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NATIONAL BUREAU OF STANDARDS REPORT

10 917

TESTING THE VALIDITY OF MODELS TO PREDICT THE INCIDENCE OF LEAD PAINT POISONING

Not for publication
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U.S. DEPARTMENT OF COMMERCE

NATIONAL BUREAU OF STANDARDS

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NATIONAL BUREAU OF STANDARDS REPORT

NBS PROJECT 4314518

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NBS REPORT 10 917

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TESTING THE VALIDITY OF MODELS TO PREDICT THE INCIDENCE OF LEAD PAINT POISONING

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Sponsored by
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PREFACE

This report can be grouped, conceptually, with 5 other NBS Reports under the blanket title "Pediatric Lead Paint Poisoning in the United States--A Survey with Preliminary Estimates." Under this arrangement, the "parts" of the study would be listed:

Part I NBS Report #10499 "The Nature of the Lead Paint Poisoning Hazard"

Part II NBS Report #10657 "Data Collection and Assimilation for the Lead Paint Poisoning Model"

Part III NBS Report #10653 "Effect of Data Aggregation in Modelling"

Part IV NBS Report #10654 "A Model to Estimate the Incidence of Lead Paint Poisoning"

Part V NBS Report #10917 "Testing the Validity of Models to Predict the Incidence of Lead Paint Poisoning"

Part VI NBS Report #10651 "National Estimates of Lead Based Paint Poisoning of Children (Estimated by Standard Metropolitan Statistical Area)"

These papers were intended as interim progress reports covering work done up to the time of publication. Reports describing validation and refinement of the models and outputs as well as analysis of the outputs will be issued subsequently. A summary report encompassing revision of the current ones and those projected above, under one cover, is anticipated.

ABSTRACT

This report describes one testing of the validity of two previously-developed mathematical models for predicting the incidence of pediatric elevated blood lead levels (EBL: greater than 40μg/100 ml). Data from Aurora, Illinois are studied to help assess the validity both of the assumptions upon which the models are based and of the magnitudes of the model-estimated EBL's. The results are generally corroborative of the models' logic and quantitative performance.

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1. INTRODUCTION

Lead poisoning, once thought of as primarily an (industrial-) occupational disease in adults, has recently been recognized as one of the major pediatric problems in the United States. Although some cities, notably New York and Chicago, have screening programs to identify children with the disease, many areas of the country are essentially unaware of the danger or do not have the funds to mount such programs.

It is desirable that an estimate be made of the magnitude and extent of lead poisoning in all areas of the country, in order to determine what level of commitment and expenditure of public resources and funds is most appropriate to alleviate this problem. To achieve this goal, the Department of Housing and Urban Development (HUD) has supported an effort by the Technical Analysis and Applied Mathematics Divisions of the National Bureau of Standards (NBS) to develop a mathematical model for estimating the incidence of children with elevated blood lead levels (EBL), defined as being greater than or equal to 40 micrograms of lead per 100 milliliters of whole blood, in 241 Standard Metropolitan Statistical Areas (SMSA's) throughout the United States. Several tentative models for this purpose are described in "A Model to Estimate the Incidence of Lead Paint Poisoning"[1], and the estimates obtained by applying two of these models to Census data for the 241 SMSA's are given in "National Estimates of Lead Based Paint Poisoning of Children (Estimated by Standard Metropolitan

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[1]NBS Report #10654, December 7, 1971.

Statistical Area)"[2]. The current report describes a study to test the validity of these two models, with results which, we believe, warrant improved confidence in these national estimates.

1.1. General Description of Validation

Model validation ideally refers to a process wherein the results predicted by a mathematical model in specific instances are compared with the corresponding events in the real world, in order to increase confidence in all model predictions, or alternatively, to learn that the model needs to be revised or discarded. Complete validation would require comparison with reality in all cases, but that is never done, since it would obviate any need for the model. (Indeed, one uses a model primarily because such observation of all relevant real-world cases is impractical.) Therefore, validation of a model refers in practice to a kind of partial validation in which the cases used to validate are carefully chosen to be representative of all the contexts in which the model is to be applied.

There are two levels of validation required. The first involves checking the assumptions upon which the model rests, those determining which factors are important and which can be omitted, as well as those determining the general mathematical form of the model. The second level of validation is the comparison of the magnitude of the phenomenon as predicted by the model and as actually occurring, to ensure that the model is a good estimator.

Validation through real world observation is not possible in all applications of modelling techniques. Verification of the results of

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[2] NBS Report #10651, December 7, 1971.

models of nuclear warfare, for instance, could be accomplished only by a kind of experimentation which is unthinkable. Models forecasting future innovative technological developments cannot be satisfactorily validated using currently available data. The lead poisoning models, however, are capable of validation through real world observation. It is clearly possible to design a controlled screening program to collect the data needed for such a validation exercise. Unfortunately, this has not been possible here because of project time and budget constraints.

One can establish, to some degree of confidence, the validity of the models by applying them in one or more areas other than those used in estimating their parameters ("calibration") and comparing model predictions with observed levels of EBL's in those areas. When the models were being developed, New Haven was the only source of data which had EBL's aggregated by Census tract. (Although New York and Chicago had detailed records which were available to the project, their use for calibration required hand address-coding of so large a volume of data as to be impractical within the scope of our study.) An additional data source became available late last fall. In the city of Aurora, Illinois, a task force (spurred by the finding that 91 out of about 450 children tested there by the Illinois Department of Public Health exhibited EBL, and by the subsequent death of one of these children) screened over 1700 children between July and October of 1971. That program, covering more than 12 percent of all children aged six and under in Aurora, certainly qualifies as a major screening effort.

The two cities, Aurora and New Haven, differ in many respects, and validation of the models with data from Aurora will thus widen the known range of the models' applicability. Aurora is in a different part of the country from New Haven, the calibration city (the Midwest as compared with the East), and has a different character as a city. New Haven itself forms an SMSA, but Aurora is part of the larger Chicago SMSA and is partly a suburban bedroom community. The center of Aurora is an old city originally built along the Fox River and the Burlington Railroad yards. However, Aurora is now included in the expanding suburbs of Chicago, and its small town character has changed much in recent years.

Verification of the models' estimates of EBL frequency for Aurora will not, of course, assure the accuracy of the models' other estimates. Although good agreement with actual Aurora findings will increase confidence in the estimates for small and medium size cities elsewhere in the East and Midwest, we will still lack verification of the estimates for other areas of the country, such as the South, the Mountain States, and the West Coast. These areas have quite different climatic characteristics, possibly different techniques of home construction and decoration, and different proportions of older housing. Data on EBL from some cities in these areas are needed to really establish the validity of the estimates there. In the current absence of such data, validation using Aurora data can at least improve our confidence in the general assumptions upon which the models were built, and in particular can assure that the models were not designed around data anomalies peculiar to New Haven.

1.2. The Models and Calibration Data

Two models were developed to estimate the nationwide magnitude and extent of lead poisoning. The first of the two models, which will be called Model 1, is

$$E = K_6 \times \frac{D}{H} \times .24$$

where E is the predicted number of children with EBL in a region of interest,

K_6 is the number of children 6 years of age or less,

D is the number of dilapidated or deteriorating housing units, and

H is the total number of housing units.

The value .24 is the result of averaging EBL incidence rates for high risk children (those living in poor quality housing) from preliminary data for 20 cities with screening programs.

A second model, which will be called Model 1A, replaces this .24 with an incidence rate I calculated separately for each city as

$$I = .747 \left(\frac{K_6}{P}\right)^{.2967} \times \left(\frac{D}{H}\right)^{.2484}$$

where K_6, D, and H are as in Model 1, and P is the total population. Thus for Model 1A

$$E = K_6 \times \frac{D}{H} \times I.$$

The parameters in Model 1A (i.e., the quantities evaluated as .749, .2967, and .2487) were estimated using data from the city of New Haven, Connecticut, the only city whose incidence data were available already aggregated by Census tract. Data from other cities were recorded only as totals over the whole city, or were broken down by some non-Census zonal system, such as health districts. Since the current application of the models relies on Census data for the population characteristics, it is necessary to obtain incidence data aggregated by a zonal system compatible with that of the Census Bureau.

Thus the New Haven data were used for model calibration, even though these data did not meet all of the desirable criteria for such data (that they result from mass screening, be unbiased, and be from a macro blood lead test)*. The city of New Haven had a mass screening program in 1970 but funding was not available to continue this into 1971. Thus in 1971, only those children brought into hospitals or clinics were screened, creating a possible bias since many such children are already sick. Some of those children screened in 1970 received only an ALA urine test† and no follow-up blood test. Since the ALA test is not as reliable as the blood test, children screened using this test alone were not included in the calibration data. As a result the final sample consisted of 1300 children tested, representing only 3 percent of the New Haven children six years old or less. The New Haven program did go out into the community during the summer of 1970 to persuade parents to bring in their children for the test, and so results from this testing period (those actually used) ought to be less biased than those from periods when testing was conducted only in clinics or hospitals.

This description of the problems known to be associated with the New Haven data illustrates the two main reasons it is necessary to validate a model:

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*See "Data Collection and Assimilation for the Lead Paint Poisoning Model", NBS Report #10657, for a further discussion of these criteria.

†Davis, J. R., and Andelman, S. L., "Urinary Delta-aminolevulinic Acid (ALA) Levels in Lead Poisoning. I.A. Modified Method for the Rapid Determination of Urinary Delta-aminolevulinic Acid Using Disposable Ion-exchange Chromatography Columns", Arch. Environ. Health 15:53, 1967.

1. Data anomalies peculiar to one region or situation may not be recognized as such and may become major determinants in the model.
2. Model hypotheses based on the analysis of a phenomenon in one context may not carry over into others.

For instance, in New Haven, 80 to 90 percent of the housing in most Census tracts was built before 1940, so that age of housing did not vary enough to discriminate between high risk lead poisoning tracts and lower risk ones. Yet such a variable might be useful for such discrimination on a nation-wide basis. The only variables which emerged from the analysis of the New Haven data as major determinants of EBL's were the relative size of the child population six years and under, and the extent of dilapidated and deteriorating housing. Thus the model was based on the hypothesis that young children living in poor housing run the greatest risk of lead poisoning. This hypothesis does not rest solely on the New Haven experience but comes also from the general findings of New York and Chicago. However the actual degree and form of the dependence, as well as the exclusion of other factors, result from the analysis of New Haven's data and must be verified elsewhere by the model validation process.

2. ANALYSIS OF THE AURORA DATA

2.1. General Description of the Aurora Data

In July of 1971 the Illinois Department of Public Health tested 449 children in Aurora, Illinois. Of these, 91 were found to have EBL's, five with high enough levels to warrant hospitalization. This testing in Aurora was part of a 10 city survey conducted by the Department to ascertain why, of the total of over 2000 lead poisoning cases reported to them each year, only a handful occurred outside the City of Chicago, although less than half of the children in the applicable age range live in Chicago, and housing conditions similar to those in Chicago's poorer areas are also found in other cities in the state. The results of the Aurora tests and those in other Illinois cities proved that the disease is widespread outside Chicago but has remained largely unrecognized. This is an excellent example of the circumstance, noted by many experts on lead poisoning, that the number of children found with EBL's depends directly on the effort spent in searching.

Once the presence of lead poisoning in Aurora became known, a program directed by the Aurora Service Center of the Kane County Council of Economic Opportunity (staffed almost wholly by volunteers) was launched to test the remainder of those children in Aurora living in neighborhoods containing poor quality housing. To date, 1707 children, 12.8% of all children 6 years or less in Aurora, have been tested. (This figure includes the 449 originally tested by the Illinois Department of Public Health, but does not include 86 ostensibly non-high risk "middle class" children tested for statistical control purposes.) 321 of these, or 18.8 percent, have EBL's. Table 1 gives, for each Census tract in Aurora, the total number of children 6 years and under (from the 1970 Census), the number of children screened, the percent of children screened, the number of those children screened found with EBL's, and the percentage of those screened with EBL. It should be noted that in only one Census tract were less than 5 percent of the children screened, while in four tracts more than 20 percent were screened.

Aurora officials have estimated that all high risk children have been screened in this program. Their estimate of 1700 children in high risk neighborhoods is quite naturally greater than the NBS estimate of over 1300 in high risk housing units, and it is clear that any program will have to screen more than the bare minimum of children, since it is impossible to draw neighborhood boundaries strictly enough to include only children living in poor housing. Also, programs run by government affiliated groups must accept all children whose parents request a test. In addition, health officials see great benefit in testing any child, regardless of socio-economic status, who might have been exposed to the lead hazard. The problem for most programs is not that of having to turn away children desiring the test, but that of persuading parents of exposed children to allow the test to be done. The Aurora program which tested over 12 percent of all children has succeeded well in this respect and it is very probable that most, if not quite all, of the high risk children have been tested.

Table 1*

Aurora Screening Statistics by Census Tract

CENSUS TRACT	TOTAL CHILDREN	CHILDREN SCREENED	PERCENT SCREENED	TOTAL ELEVATED BLOODS	PERCENT ELEVATED BLOODS
8529	2116.	173.	8.2	25.	14.5
8530	2109.	73.	3.5	9.	12.3
8531	391.	20.	5.1	5.	25.0
8532	944.	100.	10.6	28.	28.0
8533	380.	49.	12.9	6.	12.2
8534	1122.	283.	25.2	64.	22.6
8535	556.	96.	17.3	11.	11.5
8536	772.	225.	29.1	48.	21.3
8537	30.	5.	16.7	1.	20.0
8538	386.	49.	12.7	11.	22.4
8539	826.	41.	5.0	7.	17.1
8540	1099.	240.	21.8	50.	20.8
8541	517.	82.	15.9	19.	23.2
8542	527.	58.	11.0	7.	12.1
8543	827.	42.	5.1	3.	7.1
8544	788.	172.	21.8	27.	15.7
Total	13390.	1708.	12.8	321.	18.8

*Values in the tables are computer output and subject to round-off error. For this reason totals from different tables may not agree and percentages may not total 100.

The percentage of EBL's found in the Aurora program is generally compatible with that recorded by other areas. Chicago, which has the longest running large program, finds EBL's in about 10 percent of those screened each year. This is the lowest percent among screening programs. The longevity of the program may explain this, in that Chicago parents have become more aware of the problem and thus perhaps better equipped to institute preventive measures on their own. A second possible explanation is that the gross Chicago statistics may include retests. If a significant fraction of the tests performed each year are retests, this could lead to lower overall EBL rates. For instance, if all children whose original blood test was 40 μg/100 ml or more are retested after treatment, when presumably the blood lead level has been reduced below this level, the total (cumulative) number of tests will increase by the number of retests, but the number of EBL's will remain the same, thus of course reducing the fraction of tests which are EBL's. At present it is unknown whether the low Chicago rate results from the inclusion of retests, stems primarily from an excellent education program, or is due to some other factor such as imperfect blood test analysis procedures.

Although the Aurora EBL fraction is greater than that of Chicago, it is less than that of New York City (.287 in 1970) and some other programs. Many of these have screened a much smaller fraction of all children and have concentrated on the areas of greatest risk. This concentration can be more intense in a program testing a smaller percentage of all children than in a larger program. Some programs have screened primarily those children reporting to clinics or hospitals and therefore most likely to exhibit symptoms. However, the New York City program utilizing outreach procedures has screened a large fraction of all children and still has a higher EBL rate than Aurora. One contributing factor may be that the areas of housing blight are larger and better defined in the larger city, thus insuring that (almost) all children tested in a neighborhood are really high risk children. At any rate, the EBL rate observed in Aurora is not far out of line with other rates, falling between those observed by the nation's two largest existing screening programs.

One other possible reason for the low EBL rates observed in Aurora is that some of the tests were performed in the Fall. Most programs have noted that blood lead levels fluctuate during the year, peaking highest in June and dropping lowest in January. This may stem in part from the availability of summertime volunteers to locate and bring in high risk children who ordinarily have little contact with organized medicine. However, the peaking phenomenon was noticed even when no mass screening occurred. In addition, deaths almost invariably occur in the summer months. Medical researchers have postulated a relationship between the amount of ultraviolet radiation and blood lead level, but the mechanism is not yet fully understood.* At any rate, it is generally accepted that blood lead levels are higher in the summer, and thus most programs screen children primarily during the summer months. The first 449 children screened in Aurora were tested in July; 91 or 20.2 percent, had EBL. For all 1707 children the rate was 18.8 percent, 1.4 percentage points lower. About four hundred of the children were tested in early October and the remainder in late August. Thus a measurable but small reduction in EBL rate is noted for the later tests.

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*"Facts About Lead and Pediatrics", Lead Industries Assn., Inc.

2.2. Factors Associated with EBL

The Aurora officials allowed NBS staff access to the forms which were filled out for each child. These forms had information concerning the child and his family in addition to the blood lead level. This information was coded and punched at NBS on computer cards for an anlyysis of characteristics actually associated with children with EBL. The forms only contained the street address for each child's home, but the correct Census tract was coded for each address by hand using a street directory and street maps of the Aurora area. A small number (fewer than 10 forms) could not be coded because the street could not be found in the directory or on the maps, the street was found in a tract not included in our study, or only a Post Office box number was given as an address. As noted below and in NBS report #10657, "Data Collection and Assimilation for the Lead Paint Poisoning Model", project time and budget constraints precluded such address coding for the large New York or Chicago data sets, but the Aurora data set was small enough to hand code within a reasonable time frame.

From the Aurora forms the following information was coded for each child:

1. blood lead level
2. Census tract
3. sex of child
4. age of child
5. race or ethnic origin
6. whether the child has a family doctor
7. time of residence at the present address

8. whether the family owns or rents its home

9. whether the family receives public aid

10. a family number to identify children in the same family

11. condition of the house the child lives in

12. retest blood lead level, if child was retested.

Not all forms contained all twelve items, of course. Some items were not filled in on some forms, and these items were coded as blanks, unless other information, such as a form for another child in the same family (which could be used for all but items 1, 3, 4 and 12) or the child's name (which could be used to determine the child's sex), was available to fill in the blank. Three different forms had been used for the three different test dates: the first contained only items 1 through 6, the second contained all items except 11; and the third contained all 12 items. The use of these different forms thus accounts for many of the blanks observed in the data. Table 2 records the number of blanks found for each of items 2 through 12. There are no blanks for blood lead level, since any form lacking this information was discarded. Only 19 retests were included in this study, and therefore any conclusions about them are based on a very small sample.

2.2.1. Distribution of Blood Lead Levels

Table 3 displays the distribution of blood lead levels for the Aurora children, separately for first time tests and for retests. As just noted, the number of retests is too small to make sound generalizations possible. The fact that only those children whose initial tests were high were retested may explain why the distribution of retest blood lead levels

Table 2

Aurora, Illinois Data Statistics

There are	3 blanks in the column for	(2) tract
	0	(3) sex
	17	(4) age
	22	(5) race
	20	(6) doctor
	331	(7) transiency
	363	(8) tenure
	352	(9) aid
	1361	(11) condition

There is a total of 1726 tests of which 19 are retests. The total number of families is 1044. The numbers in parentheses are the indices used in the list on page 13.

Table 3
Blood Lead Distribution for Aurora, Ill.

Blood Lead Level*	Number of Initial Tests
0 - 9	246.
10 - 19	389.
20 - 29	461.
30 - 39	293.
40 - 49	178.
50 - 5	71.
60 - 69	29.
70 - 79	17.
80 - 89	12.
90 - 99	6.
100 AND UP	8.

Blood Lead Level	% Initial Tests
0 - 9	14.3
10 - 19	22.5
20 - 29	26.7
30 - 39	17.0
40 - 49	10.3
50 - 59	4.1
60 - 69	1.7
70 - 79	1.0
70 - 89	.7
90 - 99	.3
100 AND UP	.5

Blood Lead Level	Number of Retests
0 - 9	0.
10 - 19	3.
20 - 29	1.
30 - 39	5.
40 - 49	6.
50 - 59	4.
60 - 69	0.
70 - 79	0.
80 - 89	0.
90 - 99	0.
100 AND UP	0.

Blood Lead Level	% Retests
0 - 9	.0
10 - 19	15.8
20 - 29	5.3
30 - 39	26.3
40 - 49	31.6
50 - 59	21.1
60 - 69	.0
70 - 79	.0
80 - 89	.0
90 - 99	.0
100 AND UP	.0

*Blood lead level is measured as μg lead per 100 ml whole blood.

has a higher mean than that for first time tests. Table 3 contains not only (on the right) the percentage distribution of blood lead levels, but also (on the left) the actual numbers found in each category. While percentages do not seem to have a great impact on ones emotions, and observation that 26 children tested in Aurora had blood lead levels greater than 80 μg/100 ml, which the Surgeon General recommends as the level at which the child be considered lead poisoned and already probably suffering irreparable brain damage, conveys the enormity of the problem more graphically. One of these children has died. It should be remembered that Aurora is only a small city, and that there are many others like it with no programs to screen for or treat lead poisoning. In addition to the 26 children with defined lead poisoning cases, some of the 46 children with levels between 60 μg/100 ml and 80 μg/100 ml may be exhibiting other symptoms* and may have suffered brain damage.

2.2.2. Retests

Table 4 gives a breakdown of the children with EBL by first time tested versus retests. Again both the absolute numbers as well as the percentages are recorded, as they will be in succeeding tables. Only 1.1 percent of all tests were retests, and only children whose first test indicated an EBL were retested. Almost half of the children's blood levels were below 40 μg/100 ml on retest. Whether this is because of treatment, inexactitude in one of the tests, or increased surveillance by a parent is not known. This means that slightly more than half have levels still above 40 μg/100 ml and thus remain in danger. This agrees with findings in other

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*Follow-up medical diagnoses were not available to the project.

Table 4

Breakdowns of EBL's by Tests and Retests

Testing	Number Under 40*	Number 40 and Above	Total
First Time	1390.	318.	1708.
Retests	9.	10.	19.

Testing	% Under 40	% 40 and Above	Total
First Time	81.4	18.6	98.9
Retests	47.4	52.6	1.1

*The number 40 in the headings of this and other similar tables refers to a blood lead level of 40 μg lead per 100 ml whole blood.

cities that indicate high incidence of recurrence of EBL if the child is returned to a contaminated environment. Aurora authorities ran their screening program virtually on a shoestring, and were thus able to do no more about the environment in which the children lived than to warn parents of the danger. Only one house, that of the child who died, was deleaded. It is not known if there are other cases in which a landlord or homeowner, informed of the danger by the screening program, deleaded a property on his own initiative.

2.2.3. Census Tract

Table 5 lists the number of EBL's found in each Census tract. Figure 1 is a map of Aurora showing the geographic locations of all sixteen of these Census tracts. As can be seen from the table, the percentage of children with EBL varies from a low of 7.1 in tract 8543 to a high of 28 in tract 8532. However, the tract with the lowest absolute number of children with EBL is 8537, a downtown area with few residences. The highest number of EBL (64) is found in 8534. Other tracts with many EBL's are 8540 with 50 and 8536 with 48.

2.2.4. Sex

Table 6 gives the breakdown of EBL by sex of child. The Aurora screening program tested girls and boys in almost equal numbers and the fractions of those tested having EBL are almost the same. From this table one can conclude that lead poisoning is a disease afflicting both males and females, with very little difference in the incidence rates for the two, a fact which agrees with findings elsewhere.

Table 5
Breakdowns of EBL's by Census Tract

Tract	Number Under 40	Number 40 and Above	Total
8529	148.	25.	173.
8530	64.	9.	73.
8531	15.	5.	20.
8532	72.	28.	100.
8533	43.	6.	49.
8534	219.	64.	283.
8535	85.	11.	96.
8536	177.	48.	225.
8537	4.	1.	5.
8538	38.	11.	49.
8539	34.	7.	41.
8540	190.	50.	240.
8541	63.	19.	82.
8542	51.	7.	58.
8543	39.	3.	42.
8544	145.	27.	172.
Total	1387.	321.	1708.

Tract	% Under 40	% 40 and Above	Total
8529	85.5	14.5	10.1
8530	87.7	12.3	4.3
8531	75.0	25.0	1.2
8532	72.0	28.0	5.9
8533	87.8	12.2	2.9
8534	77.4	22.6	16.6
8535	88.5	11.5	5.6
8536	78.7	21.3	13.2
8537	80.0	20.0	.3
8538	77.6	22.4	2.9
8539	82.9	17.1	2.4
8540	79.2	20.8	14.1
8541	76.8	23.2	4.8
8542	87.9	12.1	3.4
8543	92.9	7.1	2.5
8544	84.3	15.7	10.1
Total	81.2	18.8	

Figure 1

Map of the Aurora Census Tracts

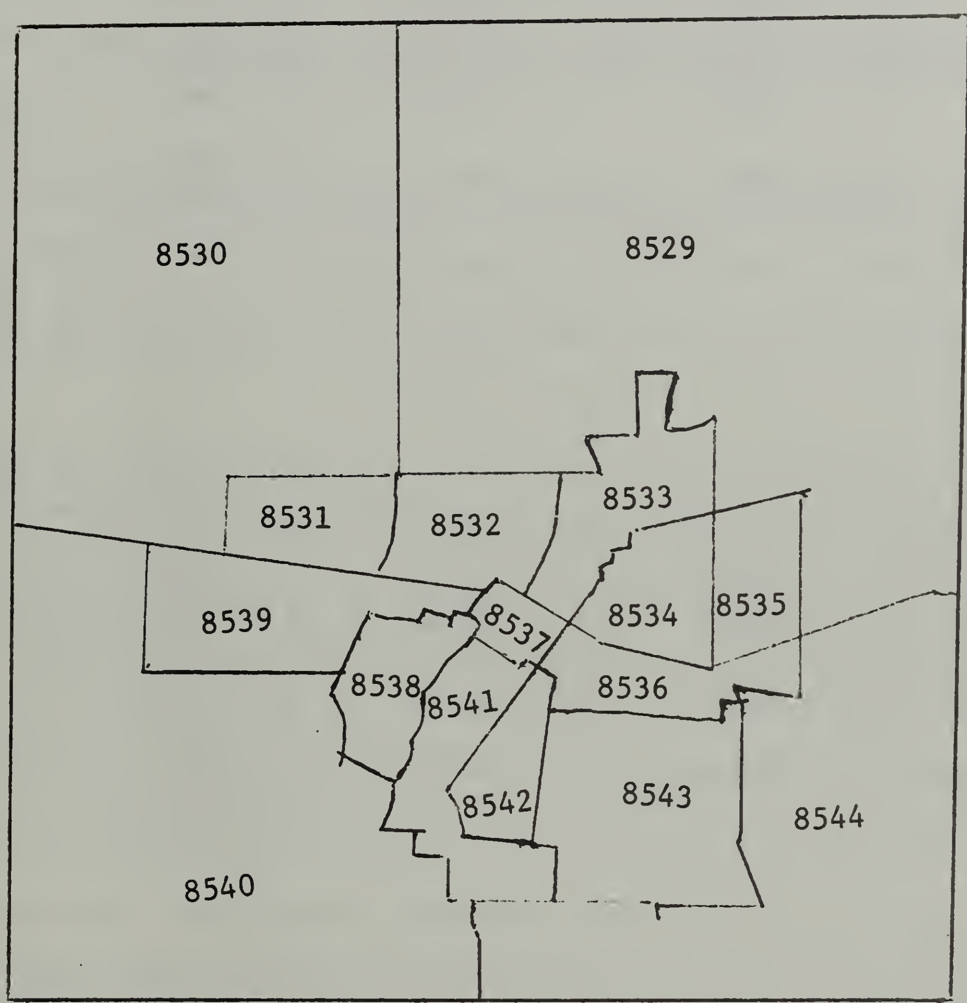

Table 6

Breakdowns of EBL's by Sex of Child

Sex	Number Under 40	Number 40 and Above	Total
Male	706.	176.	882.
Female	683.	145.	828.

Sex	% Under 40	% 40 and Above	Total
Male	80.0	20.0	51.6
Female	82.5	17.5	48.4

2.2.5. Age

Table 7 gives the breakdown of EBL by age of the child. Aurora screened approximately equal numbers of children in each of the yearly age ranges 1 to 6. Only about 4 percent of the children screened were 7 or 8. The EBL rates for each of the ages 1 to 6 are approximately the same, with only a slightly higher rate for 2 year olds. This differs from results reported by other programs, which found relatively many more children in the 2 to 3 year old range to have EBL. The reason for this discrepancy is not known.

One additional observation is relevant at this point. The EBL rate of 18.8 percent in Aurora should not be interpreted as the probability that a given child will have an EBL some time in his first six years of life.

In fact, the probability a child will experience EBL at some time is probably considerably greater than that described by the average of those exhibiting it at one point in time. All screening programs give a sort of "snapshot" view of the magnitude of the problem. The rates observed in such programs can be used with greatest confidence only to estimate how many children could be expected to be found by a similar testing program. One cannot interpret these results to yield a probability over a given length of time that a typical child will have EBL, because this snapshot view does not yield any information on how blood lead level fluctuates in a particular child over time.

Table 7

Breakdowns of EBL's by Age of Child

Age	Number Under 40	Number 40 and Above	Total
1	192.	40.	232.
2	231.	69.	300.
3	243.	60.	303.
4	212.	51.	263.
5	239.	50.	289.
6	202.	39.	241.
7	50.	9.	59.
8	5.	0.	5.

Age	% Under 40	% 40 and Above	Total
1	82.8	17.2	13.7
2	77.0	23.0	17.7
3	80.2	19.8	17.9
4	80.6	19.4	15.5
5	82.7	17.3	17.1
6	83.8	16.2	14.2
7	84.7	15.3	3.5
8	100.0	.0	.3

2.2.6. Ethnic Origin

Table 8 gives the breakdowns of EBL by race or ethnic origin of the child. Black children have the highest rate, 24.2 percent. Spanish surnamed children have the intermediate rate of 20.6 percent. White children are lowest with 14.2 percent. The Aurora sample contained a larger proportion of black and Spanish surnamed children than would be found in the population as a whole. This is undoubtedly because the program sought to test all high risk children (i.e., those living in poor quality housing), and it is known that these minority groups make up a disproportionate fraction of the lower income groups living in such housing.

The finding here that children in some ethnic groups have a higher proportion of EBL corroborates that finding by other programs. However, it is much more difficult to determine why it should be so. Reports linking the absorption of ultraviolet rays* (which depends on skin pigmentation) to lead metabolism may provide some answer, and it is to be hoped that continued research along this line will prove or disprove this theory. Another theory linking lead metabolism to the sickle cell trait might explain the higher incidence among blacks.† Again further research is clearly necessary to demonstrate the validity of this conjecture. In the absence of a clear proven medical explanation, one can only speculate that either cultural or economic differences are the causative factors. Some experts have suggested that blacks from the South show an increased

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*See footnote, page 12.

†"Car Fumes Seen Child Threat", The Washington Post, Feb. 13, 1972.

Table 8

Breakdowns of EBL's by Race or Ethnic Origin

Race	Number Under 40	Number 40 and Under	Total
White	647.	107.	754.
Black	338.	108.	446.
Spanish	389.	101.	490.

Race	% Under 40	% 40 and Above	Total
White	85.8	14.2	44.6
Black	75.8	24.2	26.4
Spanish	79.4	20.6	29.0

cultural acceptance of pica, an unreasonable craving for non-food substances, because of such practices as clay and starch eating which are prevalent among some groups in the South. Again this remains in the realm of conjecture. A further, and at the moment we believe the most tenable, explanation is that the minority groups are the lowest on the economic ladder and thus live in the poorest housing. Even those whose economic status is such that they could afford better housing may be forced into poor housing by discrimination, in spite of open housing laws. This may provide the most reasonable explanation for the differences in EBL rates among the three ethnic groups and is certainly the only proven fact that might account for the differences.

2.2.7. Family Doctor

Table 9 gives the breakdowns of EBL by whether the child has a family doctor. This table is included to test the hypothesis that a child who has a regular contact with the medical establishment has less of a chance to have an EBL. As can be seen clearly, however, this is not true in Aurora. The EBL rates are almost identical whether or not the child has a family doctor. The most surprising statistic to emerge from this table is that over 90 percent of the children had a family doctor. The actual figure may not in fact be quite so high. In at least two cases the mother noted on the form that the doctor listed was "mother's baby doctor". Also since treatment of EBL's was done by local physicians, we believe that mothers were urged to write down the name of the doctor they would take their child to if he had an EBL.

The 90 percent figure is suspiciously high, but even a figure of 70 or 80 percent would indicate a higher acquaintanceship of these small city

Table 9

Breakdowns of EBL's by Whether the Child Has a Family Doctor

Doctor	Number Under 40	Number 40 and Above	Total
Yes	1242.	289.	1531.
No	130.	29.	159.

Doctor	% Under 40	% 40 and Above	Total
Yes	81.1	18.9	90.6
No	81.8	18.2	9.4

families with the regular medical profession than that of large city poor families. Increasing the doctors' awareness of the danger posed by lead paint and the symptoms of lead poisoning may by itself provide a great payoff in lead poisoning control. It would have less effect in a large city, where a smaller proportion of poor people see a private doctor. In such a city an educational program aimed at public health and hospital emergency room personnel might have larger payoff. However, the experience of both New York and Chicago indicates that only an outreach program, in which health people go into the neighborhoods, will bring many of the poor into contact with any formal health program. Thus this greater contact of the poor with the medical establishment may be a characteristic which differentiates the types of programs which are needed in large and small cities.

2.2.8. Transiency

Table 10 gives the breakdown of EBL's by duration of the family's residence at its present address. It has been speculated that poorer families are more transient. Therefore it was hoped that transiency rates could be used to distinguish those with high EBL rates. However Table 10 shows that there is not a great deal of difference in EBL rate among the various lengths of residence, and the differences which exist do not form the pattern expected under the above hypothesis. Why the highest rate, 27.1 percent, should be for those who have lived at their present address for four years is not at all clear, when the corresponding rate for three years is 20.8 percent and for 5 years is 19.0. The low rate of 16.5 for those living at the same address 5 or more years is in the direction

Table 10

Breakdowns of EBL's by Time of Residence at the Present Address

Time of Residence at this Address	Number Under 40	Number 40 and Above	Total
Less than 1 month	47.	12.	59.
Less than 6 months	161.	50.	211.
Less than 1 year	137.	36.	173.
Less than 2 years	143.	45.	188.
Less than 3 years	99.	26.	125.
Less than 4 years	70.	26.	96.
Less than 5 years	34.	8.	42.
At least 5 years	405.	80.	485.

Time of Residence at this Address	% Under 40	% 40 and Above	Total
Less than 1 month	79.7	20.3	4.3
Less than 6 months	76.3	23.7	15.3
Less than 1 year	79.2	20.8	12.5
Less than 2 years	76.1	23.9	13.6
Less than 3 years	79.2	20.8	9.1
Less than 4 years	72.9	27.1	7.0
Less than 5 years	81.0	19.0	3.0
At least 5 years	83.5	16.5	35.2

expected, but is not different enough to be statistically significant. The figures in Table 10 may just reflect the fact that frequent changes of residence are characteristic of life today. One demurrer must be placed on these statistics, however. Many of the forms only recorded the address of the family back to the child's birth (only up to 3 years ago, for instance, for a 3 year old child) and left the other spaces blank. If the address was the same as the present address, the family was usually coded as having lived there at least 5 years since there was no other address listed. This practice may have led to the high percentage of those tested recorded as living at their present address "at least 5 years", and low percentages for less than 4 or 5 years.

2.2.9. Tenancy

Table 11 gives the breakdown of EBL's by whether the family owns or rents its home. In the larger cities a high percentage of the population at all income levels rents housing. In a smaller city one would expect that a smaller percentage rents, and that the poor are more likely to rent than those more affluent. Thus lead poisoning may be higher among renters. The Aurora sample of high risk children is divided almost evenly among renters and owners. The EBL rates are almost the same for the two categories, and thus it is not the case that children of renters have a higher probability of contracting EBL. One could suggest all sorts of explanations for this. Apartment buildings in a small city may be newer than those in larger cities and may not actually contain lead paint. There may be fewer absentee landlords and community pressure may be greater to maintain apartment buildings. More of the renters may live in single family homes

Table 11

Breakdowns of EBL's by Whether the Family Owns or Rents Its Home

Tenancy	Number Under 40	Number 40 and Above	Total
Own	530.	124.	654.
Rent	542.	151.	693.

Tenancy	% Under 40	% 40 and Above	Total
Own	81.0	19.0	48.6
Rent	78.2	21.8	51.4

in neighborhoods where many homes are owner occupied. This may also contribute to better maintenance. However, there is no proof of any of these suggested explanations; so the best that can be said at this time is that in Aurora EBL rates are not appreciably different for owners' and renters' children.

2.2.10. Public Aid

Table 12 gives the breakdown of EBL's by whether the family receives some form of public aid. The most common kinds of aid listed were food stamps and ADC (Aid to Dependent Children), commonly called welfare. This was the only question on the form which was specifically related to income, since a family must be in the lowest income bracket to receive public aid. As expected, those on an aid program had a much higher probability of having an EBL than those not on aid. A more detailed breakdown of income and EBL would have been desirable, but it is clear from Table 12 that those below the poverty level have higher EBL rates than even other high risk children. This may be modified somewhat in Aurora in the future since a new public housing project, presumably not containing lead paint, has been opened recently. However, until the units formerly occupied by these new public housing residents are deleaded, the hazard still exists for whoever lives in those units.

2.2.11. Condition of House

Table 13 gives a breakdown of EBL by the condition of the house occupied by the child. The conditions listed are "(1) very poor, paint is chipped and peeling on doors, windowsills, and/or on the outside of the

Table 12

Breakdowns of EBL's by Whether the Family Receives Public Aid

Public Aid	Number Under 40	Number 40 and Above	Total
On Aid	142.	53.	195.
Not	939.	224.	1163.

Public Aid	% Under 40	% 40 and Above	Total
On Aid	72.8	27.2	14.4
Not	80.7	19.3	85.6

Table 13

Breakdowns of EBL's by the Condition of the Housing Unit Occupied by the Family

Housing Condition	Number Under 40	Number 40 and Above	Total
Poor	9.	2.	11.
Fair	90.	24.	114.
Good	204.	24.	228.

Housing Condition	% Under 40	% 40 and Above	Total
Poor	81.8	18.2	3.1
Fair	78.9	21.1	32.3
Good	89.5	10.5	64.6

house, (2) not too bad, some peeling, could easily be improved, and (3) good, walls are firm, no chipping or peeling on outside or inside of house". The responses are of course the subjective assessments of the residents of their own housing. What one family might term as good, because it was much better than their previous housing, another might think is only fair. A homeowner might believe some item could be easily repaired and therefore term his house in fair condition, while a renter, who has to rely on someone else to fix the item, might feel it was more difficult to repair and thus term the same home in poor condition. However, even taking into account the subjectiveness of this categorization, there is a great difference (a factor of 2) in the EBL rates for housing termed good versus that termed fair or poor. This is certainly a corroboration of the basic premise of the model, that children living in housing in poor condition suffer a higher risk of EBL.

That so many of these supposedly high risk children included in the screening program live in housing in good condition also indicates a discrepancy in the definition of high risk. As noted earlier in this chapter, a program such as the one in Aurora screens all children who come to be tested regardless of their status. In addition a small city may have small pockets of poor condition homes in otherwise good neighborhoods. In order to reach the children in these pockets, all children in the neighborhood are screened. Larger cities have for the most part much larger areas of blight, and screening centers can thus concentrate their efforts more effectively. An area with a diameter of half a mile in a large city may be wholly within a section of blight, while the same size area in a smaller city is more likely to contain some good quality housing.

2.2.12. Family Size

Table 14 gives a breakdown by family size of the number of children in the same family with EBL. This table shows that as the number of children in a family goes up, the probability that at least one child in the family will have an EBL also rises (except for a slight decrease in 5 children families), which would be expected even if EBL's do not tend to run in families. If the tendency of EBL to run in families were perfect, i.e., if all children in a family had EBL whenever any one of them did, the table would be as follows.

	0	1	2	3	4
1	471	109	-	-	-
2	245	0	57	-	-
3	99	0	0	23	-
4	25	0	0	0	6

(We have omitted 5 children families because there are too few of them to generalize from.) This is not the case in Table 14, since non-zero entries occur. At the opposite extreme, if there were no such tendency at all and the probability that a child had an EBL is the average .188 observed for all children, the numbers occurring in Table 14 (omitting 5 children families as above) would be as follows.

Table 14

Number of Families of Each Family Size Having a Given Number of Children with Elevated Blood Lead Levels

Family Size (Children 7 and Under)	Number of Children in the Same Family With Elevated Blood Lead Levels						
	0	1	2	3	4	5	All
1	471.	109.	-	-	-	-	580.
2	196.	91.	15.	-	-	-	302.
3	72.	36.	11.	3.	-	-	122.
4	17.	10.	4.	0.	0.	-	31.
5	4.	1.	2.	0.	0.	0.	7.

Percent of Families of Each Family Size Having a Given Number of Children with Elevated Blood Lead Levels

Family Size (Children 7 and Under)	Number of Children in the Same Family With Elevated Blood Lead Levels						
	0	1	2	3	4	5	All
1	81.2	18.8	-	-	-	-	55.7
2	64.9	30.1	5.0	-	-	-	29.0
3	59.0	29.5	9.0	2.5	-	-	11.7
4	54.8	32.3	12.9	.0	.0	-	3.0
5	57.1	14.3	28.6	.0	.0	.0	.7

	0	1	2	3	4	5
1	471	109	-	-	-	580
2	199	92	11	-	-	302
3	65	45	11	1	-	122
4	13	13	4	1	0	31

The differences between those observed in Table 14 and those expected under the assumption that EBL's do not run in families are displayed below. These differences are all quite small.

	0	1	2	3	4
1	0	0	-	-	-
2	-3	-1	4	-	-
3	7	-9	0	2	-
4	4	-3	0	-1	0

A Chi-square test* was performed separately on each of rows 1, 2, and 3 (the last two entries in row 4 of Table 14 are too small for the test to be applicable there) to test if, for families of a fixed size, the tendency toward EBL runs in the family. This was strongly not the case for each of the family sizes 1 child, 2 children, and 3 children 7 years or younger.

The fact that EBL's do not run in families means that testing and deleading programs cannot take advantage of the spatial concentration of

*Natrella, Mary Gibbons, Experimental Statistics, National Bureau of Standards Handbook 91, U.S. Department of Commerce 1963, pp. 9-8 through 9-10.

children in families. If EBL's ran in families, then one could screen families by testing only one child in the family, and (assuming homes are deleaded whenever any child in the family has an EBL) fewer units would require deleading. But since the probability that a child has an EBL does not depend significantly on whether others in his family have EBL's, screening programs must screen as many children as possible, regardless of the number of families they represent. The number of units to be deleaded is approximately the number of EBL's found divided by the average number of children in the same family in the applicable age range.

2.3. Statistical Tests of Association of Factors with EBL

Chi square tests, designed to reveal which factors are statistically associated with EBL, were run on the 10 factors shown in Tables 4 through 13 and discussed above. Table 15 summarizes the results of these tests. The high confidence level for retests stems from the fact, noted in the discussion of Table 4, that children are retested only if they had an EBL the first time. Thus without a deleading of the child's environment one would expect retests to have higher blood lead levels than the ordinary population. The high confidence level for Census tracts reassures us that the modelling effort is indeed possible, for if blood lead levels do not differ from one tract to the next, one could never hope to calibrate a model, i.e., one cannot model differences in EBL rates among Census tracts if such differences do not exist.

The other three items which turn out to be statistically significant also reinforce our confidence in the model which has been developed. Housing condition has proved to be significant, and being a member of a

Table 15

Results of Chi Square Tests

Item	Chi Square	Degrees of Freedom	Confidence Level
Retest	14.12	1	99%
Census Tract	27.35	15	95%
Sex	1.67	1	-
Age	7.25	7	-
Race	20.19	2	99%
Doctor	.04	1	-
Transiency	10.08	7	-
Tenure	1.66	1	-
Public Aid	6.45	1	95%
Housing	7.08	2	95%

minority group or on public aid are closely associated with income level which determines who lives in housing in poor condition. Such factors as the age of the child (note that all children tested were under 8 and most were 6 and under, so we are not referring to older children), the child's sex, whether the child has a family doctor, how long the family has resided at its present address, or whether the family owns or rents its home are not statistically significant, although at first thought most might have some influence on EBL. The emphasis on poor housing to the exclusion of other factors, discovered in the course of the calibration on New Haven data, is confirmed by the data from Aurora. The Aurora data are particularly useful for these kind of tests, since one could associate the particular characteristics of one child with his blood lead level.

The analysis of the Aurora data generally supports the assumptions built into the lead poisoning model developed by NBS. These analyses have also increased our knowledge of factors associated with EBL, even if only by ruling out some plausible associates. Such negative results help us focus on the major factors: poor housing condition and low income.

3. VALIDATION

3.1. Numerical Comparison

The primary purpose for which the Aurora data was desired was the validation of the model. In the previous chapter we have discussed the use of the Aurora data to validate the main idea on which the model was constructed, namely that the major factor associated with lead poisoning is poor housing and that most other factors are secondary. The analysis described in Chapter 2 has shown two other factors, race and being on public aid, as also important. However, both of these are closely associated with poor housing, since they are associated with low income and de facto housing restrictions. Therefore the analysis of the Aurora data has, for the most part, corroborated the model assumptions, particularly the inclusion of housing condition and the exclusion of other variables.

A second part of the validation process will be included in this chapter: the checking of model-predicted EBL frequencies against those discovered in the Aurora screening program. Table 16 gives the number of EBL's found in the Aurora screening effort and those predicted by each of the two models, Model 1 and Model 1A, described in Chapter 1. As can be seen from a glance at this table, there is substantial agreement between the predictions of the two models for each Census tract. In addition, the model predictions agree quite well with the EBL's actually found in the program. To confirm this, a statistical test associated with Kendall's rank correlation coefficient tau* was performed, leading to a 99 percent

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*Siegel, Sidney, Nonparametric Statistics for the Behavioral Sciences, McGraw-Hill, pp. 213-223 (1956).

Table 16

EBL's by Census Tract from the Aurora Data and as Predicted by Model 1 and Model 1A

Census Tract	Aurora Screening	Model 1 Predicted EBL	Model 1A Predicted EBL
8529	25	30	26
8530	9	30	27
8531	5	6	5
8532	28	15	14
8533	6	5	4
8534	64	48	57
8535	11	24	27
8536	48	42	51
8537	1	1	1
8538	11	16	19
8539	7	10	8
8540	50	31	31
8541	19	23	26
8542	7	7	6
8543	3	9	7
8544	27	22	22
Total	321	319	331

confidence level for the agreement between the predictions of Model 1 and also of Model 1A with the Aurora data. Since this statistical test only compares the rank orders within the two columns, one might still question the agreement, were it not for the fact that there is only about 3 percent difference in the total predicted by Model 1A and that actually found. The degree of agreement between predicted EBL's and those actually found is in our opinion astonishing, in view of the many problems known to exist with the data.

Table 17 gives the percentage of high risk children predicted by Model 1A to have EBL, and the percentage of the screened children with EBL. These two columns of numbers are not at all in the same kind of agreement as those in Table 16. Even the overall percentages differ by 5 percentage points. Thus in spite of the fact that the number of children found with EBL agrees with the number predicted by either Model 1 or Model 1A, the fractions of high risk children as calculated by those models do not agree with the fractions observed in children screened. An explanation for the fact that the number of EBL's are in agreement but the percentages of high risk children predicted and observed do not agree, lies in the equating of high risk children with those screened. Table 18 gives the number of children screened in each Census tract and the number of high risk children as predicted by the models. The model regards high risk children as those living in unsound (i.e., dilapidated or deteriorating) housing and calculates the number of them as

$$K_6 \times \left(\frac{D}{H}\right),$$

Table 17

Comparison of Percent of High Risk Children Found with EBL with Those Predicted by Model 1A

Census Tract	% EBL as Found	% EBL as Predicted By Model 1A
8529	14.4	20.7
8530	12.3	22.0
8531	25.0	19.9
8532	28.0	21.9
8533	12.2	18.9
8534	22.6	28.8
8535	11.4	27.4
8536	21.1	29.5
8537	20.0	23.4
8538	22.2	28.0
8539	17.0	18.3
8540	20.8	24.1
8541	23.1	26.6
8542	12.0	19.4
8543	7.1	18.3
8544	15.7	24.6
Total	18.8	24.9

Table 18

<u>Children Tested in the Aurora Screening Program
Versus Children at Risk as Calculated by the Models</u>

Census Tract	Children Tested	Children At Risk	Difference (Tested-Predicted)
8529	173	124	49
8530	73	124	- 51
8531	20	27	- 7
8532	100	64	36
8533	49	20	19
8534	283	199	84
8535	96	98	- 2
8536	227	174	53
8537	5	6	- 1
8538	49	69	- 20
8539	41	42	- 1
8540	240	127	113
8541	82	96	- 14
8542	58	26	32
8543	42	39	3
8544	172	91	81
Total	1710	1326	470 - 96 = 374

where K_6 is the number of children six years old or less,

D is the number of unsound housing units, and

H is the total number of housing units.

The assumption needed to interpret this formula as the number of children living in unsound housing is that the number of children per household is the same for those living in poor housing as for those living in better housing.

The Aurora screening program defined high risk children as those living in poor neighborhoods which contain poor housing. As discussed in the previous chapter, it is impossible for a program such as that in Aurora to draw boundaries to specify exactly which children will be tested. Survey workers cannot agree to test one child because he lives in poor housing and refuse to test a neighbor because his house is in better condition. They merely choose a blood sampling site to maximize their chances of at least testing all children living in housing presenting a lead hazard, and test all children who ask to be tested. They can also concentrate announcements of the test in areas of greatest risk. Table 18 shows that 374 more children were tested than were predicted to be high risk by the models. If these are actually children living in good housing and thus less likely to have EBL's, this would explain the lower rates observed. Of course one could always take the position that the model has under-predicted the children at risk. However, since the Aurora officials believe their program has at least included all high risk children, and for the reasons described above and in Chapter 2 it is reasonable to expect that any screening program in a small city will include some low risk children also, it is probable that the number of children screened in Aurora is more than the number of children at risk. How many more is not known, but an inflation of 28.1 percent does not seem entirely out of line.

3.2. Conclusions

The full validity of the models is not proved by the analysis of the data from Aurora. As noted in Chapter 1, this would not have been possible to achieve anyway, since we still do not have information concerning EBL rates in such areas of the United States as the South and West.

The analysis of the Aurora data has, however, somewhat increased confidence in the models in two ways. Analysis of various factors which could be associated with lead poisoning shows that the major factor is poor housing. This was the main assumption upon which the models were built, and the analysis has corroborated that assumption. The second finding which has increased confidence in the models is the remarkable agreement between the EBL's predicted and those actually found. This indicates that at least for Aurora the models could only be underpredicting the number of children with EBL, since the number predicted have already been found and only 12 percent of all children have been tested. If indeed all high risk children have been tested, then one would expect the rates for the remaining children to be lower. The models included rates only for high risk children since little information is yet available on other groups. Such data are now obviously needed to obtain better estimates of the magnitude of the problem in all segments of the population. In addition to the agreement between the predicted and observed citywide EBL totals, there was surprising agreement between the two for each Census tract.

Thus, although the results of this exercise do not completely validate Models 1 and 1A, they have increased confidence both in the order of magnitude of the estimates and in their relative sizes for different SMSA's. In particular they indicate that it is very unlikely that the nationwide estimates of the incidence of EBL have been overestimated. Further information, including data from screening in the South and West, data to determine an accurate description of the children at risk, and data on non-high risk EBL's, is needed to be able more fully to assure the validity of the models.