Journal of the Minnesota Academy of Science

Volume 50 | Number 1 Article 5

1984

Urban Lead in Minnesota: Soil Transect Results of Four Cities

Howard W. Mielke
Macalester College

Sara Burroughs

Randall Wade

Timothy Yarrow

Paul W. Mielke

Urban Lead in Minnesota: Soil Transect Results of Four Cities

HOWARD W. MIELKE,* SARA BURROUGHS, RANDALL WADE, TIMOTHY YARROW, PAUL W. MIELKE

ABSTRACT — The focus of this field study was the development of a soil collection and analysis method for the rapid assessment of urban lead (Pb) buildup in four Minnesota cities, Minneapolis, St. Paul, Duluth, and Rochester. The results show that soil Pb buildup is mainly a function of urban size, although specific geographic factors, such as a bluff that constrains city development along a narrow corridor, also play a role in Pb distribution and concentration. Maximum urban Pb concentrations were approximately 25, 70, and 100 times rural soil Pb levels, in Rochester, Duluth, and the centers of Minneapolis and St. Paul respectively. The primary source of Pb measured in this study was assumed to be Pb aerosols exhausted from the use of leaded gasoline during the past four or five decades. A portion of the total state Pb exhausts were estimated for each city from state daily vehicle mile (DVM) data. The chain of movement which exposes children to excessive Pb levels from aerosol accumulations in the soil is described along with the remedy to alleviate continued urban Pb buildup.

Introduction

Medical evidence and a national blood lead (Pb) survey done between 1976 and 1980 revealed that the average child in the United States has a higher blood Pb level than that which may impair intellectual capabilities (1,2,3). The critical concentration of Pb in blood is considered to be 15 ug/dl or lower (2,4). Blood Pb levels have been related to where children live. Children's blood Pb levels average 13.9 ug/dl in rural areas, 16.5 ug/dl in small cities (<1,000,000), 18.0 ug/dl in large cities (>1,000,000) and 20.0 ug/dl in central cities (1). Because the city is the major population site of our society, it is imperative to evaluate the processes that create this situation.

A major study done on the distribution of soil Pb in Baltimore, Md., revealed that high Pb soils were tightly clustered within communities located around the center of Baltimore (5). The degree of clustering of high Pb soils was determined by multi-response permutation procedures (MRPP) that gave a p-value of 10^{-23} for the Pb pattern. That is, the pattern of high Pb soils could only be explained by random error in about one chance in a trillion raised to the second power. Since we could not imagine any major differences of sources of Pb between Baltimore and other large cities, we concluded that it is probable that all large urban centers in the United States are also contaminated with Pb. In view of the extremely low p-value, the degree of the Pb problem should be accessible with less arduous, more rapid sampling techniques than were employed in the four years of collection and analysis required in the Baltimore study. The purpose of this study was to examine the general distribution of soil Pb along a transect through Minnesota cities of Minneapolis/St. Paul, Duluth, and Rochester, by employing simple collection procedures.

Methods

Urban Pb levels were assessed by collecting soil samples at specified sites along transects. Collection strategy was planned in advance of fieldwork using city maps. On each map a transect was drawn that started in a rural area, passed through the central business district of the city, continued past the city limits and ended in the rural countryside. An attempt was made to draw the transect so as to avoid any single road or major transportation corridor, although in the Twin Cities and Duluth some portion of a major transportation corridor was included. In the Twin Cities the transect followed the transportation corridor through the heavily traveled Midway district between St. Paul and Minneapolis. The Duluth transect was confined by topographic constraints to a narrow corridor along the shore of Lake Superior. Thus in Duluth the transect was drawn along the length of the most populated section of the city, which also coincides with the major transportation corridor of the city.

Soil samples were collected from road rights-of-way. Bare soil areas were avoided in order to exclude soils that had a high probability of being contaminated, as indicated by the fact that they do not support vegetation. In the rural areas, soil samples were collected near fences of fields. In suburban and urban areas, soils were collected next to sidewalks. At sites where grass or other vegetation was continuous, a 5-8 cm deep section of turf was removed, and a sample of soil was collected that consisted of soil knocked free from the roots of the sod, and soil immediately beneath the sod up to a total of 10 cm deep. The collected soils were placed into labelled plastic bags for transit to the laboratory.

Samples were air dried and sieved with a stainless steel (USGS #10) 2mm mesh screen. Samples were prepared for Pb analysis by shaking 10 g of air-dried soil in 40 ml of 1M nitric acid extraction solution for a period of two hours. The extracts were filtered and were analyzed for Pb using an IL 357 atomic absorption spectrophotometer with deuterium background correction. Extracts with Pb concentrations that exceeded the range of the spectrophotometer were diluted with 1M nitric acid and re-analyzed.

Results

The results of the transect surveys are illustrated in Figures 1 through 3 for metropolitan Twin Cities, Duluth, and Rochester respectively. There are similarities and differences in the pattern of distribution of soil Pb in each city. In general, the soil Pb levels increase markedly toward the central business

*Dept. of Geography, Macalester College

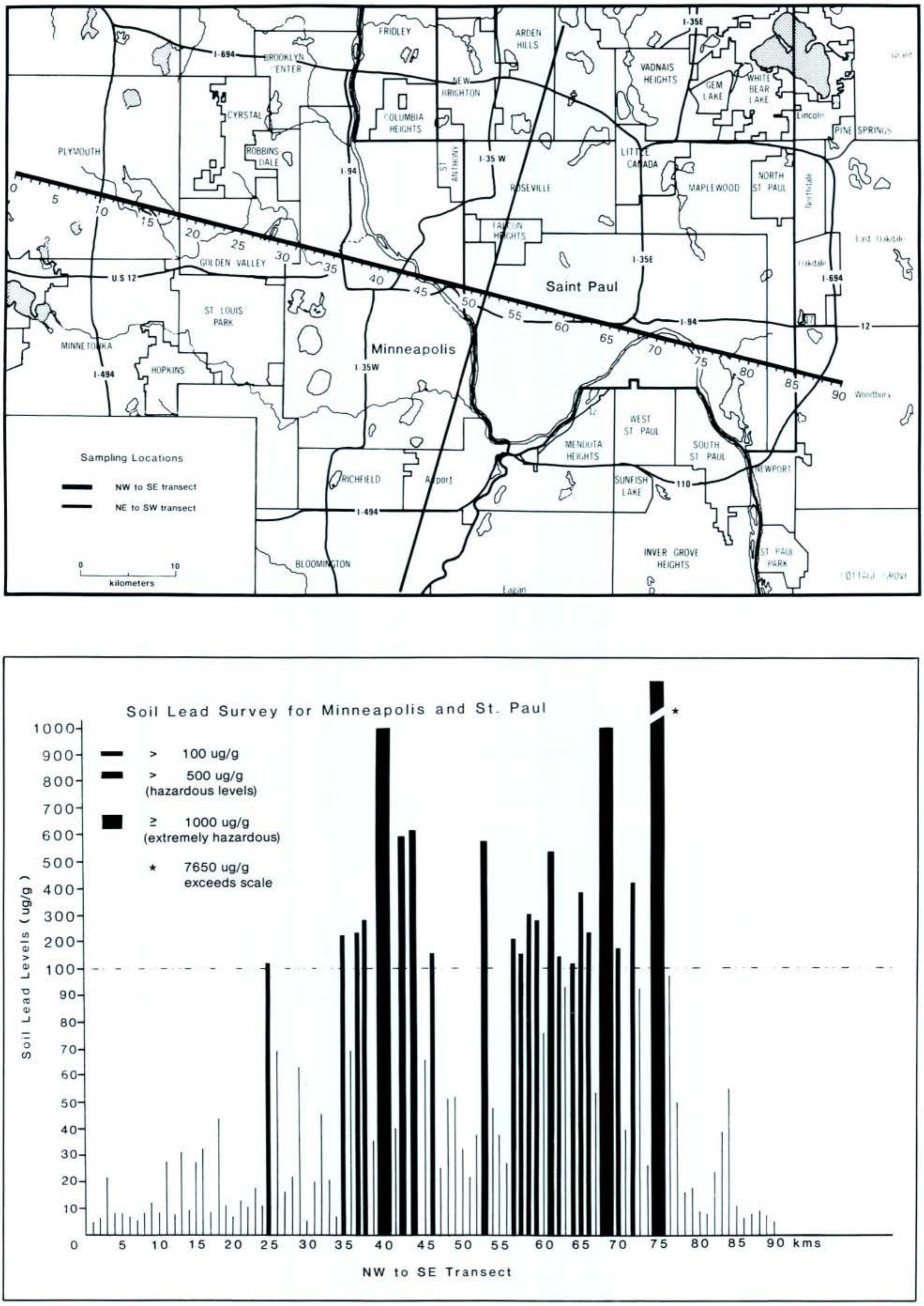

Figure 1. Lead in the Twin Cities: (1a), Minneapolis and St. Paul metropolitan map; (1b), lead distribution graph of soil samples taken at 1.0 kilometer intervals.

district. For example, the rural soil Pb level west of Minneapolis is 5 ug/g; soil Pb levels increase ten-fold near the city limits and another ten-fold between the city limits and downtown Minneapolis. Thus, we see a total of a hundred-fold increase between the rural area and the inner city. The Rochester transect was similar but more attenuated. The soil Pb levels in the center of the city were less than 25 times the 6 ug/g found in the rural area. In Duluth, the soil Pb levels of the transect were the least variable, ranging from 75 to 420 ug/g, or less than a six-fold increase from the city outskirts to the central business district. Another Duluth transect (not shown) was sampled perpendicular to the initial transect. The most rural soils of this second transect contained 6 ug/g of Pb, resulting in a 70-fold increase of Pb between the rural and inner city soils. Table 1 lists the arithmetic means, F statistics and P-values for each city on the basis of the location of the samples (i.e., rural, non-central city and central city). Analysis of variance (ANOVA) given in Table 1 demonstrates the fact that the differences are significant for each of the cities examined in this survey.

Discussion

It is assumed that the main source of the Pb extracted from most of these soil samples is the use of leaded gasoline by vehicular traffic within each of these cities. Based on industry figures that give the amount of leaded gasoline used per state per year during the past two decades, and the amount of Pb per gallon of gasoline each year, the quantity of Pb used in gasoline was calculated for Minnesota (7,8). From 1961 to 1981, 62,556 metric tons of Pb were consumed in the form of leaded gasoline. Thus, we estimate that during the past 4 to 5 decades between 60,000 and 120,000 metric tons of Pb have been released into the atmosphere by vehicle traffic in Minnesota.

Pb has not been evenly distributed within the environment, but has accumulated in patterns similar to the flow of vehicle traffic in the state. The positive relationship between traffic volume and Pb levels in roadside dust and soil is well described in the literature and the results from Minnesota appear to follow the same trend (9).

A rough estimate of the amount of Pb that has been deposited in each city was calculated from 1981 daily vehicle mile (DVM) data for the counties in which each city is located (10). We believe that these data underestimate the amount of Pb distributed in the city because stop-and-go traffic uses more gasoline per mile (and thus exhausts more Pb) than high speed freeway traffic. For example, sales data obtained from the Minnesota Department of Revenue shows that 45% ± 5% of the leaded gasoline sold in Minnesota was purchased in the seven county metropolitan area of the Twin Cities (11). If half of the leaded gasoline sold in the seven county area was used in Hennepin and Ramsey counties, then the actual amount of leaded gasoline used in St. Paul and Minneapolis is about 20% instead of 10% of the state total as assumed in Table 2.

Table 2. Estimated lead from gasoline[a].

City	%DVM[b]	Lead Deposition (metric tons)[c]
Minneapolis	5.9	3700-7400
St. Paul	4.5	2800-5600
Duluth	1.6	1000-2000
Rochester	0.7	440- 880

[a] Range for past 4 to 5 decades arrived at by doubling the 1961-1981 value.

[b] Calculated from 1981 data as percent of total state travel.

[c] %DVM times state total of 62556 metric tons of Pb for 1961-1981, and rounded.

According to gasoline sales data this method of calculating urban Pb deposition probably underestimates the actual deposition by a factor of two.

Although our study focused on the Pb levels in the rights-of-way of streets and highways, the impact of Pb reaches beyond the roadways. Several critical links have been described that relate vehicle sources of Pb to the Pb risk for human beings. First, there is a close relationship between the amount of Pb consumed in gasoline and the blood Pb levels in the population (12).

Second, there is evidence that Pb aerosols collect on the sides of buildings and are washed into the soil from rain (14,5). These mechanisms provide the critical link between traffic intensity and soil Pb levels within the yards of homes in the city. Thus, we expect that exposure to airborne Pb is greatest toward the inner city where commuter traffic is heaviest.

Children are the group most sensitive to Pb. They absorb and retain about 50% of the Pb ingested compared to an absorption and retention of 8% for adults (13). Because children exhibit hand-to-mouth behavior as part of their exploration of the environment, they are more likely to ingest Pb (15). Pb in soil has been shown to be at least as easy to absorb from the digestive tract into the blood as paint Pb (16). In a study of Minneapolis inner city neighborhoods, more than 78 percent of the homes had soil Pb levels which exceeded 500 ug/g (17). At a concentration of 500 ug/g, 0.5 grams of soil orally ingested would contain 250 ug of Pb, which is almost double the 150 ug maximum permissible daily intake suggested for children six months to two years of age (18). It has been shown that if floors and childrens' hands are kept clean, children have a significant reduction in their blood Pb levels (19,20).

Other environmental sources of Pb are also relevant to the problem. Leaded paint has been the primary focus of attention in the child Pb problem. In view of the age and state of maintenance of many homes of inner city neighborhoods, paints also represent a serious risk to children.

For the city to be a healthy environment, it must not be detrimental to any stage in the life cycle of the human being, from birth to old age. However, we find that inner city children are at maximum risk to exposure to environmental Pb. They live in older homes that were painted with leaded

Table 1. Table of analysis of variance results including arithmetic means, F statistics and P-values of soil lead levels of three Minnesota cities.

	Twin Cities	Duluth	Rochester	F Statistic	P-value*
Rural	6.71	9.20	8.29	3.75	0.036
Non-central	28.60	106.88	29.67	73.99	0.000005
Central	423.33	362.66	83.17	3.23	0.052
F Statistic	13.78	21.66	11.21		
P-value*	0.00005	0.0002	0.001		

*P-values are based on permutation procedures as described in (6).

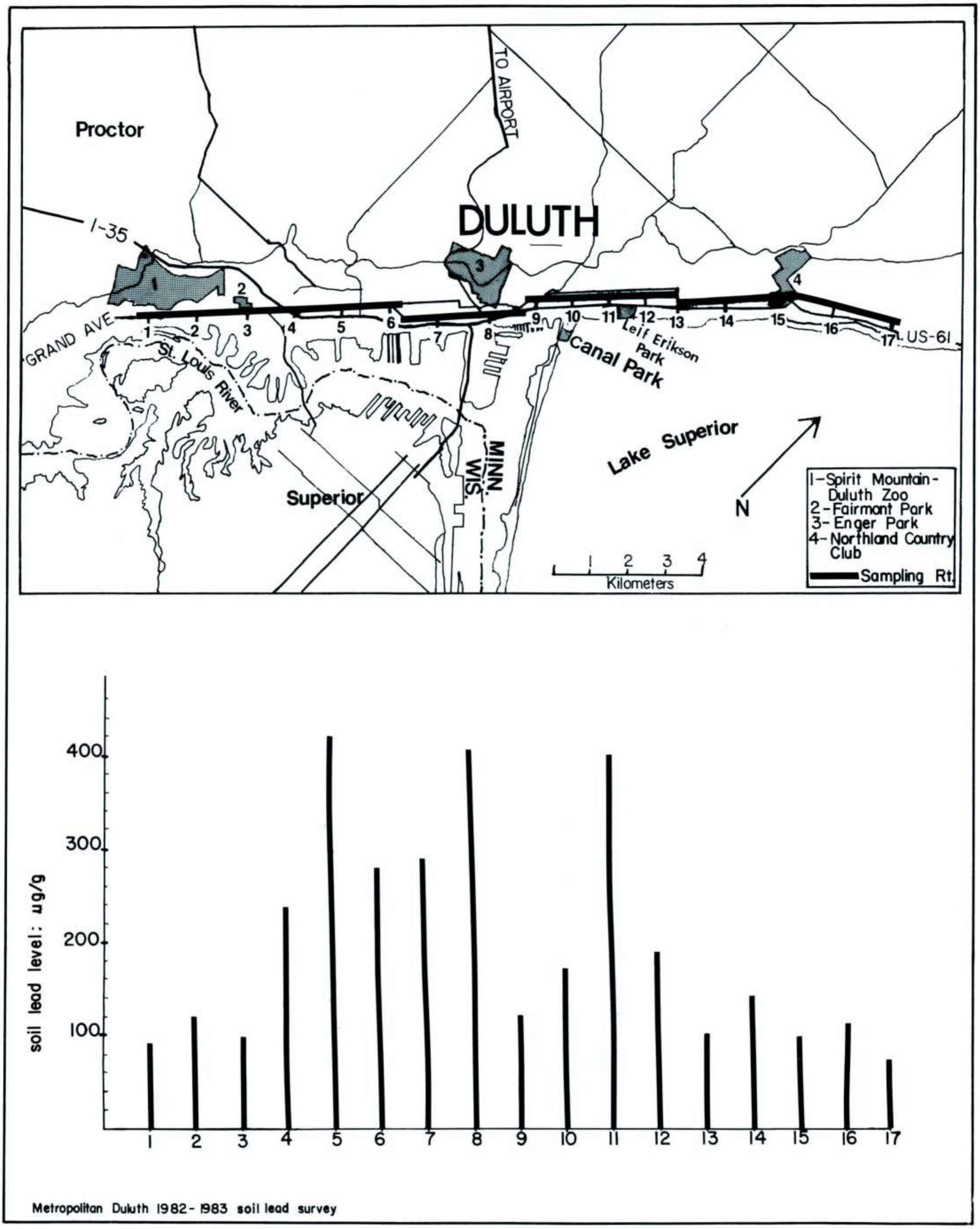

Figure 2. Duluth map and corresponding lead distribution graph of soil samples taken at 1.0 kilometer intervals.

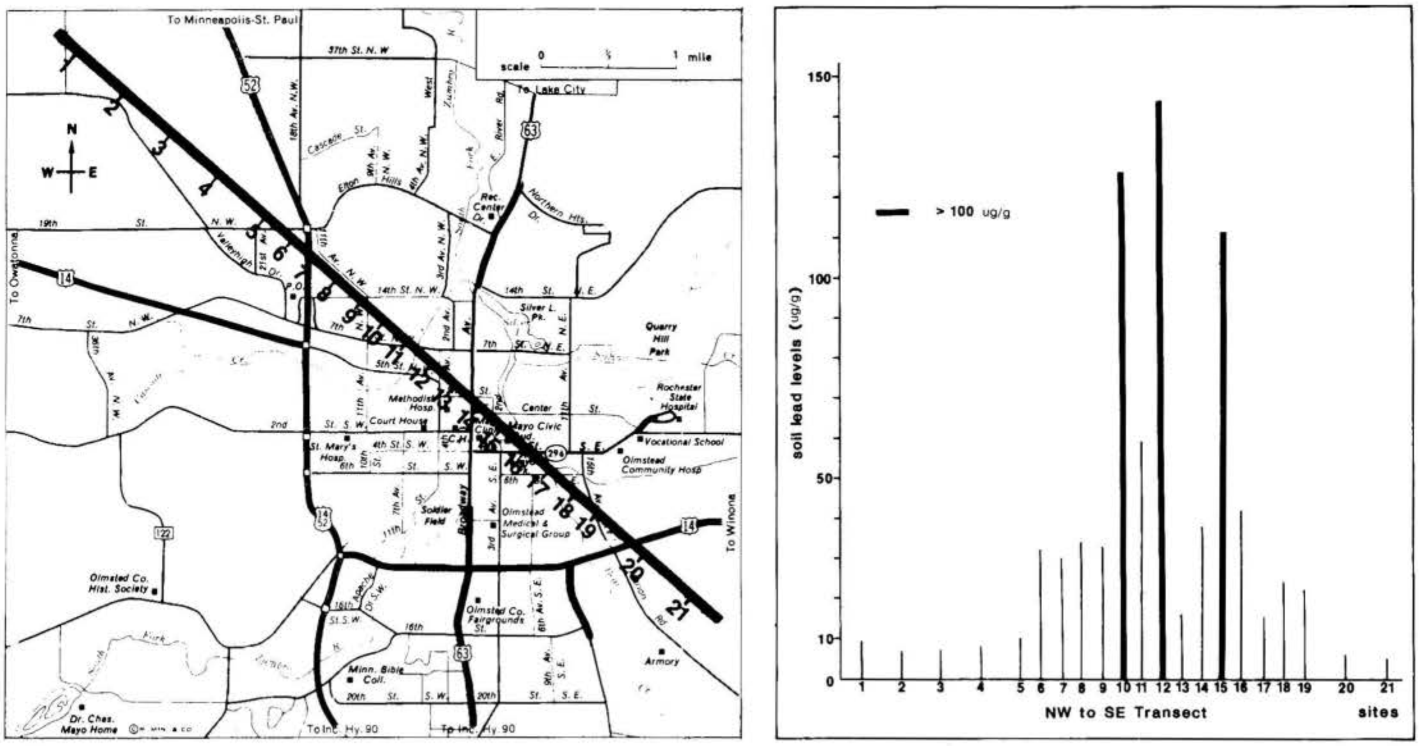

Figure 3. Rochester map and corresponding lead distribution graph of soil samples taken at 0.5 and 1.0 kilometer intervals.

paints. They play in soils that are contaminated with Pb and they breathe higher levels of Pb aerosols than children living in less densely populated places. They are also more likely to be undernourished or malnourished, resulting in increased vulnerability to the effects of Pb (21).

The Pb issue is a tragic problem because it is manmade and completely preventable. Several steps have been taken during the past decade which demonstrate that the dangers have been recognized. High lead paints have been regulated and catalytic converters that prohibit the use of leaded gasoline have been installed as standard equipment on most new automobiles, reducing the amount of leaded gasoline consumed. Unfortunately, this progress has been curtailed as a result of lack of attention to details of the problem. For example, in Minnesota higher Pb levels were emitted by vehicles in 1983 than in 1982. This is due to three facts. First, there was a change in federal standards concerning the addition of Pb to gasoline in November, 1982. The prior standard was based on the total consumption of gasoline (leaded and unleaded) and allowed 0.5 g per gallon to be averaged for the total. The new standards are based on the leaded gasoline portion only and allow 1.1 g Pb per gallon. Second, Minnesota consumes more leaded gasoline (about 55%) as a percentage of our fuel than the national average (43%). Thirdly, many cars (10%-20%) that were designed for unleaded gasoline are being misfueled with leaded gasoline.

The combination of the above facts has resulted in a substantial increase in Pb aerosol emissions in Minnesota. Because we consume roughly about 2,000 million gallons of gasoline in Minnesota we have had an increase from roughly 1,000 metric tons of Pb in 1982 to roughly 1,210 metric tons of Pb in 1983. The trend continues to remain unchanged in 1984. With 20 percent of the total gasoline consumption, the Twin Cities increased from about 200 metric tons in 1982 to 242 metric tons in 1983. These quantities of Pb dwarf the stationary sources of Pb (5 tons per year for the state) that are currently regulated by the Minnesota Pollution Control Agency. Aerosols from leaded gasoline are the major source of Pb currently accumulating in the urban environment.

This survey of Pb in soils demonstrates that the inner cities in Minnesota are highly contaminated with Pb. It supports the prediction of the Baltimore study that all major cities have the same process operating to cause an accumulation of lead and that the accumulations have been so concentrated as to be easily detected using relatively simple soil collection techniques. The medical literature shows that much relief to children could be obtained by removing Pb aerosols (12). Because at least 95% of the Pb aerosols originate with gasoline, further contamination of Minnesota cities can be prevented by removing this Pb source from the urban environment.

References

1. Mahaffey, K.R., Annest, J.L., Roberts, J., and Murphy, R.S. 1982. National estimates of blood lead levels: United States, 1976-1980; association with selected demographic and socioeconomic factors. *N. Engl. J. Med.* 307:537-579.
2. Yule, W., Lansdown, R., Millar, I.B., and Urbanowicz, M. 1981. The relationship between blood lead concentration, intelligence and attainment in a school population: a pilot study. *Develop. Med. Child, Neurol.* 23:567-576.
3. David, O.J., Grad, G., McGann, B., and Koltun, A. 1982. Mental retardation and "non-toxic" lead levels. *Am. J. Psychiatry* 139:806-809.
4. Schwartz, J., Leggett, J., Ostro, B., Pitcher, H., Levin, R. 1984. *Costs and Benefits of Reducing Lead in Gasoline.*

Draft final report, Office of Policy Analysis, Environmental Protection Agency, Washington, D.C.
5. Mielke, H.W., Anderson, J.D., Berry, K.J., Mielke, P.W., Chaney, R.L., and Leech, M. 1983. Lead concentrations in inner city soils as a factor in the child lead problem. *Am. J. Pub. Health* 73:1366-1369.
6. Berry, K.J. and Mielke, P.W. 1983. Moment approximations as an alternative to the F test in analysis of variance. *British J. of Mathematical and Statistical Psychology* 36:202-206.
7. Ethyl Corporation: *Yearly Report of Gasoline Sales by States — 1982.* Ethyl Petroleum Chemicals, 2 Houston Center, Suite 900, Houston, Texas 77010.
8. Shelton, E.M., Whisman, M.L., and Woodward, P.W. 1982. Long-term historical trends in gasoline properties are charted. *Oil and Gas Journal* August 2, pp 95-99.
9. Lau, W.M. and Wong, H.M. 1982. An ecological survey of lead contents in roadside dusts and soils in Hong Kong. *Environ. Res.* 28:39-54.
10. James W. Johnson, Minnesota Department of Transportation, personal communication.
11. Letter to Richard Braun, Commissioner, Minnesota Department of Transportation, from Mike Murphy, Assistant Commissioner, Division of Energy, dated March 23, 1983 on the subject of gasoline sales data. The letter concludes, "Approximately 45% ± 5% of Minnesota's retail motor gasoline sales (gallons) occur in the metro area." Metro area refers to the MSA metro area of Anoka, Carver, Dakota, Hennepin, Ramsey, Scott, and Washington counties. The conclusion was based on data from the monthly gasoline sales survey.
12. Annest, J.L., Pirkle, H.L., Makuc, D., Neese, J.W., Bayse, D.D., and Kovar, M.G. 1983. Chronological trend in blood lead levels between 1976 and 1980. *N. Engl. J. Med.* 308:1373-1377.
13. Hammond, P.B. 1982. Metabolism of lead. In: Chisolm, J.J. and O'Hara (eds), *Lead Absorption in Children,* pp. 11-20. Baltimore: Urban and Schwarzenberg.
14. Rolfe, G.L. and Haney, A. 1975. *An Ecosystem Analysis of Environmental Contamination by Lead.* 133 pp. University of Illinois at Urbana-Champaign: Institute for Environment Studies.
15. Sayer, J.W. 1981. Dust lead contribution to lead in children. In: R. Lynam, L.G. Piantanide, J.F. Cole (eds), *Environmental Lead,* pp. 23-40. New York: Academic Press.
16. Day, J.P., Fergusson, J.E., and Chee, T.M. 1981. Solubility and potential toxicity of lead in urban street dust. *Bull. Environ. Toxicol.* 23:497-502.
17. Mielke, H.W., Blake, B., Burroughs, S., and Hassinger, N. 1984. Urban lead levels of Minneapolis: The case of the Hmong children. *Env. Res.* 34:64-76.
18. Mahaffey, K.R. 1977. Relation between quantities of lead ingested and health effects of lead in humans. *Pediatric NY* 59:448-456.
19. Charney E. 1982. Lead poisoning in children: the case against household lead dust. In: J.J. Chisolm, D.M. O'Hara (eds), *Lead Absorption in Children: Management, Clinical and Environmental Aspects,* pp. 79-88. Baltimore: Urban and Schwarzenberg.
20. Charney, E., Kessler, B., Farfel, M., and Jackson, D. 1983. Childhood lead poisoning: A controlled trial of the effect of dust-control measures on blood lead levels. *N. Engl. J. Med.* 309:1089-1093.
21. Mahaffey, K.R., and Michaelson, I.A., 1980. The interaction between lead and nutrition. In: H.L. Needleman (ed), *Low Level Lead Exposure: The Clinical Implications of Current Research,* pp. 159-200. New York: Raven Press.