lead data became available through February, 1996. Seasonality trends were reevaluated with the new data, and adjustment factors were calculated for the extended time period January 1, 1990 through February 15, 1996. The basic methodology for calculating these new adjustment factors is as before. Methodological details are given in the following text. The new adjustment factors are given in Tables E1 though E3.

Step-by-Step Details of the Adjustment Process

Seasonal adjustment factors for the log transformed data were calculated through a six-step procedure.

First, the log transformed data were adjusted to account for differences associated with the address zip codes of the screened children. This adjustment was done through an analysis of variance (ANOVA). The dependent variable was the log (PbB) value; the (three) independent classification variables were based on 1) the six bimonthly periods of the year (e.g., January - February, March - April, etc.), 2) (ten) half-year time intervals (first half of 1990, ..., last half of 1995), 3) zip codes (zip codes with less than 1000 children were combined). Each child's adjusted log(PbB) value was then set equal to the log(PbB) value minus the least squares mean value corresponding to the child's zip code.

Second, the 90th percentile values were calculated for each semi-month period from January 1, 1990 through December 31, 1995.

Third, the 90th percentile values were fit using the model:

$$(11)\ \log(Y_i) = \alpha + \beta_1 t_i + P_i + S_i(\phi) + \beta_2 t_i^2 + \beta_{11} A_1(t_i) + \beta_{12} A_2(t_i) + \ldots + \beta_{18} A_8(t_i).$$

where t = time in years (for January 1, 1990, t=0).

$A_1(t) = 4t$ for $t < 0.25$; $A_1(t) = 1$ for $t \geq 0.25$.
$A_2(t) = 2t$ for $t < 0.5$; $A_2(t) = 1$ for $t \geq 0.50$.
$A_3(t) = (4/3)t$ for $t < 0.75$; $A_3(t) = 1$ for $t \geq 0.75$.
$A_4(t) = t$ for $t<1$; $A_4(t) = 1$ for $t\geq 1$.
$A_5(t) = 0.8t$ if $t<1.25$; $A_5(t) = 1$ for $t \geq 1.25$.
$A_6(t) = (2/3)t$ for $t < 1.5$; $A_3(t) = 1$ for $t \geq 1.5$.
$A_7(t) = (4/7)t$ for $t<1.75$; $A_4(t) = 1$ for $t \geq 1.75$
$A_8(t) = 0.5t$ if $t<2$; $A_5(t) = 1$ for $t \geq 2$.

This is just an elaboration of the Beta model described in Section 3.2.2 and 3.2.3. Without the last five terms on the right-hand side, equation (11) is identical to equation (6) in Section 3.2.3. The quadratic term ($\beta_2 t_i^2$) was included to better account for nonlinearity in the long-term trend. The last four terms are included to account for medium-term nonseasonal fluctuations in the observed PbB values associated with the expansion of the screening program between January 1, 1990 and December 31, 1991.

The fourth step is "detrending" the time series by subtracting out the components associated with the linear trend, P_i, and the last five terms in equation 9. The fifth step is calculating a moving average of the detrended time series. Finally, the adjustment factors are set equal to the smoothed value at time t=73 (corresponding to January 1, 1993) minus the smoothed value for the time period when the child's blood sample was collected.

The same procedure was used to calculate adjustment factors directly from the untransformed data, but with two exceptions. First, the PbB values were never adjusted using zip code information. Second (obviously), the log transformation was never used.

The next paragraph describes the procedure for calculating age adjustment factors for the log transformed data.

First, the log transformed data were adjusted to account for differences associated with the address zip codes of the screened children, and also differences associated with trends in PbB values over time. This adjustment was done through the analysis of variance (ANOVA) described above. Each child's adjusted log(PbB) value was first set equal to the log(PbB) value minus the least squares mean value corresponding to the child's zip code. Each zip code adjusted value was then adjusted for the time trend by subtracting the least squares value associated with the six month time interval (when the child's blood sample was collected). Average adjusted log(PbB) values were then calculated for thirteen predefined age categories. For each age category, the age adjustment was then set equal to the average for the age category minus the average for a reference category (1.75 through 2.0 years).

Multiplicative age adjustments for unadjusted data were calculated by simply applying the exponential function to the adjustments for the log transformed data.

As described in Section 4.4.1, untransformed data could be adjusted directly using the formula (equation 9, Section 4.4.1):

$y^* = (y+A_i)*M_k$.

Here, M_k is the multiplicative age adjustment factors shown in Table 3 (for the kth age group); A_i is the additive seasonality adjustment factor from Table 2 (for the ith time period).

The seasonal and age adjusted log transformed data would be equal to the log transformed data plus the sum of the corresponding age (Table 3) and seasonality adjustments (Table 2). Examples for using the tables follow:

Example 1: Suppose Pbb value on September 1, 1992 is 25.

Then log(Pbb) = 3.219.

log(Pbb) (adjusted for seasonality from Table 1)
= 3.219-0.241 = 2.978.

Seasonally adjusted Pbb = exp(2.978) = 19.6. (This represents the equivalent Pbb value for a measurement made January 1, 1993 using the adjustments that were based on the log transformed values).

Example 2: Suppose Pbb value on September 1, 1992 is 25.

Adjusted PbB = 25-5.729 = 19.3.

(This represents the equivalent Pbb value for measurement made in Jan., 1993 based on the analysis of the untransformed values).

Note that the adjustments from Tables E.1 and E.2 do not yield identical results. Adjustments from Table E.1 are being used for a retrospective analysis of paint abatements in Milwaukee.

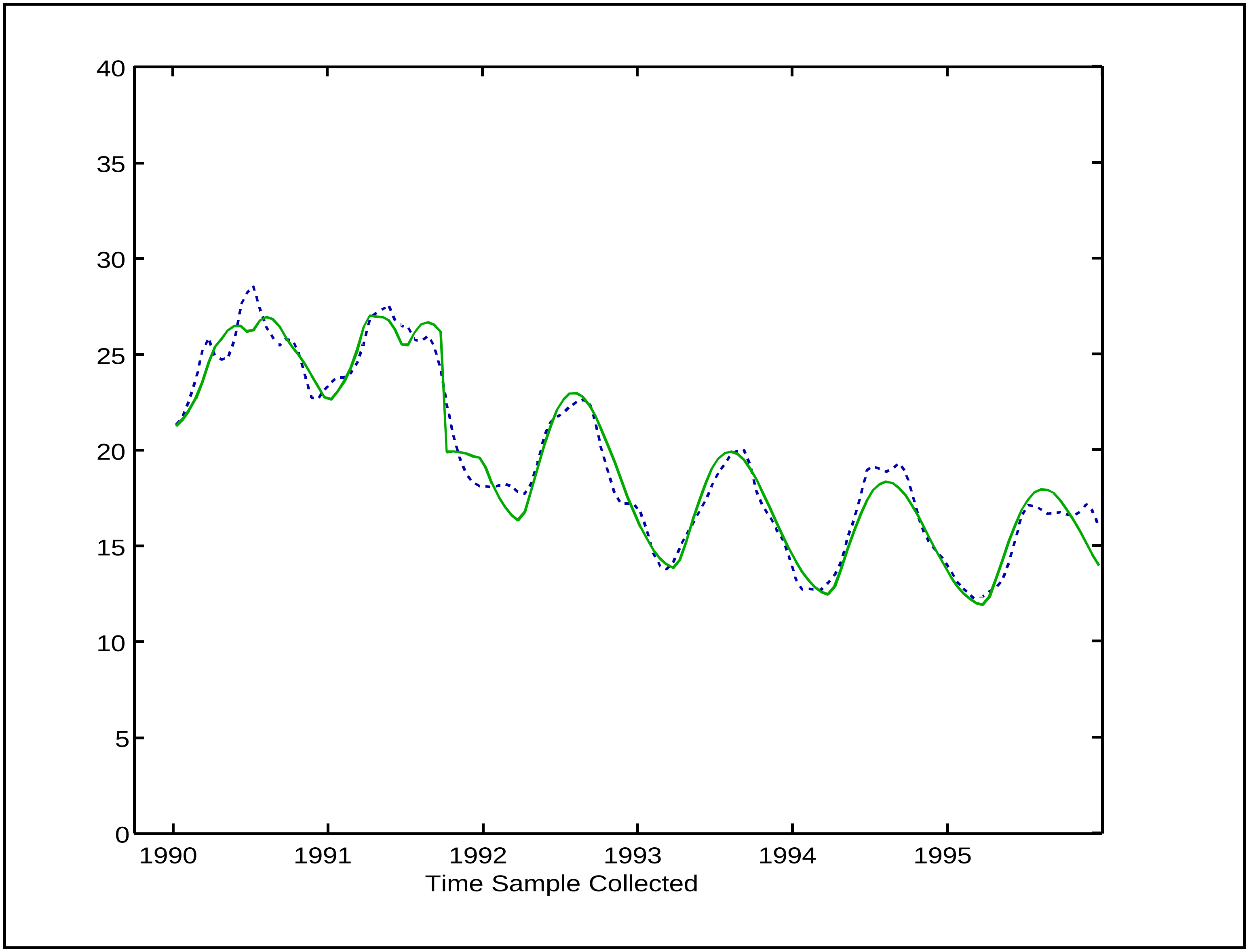

Figure 17. Modelled (solid line) and Smoothed (dashed line) 90th Percentile Blood Lead Levels Using Log Transformed Data from 1990 to 1996

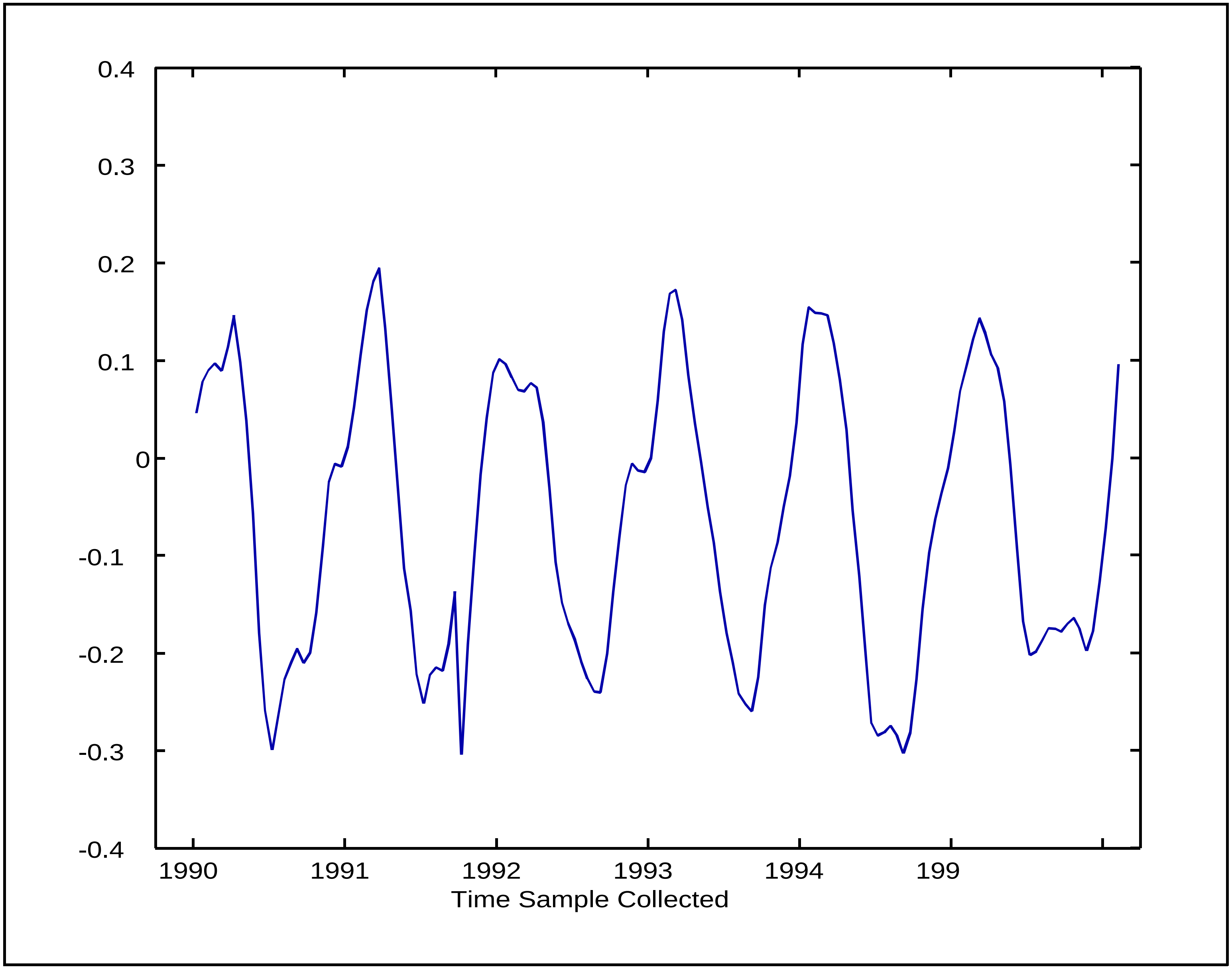

Figure 18. Seasonal Adjustment Factors (1990-96) for Log Transformed Data

Table E1. Seasonal Adjustment Factors for Log Transformed PbB Data from 1990 through February, 1996.

Year 1990			
Time Period Starting Date	90th Percentile PbB	Smoothed 90th Percentiles	Adjustment Factors
Jan 1, 90	3.043	3.060	0.046
Jan 16	3.060	3.080	0.077
Feb 1	3.081	3.119	0.090
Feb 16	3.121	3.164	0.097
Mar 1	3.272	3.224	0.089
Mar 16	3.431	3.251	0.114
Apr 1	3.127	3.217	0.146
Apr 16	3.174	3.208	0.098
May 1	3.179	3.212	0.038
May 16	3.135	3.251	-0.057
Jun 1	3.494	3.316	-0.180
Jun 16	3.249	3.339	-0.259
Jul 1	3.536	3.351	-0.300
Jul 16	3.217	3.312	-0.263
Aug 1	3.282	3.273	-0.227
Aug 16	3.242	3.253	-0.210
Sep 1	3.174	3.237	-0.195
Sep 16	3.265	3.249	-0.210
Oct 1	3.289	3.247	-0.200
Oct 16	3.307	3.223	-0.159
Nov 1	3.168	3.173	-0.091
Nov 16	3.003	3.124	-0.025
Dec 1	3.088	3.123	-0.006
Dec 16	3.187	3.143	-0.008

Table E1 (continued) - Year 1991			
Time Period Starting Date	90th Percentile PbB	Smoothed 90th Percentiles	Adjustment Factors
Jan 1, 91	3.161	3.159	0.011
Jan 16	3.203	3.171	0.052
Feb 1	3.159	3.170	0.106
Feb 16	3.146	3.178	0.151
Mar 1	3.164	3.202	0.181
Mar 16	3.216	3.241	0.195
Apr 1	3.394	3.292	0.133
Apr 16	3.296	3.301	0.050
May 1	3.250	3.308	-0.032
May 16	3.461	3.316	-0.113
Jun 1	3.156	3.285	-0.157
Jun 16	3.324	3.276	-0.222
Jul 1	3.288	3.272	-0.252
Jul 16	3.258	3.249	-0.223
Aug 1	3.121	3.247	-0.215
Aug 16	3.375	3.256	-0.218
Sep 1	3.241	3.235	-0.191
Sep 16	3.289	3.187	-0.137
Oct 1	3.048	3.107	-0.304
Oct 16	3.002	3.030	-0.191
Nov 1	2.977	2.973	-0.098
Nov 16	2.881	2.929	-0.017
Dec 1	2.914	2.907	0.041
Dec 16	2.858	2.897	0.087

Table E1 (continued) - Year 1992			
Time Period Starting Date	90th Percentile PbB	Smoothed 90th Percentiles	Adjustment Factors
Jan 1, 92	2.953	2.897	0.101
Jan 16	2.835	2.894	0.096
Feb 1	2.914	2.899	0.082
Feb 16	2.905	2.903	0.070
Mar 1	2.951	2.896	0.068
Mar 16	2.868	2.879	0.077
Apr 1	2.809	2.876	0.072
Apr 16	2.847	2.904	0.036
May 1	2.924	2.964	-0.032
May 16	3.158	3.032	-0.107
Jun 1	3.065	3.066	-0.149
Jun 16	3.098	3.079	-0.170
Jul 1	3.029	3.088	-0.186
Jul 16	3.157	3.103	-0.209
Aug 1	3.072	3.114	-0.226
Aug 16	3.146	3.120	-0.239
Sep 1	3.169	3.114	-0.241
Sep 16	3.135	3.067	-0.201
Oct 1	2.934	2.996	-0.137
Oct 16	2.968	2.934	-0.081
Nov 1	2.817	2.875	-0.028
Nov 16	2.790	2.846	-0.006
Dec 1	2.845	2.846	-0.013
Dec 16	2.865	2.841	-0.014

Table E1 (continued) - Year 1993			
Time Period Starting Date	90th Percentile PbB	Smoothed 90th Percentiles	Adjustment Factors
Jan 1, 93	2.923	2.821	0.000
Jan 16	2.787	2.757	0.058
Feb 1	2.595	2.679	0.129
Feb 16	2.601	2.635	0.168
Mar 1	2.560	2.625	0.172
Mar 16	2.637	2.650	0.141
Apr 1	2.702	2.701	0.085
Apr 16	2.806	2.745	0.035
May 1	2.723	2.779	-0.004
May 16	2.873	2.820	-0.050
Jun 1	2.784	2.852	-0.087
Jun 16	2.928	2.897	-0.137
Jul 1	2.969	2.935	-0.180
Jul 16	2.940	2.959	-0.209
Aug 1	3.005	2.987	-0.242
Aug 16	2.958	2.993	-0.252
Sep 1	3.091	2.996	-0.260
Sep 16	3.068	2.956	-0.225
Oct 1	2.737	2.878	-0.151
Oct 16	2.839	2.836	-0.113
Nov 1	2.804	2.805	-0.087
Nov 16	2.769	2.765	-0.050
Dec 1	2.751	2.729	-0.019
Dec 16	2.806	2.672	0.036

Table E1 (continued) - Year 1994			
Time Period Starting Date	90th Percentile PbB	Smoothed 90th Percentiles	Adjustment Factors
Jan 1, 94	2.431	2.587	0.117
Jan 16	2.472	2.545	0.154
Feb 1	2.578	2.547	0.149
Feb 16	2.609	2.545	0.149
Mar 1	2.455	2.544	0.146
Mar 16	2.576	2.569	0.117
Apr 1	2.577	2.604	0.080
Apr 16	2.618	2.652	0.029
May 1	2.766	2.732	-0.054
May 16	2.779	2.796	-0.121
Jun 1	2.789	2.871	-0.199
Jun 16	3.143	2.942	-0.272
Jul 1	2.926	2.952	-0.285
Jul 16	2.993	2.946	-0.281
Aug 1	2.814	2.937	-0.275
Aug 16	2.958	2.946	-0.285
Sep 1	3.010	2.962	-0.303
Sep 16	3.045	2.939	-0.282
Oct 1	2.868	2.882	-0.227
Oct 16	2.806	2.808	-0.155
Nov 1	2.652	2.748	-0.097
Nov 16	2.751	2.712	-0.062
Dec 1	2.652	2.685	-0.037
Dec 16	2.741	2.658	-0.011

Table E1 (continued) - Year 1995			
Time Period Starting Date	90th Percentile PbB	Smoothed 90th Percentiles	Adjustment Factors
Jan 1, 95	2.563	2.619	0.027
Jan 16	2.586	2.576	0.069
Feb 1	2.525	2.548	0.096
Feb 16	2.591	2.522	0.122
Mar 1	2.346	2.499	0.144
Mar 16	2.549	2.514	0.128
Apr 1	2.571	2.536	0.105
Apr 16	2.560	2.549	0.091
May 1	2.485	2.583	0.058
May 16	2.606	2.647	-0.007
Jun 1	2.742	2.732	-0.092
Jun 16	2.901	2.808	-0.168
Jul 1	2.899	2.842	-0.202
Jul 16	2.837	2.839	-0.199
Aug 1	2.812	2.827	-0.187
Aug 16	2.782	2.815	-0.174
Sep 1	2.800	2.816	-0.175
Sep 16	2.900	2.820	-0.178
Oct 1	2.792	2.812	-0.170
Oct 16	2.757	2.807	-0.164
Nov 1	2.747	2.820	-0.176
Nov 16	2.989	2.843	-0.198
Dec 1	2.867	2.824	-0.178
Dec 16	2.723	2.774	-0.127

Table E1 (continued) - Year 1996			
Time Period Starting Date	90th Percentile PbB	Smoothed 90th Percentiles	Adjustment Factors
Jan 1, 96	2.720	2.721	-0.072
Jan 16	2.738	2.651	-0.001
Feb 1	2.596	2.556	0.096

Table E2. Seasonal Adjustment Factors for 1990 to February, 1996 Based on Analysis of Untransformed Data.

Year 1990			
Time Period Starting Date	90th Percentile PbB	Smoothed 90th Percentiles	Adjustment Factors
Jan 1, 90	23.0	23.985	0.062
Jan 16	25.0	24.518	0.341
Feb 1	23.4	25.416	0.256
Feb 16	27.0	26.395	0.091
Mar 1	27.2	27.350	-0.050
Mar 16	34.1	27.800	0.316
Apr 1	22.3	26.600	1.679
Apr 16	23.0	26.615	1.173
May 1	30.0	28.025	-0.727
May 16	28.4	29.340	-2.531
Jun 1	32.9	30.850	-4.529
Jun 16	30.4	31.760	-5.926
Jul 1	35.7	31.965	-6.487
Jul 16	30.0	30.965	-5.712
Aug 1	31.6	29.760	-4.733
Aug 16	26.1	28.475	-3.671
Sep 1	24.2	27.910	-3.328
Sep 16	31.0	28.670	-4.310
Oct 1	32.0	28.565	-4.376
Oct 16	27.4	27.355	-3.285
Nov 1	24.0	25.920	-1.967
Nov 16	23.2	25.150	-1.314
Dec 1	26.1	25.050	-1.331
Dec 16	24.8	25.145	-1.541

Table E2 (continued) - Year 1991			
Time Period Starting Date	90th Percentile PbB	Smoothed 90th Percentiles	Adjustment Factors
Jan 1, 91	27.0	25.010	-1.108
Jan 16	23.0	24.570	0.044
Feb 1	25.3	24.130	1.197
Feb 16	21.0	24.010	2.031
Mar 1	26.5	24.480	2.275
Mar 16	23.0	25.070	2.400
Apr 1	28.0	26.200	1.273
Apr 16	25.0	27.105	-0.343
May 1	28.1	28.310	-2.257
May 16	33.8	29.550	-4.206
Jun 1	27.6	29.355	-4.718
Jun 16	28.2	29.240	-5.310
Jul 1	31.0	29.510	-5.728
Jul 16	30.3	29.130	-4.937
Aug 1	24.9	28.960	-4.354
Aug 16	31.4	29.355	-4.336
Sep 1	30.4	29.145	-3.712
Sep 16	32.0	27.845	-1.998
Oct 1	21.9	25.280	-7.171
Oct 16	23.0	23.100	-4.711
Nov 1	22.0	21.190	-2.520
Nov 16	18.0	19.395	-0.443
Dec 1	18.0	18.405	0.830
Dec 16	16.0	18.045	1.474

Table E2 (continued) - Year 1992			
Time Period Starting Date	90th Percentile PbB	Smoothed 90th Percentiles	Adjustment Factors
Jan 1, 92	20.0	18.340	1.270
Jan 16	17.1	18.620	0.888
Feb 1	20.7	19.130	0.277
Feb 16	19.0	19.250	0.056
Mar 1	19.0	19.025	0.182
Mar 16	20.0	18.935	0.173
Apr 1	18.0	18.650	0.361
Apr 16	16.0	18.800	0.114
May 1	20.0	20.100	-1.282
May 16	24.0	21.450	-2.727
Jun 1	21.0	22.200	-3.572
Jun 16	24.0	23.000	-4.465
Jul 1	23.0	23.450	-5.007
Jul 16	24.0	23.750	-5.399
Aug 1	24.0	24.100	-5.840
Aug 16	25.0	24.105	-5.935
Sep 1	24.0	23.810	-5.729
Sep 16	24.0	23.020	-5.027
Oct 1	21.1	21.930	-4.024
Oct 16	22.0	20.820	-3.001
Nov 1	18.0	19.560	-1.826
Nov 16	19.0	18.755	-1.106
Dec 1	18.0	18.200	-0.635
Dec 16	17.0	17.650	-0.168

Table E2 (continued) - Year 1993			
Time Period Starting Date	90th Percentile PbB	Smoothed 90th Percentiles	Adjustment Factors
Jan 1, 93	18.0	17.400	0.000
Jan 16	18.0	16.800	0.519
Feb 1	15.0	15.950	1.288
Feb 16	15.0	15.450	1.709
Mar 1	14.0	15.300	1.780
Mar 16	16.0	15.700	1.302
Apr 1	17.0	16.370	0.556
Apr 16	16.0	16.840	0.010
May 1	17.0	17.630	-0.856
May 16	20.4	18.470	-1.770
Jun 1	18.0	18.730	-2.103
Jun 16	19.0	19.140	-2.586
Jul 1	20.0	19.620	-3.138
Jul 16	19.0	20.150	-3.738
Aug 1	21.0	21.000	-4.658
Aug 16	22.0	21.610	-5.338
Sep 1	25.0	21.690	-5.486
Sep 16	21.0	20.530	-4.393
Oct 1	16.2	18.940	-2.870
Oct 16	18.4	18.125	-2.120
Nov 1	18.0	17.590	-1.650
Nov 16	16.0	16.945	-1.069
Dec 1	16.3	16.730	-0.917
Dec 16	20.2	16.280	-0.529

Table E2 (continued) - Year 1994			
Time Period Starting Date	90th Percentile PbB	Smoothed 90th Percentiles	Adjustment Factors
Jan 1, 94	12.3	14.960	0.730
Jan 16	13.0	14.245	1.384
Feb 1	14.0	14.240	1.330
Feb 16	16.0	14.215	1.296
Mar 1	13.0	14.150	1.303
Mar 16	14.0	14.450	0.946
Apr 1	14.0	15.110	0.230
Apr 16	16.0	16.170	-0.885
May 1	19.0	17.790	-2.559
May 16	18.2	18.945	-3.768
Jun 1	18.0	20.470	-5.345
Jun 16	27.0	22.130	-7.057
Jul 1	21.7	22.260	-7.238
Jul 16	23.2	22.050	-7.078
Aug 1	20.0	21.710	-6.787
Aug 16	20.0	21.555	-6.681
Sep 1	23.0	22.010	-7.183
Sep 16	25.0	21.850	-7.069
Oct 1	21.0	20.500	-5.765
Oct 16	17.0	18.650	-3.960
Nov 1	17.0	17.350	-2.704
Nov 16	16.0	16.200	-1.597
Dec 1	14.0	15.550	-0.989
Dec 16	18.0	15.350	-0.830

Table E2 (continued) - Year 1995			
Time Period Starting Date	90th Percentile PbB	Smoothed 90th Percentiles	Adjustment Factors
Jan 1, 95	13.0	14.550	-0.071
Jan 16	14.0	13.900	0.539
Feb 1	14.0	13.550	0.851
Feb 16	13.0	12.880	1.483
Mar 1	10.0	12.660	1.666
Mar 16	15.0	12.970	1.320
Apr 1	12.6	13.030	1.225
Apr 16	14.0	13.070	1.150
May 1	11.0	13.460	0.727
May 16	14.0	14.580	-0.426
Jun 1	15.0	16.250	-2.128
Jun 16	21.0	18.095	-4.004
Jul 1	21.0	18.790	-4.729
Jul 16	17.0	18.480	-4.448
Aug 1	18.9	18.325	-4.321
Aug 16	16.0	17.940	-3.964
Sep 1	19.0	18.110	-4.160
Sep 16	20.1	18.075	-4.151
Oct 1	16.0	17.470	-3.571
Oct 16	17.0	17.210	-3.335
Nov 1	16.0	17.145	-3.293
Nov 16	19.0	17.330	-3.500
Dec 1	17.0	17.195	-3.387
Dec 16	16.8	16.810	-3.022

Table E2 (continued) - Year 1996			
Time Period Starting Date	90th Percentile PbB	Smoothed 90th Percentiles	Adjustment Factors
Jan 1, 96	17.0	16.150	-2.382
Jan 16	15.7	14.940	-1.191
Feb 1	14.0	13.480	0.252

Table E3. Age Adjustment Factors for 1990-February, 1996 Milwaukee PbB Data

Age Category (Years)	Adjustment for Log (PbB) Values	Multiplicative Adjustment for Untransformed Data
0.5 - 0.75	0.812	2.252
0.75 - 1	0.279	1.322
1.0 - 1.25	0.096	1.101
1.25 - 1.5	0.039	1.040
1.5 - 1.75	-0.028	0.972
1.75 - 2	0	1.000
2 - 2.25	-0.018	0.982
2.25 - 2.5	-0.033	0.968
2.5 - 3	0.039	1.040
3 - 4	0.107	1.113
4 - 5	0.169	1.184
5 - 6	0.207	1.230
6 - 7	0.262	1.300

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15. Supplementary Notes

In addition to the authors listed above, Jill LeStarge of Quantech was a major contributor to the study.

16. Abstract (Limit: 200 words)

Most studies of the effectiveness of the interventions for reducing children's blood lead levels (PbB) have not distinguished declines in PbB due to program effectiveness from seasonal and age-related fluctuations in PbB. In this report, seasonal fluctuations and age effects in 1990-93 blood lead levels for a northern urban environment are studied, using data from 13,476 children screened for blood lead in Milwaukee, Wisconsin. The Milwaukee data showed sizeable seasonal and age trends in Milwaukee children's PbB levels. Blood lead levels were about 40% higher in the summer than the winter, and about 15-20% higher at ages two to three years than at age less than one year or ages five to seven years. Statistical methodology was developed to account for these fluctuations, so that the effectiveness of intervention programs may be quantified. The methodology was described in considerable detail to facilitate analyses of seasonal and age effects in PbB in other environments. Seasonal fluctuations in PbB are probably greater in cooler environments such as Milwaukee's, where seasonal changes in exposure to outdoor lead sources and sunlight are more extreme. A tentative result suggests the magnitude of the seasonal PbB fluctuations may be greatest for children less than four years old.

17. Document Analysis a. Descriptors

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