RESIDENTIAL SOURCES OF LEAD

NOTE: **DISPONIBLE AUSSI EN FRANÇAIS SOUS LE TITRE:**

SOURCES DE PLOMB DANS LES HABITATIONS

Residential Sources of Lead

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Disclaimer

This study was conducted for Canada Mortgage and Housing Corporation under Part IX of the National Housing Act. The analysis, interpretations and recommendations are those of the consultant and do not necessarily reflect the views of Canada Mortgage and Housing Corporation.

Abstract

Five hundred homes had been selected in Saint John, New Brunswick to evaluate the relationship between lead in blood and lead in drinking water. From this sample one hundred were selected to examine the additional contribution of lead from food, soil, dust, and paint to the blood lead levels of residents. Fifty homes were selected where residents were known to have raised blood lead levels, and 50 further homes were selected where residents were known to have low blood lead levels. All 100 homes were visited and one food, two soil, and three dust samples were taken, and multiple measurements of lead in paint performed. A statistical model was developed to explain the data. The primary predictors of raised blood lead levels in the residents were found to be resident age, household water lead level, and lead in paint, and the primary residential source was confirmed to be lead in household water.

Key Words

Lead in paint
Lead in dust
Lead in food
Lead in soil
X-ray fluorescence
Lead in blood
Lead in water
Household lead sources

Executive Summary

Metro Health Services Inc. was retained by Canada Mortgage and Housing Corporation to conduct a field research project to assess the contribution of lead in soil, dust, and food to raised blood lead levels in residents of Saint John, New Brunswick. New-Tox was retained by Canada Mortgage and Housing Corporation to conduct jointly a field research project to evaluate the contribution of lead in paint, measured using XRF technology.

Another study, conducted immediately prior to this study, evaluated the link between lead in household water and lead in the residents of the same homes (Scott et al, 1995.) That study provided blood lead and water lead data, and additional questionnaire data concerning other potential sources of lead. This current project utilised these data for the homes selected.

Using the blood lead data from the earlier study, homes were divided into those with high blood lead in residents and those with low blood lead in residents. Homes with the highest and lowest 'mean household blood lead' levels for residents were recruited for the study until 50 were obtained from each category. These homes became the study population for further assessment. This selection process was intended to amplify any differences between the two groups, allowing clearer identification of significant residential sources of lead. It was also viewed as being the most cost-effective means of investigating residential sources.

A total of 100 homes were visited. Consistency in sampling was ensured by only two study workers conducting home visits and sampling. A questionnaire was administered, and samples of soil (front and rear garden) and house dust (entrance way, most frequented living area, and master bedroom) were taken for lead analysis. In addition a representative cross section of food items were taken from the home using a 'rummage' method, developed for this survey. Finally, multiple lead-in-paint measurements were made using in-situ, non-destructive XRF analysis. These data, together with the blood lead, water lead, and questionnaire data from

the earlier study were analysed for the 100 homes to identify which sources of residential lead were associated with having high versus low blood lead levels.

Review of study data showed results for lead in soil, dust, food, and paint to be comparable to available Canadian data. Statistical analysis of data from the prior study had indicated that resident's age and household water lead levels were the primary factors contributing to raised blood lead levels in residents of Saint John. Further statistical analysis that included the new data showed that homes in which residents with low blood lead resided consistently had lower levels of lead in soil, dust, food, and paint. Also, statistically significant relationships were found between blood lead levels and lead levels in soil, food, and paint, but not dust. The final statistical model indicated that of the new parameters studied (lead in soil, dust, food, and paint), only lead in paint provided a further, small contribution to raised blood lead levels in residents of Saint John.

It is concluded that the main contributory factors responsible for raised blood lead levels in residents of the City of Saint John, New Brunswick are resident's age, household water lead level, and lead in paint, and that the primary residential source of lead is household water (leached from lead service lines.) In view of these results, commonsense precautions can be offered to residents to minimise exposure to residential sources of lead.

1. INTRODUCTION

Metro Health Services Inc. and NewTox Consulting were retained by the Research Division of the Canada Mortgage and Housing Corporation to conduct a field research project to investigate sources of residential lead exposure and their contribution to raised blood lead levels of residents of the City of Saint John, New Brunswick. This document is the final report of this project.

1.1 Background

During the Spring of 1993 a research project funded by the New Brunswick Medical Research Fund investigated the contribution of lead in household water to the blood lead level of residents of Saint John, New Brunswick (Scott et al, 1995.) Using flushed water samples, blood samples, and questionnaire data the relationship between water and blood lead was investigated in 500 homes. Analysis of the data showed a correlation between blood lead level and age of residents, and lead content of household water. The study provided a unique data base and research population that was then used by Canada Mortgage and Housing Corporation to investigate the impact of additional residential sources of lead - paint, soil, dust, and food - on blood lead levels of residents.

It has been recognised for decades that lead interferes with many bodily functions, tending to undermine health. Recently, a Canadian review (Health Canada, 1994) concluded that studies have shown :

- an adverse effect on the neurobehavioural and cognitive development in fetuses, infants, and pre-school children with blood levels of 0.5 to 0.75 umol/L or perhaps lower;

- that no clear evidence of a threshold has been shown for the effects of lead although they are dose related and are quantitatively small where blood leads are in the 0.5 - 1.5 umol/L range;
- that one might expect up to 5% of Canadian children to have blood lead levels above 0.5 umol/L;
- that effects on blood pressure in adults have been observed in the blood lead range of 0.35 - 1.7 umol/L and reproductive effects in the 1.5 - 2.0 umol/L range; and
- that the populations most at risk include children and women of child-bearing age living in high-risk communities, and individuals exposed at work.

Improved industrial hygiene and both regulatory and voluntary efforts have, in recent years, significantly reduced industrial and environmental sources of lead (e.g. lead in gas, lead in canned goods, lead in paint.) This has shifted the balance, raising the relative contribution of formerly less significant sources of lead. Since there is little Canadian data on the direct contribution of residential sources of lead to the blood lead level of residents (Hilcon Associates, 1992), and Canada has now adopted a lower 'acceptable' blood lead level for the entire population (Health Canada, 1994), a change in perspective is required when evaluating current exposure to lead.

1.2 Project Objectives

Objectives of the study were to 1) identify and evaluate residential determinants of raised blood lead levels in residents of Saint John, 2) compare findings with those from other studies, and 3) assess what precautions and protective actions residents can take to minimise their exposure based on the findings of the study.

1.3 Methods

1.3.1 Previous study data -

Certain activities conducted during the prior study (Scott et al., 1995) are relevant to the current study, as follows. Blood collection and administration of the questionnaire took place between the months of February and March 1993, with water sampling between the months of February to April. Teams of two nurses attended each home to obtain informed consent, administer the questionnaire, take venous blood specimens, obtain a flushed water sample and arrange for pre-flushed water samples to be taken and picked up. All blood and water samples were taken to the Metro Health Services Trace Element Laboratory (Saint John Regional Hospital) for analysis using graphite furnace atomic absorption spectrometry. The laboratory participates in two external blood lead proficiency testing programs and has shown consistent satisfactory performance. Blanks, quality control samples (tri-level), or standard reference materials were analysed concurrently with specimens. The Saint John Regional Hospital is an accredited health institution.

1.3.2 Recruitment -

Recruitment for the present study was conducted as follows. Using the blood lead data from the prior study, homes were ranked based on the 'mean household blood lead' level. Residents were contacted sequentially (from the highest mean blood lead level downwards, and from the lowest mean blood lead level upwards) to seek their voluntary participation for further studies. A brief description of the project and their potential involvement was presented, and then the householder asked if they would participate. This process was continued until 50 homes in each category had been enlisted. Signed and witnessed informed consent was obtained subsequently at the start

of each visit.

1.3.3 Procedure -

Residential samples were obtained from each participating household by a single team of two. In each home attempts were made to obtain two composite soil samples (one front and one rear), three household dust samples (one from the main entrance way, one from the most frequented 'family' room in the house, and one from the master bedroom), one composite food sample (rummage method), and multiple lead-in-paint determinations (using XRF technology.) All samples were taken to the Metro Health Services Trace Element Laboratory for analysis using graphite furnace atomic absorption spectrometry (dust, food, and some soil samples) or flame atomic absorption spectrometry (some soil samples.)

2 TESTING PROCEDURES

2.1 Schedule

An initial trial of 5 homes was performed for evaluating which method would be used for assessing the lead content of food. Three options were considered : 1) Collection of duplicate food samples over a three day period (with subsequent laboratory analysis), 2) maintenance of a food consumption 'diary' (with subsequent calculation of lead content from available references on lead in food types), and 3) rummage of the food content of the homes (with subsequent laboratory analysis.) The rummage method consisted of collecting one composite food sample for each home by removing representative samples from all food items (dried, fresh, frozen, packaged, and canned goods, including routinely used herbs and spices). Comparison of the estimated lead

levels from these three methods for the 5 homes showed the diary to be least effective, and the duplicate sampling and rummage methods to give parallel results. The rummage method tended to give proportionately higher results than the duplicate diet method, but was much simpler to administer and was selected.

A training session was provided by Allied Science Associates for the correct and safe calibration and handling of the XRF instrument. During this period it became clear that flat surfaces were the most appropriate with slight moulding on trim being acceptable. Care was required when measuring trim.

Home visits took place during the summer of 1993. Specimen analysis, data collation and statistical analysis was completed thereafter.

2.2 Measurement of Lead in Paint

For on-site measurement of lead in exterior and interior paint, non-destructive X-ray fluorescence (XRF) analysis was used. A portable, hand-held Princeton Gamma Tech model PGT-XK3 was selected. The XK3 was calibrated to measure lead in the range of 0 - 10 mg/cm^2 of surface area. It was capable of measuring the total lead content through multiple layers (25 - 30) of paint over a variety of substrates.

2.2.1 Triplicate measurements were made on each wall, ceiling, or trim surface selected from the schedule below. When desired surfaces were unsuitable for testing (e.g. walls tiled or panelled; siding on exterior) alternative locations were often selected (e.g. dining room, workroom.) Measurements of greater than or equal to 10 mg/cm^2 were documented as 10 mg/cm^2.

XRF testing schedule :

1.	Kitchen ceiling	2.	Kitchen wall
3.	Master bedroom wall	4.	Master bedroom trim
5.	Bathroom wall	6.	Bathroom trim
7.	Family room wall	8.	Living room wall
9.	Living room trim	10.	Exterior (wall or porch)

2.2.2 Following manufacturers instructions the instrument was checked for calibration at each home prior to testing, using a known zero and 1.5 mg/cm^2 lead painted surface. The instrument was considered out of calibration if the reading of the standard differed by more than 0.5 mg/cm^2. When readings of 10 mg/cm^2 were obtained, the instrument was reset and the calibration was rechecked. Three measurements were taken from each test surface, and the mean reported for data analysis.

2.3 Lead Analysis in Soil, Dust, and Food

Zeeman corrected graphite furnace atomic absorption spectrometry was selected for these analyses. For a small number of specimens with high lead content, flame atomic absorption spectrometry was used. All analyses were performed on a Hitachi Z8200 Zeeman Atomic Absorption Spectrometer. A dedicated trace element laboratory was used throughout, with freshly deionised (lead free) water used for all procedures, and standard solutions and quality control solutions prepared using trace element grade nitric acid and a certified lead reference standard. To match the samples, all standards and control solutions were prepared to the same acid concentration as test samples. Recovery and reproducibility studies showed good analytical performance. Controls (blanks, quality control solutions, SRM's [Standard Reference Materials], or spiked samples) were run with each set of test samples. The detection limit was approximately 2 ug lead / L of final solution.

2.4 Measurement of Lead in Soil

A collection and analysis procedure similar to that from the Trail study was used (Hertzman, 1990.) To better reflect realistic soil conditions the soil material was not screened, and only a mild acid extraction was performed. Two composite soil samples from two separate sites were obtained. Each sample was identified by the assigned house number, surname, sample site, date, time, and year.

2.4.2 Collection -

For homes with children, soil collection was from either an area of exposed soil where children played or the vegetable garden (if there was one, and children ate produce from it.) When these sites were unavailable soil collection was from a functional area used regularly by the children. If there were no children in the household, soil collection was from either a functional area (front or back yard) or the vegetable garden (if there was one, and family members ate produce from it.)

The general protocol for soil sample collection was to select the area, then draw a circle one metre in diameter and collect subsamples (one from each of the four compass points and one from the centre), to a depth of no more than 2-3 cm. These subsamples were combined in one ziplock freezer bag to form a single composite soil sample. Two such samples were collected per home and transported to the laboratory for storage and analysis.

2.4.3 Sample preparation -

Each bagged soil sample was first manipulated by hand to break up larger pieces, shaken for 1 minute to ensure homogeneity, and then a representative sample removed

for analysis. A reproducibility study was conducted on several specimens and the procedure shown to produce homogenous subsamples and consistent results. Additionally 3 randomly selected ziplock bags were leached overnight with 10% nitric acid and shown to have non-detectable levels of lead.

To extract the sample, a 50 mL polypropylene Falcon tube (cap removed) was tared and a 1.0g (+/- 0.01g) representative soil sample was transferred to the tube (transfer of obvious stones or plant material (e.g. roots) that would have skewed the lead value were avoided.) The cap was secured, before storing for later extraction. To the 1.0g soil sample 25mL of 10% nitric acid was added, and the tubes mixed for 1 hour using a wrist action shaker, adjusted so that tubes were approximately 5 degrees off horizontal (preliminary evaluations indicated this arrangement of volume and angle provided optimal mixing.) After this time the volume was made up to 50 mL with 10% nitric acid and the extraction process halted by centrifuging (2,000 rpm for 15 minutes) to clarify the solutions and then transferring 30-40mL of the contents to new 50mL Falcon tubes for storage at room temperature until analysis. Studies indicated non-detectable levels of lead in the Falcon tubes.

2.5 Measurement of Lead in Dust

A standardised collection and analysis procedure was used (see below), which was similar to that from the Trail study (Hertzman, 1990.) To collect uniform dust samples, an SKC Universal Flow Sample Pump (Model 224-PCXR7) and matched weight (+/- 0.1 mg) mixed cellulose ester filters (0.80 micron pore size) preloaded into 3 piece disposable 37 mm cassettes were used. Cassettes were connected by the outlet port to the pump using a short length of Tygon flexible plastic tubing which was replaced periodically. Extending from the inlet port of the cassette was a length of the same Tygon tubing cut to an angle (about 30 - 45°) at its free end to form an inlet

nozzle. To eliminate cross contamination, this piece of tubing was discarded and replaced after each cassette sample was collected.

The pump was calibrated and maintenance performed daily according to manufacturers instructions. The pump flow rate was checked and adjusted prior to each collection using the rotameter flow indicator, integral to the pump, which was set to a consistent flow rate of 2.5 - 3.0 litres/minute.

2.5.1 Sampling technique -

Dust was collected from a measured area, using a template 25 x 25 cm. The pump and fresh Millipore cassette (appropriately identified) were assembled. With template securely in place the nozzle was held at a 45° angle to the surface and drawn from one side of the template to the other at about 6 seconds per stroke until the entire area had been covered (about 25 strokes / collection in each direction.) This was then repeated in the perpendicular direction, and again in the original direction (i.e. 3 passes.) The cassette was disconnected, plugs replaced over the inlet and outlet ports, appropriately identified (with assigned house number, surname, sample site, date, time and year), and then placed upright in the manufacturer's box for transport to the laboratory. Cassettes were equilibrated to ambient laboratory temperature and humidity for several hours prior to weighing. A batch of cassettes were opened and filters removed only immediately prior to sample preparation.

2.5.2 Sample Preparation -

Each filter holder was opened at the outlet end. The matched Millipore filter was removed from its backing material, placed on the balance and the balance tared. The second matched filter plus dust sample was then removed and placed on the balance

and the weight recorded. This represented the weight of dust collected. For some samples a negative weight resulted, in which case a zero dust loading was noted and the data discarded from statistical analysis.

2.5.3 Total Digestion Protocol -

Each filter was placed in a labelled 150 mL beaker. For every 20 test filters processed 2 reagent blanks and 2 control filters were processed concomitantly, which showed non-detectable levels of lead. To each beaker was added 10 mL of trace element grade nitric. All beakers were placed on padded hotplates and taken to dryness, but not baked. After removal and cooling, 10 mL of deionised water and 2.5 mL of nitric acid were added. Beakers were heated to dissolve salts, cooled, and diluted to 25 mL in 50 mL polypropylene tubes, and mixed thoroughly.

2.6 Measurement of Lead in Food

2.6.1 A rummage sample was taken from available food sources in the home, and a listing of canned and packaged goods was prepared noting brand name and contents. Representative samples of these canned and packaged goods were purchased from local stores and samples added to the rummage sample in the laboratory prior to bulk preparation and analysis.

2.6.2 Homogenisation -

Each sample was weighed and, where appropriate, its volume measured. Homogenisation was achieved using a Vita-Mix unit, which had been previously tested and showed negligible lead contamination. Deionised (lead free) water was added to the homogenate as required to obtain a uniform and fluid sample in each case, and the

final volume measured.

2.6.3 Digestion -

A 40% nitric acid and 10% perchloric acid mixture was used. Forty-five millilitres of the acid mixture was added to homogenised samples that represented 2 - 10g (average 4g) of food. Specimens were heated at 110°C for 90 minutes using a Tecator 1009 Digestion system. Each clear sample solution was made up to a final volume of 100 mL with deionised water and mixed prior to analysis.

2.7 Questionnaire administration

A supplementary questionnaire was administered targeted towards assessing additional sources of lead for children.

2.8 Statistical analysis

The existing database for blood lead, flushed water lead, and questionnaire data from the first study was expanded by entry of data for lead in soil, dust, food, and paint for the selected homes. Using a variety of techniques the relative contribution of the additional sources was evaluated (see section 3.6.)

3. RESULTS AND DISCUSSION

Tables and Figures are presented as appendices below. Comprehensive results, analytical details, and the questionnaire are contained in a separately bound appendix. Table 1 presents summary descriptive statistics for lead in blood, water, soil, dust and

food. Table 2 presents summary descriptive statistics for lead in paint. Table 3 summarises responses to the questionnaire. Table 4 presents a summary of changes to the statistical model after consideration of each new potential predictor. Table 5 presents a matrix summarising the correlations for some predictors. Figures 1 and 2 compare the data for lead in paint between households with 'high blood lead' and those with 'low blood lead.'

3.1 Lead in Soil

Soil is believed to be a major contributor to lead intake in young children, particularly when they live in the vicinity of an industrial point source. Its contribution in adults is less pronounced. It has been acknowledged that there are gaps in our understanding of the levels of lead in soil, and their relationship to lead in dust, and ultimately the body (Fleming, 1994.)

Some data are available for lead in soil in Canada. For inner city sites soil lead levels of 150 - 3000 ug/g have been reported (Nriagu, 1986.) In Ontario, data collected by the Ministry of Environment and Energy between 1972 and 1982 for sites removed from point sources showed the following means and ranges : urban - 123 (5 - 845) ug/g; small town - 73 (2 - 133) ug/g; rural - 35 (<5 - 360) ug/g. Toronto garden soil was found to have a background, geometric mean level of 99 ug/g, with a downtown area showing 482 (10 - 1450) ug/g (Roberts et al., 1974.) More recent evaluations of data show urban residential mean concentrations of 121 (+/- 142) ug/g for Toronto, and 119 (+/- 95) ug/g for Windsor, and 150 (+/- 93) ug/g for Guelph (Fleming, 1994.) Levels of 31 ug/g have been found in Thunder Bay and 13 ug/g in North Bay (Goos, Gilroy and Associates, 1989.)

Data from Saint John show for 98 homes an average soil lead level of 118 ug/g

(geometric mean 49 ug/g), ranging from 2 - 1060 ug/g in the soil from front gardens and 2 - 2730 ug/g for soil from rear gardens. These results are comparable to those noted above for inner city soil levels (Nriagu, 1986; Fleming, 1994), lower than that found for Toronto garden soil (Roberts et al., 1974), and somewhat higher than those found in more recent studies from Canadian cities (Goos, Gilroy and Associates, 1989.)

Review of Table 1 shows no difference between the lead level in soil from the front and rear gardens for the 'low blood lead' homes (geometric means of 28 and 29 ug/g, respectively.) In contrast, for 'high blood lead' homes a slightly higher lead level is seen in samples from the front versus the rear gardens (geometric means of 81 versus 66 ug/g.) Of note is the higher soil lead content for 'high blood lead' versus 'low blood lead' homes seen above, with an approximately three-fold higher soil lead level for front gardens and a two-fold higher soil lead level for rear gardens when comparing geometric means.

3.2 Lead in Dust

The main source for dust lead is considered to be lead in soil. The upper layer (soil dust) can be re-distributed by wind and human activity allowing it to be considered a continuous source of lead for outdoor and indoor dusts (USEPA, 1989.) Other sources would be direct deposition from the atmosphere, motor vehicle and industrial emissions, and weathering and renovation of lead-containing paint work. Little information is available concerning the relative contribution of each source to lead in dust but with the phase out of leaded gasoline, motor vehicle emissions can be considered negligible.

The relative contribution of dust to human lead exposure will depend upon factors

such as the time spent outdoors and indoors, and the prevailing weather conditions (e.g. recent rainfall, wind), and proximity to a point source. A mean street dust concentration of 1000 ug/g has been reported for urban Toronto (Roberts et al, 1974) and a range of 250 - 2000 ug/g has been suggested for Canadian street dust (Nriagu, 1986.) These values may be higher than current values due to the removal of lead from gasoline.

Levels of lead in household dust is influenced by variables such as house cleaning practices (frequency, technique), seasonal conditions, particle size, ambient air lead concentrations, household air tightness, and the quantity of dust / soil trafficked into the home by children, adults, and pets. For Canada, household dust lead levels of 50 - 400 ug/g have been reported for suburban locations (Nriagu, 1986), whereas levels in a Toronto urban control area ranged 351 - 2010 ug/g, averaging 845 ug/g (Roberts et al., 1974.) More recent Canadian data and 1990's data for house dust were not found by the Ontario Ministry of Environment and Energy (Fleming, 1994.) In this latter document it was cautioned that data for household dust are limited both in quantity and in quality due to lack of assessment of factors such as spatial and temporal variation and lack of a standardised methodology for sampling and analysis, rendering interpretation of dust data difficult.

In Saint John, residential dust lead levels averaged 42 ug/g in entrance ways (range 1 - 522 ug/g), to 73 ug/g in living areas (range 1 - 722 ug/g), to 319 ug/g in master bedrooms (range 5 - 6601 ug/g .) These data are similar to those shown above for Canadian households, particularly in urban Toronto.

Of note were the differences between 'high blood lead' and 'low blood lead' homes, and the similar spatial differences in both sets of homes (see Table 1.) For example, between the two sets of homes the levels of lead in each area (entrance way, living

area, and bedroom) were consistently less in the 'low blood lead homes' (60 -70% less when considering the geometric means.) Further, in both sets of homes the lead content of dust increased from the entrance way through to the living area by approximately two-fold, and from the living area to the master bedroom by approximately three fold.

3.3 Lead in Food

Lead can be found in many food types, entering the food during growth (e.g. fallout onto crops, soils, and forage areas), harvesting, production, distribution (e.g. processing dusts, machinery, solder), storage (lead containing utensils, pottery), and cooking (lead in water, lead containing utensils.) Some studies indicate that lead levels in food may increase 2 - 12 fold during processing and packaging (Wolnick, 1983.) Lead leaching from soldered cans has decreased significantly in recent years due to regulatory and voluntary activity. In Canada a voluntary phase-out program of old canning technology resulted in 65% of lead seamed cans being converted to seamless processes by 1988, with some beverage cans reaching nearly 100% (Fleming, 1994.) In addition low lead solders and improved hygiene further reduced lead levels.

Information on the lead content of food is seen from the Duplicate Diet Study of Canadian adults (Dabeka et al., 1986.) In this 1981 survey, 24 hour duplicate diets (including drinking water and snacks) were collected from 24 adults living in five Canadian cities. The range of lead levels was 8.8 - 654 ng/g, with a mean of approximately 32 ng/g. Large variations were found both between and within food categories, but the study data were in agreement with a larger study (the adult Total Diet Study) performed in the US (Gartrell et al., 1986.)

More recent and comprehensive data for lead levels in Canadian food are found from a total diet study of lead and cadmium (Dabeka and MacKenzie, 1991.) This study analysed canned and raw food purchased at the retail level in six Canadian cities. The foods were prepared in typical fashion, and then combined into 112 composites prior to analysis. Lead levels were as follows : mean - 29 ng/g; median - 14.7 ng/g; range 1.42 - 407 ng/g. The mean of 29 ng/g agreed well with the previously determined mean of 32 ng/g.

Data from Saint John show for 100 homes an average 'rummage' food lead level of 54.2 ng/g (geometric mean 40 ng/g), ranging from 15 - 377 ng/g (Table 1.) Although the range is narrower than seen for the Duplicate Diet Study, the mean value for Saint John is higher than for those studies summarised above. The food types collected in the Saint John and Dabeka and MacKenzie studies are somewhat similar in that the food was taken from canned and raw foods seen in the homes. However, the manner by which the food was collected in the present study, a single grab sample, is markedly different. Also, the food preparation in the study by Dabeka and MacKenzie was most probably conducted with lead free water, unlike that performed in many of the homes during this present study. Here, the mean and maximum flushed water lead levels for 'high blood lead' homes were 75 ug/L and 513 ug/L, respectively, versus 4 ug/L and 50 ug/L for the 'low blood lead' homes. These differences may explain the slightly higher average results seen from the present study. An alternative explanation might be a local diet higher in fish and game, but this was not evaluated.

Again, differences were seen between 'high blood lead' and 'low blood lead' homes, with the 'high blood lead' homes having approximately a 25% higher lead content in their food (geometric mean of 49 ng/g versus 39 ng/g.)

3.4 Lead in Paint

Various lead compounds have been used extensively as pigments, drying agents, and rust inhibitors in both interior and exterior paints. In Canada the Hazardous Products Act has, since 1975, limited the use of lead based pigments for interior consumer paints and paints applied to children's toys and furniture. The Act requires that the lead content must not exceed 0.5% (5000 ppm.) Although more lead may be added to paints used for other purposes, very little lead is found in newer paints. Exceptions include some road and safety paints that use lead chromate for bright yellow markings (and school buses) and other paints used for prevention of corrosion that contain lead oxide.

In the US, lead based paint in old, deteriorating, or renovated homes is considered the major source of lead exposure in children. This has not been viewed with as much concern in Canada, although there is likely to have been a similar use of lead based paints here as in the US. Certainly lead poisoning of Ontario children has been reported in association with both home renovation activity and weathering of external, lead based paints (Fleming, 1994.) Levels of lead in dust during paint removal have been reported up to 500,000 ug/g (Inskip and Atterbury, 1983.) Another report cited indoor air lead concentrations of 550 ug/m^3 after 5 minutes of sanding a windowsill coated in paint with a lead content of only 0.8 - 0.9 mg/cm^2 (Elias, 1985.)

Levels of lead found in paint in Saint John averaged 0.68 mg/cm^2 for 'High Blood Lead' homes, and 0.39 mg/cm^2 for 'Low Blood Lead' homes. In both cases data ranged from 0 - >10 mg/cm^2. Despite these summary statistics, Figures 1 and 2 show that most 'High Blood Lead' homes had raised paint levels, and in contrast nearly all 'Low Blood Lead' homes had very low lead in paint levels.

3.5 Questionnaire data

The questionnaire focussed on the activity of children in the household, but most homes had few or no children. As a consequence detailed statistical analysis was not practicable, and descriptive analysis only was performed (responses are summarised in Table 3.)

3.6 Statistical summary

3.6.1 Selection of Subset -

Using data derived from an earlier study (Scott et al., 1995) the study reported here was restricted to 100 homes (out of 500) and 217 individuals (out of 1257). The 'mean household blood lead' was calculated for each of the original 500 homes, and then these homes sorted by this criterion. Thereafter 50 of the homes with the highest, and 50 of the homes with the lowest, mean household blood lead values were recruited for the study. This method of selecting the subset censored out homes in which individuals with middle range blood lead values might reside. It was intended that this would accentuate differences between the groups, highlighting those factors that most contributed to raised blood lead levels in residents.

3.6.2 New Predictors -

Four new potential predictors were investigated during this study - dust, soil, food and paint. The distribution of each of these variables was heavily skewed towards small positive values and therefore the data was transformed (log transformation). Except for lead in food, the data were also multivariate in nature, and was combined to yield, for each variable, one overall measure per home, as follows : lead in dust - 3

measures per home were transformed to logarithms and averaged (0 values were treated as missing data); lead in soil - 2 measures per home (back and front) were transformed to logarithms and averaged; lead in food - one measure per home transformed directly to logarithms; lead in paint - several measures per home, these were transformed first by a change of scale (multiplication by 100) and then logarithms. All resulting measures were averaged (original values of 0 remain 0 and other measures were above 0.)

3.6.3 Evaluating Predictors -

A regression analysis, with 'Log Blood Lead' as the dependent variable, was used. The basic regression model involved the independent variables 'Age' (of the resident) and 'Log Water Flush' (lead level in the flushed household water sample.) The regression model obtained for the present study (based on 199 individuals) was :

$$\text{Log Lead} = -0.303 + 0.374\ (\text{Log Water Flush}) + 0.019\ (\text{Age}) \qquad R^2 = 0.666$$

This is very different from the model obtained for the earlier study with higher slopes (in particular for Log Water Flush), a negative intercept, and an increased coefficient of determination (from 0.433 to 0.666.) The difference is due to the factors discussed in 3.6.1.

Twenty-two potential predictors were identified. They were all categorical except for Length of Stay (Residency), and Lead in Soil, Dust, Food and Paint. The usefulness of the potential predictors was first examined individually by adding the new predictor and seeing if the new model (Age, Log Water Flush and the new predictor) was significantly different from the basic model. The addition of the new predictor might or might not change the intercept (-0.303), the slope for Age (0.019) or the slope for

Log Water Flush (0.374). Table 4 shows comparisons of these predictors during a step-wise forward regression analysis; intercepts are often not significantly different from zero, and some R^2 values differ due to missing data points.

A stepwise forward regression procedure using the dependent variables Age, Log Water Flush, Dust, Soil, Food and Paint was also performed. The regression model obtained was :

$$\text{Log Blood Lead} = -0.442 + 0.020\ (\text{Age}) + 0.346\ (\text{Log WF}) + 0.250\ (\text{Log Paint})$$

$$R^2 = 0.701$$

The variables Dust, Soil and Food did not enter the equation. The model was also tested with interactions and resulted in no change.

A stepwise forward regression analysis was conducted with all of the predictors, but not taking into account interactions other than with Age and Log Water Flush. The predictors deemed useful by this procedure were Age, Water Flush, Drinking (alcoholic beverages), Paint, Exterior Last Painted and Forced Air. The remaining variables did not enter the equation. Notice that Water Flush did not enter directly into the equation but that the indicator variable High and Low Water Flush did. When running the procedure, Log Water Flush was the first variable to enter the model **(as it has the strongest correlation with Log Blood Lead)** but was later withdrawn from the model.

A second regression analysis was run with the inclusion of interactions with Paint. In this case the predictors deemed useful by this model were Age, Water Flush, Paint, Drinking, Exterior Last Painted, Forced Air (home heating system), Hot Tap Water

and Home Age, and none of the other variables entered the equation.

3.6.4 Discriminant Analysis -

Clearly which predictors influence the outcome varies with the model. One means of assessing the validity of the predictors is to see if individuals would be correctly classified as either low blood lead or high blood lead using the available lead and questionnaire data for the most significant predictors. This is a classification problem, or 'discriminant analysis'. Discriminant analysis is exploratory in nature and geared to understanding complicated data sets and how we can best separate two groups and which variables are useful discriminators. Classification is similar but the emphasis is more on classifying future data to 2 or more populations or groups.

When this multivariate technique is applied for the variables Age, Water Flush, Length of Stay, and Lead in Dust, Soil, Food and Paint, an optimal discriminating rule is obtained that, for every value of these predictors, assigns an individual to one of only two groups: either Low Blood Lead or High Blood Lead.

One of four possible outcomes can occur :

True High	:	where the individual has a HIGH blood lead and was predicted by the model to have HIGH blood lead
False High	:	where the individual has a LOW blood lead and was predicted by the model to have HIGH blood lead
True Low	:	where the individual has a LOW blood lead and was predicted by the model to have LOW blood lead
False Low	:	where the individual has a HIGH blood lead and was predicted by the model to have LOW blood lead

	Predicted by Model	
Actual Blood Lead	Low	High
Low	True Low	False High
High	False Low	True High

A good model will minimize false high and false low results (ideally zero values), and thereby maximise true high and true low results (ideally close to 100 %.)

Using all of the predictors Age, Water Flush, Length of Stay, Dust, Soil, Food and Paint, the following classifications are obtained:

	Predicted by Model	
Actual Blood Lead	Low	High
Low	106	2
High	18	59

From this the percentage of correct classifications is **89.2%**.

If classification to low blood lead is performed using only the predictor Water Flush > 15 ug/l, then the following classifications are obtained:

	Predicted by Model	
Actual Blood Lead	Low	High
Low	116	3
High	26	54

From this the percentage of correct classifications is **85.4%**.

Finally, when the stepwise procedure regression procedure is used, only three variables remained as the most important predictors - Age, Water Flush and Paint. Using these predictors to classify we then obtain the following :

	Predicted by Model	
Actual Blood Lead	Low	High
Low	102	6
High	15	62

From this, the percentage of correct classifications is **88.6%**.

This discriminant analysis indicates that of all the predictors Water Flush is the main one, being able to correctly classify in 85.4% of cases. Length of Stay, and Lead in Soil, Dust, and Food each have minimal impact (89.2 - 88.6 = 0.6%). The three variables House Age, Water Flush and Paint, found by stepwise regression to be the main predictors, correctly classify in 88.6% of cases, but of these three variables, lead in Water Flush contributes maximally.

3.6.5 The Relative Contribution of Lead in Paint vs Lead in Food, Soil and Dust -

The data indicate that Water Flush is the most important contributor in explaining the variability in the Blood Lead levels. The data also indicate that there exist statistically significant associations between Blood Lead and Lead in (I) Soil, (ii) Food, and (iii) Paint (see Table 5.) However, the evidence inferred from the data indicates that of these four variable (lead in Paint, Soil, Dust and Food), only lead in Paint remains associated in any significant way with Log Blood Lead after having taken into account the effect of the other main contributing independent variables. This is seen in Table 4, where the results of the stepwise regression procedures are shown, as well as by the

discriminant analysis procedure described above. In effect, the partial coefficients of determination (or correlation) become non significantly different from zero for the variables Dust, Soil and Food as the analysis proceeds.

3.6.6 Confounding Variables -

Table 5 shows that Home Age is strongly related to Log Blood Lead (r=0.449), but also, and not surprisingly, to Resident Age, Log Water Flush, and Paint. Older homes would be expected to be more likely to have lead service lines (and therefore a raised flushed water lead level), to have been painted with lead containing paint at some time in their history (over 25 years ago), and to perhaps house residents of greater age. Clearly each of these four variables are confounded by one another, and such complex interactions cannot always be satisfactorily separated. When coupled with the main contributing independent variables, Log Water Flush and Resident Age, Home Age is seen to have a significant effect (Table 4), but in the stepwise regressions, Home Age is not included in the final model (this does not imply that Home Age, as a substitute for Paint, could not be part of an equally good model.)

4.0 CONCLUSIONS

Based on the data collected during this study, the following conclusions are drawn :

4.1 The primary source of residential lead that contributes to a raised blood lead level in residents of Saint John, New Brunswick is lead in household water.

4.2 A stepwise regression analysis provided a model that indicated the main predictors of raised blood lead levels in residents of Saint John, New Brunswick were age of the

residents, lead level in flushed water samples, and lead level in paint. (Note that the step-wise regression model used for data analysis selects for those features that correlate most significantly to raised blood lead levels. The exclusion of other features (e.g. soil lead, dust lead, food lead) does not mean that they did not contribute, only that in the particular population studied and analysis performed these factors did not contribute as greatly.)

4.3 'Low blood lead' homes consistently showed lower geometric mean levels of lead in soil, dust, food, and paint, when compared to 'high blood lead' homes. Of these new predictors, only lead in paint remained as a minor contributor in the final model.

4.4 When considering age of resident, water flush lead content, length of stay, and lead in dust, soil, food and paint as predictors, correct classification of residents into raised or low blood lead categories was achieved in approximately 89% of cases. When considering only age of resident, water flush lead content, and lead in paint correct classification of residents was achieved in approximately 88% of cases. When considering water flush lead content < 15 ug/L, correct classification was achieved in 85% of cases.

4.5 Knowing the primary source of household lead allows straightforward advice to be given to residents to minimise their exposure.

5. REFERENCES

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6. APPENDICES

Comprehensive results and analytical details are contained in a separately bound appendix available from CMHC.

6.1 Tables

Table 1. Summary of descriptive statistics for lead levels in blood, water, soil, dust, and food.

Table 2. Summary of descriptive statistics for lead in paint.

Table 3. Summary of responses to questionnaire.

Table 4. Summary of changes to the statistical model after consideration of each new predictor using a stepwise forward regression analysis.

Table 5. Correlation matrix for some predictors.

6.2 Figures

Figure 1. Scattergram of lead in paint data for 'Low Blood Lead' homes.

Figure 2. Scattergram of lead in paint data for 'High Blood Lead' homes.

Table 1 - Summary of descriptive statistics for lead in blood, water, soil, dust, and food.

	Blood Lead (umol/L)		Flushed Water Lead (ug/L)	Lead in Soil (ug/g)		Lead in Dust (ug/g)			Food Lead (ng/g)
	Mean	Individual		Front	Rear	Entrance	Living	Bedroom	
All 100 Homes									
Count	100	199	100	96	98	69	91	96	100
Mean	0.47	0.40	39	109	127	42	73	319	54
Minimum	0.05	0.03	2	2	2	1	1	5	15
Maximum	2.09	2.16	513	1060	2730	522	772	6601	377
Geometric Mean	0.29	0.22	9	47	44	21	43	125	44
Median	0.25	0.14	3	46	37	18	41	111	40
50 'High Blood Lead' Homes									
Count	50	82	50	48	48	35	47	48	50
Mean	0.83	0.82	75	153	178	56	91	459	62
Minimum	0.33	0.15	2	6	3	3	4	5	15
Maximum	2.09	2.16	513	990	2730	522	772	6601	377
Geometric Mean	0.77	0.74	30	81	66	26	51	149	49
Median	0.76	0.73	55	88	53	22	54	131	46
50 'Low Blood Lead' Homes									
Count	50	117	50	48	50	34	44	48	50
Mean	0.11	0.10	4	65	78	28	54	180	46
Minimum	0.05	0.03	2	2	2	1	1	11	21
Maximum	0.16	0.17	50	1060	784	160	209	1347	274
Geometric Mean	0.11	0.09	3	28	29	16	36	104	39
Median	0.12	0.10	2	21	26	14	37	85	37

Table 2 - Summary of descriptive statistics for lead-in-paint [1] data

	Mean Home Blood Lead - umol/L	Kitchen			Master Bedroom		Bathroom		Family Room		Living Room		Exterior		Other exterior locations	Other interior locations	House Means
		Ceiling	Wall	Trim	Wall	Trim	Wall	Trim	Wall	Trim	Wall	Trim	Wall	'Trim'			
All 100 Homes																	
Count	100	93	84	3	77	62	70	18	33	2	80	58	36	9	37	18	
Mean	0.47	0.28	0.67	2.67	0.23	1.47	0.45	0.31	0.35	5.00	0.39	0.73	1.67	1.97	0.52	0.51	0.51
Min	0.05	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
Max	2.09	10	10	8	3.3	10	5.9	3.2	5	10	9.8	10	10	10	2.4	2.4	3.74
50 'High Blood Lead' Homes																	
Count	50	43	43	2	35	36	30	13	11	1	34	30	15	5	18	10	
Mean	0.84	0.25	1.10	4.00	0.28	1.86	0.63	0.41	0.81	10	0.68	0.93	1.55	2.76	0.51	0.60	0.68
Min	0.33	0	0	0	0	0	0	0	0	0	10	0	0	0	0	0	
Max	2.09	2.1	10	8	3.3	10	5.9	3.2	5	10	9.8	7.9	10	10	2.4	2.4	3.74
50 'Low Blood Lead' Homes																	
Count	50	50	41	1	42	26	40	5	22	1	46	28	21	4	19	8	
Mean	0.11	0.31	0.21	0	0.19	0.94	0.31	0.06	0.13	0	0.18	0.51	1.75	0.98	0.53	0.39	0.33
Min	0.05	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
Max	0.16	10	1.3	0	0.9	10	3.1	0.1	0.6	0	0.9	10	10	3.1	1.9	1.2	2.56

1 - Lead measured as mg/cm^2; maximum detectable level of XRF instrument was 10 mg/cm^2, therefore values of 10 may be greater than or equal to 10 mg/cm^2.

Table 3 - Summary of responses to questionnaire	
Childrens questions - 16 homes with children	
Question	Responses
1	Child sucking or chewing fingers / hands : 7 daily; 1 weekly; 3 never
2	Child sucking or chewing non-food items inside residence : 6 daily; 2 weekly; 2 never
3	Child sucking or chewing non-food items outside residence : 4 daily; 6 never
4	Child place dirt / gravel in mouth : 2 daily; 6 never
5	Supplements / vitamins / medications : 7 daily; 6 monthly; 2 never
6	Change clothing more than once per day during summer : 6 daily; 1 weekly; 6 never
7a	Food or drink outside to play : 10 daily; 2 several times a week; 4 weekly
7b	Currently receiving medications : 2 yes; 9 no
8	Child's favourite outside play area : 16 own yard
9	Percentage of bare unsodded ground in play area : 1 < 50%; 15 < 25%
10a	Sandbox : 7 yes, 9 no
10b	Frequency of play in sandbox : 3 several times a week; 6 weekly; 1 monthly
11	Child's favourite play area inside home : 5 playroom; 1 own bedroom; 4 kitchen; 5 basement
12	Flooring in above play area : 12 broadloom; 3 bare hardwood
13	Above play area last painted : 3 within last year; 5 2-3 years ago; 3 4-5 years ago; 4 > 5 years ago
14	Flooring in child's bedroom : 11 broadloom; 5 bare hardwood
15	Child's bedroom last painted : 3 within last year; 7 2-3 years ago; 3 4-5 years ago; 3 > 5 years ago
Other questions - 99 households	
16a	Pets that go in and out f home : 65 no; 34 yes
17	Additions to surface of yard in last 6 years : topsoil - 61 no, 38 yes; fill - 84 no, 15 yes
18	Unsodded patches in yard : 76 no, 32 yes
19	Dust allergies in family : 80 no, 19 yes
20	Frequency of vacuuming / dusting : 9 several times per week; 72 weekly; 13 biweekly; 2 monthly; 3 bimonthly
21a	Change of interior flooring : 80 no, 19 yes
22	Tap run for 2.5 minutes in morning : 61 no, 37 yes
23a	Use canned milk : 76 no, 23 yes
23b	How often : 7 daily; 5 weekly; 5 monthly; 6 less frequently (= 23 responses)
23d	Cans per month : 1 - 32 cans; 1 - 6 cans; 1 - 5 cans; 3 - 4 cans; 3 - 3 cans; 1 - 2 cans; 8 - 1 can; 1 one per year

Table 4 - Summary of changes to the statistical model after consideration of each new potential predictor using a stepwise forward regression analysis.

New Predictor	Category	r^2	Intercept	Slope (Age)	Slope (Log Flushed Water)
[Basic Model]		0.666	-0.303	0.019	0.374
Smoking	Smoker	0.666 (does not enter)	-0.303	0.019	0.374
	Non-Smoker		-0.303	0.019	0.374
Drinking	Drinker	0.700	0.277	0.019	0.356
	Non-Drinker		-0.270	0.019	0.356
Work Exposure	Exposed	0.665 (does not enter)	-0.297	0.019	0.374
	Non-Exposed		-0.297	0.19	0.374
Number of drinks of water (per day)	0 - 1	0.666 (does not enter)	-0.315	0.019	0.374
	2 - 4		-0.315	0.019	0.374
	5 - 6		-0.315	0.019	0.374
	> 6		-0.315	0.019	0.374
Home Age	> 25 years	0.686 (Log Flushed Water comes out)	-0.091	0.018	0.365
	< 25 years		1.609	0.018	0.000
Stripped Paint	Yes	0.666 (does not enter)	-0.303	0.019	0.374
	No		-0.303	0.019	0.374
Renovations	Yes	0.666 (does not enter)	-0.303	0.014	0.268
	No		-0.303	0.014	0.268
Exterior last painted	> 1975	0.630 (does not enter)	-0.181	0.020	0.352
	< 1975		-0.181	0.020	0.352

Table continued .....

Table 4 (continued) - Summary of changes to the statistical model after consideration of each new potential predictor using a stepwise forward regression analysis.

Water Flush : High / Low	> 15 ug/L	0.666 (does not enter)	-0.303	0.019	0.374
	< 15 ug/L		-0.303	0.019	0.374
Forced Air	Yes	0.661 (does not enter)	-0.309	0.019	0.376
	No		-0.309	0.019	0.376
Fireplace	Yes	0.666 (does not enter)	-0.303	0.019	0.374
	No		-0.303	0.019	0.374
Coloured Inks and Papers burnt	Yes	0.666 (does not enter)	-0.303	0.019	0.374
	No		-0.303	0.019	0.374
Filter used with City Water	Yes	0.666 (does not enter)	-0.303	0.019	0.374
	No		-0.303	0.019	0.374
Electric kettle used	Yes	0.666 (does not enter)	-0.303	0.019	0.374
	No		-0.303	0.019	0.374
Gender	Female	0.666 (does not enter)	-0.303	0.019	0.374
	Male		-0.303	0.019	0.374
Residency (years)	All	0.666 (does not enter)	-0.303	0.019	0.374
Use hot tap water	Yes	0.678 (does not enter)	-0.076	0.020	0.374
	No		-0.387	0.020	0.374
Dust lead	All	0.661 (does not enter)	-0.275	0.019	0.369
Soil lead	All	0.689 (does not enter)	-0.363	0.020	0.381
Food lead	All	0.666 (does not enter)	-0.303	0.019	0.374
Paint lead	All	0.675	-0.148	0.015 + 0.003 (age x paint)	0.349

Table 5 - Correlation matrix for some predictors

Predictor	Log Blood Lead	Age	Log Water Flush	Dust	Soil	Food	Paint	Home Age
Log Blood Lead	1.0000							
Age	0.6663 *	1.0000						
Log Water Flush	0.7468 *	0.4707 *	1.0000					
Dust	0.1121	0.0982	0.0389	1.0000				
Soil	0.2589 *	0.2919 *	0.2306 *	0.2298 *	1.0000			
Food	0.2273 *	0.3058 *	0.2478 *	-0.1181	0.0029	1.0000		
Paint	0.3940 *	0.2089 **	0.3428 *	0.1073	0.1561	-0.0541	1.0000	
Home Age	0.449 *	0.335 *	0.332 *	-0.004	0.327 *	0.191 **	0.539 *	1.0000

n = 185 cases

* - 1 tailed significance - 0.001 ** - 1 tailed significance - 0.01

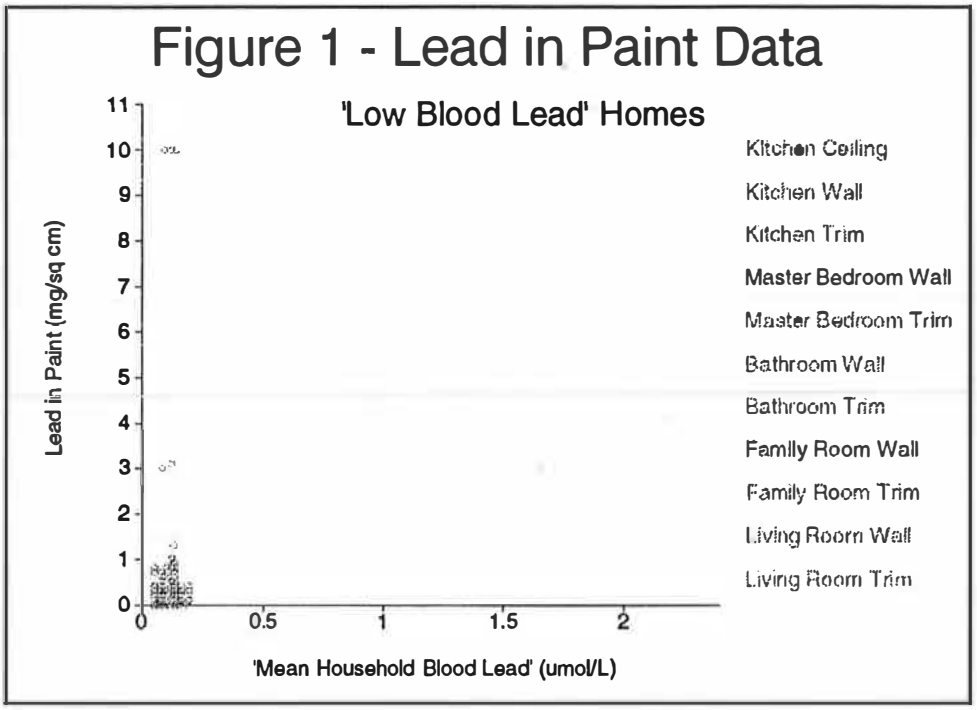
Figure 1 - Lead in Paint Data
'Low Blood Lead' Homes
Lead in Paint (mg/sq cm)
'Mean Household Blood Lead' (umol/L)
Kitchen Ceiling
Kitchen Wall
Kitchen Trim
Master Bedroom Wall
Master Bedroom Trim
Bathroom Wall
Bathroom Trim
Family Room Wall
Family Room Trim
Living Room Wall
Living Room Trim

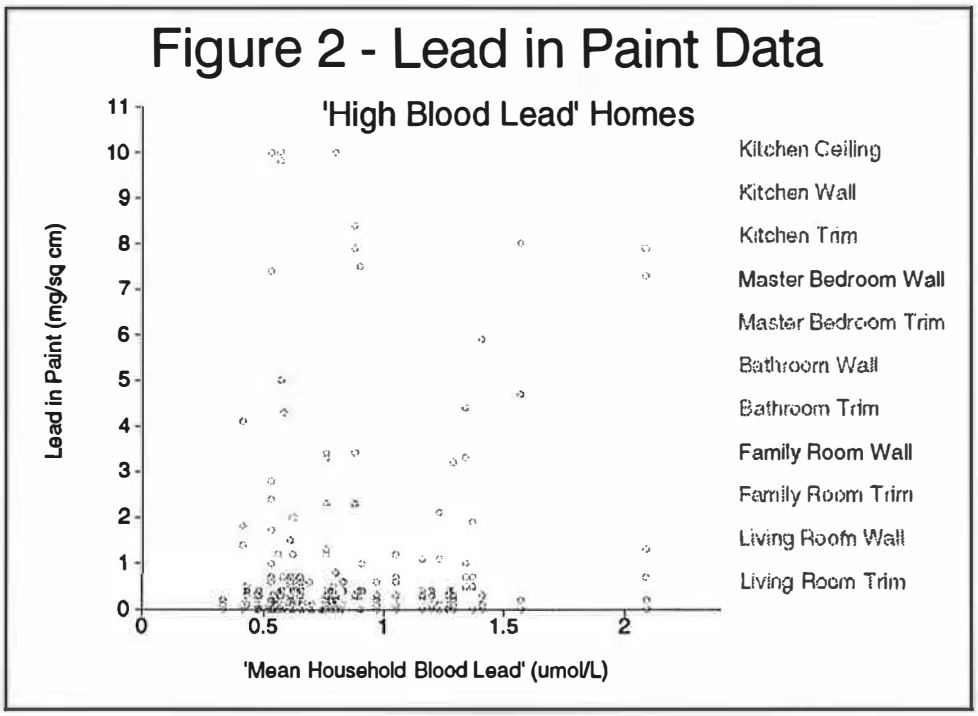
Figure 2 - Lead in Paint Data
'High Blood Lead' Homes
Lead in Paint (mg/sq cm)
'Mean Household Blood Lead' (umol/L)
Kitchen Ceiling
Kitchen Wall
Kitchen Trim
Master Bedroom Wall
Master Bedroom Trim
Bathroom Wall
Bathroom Trim
Family Room Wall
Family Room Trim
Living Room Wall
Living Room Trim