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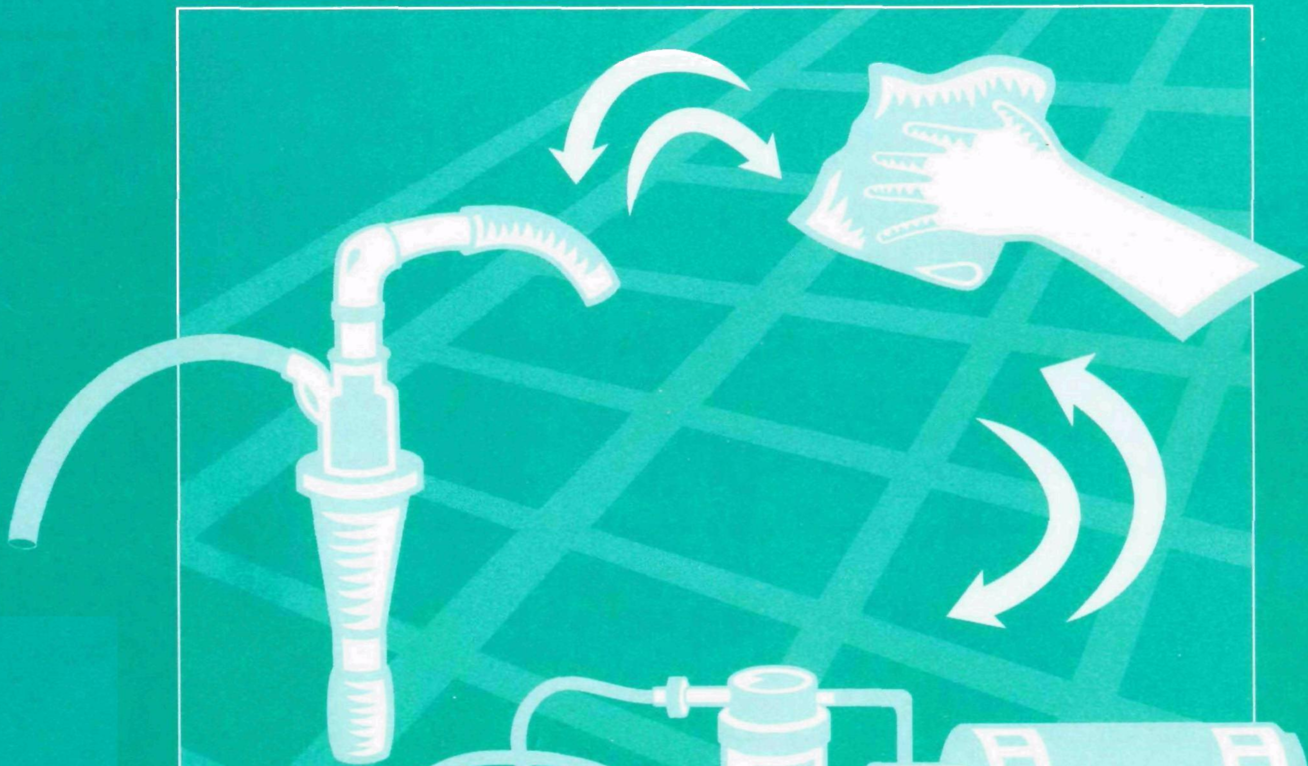

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CONVERSION EQUATIONS FOR USE IN SECTION 403 RULEMAKING

Final Report

Technical Branch
National Program Chemicals Division
Office of Pollution Prevention and Toxics
Office of Prevention, Pesticides, and Toxic Substances
U.S. Environmental Protection Agency
Washington, D.C. 20460

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CONTRIBUTING ORGANIZATIONS

This study was funded and managed by the U.S. Environmental Protection Agency. The analysis was conducted by Battelle Memorial Institute under contract to the Environmental Protection Agency. Each organization's responsibilities are listed below.

Battelle Memorial Institute (Battelle)

Battelle was responsible for identifying the relevant studies and obtaining the data, fitting models to the data from the individual studies, developing an approach for combining data across studies, and writing the report on the methodology and results.

U.S. Environmental Protection Agency (EPA)

The Environmental Protection Agency was responsible for providing objectives for the data analyses and the report, for contributing to the development of conclusions and recommendations, for reviewing draft versions of the report, and for managing the peer review and publication of the report. The EPA Work Assignment Managers were Janet Remmers and Todd Holderman. The Deputy Work Assignment Managers were John Schwemberger and Brad Schultz. The Project Leader for this report was John Schwemberger. The EPA Project Officers were Sineta Wooten and Karen Maher.

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EXECUTIVE SUMMARY

1. WHAT DOES THIS REPORT SAY?

This report presents equations used to carry out various conversions between wipe lead loading and vacuum lead loading, based on two different vacuum samplers, the Blue Nozzle vacuum (BN) used in the HUD National Survey, and the modified HVS3 vacuum used in the Baltimore Repair and Maintenance Study. The modified HVS3 vacuum will be referred to as the BRM vacuum for the remainder of this report.

Two sets of equations are described using the BN vacuum sampler: 1) for converting a BN lead loading to a wipe lead loading, 2) for converting a wipe lead loading to a BN lead loading. Each set contains a separate equation for samples collected from uncarpeted floors, window sills, and window wells. For the BN to wipe conversions on uncarpeted floors, a separate equation is provided for each of three house age groups in the HUD National Survey data.

The following equations were developed for converting a BN lead loading (μg/ft²) to a wipe lead loading (μg/ft²):

Uncarpeted floors:

Homes Built Prior to 1940:	$Wipe = 5.66\ BN^{0.809}$
Homes Built 1940-1959:	$Wipe = 4.78\ BN^{0.800}$
Homes Built 1960-1979:	$Wipe = 4.03\ BN^{0.707}$
Window sills:	$Wipe = 2.95\ BN^{1.18}$
Window wells:	$Wipe = 5.71\ BN^{0.864}$

Thus, a BN lead loading of 100 μg/ft² on an uncarpeted floor, in homes built before 1940, would be converted to a wipe lead loading of 235 μg/ft², by applying the first of these equations. It has an approximate 95% confidence interval of 160 to 344 μg/ft². The 95% prediction interval is 31 to 1799 μg/ft². The confidence interval contains, with 95% probability, the average wipe lead loading associated with measured BN lead loadings of 100 μg/ft². The prediction interval contains, with 95% probability, 95 percent of individual future wipe measurements observed in the immediate vicinity of a BN lead loading of 100 µg/ft². Prediction intervals are wider because they incorporate the inherent variability in the dependent variable, whereas confidence intervals do not.

The following equations were developed for converting a wipe lead loading (µg/ft²) to a BN lead loading (µg/ft²):

Uncarpeted floors:	$BN = 0.185\ Wipe^{0.931}$
Window sills:	$BN = 0.955\ Wipe^{0.583}$
Window wells:	$BN = 4.91\ Wipe^{0.449}$

Applying the first of the above equations, for example, a wipe lead loading of 100 µg/ft² on an uncarpeted floor would be converted to a BN lead loading of 13.5 µg/ft². It has an approximate 95% confidence interval of 9.47 to 19.0 µg/ft². The 95% prediction interval is 1.912 to 94.3 µg/ft².

For samples collected with the BRM vacuum sampler, from uncarpeted floors, carpeted floors, window sills, and window wells, the following equations were developed for converting a BRM lead loading (µg/ft²) to a wipe lead loading (µg/ft²):

Uncarpeted floors:	$Wipe = 8.34\ BRM^{0.371}$
Carpeted floors:	$Wipe = 3.01\ BRM^{0.227}$
Window sills:	$Wipe = 14.8\ BRM^{0.453}$
Window wells:	$Wipe = 13.9\ BRM^{0.630}$

For example, a BRM lead loading of 100 µg/ft² on an uncarpeted floor would be converted to a wipe lead loading of 46.0 µg/ft² by applying the first equation. An approximate 95% confidence interval for this prediction is 40.5 to 52.3 µg/ft². The 95% prediction interval of the wipe loadings associated with a BRM loading of 100 µg/ft² is 5.9 to 262 µg/ft².

2. WHY WERE THESE EQUATIONS DEVELOPED?

These conversion equations were developed for reasons related to the determination of standards required by the Residential Lead-Based Paint Hazard Reduction Act of 1992 (Title X), referred to as the Section 403 standards. It is likely that the Section 403 standards for dust lead will be expressed as a measured lead loading collected by a dust wipe sample. In considering different options for this standard, it is important to evaluate the number of homes that would be affected by the different options. The HUD National Survey of pre-1980 housing (the only national survey of dust lead levels) is the best source for making this assessment [1], [2], [3]. However, the BN vacuum was used in the National Survey to collect dust samples. Therefore, in order to use this data appropriately, it was necessary to convert the raw BN lead loading data to wipe lead loadings. Also, since the Baltimore Repair and Maintenance study dust samples were collected using a BRM vacuum, a conversion to a wipe lead loading was necessary in order for this data to be applicable to Section 403 analyses, such as sensitivity/specificity analyses and prevalence statistics.

3. HOW LARGE IS THE UNCERTAINTY ASSOCIATED WITH THESE CONVERSION EQUATIONS?

There is a considerable degree of uncertainty in the conversion equations based on BN vacuum samples. For the BN vacuum to wipe conversion, there is relatively little data. For example, on uncarpeted floors, one field study produced six pairs of side-by-side wipe and vacuum measures, another produced seven pairs, and a third produced 24 pairs. A larger amount of data was available to develop the conversion equations based on BRM vacuum samples. The Rochester Lead-in-Dust study alone provided over 350 BRM and wipe pairs on each housing component. Although this large amount of data allows fairly accurate characterization of the relationship between the average wipe lead loading and an observed BRM lead loading, the inherent variability in wipe measures makes it important to recognize the wide range of plausible wipe lead loadings that could be associated with any observed BRM lead loading.

4. HOW WILL THESE CONVERSION EQUATIONS BE USED?

The BN to wipe conversion equations will be used to convert the BN dust-lead loadings measured in the National Survey to equivalent lead loadings for wipe samples. The transformed lead loadings will then be used to estimate the numbers and percentages of houses that would be affected for various options for defining dust-lead standards.

Similarly, the BRM to wipe conversion equations will be used to transform the BRM vacuum lead loadings in the Baltimore Repair and Maintenance study to equivalent wipe lead loadings for use in estimating prevalence statistics and in completing a sensitivity/specificity analysis which relates the incidence of elevated children's blood-lead levels to wipe lead loadings.

The wipe to BN conversion equations will be used in two ways for the Section 403 risk assessment. First, one window sill dust sample and one window well dust sample were collected via the wipe method in the HUD National Survey. Because the vast majority of samples were collected via the BN method, it was decided that these two samples should be converted to appropriate BN loadings for consistency. Second, two models were used to predict blood-lead levels: the IEUBK model and an empirical regression model. The empirical model uses as an input dust-lead levels measured by the BN sampler. Therefore, no conversion of the HUD National Survey data is necessary when using the empirical model to predict blood-lead levels from pre-intervention environmental-lead levels, or from post-intervention environmental-lead levels in homes where there is no expected intervention. However, in houses expected to undergo an intervention because dust- or soil-lead levels exceed options for standards, the post-intervention dust-lead loadings that are assigned in the analysis were estimated based on wipe data. These post-intervention estimates will be converted to BN lead loadings to be used as input to the empirical model.

The conversion equations presented in this report were developed for specific applications. The conversion of Blue Nozzle vacuum lead loading to wipe lead loading was developed for use with the HUD National Survey. The conversion of BRM vacuum lead loading to wipe lead loading was developed for use with the Baltimore Repair and Maintenance Study. The conversion of wipe lead loading to BN lead loading was developed primarily for converting estimated post-intervention wipe lead loadings to "equivalent" BN estimates. If the conversion equations developed in this report are used for other applications, the underlying assumptions for the statistical techniques used to derive the equations need to be confirmed for the new application.

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1.0 INTRODUCTION

The objective of this report is to present conversion equations for use in doing analyses for the Section 403 Rule. Equations were developed for converting between wipe lead loadings and vacuum lead loadings based on the Blue Nozzle (BN) vacuum sampler used in the HUD National Survey [1], [2], [3], and the modified HVS3 (BRM) sampler used in the Baltimore Repair and Maintenance study.

Specifically, three types of conversion equations were developed. The first type of equation converts a dust-lead loading collected by the BN sampler to a dust-lead loading as collected by a wipe. This type of equation was developed specifically for use with the HUD National Survey. For uncarpeted floors, this type of equation was developed separately for houses built before 1940, between 1940 and 1959, and between 1960 and 1979. A second type of equation converts a dust-lead loading of a wipe sample to an equivalent dust-lead loading of a vacuum sample collected via the BN sampler. These two types of conversion equations were developed separately for samples collected from uncarpeted floors, window sills, and window wells. A third type of equation was developed to convert from BRM vacuum lead loading to wipe lead loading. Separate equations of this type were developed for samples collected on uncarpeted floors, carpeted floors, window sills, and window wells. These were developed for use with the Baltimore R&M study data.

The three sets of conversion equations were developed for three reasons. First, to estimate the number of houses that would be affected by different options for standards requires use of the HUD National Survey (the only national survey of dust lead levels). The HUD Survey used the BN sampler, but the Section 403 standard for dust lead will likely be defined in terms of a wipe lead loading. This will require converting lead loading measurements measured with the BN sampler to an equivalent wipe lead loading for comparison with a standard. Second, two models are used to predict blood-lead levels from environmental-lead levels in the risk analysis, the IEUBK model and an empirical regression model. The empirical model uses lead loadings measured with the BN samples as input because the HUD survey used the BN sampler. However, estimating post-intervention blood-lead levels requires estimating post-intervention environmental-lead levels. Most of the data available for estimating post-intervention dust-lead levels is measured with wipes, and therefore the average levels were estimated based on wipes. For use in the empirical model, these wipe levels need to be converted to BN levels. This is the primary reason for the second conversion.

Similarly, the Baltimore Repair and Maintenance data are used to perform a sensitivity/specificity analysis and to calculate prevalence statistics. Since the BRM vacuum was used to collect data in this study, a means of converting BRM lead loadings to wipe lead loadings was required.

1.1 PEER REVIEW SUMMARY

This report was peer reviewed by three subject matter experts who were independent of the project team that developed the report. The following is a summary of the peer review comments that had an important impact on the report or are important for understanding major issues.

A reviewer commented that the discussion of measurement error was insufficient. In response, the measurement error issue was reexamined, and a type of measurement error adjustment known in the statistical literature as a transportability adjustment was found to be appropriate for some of the situations in the report. The report methodology was changed where necessary and the discussion of measurement error was re-written in the text.

Another review comment indicated that there was insufficient reference to the work of others in the area of conversion equations. In response, all the known references were examined with respect to methodology and results. Two references included consideration of within-house correlation. The issue of within-house correlation was examined, and for some of the situations in the report, within-house correlation was found to be statistically significant. The methodology in the report was modified to take within-house correlation into consideration in these cases. The text dealing with the discussion of the work of other researchers was re-written.

Two reviewers commented on the lack of discussion of variability in one of the adjustment factors introduced to make data from two studies comparable to data from other studies. (The adjustment in question adjusts "bioavailable lead" measurements to "total lead" measurements.) An examination of the appropriate data showed that there was a better way to make the adjustment which reduced the variability in the adjustment factor. There is still random variability in the adjustment, and this is noted in the report.

A reviewer noted that the range of the data for the Blue Nozzle conversion equation did not match the range of the data for the Blue Nozzle dust collection in the HUD National Survey. In general, the Blue Nozzle data collected in the HUD National Survey are lower than the Blue Nozzle data from which the conversion equations were developed. This is a situation in which a transportability adjustment may apply, and for the conversions from Blue Nozzle measurements to wipe measurements for floors and window sills, a transportability adjustment was carried out. Furthermore, it is worth noting that the values for options for dust standards under the EPA 403 rule will most likely be at the middle to high end of the data range. Hence low values from the HUD National Survey will not be as applicable with respect to determining a dust standard.

A reviewer commented that the Blue Nozzle data in the report seemed to be inadequate to serve as the basis for making national policy decisions. In response, a number of points should be considered. This study utilized the only national survey of lead in residential housing, the HUD National Survey, which used the Blue Nozzle vacuum to collect house dust. The wipe method is the most commonly used method of dust collection, and is the method for which EPA is likely to develop standards for the EPA 403 Rule. This report uses all available data to develop a conversion from Blue Nozzle measurements to wipe measurements. Collection of new data was not an option under the time constraints of the 403 analyses.

At the time of peer review, the report contained a conversion equation from a lead loading as collected by a wipe sample to a lead concentration as collected by a Blue Nozzle vacuum. After the peer review was completed, EPA decided to pursue alternative approaches in the 403 analyses that have made use of the wipe loading to Blue Nozzle concentration conversion equation unnecessary. All the material related to this conversion equation has been moved to an appendix to document the developmental work that was done; however, it is unlikely the wipe loading to Blue Nozzle concentration equation will be used in 403 analyses.

After completion of peer review, this report was substantially revised. The report was included as an appendix to a report on the risk analysis for the 403 rule. This risk analysis was peer reviewed by individuals different from those who peer reviewed this report initially. In this review, a reviewer commented on the lack of an adjustment for measurement error, and further commented that the absence of an adjustment for measurement error limited the usefulness of the conversion equations outside the context of the rulemaking process. An additional comment was received recommending the collection of more data.

In response, the reviewer appears to be referring to an errors-in-variables adjustment. In regression analysis, the independent variable is assumed to be known without error. An errors-in-variables adjustment is generally done to adjust for the variability in the independent variable. However, in this report, what is desired is a conversion from one observed value to another, so that the independent variable is by definition known without error. Therefore, an errors-in-variables approach, by itself, is not appropriate for this report. However, a type of measurement error adjustment known as a transportability adjustment was appropriate for some cases in this report and was carried out, as stated above. This adjustment involved an errors-in-variables adjustment as an intermediate step. With respect to the collection of more data, this was not possible under the time constraints of the 403 analyses.

EPA has established a public record for the peer review of this report under Administrative Record 169. This Administrative Record is available in the TSCA Non-Confidential Information Center, which is open from noon to 4 pm Monday through Friday, except on legal holidays. The TSCA Non-Confidential Information Center is located in Room NE-B607, Northeast Mall, 401 M Street SW, Washington, D.C.

1.2 DOCUMENT OVERVIEW

This chapter (Chapter 1) is the introduction to the report. It explains why the analyses in the report were done. A summary of the peer review of the report and an overview of the layout of the rest of the report are also included in Chapter 1. Chapter 2 discusses the data, which studies were involved, descriptive statistics, range of the data and other technical issues. Chapter 3 presents the statistical approach used in developing the conversion equations. Detailed explanations of measurement error, within house correlation, combining results across studies, and confidence and prediction intervals are included. Chapter 4 presents the results (with figures and tables) of the analyses for the Blue Nozzle Vacuum and for the BRM Vacuum. Chapter 5 is a discussion of the analyses and a summary of related efforts by other researchers. Chapter 6 is a list of references. Appendix A explains the development of two correction factors employed in the conversion equations analysis. Appendix B presents the distribution of the data used to develop the BN and BRM vacuum conversion equations. Appendix C presents details of the development of the BN to wipe conversion equations. This includes figures and tables which justify the statistical analysis, and validation of the models used. Individual study regressions, residual analyses, and influential observation analyses are provided. Appendices D and E present details of developing the wipe to BN and BRM to wipe conversion equations, respectively, including model building, residual analysis, and influential observations analysis. Appendix F provides a wipe lead loading to BN lead concentration conversion based on the same approach used for the loading to loading conversions discussed in the main body of the report.

2.0 DATA

A wide range of samplers and sampling protocols have been used in environmental-lead studies for the collection of dust samples. This section describes the data used for determining relationships between lead loadings as measured by the wipe and BN methods. A description of the data used to determine the relationship between wipe and BRM vacuum lead loadings is also presented.

2.1 STUDIES INCLUDED

Table 1 provides information on the studies used to develop the conversion equations discussed in this report. Details regarding the design of each study and the intervention history of the houses included in each study are presented. Comments are also provided to identify limitations or special considerations, such as correction factors, associated with each study.

Three studies report side-by-side paired data on wipe lead loading and Blue Nozzle vacuum lead loading and were used to develop the conversion equations for the BN vacuum:

1. CAP Pilot study [4]
2. National Center for Lead-Safe Housing (NCLSH)/Westat study [5]
3. Baltimore Repair and Maintenance (R&M) Pilot study [6, 7]

In the CAP Pilot and NCLSH/Westat studies, wipe samples were analyzed using the hot nitric acid/peroxide digestion method typically used in HUD-related work, while the R&M Pilot study employed the cold hydrochloric acid digestion procedure used in the State of Maryland. Therefore, it is necessary to use an additional correction factor to convert the wipe lead measurements in the R&M Pilot study to equivalent HUD wipe measurements. An estimate of the correction factor was obtained from a log-linear regression analysis of total available lead loading (hot nitric acid/peroxide) versus bioavailable lead loading (cold hydrochloric acid) using data reported in the NCLSH 5-Method Comparison study [9]. This study reported wipe measurements that were analyzed by both chemical extraction procedures. The regression results indicate that the bioavailable lead loading, denoted by B, should be multiplied by $B^{0.1416}$ to

Table 1. Summary Table for the Studies from which Data were Used to Develop Conversion Equations.

Vacuum Type	Study	Surface Type	(N)[a]	Relevant Issues of Study Design	Intervention History	Comments
Blue Nozzle	CAP Pilot Study [4]	Uncarpeted Floors Window Sills	(6) (6)	On floors, two side-by-side vacuum samples, each four square feet in area, were taken near two side-by-side wipe samples, each one square foot in area. Geometric average of wipe pairs was related to geometric average of BN pairs. On window sills, one wipe half-window sill sample was taken adjacent to one BN half-window sill sample.	2 methods of abatement: 2 homes were abated primarily by encapsulation/enclosure methods, and 2 homes were abated primarily by removal methods approximately 1 year prior to sampling. 2 homes had relatively few lead-based paint components, which were unabated.	Reduced variability resulting from averaging side-by-side samples was taken into account.
Blue Nozzle	NCLSH/ Westat [5]	Uncarpeted Floors Window Sills Window Wells	(7) (42) (6)	Side-by-side wipe and BN vacuum samples were collected from uncarpeted floors, window sills, and window wells.	Forty homes owned by the Baltimore Housing Authority were included in this study. Of these, 30 were rehabilitated and 10 were not. No description of the rehabilitation of the homes was provided. Additional samples were collected from 5 homes owned by City Homes after the samples from the forty homes initially in the study were analyzed. The intervention status of those 5 homes was not available from the reference. No interventions were performed as a part of the NCLSH/Westat Study.	BN concentrations were not available to characterize the relation between wipe and BN concentrations.
Blue Nozzle	R&M Pilot Study [6], [7]	Uncarpeted Floors Window Sills Window Wells	(24) (23) (24)	Side-by-side wipe and BN vacuum samples were collected from uncarpeted floors, window sills, and window wells.	Of the 6 homes in the study, 2 homes were occupied and had received comprehensive abatement in 1986-87, 2 homes were vacant, unabated, older urban homes, and 2 homes were vacant modern urban homes. No interventions were performed as a part of the R&M Pilot Study.	In the R&M Pilot study, the bioavailable (cold HCl acid) digestion method was used to determine the lead content in wipe samples.

Table 1. Summary Table for the Studies from which Data were Used to Develop Conversion Equations (Continued).

Vacuum Type	Study	Surface Type (N)[a]	Relevant Issues of Study Design	Intervention History	Comments
BRM	R&M Mini Study [8]	Uncarpeted Floors (25) Window Sills (27) Window Wells (25)	Side-by-side wipe and BRM vacuum samples were collected from uncarpeted floors, window sills, and window wells.	Seven pre-1940, vacant homes in Baltimore City were included in this study. These homes were not known to have undergone any lead paint abatement. However, one home was known to be free of LBP. No interventions were carried out as a part of the R&M Mini Study.	The bioavailable (cold HCl acid) digestion method was used to determine the lead content in wipe samples.
	NCLSH 5 Method Comparison Study [9]	Uncarpeted Floors (68) Carpeted Floors (67)	Side-by-side wipe and BRM vacuum samples were collected from uncarpeted and carpeted floors.	No interventions were carried out as a part of the NCLSH 5-Method Comparison Study.	Wipe lead loadings were multiplied by 1.25 to correct for only including 80% of wipe samples in the chemical analyses.
	Rochester Lead-in-Dust Study[10]	Uncarpeted Floors(389) Carpeted Floors (398) Window Sills (362) Window Wells (403)	Side-by-side wipe and BRM vacuum samples were collected from uncarpeted floors, carpeted floors, window sills, and window wells.	The 205 homes in this study were known to have not undergone extensive renovation or remodeling within the year prior to the eligibility interview. No interventions were performed as a part of the Rochester Study.	None
	Milwaukee Low Cost Interventions Study [11]	Uncarpeted Floors(135)	Side-by-side wipe and BRM vacuum samples were collected from uncarpeted floors.	No interventions were received by residents in the included homes, and no homes had undergone abatement prior to the study.	Duplicate vacuum samples were excluded in determining the relationships.

(a) Number of pairs.

represent total lead loading. Using a correction factor that depends on the amount of lead measured was found to significantly reduce the observed variability about the correction, although variability still remains in the correction factor. Thus, wipe lead loadings in the R&M Pilot study were adjusted to be more reflective of HUD wipe measurements. Appendix A provides details on the development of this correction factor and addresses its applicability to the studies involved in this analysis. Appendix B contains tables of the distribution of the Blue Nozzle data. These tables present the number of pairs of side-by-side wipe and vacuum samples within various ranges for each component in each of the three studies included.

The CAP Pilot study collected two side-by-side wipe and BN vacuum samples in each house. The geometric average of these replicate samples was used in the development of the conversion equations. The reduced variability associated with averaging side-by-side samples was taken into account in developing the conversion equations.

Four studies report side-by-side paired data on wipe lead loading and BRM vacuum lead loading and were used to develop the BRM loading to wipe loading conversion equations:

1. R&M Mini study [8]
4. NCLSH 5-Method Comparison study [9]
3. Rochester Lead-in-Dust study [10]
4. Milwaukee Low Cost Interventions study [11]

Notice from Table 1 that the housing components sampled varied by study. The Rochester Lead-in-Dust study was the only study for which side-by-side wipe and BRM samples were collected on all four components: uncarpeted floors, carpeted floors, window sills and window wells. In the Rochester Lead-in-Dust, NCLSH 5-Method Comparison, and Milwaukee Low Cost Interventions studies, wipe samples were analyzed using the hot nitric acid/peroxide digestion method which yields total lead loading. The R&M Mini study, however, reported bioavailable lead loadings using the cold hydrochloric acid digestion procedure mentioned above. The correction factor discussed above for the R&M Pilot study was also used to adjust these loadings.

In the NCLSH 5-Method Comparison study, only 80 percent of each sample collected by wipe was extracted using the hot nitric acid/peroxide digestion method (total lead digestion). The lead loadings for total lead digestion reported in the NCLSH 5-Method Comparison study were therefore multiplied by 100/80 = 1.25 to adjust for the chemical analysis of a reduced sample. Appendix A describes the derivation of the two correction factors used. The appendix also motivates the use of these adjustments.

In the Milwaukee Low Cost Interventions study, there were duplicate BRM samples collected from a location adjacent to the side-by-side samples provided for this analysis. These duplicates were not included in the development of these conversion equations.

2.2 DESCRIPTIVE STATISTICS

Table 2 presents descriptive statistics for the variables used in developing the various conversion equations in this report. Data were available for the relationship between wipe and BN on uncarpeted floors, window sills, and window wells. No data regarding this relationship on carpeted floors were found. For exploring the relationship between wipe loadings and BRM loadings, data were available from uncarpeted floors, carpeted floors, window sills, and window wells.

2.3 RANGE ISSUES

This section deals with issues involving the ranges of the data used to develop the conversion equations and the impact of these ranges on the applicability of the equations. The BN to wipe conversion equations will be used to convert the BN dust-lead loadings measured in the National Survey to equivalent lead loadings for wipe samples. The transformed lead loadings will then be used to determine the numbers and percentages of houses that would be affected for various options for a lead dust standard.

The BN loadings used to develop the BN lead loading to wipe lead loading conversion equation range from 1 to 2164 $\mu g/ft^2$ for uncarpeted floors. The BN lead loadings for private housing in the HUD National Survey range from 0.014 to 380 $\mu g/ft^2$ for uncarpeted floors. Of the 364 non-missing BN vacuum lead loadings from uncarpeted floors for private housing in the HUD National Survey, 190 (52%) fall below the minimum BN vacuum lead loading used to develop the BN loading to wipe loading conversion equation. Of the 284 homes surveyed, 150 had at least one uncarpeted floor dust-lead loading falling below the range of the conversion data.

Table 2. Descriptive Statistics for Vacuum Dust Lead Measures and Wipe Lead Loadings by Study.

Vacuum Type	Study	Surface Type	No. of Pairs	Vacuum Loading (μg/ft²)		Wipe Loading (μg/ft²)	
				Geometric Mean	Log Std. Dev.	Geometric Mean	Log Std. Dev.
Blue Nozzle	CAP Pilot Study [4]	Uncarpeted Floors	6[a]	10.7	1.66	51.0	1.93
		Window Sills	6[b]	36.0	1.72	164	1.87
	NCLSH/ Westat [5]	Uncarpeted Floors	7	11.2	0.526	50.6	0.362
		Window Sills	42	14.7	0.832	133	1.28
		Window Wells	6	171	0.863	13,400	2.03
	R&M Pilot Study[c] [6], [7]	Uncarpeted Floors	24	16.6	2.27	128	2.06
		Window Sills	23	48.1	2.62	582	3.77
		Window Wells	24	6,030	2.73	4,800	2.98
BRM	R&M Mini Study[c] [8]	Uncarpeted Floors	25	320	2.62	288	1.99
		Window Sills	27	4,400	4.08	5,260	3.46
		Window Wells	25	262,000	3.80	108,000	2.80
	NCLSH 5 Method Comparison Study[d] [9]	Uncarpeted Floors	68	26.6	2.43	25.8	1.52
		Carpeted Floors	67	413	1.17	4.97	0.79
	Rochester Lead-in-Dust Study [10]	Uncarpeted Floors	389	12.8	2.07	16.6	1.25
		Carpeted Floors	398	180	1.73	11.3	1.13
		Window Sills	362	227	2.42	163	1.53
		Window Wells	403	11,400	3.39	2,590	2.61
	Milwaukee Low Cost Interventions Study [11]	Uncarpeted Floors	135	37.1	2.19	38.4	1.18

(a) On floors, two side-by-side vacuum samples, each four square feet in area, were taken next to two side-by-side wipe samples, each one square foot in area, from each house in the CAP Pilot Study. Each member of each wipe-vacuum pair is an average of two side-by-side samples. Statistics were calculated from these averages.

(b) On window sills, one wipe half-window sill sample was taken adjacent to one BN half-window sill sample.

(c) Wipe loading statistics were calculated using total wipe loadings adjusted from bioavailable wipe loadings.

(d) Wipe loading statistics were calculated using reported total wipe loadings multiplied by 1.25 to adjust for the analysis of a reduced sample.

For window sills, the BN lead loadings from the HUD National Survey range from 0.004 to 11,899 µg/ft² with 136 (35%) of the 392 non-missing observations falling outside the range of the conversion data. One BN lead loading is above the maximum of the data used to develop the window sill conversion equation (8964 µg/ft²) and 135 BN loadings are below the minimum (1.4 µg/ft²). Of the 284 homes surveyed, 107 have at least one window sill dust-lead loading falling below the range of the conversion data.

The range of the BN lead loadings used to develop the BN loading to wipe loading conversion equation for window wells is 35.5 to 761,842 µg/ft². Forty-seven (30%) of the 158 non-missing BN vacuum lead loadings from window wells in the HUD National Survey fall below the minimum of 35.5 µg/ft². Forty of the 284 homes included in the survey have at least one window well dust-lead loading falling below this minimum. Table 3 lists the ranges of the data used to develop the BN loading to wipe loading conversion equations for each housing component. Also presented are the ranges of the HUD National Survey BN loadings that will be converted using these equations. The distribution of the BN lead loadings used to develop the conversion equations ("training data") is substantially different from the distribution of BN lead loadings observed in the HUD survey ("application data"). Because of this, a "transportability adjustment" was applied, which is explained in Chapter 3.

Table 3 also includes the range of the data used in developing the BRM loading to wipe loading conversion equation for each housing component. These equations will be used to transform the BRM vacuum lead loadings in the Baltimore Repair and Maintenance study to equivalent wipe lead loadings for use in determining prevalence statistics and in completing a sensitivity/specificity analysis which relates the incidence of elevated (≥ 10 µg/dL) children's blood-lead levels to wipe lead loadings. The ranges of the Baltimore Repair and Maintenance BRM loadings are provided in Table 3 as well. With one exception for the minimum of carpeted floors, these loadings fall within the range of the data used to develop the equations for each component.

Table 3. Observed Ranges, by Housing Component and Vacuum Type, for the Dust-Lead Loading Data ($\mu g/ft^2$) Used to Develop the Vacuum Loading to Wipe Loading Conversion Equations and for the Dust-Lead Loading Data ($\mu g/ft^2$) upon Which the Conversion Equations Will Be Used.

Data Classification	Vacuum Type	Data	Housing Component: Uncarpeted Floors Min.	Uncarpeted Floors Max.	Carpeted Floors Min.	Carpeted Floors Max.	Window Sills Min.	Window Sills Max.	Window Wells Min.	Window Wells Max.
Data Used to Develop the Conversion Equations	BN	CAP Pilot, R&M Pilot, and NCLSH/Westat	1.00	2,164	NA	NA	1.40	8,964	35.5	761,842
	BRM	R&M Mini, Rochester, NCLSH 5-Method, Milwaukee	0.080	74,100	1.42	141,000	0.250	4,169,649	1.88	6,610,797
Data Upon Which the Conversion Equations Will Be Used	BN	HUD National Survey	0.014	380	0.003[(a)]	272[(a)]	0.004	11,899	0.042	40,457
	BRM	Baltimore R&M[(b)]	0.525	59,074	1.08	26,417	0.788	285,414	26.6	3,360,469

(a) There were no data to develop a conversion equation from BN to wipe for carpeted floors.

(b) Floor dust samples in the Baltimore R&M study were composited. The statistics for uncarpeted floors reflect the distribution of composite samples that included any subsamples from uncarpeted floors. Statistics for carpeted floors reflect the distribution of samples that included any subsamples from carpeted floors. These two sets of samples overlapped because some floor composite samples included both carpeted and uncarpeted subsamples. Of the 317 floor composite samples, 191 (60%) were exclusively from uncarpeted floors, 49 (16%) were exclusively from carpeted floors, and 77 (24%) were from both carpeted and uncarpeted floors.

2.4 OTHER ISSUES

Seasonal rhythms in blood lead levels have been observed in several studies. For example in the EPA report, ***Seasonal Trends in Blood Lead Levels in Milwaukee*** [12], found that lead levels in blood were approximately 40% higher in the summer (August) than in winter during 1990-1995. In addition, seasonal rhythms in environmental lead levels were observed in Boston during 1979 to 1983 as reported in the EPA report ***Seasonal Rhythms of Blood-Lead Levels: Boston, 1979-1983*** [13]. In that study, floor dust-lead loadings were on average 50 percent higher in July compared to December. Environmental samples in the HUD National Survey were collected during the winter months and may have been higher if they were collected during the summer. Because seasonal variations in dust lead are most likely a function of geographic location, the seasonal variations estimated in Boston and Milwaukee may not be applicable to the HUD National Survey. Therefore, an adjustment to the floor dust-lead loadings in the HUD National Survey to account for seasonal variations was not investigated.

The types of wipes used in the various studies are identified in Table 4, with an indication of whether there is known to be background lead in these wipes. The wipes used in the CAP and the Milwaukee studies had trace amounts of lead. These trace amounts would be expected to only slightly increase the variability, and slightly bias the relationships.

Table 4. Wipes Used in Various Studies.

Vacuum Type	Study	Wipes Used	Background Lead
Blue Nozzle	CAP Pilot	Chubbs	6-18 μg lead per wipe
	NCLSH/Westat	Little Ones Baby	None known
	R&M Pilot	WetOnes	None known
BRM	R&M Mini	WetOnes	None known
	NCLSH 5-Method Comparison	Little Ones Baby	None known
	Rochester Lead-in-Dust	Little Ones Baby	None known
	Milwaukee Low Cost Interventions	Wash-a-bye Baby	1-2 μg lead per wipe

In Table 5, information is presented related to the non-detection of lead loadings in the sets of data used to develop the conversion equations. This includes the instrument detection limit (IDL) in each study, the number of samples below the IDL, and a description of how these samples were handled in the analysis. For the BRM conversion equations, a very small percentage of the data was below the IDL, so their influence is likely to be small. For the BN conversions, the vast majority of the samples collected in the NCLSH/Westat study were below the IDL, and these were excluded. For the CAP and R&M Pilot studies, either IDL or $IDL/\sqrt{2}$ was used when non-detected results were the case. None of these points were found to be influential observations. (Appendices C and D present analyses to identify influential data points.)

Table 5. Information Related to Non-detection for Lead Measures in Various Studies.

Vacuum Type	Study	Instrument Detection Limit (IDL)	Number of Samples Below IDL	How were Below IDL samples handled in this report
Blue Nozzle	CAP Pilot	13.77 μg/sample for wipe	1[a]	IDL was used to compute wipe lead loading
	NCLSH/ Westat	5 μg for blue nozzle 25 μg for wipe	For 292 of the 351 side-by-side pairs, one or both measurements were below IDL	Only paired samples with both members of the pair above the IDL were used in analysis
	R&M Pilot	An approximate value of 7 μg for IDL of wipe samples was determined from the data set	3 wipe measurements (2 sills and 1 well)	Measurements were replaced by $IDL/\sqrt{2}$
BRM	R&M Mini	--	None	
	NCLSH 5-Method Comparison	(b)	(b)	Samples below the limit of detection for flame AA were reanalyzed by graphite furnace AA, and for these, the GFAA response was used in this report.
	Rochester Lead-in-Dust	FAA: wipe<10 μg/sample BRM <10 μg/sample GFAA: wipe < 0.25 μg/sample BRM <0.15 μg/sample	wipe: 1 uncarpeted floor 1 window sill BRM: 3 uncarpeted floors 3 window sills 1 window well These were below the IDL for GFAA analysis.	Samples below the limit of detection for flame AA were reanalyzed by graphite furnace AA, and for these, the GFAA response was used in this report. The reported values for the 9 samples below the GFAA IDL were included in the analysis with no changes.
	Milwaukee Low Cost Interventions	IDLs varied from 1.69 to 1.89 μg/ft² for wipe and from 1.08 to 48.6 μg/ft² for BRM.	1 wipe sample 9 BRM samples	Wipe and BRM loadings below and above the IDL were handled the same way. The detection limit was ignored in reporting of instrument responses.

(a) Both wipe samples in a vacuum-wipe pairing were below the appropriate IDL for the analysis of the wipe samples. The vacuum samples in the pairing were both above the appropriate IDL for the analysis of the vacuum samples. The wipe sample IDL was used to compute the lead loading for the wipe samples in the pairing. The final calculated loading depended on the sample dilution.

(b) Could not be determined from the report.

3.0 STATISTICAL APPROACH

A log-linear model was used to characterize the relationship between lead loadings for two different samplers on all housing components. For instance, the model relating wipe lead loading to Blue Nozzle lead loading may be written as

$$\log(BN) = \log(\theta_0) + \theta_1 \log(W) + \log(E),$$

or equivalently as,

$$BN = \theta_0 W^{\theta_1} E,$$

where BN=Blue Nozzle lead loading and W=wipe lead loading. E represents a random error term.

A similar model is recommended for converting a lead loading from either vacuum sampler to a wipe lead loading:

$$\log(W) = \log(\theta_0) + \theta_1 \log(V) + \log(E),$$

or equivalently as,

$$W = \theta_0 V^{\theta_1} E,$$

where V=Blue Nozzle or BRM vacuum lead loading and W=wipe lead loading, with E representing a random error term.

Depending on the conversion, different methods were used to obtain point estimators of the model parameters, namely, θ_0 and θ_1. Figures 1, 2, and 3 illustrate the procedures used to derive the three types of conversion equations. Figure 1 describes the procedure used to derive the conversion from BN to wipe lead loading, with one exception. Figure 2 describes the procedure used to estimate conversions from wipe to BN lead loading. Figure 3 describes the procedure used to derive the conversion from BRM to wipe lead loading. The exception to Figure 1 is the conversion for window wells from BN to wipe lead loading, which follows the procedure in Figure 2.

In these diagrams, the circles represent the data sets, the triangles represent the statistical methods performed on the data set, the boxes represent the outcomes of the analytical step or steps. The statistical methods named within each triangle are described in the subsections of 3.1. The relevant section number is indicated within each triangle. In Figure 1, BN and the θ parameters represent the observed values and the observed regression parameters, respectively.

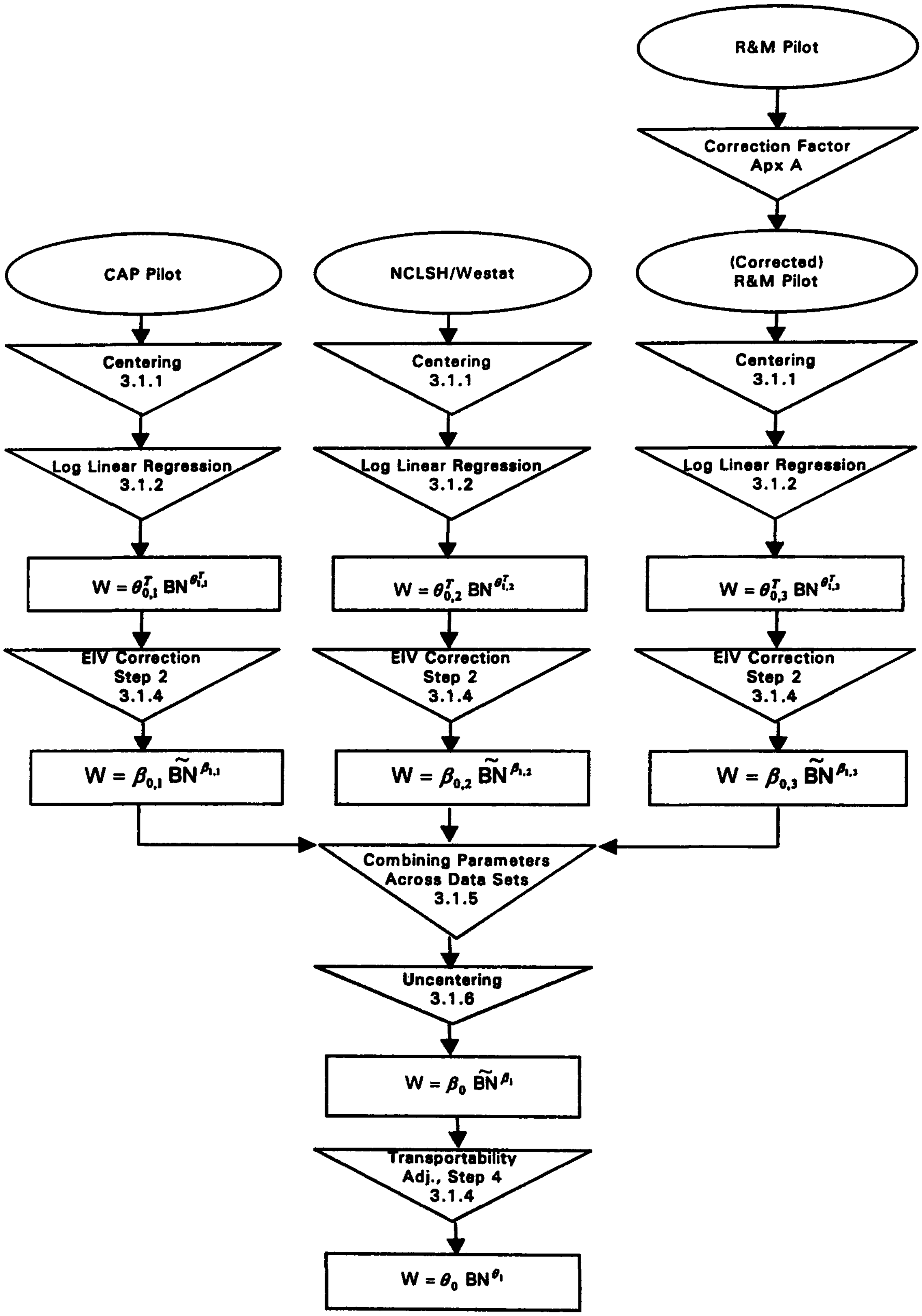

Figure 1. Methods for Converting BN to Wipe Lead Loadings on Uncarpeted Floors and Window Sills.

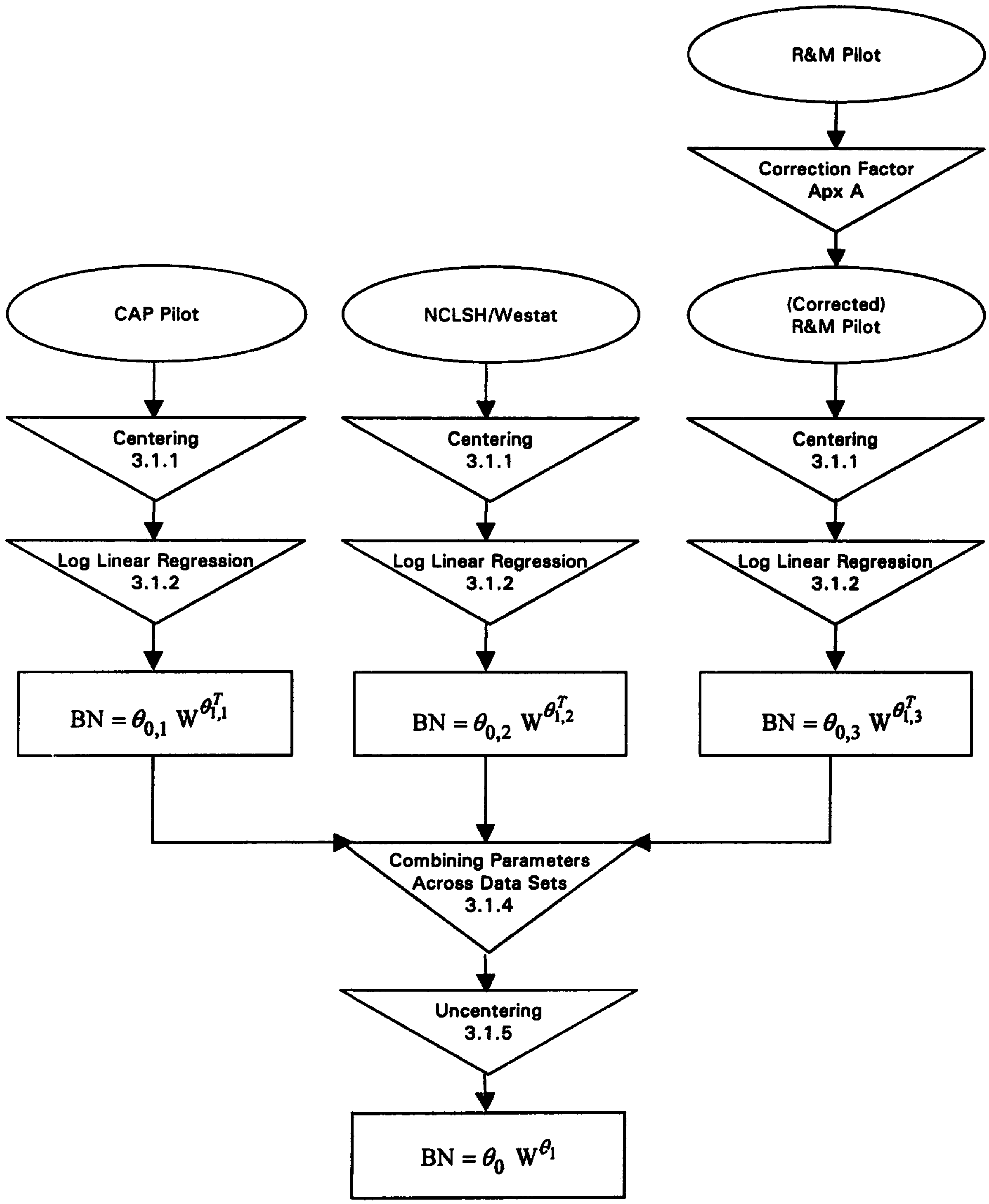

Figure 2. Methods for Converting Wipe to BN Lead Loadings on Uncarpeted Floors, Window Sills, and Window Wells, and Methodology for Converting BN to Wipe Lead Loadings on Window Wells.

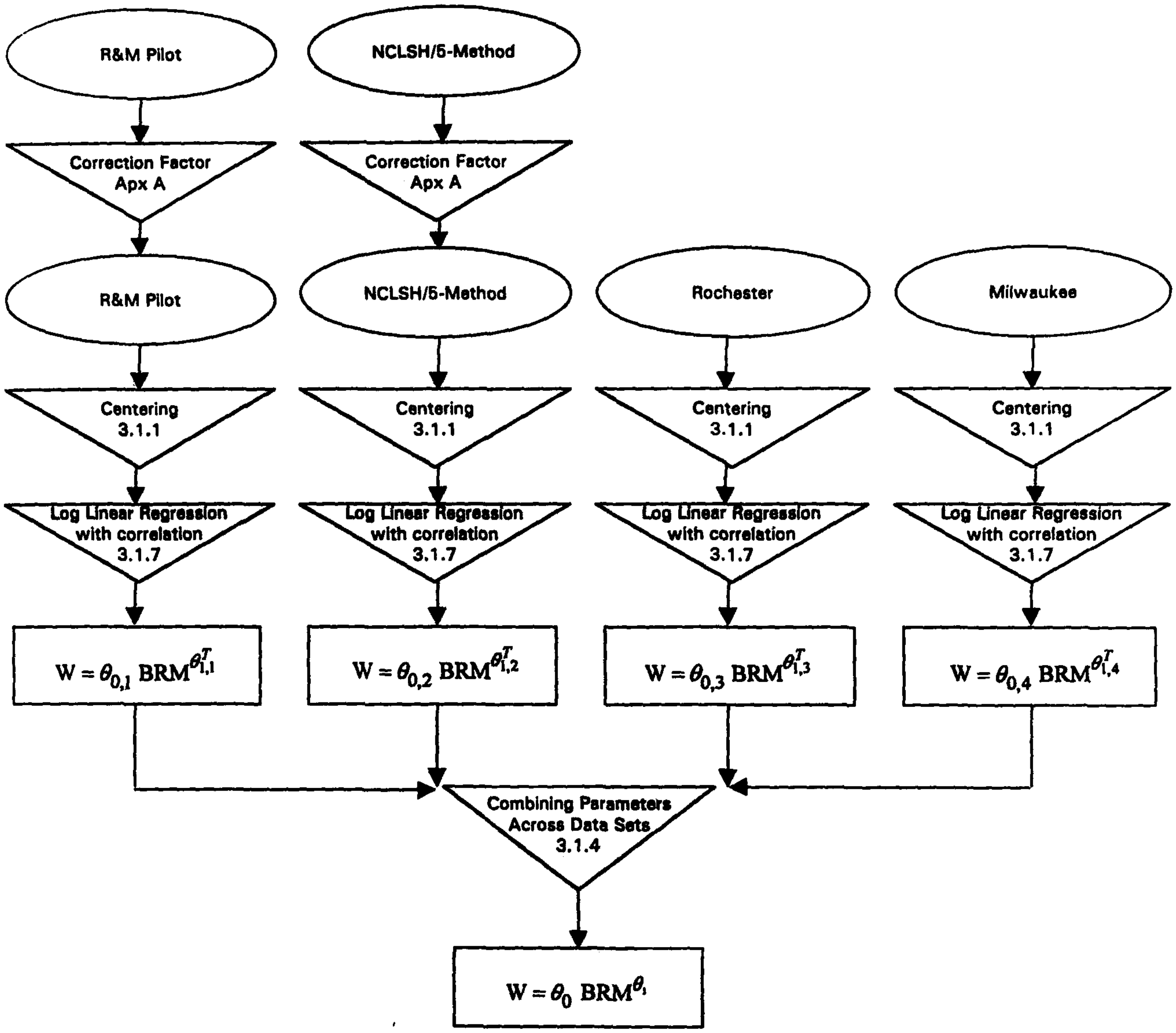

Figure 3. Methods for Converting BRM to Wipe Lead Loadings.

$\tilde{BN}$ represents theoretically "true" BN values (without measurement error). The β parameters are associated with the relationship without measurement error in the BN measurements. These are discussed in more detail in Section 3.1.3.

The procedure illustrated in Figure 1 incorporates a "transportability" adjustment documented below. This procedure was used for converting BN lead loadings to wipe lead loadings on uncarpeted floors and window sills. Making the transportability adjustment in Step 4 required a measurement error adjustment in Step 2. However, the conversion equation for window wells from BN to wipe lead loading was not done according to the Figure 1 approach because there was only one data point available to estimate measurement error for window wells. Hence a decision was made to use the methodology in Figure 2 for this type of conversion. The Figure 2 approach does not include a transportability adjustment. It was felt that the use of the Figure 2 methodology would be more reliable than the approach in Figure 1 for BN lead loadings on window wells.

3.1 STATISTICAL METHODS USED IN DEVELOPMENT OF CONVERSION EQUATIONS

This section describes the several statistical methods used to develop the conversion equations.

3.1.1 Centering

As the model is stated above, the intercept is the predicted log lead loading for an associated sample with a lead loading of 1 $\mu g/ft^2$. A lead loading of 1 $\mu g/ft^2$ (which has a logarithm of 0) is near the lower bound of the range of lead loadings in each of the studies used to develop these equations. Thus, an estimate of the intercept at a lead loading of 1 $\mu g/ft^2$ would have greater uncertainty than if the intercept was estimated near the "center" of the observed lead loadings. In fact, the uncertainty of the intercept is minimized if it is estimated at the average, or the "center," of the values taken on by the independent variable. Therefore, the log lead loading of the independent variable in each study was centered by subtracting μ_L, the average log lead loading obtained for the independent variable across the studies for which data was available for that housing component and vacuum type. The model then becomes, for example,

$$\log(W) = \log(\theta_0) + \theta_1 (\log(BN) - \mu_L) + \log(E).$$

This is done to make the estimates of slope and intercept (nearly) independent. For each study, the regression model was then fitted to the centered data.

This approach was taken when developing conversion equations for both the BN and BRM vacuum samplers for uncarpeted floors, carpeted floors (BRM only), window sills, and window wells. Separate centering constants were determined for each sample type (i.e., carpeted and uncarpeted floors, window sills or window wells), and predictor (i.e., BRM, BN, or wipe).

3.1.2 Log Linear Regression

Simple log linear regression models were used to express the relationship between each predictor variable and its converted value, e.g.,

$$\log(BN) = \log(\theta_0) + \theta_1 \log(W) + \log(E),$$

Exponentiating both sides of the model yields

$$BN = \theta_0 W^{\theta_1} E.$$

Within the log linear regression model, the parameters θ_0 and θ_1, intercept and slope, respectively, are the statistics of interest. This form of model has been used in many studies for relating one lead measurement method to another (e.g., [4], [5], [9], [11]). Including a variable, θ_1, to represent the exponent on the independent variable permits the ratio to depend on the level of the predictor.

3.1.3 Measurement Error and Transportability Assessment

What is Measurement Error?

Measurement error is the difference between the observed value (the actual vacuum lead-loading measurement) and the "true" lead loading at a location. "True" lead loading can only be defined conceptually in this application. It represents what would be the average of an infinite number of replicated samples taken in the immediate vicinity of the location sampled. True lead loading in this context does not represent the actual amount of lead present at the location. It represents the central tendency of the sampler under the present circumstances. Thus, true lead loading for the BN sampling method may not be the same as the true lead loading for the wipe sampling method.

This report uses the following notation to distinguish between observed and true values. (Note that all values are log transformed, but notation indicating the log transformation is omitted for ease of presentation.)

$X_i \equiv$ true value

$W_i \equiv$ observed value

$U_i = W_i - X_i \equiv$ measurement error.

The relationship between X and Y is assumed linear and defined as:

$$Y_i = \beta_0 + \beta_1 X_i + E_i$$

The E_i's represent the residuals from the true relationship and have variance σ_E^2. However, one does not observe X_i, but rather $W_i = X_i + U_i$. Under the assumption that the X_i's are normally distributed, Y_i has a similar, linear relationship with W_i:

$$Y_i = \theta_0 + \theta_1 W_i + \eta_i,$$

with different parameters defining the intercept, θ_0, the slope, θ_1, and the variance of the error term, σ_η^2. Given information about the magnitude of the measurement error ($var(U_i) = \sigma_U^2$) and the variability in the true X's, one can estimate the parameters of the true relationship based on estimates from the observed relationship. This is discussed in Section 3.1.4.

Transportability and When It is an Issue

The intended use of the conversion equations is for prediction of measured levels that would be obtained by another sampling method, based on the measured level of a given sampling method. In these cases it is not usually appropriate to apply an errors-in-variables measurement error adjustment. In the case where the prediction model was developed from one population (the training data set) but will be applied to another population (the application data set) measurement error is not a concern as long as the distribution of true lead loadings for the predictor variable is the same in the two data sets. This condition is referred to as "transportability".

In particular, under the assumption of normality, if the mean and variance in true lead loadings (based on the predictor method) in the data sets used to develop the conversion equations differs from mean and variance in the data sets on which the equations will be applied, then the equations need to be adjusted. This is called a lack of "transportability."

Figure 4 illustrates a situation for which there is an obvious need for a transportability adjustment. This is based on simulated data to emphasize the issue. The plot shows two sets of data points, training data represented by circles, and application data represented by pluses.

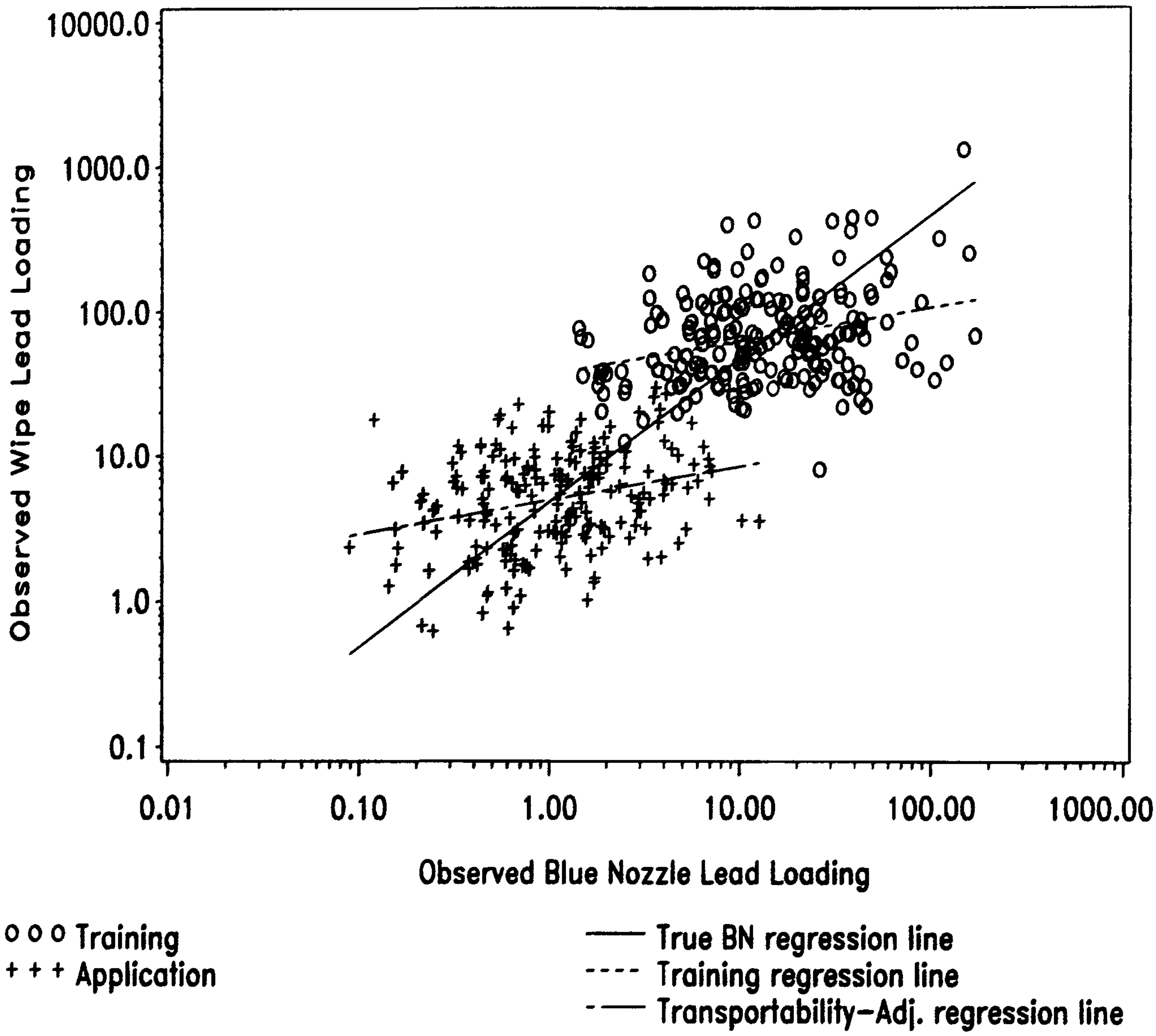

Figure 4. Illustration of Transportability Adjustment and Its Necessity

“Observed” wipe lead loading is plotted against “observed” BN vacuum lead loading[1]. Note that when developing a conversion equation for a particular application data set, the pluses cannot be plotted. Otherwise, there would be no reason to develop conversion equations. Thus, these are hypothetical data.

On the plot, there are several lines. The long solid line represents the relationship between “true” wipe and “true” BN lead loading ($Y_i = \beta_0 + \beta_1 X_i + E_i$). The short dashed line in the upper right represents the regression line based on observed wipe and BN measures in the training data set ($Y_i = \theta_0 + \theta_1 W_i + \eta_i$). If the distribution of BN vacuum lead loadings in the application data set were the same as it was in the training data set, then the dashed line would be used for prediction of wipe measures associated with BN lead loadings in the application data set. The dashed line is better for prediction than the solid line representing the true relationship because the dashed line implicitly takes into account the measurement error. Taking a careful look at the circles, it can be seen that the dashed line passes through the center of the vertical spread in the circles throughout the range of the BN measures, whereas the solid line passes through the lower range of the circles on the left side and through the upper range of the circles on the right side.

From the pluses and the circles, it is clear that the BN lead loadings in the application data set are substantially lower than the BN lead loadings in the training data set. If the dashed line developed from the training data set (which would have to be extended) were used to predict wipe lead loadings in the application data set, the predictions would clearly be too high.

A compromise would be to adjust the regression line developed from the training data for measurement error (a so-called “errors-in-variables” correction). This would result in a line close to the long solid line representing the true relationship. This line would pass through the center of the application data cloud. However, as in the training data set, this line would yield predictions that are too low for BN loadings below the mean BN loading in the application data set, and too high for BN loadings above the mean BN loading in the application data set.

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[1]“Observed” is written in quotes to remind the reader that the values are not actually *observed*, because these are only simulated data.

The solution is to "put measurement error back into the prediction equation" for the application data set. This is what is referred to as the transportability adjustment, and is illustrated by the long-dash/short-dash line in the lower left portion of Figure 4. This line represents the transportability-adjusted regression line, and reflects the best estimate of the regression line that would be obtained by regressing the (unobserved) wipe measures on the BN measures obtained in the application data set. The adjustment recognizes the error known to be present in the BN measures, and represents a substantial improvement over both the dashed line and the solid line for predicting wipe lead loadings from BN lead loadings in the application data set.

The remainder of this section discusses the differences between the training data and the application data and assesses the need to adjust for transportability. The next section discusses the calculations associated with the transportability adjustment.

Assessment of Transportability for Purposes of Section 403

An assessment of transportability is only possible for cases in which the application data set has been identified. Application data sets have been identified for only two of the these conversion equations presented in this report. The HUD National Survey is the application data set for the BN vacuum loading to wipe loading conversion equations, and the BRM vacuum loading to wipe loading conversions will be applied to data from the Baltimore Repair and Maintenance study. Because no application data set was identified for the wipe lead loading to BN lead loading conversion, no transportability adjustment was considered for that conversion.

In the presence of an application data set, the first step is to determine if a transportability adjustment is necessary. That means checking the assumption of equal means and variances between the training data and the application data. In this case multiple training data sets were used with different emphasis in the development of the conversion equations.

Table 6 presents the estimated means and variances of the training and application data sets for the BN to wipe lead loading conversions. Results are presented separately by component. Variability is expressed as the sum of within-house and between-house variance, so it represents the variance of a measurement obtained from a randomly selected observation in a randomly selected house. Generally, there are multiple training data sets identified, and just one application data set per component. However, there are three different age groups identified for the application data for uncarpeted floors, because the distribution of dust-lead loadings on uncarpeted floors was found to depend on house age. (Carpeted floor data were excluded from the determination of the application data distribution.) There was no significant effect of house age on window sills or wells.

Table 6. Distribution of Predictor Variable in Training and Application Data Sets for BN to Wipe Conversions, For Application to HUD National Survey (log scale).

	Training Data (log scale)				Application Data (log scale)	
Component	Training Data Set	Mean μ_T	Variance of Observed BN $\sigma_T^2 + \sigma_U^2$		Mean μ_A	Variance of Observed BN $\sigma_A^2 + \sigma_U^2$
Uncarpeted Floors	CAP Pilot	2.37	2.85	Pre-1940	0.895	5.62
	NCLSH/Westat	2.39	0.482	1940-1959	-0.019	5.42
	R&M Pilot	2.81	5.83	1960-1979	-0.602	3.95
Window Sills	CAP Pilot	3.58	3.07		1.30	6.21
	NCLSH/Westat	2.70	0.791			
	R&M Pilot	3.94	6.55			
Window Wells	NCLSH/Westat	4.90	1.01		4.32	7.44
	R&M Pilot	8.70	7.28			

The means of the application data sets were all below the means of the associated training data sets. There were also differences in variances between application and training data sets, but not to the extent exhibited systematically for means. The fact that the distribution of BN dust-lead loadings on uncarpeted floors was found to depend on house age indicates that there are essentially three application data sets for uncarpeted floors: homes built before 1940, homes built between 1940 and 1959, and homes built between 1960 and 1979. This would correspond, in Figure 4, to having three different sets of pluses – each representing a different house age. Each age group requires its own transportability adjustment in the BN to wipe conversions. An additional transportability adjustment was necessary for window sills. For window wells, there were insufficient available data to assess measurement error, and therefore no transportability adjustment was performed[2].

[2] Window wells were not used in the 403 risk analysis.

Table 7 presents the estimated means and variances of the training and application data sets for the BRM to wipe lead loading conversion equations in the same format. The means of the application data sets fell within the range of the means of the training data sets, in all but one case. In that case, the difference was slight. Variances in the application data sets were generally similar to the variances in the associated training data sets. Therefore, no transportability adjustment was used for the BRM to wipe conversions. However, there was much evidence of positive within-house correlation, and an adjustment for within-house correlation was made and is discussed in Section 3.1.7.

Table 7. Distribution of Predictor Variable in Training and Application Data Sets for BRM to Wipe Conversions, For Application to Baltimore R&M Study (log scale).

	Training Data (log scale)			Application Data (log scale)[a]	
Component	Data Set	Mean μ_T	Variance of Observed BRM $\sigma_T^2 + \sigma_U^2$	Mean μ_A	Variance of Observed BRM $\sigma_A^2 + \sigma_U^2$
Uncarpeted Floors	Milwaukee	3.6	5.92	5.1	4.91
	NCLSH 5-Method	3.3	7.03		
	R&M Mini	5.8	7.99		
	Rochester	2.6	5.40		
Carpeted Floors	NCLSH 5-Method	6.0	1.36	5.1	4.99
	Rochester	5.2	3.00		
Window Sills	R&M Mini	8.4	16.6	6.8	8.54
	Rochester	5.4	5.85		
Window Wells	R&M Mini	12.5	14.5	10.3	10.2
	Rochester	9.3	11.5		

(a) Dust samples in the Baltimore R&M study were composited. The statistics for uncarpeted floors reflect the distribution of composite samples that included any subsamples from uncarpeted floors. Statistics for carpeted floors reflect the distribution of samples that included any subsamples from carpeted floors. See Section 4.3 for a description of how the conversion equations were applied to mixed composites.

3.1.4 An Adjustment for a Lack of Transportability

An adjustment to the estimated slope and intercept of the regression equation can be made to correct for the lack of transportability (i.e., the difference in mean and variance of the lead loadings between the training data set and the application data set). This adjustment is based upon the following theory (using terminology defined in Section 3.1.3) [16]:

If the X_i's are normally distributed, then the relationship for observed pairs of data (W_i, Y_i) is

$$Y_i = \theta_0 + \theta_1 W_i + \eta_i, \quad (1)$$

where

$\theta_0 = \beta_0 + \mu_X (1-\lambda)\beta_1$,

$\theta_1 = \lambda\beta_1$,

η_i is normally distributed with mean 0 and variance $\sigma_E^2 + \beta_1^2\lambda\sigma_U^2$,

and

$$\lambda = \frac{\sigma_X^2}{\sigma_X^2 + \sigma_U^2},$$

where σ_U^2 represents the variance of the measurement error, U_i.

Using this theory the transportability adjustment was accomplished by the following series of steps involving a combination of statistical methods.

Step 1. The measurement error for the predictor method was estimated using data from the CAP Pilot study and the Baltimore R&M study as described in Appendix C. This provided an estimate of σ_U. Due to the differences in sampling protocols, measurement error is not the same for all studies. In particular in the CAP study, BN samples each included dust from a four square foot area, and for purposes of this analysis, a geometric average of two BN samples was paired with a geometric average of two wipe samples. Therefore, each BN sample in the CAP study represents an average lead loading over eight square feet. This is compared with BN lead loadings averaged over one square foot for the other two studies. Therefore, it is assumed that the measurement error variance for the CAP BN lead loadings is one-eighth of that for the other two studies. That is, $\sigma_U^2/8$ was used in place of σ_U^2 to represent measurement error for the CAP study.

Step 2. Using the estimate of measurement error obtained in Step 1, the parameters of the relationship between the response and the "true" predictor (i.e., β_0 and β_1 as defined in Section 3.1.3) were estimated using an errors-in-variables (EIV) approach by the method of moments.

Step 3. The variability of the X's (i.e., the true lead loadings as defined in Section 3.1.3) in the application data set was estimated as

$$\sigma_{X,A}^2 = s_{X,A}^2 - \sigma_U^2,$$

where $s_{X,A}^2$ is the estimated variance of the observed predictor in the application data set, σ_U^2 is the estimated measurement error variance estimated in Step 1, and $\sigma_{X,A}^2$ is the estimated variance in true lead loadings in the application data set.

Step 4. The transportability adjustment was made using the theory above, using the mean, $\mu_{X,A}$, variance, $\sigma_{X,A}^2$, and λ_A, calculated from the application data. That is, given estimates of β_0 and β_1, the intercept and slope of the true regression relationship, calculated in Step 2, the relevant theory yields:

$$Y^A = \theta_{0,A} + \theta_{1,A}X^A + E^A$$

where

$$\theta_{0,A} = \beta_0 + \mu_{X,A}(1 - \lambda_A)\beta_1,$$

$$\theta_{1,A} = \lambda_A\beta_1,$$

$$\lambda_A = \sigma_{X,A}^2 / (\sigma_{X,A}^2 + \sigma_U^2),$$

$\mu_{X,A}$ = the mean log lead loading in the application data set based on the predictor method,

$\sigma_U^2 =$ the estimated measurement error associated with the observed predictor, calculated in Step 1, and

$\sigma_{X,A}^2 =$ the estimated variance of the true lead loadings in the application data set calculated in Step 3.

The final conversion equation is then

$$\log(BN) = \theta_{0,A} + \theta_{1,A} \log(W).$$

Note that this methodology makes two key assumptions: 1) that the measurement error in the predictor variable, σ_U, is the same in the training and application data sets; and 2) that the relationship between true lead loadings for the predictor variable and the response, i.e.,

$$Y = \beta_0 + \beta_1 X,$$

is the same in the training data set and the application data set.

3.1.5 Combining Parameters Across Data Sets

After fitting separate regression equations to data from the appropriate studies to predict a lead loading obtained by one method from a lead loading obtained by another method (for a given surface type), a weighted average was used to obtain a single conversion equation. As is indicated in Figure 1, parameter estimates for the BN to wipe conversion equations are averaged after the initial errors-in-variables adjustment for measurement error (Step 2 in Section 3.1.4) but before the transportability adjustment (Step 4 in Section 3.1.4). This is because, prior to adjusting for measurement error, the observed relationship depends on the distribution of the predictor variable, but the underlying relationship is assumed to be fixed. However, as Figures 2 and 3 indicate, a measurement error adjustment was not applied in developing the wipe to BN or BRM to wipe conversion equations. For these, the parameter estimates were averaged without adjustment.

In either case, a linear model on a log scale is assumed to describe the relationship between wipe (W) and vacuum (V) measures within each study as well as across all studies. For example,

$$\log(W) = \log(\theta_0) + \theta_1 \log(V) + \log(E).$$

Separate estimates of θ_0 and θ_1 (or β_0 and β_1 in the case of the BN to wipe conversions) were obtained from each of the studies. A weighted average of the intercept estimates obtained from each of the studies was used to determine a final estimate of the intercept. The weighting used was the inverse of the variance of the intercept obtained in each study (that is, the squared inverse of the standard error). An estimate of the slope was obtained similarly as the average of the slope estimates obtained in the studies, each weighted by the inverse of its estimated variance.

It can be shown in general that if a single estimate is to be obtained based on two or more independent, unbiased estimates of the same, fixed parameter using a weighted average of the individual estimates, then weighting each individual estimate by the inverse of its variance minimizes the variance of the final estimate.

3.1.6 Uncentering

Let θ_0^* be the weighted average of the estimated intercept for the centered data, and θ_1^* be the weighted average of the estimated slopes. The final uncentered intercept was computed as $\theta_0 = \theta_0^* - \mu_L \theta_1^*$, where μ_L represents the average of the lead loadings measured by the predictor method across the studies included in the analysis (this is the same μ_L as described in section 3.1.1). No uncentering is necessary for the slope, that is, $\theta_1 = \theta_1^*$.

3.1.7 Accounting For Within-House Correlation

One of the assumptions that is made when using linear regression is that all of the observations are independent. If observations are correlated, then two main problems arise: 1) although parameter estimates may still be unbiased, standard regression techniques do not generally yield the most efficient estimates, and 2) the estimated uncertainties (standard errors) associated with parameter estimates are incorrect. Positive within-house correlation would lead to underestimation of standard errors.

Some of the studies providing data for conversions developed in this report included multiple observation pairs per house. A natural question arises regarding the potential correlation between repeated observations at the same house. Generally, one would expect a lead loading measured at a house to be more similar to another lead loading at the same house than to a lead loading at another house in the same study.

To investigate this, within-house correlations were estimated wherever possible for the studies included in this analysis using a method called generalized estimating equations (GEE). Tables 8 and 9 display the results of this within-house correlation analysis. Table 8 indicates the degree to which data were available to estimate the correlation, and whether the correlation estimate was statistically significant. Table 9 provides the correlation estimates that were obtained from the data.

Notice that although there were numerous opportunities to estimate the correlation, it was significant in only 5 cases. Also, whenever the correlation estimate was statistically significant, it was positive. That is, there were no negative correlation estimates that were significant. This supports the intuition described above regarding the correlation between lead loadings measured at the same house.

Table 8. Statistical Significance of Within-House Correlation.

Conversion	Study	Uncarpeted Floors	Carpeted Floors	Window Sills	Window Wells
BN Vacuum Loading to Wipe Loading	CAP Pilot	Not Estimable[1]	No Data	Not Estimable	Not Estimable
	NCLSH/Westat	Insignificant	No Data	SIGNIFICANT	(Minimal Data)
	R&M Pilot	Insignificant	No Data	Insignificant	Insignificant
Wipe Loading to BN Vacuum Loading	CAP Pilot	Not Estimable	No Data	Not Estimable	Not Estimable
	NCLSH/Westat	Insignificant	No Data	Insignificant	(Minimal Data)
	R&M Pilot	Insignificant	No Data	Insignificant	Insignificant
BRM Vacuum Loading to Wipe Loading	R&M Mini	Insignificant	No Data	Insignificant	Insignificant
	NCLSH 5-Method	Insignificant	SIGNIFICANT	No Data	No Data
	Rochester	SIGNIFICANT	SIGNIFICANT	SIGNIFICANT	Insignificant
	Milwaukee	Not Estimable	No Data	No Data	No Data

[1] Not Estimable -- *data collected in only one room per house, and therefore data did not permit estimation of within-house correlation.*

Table 9. Estimates of Within-House Correlation.

Conversion	Study	Uncarpeted Floors	Carpeted Floors	Window Sills	Window Wells
BN Vacuum Loading to Wipe Loading	CAP Pilot	Not Estimable[1]	No Data	Not Estimable	Not Estimable
	NCLSH/Westat	-0.22	No Data	0.49	0.14 (Minimal Data)
	R&M Pilot	-0.15	No Data	-0.10	0.32
Wipe Loading to BN Vacuum Loading	CAP Pilot	Not Estimable	No Data	Not Estimable	Not Estimable
	NCLSH/Westat	0.23	No Data	0.07	0.16 (Minimal Data)
	R&M Pilot	-0.15	No Data	0.02	0.49
BRM Vacuum Loading to Wipe Loading	R&M Mini	-0.09	No Data	0.01	0.01
	NCLSH 5-Method	0.35	0.53	No Data	No Data
	Rochester	0.27	0.31	0.18	0.09
	Milwaukee	Not Estimable	No Data	No Data	No Data

[1] Not Estimable -- data collected in only one room per house, and therefore data did not permit estimation of within-house correlation.

Also notice that four of nine studies study/sample type combinations used to develop the BRM to wipe conversions reflected significant within-house correlation. Only one of ten study/sample type combinations used to develop the wipe to BN or BN to wipe conversions had a significant estimate of within-house correlation. Because of this, the linear models for the BRM to wipe lead loading conversions were fitted using the GEE method to take into account correlations within houses. This approach allows either negative or positive correlations.

3.2 CONFIDENCE INTERVALS AND PREDICTION INTERVALS

When one of the equations discussed in this report is used, the outcome is a prediction (i.e., an estimate). A simple linear model was used to express each of the conversions in this report, e.g., for converting a BN to a wipe lead loading,

$$\log(W) = \log(\theta_0)+\theta_1 \log(BN).$$

Confidence intervals and prediction intervals are used to assess how "precise" the estimate is.

Confidence intervals are presented to indicate the probable range in which the mean of a distribution lies with a specified confidence level. For example, a 95 percent confidence interval is a range of values estimated by a method which will contain the mean 95 percent of the time [19].

Prediction intervals indicate a range of values estimated to contain a pre-specified proportion of the predicted population (e.g., 95%). Prediction intervals are necessarily wider than confidence intervals (holding the confidence level fixed) because they incorporate uncertainty in the estimated mean <u>and</u> random variability in the response. Throughout the remainder of this report, the terms "mean" and "geometric mean" are used interchangeably because the geometric mean is simply a mean associated with logarithmic values.

The following formulae were used to calculate an approximate 95% confidence interval on the geometric mean of a predicted lead loading from one method based on the observed lead loading, L, from another method:

$$\text{Lower Confidence Bound} = \exp(\log(\theta_0) + \theta_1(\log(L) - \bar{L}) - 2\sqrt{s^2})$$

$$\text{Upper Confidence Bound} = \exp(\log(\theta_0) + \theta_1(\log(L) - \bar{L}) + 2\sqrt{s^2})$$

where θ_0 represents the estimated intercept of the regression model, θ_1 represents the estimated slope, $\bar{L}$ represents the mean log lead loading based on the predictor method, and s^2 represents the variance associated with the predicted mean value. This variance is dependent on the observed lead loading, L, calculated as:

$$s^2 = s.e.(\theta_0)^2 + (\log(L) - \bar{L})^2 * s.e.(\theta_1)^2$$

with $s.e.(\theta_0)$ and $s.e.(\theta_1)$ being the standard errors of the parameter estimates from the combined regression model.

The calculation of approximate 95% prediction intervals utilizes the same formula, with one exception. Since the desired intervals are to encompass an estimate of a single future lead loading, an extra component must be added to the variability associated with this prediction.

Thus, for an approximate 95% prediction interval around a predicted lead loading from the above model, the following equations are used:

$$\text{Lower Prediction Bound} = \exp(\log(\theta_0) + \theta_1(\log(L) - \bar{L}) - 2\sqrt{s_*^2})$$

$$\text{Upper Prediction Bound} = \exp(\log(\theta_0) + \theta_1(\log(L) - \bar{L}) + 2\sqrt{s_*^2})$$

In these equations, θ_0, θ_1, and $\bar{L}$ are as before, and s_*^2 is the variance associated with the prediction plus the total variance of an individual observation:

$$s_*^2 = s^2 + \sigma^2,$$

with σ^2 being the best estimate of the variance associated with an individual observation.

In this analysis, θ_0 and θ_1 were estimated using three different approaches (depending on the conversion), and s^2 was calculated by a different approach in each case. Different methods were also used to estimate σ. These methods are outlined separately, by type of conversion below.

BN to Wipe Calculations

For the BN to wipe conversions for uncarpeted floors and window sills, simple linear regression was used to estimate the slopes and intercepts from the individual studies, followed by a transportability adjustment to "calibrate" the equations to be applicable to the HUD National Survey data. Details of the matrix algebra leading to the final answers are laid out at the end of Appendix C. (Equations for window wells were developed by the method described in the next section, "Wipe to BN Calculations.")

The variability measure of interest, σ, represents the standard deviation of errors (η_i's) described in equation (1) of Section 3.1.3. These errors represent deviations in observed lead loadings from the predicted lead loadings, incorporating measurement error. The formula for σ^2 is $\sigma_E^2 + \beta_1^2\lambda\sigma_U^2$, where σ_E^2 represents the variance associated with deviations from the model without measurement error, β_1 represents the slope of the relationship without measurement error, λ represents the usual slope attenuation factor, and σ_U^2 represents the variance of measurement error.

This is the general formula for residual variance in the presence of measurement error. The σ that we are interested in is the standard deviation of errors associated with the application data set (HUD National Survey), but the relationships are observed on other (training) data sets. Thus, just as for estimating the slopes and intercepts (explained in 3.1.3), parameters associated with the true relationship (β_0, β_1, and σ_E) must be estimated, and then the parameters associated with the application data set must be recalculated from the same equation, but at a different value of λ.

Since there were up to three studies available to estimate σ_E^2, three estimates were obtained, and a weighted average was taken, weighting by the degrees of freedom available to estimate the error in each study. The final formula for $\sigma^2 = \sigma_E^2 + \beta_1^2\lambda\sigma_U^2$ was then applied with this estimate of σ_E^2 to estimate σ^2.

Wipe to BN Calculations

For the wipe to BN conversions (and for the BN to wipe conversions for window wells), simple linear regression was used to estimate the slopes and intercepts from the individual studies. No transportability adjustment was applied. Standard error estimates for the slope and intercept for each individual study follow from standard linear regression theory. As was described above, the final conversion equation parameters were calculated as a weighted average of the parameters from the individual studies. So the variances of the final coefficients were calculated as the sum of squared standard errors scaled by their squared weights.

In these derivations, the mean squared error (MSE) from the individual regressions was the only residual variance estimated. A weighted average of these MSE's was taken to estimate σ^2, weighting each by the number of degrees of freedom available to estimate it.

BRM to Wipe Calculations

For the BRM to wipe conversions, the GEE method was used to fit the simple linear regression models, controlling for within-house correlation. No transportability adjustment was applied. Standard error estimates for the slope and intercept for each individual study were calculated, taking this correlation into account.

Recall that with this method, correlation within houses was estimated. In particular, if there was positive within-house correlation, this could be modeled as a within-house variance (σ_E^2), and a between-house variance (σ_H^2). In this case, the sum of the estimates of these two variance components was used to estimate σ^2 because this represents the variance of a randomly selected data point at a randomly selected home. This is the measure of variability that should be used to model the uncertainty in a future predicted value. In cases of negative correlation, the variance structure is more complicated than having two separate variance components, so the total variance associated with an individual observation was used to estimate σ^2.

4.0 RESULTS

This section presents conversion equations for determining lead loading based on one method from a lead loading based on another method. The conversions include Blue Nozzle (BN) to wipe lead loading, wipe to BN lead loading, and BRM to wipe lead loading. Separate equations are presented for each component on which data were available for this analysis.

4.1 PREDICTING WIPE LEAD LOADING FROM BLUE NOZZLE VACUUM LEAD LOADING

As discussed earlier, the BN to wipe lead loading conversion equations were developed based on data from the CAP Pilot, R&M Pilot, and NCLSH/Westat studies. Table 10 presents the final BN to wipe conversion equations for uncarpeted floors, window sills and window wells. Total sample sizes used to develop each conversion equation are also provided. Notice that, for the BN to wipe conversions on uncarpeted floors, there are three different equations corresponding to different house age groups for homes in the HUD National Survey. The age groups are: homes built before 1940, homes built between 1940 and 1959, and homes built between 1960 and 1979. That is, the predicted wipe lead loading depends not only on the observed BN lead loading, but also on the age of the home. Recall that a different methodology was used to develop the conversion equations for BN lead loadings obtained from window wells than was used to develop the equations for uncarpeted floors and window sills. (See Chapter 3.)

For nominal BN lead loading levels of 10, 40, 100, 200, 500, and 1000 µg/ft², Table 11 presents the predicted wipe lead loadings, along with confidence intervals and prediction intervals, for each housing component. Results for uncarpeted floors are also given separately for the different age groups. For example, the BN loading of 200 µg/ft² gets converted to a wipe lead loading of 332 µg/ft² for uncarpeted floors for houses built between 1940 and 1959.

The second line in each cell represents an approximate 95% confidence interval on the conversion. These represent confidence bounds on the estimate of the geometric mean level, associated with the nominal levels from which they are converted. For a house built between 1940 and 1959, with a BN vacuum lead loading of 10 µg/ft² on uncarpeted floors, the geometric mean wipe lead loading is 30.2 µg/ft², and there is 95% confidence that the geometric mean wipe lead loadings taken at the same location would be between 19.4 and 46.8 µg/ft².

Table 10. Final Blue Nozzle to Wipe Conversion Equations.

Component/House Age	Number of Observed Pairs	Conversion Equation
Uncarpeted Floors		
Pre-1940	37[b]	$Wipe = 5.66BN^{0.809}$
1940-1959	37	$Wipe = 4.78BN^{0.800}$
1960-1979	37	$Wipe = 4.03BN^{0.707}$
Window Sills	71	$Wipe = 2.95BN^{1.18}$
Window Wells	30	$Wipe = 5.71BN^{0.864}$

(a) Units are $\mu g/ft^2$ for vacuum and wipe dust-lead loadings.

(b) The same data set was used to develop the conversion equation for all three age groups in the application data.

Table 11. Predicted Wipe Lead Loadings Based on Final Conversion Equations For Selected Blue Nozzle Vacuum Lead Loadings.

Blue Nozzle Vacuum Pb Loading ($\mu g/ft^2$)	Predicted Wipe Lead Loading ($\mu g/ft^2$) by Dwelling Component (95% Confidence Interval) (95% Prediction Interval)				
	Uncarpeted Floors				
	Pre-1940	1940-1959	1960-1979	Window Sills	Window Wells
10	36.4 (24.0, 55.4) (4.72, 281)	30.2 (19.4, 46.8) (3.92, 232)	20.6 (12.6, 33.5) (2.81, 147)	44.6 (32.7, 60.9) (3.39, 589)	41.8 (5.18, 338) (0.358, 4890)
40	112 (78, 159) (14.7, 853)	91.5 (64.1, 131) (12.1, 693)	54.7 (37.4, 80.2) (7.81, 384)	229 (180, 292) (17.5, 3002)	138 (25.6, 752) (1.39, 13800)
100	235 (160, 344) (30.6, 1799)	190 (132, 275) (25.1, 1446)	105 (73.5, 149) (15.0, 730)	676 (487, 938) (51.2, 8936)	306 (72.0, 1300) (3.34, 28000)
200	411 (266, 635) (53.0, 3185)	332 (220, 501) (43.3, 2540)	171 (119, 245) (24.5, 1194)	1532 (1000, 2350) (114, 20500)	556 (155, 2000) (6.41, 48500)
500	862 (505, 1472) (109, 6840)	691 (418, 1142) (88.4, 5397)	327 (217, 493) (46.3, 2304)	4520 (2580, 8060) (327, 6240)	1230 (413, 3660) (14.9, 102000)
1000	1510 (810, 2813) (186, 12275)	1203 (669, 2161) (151, 9606)	533 (334, 852) (74.6, 3810)	10200 (5100, 20600) (721, 146000)	2240 (834, 6010) (27.7, 181000)

The third line in each cell provides an approximate 95% prediction interval for the conversions. These are bounds that are expected to contain 95% of the individual observations associated with the specified nominal levels of the prediction variables. Thus, for a BN vacuum lead loading of 10 $\mu g/ft^2$ on uncarpeted floors in a house built between 1940 and 1959, the geometric mean point estimate of the wipe lead loading is 30.2 $\mu g/ft^2$, and it is expected that 95% of individual wipe lead loadings measured at the same location will be between 3.92 and 232 $\mu g/ft^2$.

Appendix C provides the detailed analysis that led to these conversion equations. Included in Appendix C are the results of individual regression analyses by study and component, an assessment of influential data points, and a residual analysis. Because the BN to wipe conversions included a transportability adjustment (for uncarpeted floors and window sills), Appendix C also compares the observed relationship with the estimated true relationship, adjusting for measurement error.

Figure 5 displays the predicted wipe loading from the final conversion equation, associated with each BN vacuum lead loading observed in the HUD National Survey, for uncarpeted floors, by age group. Also included on the plots are the approximate 95% confidence and prediction intervals corresponding to each predicted wipe lead loading. The plot in the lower right corner displays the prediction lines of the three age groups overlaid. (Refer to Section 3.1.3 for an explanation why the conversion equation for uncarpeted floors depends on house age.) This plot illustrates the how differences in predicted values resulting from different age of home depend on the lead loading measured in the HUD survey.

Figure 6 displays the predicted wipe loading from the final conversion equations, for window sills and window wells, over the approximate range of BN vacuum lead loading observed in the HUD National Survey. As above, the plots also include the approximate 95% confidence and prediction intervals corresponding to each predicted wipe lead loading.

Note that there is greater uncertainty in predicting wipe lead loadings from BN vacuum lead loadings at the lower and upper ends of the data. The greatest precision (the narrowest portion of the confidence bounds) for predicting a wipe lead loading from a BN lead loading ranges from 20 to 100 $\mu g/ft^2$ for uncarpeted floors and window sills, and ranges from 1000 to 10,000 $\mu g/ft^2$ for window wells.

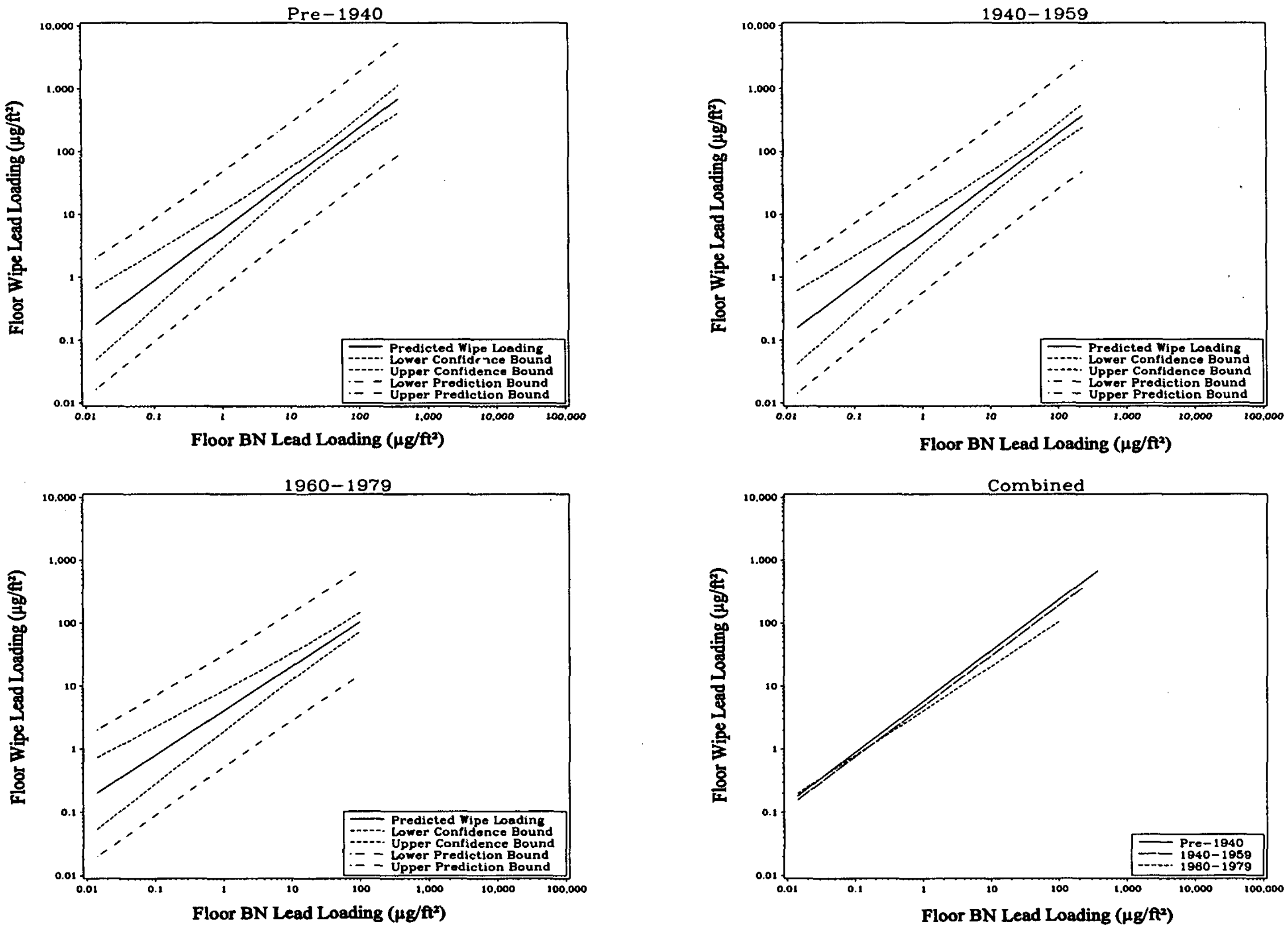

Figure 5. BN to Wipe, Final Conversion Equations for Uncarpeted Floors. Predicted Values, and 95% Confidence Bounds and Prediction Bounds; Houses Built Pre-1940, 1940-1959, and 1960-1979.

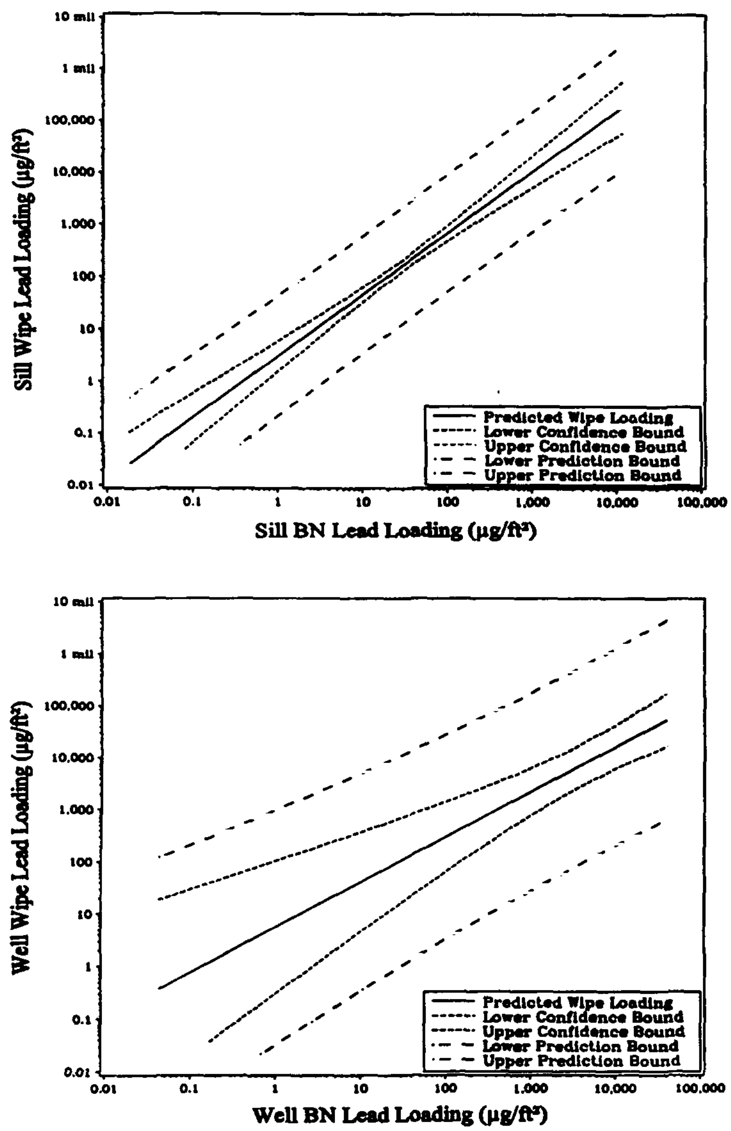

Figure 6. BN to Wipe, Final Conversion Equations for Window Sills and Window Wells. Predicted Values and 95% Confidence Intervals and Prediction Intervals.

4.2 PREDICTING BLUE NOZZLE VACUUM FROM WIPE LEAD LOADING

Table 12 presents the corresponding results for predicting BN vacuum lead loading levels associated with nominal wipe lead levels. Note that there is no distinction among house age groups for the wipe to BN conversions. Table 13 presents predicted values along with confidence intervals and prediction intervals by housing component for nominal wipe lead loadings of 10, 40, 100, 200, 500, and 1000 µg/ft^2.

Table 12. Final Wipe to Blue Nozzle Conversion Equations.

Component	Number of Observed Pairs	Conversion Equation
Uncarpeted Floors	37	$BN = 0.185\ Wipe^{0.931}$
Window Sills	71	$BN = 0.955\ Wipe^{0.583}$
Window Wells	30	$BN = 4.91\ Wipe^{0.449}$

Table 13. Predicted Blue Nozzle Vacuum Lead Loadings Based on Final Conversion Equations For Selected Wipe Lead Loadings.

Wipe Lead Loading (μg/ft²)	Predicted Blue Nozzle Lead Loading (μg/ft²) by Dwelling Component (95% Confidence Interval) (95% Prediction Interval)		
	Uncarpeted Floors	Window Sills	Window Wells
10	1.58 (0.916, 2.71) (0.215, 11.5)	3.66 (2.60, 5.14) (0.616, 21.7)	13.8 (4.75, 40.1) (0.250, 762)
40	5.74 (3.90, 8.39) (0.809, 40.4)	8.22 (6.47, 10.4) (1.41, 47.9)	25.7 (10.9, 60.9) (0.489, 1350)
100	13.5 (9.47, 19.0) (1.91, 94.3)	14.0 (11.6, 16.9) (2.42, 81.2)	38.7 (18.6, 80.6) (0.757, 1990)
200	25.7 (17.6, 37.3) 3.62, 181)	21.0 (17.6, 25.0) (3.63, 122)	52.9 (28.0, 100) (1.05, 2670)
500	60.3 (37.6, 96.0) (8.34, 433)	35.9 (30.0, 43.3) (6.18, 208)	79.7 (47.3, 135) (1.61, 3950)
1000	115 (65.2, 201) (15.5, 845)	53.8 (42,8, 67.3) (9.22, 313)	109 (69.7, 170) (2.22, 5340)

Figure 7 displays the predicted BN lead loadings, confidence intervals, and predicted intervals over a range of wipe lead loadings -- for uncarpeted floors, window sills, and window wells. There was no application data set identified for this conversion, so the ranges over which the predictions are plotted are the ranges of data used to develop the equations.

Appendix D provides the detailed analysis that led to the wipe to BN conversion equations. Included in Appendix D are the results of individual regression analyses by study and component, an assessment of influential data points, and a residual analysis.

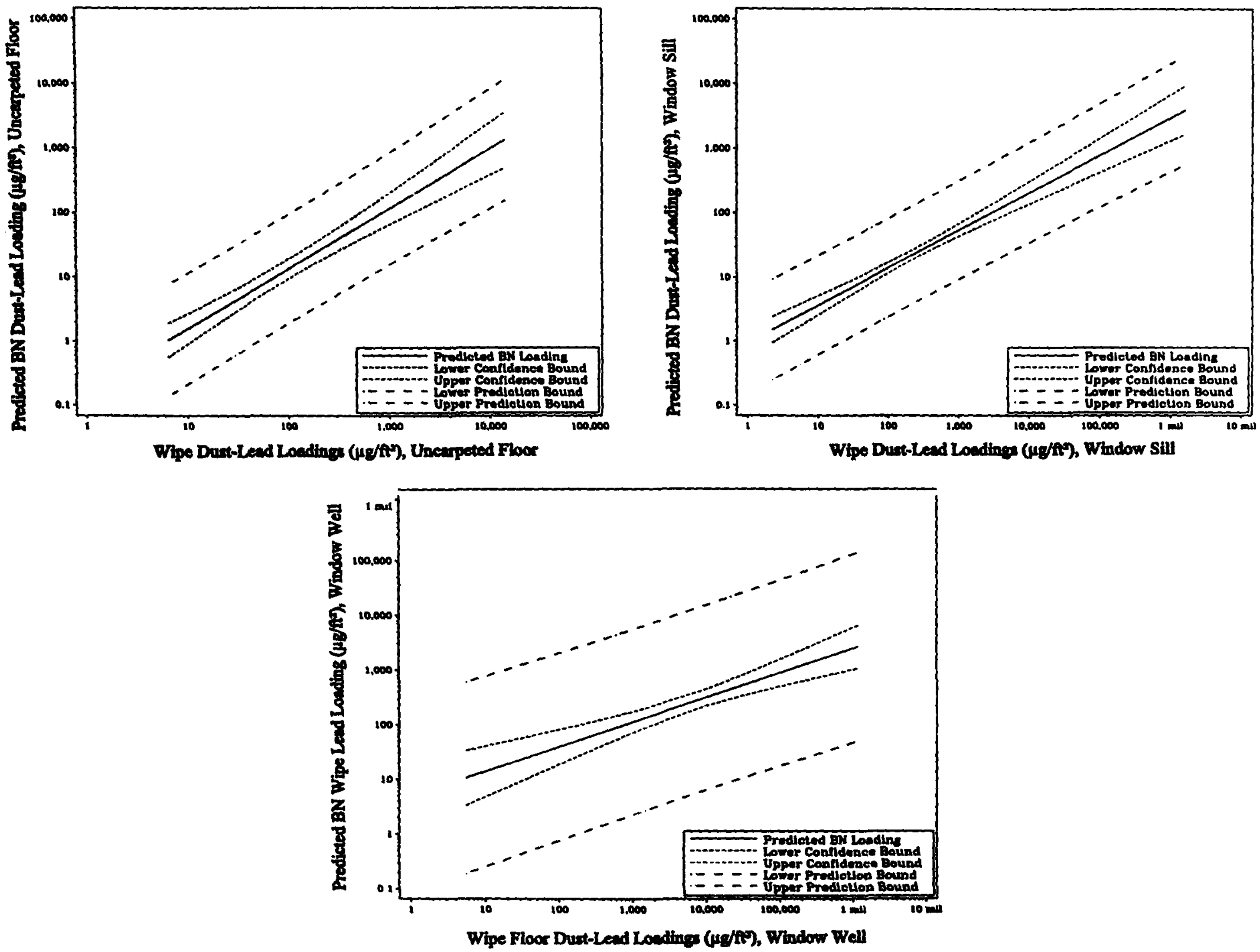

Figure 7. Wipe to BN. Final Conversion Equations for Uncarpeted Floors, Window Sills and Window Wells. Predicted Values and 95% Confidence Bounds and Prediction Bounds.

4.3 STATISTICAL ANALYSES FOR THE BRM VACUUM

The estimated conversion equations for predicting a wipe lead loading from a BRM lead loading were developed based on the R&M Mini, Rochester Lead-in-Dust, NCLSH 5-Method Comparison, and Milwaukee Low Cost Interventions studies.

Table 14 summarizes, for each of the four housing components, the final conversion equations and the total sample sizes used in developing these equations.

Table 14. Final BRM to Wipe Conversion Equations.

Dwelling	Number of Observed Pairs	Conversion Equation[a]
Uncarpeted Floors	617	$Wipe = 8.34\ BRM^{0.371}$
Carpeted Floors	465	$Wipe = 3.01\ BRM^{0.227}$
Window Sills	389	$Wipe = 14.8\ BRM^{0.453}$
Window Wells	428	$Wipe = 13.9\ BRM^{0.630}$

(a) Units are $\mu g/ft^2$ for vacuum and wipe dust-lead loadings.

Table 15 presents the predicted wipe lead loadings for nominal BRM lead loadings of 10, 40, 100, 200, 500, and 1000 $\mu g/ft^2$. For example, a BRM loading of 200 $\mu g/ft^2$ on an uncarpeted floor is converted to a wipe lead loading of 59.5 $\mu g/ft^2$. Below the predicted values are approximate 95% confidence and prediction intervals. The confidence bounds are expected to contain the geometric mean wipe lead loading with 95 percent confidence; the prediction bounds are expected to contain an individual wipe lead loading with 95 percent confidence. Thus, for a BRM lead loading of 100 $\mu g/ft^2$ from an uncarpeted floor, the estimated geometric average of wipe lead loadings is 46.0 $\mu g/ft^2$, and there is 95% confidence that the geometric average wipe lead loadings taken at the same location would be between 40.5 and 52.3 $\mu g/ft^2$.

Table 15. Predicted Wipe Lead Loadings Based on Final Conversion Equations For Selected BRM Vacuum Lead Loadings.

BRM Vacuum Lead Loading (μg/ft²)	Predicted Wipe Lead Loading (μg/ft²) by Dwelling Component (95% Confidence Interval) (95% Prediction Interval)			
	Uncarpeted Floors	Carpeted Floors	Window Sills	Window Wells
10	19.6 (17.6, 21.8) (2.50, 154)	5.07 (3.61, 7.13) (0.674, 38.2)	41.9 (33.7, 52.2) (4.63, 379)	59.2 (42.9, 81.7) (4.03, 869)
40	32.0 (29.4, 36.5) (4.16, 258)	6.95 (5.63, 8.57) (0.939, 51.4)	78.5 (66.3, 93.0) (8.72, 708)	141.8 (108, 186) (9.71, 2070)
100	46.0 (40.5, 52.3) (5.84, 262)	8.55 (7.41, 9.86) (1.16, 62.9)	119 (103, 138) (13.2, 1069)	252 (198, 322) (17.3, 3680)
200	59.5 (51.3, 69.0) (7.54, 4.69)	10.01 (8.86, 11.3) (1.36, 73.5)	162 (142, 187) (18.1, 1460)	391 (312, 488) (26.9, 5680)
500	83.6 (69.7, 100) (10.6, 661)	12.32 (10.5, 14.4) (1.67, 90.6)	265 (214, 283) (27.4, 2220)	695 (571, 847) (47.9, 10100)
1000	108 (87.7, 133) (13.6, 857)	14.4 (11.7, 17.8) (1.95, 107)	337 (290, 392) (37.5, 3040)	1076 (899, 1289) (74.3,15600)

Figure 8 displays the predicted wipe versus BRM lead loading, by housing component, over the range of most BRM lead loadings observed in the Baltimore R&M study. Included on the plots are the approximate 95% confidence and prediction intervals corresponding to each predicted wipe lead loading. With the exception of the minimum dust-lead loading on carpeted floors, the Baltimore R&M data fall within the range of the data used to develop the equations. The BRM conversion equations are based on considerably more data than the BN to wipe conversions, so the confidence interval widths are much narrower across the range of application than are the widths of the analogous BN confidence intervals.

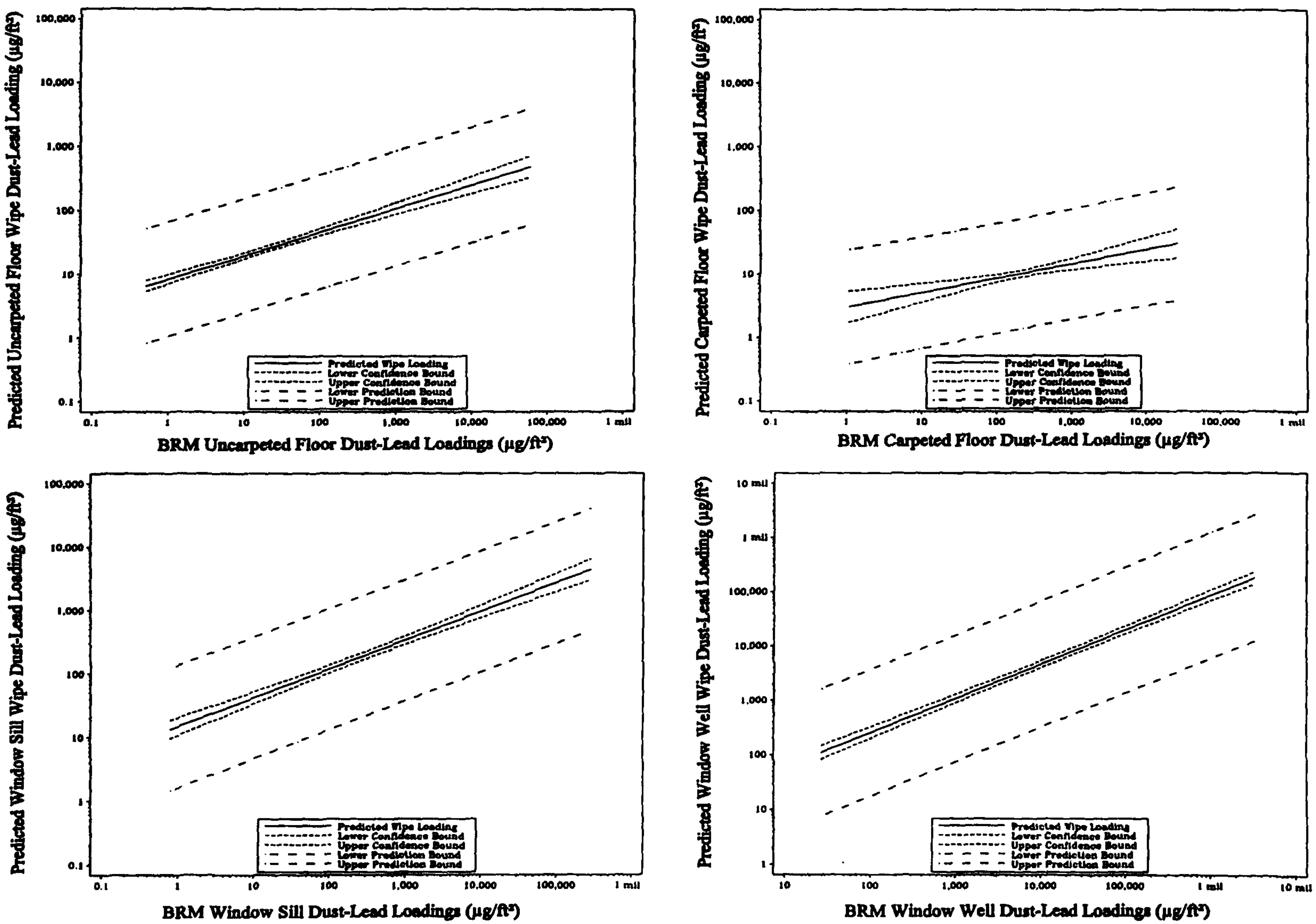

Figure 8. BRM to Wipe, Final Conversion Equations for Carpeted Floors, Uncarpeted Floors, Window Sills, Window Wells. Final Predicted Values and 95% Confidence Bounds and Prediction Bounds.

It should be noted that some of the variability associated with the various equations is due to the inherent variability in wipe sampling. Estimates of the measurement error in wipe samples obtained from the Comprehensive Abatement Performance (CAP) pilot [4] and full studies [14, 15], and the Rochester Lead-in-Dust study [10] were used to characterize the uncertainty in individual wipe measures. Point estimates based on side-by-side variability predict that five percent of the time a wipe measure will vary by a factor of at least 1.8 to 3.0 (depending on which study is referenced) from the mean at that location (log standard deviation of estimates of side-by-side wipe samples range form 0.30 to 0.55). Nonetheless, the range of prediction intervals for BRM to wipe conversions are significantly larger than a factor of 9 (3 x 3) suggesting that the wipe prediction intervals are due to more than just wipe measurement error (e.g., BRM measurement error).

Compositing. In the sensitivity/specificity analysis each floor sample from the Baltimore R&M study was converted using both the uncarpeted floor and carpeted floor conversion equations, weighted by the proportion of the sample from the given substrate (carpeted or uncarpeted). For example, a composite BRM vacuum lead loading of 100 $\mu g/ft^2$ that consists of 8 subsamples (6 uncarpeted, 2 carpeted) would be converted in the following manner:

1. Convert the composite BRM vacuum loading to a wipe loading using the uncarpeted floor conversion equation:

   $$\text{Wipe} = 8.34 * (100)^{0.371} = 46.0 \ \mu g/ft^2$$

2. Convert the composite BRM vacuum loading to a wipe loading using the carpeted floor conversion equation:

   $$\text{Wipe} = 3.01 * (100)^{0.227} = 8.56 \ \mu g/ft^2$$

3. Compute a weighted average of the uncarpeted floor prediction and the carpeted floor prediction, with the weights corresponding to the proportion of total subsamples represented by the given floor type:

   $$\text{Wipe} = \frac{6*(46.0)+2*(8.56)}{8} = 36.7 \ \mu g/ft^2$$

This approach was utilized because the conversion equations were not developed from composite samples with varying proportions of carpeted and uncarpeted subsamples. This strategy attempts to account for the differences in the carpeted and uncarpeted floor conversion equations. The additional uncertainty associated with conversions of composite samples is not addressed in this report.

5.0 DISCUSSION

There have been several studies that included a characterization of the relationship between wipe lead loading and vacuum lead loading. This section discusses 1) the assumptions that were commonly made in those studies, and 2) important characteristics of the study design and analysis relative to the wipe/vacuum relationship.

5.1 ASSUMPTIONS COMMON IN PREVIOUS RESEARCH

Certain assumptions have been made consistently by researchers when studying the relationship between different lead sampling methods. (See [4], [5], [9], [11]). These include:

1. The wipe and vacuum data are each lognormally distributed and
2. The relationship between the log transformed measurements on the same surface type is linear: $\log(Y) = A + B \log(X) + \text{error}$.

In some studies it has been further assumed that loadings measured by different methods on the same surface will be proportional to each other. This assumption is driven by the intuitive assumption that measured loadings are proportional to the amount of dust present. This corresponds to assuming that the slope, B, equals 1 in the equation above in item (2). In the development of the conversion equations in this report, there was no assumption made that the slope would be equal to one. The slope parameter, B, was treated as random and allowed to take on whatever value was necessary to fit the regression.

Some researchers have taken into account estimates of within-house correlation when estimating the relationship between wipe and vacuum sampling methods. For each of the three conversions developed for this report, within-house correlation was investigated. Only the data for the BRM to wipe conversions exhibited significant within-house correlation. This correlation was incorporated into the analysis for developing the BRM to wipe conversion equations.

5.2 IMPORTANT CHARACTERISTICS OF THE STATISTICAL DESIGN AND ANALYSIS FROM THE INDIVIDUAL STUDIES

Despite similar basic assumptions, different statistical design and analysis approaches were described in the reports for the seven studies included in this analysis. Following is a summary of the distinctions relevant to this report. First, the BN studies are discussed, then the BRM studies are discussed.

BN/Wipe Conversion

The CAP Pilot study included one BN vacuum-wipe grouping from each house [4]. Thus, within-house correlation was not an issue. However, two issues should be pointed out regarding the CAP data. First, by design, each BN vacuum sample in the CAP Pilot study covered four square feet and was normalized to units of $\mu g/ft^2$. Second, one of the objectives of the CAP study was to estimate the *true* relationship between wipe loading and BN vacuum loading. Therefore, replicate side-by-side samples were taken with each method (wipe and vacuum). These replicates permitted estimation of replicate sampling error for both methods and therefore permitted an errors-in-variables correction of the observed relationship between wipe and vacuum lead loading. Both in that analysis, and in this one, instead of discarding the replicate samples of the same type, they were averaged (geometric means) before estimating their relationship. Thus, for the CAP data, two wipes covering one square foot each were averaged (on a log scale) and two vacuum samples covering four square feet each were averaged (on a log scale) and used for the regressions in this report. Because of this up-front "averaging", and the fact that the BN samples were collected over a larger area, the error variability of the (geometric mean) wipe and vacuum loading measures can be expected to be smaller from the CAP study than from the other studies. In Section 3.1.4, step 1, it is explained how the differences in the CAP sampling protocol were taken into account in this analysis to ensure a "level playing field" across studies.

The goal of the NCLSH/Westat Blue Nozzle Study [5] was to "describe the observed statistical relationship between the two sampling methods and to predict, from the HUD National Survey, the measurements which would have been obtained if the wipe sampling method had been used." In the original analysis (reported in [5]), the same variability was assumed for the log transformed BN and log transformed wipe measures. Within-house correlation was considered, but was eventually disregarded because there was insufficient data on floors and window wells to estimate it. In addition, regression results based on house-aggregated data were similar to results based on individual observations. Finally, because most of the observation pairs from floors and wells had at least one measurement below the detection limit, and what was available was not sufficient to reject the hypothesis that the slope was different from 1.0, the final relationship was reported as a ratio. There was significant evidence that the log-linear relationship on window sills had a slope greater than 1.0, and therefore the two-parameter log-linear model was used in the report [5] to characterize the relationship on window sills.

Based on the R&M Pilot study data, Farfel, et. al., [6], [7], found no significant interaction between the slope associated with BN (on a log scale) and surface type for predicting BN loadings from wipe lead loadings. (Results were not published in the opposite direction.) Therefore, in their analysis, a common slope term was assumed across floors, window sills, and window wells. In fitting the model, a term was included in the model for within-house correlation.

BRM/Wipe Conversions

In the R&M Mini study, Farfel, et. al., [8] again found no significant interaction between the log(BRM) and surface type (floor, window sill, window well), and therefore estimated the slope (B, in the above model) using data from all three surfaces. Separate intercepts were estimated for each of the three surface types. A term was also included in the model for possible correlation between repeated measures within houses.

A simple linear regression was performed to estimate the relationship between the wipe and BRM lead loadings using data collected from the NCLSH 5-Method study [9]. An analysis of variance showed that lead dust loadings were significantly different according to sampling method, locations within houses, and locations within rooms.

A primary goal of the Rochester study [10,20] was to determine which method of lead dust collection was most correlated with blood-lead concentrations. Therefore, although the

Rochester study contributed the most data to this analysis, little has been documented regarding the relationships between different dust lead collection methods. Emond et al. [21] characterized the error in dust lead measurements made by five different measurement methods and described the impact of measurement error when estimating the relationship between lead in dust and children's blood lead levels.

The Milwaukee study included only one pair of wipe and BRM samples (from uncarpeted kitchen floors) to characterize the log linear relationship between the two methods [12]. Thus, no within-house correlation needed to be accounted for in the analysis. An errors-in-variables approach was used to estimate the parameters in the model, using the estimate of the measurement error associated with the BRM sampling method (obtained by side-by-side BRM samples). Although side-by-side wipe samples were not collected in Milwaukee, wipe measurement error was estimated from the Milwaukee data under the constraint that models estimated in both directions would be "commutative." In this context, commutative refers to the property that if a wipe value of x is converted to a vacuum value of y, then a vacuum value of y would be converted to a wipe value of x. The Milwaukee study also examined this relationship using simple log-linear OLS regression models, which did not take measurement error into account.

5.3 SUMMARY OF RESULTS

The data included in this analysis indicate that, in general, the BN vacuum method yields lower lead loadings than the wipe method which, in turn, yields lower lead loadings than the BRM vacuum method. With some exceptions, this was supported by the data sets examined. An additional study, published in the EPA report "Laboratory Evaluation of Dust and Dust Lead Recoveries for Samplers and Vacuum Cleaners, Volume I: Objectives, Methods and Results" [22], which was not part of this analysis (because it was a laboratory analysis which did not include results for side-by-side wipe and vacuum samples) exhibited similar relationships between these three sampling methods.

In addition, ratios of wipe to BN, and wipe to BRM depend on the magnitude of the lead loading and component being sampled. That is, over the full range of loadings observed, the relationships cannot be described simply by a scale factor, which has been done in some cases in the past. The only possible exception is the conversion of wipe to BN on uncarpeted floors, where BN lead loadings are estimated at about one fifth of wipe lead loadings.

The results here represent an aggregation of data from several studies, and therefore are a compromise in the relationships observed in each of the studies included. In general, the aggregated relationships reflect trends from all data sets represented.

6.0 REFERENCES

[1] U.S. Environmental Protection Agency (April, 1995) "Report on the National Survey of Lead-Based Paint in Housing: Base Report." Office of Pollution Prevention and Toxics, U.S. Environmental Protection Agency, EPA Report No. 747-R95-003.

[2] U.S. Environmental Protection Agency (April, 1995) "Report on the National Survey of Lead-Based Paint in Housing: Appendix I: Design and Methodology." Office of Pollution Prevention and Toxics, U.S. Environmental Protection Agency, EPA Report No. 747-R95-004.

[3] U.S. Environmental Protection Agency (April, 1995) "Report on the National Survey of Lead-Based Paint in Housing: Appendix II: Analysis." Office of Pollution Prevention and Toxics, U.S. Environmental Protection Agency, EPA Report No. 747-R95-005.

[4] U.S. Environmental Protection Agency (February, 1995) "Comprehensive Abatement Performance Pilot Study, Volume I: Results of Lead Data Analyses," EPA Report No. 747-R-93-007.

[5] NCLSH Westat Blue Nozzle Study. Prepared by Westat Inc. Revised January, 1995.

[6] U.S. Environmental Protection Agency (August, 1996) "Lead-Based Paint Abatement and Repair and Maintenance Study in Baltimore: Pre-Intervention Findings." EPA Report No. 747-R-95-012.

[7] Farfel, M.R., Las, P.S.J., Rhode, C.A., Lim, B.S., Bannon, D. and Chisolm J.J., Jr., "Comparison of a Wipe and a Vacuum Collection Method for the Determination of Lead in Residential Dusts," *Environmental Research*, 65, 290-301 (1994).

[8] Farfel, M.R., Las, P.S.J., Rhode, C.A., Lim, B.S., and Bannon, D., "Comparison of Wipe and Cyclone Methods for the Determination of Lead in Residential Dusts," *Applied Occupational and Environmental Hygiene*, 9:1006-1012 (1994).

[9] "Comparison of Five Sampling Methods for Settled Lead Dust: A Pilot Study." (June, 1993). Preliminary Draft Report prepared by The National Center for Lead-Safe Housing, Columbia, Maryland.

[10] "The Relation of Lead-Contaminated House Dust and Blood Lead Levels Among Urban Children." Volumes I and II (June, 1995). Final Report to the U.S. Department of Housing and Urban Development, The University of Rochester School of Medicine, Rochester, New York, and The National Center for Lead-Safe Housing, Columbia, Maryland.

[11] Schultz, B., Strauss, W., Murphy, A., Kanarek, M. (1997) "Comparison of Wipe and Vacuum Sampling Methods for Assessing Dust Lead Levels in Homes: Data from the Milwaukee Lead Intervention Study," draft journal article.

[12] U.S. Environmental Protection Agency (August, 1996) "Seasonal Trends in Blood Lead Levels in Milwaukee," EPA Report No. 747-R-95-010.

[13] U.S. Environmental Protection Agency (September, 1995) "Seasonal Rhythms of Blood-Lead Levels: Boston, 1979-1983," EPA Report No. 747-R-94-003.

[14] U.S. Environmental Protection Agency (April, 1996) "Comprehensive Abatement Performance Study, Volume 1: Summary Report," EPA Report No. 230-R-94-013a.

[15] U.S. Environmental Protection Agency (April, 1996) "Comprehensive Abatement Performance Study, Volume 2: Detailed Statistical Results," EPA Report No. 230-R-94-013b.

[16] Carroll, R.J., Measurement Error in Nonlinear Models, (1995), Chapman & Hall.

[17] Draper, N.R., and Smith, H., Applied Regression Analysis, (1981), John Wiley & Sons.

[18] Fuller, W.A., Measurement Error Models, (1989), John Wiley & Sons.

[19] Neter, J., Wasserman, W., Kutner, M.H., Applied Linear Statistical Models, (1990), Richard D. Irwin, Inc.

[20] Lanphear, B.P., Emond, M. Jacobs, D.E., Weitzman, M., Tanner, M., Winter, N.L., Yakir, B., and Eberly, S., "A Side-by-Side Comparison of Dust Collection Methods for Sampling Lead-Contaminated Dust," *Environmental Research*, 68, 114-123 (1995).

[21] Emond, M.J., Lanphear, B.P., Watts, A., Eberly, S., and Members of the Rochester Lead-in-Dust Study Group, "Measurement Error and Its Impact on the Estimated Relationship Between Dust Lead and Children's Blood Lead," *Environmental Research*, 72, 82-92 (1997).

[22] U.S. Environmental Protection Agency (March, 1995) "Laboratory Evaluation of Dust and Dust Lead Recoveries for Samplers and Vacuum Cleaners, Volume I: Objectives, Methods, and Results," EPA Report No. 747-R-94-004A.

APPENDIX A

Correction Factor Development

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Correction Factor Development

As described in Section 2.1, two separate correction factors were employed in the conversion equations analysis. An adjustment was made to the wipe samples from the NCLSH 5-Method Comparison study to compensate for the chemical analysis of reduced samples, and a separate correction factor was used to convert the bioavailable wipe lead loadings reported in the R&M Pilot and R&M Mini studies to total available wipe lead loadings. The latter correction was necessary for the wipe loadings to be consistent with those in the other studies which reported total available lead loadings.

Adjustment for the Analysis of a Reduced Sample

Each wipe sample in the NCLSH 5-Method Comparison study was split and analyzed using both the cold hydrochloric acid digestion procedure, which yields "bioavailable" lead loadings, and the hot nitric acid/peroxide digestion method, which yields total lead loadings. Only 80% of each sample was analyzed using the hot nitric acid/peroxide digestion procedure. As a result, the reported total lead loadings are based on a reduced sample. Assuming the lead is uniformly distributed throughout the wipe, multiplying the total loading by 1.25 will estimate the total available lead loading based on 100% of the sample (100/80 = 1.25). Thus, the total wipe lead loadings from the NCLSH 5-Method Comparison Study were multiplied by 1.25 for use in the development of the BRM loading to wipe loading conversion equations.

Adjustment for Bioavailable to Total Available Lead Loadings

The NCLSH 5-Method Comparison study collected wipe samples from floors of varying substrates, such as vinyl, wood, concrete, low-pile carpet, high-pile carpet, and "other." Using the data from this study, a correction factor was developed to translate bioavailable lead loadings to equivalent total available lead loadings in the R&M Pilot and R&M Mini studies. Since these studies do not contain data from carpeted floor samples, the correction factor is calculated using data from only the uncarpeted substrates (vinyl, wood, concrete, and "other"). Before the correction factor can be calculated, the total available loadings must be multiplied by the 1.25 adjustment described above to compensate for the analysis of a reduced sample.

Figure A-1 displays the ratio of total lead to bioavailable lead versus bioavailable lead for each of the uncarpeted substrates sampled. Included on the graphs are a fitted regression line and a reference line at 1.58. This reference line represents the geometric mean of the ratio of total lead to bioavailable lead. Originally, this geometric mean was used as a constant correction factor for translating bioavailable loadings to total available loadings. The plots in Figure A-1 illustrate that utilizing this constant correction factor overestimates the relationship between bioavailable lead and total available lead at lower levels of bioavailable lead, and underestimates the relationship at higher levels of bioavailable lead.

This underrepresentation of the relationship between bioavailable and total available lead highlights the need for a more efficient correction factor. Thus, a regression analysis was performed on the natural log-transformed total lead loadings (based on a full sample) versus the natural log-transformed bioavailable lead loadings. The following model was fit:

$$\log(T) = \beta_1 * \log(B) + \text{error}$$

where T represents the total available lead and B represents the bioavailable lead determined using wipes. It was found that the ratio of total available to bioavailable lead is significantly dependent on the amount of lead in the sample ($p=0.0001$), but not on the substrate from which the sample was collected ($p = 0.6996$). The plots in Figure A-1 illustrate that the fit of the regression line to the data is much better than that of the reference line, and is consistent across the substrates. From the regression analysis, the correction factor is as follows:

$$T = B^{1.1416} = B * B^{0.1416}.$$

The variability in the ratio about the regression-based correction is approximately 13% smaller than the variability about the constant 1.58 correction factor.

The bioavailable lead to total available lead correction factor was developed from uncarpeted floor samples, but was also applied to samples from window sills and window wells. No data were available to derive separate correction factors for these housing components. However, because the relationship was not found to depend on substrate, it was assumed that the correction factor would not significantly depend on the housing component sampled. Thus, the bioavailable lead loadings from the R&M Pilot and R&M Mini studies, denoted by B, were multiplied by $B^{0.1416}$ for use in the development of the various BN and BRM conversion equations.

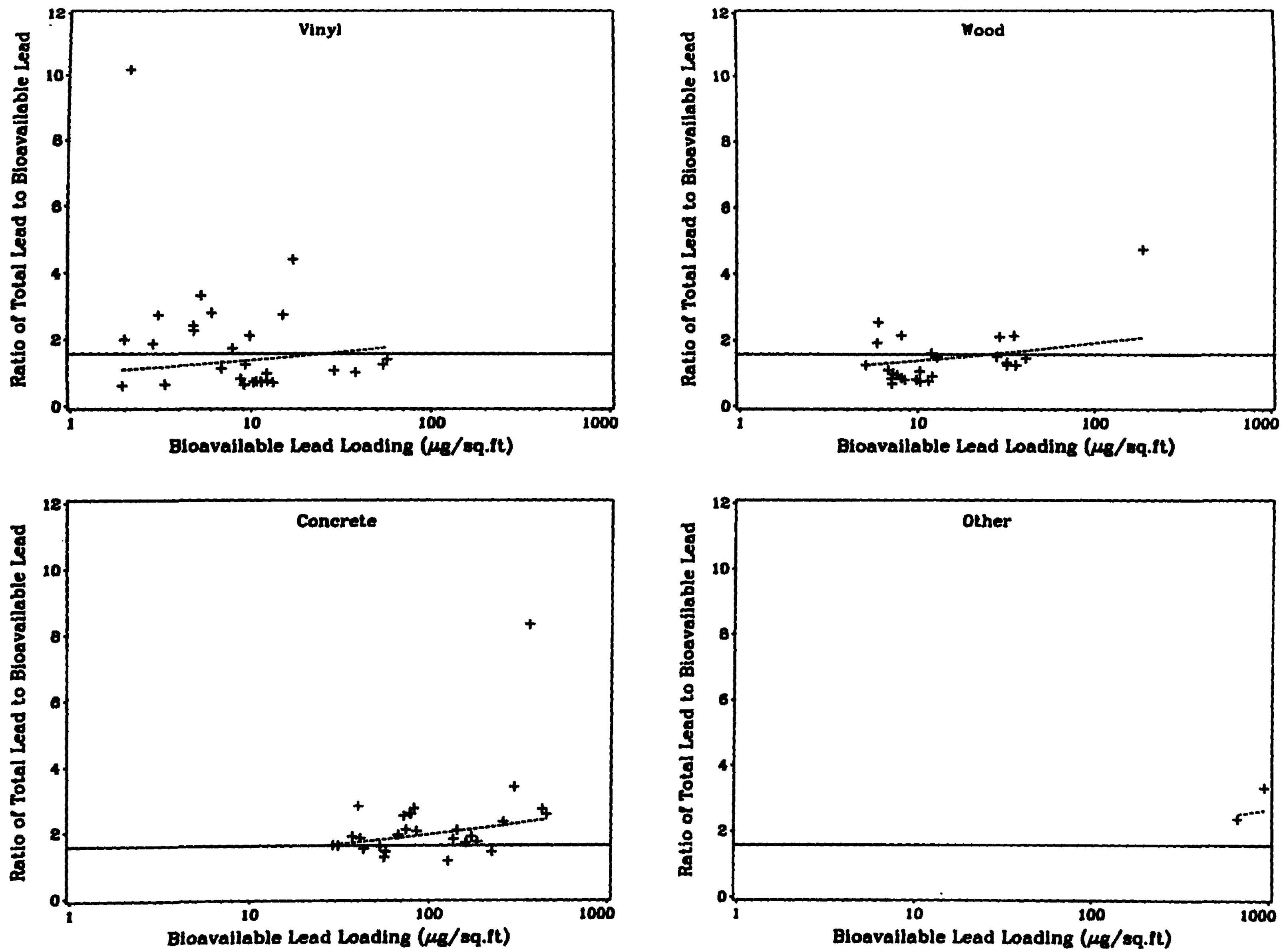

Figure A-1. Ratio of Total Lead to Bioavailable Lead versus Bioavailable Lead Loading (µg/ft²) from Uncarpeted Substrates in the NCLSH 5-Method Comparison Study

APPENDIX B

Distribution of the Data used to Develop the Conversion Equations

APPENDIX B

Distribution of the Data used to Develop the Conversion Equations

Blue Nozzle/Wipe Data

Table B-1 presents the number of uncarpeted floor samples by groupings of wipe lead loading and vacuum lead loading for the CAP Pilot study. Similarly, Table B-2 provides combined information for uncarpeted floors and window sills. In Tables B-3 through B-6, results are presented in a similar manner for the R&M Pilot and NCLSH/ Westat studies. As seen in the tables, the bulk of the data for uncarpeted floors are available for vacuum lead loadings less than 50 μg/ft² and wipe lead loadings less than 200 μg/ft². Data are present at the higher ends of the ranges for window sills and window wells.

Table B-1. Number of Samples by Wipe Lead Loading and Vacuum Lead Loading, CAP Pilot Study — Uncarpeted Floors.

Wipe Lead Loading (μg/ft²)	Blue Nozzle Vacuum Lead Loading (μg/ft²)				
	0-50	50-100	100-150	200+	Total
0-50	5	0	0	0	5
150-200	0	0	0	0	0
200+	0	0	1	0	1
Total	5	0	1	0	6

Table B-2. Number of Samples by Wipe Lead Loading and Vacuum Lead Loading, CAP Pilot Study — Uncarpeted Floors and Window Sills.

Wipe Lead Loading (μg/ft²)	Blue Nozzle Vacuum Lead Loading (μg/ft²)				
	0-50	50-100	100-150	200+	Total
0-50	7	0	0	0	7
150-200	1	1	0	0	2
200+	1	0	1	1	3
Total	9	1	1	1	12

Table B-3. Number of Samples by Wipe Lead Loading and Vacuum Lead Loading, R&M Pilot Study — Uncarpeted Floors.

Wipe Lead Loading (μg/ft²)	Blue Nozzle Vacuum Lead Loading (μg/ft²)								
	0-25	25-50	50-75	75-100	100-150	150-200	200-400	400+	Total
0-25	9	0	0	0	0	0	0	0	9
25-50	0	0	0	0	0	0	0	0	0
50-75	4	0	0	0	0	0	0	0	4
75-100	0	0	0	0	0	0	0	0	0
100-150	2	0	0	0	0	0	0	0	2
150-200	1	0	0	0	1	0	0	1	3
200 - 400	0	1	1	0	0	0	0	0	2
400+	0	0	0	1	0	0	0	3	4
Total	16	1	1	1	1	0	0	4	24

Table B-4. Number of Samples by Wipe Lead Loading and Vacuum Lead Loading, R&M Pilot Study — Uncarpeted Floors, Window Sills, and Window Wells.

Wipe Lead Loading (μg/ft²)	Blue Nozzle Vacuum Lead Loading (μg/ft²)								
	0-25	25-50	50-75	75-100	100-150	150-200	200-400	400 +	Total
0-25	17	0	0	0	0	0	0	1	18
25-50	0	0	0	0	0	0	0	0	0
50-75	5	0	0	1	0	0	0	0	6
75-100	0	0	0	0	0	0	0	0	0
100-150	2	0	0	0	0	0	0	1	3
150-200	2	0	0	0	1	0	0	2	5
200 - 400	1	1	1	0	1	2	0	2	8
400+	0	1	0	2	0	0	2	26	31
Total	27	2	1	3	2	2	2	32	71

Table B-5. Number of Samples by Wipe Lead Loading and Vacuum Lead Loading, NCLSH/Westat Study — Uncarpeted Floors.

Wipe Lead Loading ($\mu g/ft^2$)	Blue Nozzle Vacuum Lead Loading ($\mu g/ft^2$)						
	0-25	25-50	100-150	150-200	200-400	400 +	Total
25-50	3	0	0	0	0	0	3
50-75	3	0	0	0	0	0	3
75-100	1	0	0	0	0	0	1
100-150	0	0	0	0	0	0	0
150-200	0	0	0	0	0	0	0
200 - 400	0	0	0	0	0	0	0
400+	0	0	0	0	0	0	0
Total	7	0	0	0	0	0	7

Table B-6. Number of Samples by Wipe Lead Loading and Vacuum Lead Loading, NCLSH/Westat Study — Uncarpeted Floors, Window Sills, and Window Wells.

Wipe Lead Loading ($\mu g/ft^2$)	Blue Nozzle Vacuum Lead Loading ($\mu g/ft^2$)						
	0-25	25-50	100-150	150-200	200-400	400 +	Total
25-50	10	0	0	0	0	0	10
50-75	13	1	0	0	0	0	14
75-100	6	0	0	0	0	0	6
100-150	4	1	0	0	0	0	5
150-200	3	0	0	0	0	0	3
200 - 400	3	2	0	0	0	0	5
400+	1	3	3	2	2	1	12
Total	40	7	3	2	2	1	55

BRM/Wipe Data

Table B-7 presents the distribution of uncarpeted floor samples by interval of wipe lead loading and vacuum lead loading for the R&M Mini study. Similarly, Table B-8 provides combined information for uncarpeted floors, window sills, and window wells. Table B-9 presents the distribution of uncarpeted floor samples by interval for the NCLSH 5-Method study, and Table B-10 presents the analogous results for uncarpeted and carpeted floors, combined. Table B-11 presents the distribution of uncarpeted floor sample results by interval for uncarpeted floors sampled in the Rochester study; Table B-12 presents the corresponding results pooled across all sample types represented in the Rochester study (uncarpeted floors, carpeted floors, window sills, and window wells). Table B-13 shows the distribution of uncarpeted floor sample results obtained in the Milwaukee Low Cost Intervention study. As seen in the tables, the range of the data from uncarpeted floors varies significantly from study to study.

Table B-7. Number of Samples by Wipe Lead Loading and Vacuum Lead Loading, R&M Mini Study — Uncarpeted Floors.

Wipe Lead Loading (μg/ft²)	BRM Vacuum Lead Loading (μg/ft²)				
	0-25	150-200	200-400	400+	Total
0-25	2	0	0	0	2
25-50	4	0	1	0	5
100-150	0	0	0	2	2
200-400	0	1	0	6	7
400+	0	0	1	8	9
Total	6	1	2	16	25

Table B-8. Number of Samples by Wipe Lead Loading and Vacuum Lead Loading, R&M Mini Study — Uncarpeted Floors, Window Sills, Window Wells.

Wipe Lead Loading (μg/ft²)	BRM Vacuum Lead Loading (μg/ft²)						
	0-25	25-50	100-150	150-200	200-400	400+	Total
0-25	5	1	0	0	0	0	6
25-50	4	0	1	0	1	0	6
100-150	0	0	0	0	0	2	2
150-200	2	0	0	0	0	0	2
200-400	0	0	0	1	1	6	8
400+	0	0	0	0	2	51	53
Total	11	1	1	1	4	59	77

Table B-9. Number of Samples by Wipe Lead Loading and Vacuum Lead Loading, NCLSH 5 Method Comparison Study — Uncarpeted Floors.

Wipe Lead Loading (μg/ft²)	BRM Vacuum Lead Loading (μg/ft²)							
	0-25	25-50	75-100	100-150	150-200	200-400	400+	Total
0-25	32	2	0	1	0	4	1	40
25-50	4	1	0	0	0	2	1	8
50-75	2	0	0	0	1	1	0	4
75-100	1	0	1	0	1	0	0	3
100-150	0	0	0	1	0	1	0	2
150-200	0	0	0	0	0	0	1	1
200-400	0	0	0	0	0	1	6	7
400+	0	0	0	1	0	0	2	3
Total	39	3	1	3	2	9	11	68

Table B-10. Number of Samples by Wipe Lead Loading and Vacuum Lead Loading, NCLSH 5 Method Comparison Study — Uncarpeted Floors, Carpeted Floors.

Wipe Lead Loading ($\mu g/ft^2$)	BRM Vacuum Lead Loading ($\mu g/ft^2$)								
	0-25	25-50	50-75	75-100	100-150	150-200	200-400	400+	Total
0-25	32	3	5	3	3	9	21	29	105
25-50	4	1	0	0	0	0	2	1	8
50-75	2	0	0	0	0	1	1	2	6
75-100	1	0	0	1	0	1	0	0	3
100-150	0	0	0	0	1	0	1	0	2
150-200	0	0	0	0	0	0	0	1	1
200-400	0	0	0	0	0	0	1	6	7
400+	0	0	0	0	1	0	0	2	3
Total	39	4	5	4	5	11	26	41	135

Table B-11. Number of Samples by Wipe Lead Loading and Vacuum Lead Loading, Rochester Lead-in-Dust Study — Uncarpeted Floors.

Wipe Lead Loading ($\mu g/ft^2$)	BRM Vacuum Lead Loading ($\mu g/ft^2$)								
	0-25	25-50	50-75	75-100	100-150	150-200	200-400	400+	Total
0-25	214	22	8	3	4	4	3	10	268
25-50	45	9	5	3	2	1	1	5	71
50-75	9	3	2	0	1	1	4	2	22
75-100	1	1	1	0	0	1	1	3	8
100-150	3	1	0	2	1	0	1	0	8
150-200	0	1	0	0	1	0	0	2	4
400+	2	0	0	1	0	0	1	4	8
Total	274	37	16	9	9	7	11	26	389

Table B-12. Number of Samples by Wipe Lead Loading and Vacuum Lead Loading, Rochester Lead-in-Dust Study — Uncarpeted Floors, Carpeted Floors, Window Sills and Window Wells.

Wipe Lead Loading ($\mu g/ft^2$)	BRM Vacuum Lead Loading ($\mu g/ft^2$)								
	0-25	25-50	50-75	75-100	100-150	150-200	200-400	400+	Total
0-25	278	72	48	27	28	24	60	103	640
25-50	62	15	12	10	11	6	17	34	167
50-75	17	12	10	2	7	2	6	11	67
75-100	9	11	7	9	3	3	7	11	60
100-150	8	13	10	9	8	7	9	20	84
150-200	4	3	3	4	9	5	8	16	52
200-400	3	5	3	1	7	5	15	58	97
400+	6	2	3	4	3	7	27	333	385
Total	387	133	96	66	76	59	149	586	1552

Table B-13. Number of Samples by Wipe Lead Loading and Vacuum Lead Loading, Milwaukee Low Cost Intervention Study — Uncarpeted Floors.

Wipe Lead Loading ($\mu g/ft^2$)	BRM Vacuum Lead Loading ($\mu g/ft^2$)								
	0-25	25-50	50-75	75-100	100-150	150-200	200-400	400+	Total
0-25	36	5	4	1	1	1	1	1	50
25-50	15	6	1	0	3	1	3	2	31
50-75	4	5	2	2	0	0	3	4	20
75-100	4	0	0	0	0	0	0	2	6
100-150	4	1	2	0	1	1	0	0	9
150-200	1	0	0	1	1	1	1	2	7
200-400	2	0	1	0	0	0	1	4	8
400+	0	0	0	0	1	0	1	2	4
Total	66	17	10	4	7	4	10	17	135

APPENDIX C

Residual Analysis, Influential Observations and Computation Details for the BN Vacuum to Wipe Conversion Equations

APPENDIX C

Residual Analysis, Influential Observations and Computation Details for the BN Vacuum to Wipe Conversion Equations

Model Development

The individual regression equations for predicting a wipe lead loading from a Blue Nozzle vacuum lead loading based on the CAP Pilot, NCLSH/Westat, and R&M Pilot studies are displayed in Table C-1. Results for uncarpeted floors, window sills, and window wells are presented separately in each table. As described in the main body of the report, the regression models were fitted as $\log(W) = \log(\alpha) + \beta*\log(BN)$, with log referring to natural logarithm. The results in Table C-1 are presented using the actual scale of the data as $W = \alpha*BN^{\beta}$.

Table C-1. Regression Equations for Predicting Wipe Lead Loading from Blue Nozzle Vacuum Lead Loading.

Surface	Estimated Regression Model for Blue Nozzle Vacuum Pb Loading to Wipe Pb Loading[a]		
	CAP Pilot	NCLSH/Westat	R&M Pilot
Floors (Uncarpeted)	$W = 5.16*BN^{0.965}$ n=6 R^2=0.683[b] Range W: 13.8 - 2498.5 Range BN: 1.9 - 149.1	$W = 48.9*BN^{0.016}$ n=7 R^2=0.001 Range W: 33.5 - 81.4 Range BN: 5.4 - 20.9	$W = 12.9*BN^{0.816}$ n=24 R^2=0.810 Range W: 6.3 - 13969 Range BN: 1 - 2164
Window Sills	$W = 3.90*BN^{1.04}$ n=6 R^2 =0.927 Range W: 24.4 - 4217 Range BN: 6.3 - 600	$W = 7.61*BN^{1.07}$ n=42 R^2-0.476 Range W: 26.7 - 6197 Range BN: 4.2 - 149	$W = 4.26*BN^{1.27}$ n=23 R^2 =0.777 Range W: 2.2 - 1578000 Range BN: 1.4 - 8964
Window Wells	(c)	$W = 0.262*BN^{2.11}$ n=6 R^2=0.806 Range W: 229.3 - 47616 Range BN: 35.5 - 479	$W = 8.94*BN^{0.723}$ n=24 R^2 =0.438 Range W: 5.5 - 1206000 Range BN: 78 - 762000

(a) Units are $\mu g/ft^2$ for vacuum and wipe dust-lead loadings.
(b) R^2 represents the amount of variation explained by the log-linear regression model.
(c) Equation was not fitted because data were insufficient.

Figures C-1, C-2, and C-3 display the modeled relationships for BN vacuum to wipe lead loadings for the CAP Pilot, NCLSH/Westat, and R&M Pilot studies, respectively. In each of these figures, the relationships for floors, sills, and wells are plotted individually. In addition, the plots for uncarpeted floors and window sills also display the estimated "true regression relationship" as a dashed line, after making the errors-in-variables correction described in Chapter 3 of the report. All relationships are plotted on axes with the same scales for ease of comparison and interpretation.

In the figures, notice how similar the estimated true relationship is to the observed relationship, but in each case the slope is slightly steeper after an errors-in-variables correction was made. The estimated true relationship based on different studies should be more similar to each other than to the observed relationships. This was more evident for window sills than for floors. Differences are due in part to the scarcity of the BN data and are minimized by the errors-in-variables correction.

Figures C-4, C-5 and C-6 present graphs for the wipe lead loading versus BN lead loading for uncarpeted floors, window sills and window wells, respectively. The data from each of the three studies are plotted with different symbols. Included in these graphs are the estimated true regression lines from the individual studies, with the combined true regression line overlaid. Using these plots, a comparison can be made of the estimated relationships across the three studies.

Figure C-4 for uncarpeted floors and Figure C-5 for window sills illustrate that, for the most part, the combined true regressions appear to fit the data. Figure C-6 for window wells exhibits considerable discordance between the individual regression relationships. However, the R&M Pilot study has by far the greater amount of data and is given more weight than the NCLSH/Westat equation.

Influential Observations

When conducting a regression analysis, it is important to note any points that are influential. There are several approaches to determining influential data points. One measure of influence is known as the DFBETA statistic, which is a scaled measure of the influence of any one data value upon the separate parameter estimates. For a simple linear regression, DFBETA is calculated for the intercept (α) and for the slope (β), respectively. The statistic is a measure of the difference between the parameter estimate (α or β) as calculated by including all data values and as calculated by excluding the i^{th} data value. The threshold value for determining which points are most influential is recommended by Belsley, Kuh, and Welsch to be 2[1]. Thus, for each regression performed in this analysis, DFBETA was calculated for α and β, and compared to the threshold value of 2. In figures C-1, C-2, C-3, the data for the individual regression is plotted with triangles indicating the observations with significant influence on the intercept, squares indicating the observations with significant influence on the slope, and circles indicating the observations with significant influence on both the intercept and the slope.

Figures C-1, C-2, C-3 display the data, with indicated influential observations, for predicting a wipe lead loading from a BN lead loading from uncarpeted floors, window sills and window wells, for CAP Pilot, NCLSH/Westat, and R&M Pilot, respectively.

It should be noted that only 2 observations are influential in the BN to wipe regressions (see figures C-1 and C-2). In both cases, the data point is influential to the estimate of both the intercept and the slope. One influential observation is in the CAP Pilot study regression for uncarpeted floors. One influential observation is in the NCLSH/Westat study regression for window wells. Each of the influential observations had predicted value significantly distant from the other observations in the data set. This is not surprising given the limited amount of data available in these two studies. Note that if an influential observation is removed, and the regression repeated, the parameter estimates from that study may change substantially. However, the methodology employed in this analysis to combine the parameter estimates from the individual studies weights each estimate according to the inverse of the uncertainty associated with it. Therefore, if a study has little data or much variability in its parameter estimates, removing an influential point from that study will not significantly affect the combined parameter estimates.

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[1] SAS/STAT User's Guide, Version 6, Fourth Edition, Volume 2, 1990, SAS Institute Inc., pg 1419.

For instance, consider the regression of wipe lead loading on BN vacuum lead loading for uncarpeted floors shown in Figure C-1. When the influential point in the CAP Pilot Study is removed, the estimates of α and β change for this study. The estimate of α including the point is 4.22 with a standard error of 0.51. By excluding the observation, the estimate of α becomes 3.28 with a standard error of 0.19. Likewise, the estimate of β is 0.97 with a standard error of 0.33 with the influential observation and 0.17 with a standard error of 0.15 without the influential observation. In addition, the estimates of α in the other two studies change minimally due to the centering of the data by the overall mean log BN vacuum lead loading which was altered slightly by the removal of the data value. However, the combined conversion equation is not significantly affected by this deletion.

The equations developed for uncarpeted floors based on all data points are compared with the equations developed for uncarpeted floors after removing the most influential observations in Table C-2. Three different equations are presented to reflect the transportability adjustment that was necessary. Details of this adjustment are discussed in Sections 3.1.3 and 3.1.4 of this report.

Table C-2. A Comparison of Final Conversion Equations With and Without Influential Observation, Uncarpeted Floors

Uncarpeted Floor Samples for Houses Built	Equations Based on Data with Influential Data Points Removed	Equations Based on All Data Points
Pre-1940	$Wipe = 6.12BN^{0.617}$	$Wipe = 5.66BN^{0.809}$
1940-1959	$Wipe = 5.38BN^{0.610}$	$Wipe = 4.79BN^{0.800}$
1960-1979	$Wipe = 4.73BN^{0.539}$	$Wipe = 4.03BN^{0.707}$

The final conversion equations are similar because the uncertainty associated with the slope in the CAP Pilot Study (using all observations) is high, thereby lessening its contribution to the combined slope estimate. However, there is no basis for eliminating any of the influential observations from this analysis. The design of the analysis minimizes the effect of such observations.

Residual Analysis

There are also underlying assumptions that are made when conducting a regression analysis that must be validated. One such assumption is that the variability in the data remains constant across the range of the data. Residual plots (i.e., residual values (log scale) versus predicted values) have been provided for all BN regressions performed. A random scatter of the points on the graph around the reference line at zero with similar range across predicted values is an indication that the assumption of the homogeneity of variance is satisfied. However, if there are more data points at one predicted value than at another, the range should be commensurately wider because there is greater likelihood of observing more extreme values with more observations.

Figure C-7 presents the residuals versus the predicted wipe loadings from the regression of wipe loading on BN loading for uncarpeted floor samples from CAP Pilot, NCLSH/Westat and R&M Pilot studies. Figures C-8 and C-9 present analogous information for window sills and window wells. Regarding the residual plots, no patterns or trends can be seen, and variability appears constant across predicted values for each of the regressions performed.

Calculation of Measurement Error Estimates Used in the BN to Wipe Conversions

Although there were three types of conversions developed in this report, only the BN to wipe conversion included a measurement error adjustment. A justification for this is provided elsewhere in this report. To apply the adjustment, it is necessary to have an estimate of σ_U^2 -- the variance associated with the errors (U_i). Side-by-side data from floors and window sills sampled in the CAP Pilot study were used to derive these estimates.

Because of differences in the sampling protocols on uncarpeted floors between the CAP pilot study and the other studies, BN measurement error estimated from the CAP data was adjusted appropriately to reflect measurement error in the other two BN studies (i.e., measurement error associated with side-by-side, 1 ft^2 samples).

The point estimate of measurement error (obtained in the CAP study) was larger than the total variability in the measured BN values observed in the NCLSH/Westat study. This would prevent a measurement error adjustment for this study. Therefore, the lower 95 percent confidence bound on the estimate of measurement error was used for adjusting the regression relationships observed for the NCLSH/Westat data. Regardless of the measurement error assumed, the parameter estimates obtained from the NCLSH/Westat study had the greatest uncertainty (by up to a factor of 400 to 1), and therefore are given the least weight in deriving the final estimates. Thus, the point estimate from the CAP Pilot study was used to adjust the CAP pilot regression parameter estimates and the R&M pilot regression parameter estimates and the lower 95 percent confidence bound on the measurement error estimate was used to adjust the NCLSH/Westat estimates. (The actual choice of a measurement error estimate for the latter study had little impact on the final estimates because of the relatively low weight the NCLSH/Westat estimates are given.)

Data from the R&M pilot study were also used to obtain separate estimates of the spatial, side-by-side, and laboratory analysis variability. This analysis resulted in a comparable estimate of side-by-side variance on uncarpeted floors as was estimated from the CAP pilot study.

Matrix Algebra for Computing BN to Wipe Confidence Intervals and Prediction Intervals.

This section describes the approach used to estimate confidence and prediction intervals for the BN to wipe conversion.

Beginning with the parameters for the centered regressions

$$\theta_i = \begin{bmatrix} \theta_{0,i} \\ \theta_{1,i} \end{bmatrix} \quad i = 1,2,3 \text{ for the three training data sets.}$$

Estimates of the parameters of the regression relationship, after correcting for measurement error, are

$$\beta_i = \begin{bmatrix} \beta_{0,i} \\ \beta_{1,i} \end{bmatrix},$$

where

$$A_i = \begin{bmatrix} 1 & -\mu_{T,i} & (1-\lambda_{T,1}) & /\lambda_{T,1} \\ 0 & \lambda_{T,i} & & \end{bmatrix} \text{ and } \beta_i = A_i\theta.$$

But then, the variance of β_i is $A_i \sum_{\theta_i} A_i'$. The variance of the combined vector of parameter estimates, $(\beta_1, \beta_2, \beta_3)$, is $\begin{bmatrix} \sum_{\beta_1} & 0 & 0 \\ 0 & \sum_{\beta_2} & 0 \\ 0 & 0 & \sum_{\beta_3} \end{bmatrix}$. Note that, because the individual β_i's are actually bivariate vectors, this covariance matrix has 6 rows and 6 columns.

A weighted average of the β_i's (from the individual studies) was then taken; the weights used were the inverses of the squared standard errors of the individual parameter estimates. This can be written out as a linear combination of the β_i's. Let

$$B = \begin{bmatrix} W_{0,1} & 0 & W_{0,2} & 0 & W_{0,3} & 0 \\ 0 & W_{1,1} & 0 & W_{1,2} & 0 & W_{1,3} \end{bmatrix}, \text{ where}$$

$W_{0,i}$ = normalized weights associated with the centered intercept estimates, and
$W_{1,i}$ = normalized weights associated with the centered slope estimates.

Then $\beta_{centered} = B\ \beta_{new}$ and $\sum_{\beta_{centered}} = B \sum_{\beta_{new}} B'$.

For uncentering, $\beta_{uncentered} = \begin{bmatrix} \beta_0^* \\ \beta_1^* \end{bmatrix} = C\ \beta_{centered}$, where $C = \begin{bmatrix} 1 & -\mu_L \\ 0 & 1 \end{bmatrix}$, and μ_L represents the overall mean of natural log-transformed lead loadings across studies.

To represent the transportability adjustment, let $D = \begin{bmatrix} 1 & \mu_A(1-\lambda_A) \\ 0 & \lambda_A \end{bmatrix}$, where μ_A represents the mean of natural log-transformed lead loadings in the application data set, and $\lambda_A = \frac{\sigma^2_{X,A}}{\sigma^2_{X,A} + \sigma^2_U}$ with the numerator representing variability in true log lead loadings in the application data set, and the denominator representing the same plus measurement error. Then the adjusted parameter estimates of the prediction equation for the application data set are given by

$$\theta_A = \begin{bmatrix} \theta_0 \\ \theta_1 \end{bmatrix} = D\beta_{uncentered}.$$

Its covariance matrix is given by $\sum_\theta = D \sum_{\beta_{uncentered}} D'$. This is the covariance matrix of interest and can be derived using the above steps as follows:

$$\begin{aligned} \textstyle\sum_\theta &= D \textstyle\sum_{\beta_{uncentered}} D' \\ &= DC \textstyle\sum_{\beta_{centered}} C'D' \\ &= DCB \textstyle\sum_{\beta_{new}} B'C'D' \end{aligned}$$

where

$$\textstyle\sum_{\beta_{new}} = \begin{bmatrix} \sum_{\beta_1} & 0 & 0 \\ 0 & \sum_{\beta_2} & 0 \\ 0 & 0 & \sum_{\beta_3} \end{bmatrix} = \begin{bmatrix} A_1 \sum_{\theta_1} A_1' & 0 & 0 \\ 0 & A_2 \sum_{\theta_2} A_2' & 0 \\ 0 & 0 & A_3 \sum_{\theta_3} A_3' \end{bmatrix}.$$

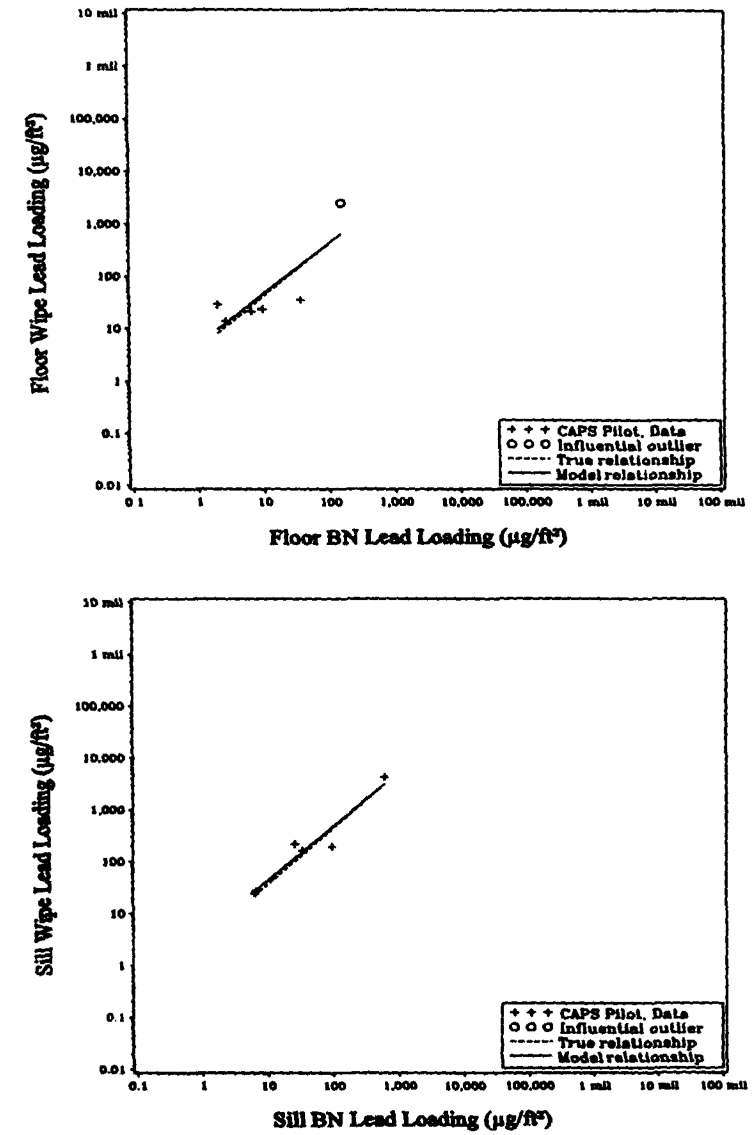

Figure C-1. Modeled Relationship Between Wipe and BN lead loadings, Before and After Correcting for Measurement Error (Errors in Variable Correction); Uncarpeted Floors and Window Sills, CAP Pilot Study.

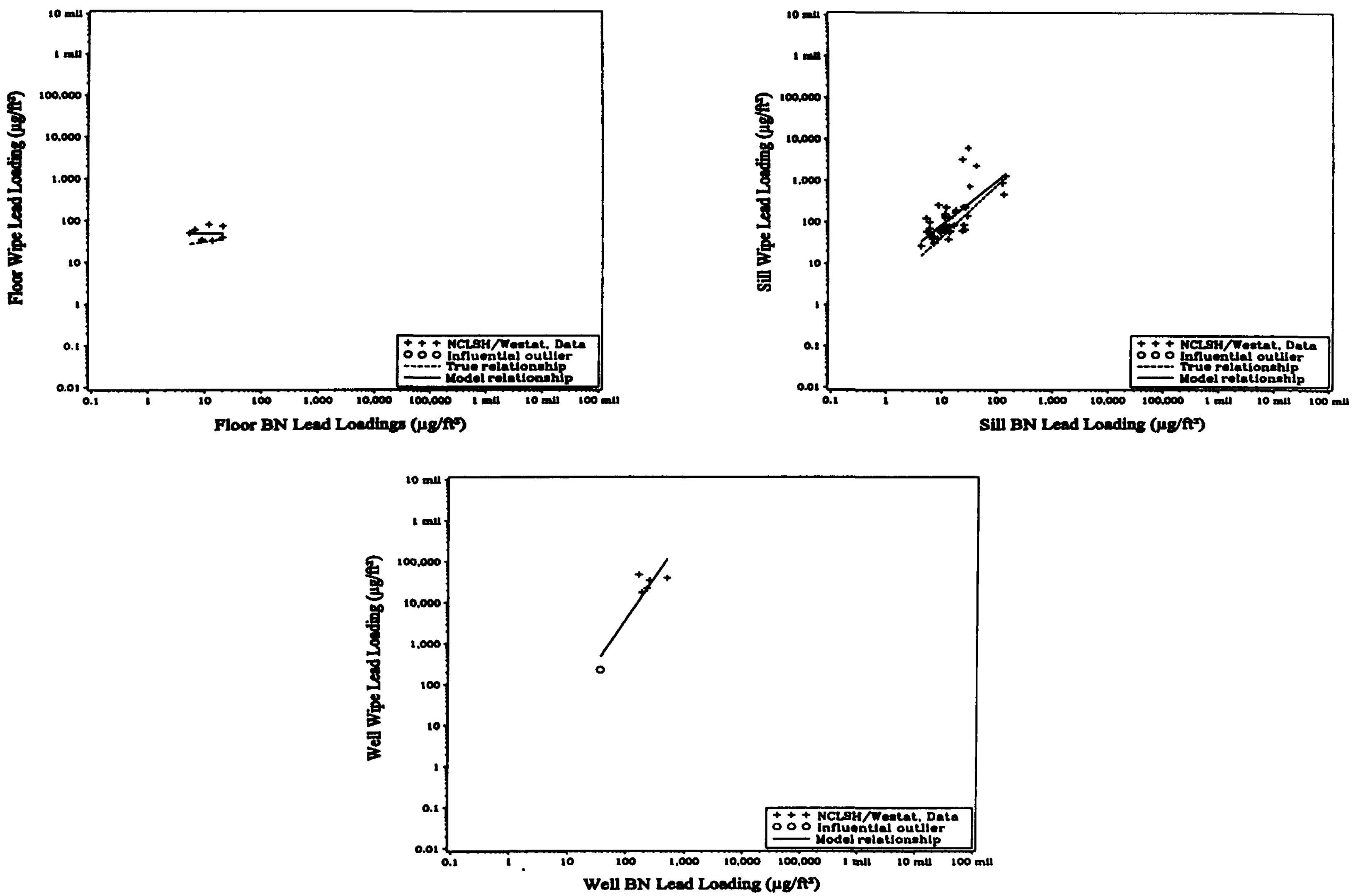

Figure C-2. Modeled Relationship Between Wipe and BN lead loadings, Before and After Correcting for Measurement Error (Errors-in-Variables Correction), Uncarpeted Floors, Window Sills, and (No Correction for Measurement Error) Window Wells, NCLSH/Westat.

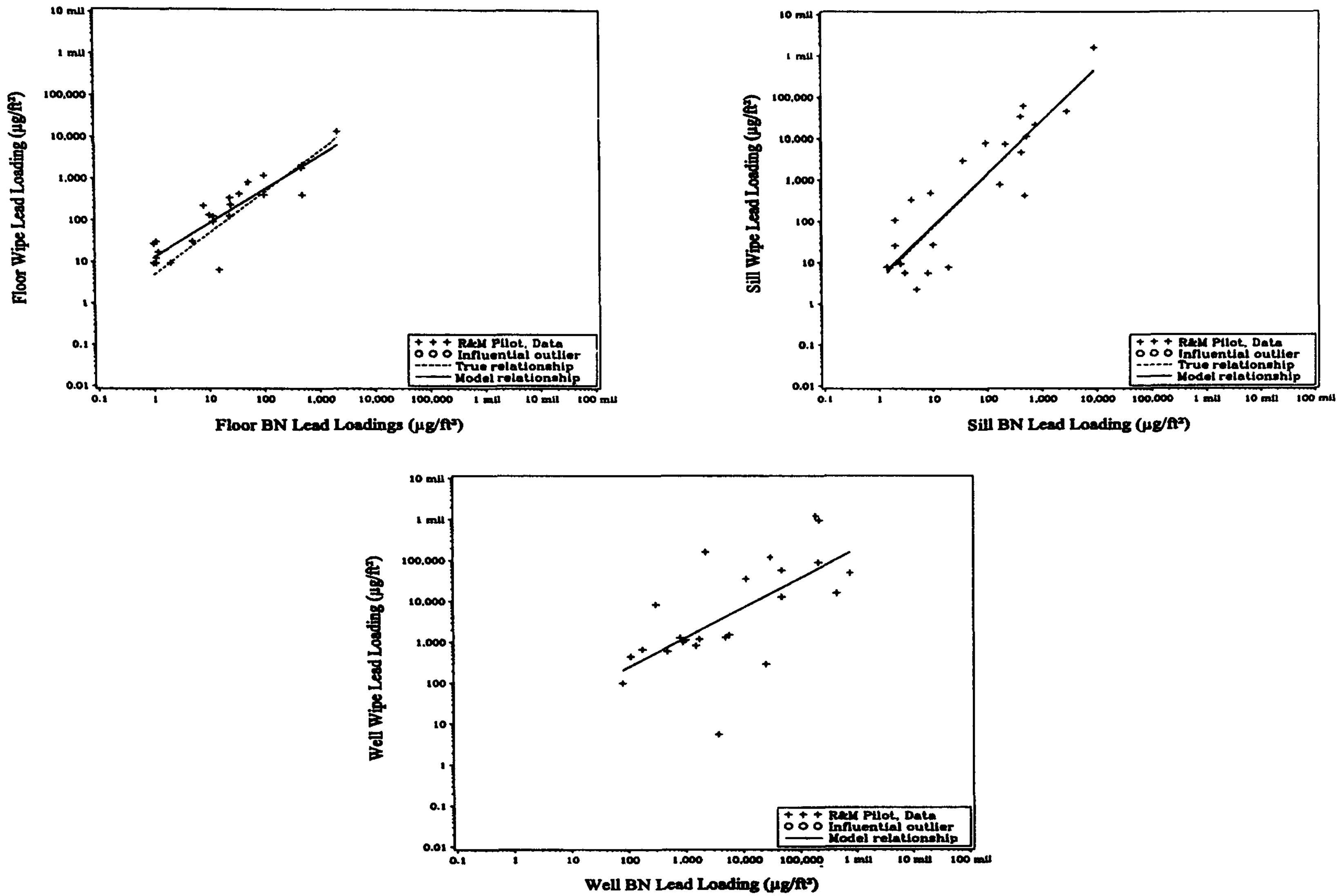

Figure C-3. **Modeled Relationship Between Wipe and BN lead loadings, Before and After Correcting for Measurement Error (Errors-in-Variables Correction), Uncarpeted Floors, Window Sills, and (No Correction for Measurement Error) Window Wells, R&M Pilot.**

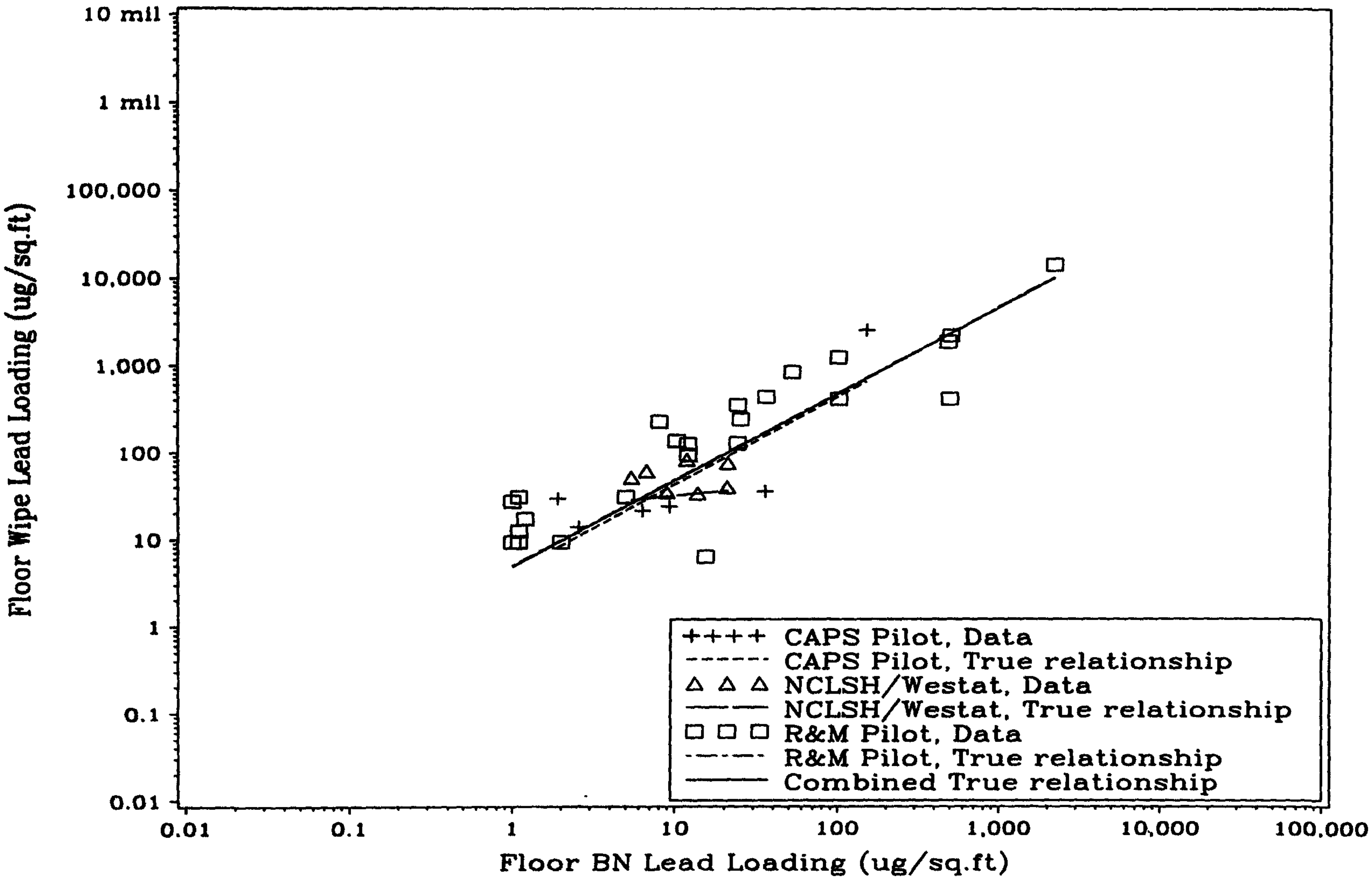

Figure C-4. Errors-in-Variables Corrected BN to Wipe Relationship Based on Individual Studies and Averaged Across Studies; Uncarpeted Floors.

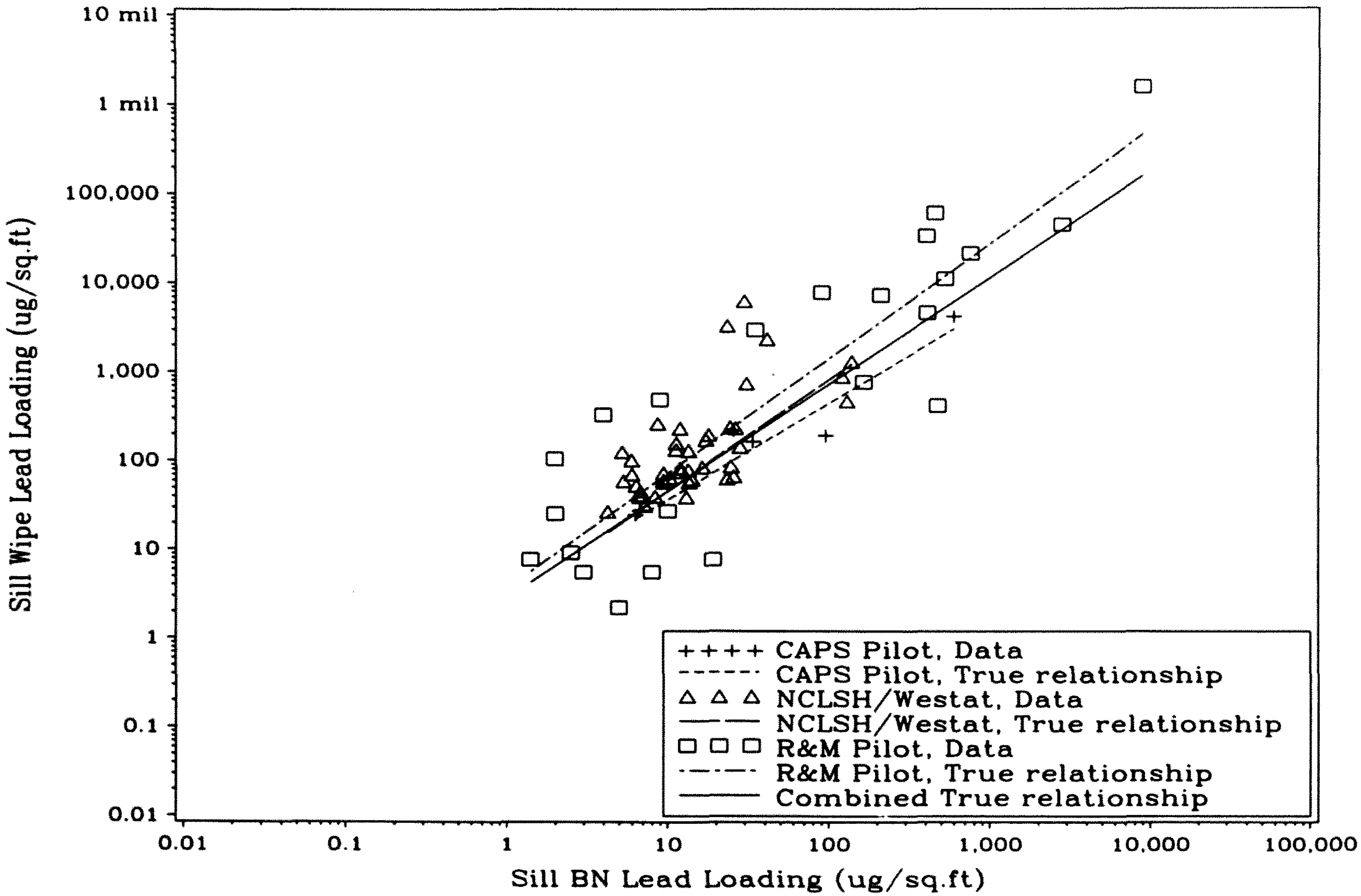

Figure C-5. Errors-in-Variables Corrected BN to Wipe Relationship Based on Individual Studies and Averaged Across Studies; Window Sills

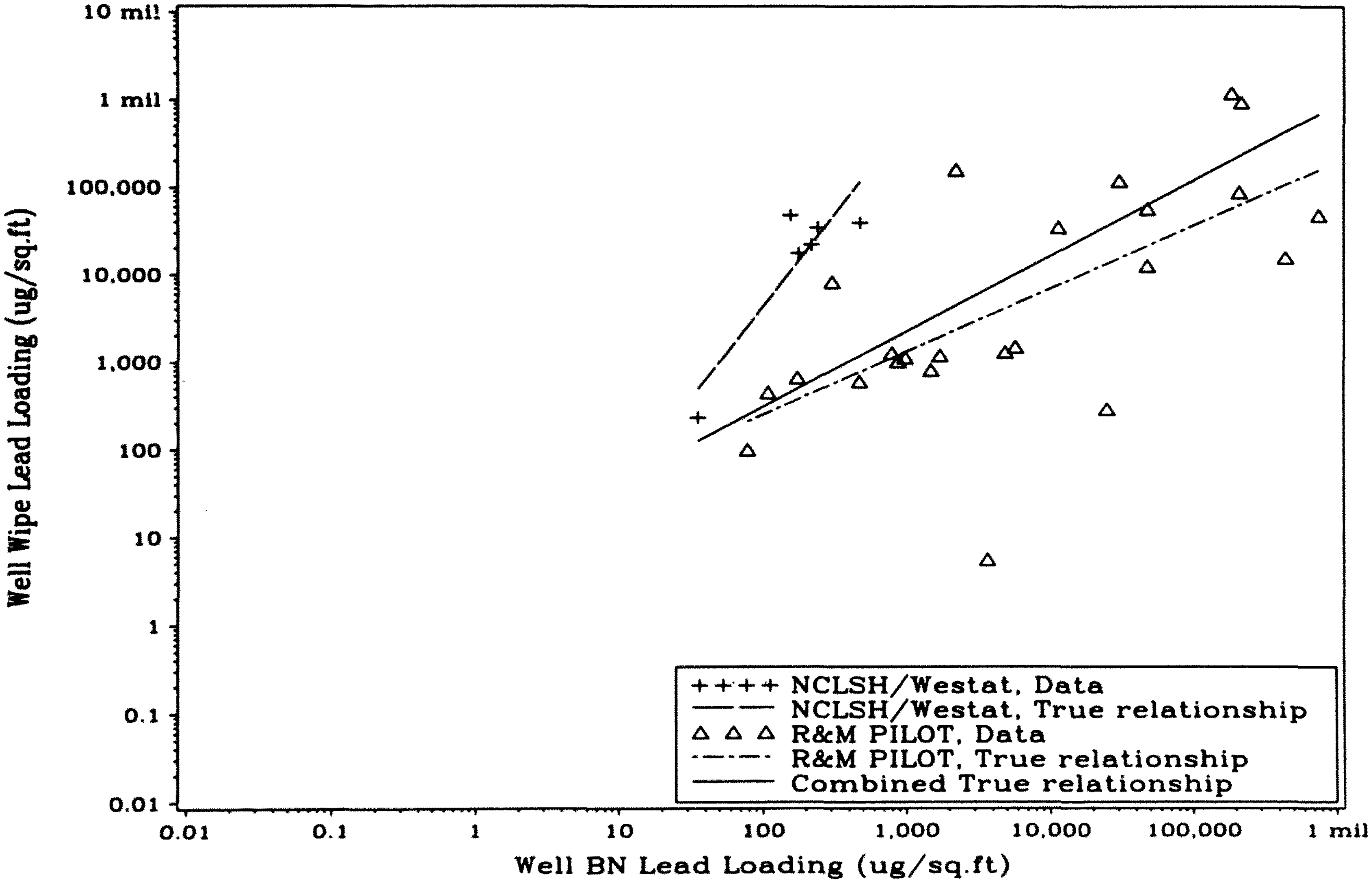

Figure C-6. Estimated BN to Wipe Relationship, Without Adjusting for Measurement Error, Based on Individual Studies and Averaged Across Studies; Window Wells

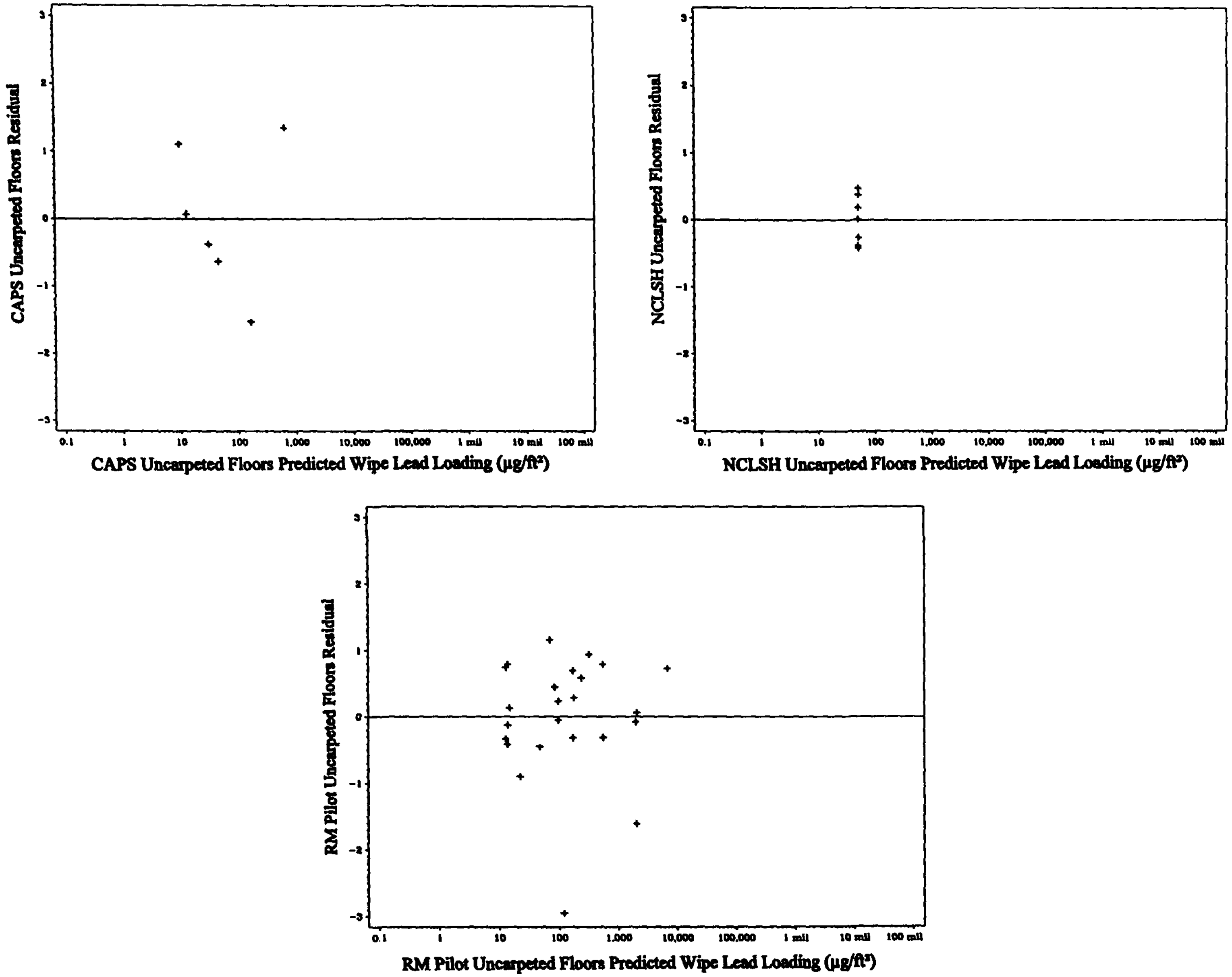

Figure C-7. Residual (Log Scale) versus Predicted Wipe Lead Loading from the Regression of Wipe Lead Loading on Blue Nozzle Lead Loading for Uncarpeted Floors from the CAP Pilot, NCLSH/Westat, and R&M Pilot Studies.

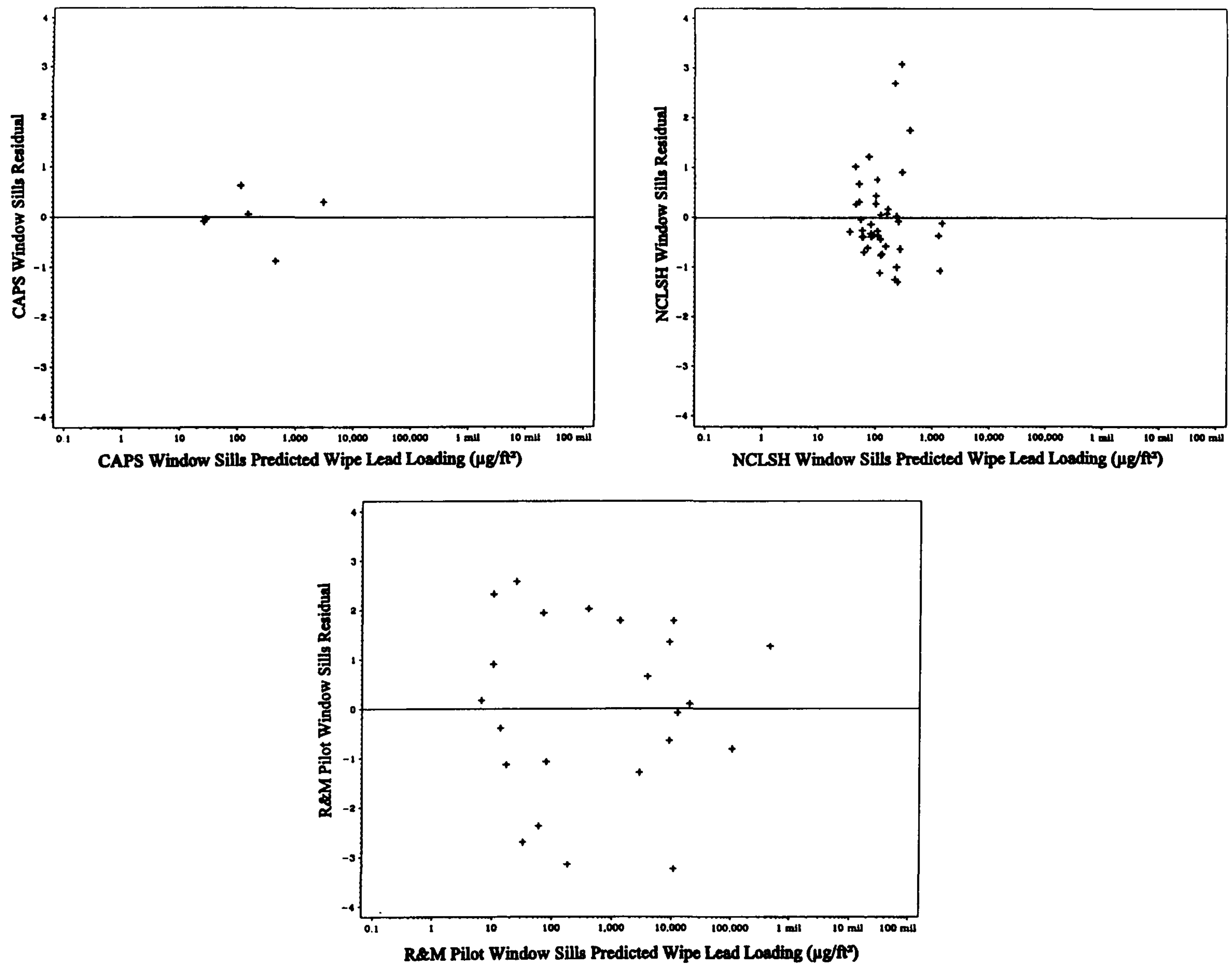

Figure C-8. **Residual (Log-Scale) and Predicted Wipe Lead Loading from the Regression of Wipe Lead Loading on Blue Nozzle Vacuum Lead Loading for Window Sills from the CAP Pilot, NCLSH/Westat, and R&M Pilot Studies.**

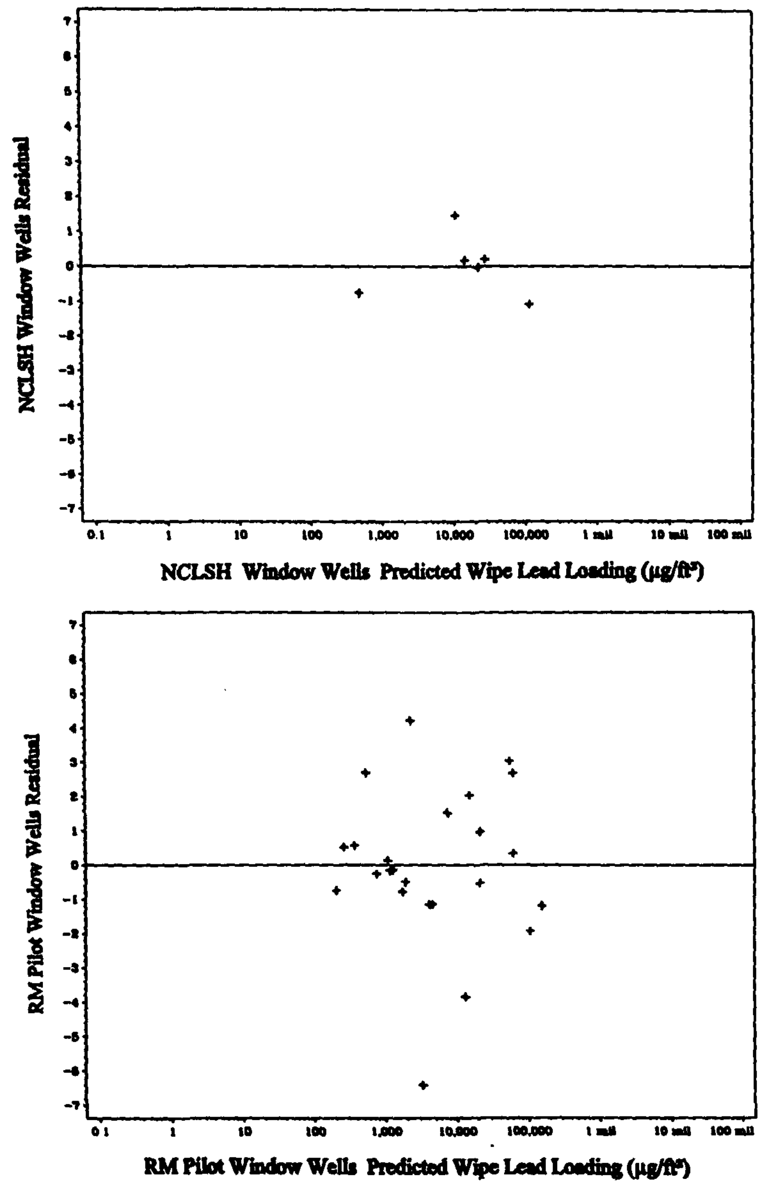

Figure C-9. Residual (Log Scale) and Predicted Wipe Lead Loading from the Regression of Wipe Lead Loading on Blue Nozzle Vacuum Lead Loading for Window Wells from the NCLSH/Westat and R&M Pilot Studies.

APPENDIX D

Residual Analysis, Influential Observations and Computation Details for the Wipe to BN Vacuum Conversion Equations

APPENDIX D

Residual Analysis, Influential Observations and Computation Details for the Wipe to BN Vacuum Conversion Equations

Model Development

The individual regression equations for predicting a BN vacuum lead loading from a wipe lead loading for the CAP Pilot, NCLSH/Westat, and R&M Pilot studies are displayed in Table D-1. Results for uncarpeted floors, window sills, and window wells are presented separately in each table. As described in the main body of the report, the regression models were fit as log(W) = log(α) + β*log(BN), with log referring to natural logarithm. The results in Table D-1 are presented using the actual scale of the data as W = α*BN$^{\beta}$.

Table D-1. Regression Equations for Predicting Blue Nozzle Vacuum Lead Loading from Wipe Lead Loading.

Surface	Estimated Regression Model for Wipe Pb Loading to Blue Nozzle Vacuum Pb Loading[(a)]		
	CAP Pilot	NCLSH/Westat	R&M Pilot
Floors (Uncarpeted)	BN = 0.662*$W^{0.708}$ n=6 R^2=0.683[(b)] Range W : 13.8 - 2498.5 Range BN : 1.9 - 149.1	BN = 9.87*$W^{0.034}$ n=7 R^2=0.001 Range W: 33.5 - 81.4 Range BN: 5.4 - 20.9	BN = 0.134 *$W^{0.993}$ n=24 R^2=0.810 Range W: 6.3 - 13969 Range BN: 1 - 2164
Window Sills	BN = 0.390*$W^{0.887}$ n=6 R^2 =0.927 Range W: 24.4 - 4217 Range BN: 6.3 - 600	BN = 1.66*$W^{0.447}$ n=42 R^2=0.476 Range W: 26.7 - 6197 Range BN: 4.2 - 140	BN = 0.977*$W^{0.612}$ n=23 R^2 =0.777 Range W: 2.2 - 1578000 Range BN: 1.4 - 8964
Window Wells	(c)	BN = 4.53*$W^{0.383}$ n=6 R^2=0.806 Range W: 229.3 - 47616 Range BN: 35.5 - 479	BN = 35.2*$W^{0.607}$ n=24 R^2 =0.438 Range W: 5.5 - 1206000 Range BN: 78 - 762000

(a) Units are $\mu g/ft^2$ for vacuum and wipe dust-lead loadings.
(b) R^2 represents the amount of variation explained by the log-linear regression model.
(c) Equation was not fitted because data were not available or insufficient.

Figures D-1, D-2, and D-3 display the modeled relationships for wipe to BN vacuum lead loadings for the CAP Pilot, NCLSH/Westat, and R&M Pilot studies, respectively. In each of these figures, the relationships for floors, sills, and wells are displayed simultaneously. All relationships are plotted on axes with the same scales for ease of comparison and interpretation.

The reader is reminded that since there is no application data set for the conversion of wipe lead loading to BN vacuum lead loading, so no errors-in-variables conversion or transportability adjustment was made for this set of conversion equations.

Figures D-1, D-2, and D-3 reveal differences in the relationships between wipe lead loading and BN loading among the three studies. This is due in part to the scarcity of the BN data. For example, consider the uncarpeted floor lead loading plot. The estimated slope is much lower for the NCLSH/Westat study.

Figure D-4 displays the BN lead loading versus wipe lead loading results observed for uncarpeted floors with the data from each of the three studies plotted with different symbols. Included in this graph are the regression lines from the individual studies and a solid line representing the estimated average relationship across studies. Using this plot, a comparison can be made of the relationships across the three studies with the combined estimate.

Figures D-5 and D-6 present similar information on window sills and window wells. Figures D-4 for uncarpeted floors and D-5 for window sills, illustrate that for the most part the combined regression equations appear to fit the data. In particular, although the estimated relationship from the NCLSH/Westat study does not agree with the other two studies, it can be observed that the range of the relationship estimated from this study is very narrow compared with the other two studies. When all the data are combined and overlaid with the (combined) estimated average relationship, the fit is reasonable across the range.

However, Figure D-6 for window wells exhibits considerable discordance between the individual regression relationships. Consider Figure D-6. Note the number of data points contained in each study. The R&M Pilot study has by far the greater amount of data. However, when the regression equations are combined, more weight is given to the NCLSH/Westat equation. This is because the uncertainty in the parameter estimates from the NCLSH/Westat study is estimated to be smaller than the uncertainty in the parameter estimates from the R&M Pilot study.

Influential Observations

When conducting a regression analysis, it is important to note any points that are influential. There are several approaches to determining influential data points. One measure of influence is known as the DFBETA statistic, which is a scaled measure of the influence of any one data value upon the separate parameter estimates. For a simple linear regression, DFBETA is calculated for the intercept (α) and for the slope (β), respectively. The statistic is a measure of the difference between the parameter estimate (α or β) as calculated by including all data values and as calculated by excluding the i^{th} data value. The threshold value for determining which points are most influential is recommended by Belsley, Kuh, and Welsch to be 2[1]. Thus, for each regression performed in this analysis, DFBETA was calculated for α and β, and compared to the threshold value of 2. In figures D-1, D-2, D-3, the data for the individual regression is plotted with triangles indicating the observations with significant influence on the intercept, squares indicating the observations with significant influence on the slope, and circles indicating the observations with significant influence on both the intercept and the slope.

Figures D-1, D-2, D-3 display the data, with indicated influential observations, for predicting a wipe lead loading from a BN lead loading from uncarpeted floors, window sills and window wells, for CAP Pilot, NCLSH/Westat, and R&M Pilot study data, respectively.

It should be noted that only 1 observation is influential in the wipe to BN regressions (see Figure D-1). This data point is influential to the estimate of both the intercept and the slope. This influential observation is in the CAP Pilot regression for uncarpeted floors. This influential observation had a predicted value significantly distant from the other observations in the data set. This is not surprising given the limited amount of data available in this study. Note that if an influential observation is removed, and the regression repeated, the parameter estimates from that study may change substantially. However, the methodology employed in this analysis to combine the parameter estimates from the individual studies weights each estimate according to the inverse of the uncertainty associated with it. Therefore, if a study has little data or much variability in its parameter estimates, removing an influential point from that study will not significantly affect the combined parameter estimates.

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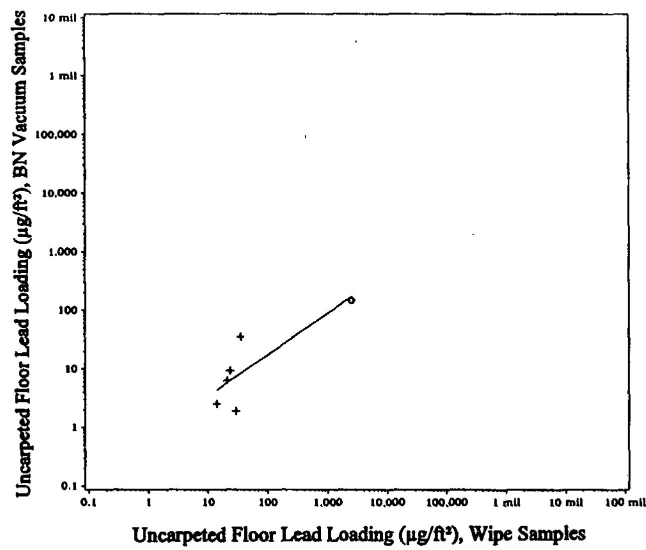
[1] SAS/STAT User's Guide, Version 6, Fourth Edition, Volume 2, 1990, SAS Institute Inc., pg 1419.

The effects removing an influential observation are illustrated in Appendix C for the conversion of BN vacuum samples to wipe lead loading values. The basic result is that the final conversion equations are similar because the uncertainty associated with the slope in the CAP Pilot Study (using all observations) is high, thereby lessening its contribution to the combined slope estimate. However, that there is no basis for eliminating this point (or any of the other influential observations) from this analysis. The design of the analysis minimizes the effect of such observations.

Residual Analysis

There are also underlying assumptions that are made when conducting a regression analysis that must be validated. One such assumption is that the variability in the data remains constant across the range of the data. Residual plots (i.e., residual values (log scale) versus predicted values) have been provided for all BN regressions performed. A random scatter of the points on the graph around the reference line at zero with similar range across predicted values is an indication that the assumption of the homogeneity of variance is satisfied. However, if there are more data points at one predicted value than at another, the range should be commensurately wider because there is greater likelihood of observing more extreme values with more observations.

Figure D-7 presents the residuals versus the predicted wipe loadings from the regression of wipe loading on BN loading for uncarpeted floor samples form CAP Pilot, NCLSH/Westat and R&M Pilot studies. Figures D-8 and D-9 present analogous information for window sills and window wells. Regarding the residual plots, no patterns or trends can be seen, and variability appears constant across predicted values for each of the regressions performed.



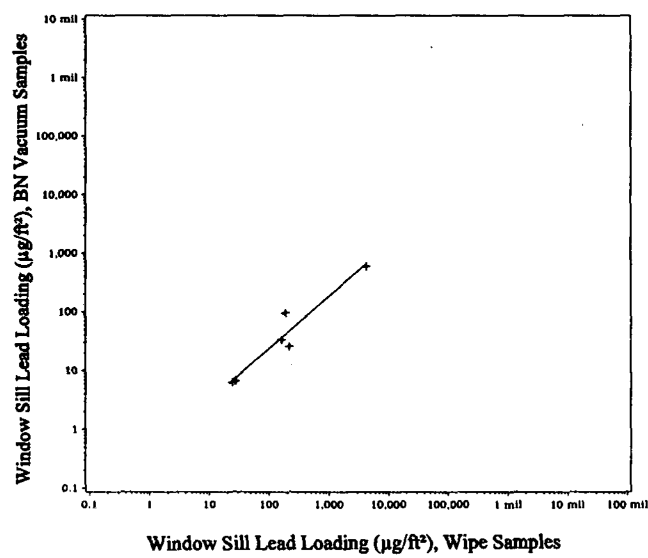


Figure D-1. Blue Nozzle Vacuum Lead Loading versus Wipe Lead Loading for Uncarpeted Floors and Window Sills from the CAP Pilot Study.

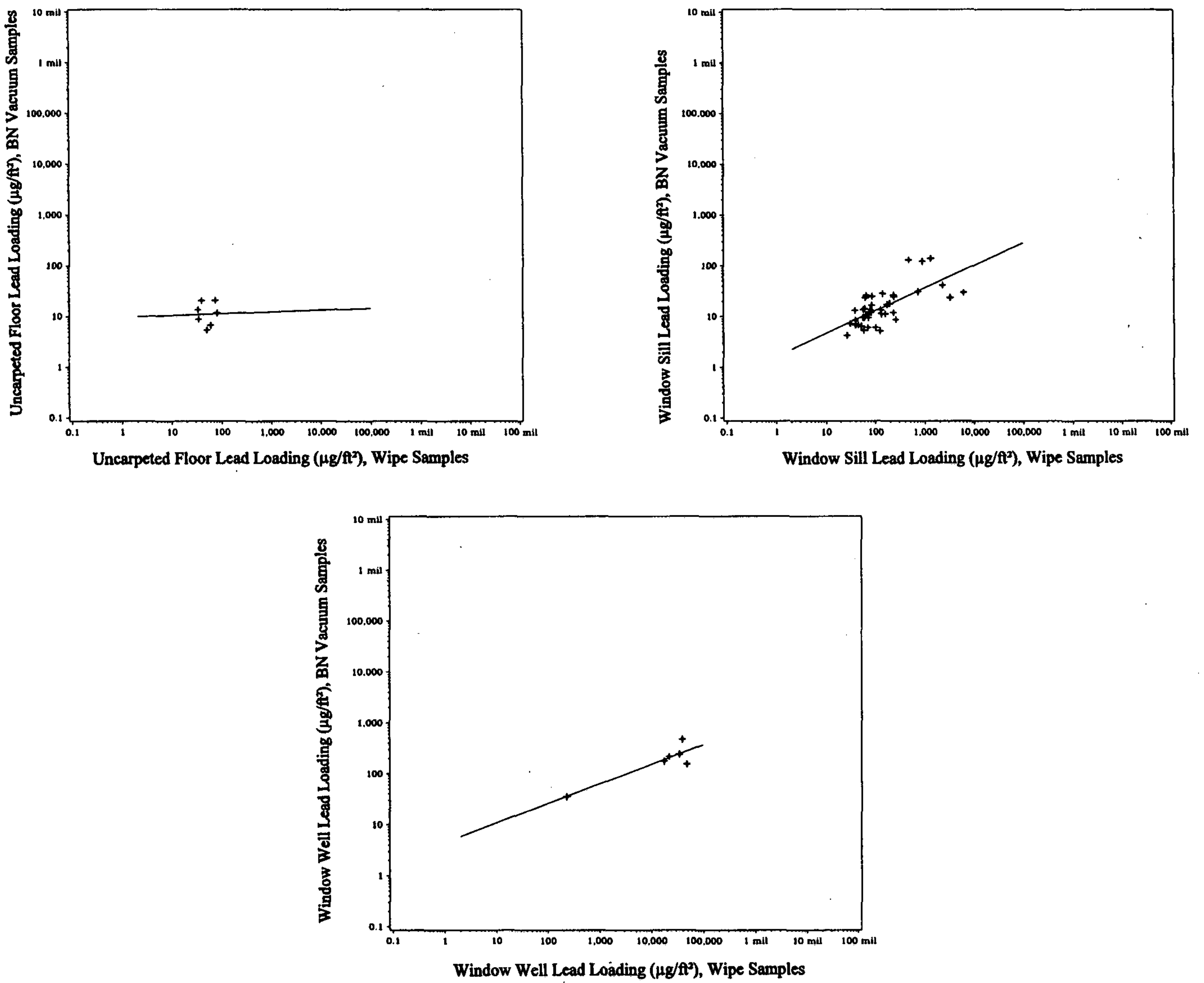


Figure D-2. Blue Nozzle Vacuum Lead Loading versus Wipe Lead Loading for Uncarpeted Floors, Window Sills, and Window Wells from the NCLSH/Westat Study.

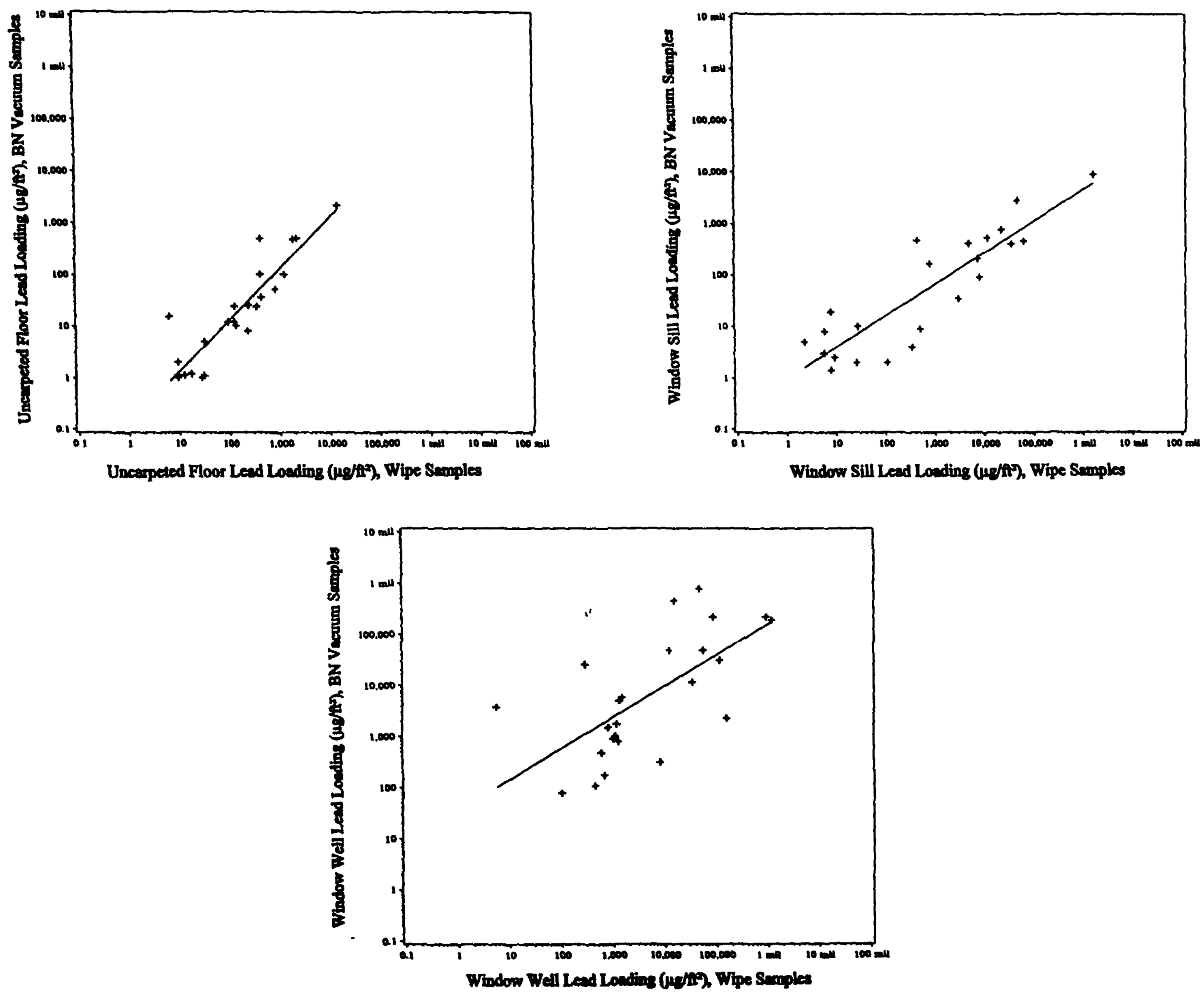


Figure D-3. Blue Nozzle Vacuum Lead Loading versus Wipe Lead Loading for Uncarpeted Floors, Window Sills, and Window Wells from the R&M Pilot Study.

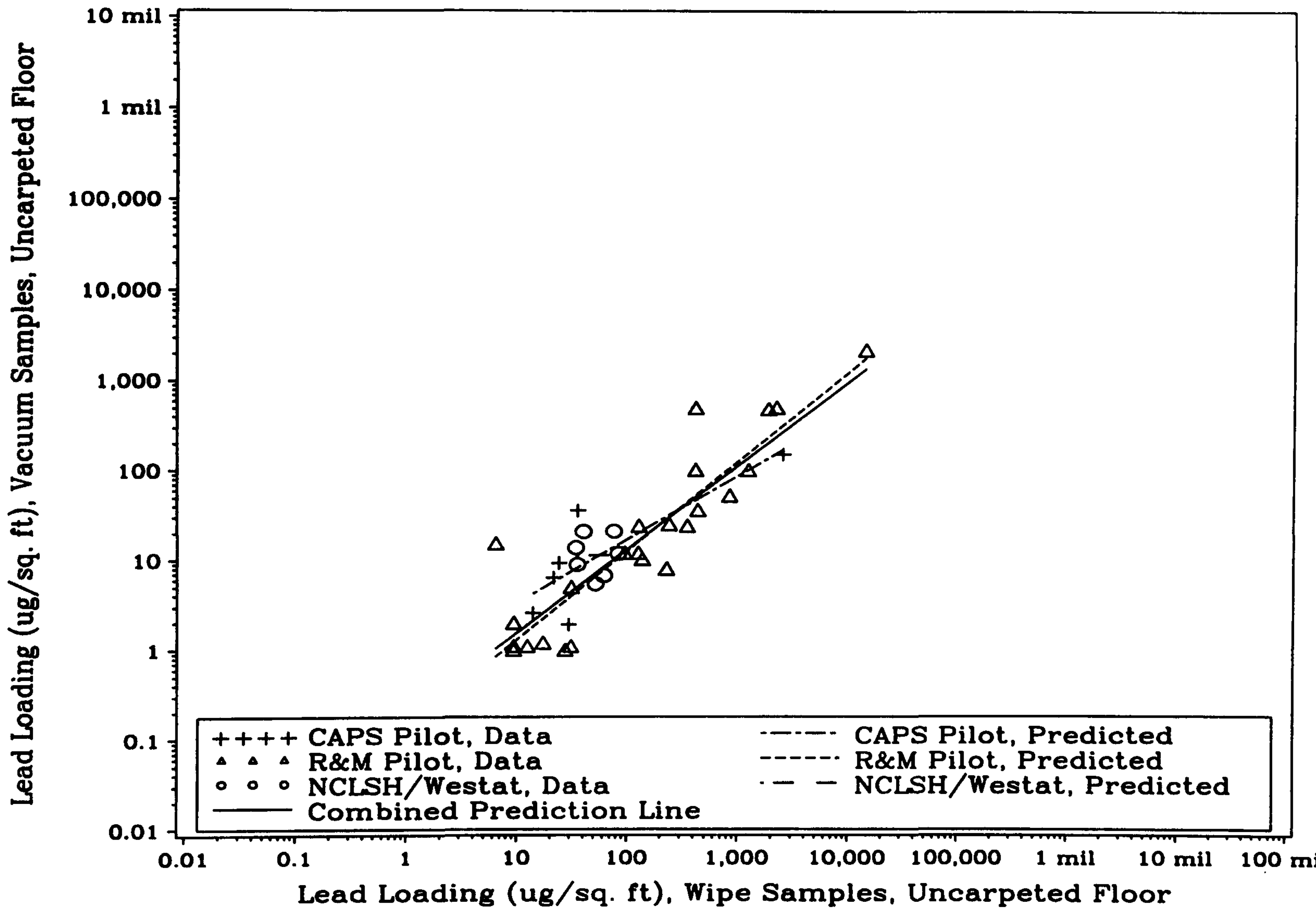


Figure D-4. **Estimated Wipe to BN Relationship; Without Adjusting for Measurement Error, Based on Individual Studies and Averaged Across Studies; Uncarpeted Floors.**

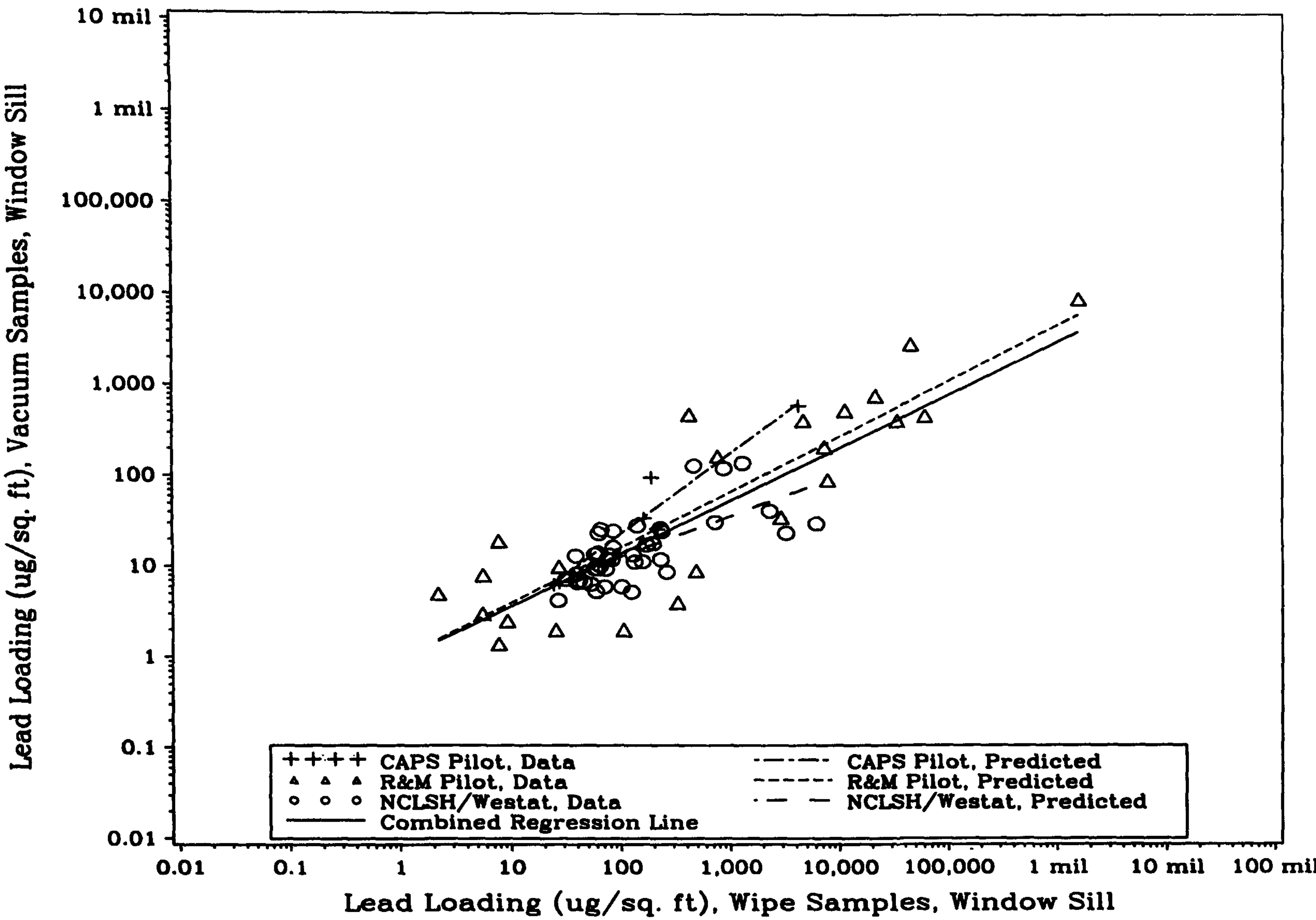


Figure D-5. Estimated Wipe to BN Relationship; Without Adjusting for Measurement Error, Based on Individual Studies and Averaged Across Studies; Window Sills.

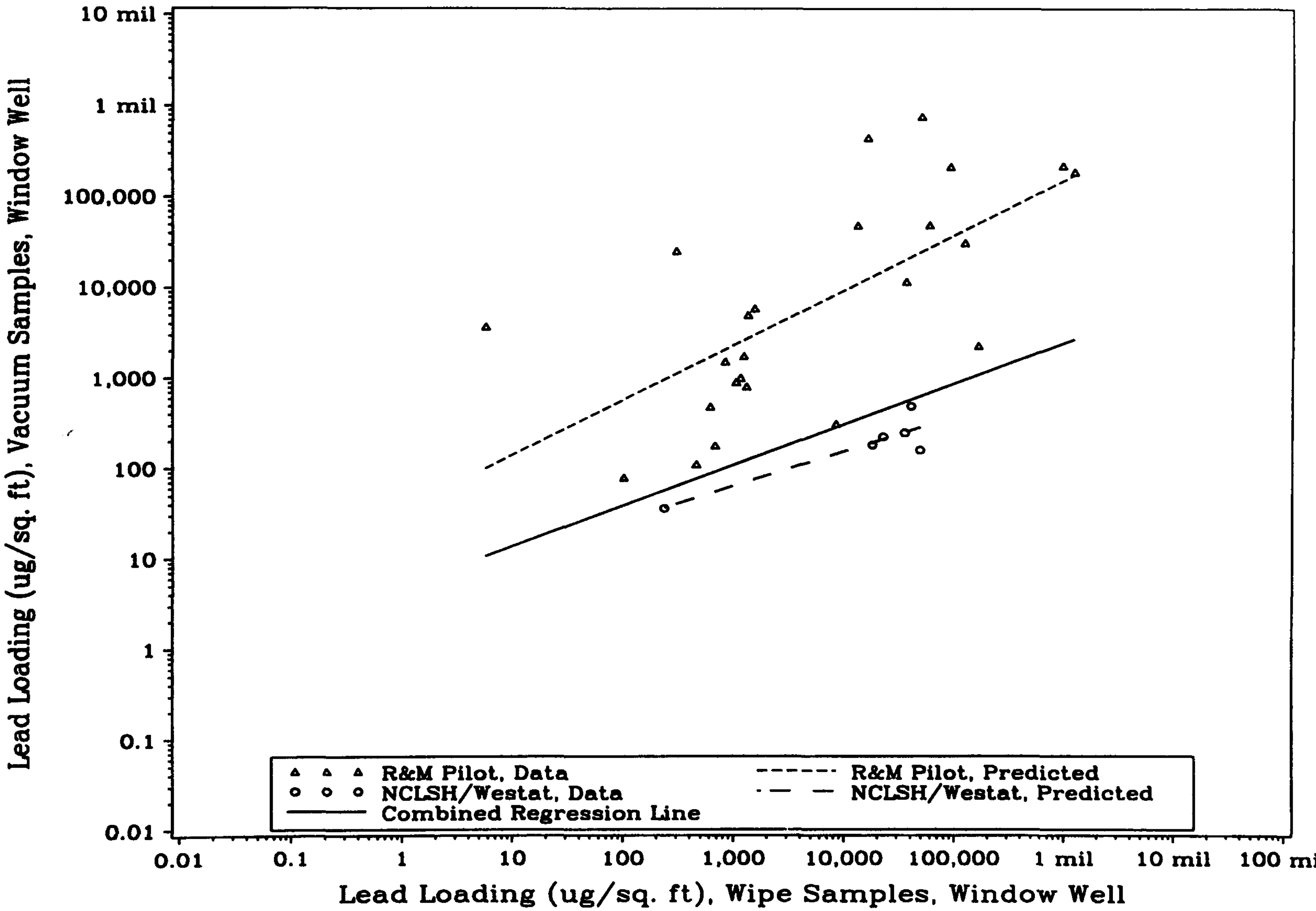


Figure D-6. **Estimated Wipe to BN Relationship, Without Adjusting for Measurement Error, Based on Individual Studies and Averaged Across Studies; Window Wells.**

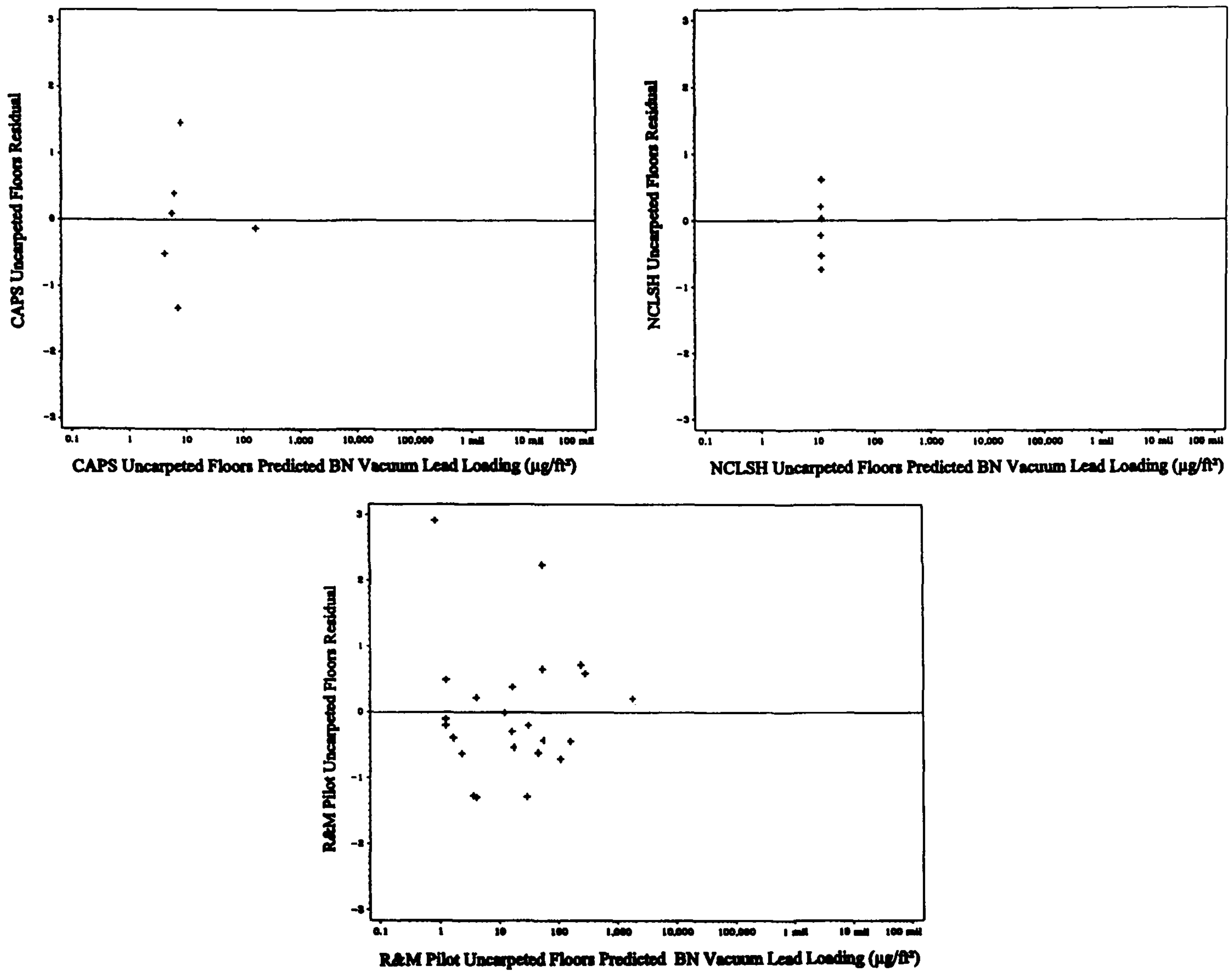


Figure D-7. Residual (Log Scale) versus Predicted Blue Nozzle Vacuum Lead Loading from the Regression of Blue Nozzle Lead Loading on Wipe Lead Loading for Uncarpeted Floors from the CAP Pilot, NCLSH/Westat, and R&M Pilot Studies.

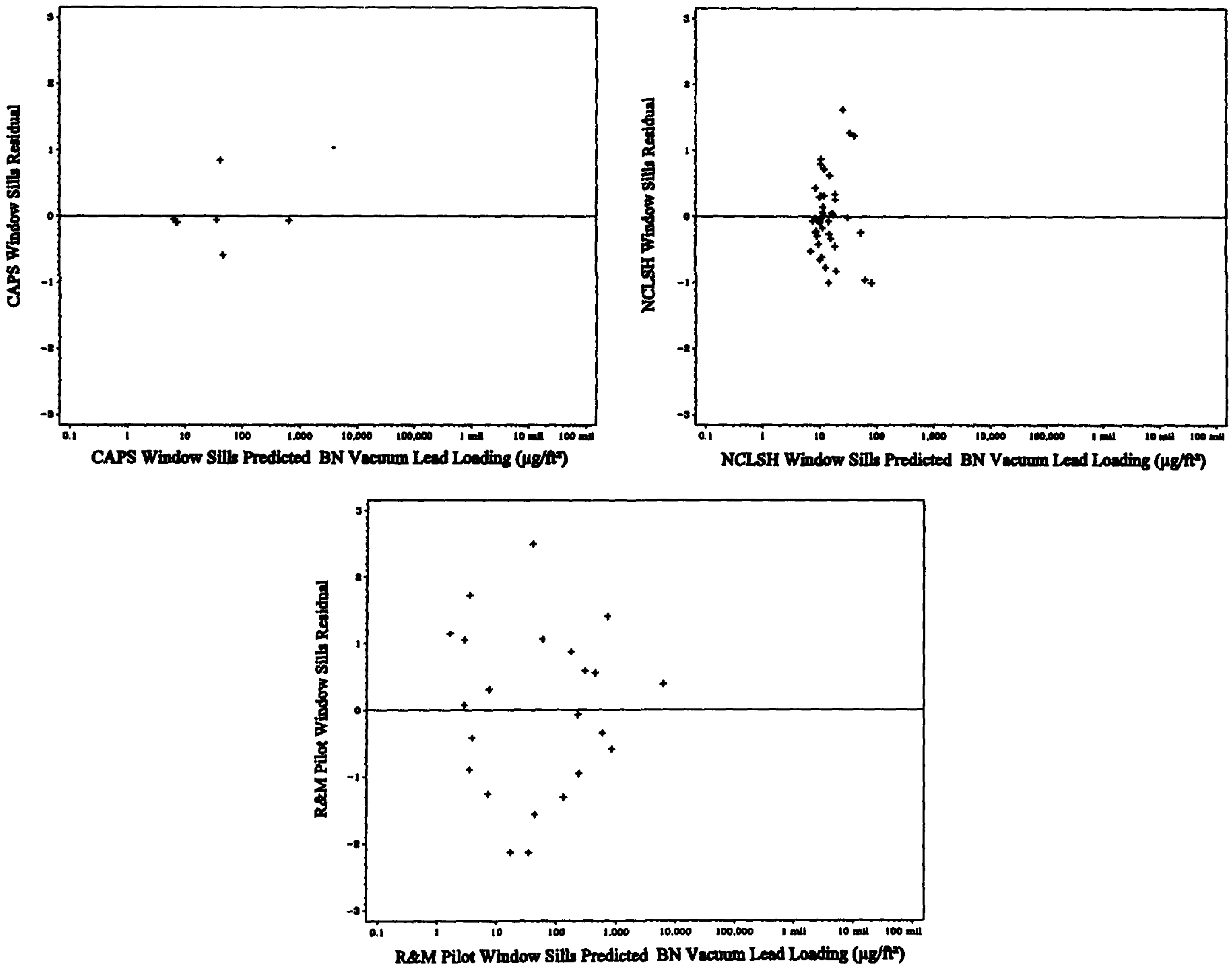


Figure D-8. Residual (Log Scale) and Predicted Blue Nozzle Vacuum Lead Loading from the Regression of Blue Nozzle Lead Loading on Wipe Lead Loading for Window Sills from the CAP Pilot, NCLSH/Westat, and R&M Pilot Studies.

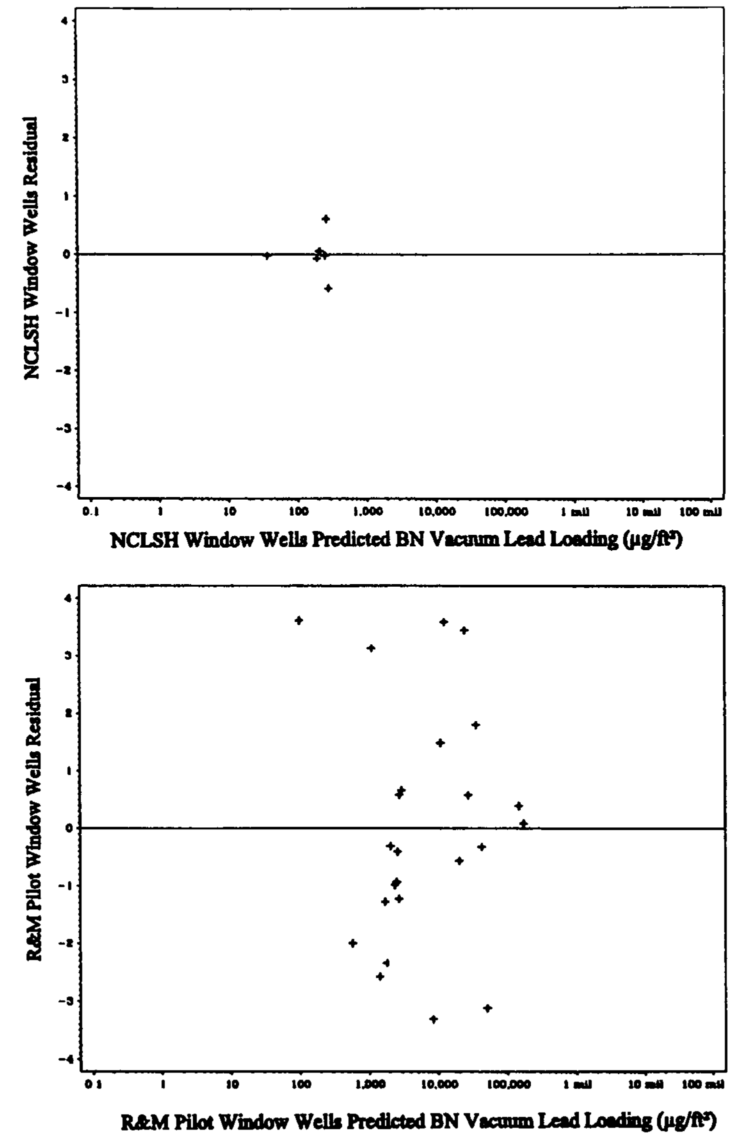


Figure D-9. Residual (Log Scale) and Predicted Blue Nozzle Lead Loading from the Regression of Blue Nozzle Vacuum Lead Loading on Wipe Lead Loading for Window Wells from the NCLSH/Westat and R&M Pilot Studies.

APPENDIX E

Residual Analysis, Influential Observations and Computation Details for the BRM to Wipe Conversion Equations

APPENDIX E

Residual Analysis, Influential Observations and Computation Details for the BRM to Wipe Conversion Equations

Model Development

The individual regression equations for predicting a wipe lead loading (W) from a BRM lead loading for the R&M Mini, Rochester Lead-in-Dust, NCLSH 5-Method Comparison, and Milwaukee Low Cost Interventions studies are displayed in Table E-1. The regression models were fit as $\log(W) = \log(\alpha) + \beta*\log(BRM)$, with log referring to natural logarithm. However, the results in Table E-1 are listed using the actual scale of the data as $W = \alpha*BRM^{\beta}$. As explained in Section 3.1.7, within-house correlation was taken into account in the estimation process.

As described in Section 2, the results presented for the R&M Mini study in Table E-1 include an adjustment for the chemical extraction procedure employed for the HUD wipe samples. The correction factor is based on uncarpeted floor samples but was applied to all samples.

Figures E-1 to E-4 display the modeled relationships for wipe to BRM lead loadings for the R&M Mini, NCLSH 5-Method Comparison, Rochester Lead-in-Dust, and Milwaukee Low Cost Interventions studies, respectively. In each of these figures, the relationships for all housing components sampled are displayed individually. All plots use axes with identical scales for ease of interpretation and comparison.

Figure E-5 presents the data from each of the four studies plotted with different symbols, for wipe lead loading versus BRM lead loading results observed for uncarpeted floors. Included in this graph are the regression lines from the individual studies and the combined regression line. Using this plot a comparison can be made of the BRM loading to wipe loading relationship across the four studies. Figures E-6, E-7, and E-8 display the same type of information for carpeted floors, window sills, and window wells, respectively; information was available from fewer than four studies for these three housing components. It can be seen in these figures that the combined regression equation averaged across studies appears to fit the data in each case.

Consider Figure E-7 for window sills. The slope of the R&M Mini regression line is steeper than that for Rochester. However, the combined regression equation is more reflective of the Rochester regression. This is because the Rochester study has 362 observations compared to 27 for the R&M Mini study. The method of combining the regression equations across studies ensures more weight is given to the study with more precise parameter estimates.

Influential Observations

When conducting a regression analysis, it is important to note any points that are influential. There are several approaches to determining influential data points. One measure of influence is known as the DFBETA statistic, which is a scaled measure of the influence of any one data value upon the separate parameter estimates. Although the individual regression displayed in Table E-1 were estimated using GEE (generalized estimating equations), values for the statistic DFBETA were calculated based on simple linear regression to identify influential data points. For a simple linear regression, DFBETA is calculated for the intercept (α) and for the slope (β), respectively. The statistic is a measure of the difference between the parameter estimate (α or β) as calculated by including all data values and as calculated by excluding the i^{th} data value. The threshold value for determining which points are most influential is recommended by Belsley, Kuh, and Welsch to be 2[1]. Thus, for each regression performed in this analysis, DFBETA was calculated for α and β, and compared to the threshold value of 2. No individual data points were identified as being significantly influential according to this method.

Residual Analysis

There are also underlying assumptions that are made when conducting a regression analysis that must be validated. One such assumption is that the variability in the data remains constant across the range of the data. Residual plots (i.e., residual values on a log scale versus predicted values) have been provided for all BRM regressions performed. A random scatter of

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[1] SAS/STAT User's Guide, Version 6, Fourth Edition, Volume 2, 1990, SAS Institute Inc., pg 1419.

the points on the graph around the reference line at zero with similar range across predicted values supports the homogeneity of variance assumption of the log linear regression model.

Figure E-9 presents the corresponding residuals versus the predicted wipe loadings from the regression of wipe loading on BRM loading for uncarpeted floor samples from the four studies included in the analysis. Figure E-10 presents similar information for carpeted floors. Analogous information is displayed in Figure E-11 for window sills and E-12 for window wells. No patterns or trends can be seen in the residual plots from the BRM regressions. The analysis did not reveal any deviations from underlying assumption for the model used to develop the BRM conversion equations.

Table E-1. Regression Equations for Predicting Wipe Lead Loading From BRM Vacuum Lead Loading.

Surface	Estimated Regression Model for BRM Vacuum Pb Loading to Wipe Pb Loading[a]			
	R&M Mini[b]	NCLSH 5-Method[c]	Rochester Lead-in-Dust	Milwaukee Low Cost Interventions[d]
Floors (Uncarpeted)	$W = 3.965 * BRM^{0.617}$ n=25 Range W : 11.1 - 18960 Range BRM : 1.1 - 8337	$W = 3.151 * BRM^{0.481}$ n= 68 Range W : 1.0 - 918 Range BRM : 0.5 - 7770	$W = 2.898 * BRM^{0.235}$ n=389 Range W : 0.1 - 18130 Range BRM : 0.1 - 74100	$W = 3.47 * BRM^{0.283}$ n=135 Range W : 0.4 - 636 Range BRM : 0.2 - 22600
Floors (Carpeted)	(e)	$W = 1.453 * BRM^{0.213}$ n= 67 Range W : 0.8 - 60 Range BRM : 47.0 - 5640	$W = 2.432 * BRM^{0.232}$ n=398 Range W : 0.5 - 34600 Range BRM : 1.4 - 141000	(e)
Window Sills	$W = 6.524 * BRM^{0.739}$ n=27 Range W : 6.0 - 261400 Range BRM : 0.8 - 4170000	(e)	$W = 5.174 * BRM^{0.372}$ n=362 Range W : 0.4 - 420100 Range BRM : 0.3 - 231000	(e)
Window Wells	$W = 9.551 * BRM^{0.691}$ n=25 Range W : 174 - 2220000 Range BRM : 2.4 - 4540000	(e)	$W = 7.967 * BRM^{0.550}$ n=403 Range W : 2.7 - 1362000 Range BRM : 1.9 - 6611000	(e)

(a) Units are $\mu g/ft^2$ for vacuum and wipe dust-lead loadings.
(b) Bioavailable wipe lead loadings in the R&M Mini study were adjusted to represent total available lead loadings.
(c) Wipe lead loadings in the NCLSH 5-Method study were multiplied by 1.25 to correct for only including 80% of wipe samples in chemical analyses.
(d) Duplicate vacuum samples were excluded in determining the relationship.
(e) Equation was not fitted because data were not available or insufficient.

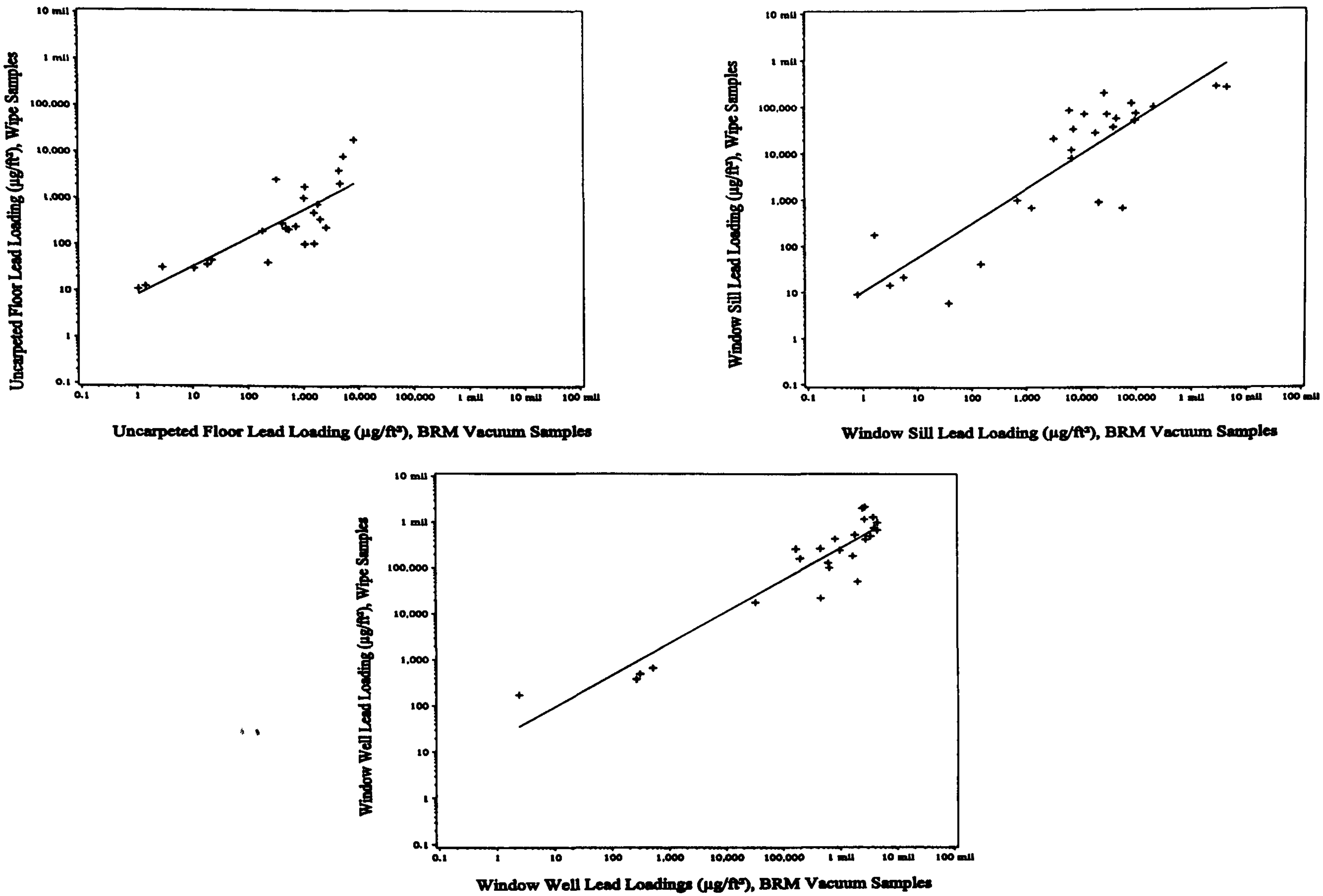

Figure E-1. Modeled Relationship Between Wipe and BRM Lead Loadings, Controlling for Within-House Correlation; R&M Mini Study.

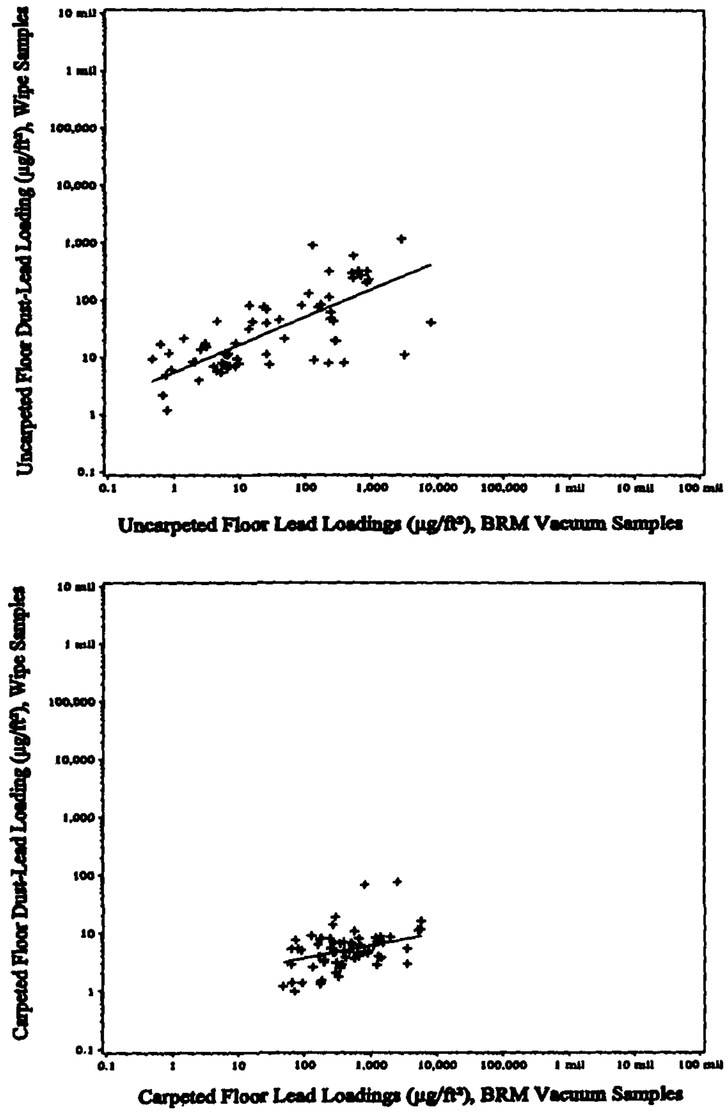

Figure E-2. Modeled Relationship Between Wipe and BRM Lead Loadings, Controlling for Within-House Correlation; NCLSH 5-Method Comparison Study.

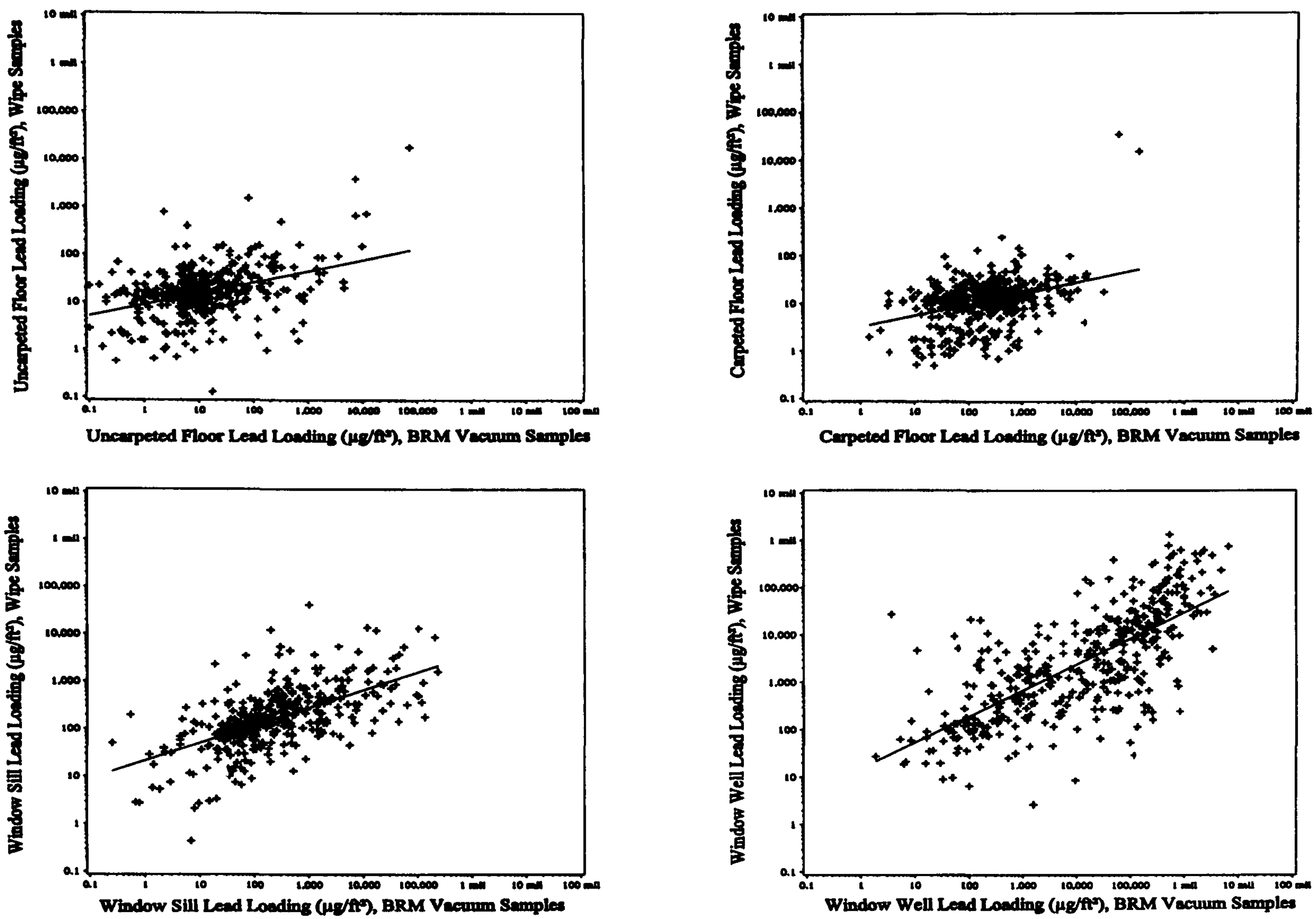

Figure E-3. Modeled Relationship Between Wipe and BRM Lead Loadings, Controlling for Within-House Correlation; Rochester Lead-In-Dust Study.

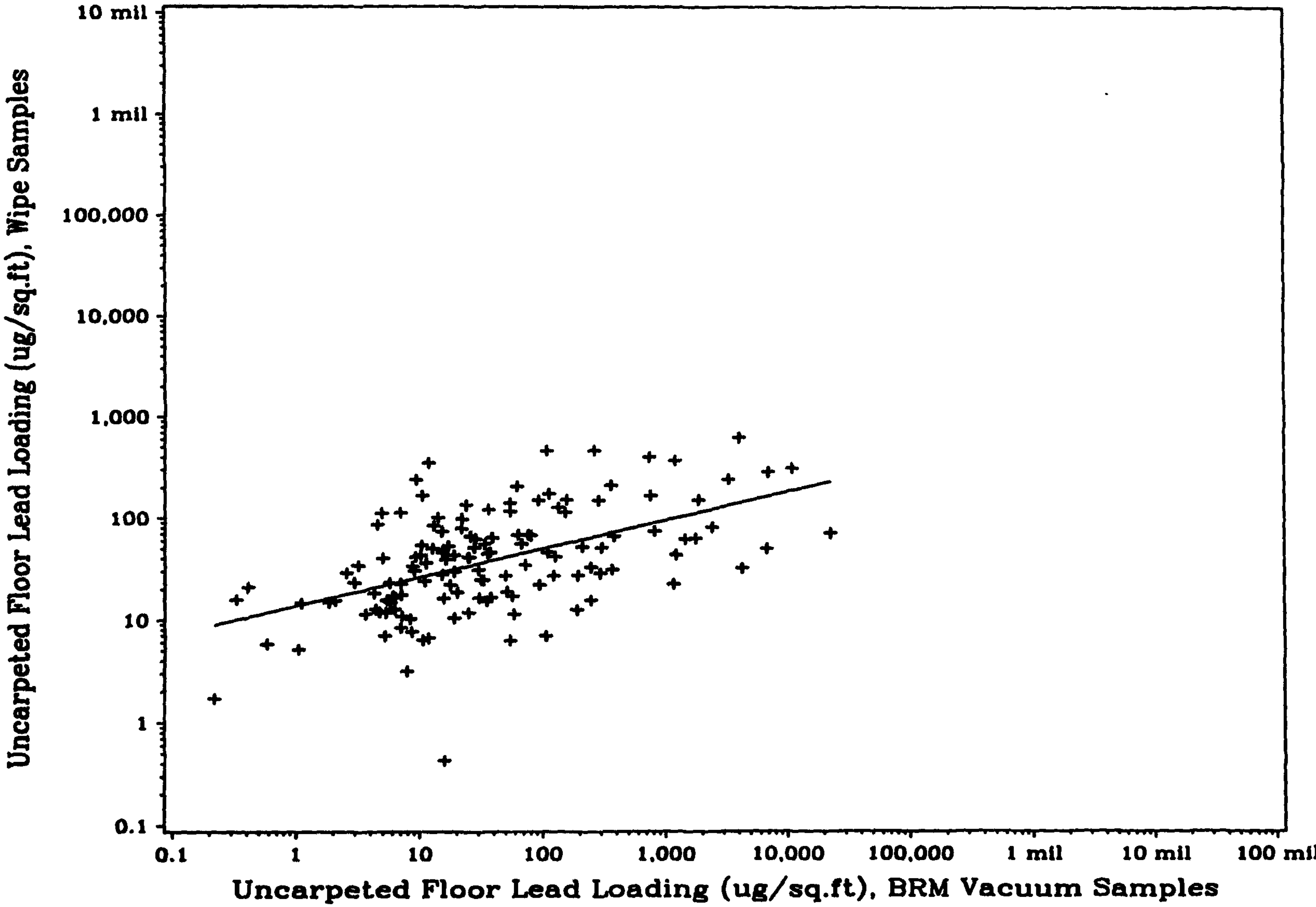

Figure E-4. Modeled Relationship Between Wipe and BRM Lead Loadings, Controlling for Within-House Correlation; Milwaukee Low Cost Interventions Study.

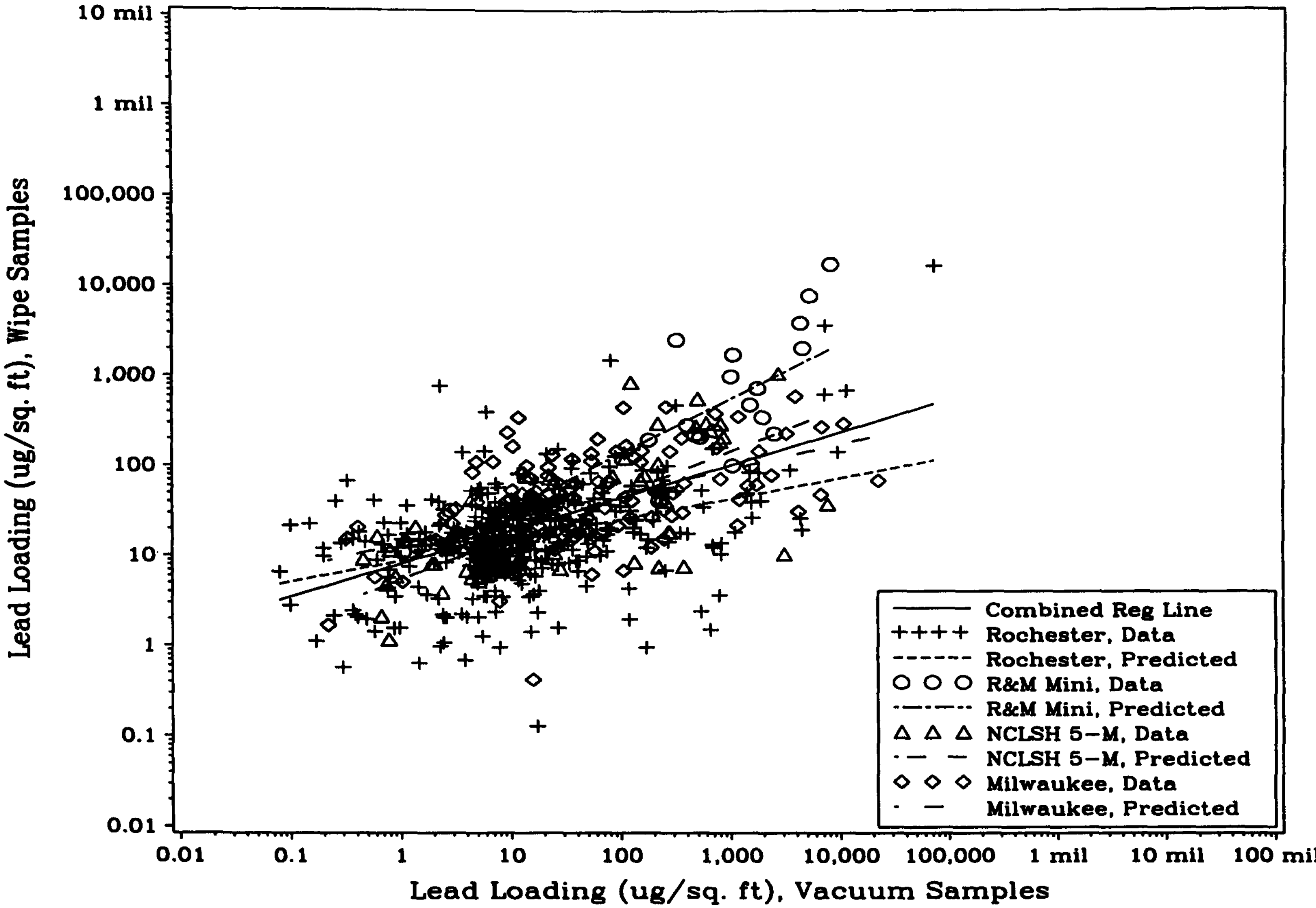

Figure E-5. Estimated BRM to Wipe Relationship, Controlling for Within-House Correlation, Based on Individual Studies and Averaged Across Studies; Uncarpeted Floors.

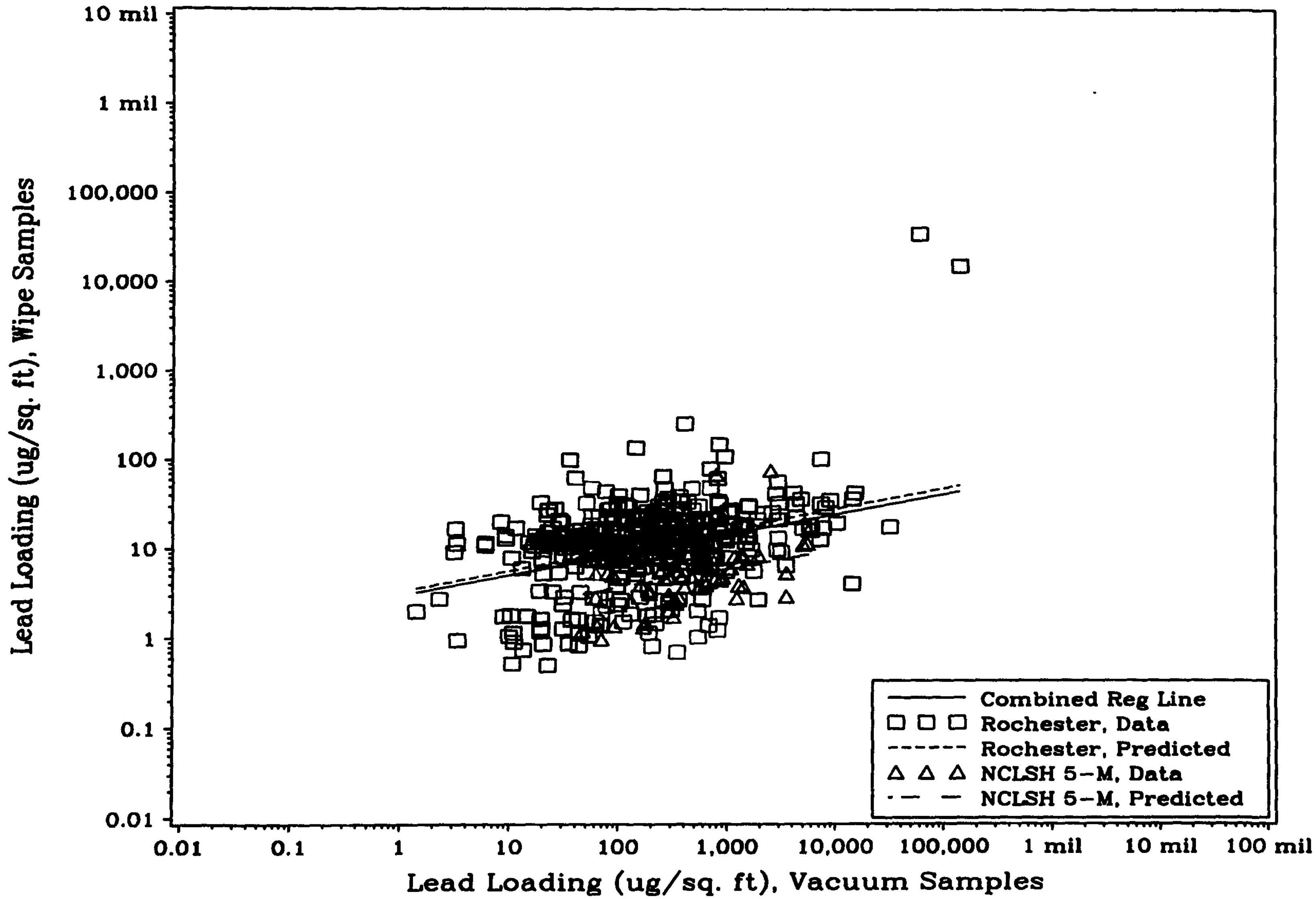

Figure E-6. Estimated BRM to Wipe Relationship, Controlling for Within-House Correlation, Based on Individual Studies and Averaged Across Studies; Carpeted Floors.

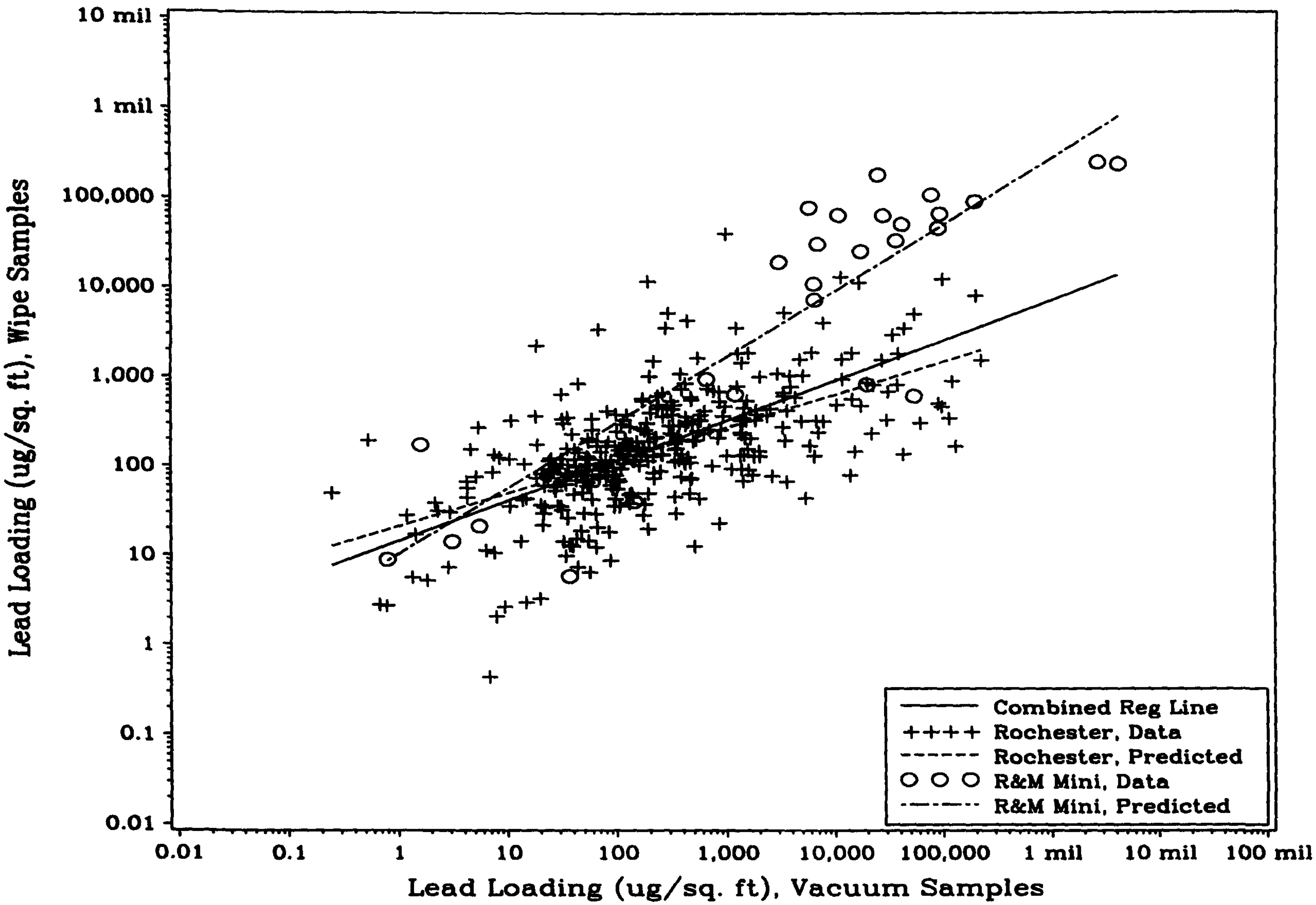

Figure E-7. Estimated BRM to Wipe Relationship, Controlling for Within-House Correlation, Based on Individual Studies and Averaged Across Studies; Window Sills.

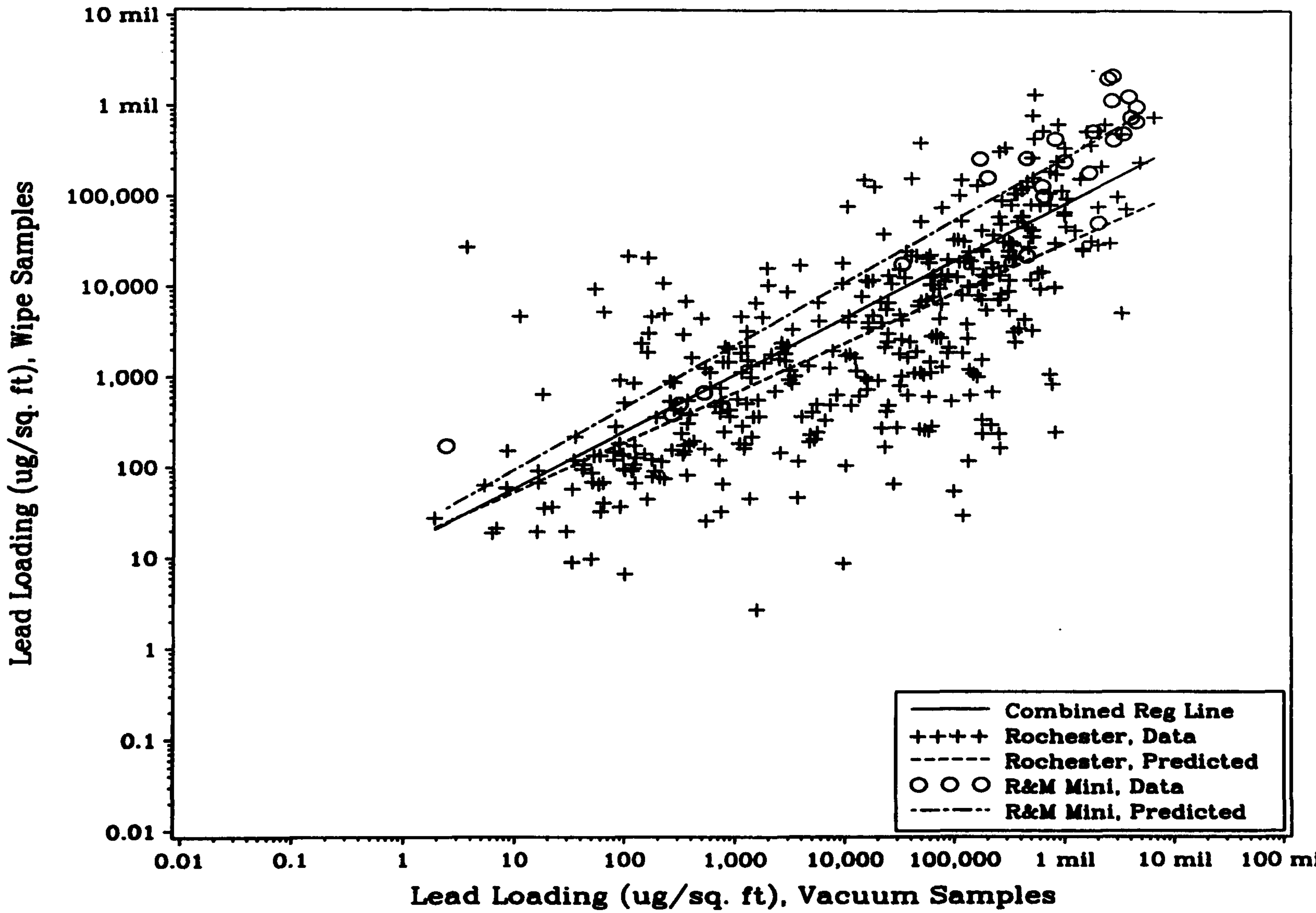

Figure E-8. **Estimated BRM to Wipe Relationship, Controlling for Within-House Correlation, Based on Individual Studies and Averaged Across Studies; Window Wells.**

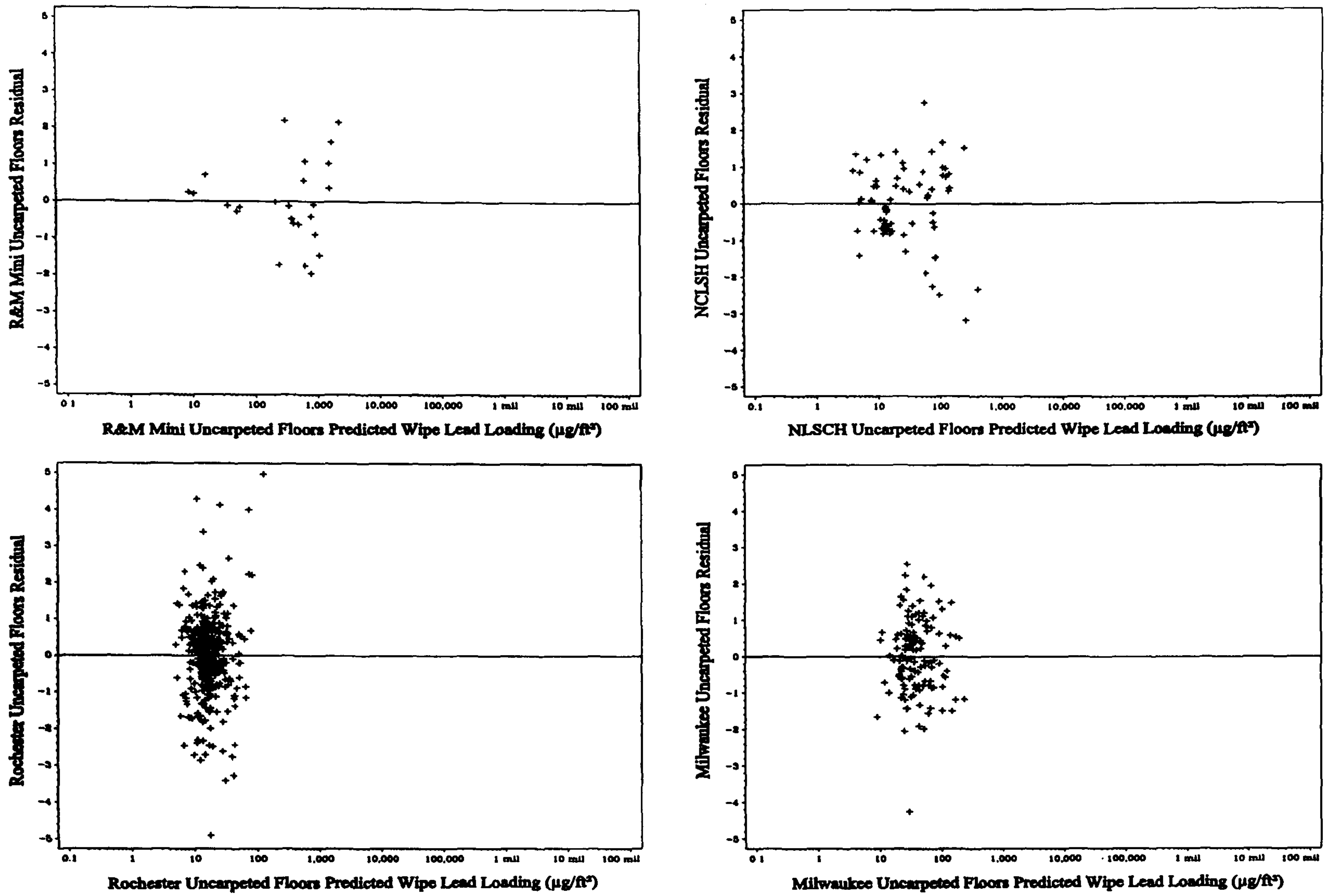

Figure E-9. Model Residuals (Log Scale) versus Predicted Wipe Lead Loading from the Regression of Wipe Lead Loading on BRM Vacuum Lead Loading for Uncarpeted Floors.

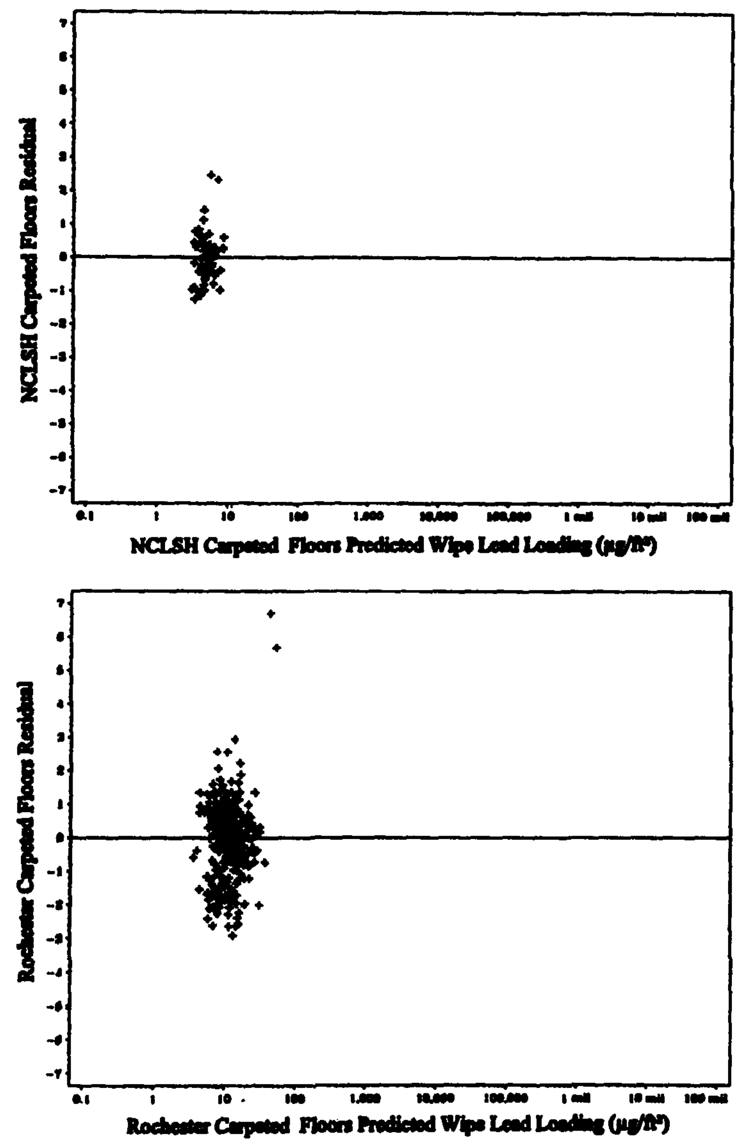

Figure E-10. Model Residual (Log Scale) and Predicted Wipe Lead Loading from the Regression of Wipe Lead Loading on BRM Vacuum Lead Loading for Carpeted Floors.

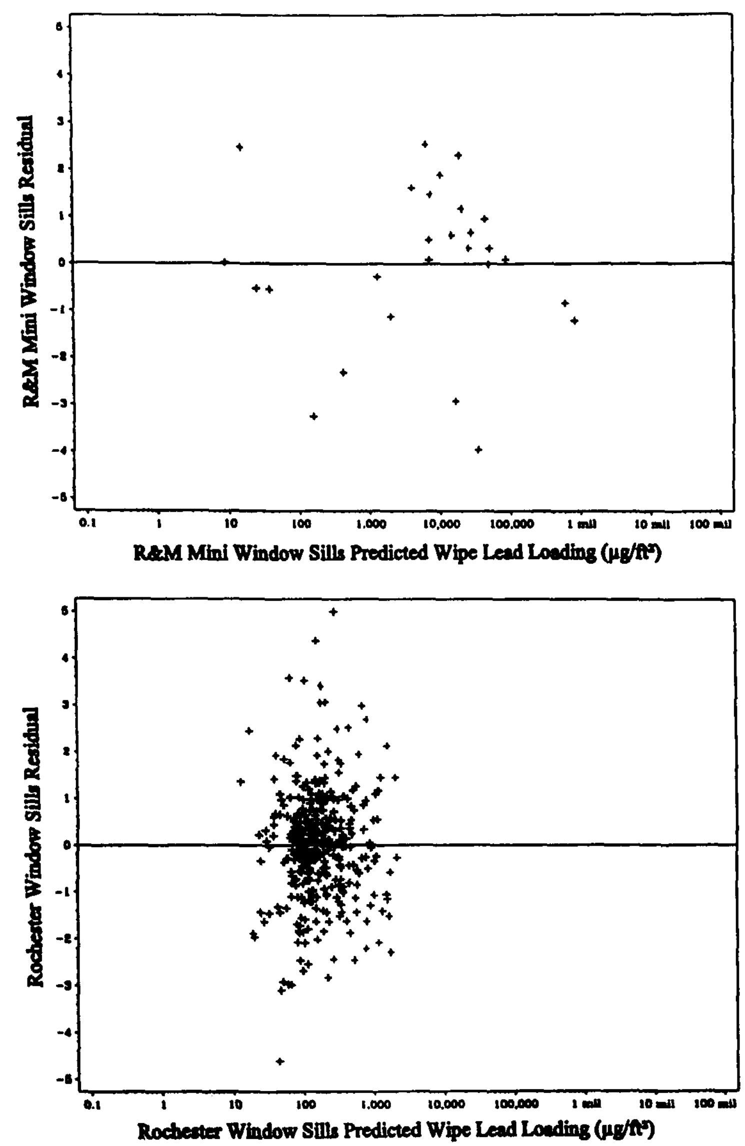

Figure E-11. Model Residual (Log Scale) and Predicted Wipe Lead Loading from the Regression of Wipe Lead Loading on BRM Vacuum Lead Loading for Window Sills.

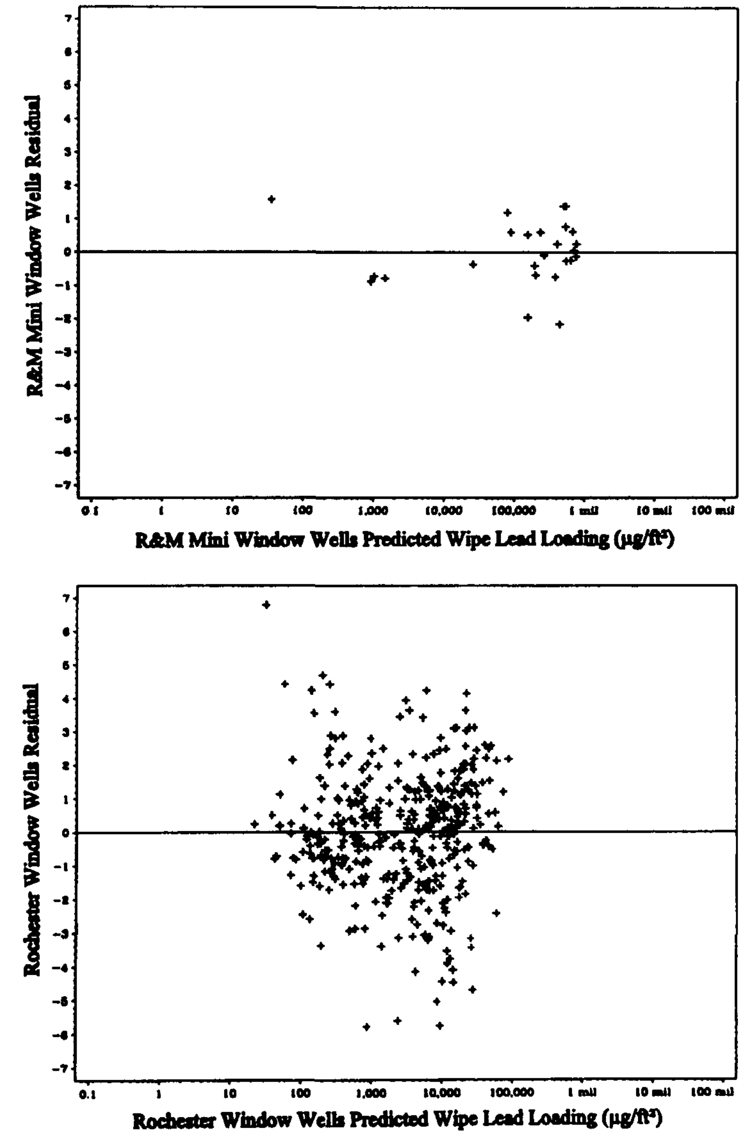

Figure E-12. Model Residual (Log Scale) and Predicted Wipe Lead Loading from the Regression of Wipe Lead Loading on BRM Vacuum Lead Loading for Window Wells.

APPENDIX F

Conversions from Wipe Lead Loading to BN Lead Concentration

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Conversions from Wipe Lead Loading to BN Lead Concentration

This appendix presents the development of a set of equations for converting a wipe lead loading to a BN vacuum lead concentration using data from the CAP Pilot and R&M Pilot studies. The development of these equations was motivated by the use of the IEUBK model to predict post-intervention blood-lead levels from an assumed post-intervention dust-lead level that will be stated as a wipe lead loading. Because lead concentrations are used as inputs to the IEUBK model, an intermediate step is required to bridge the gap between a wipe lead loading and a vacuum lead concentration. The conversion equations presented in this appendix were previously used to convert the post-intervention dust-lead loading based on a wipe sample to a comparable BN dust-lead concentration. This dust-lead concentration was then to be used as input to the IEUBK model to predict a childhood blood-lead concentration. This approach was initially used in the Section 403 risk analysis. It was later dropped in favor of a more direct approach. It is included here to document all major work done on the Section 403 risk analysis.

Distribution of Data

Tables F-1 through F-4 display the distribution of data by groupings of wipe lead loading and BN vacuum lead concentration for the CAP Pilot and R&M Pilot studies. Tables F-1 and F-2 show that about half of the data from the CAP Pilot study have wipe lead loadings less than 50 $\mu g/ft^2$. Tables F-3 and F-4 indicate that a large portion of the R&M Pilot study has vacuum lead concentrations greater than 400 $\mu g/g$.

Abated versus Unabated

It is reasonable to suggest that children's blood-lead concentrations will differ depending on whether or not they reside in a dwelling that has undergone some sort of lead intervention. Therefore, it may be important to account for this in the wipe loading to BN concentration conversion equation, since the converted concentration could be used to predict post-intervention blood-lead levels. Figure F-1 displays all of the data used to develop the wipe loading to BN concentration conversion equation (i.e., CAP Pilot and R&M Pilot) for each housing component. Abated and unabated homes are plotted with different symbols. It can be seen that for each housing component, both types of homes span the range of the data. This suggests that there is no reason to separate abated homes from unabated homes to develop the wipe loading to BN concentration conversion equation.

Statistical Approach and Results

A model analogous to that described in the report for converting a wipe lead loading to a BN lead loading is useful for characterizing the relationship between wipe lead loading and BN lead concentration. The model can be written as follows:

$$\log(BN) = \log(\alpha)+\beta \log(W)+\log(E)$$

or equivalently as,

$$BN = \alpha W^{\beta} E,$$

where BN represents Blue Nozzle vacuum lead concentration, W represents wipe lead loading, and E represents a random error term. Similar models were fit separately for each study and housing component. The parameter estimates were then combined across studies as described in Section 3.1.5 of the report.

Table F-5 presents the equations for predicting a Blue Nozzle lead concentration from a wipe lead loading for the CAP Pilot and R&M Pilot studies. Equations are presented separately for uncarpeted floors, window sills, and window wells. The results presented for the R&M Pilot study in Table F-5 include an adjustment for the chemical extraction procedure employed for the HUD wipe samples. Figures F-2 and F-3 illustrate the modeled relationships between wipe lead loading and Blue Nozzle vacuum lead concentration for each housing component in the studies involved. Table F-6 presents the final conversion equations for uncarpeted floors, window sills and window wells, as well as the number of samples included in the analysis. Table F-7 displays the predicted levels associated with nominal wipe lead loadings of 10, 40, 100, 200, 500, and 1000 μg/ft² for uncarpeted floors, window sills, and window wells. For example, an uncarpeted floor wipe loading of 200 μg/ft² would be converted to a BN lead concentration of 799 μg/g.

The second line in each cell of Table F-7 represents an approximate 95% confidence interval on the conversion. These represent confidence bounds on the estimate of the geometric mean level, associated with the nominal levels from which they are converted. Thus, for an uncarpeted floor wipe lead loading of 100 μg/ft², the geometric mean BN lead concentration is 545 μg/g, and there is 95% confidence that the geometric mean of the BN lead concentrations taken at the same location would be between 433 and 684 μg/g.

The third line in each cell provides an approximate 95% prediction interval for the conversions. These are bounds that are expected to contain 95% of the individual observations associated with the specified nominal levels of the prediction variables. Thus, for an uncarpeted floor wipe lead loading of 100 μg/ft², the geometric mean point estimate of the BN lead concentration is 545 μg/g, and it is expected that 95% of BN concentration loadings measured at the same location will be between 157 and 1,890 μg/g.

Figure F-4 displays the BN lead concentration versus wipe lead loading relationship for uncarpeted floors. The first plot in the figure presents the data from the CAPS Pilot and R&M Pilot studies plotted with different symbols. Included in this graph are the regression lines from the individual studies. Using this plot, a comparison can be made of the wipe loading to BN concentration relationships across the two studies. The second graph in the figure displays the data for each study, and the combined regression line and its approximate 95% confidence bounds. Figures F-5 and F-6 display analogous information for window sills and window wells, respectively.

Influential Observations and Residual Analysis

Figures F-7, F-8, and F-9 display the data for predicting a BN lead concentration from a wipe loading from uncarpeted floors, window sills and window wells, respectively, indicating those data values which were significantly influential in estimating the relationship between BN lead concentration and wipe lead loading. (See Appendices C and D for a description of the statistical analysis used to identify influential data values.) The figures for uncarpeted floors and window sills each indicate one observation as significantly influential, for both alpha and beta. The influential observations have predicted values significantly distant from the other observations in each data set. Both of these influential points are from the CAP Pilot study.

Figures F-10, F-11, and F-12 present the corresponding residuals versus the predicted BN lead concentrations obtained from the respective regression analyses, for uncarpeted floors, window sills and window wells. No notable departures from the model assumptions were demonstrated by the residual analysis.

An important assumption in the development of these conversion equations is that dust levels in the houses used to develop the equations are similar to dust levels in the houses on which the equations will be applied. The relationship between dust-lead loading and dust-lead concentration is dictated by the amount of dust present. Before using the conversion equations provided in this section, it would be necessary to check this assumption.

Table F-1. Number of Samples by Wipe Lead Loading and Vacuum Lead Concentration, CAP Pilot Study — Uncarpeted Floors.

Wipe Lead Loading (μg/ft²)	Blue Nozzle Vacuum Lead Concentration (μg/g)					
	50-100	100-200	200-300	300-400	400 +	Total
0-50	2	1	1	1	0	5
50-200	0	0	0	0	0	0
200+	0	0	0	0	1	1
Total	2	1	1	1	1	6

Table F-2. Number of Samples by Wipe Lead Loading and Vacuum Lead Concentration, CAP Pilot Study — Uncarpeted Floors and Window Sills.

Wipe Lead Loading (μg/ft²)	Blue Nozzle Vacuum Lead Concentration (μg/g)					
	50-100	100-200	200-300	300-400	400 +	Total
0-50	2	1	1	2	1	7
50-200	0	1	0	0	1	2
200+	0	0	0	0	3	3
Total	2	2	1	2	5	12

Table F-3. Number of Samples by Wipe Lead Loading and Vacuum Lead Concentration, R&M Pilot Study — Uncarpeted Floors.

Wipe Lead Loading (μg/ft²)	Blue Nozzle Vacuum Lead Concentration (μg/g)					
	75-100	100-150	150-200	200-400	400 +	Total
0-25	1	1	3	3	1	9
25-50	0	0	0	0	0	0
50-75	0	0	0	2	2	4
100-150	0	0	0	0	2	2
150-200	0	0	0	0	3	3
200-400	0	0	0	0	2	2
400+	0	0	0	0	4	4
Total	1	1	3	5	14	24

Table F-4. Number of Samples by Wipe Lead Loading and Vacuum Lead Concentration, R&M Pilot Study — Uncarpeted Floors, Window Sills, and Window Wells.

Wipe Lead Loading (µg/ft²)	Blue Nozzle Vacuum Lead Concentration (µg/g)					
	75-100	100-150	150-200	200-400	400 +	Total
0-25	1	2	4	6	5	18
25-50	0	0	0	0	0	0
50-75	0	0	0	2	4	6
100-150	0	0	0	0	3	3
150-200	0	0	0	0	5	5
200-400	0	0	0	2	6	8
400+	0	0	0	1	30	31
Total	1	2	4	11	53	71

Table F-5. Regression Equations for Predicting Blue Nozzle Vacuum Lead Concentration From Wipe Lead Loading.

Surface	Estimated Regression Model for Wipe Pb Loading[(a)] to Blue Nozzle Vacuum Pb Concentration[(b)]	
	CAP Pilot	R&M Pilot
Floors (Uncarpeted)	$BN = 26.6 \cdot W^{0.528}$ n=6 R^2=0.781[(c)] Range W: 13.8 - 2498.5 Range BN: 82.2 - 1772.3	$BN = 47.9 \cdot W^{0.556}$ n=24 R^2=0.785 Range W: 6.3 - 13969 Range BN: 91 - 9052
Window Sills	$BN = 83.1 \cdot W^{0.382}$ n=6 R^2 =0.520 Range W: 24.4 - 4216.9 Range BN: 176.8 - 3580.9	$BN = 183 \cdot W^{0.404}$ n=23 R^2 =0.687 Range W: 2.2 - 1578393 Range BN: 150 - 52547
Window Wells	(d)	$BN = 32.1 \cdot W^{0.590}$ n=24 R^2 =0.534 Range W: 5.5 - 1205554 Range BN: 235 - 366121

(a) Units are µg/ft² for wipe dust-lead loadings.
(b) Units are µg/g for vacuum dust-lead concentrations.
(c) R^2 represents the amount of variation explained by the log-linear regression model.
(d) Equation was not fitted because data were not available or insufficient.

Table F-6. Final Conversion Equations for Uncarpeted Floors, Window Sills and Window Wells Based on Combined Data.

Wipe Loading to BN Concentration Conversion	Number of Observed Pairs	Conversion Equation
Uncarpeted Floors	30	$BN = 43.0*W^{0.551}$
Window Sills	29	$BN = 144.0*W^{0.402}$
Window Wells	24	$BN = 32.1*W^{0.580}$

Table F-7. Predicted Vacuum Lead Concentrations For Selected Wipe Lead Loadings Based on Weighted Average of Regression Coefficients on Uncarpeted Floors, Window Sills and Window Wells.

Wipe Pb Loading (µg/ft²)	Uncarpeted Floors	Window Sills	Window Wells
	Blue Nozzle Vacuum Concentration (µg/g) (95% Confidence Interval) (95% Prediction Interval)	Blue Nozzle Vacuum Concentration (µg/g) (95% Confidence Interval) (95% Prediction Interval)	Blue Nozzle Vacuum Concentration (µg/g) (95% Confidence Interval) (95% Prediction Interval)
10	153 (108, 218) (42.8, 546)	364 (207, 645) (44.5, 3000)	125 (25.2, 618) (3.03, 5140)
40	329 (255, 423) (94.2, 1150)	636 (401, 1010) (79.8 , 5090)	283 (75.9, 1050) (7.68, 10400)
100	545 (433, 684) (157, 1890)	919 (610, 1390) (117, 7270)	486 (156, 1510) (14.0, 16800)
200	799 (628, 1010) (229, 2770)	1210 (826, 1790) (155, 9560)	731 (265, 2010) (21.9, 24400)
500	1320 (992, 1760) (376, 4650)	1760 (1200, 2560) (224, 13800)	1260 (527, 2990) (39.1, 40200)
1000	1940 (1380, 2730) (544, 6900)	2320 (1580, 3420) (296, 18300)	1890 (867, 4110) (60.2, 59300)

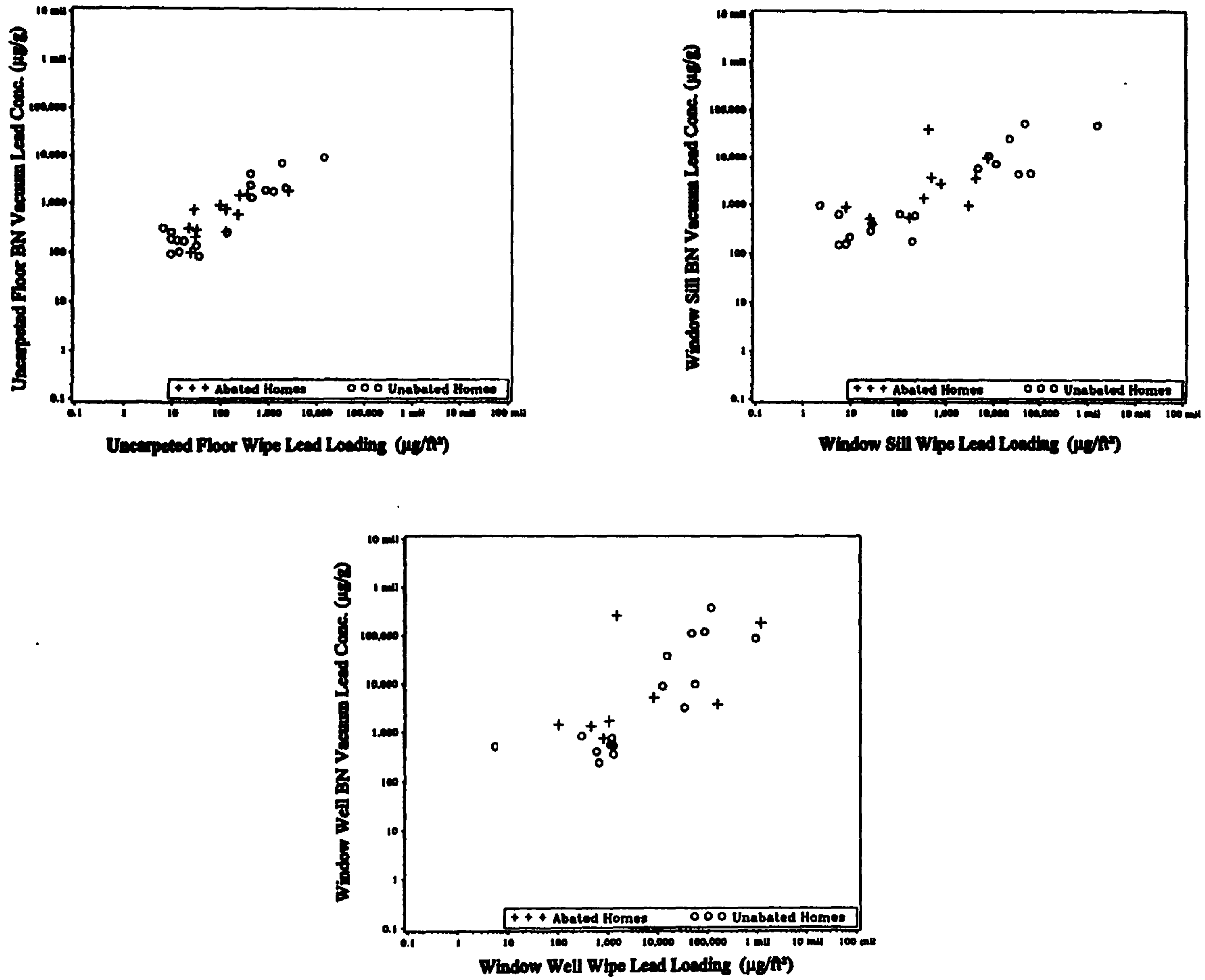


Figure F-1. Blue Nozzle Vacuum Concentration versus Wipe Lead Loading Displaying the Distribution of Abated and Unabated Homes Across the CAP Pilot and R&M Pilot Data Used to Develop the Conversion Equations for Uncarpeted Floors, Window Sills, and Window Wells.

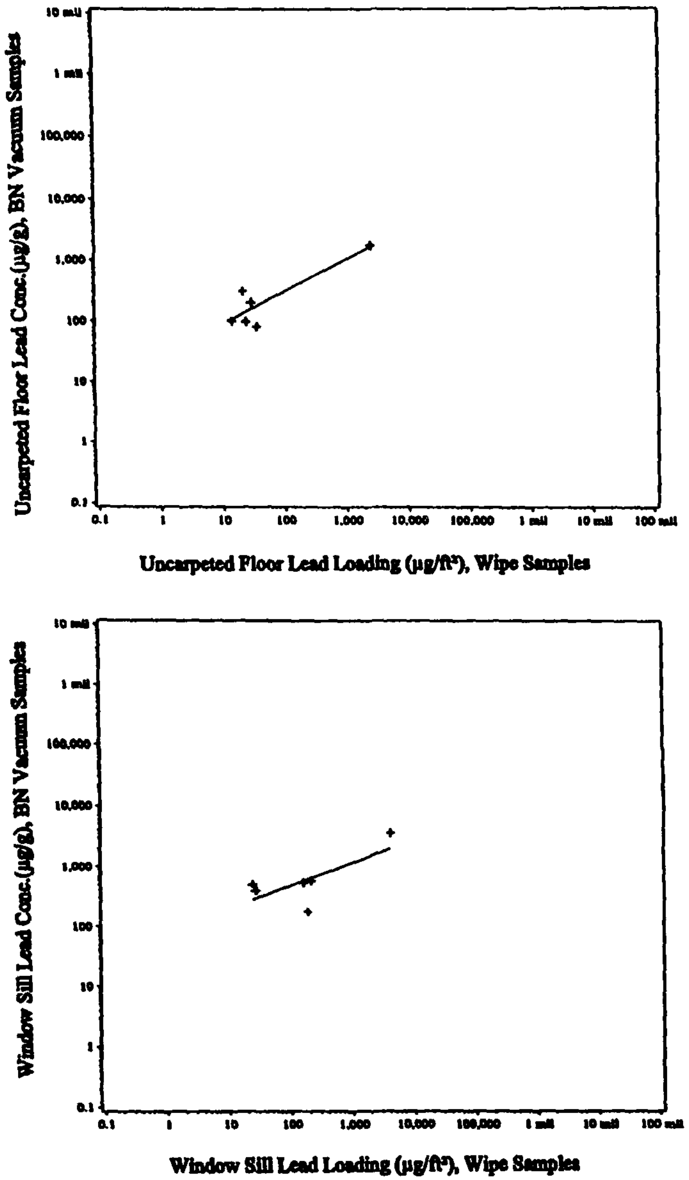


Figure F-2. Blue Nozzle Vacuum Lead Concentration versus Wipe Lead Loading for Uncarpeted Floors and Window Sills from the CAP Pilot Study.

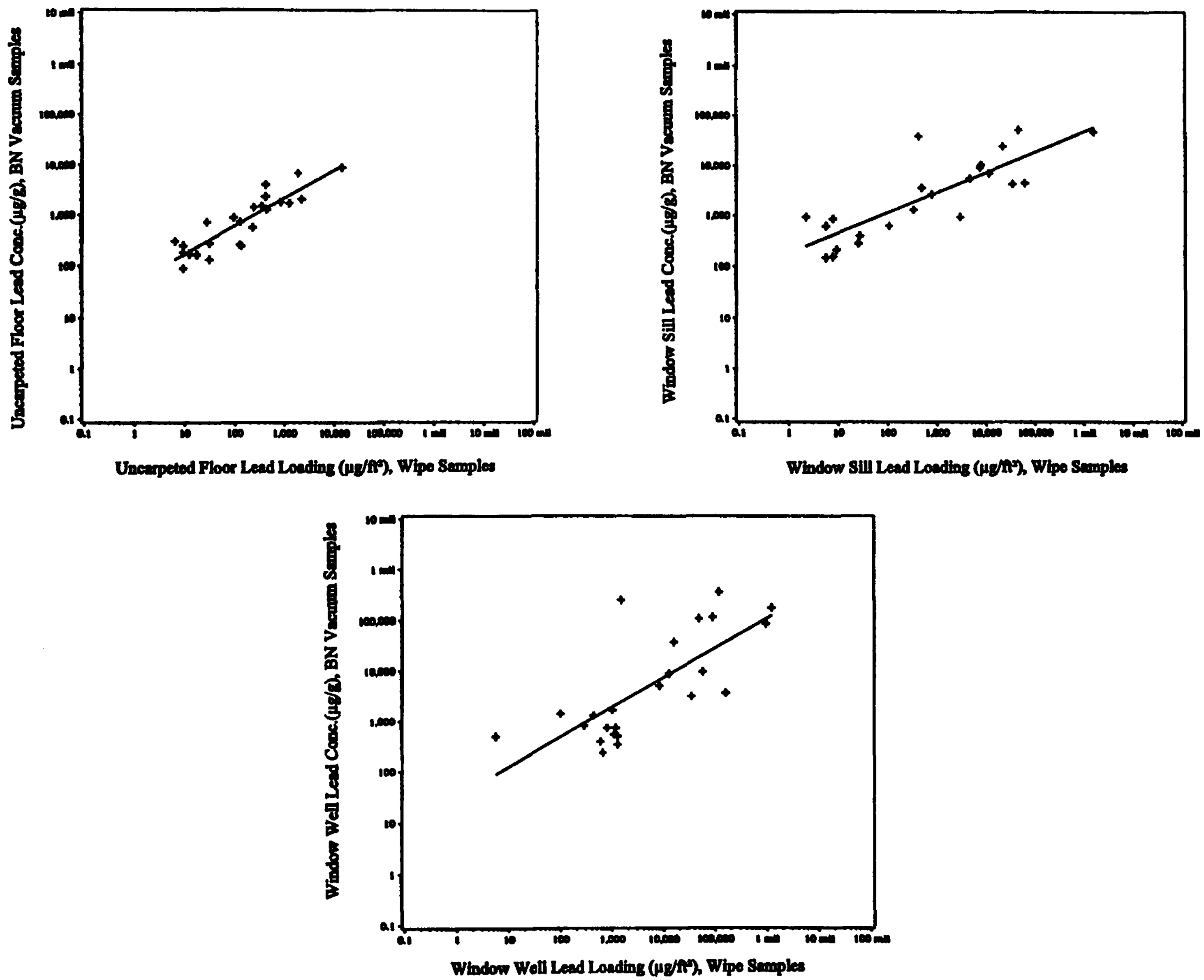
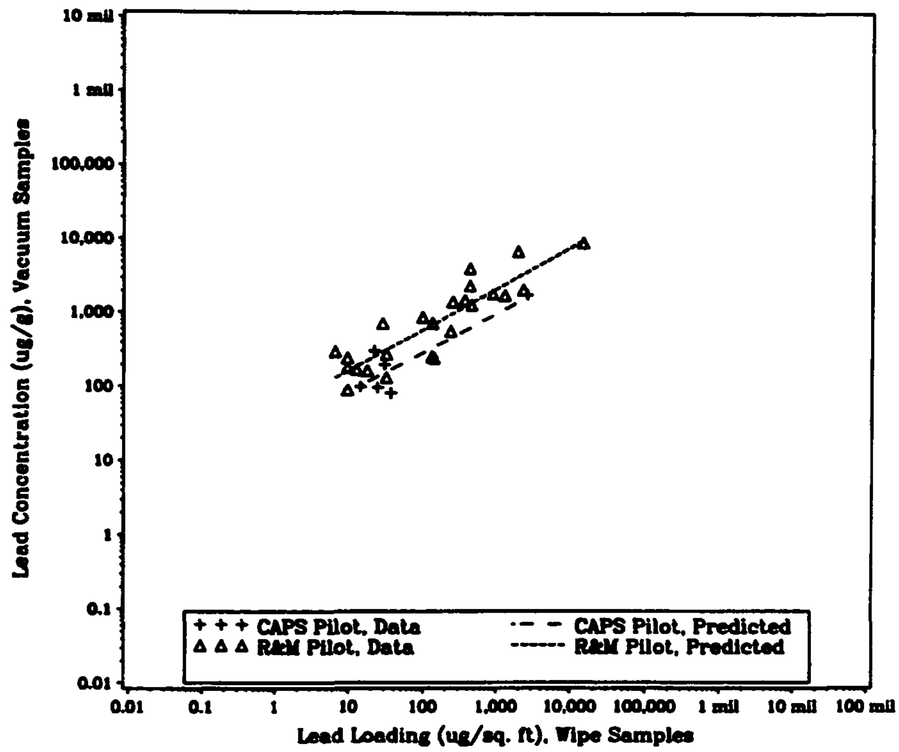


Figure F-3. Blue Nozzle Lead Concentration versus Wipe Lead Loading for Uncarpeted Floors, Window Sills, and Window Wells from the R&M Pilot Study.



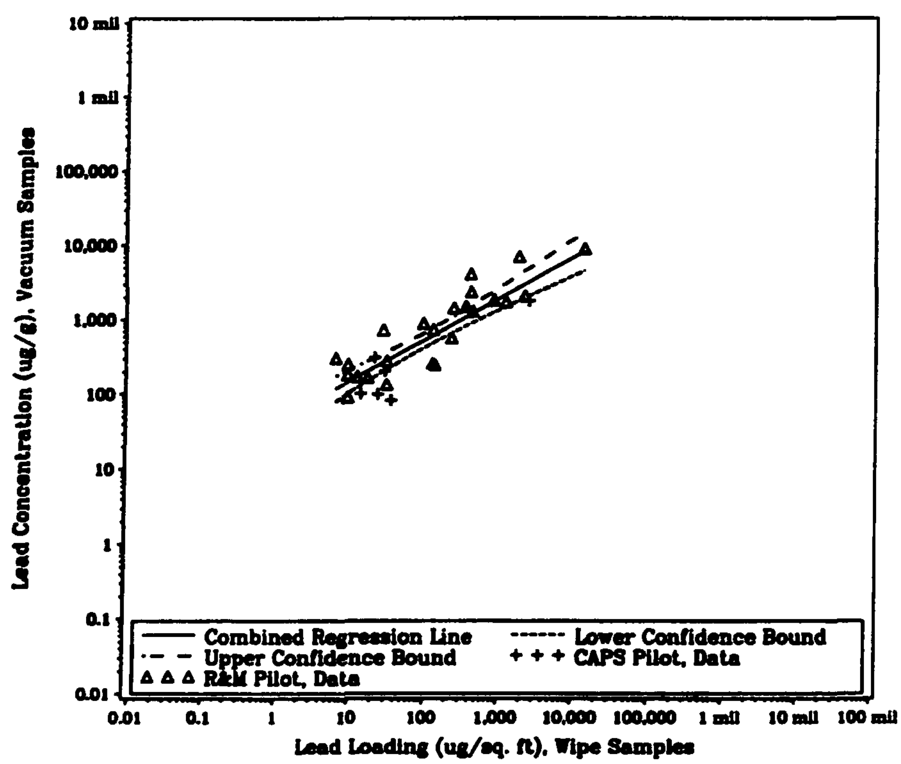
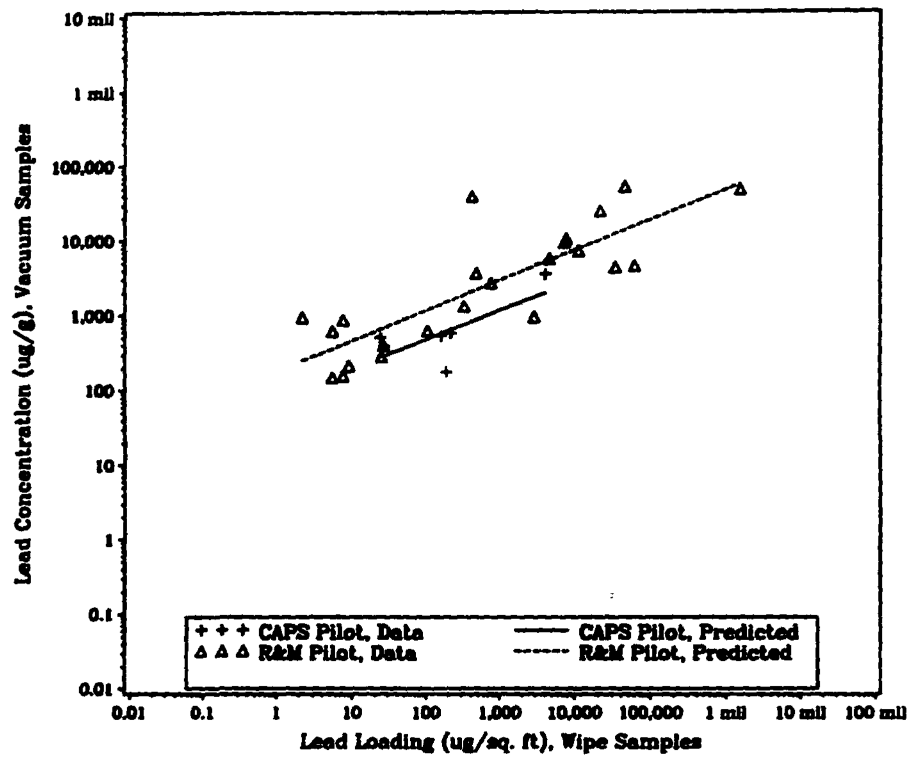


Figure F-4. Predicted BN Lead Concentration Versus Wipe Lead Loading on Uncarpeted Floors, Individual and Combined Regressions. Confidence Bands for Combined Regressions and Data Overlaid.



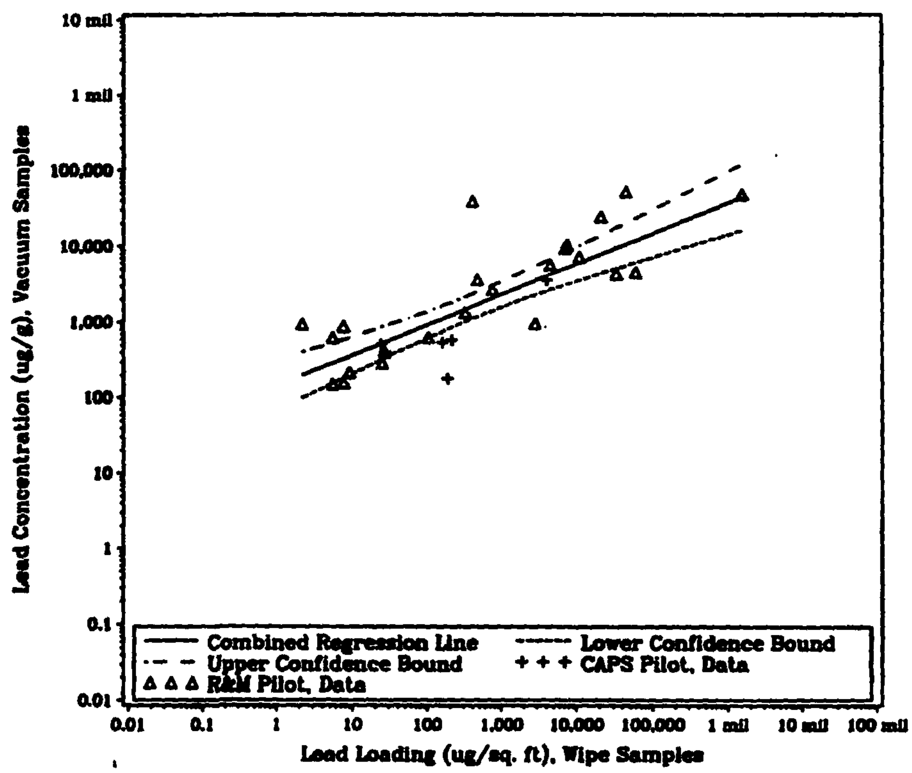


Figure F-5. Predicted BN Lead Concentration Versus Wipe Lead Loading on Window Sills, Individual and Combined Regressions. Confidence Bands for Combined Regressions and Data Overlaid.

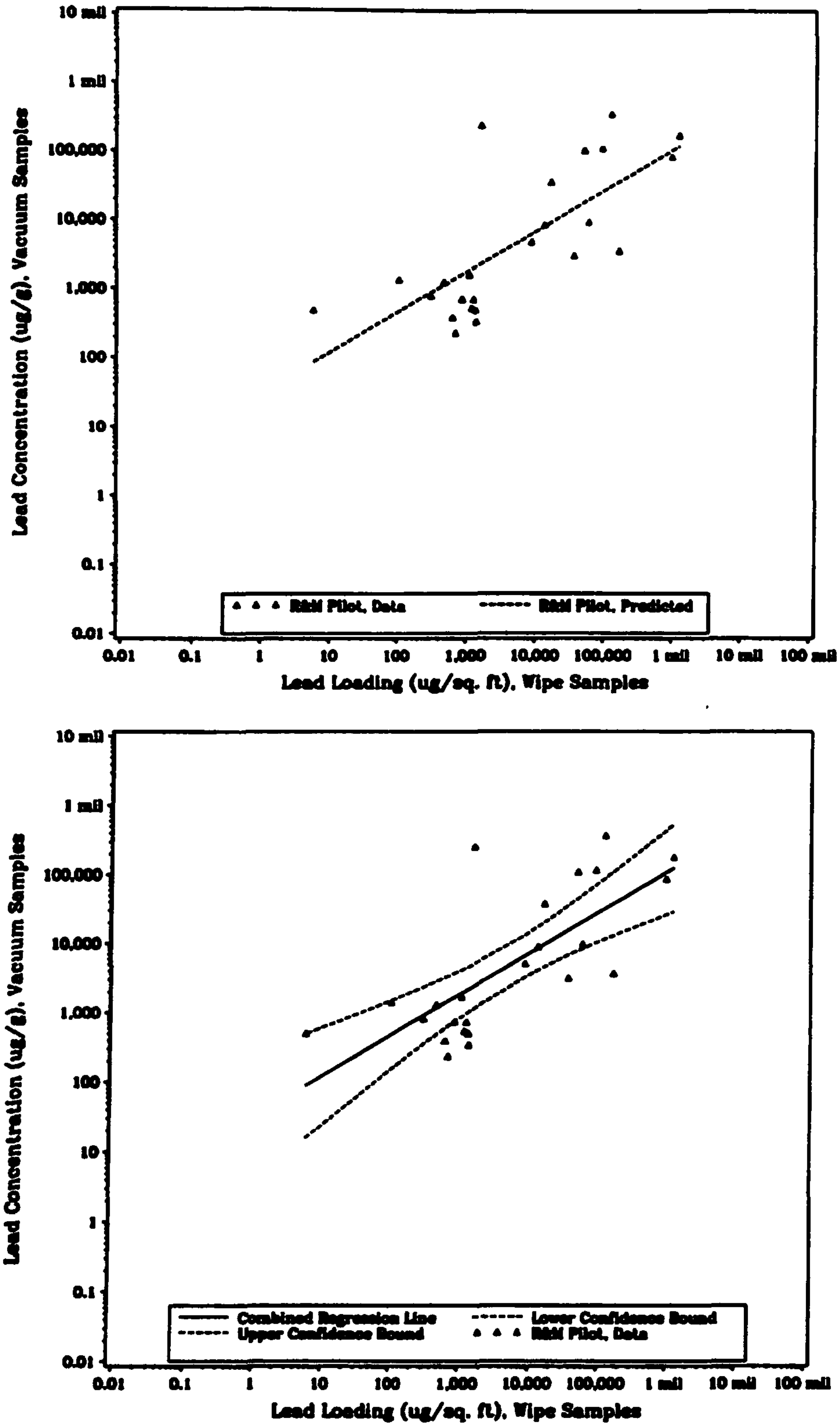


Figure F-6. Predicted BN Lead Concentration Versus Wipe Lead Loading on Window Wells, Individual and Combined Regressions. Confidence Bands for Combined Regressions and Data Overlaid.

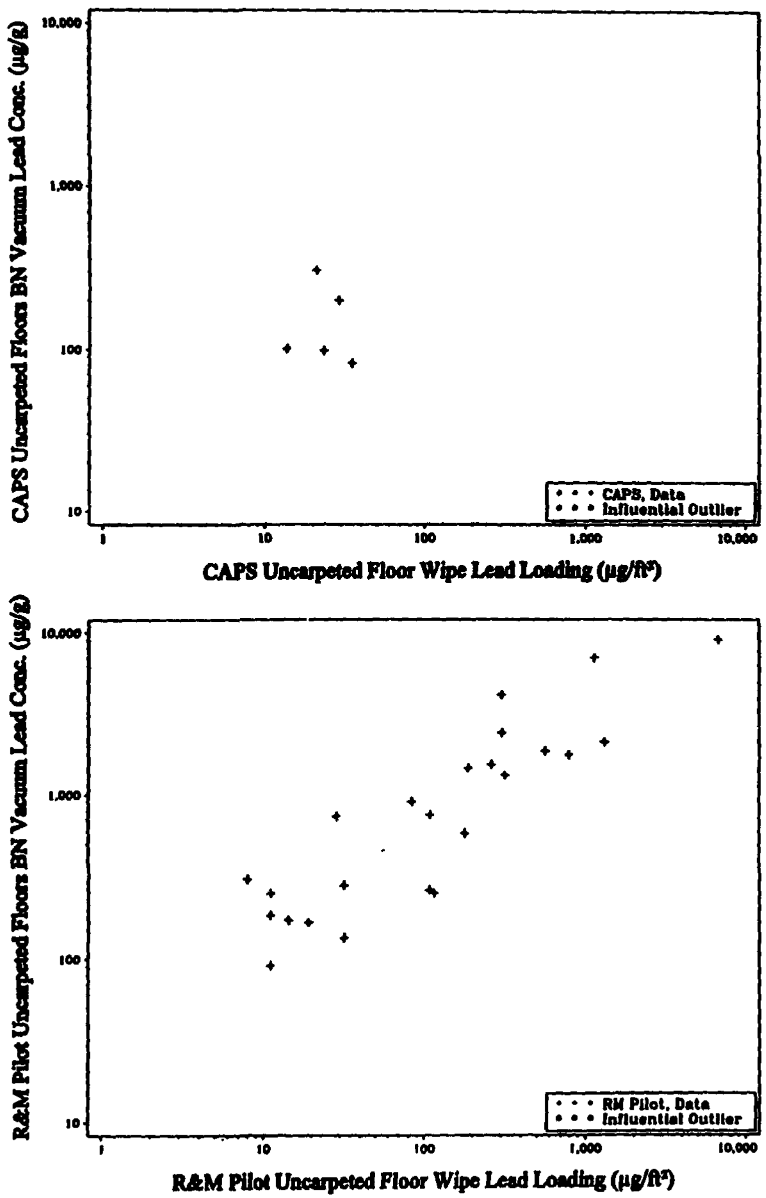


Figure F-7. Influential Observations in the Regression of Blue Nozzle Lead Concentration on Wipe Lead Loading for Uncarpeted Floors from the CAP Pilot and R&M Pilot Studies.

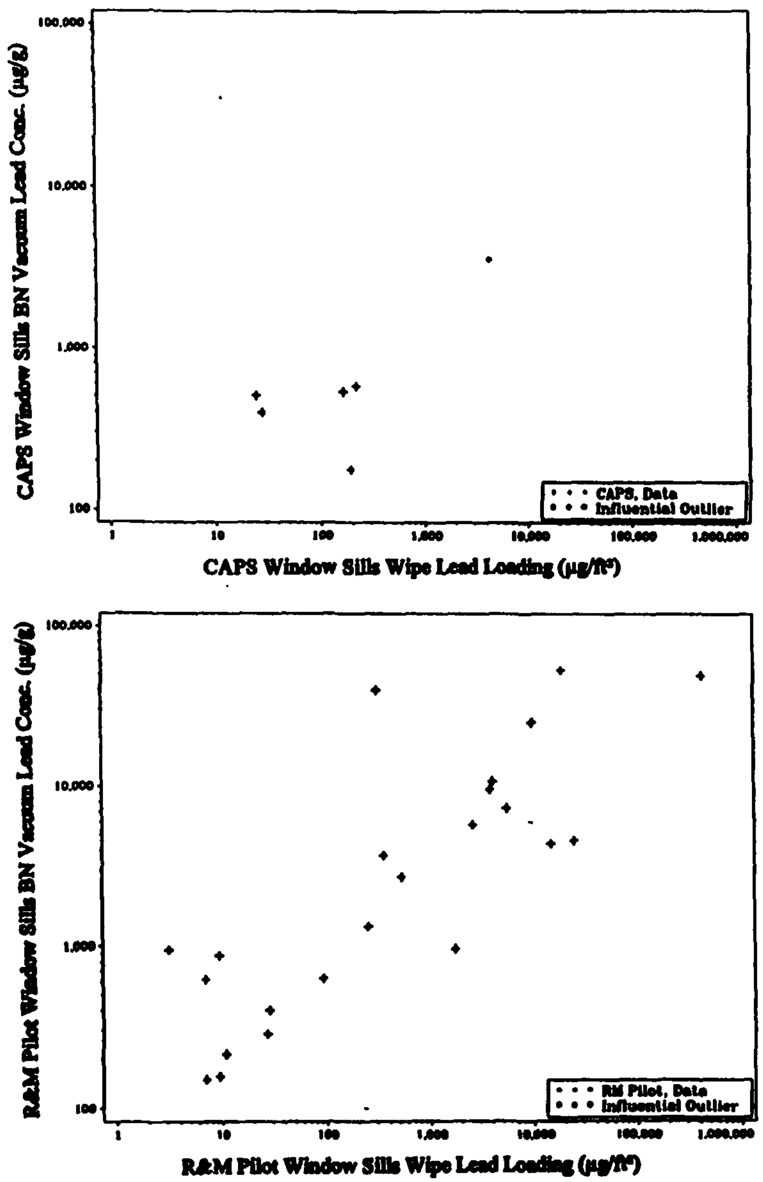


Figure F-8. Influential Observations in the Regression of Blue Nozzle Vacuum Lead Concentration on Wipe Lead Loading for Window Sills from the CAP Pilot and R&M Pilot Studies.

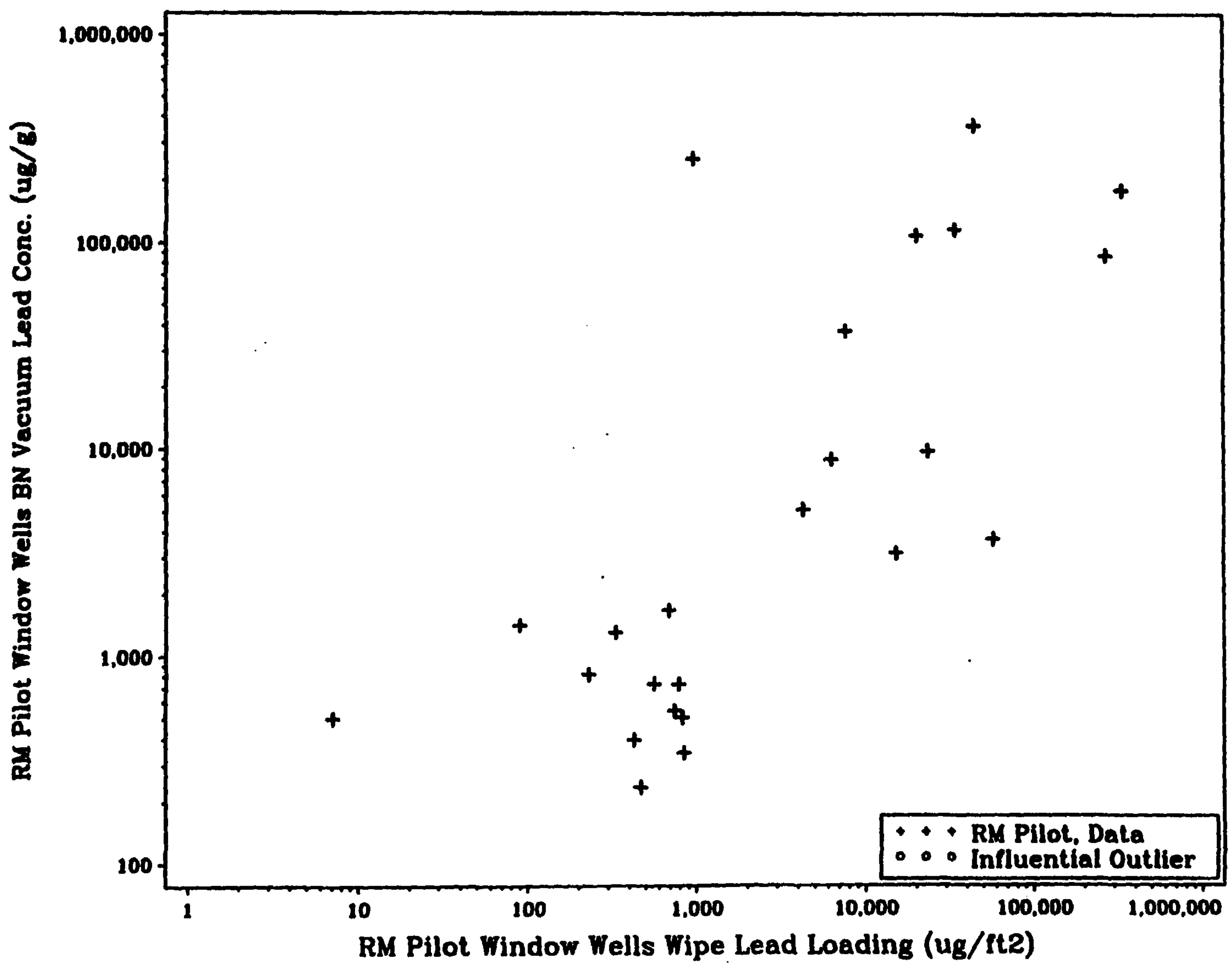


Figure F-9. Individual Observations in the Regression of Blue Nozzle Vacuum Lead Concentration on Wipe Lead Loading for Window Wells from the R&M Pilot Study.

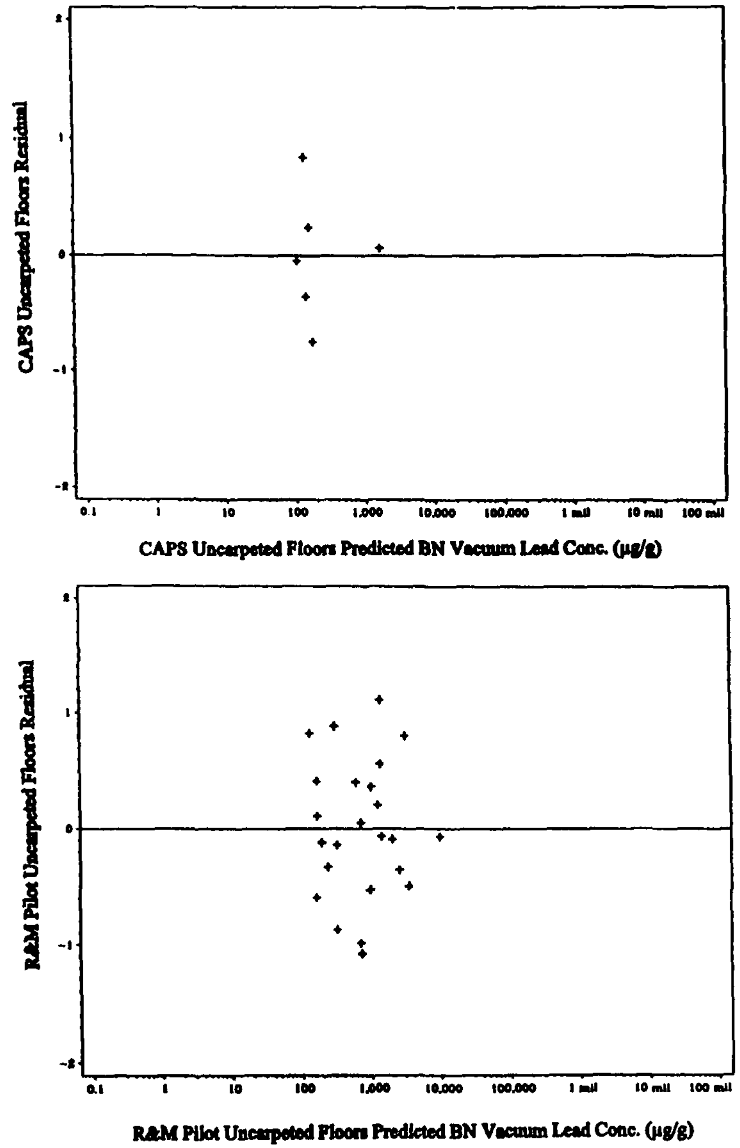


Figure F-10. Residual (Log Scale) and Predicted Blue Nozzle Lead Concentration from the Regression of Blue Nozzle Vacuum Lead Concentration on Wipe Lead Loading for Uncarpeted Floors from the CAP Pilot and R&M Pilot Studies.

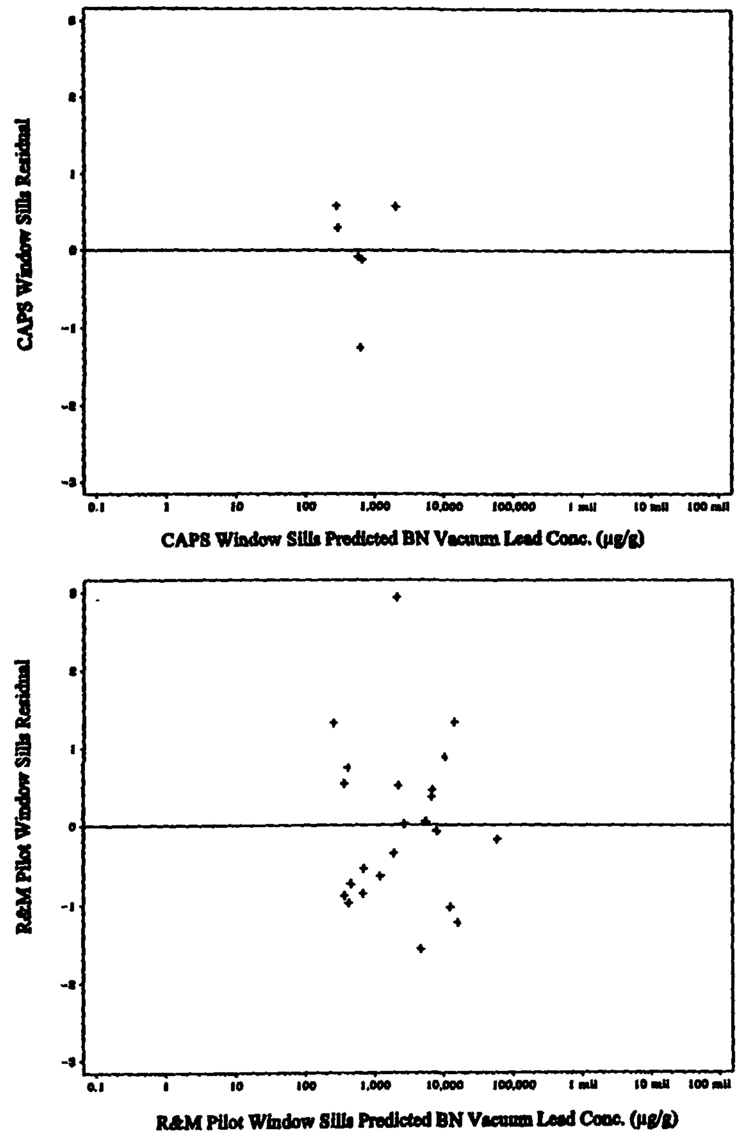


Figure F-11. Residual (Log Scale) and Predicted Blue Nozzle Lead Concentration from the Regression of Blue Nozzle Vacuum Lead Concentration on Wipe Lead Loading for Window Sills from the CAP Pilot and R&M Pilot Studies.

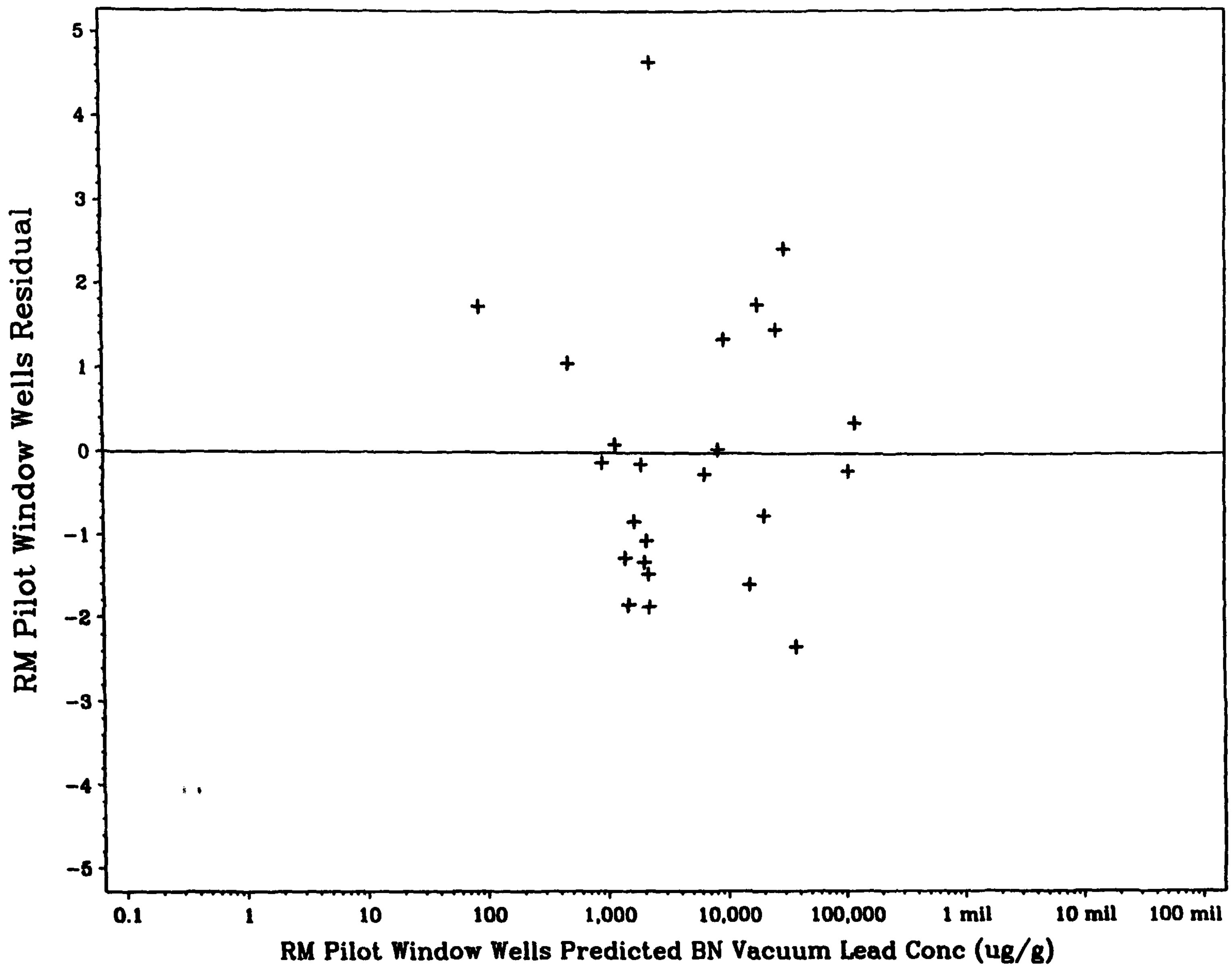


Figure F-12. Residual (Log Scale) and Predicted Blue Nozzle Vacuum Lead Concentration from the Regression of Blue Nozzle Vacuum Lead Concentration on Wipe Lead Loading for Window Wells from the R&M Pilot Study.

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15. Supplementary Notes

Other Battelle staff involved in the production of this report included Ron Menton, Priti Kumar, Ying-Liang Chou, Jyothi Nagaraja, and Melissa Smith. Dr. Ray Carroll of Texas A&M University was a consultant to Battelle.

16. Abstract (Limit 200 words)

This report presents equations used to carry out various conversions between wipe lead loadings and vacuum lead loadings and vacuum concentrations, based on two different vacuum samplers, the Blue Nozzle (used in the HUD National Survey) and the BRM (used in the Baltimore Repair and Maintenance study). These equations were developed for use in the determination of health-based standards of environmental lead in residential settings as required by Section 403 of Title IV TSCA. Various equations were derived to facilitate the development of a proposed set of options for the Section 403 standards, to enable a risk analysis of these options to be conducted, and to provide a means of predicting the post-Section 403 blood-lead levels nationally.

17. Document Analysis

a. Descriptors

Lead, Lead in Dust, Vacuum Collection of Dust, Wipe Collection of Dust, Conversion Equations

b. Identifiers/Open-Ended Terms

Blue Nozzle (BN) Vacuum, BRM Vacuum, Measurement Error, Transportability Adjustment, Conversion Equations, Regression

c. COSATI Field/Group

18. Availability Statement	19. Security Class (This Report)	21. No. of Pages
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