Lead Loading of Urban Streets by Motor Vehicle Wheel Weights

Robert A. Root

Albuquerque, New Mexico, USA

This study documents that lead weights, which are used to balance motor vehicle wheels, are lost and deposited in urban streets, that they accumulate along the outer curb, and that they are rapidly abraded and ground into tiny pieces by vehicle traffic. The lead is so soft that half the lead deposited in the street is no longer visible after little more than 1 week. This lead loading of urban streets by motor vehicle wheel weights is continuous, significant, and widespread, and is potentially a major source of human lead exposure because the lead is concentrated along the outer curb where pedestrians are likely to step. Lead deposition at one intersection in Albuquerque, New Mexico, ranged from 50 to 70 kg/km/year (almost 11 g/ft^2/year along the outer curb), a mass loading rate that, if accumulated for a year, would exceed federal lead hazard guidelines more than 10,000 times. Lead loading of major Albuquerque thoroughfares is estimated to be 3,730 kg/year. Wheel weight lead may be dispersed as fugitive dust, flushed periodically by storm water into nearby waterways and aquatic ecosystems, or may adhere to the shoes of pedestrians or the feet of pets, where it can be tracked into the home. I propose that lead from wheel weights contributes to the lead burden of urban populations. *Key words*: antimony, antimonious lead, lead, lead loading, lead poisoning, lead pollution, motor vehicle wheel weights, street lead, urban lead, wheel weights. *Environ Health Perspect* 108:937–940 (2000). [Online 29 August 2000]
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In 1997, the U.S. Public Health Service reaffirmed its 1991 call for a society-wide effort to eliminate childhood lead poisoning, one of the most common and preventable pediatric health problems (*1*). Lead affects virtually every system in the body, especially the developing brain and nervous system of fetuses and young children (*2*). Some 890,000 children in the United States have blood lead levels high enough to cause adverse effects on their ability to learn, and 2.7 million children have increased dental cavities attributable to lead exposure (*1,3*). A highly significant association has been found between lead exposure and children's IQ, and there is no evidence of a threshold down to blood lead concentrations as low as 1 μg/dL (*4*). Virtually all children are at risk for lead poisoning, and the risk for lead exposure is disproportionately high for children living in large metropolitan areas (*2,5*). Lead-contaminated dusts and soils are one of the primary pathways of lead exposure for children, especially in urban populations (*2,6,7*).

Lead levels in roadside soil along some heavily traveled roads have been reported as high as 10,000 ppm (*2,7,8*). The U.S. Environmental Protection Agency (U.S. EPA) assumes that the large amount of lead near busy streets comes from the prior use of leaded gasoline (*9*). Motor vehicle wheel weights, which are 95% lead, are potentially a major source of lead exposure that heretofore has not been recognized.

Automobile and light truck wheel weights are lead castings 5–150 mm long and weigh 7–113 g. They contain approximately 5% antimony to increase hardness. This alloy is known as antimonious lead. To ensure that a newly balanced wheel runs smoothly, wheel weights are affixed at appropriate locations by a steel clip to both the inner and outer wheel rims. A few wheels are balanced by gluing the weights to the inside of the rim with adhesive strips. Automobile and light truck wheels typically require one and usually two weights per wheel to achieve balance.

Methods and Results

I conducted studies in Albuquerque, New Mexico, to ascertain the baseline or steady state amount of metallic lead found in urban streets, the rate of lead deposition, and the rate of lead abrasion.

Steady-state surveys. To estimate the steady-state amount of lead found in urban streets, I surveyed eight six-lane divided street segments, totaling 19.2 km, by walking along the sidewalk adjacent to the outer lane and retrieving any lead found along the outer curb, in the street, and on the sidewalk. The sidewalk was adjacent to the outer curb along most segments. Along some segments the sidewalk was set back approximately 1 m and the space between the sidewalk and curb was occupied by gravel, cobbles, or low shrubs. These obstacles made searching for wheel weights more difficult. Curbside parking did not occur on any of the streets surveyed. I attempted only one survey along the median because of the potential danger; the posted speed limit on these streets is 65 km/hr, and the average weekday traffic volume is as high as 45,000 vehicles/day (*10*).

These initial surveys are referred to as steady-state surveys because the amount of lead deposited and worn away, if undisturbed, should not change substantially over time. The cleaning history of the eight streets is unknown; however, they appear, based on the interstreet consistency of the amount of lead found, to have achieved a steady-state condition. The pieces of lead found in the street averaged 21 g each; the smallest found was approximately 3 g. Virtually all lead was found in either the 0.6-m-wide outer curb area (i.e., the concrete gutter) or the 25-cm-wide median curb area. Approximately 1% of the lead was found outside the curb area—about half in the street and half on the sidewalk. Metallic lead is very soft and highly malleable (*11*). Once the wheel weights are deposited in the street they are easily abraded and broken into tiny pieces as vehicles run over them. Figure 1 shows street-abraded wheel weights.

I weighed lead found during these eight steady-state surveys to the nearest 0.1 g. The lead ranged from 0.35 to 1.1 kg/km, with a geometric mean of 0.50 kg/km. More than 97% of the lead found was recognizable as whole or pieces of wheel weights. I resurveyed two of the eight street segments to confirm that their steady states were consistent over time. Total lead for each resurveyed street varied by 25% from the mean, and right-side versus left-side deposition varied approximately 5% for each.

The survey results are considered conservative (in the sense that the quantity of lead deposited is underestimated) because it is impossible to ensure complete recovery of all lead pieces by visual inspection. Many pieces of lead are the size, shape, and color of roadside debris. Indeed, on several occasions when the survey route was immediately retraced, approximately 10% more lead was found.

Biweekly surveys. To determine the rate of wheel weight deposition, I conducted surveys in the same manner as the steady-state surveys every other week for 46 weeks along a 2.4-km six-lane divided street segment, designated JTML. JTML was selected

because more wheel weights were found in the initial steady-state survey along this segment than along any of the other seven streets. JTML has an average daily traffic flow of 41,500 vehicles/day (*10*). These biweekly surveys were conducted at midday to ensure that the lead was not obscured by curbside shadows. Figure 2 presents the JTML steady-state and biweekly survey results. The mean steady-state level was 1.09 kg/km. On average, 0.35 kg/km was found during the biweekly surveys, an accumulation equivalent to 9.1 kg/km/year.

During the steady-state and biweekly surveys, approximately 60% of the lead was found on the west side of JTML and 40% on the east side (Figure 3). Knowledge of Albuquerque's terrain and the fact that the middle of streets usually has a crown to promote drainage are important in understanding this pattern of deposition. East of the Rio Grande, the terrain dips gently to the west from the base of the Sandia Mountains. JTML runs north–south perpendicular to the slope, such that the east side of JTML is somewhat uphill and the west side is somewhat downhill. Thus, the street slopes less on the east side and more on the west side. In general, the east side of the JTML street surface is flatter and at some intersections slopes toward the median. Conversely, the west side of the street is more steeply sloped, its surface is rarely level, and it has no surfaces that slope toward the median except for left turn lanes carved into the median. Street slope is significant because it affects the direction and time it takes for wheel weights to migrate to the side of the street. Longer migration time would result in greater wheel weight wear. Wheel weight deposition on relatively flat urban streets is therefore likely to be underestimated.

The effect of street slope is illustrated by the steady-state survey of the JTML median. On the east side of JTML, where the street slope is reduced by the dipping terrain and where 40% of the wheel weight lead was found, wheel weights along the median were
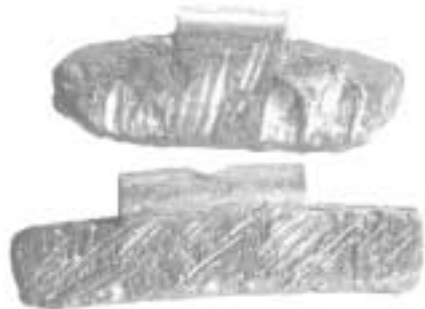
50% of the steady state. On the west side, with steeper slopes and 60% of the wheel weight lead, the wheel weights along the median were 10% of the steady state. Overall, wheel weights along the median were 25% of the steady state.

Wheel weight deposition was more frequent in the vicinity of businesses, side streets, and intersections where motorists slow down rapidly. For example, 90% of the lead found on the west side of JTML was concentrated along the southwestern quarter of the street segment (Figure 4). (Deposition along two blocks at the southern end of the west side of JTML, a distance of 600 m, was significantly greater than for any other street segment. This two-block segment, which was one-quarter of the west side of JTML, is referred to as the southwestern quarter. The remainder of the west side of JTML is referred to as the northwestern three-quarters.) The 1,800-m northwestern three-quarters has few businesses frequented by motorists, whereas the southwestern quarter has six such business (brake repair, two tire shops, donut shop, restaurant, supermarket), two frequently used side streets, and a traffic light intersection whose incoming lanes all slope toward the outer curb. Wheel weight deposition on the east side of JTML, where business and intersections are more evenly distributed, was more uniform.

Degradation study. To determine the rate at which wheel weights are abraded in the street, I conducted a degradation study on the same street but not within the JTML segment included in the surveys. The study was initiated by clearing all lead from the study area. Then, every day for 14 days, I scattered five or six previously used wheel weights ranging from 14 to 84 g near the center of each of three lanes on one side of the street; each day's weights totaled approximately 0.50 kg. A total of 7.0 kg was deposited in this way. On the 15th day, I searched the entire area and retrieved lead from along the outer curb, the sidewalk, the paved area beyond the sidewalk, the street, along the median curb area, and from the median itself.
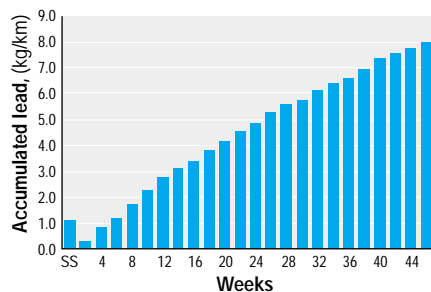
Only 4.0 kg of the 7.0 kg of wheel weights was found on the 15th day. Approximately 2.7 kg, or 38% of the amount deposited, was found in the street, along the outer curb, and on the sidewalk—the areas searched during the biweekly surveys. No adjustment was made for wheel weights potentially lost from motor vehicles because the biweekly survey estimated that only 14 g would, on average, have been deposited. This bias is small and would increase slightly the lead found, and thereby reduce the estimate of lead apparently lost through abrasion. Most wheel weights were found along the outer curb "upstream" from their original locations. Apparently, as vehicles run over wheel weights, the torque from the vehicle's drive wheels skids the weights against the traffic flow. Most wheel weights showed signs of abrasion, some severe, as shown in Figure 1. Many of the weights were broken into two or more pieces. About two-thirds migrated laterally to the outer curb and one-third to the median curb. In the degradation study, half of the wheel weight lead deposited in the street was not visible after 8 days.

Rate of lead deposition. Comparison of the amount of steady-state lead with the lead accumulated biweekly (Figure 2) and the rapid rate of lead abrasion found during the degradation study indicate that lead deposited in a busy street is rapidly worn away, to the extent that a significant fraction of the amount deposited would not be found in
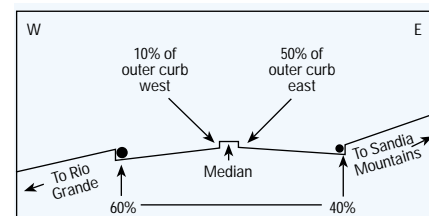
Figure 3. A schematic profile of JTML showing the effect of terrain on the deposition of wheel weights. Approximately 60% of lead was found on the steeper sloping west side of the street and 40% on the east. The inner (median) curb on the east side had 50% as much lead as the outer curb on that side, whereas the inner curb on the west side had only 10% as much as the outer curb.
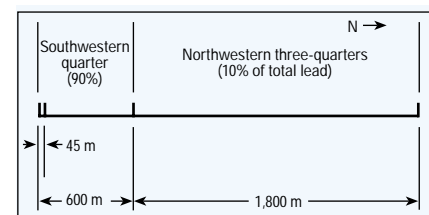
Figure 4. A schematic of the west side of JTML showing the uneven deposition of wheel weight lead. Of the lead found along the southwestern quarter, 15–22% was found within 45 m of the intersection at the southern end of JTML.

Figure 1. Abraded wheel weights. Note the scratches, scrapes, and gouges resulting from the weights being run over by motor vehicles.

Figure 2. JTML steady-state (SS) and biweekly survey results. Bars indicate the accumulated total of lead found biweekly.

the biweekly surveys. I used two approaches to adjust for this lead loss. First, the daily fraction of lead that is worn away was obtained mathematically from the results of the steady-state and biweekly surveys, as shown below.

The relationship between the lead deposited in kilograms per kilometer per day (D) and the lead retrieved at the end of 2 weeks in kilograms per kilometer (R_{14}) can be expressed as follows:

$$R_{14} = \frac{Dp(1-p^{14})}{(1-p)}, \qquad [1]$$

where D is the amount of lead deposited per kilometer per day, and p is the fraction remaining each day from the previous day's lead deposition. The steady state amount of lead in kilograms per kilometer (S) is, therefore,

$$S = R_\infty = \frac{Dp}{(1-p)}. \qquad [2]$$

To estimate p from the observed values of R_{14} and S, divide Equation 1 by Equation 2:

$$\frac{R_{14}}{S} = 1 - p^{14},$$

which is equivalent to

$$p = \sqrt[14]{1 - \frac{R_{14}}{S}}. \qquad [3]$$

Accumulation during the biweekly surveys, R_{14}, was 0.35 kg/km. The steady-state surveys yielded a value for S of 1.094 kg/km. Using Equation 3, the estimated value for p is 0.9728, implying that 2.72% of the lead deposited each day is worn away by the next day.

To estimate the actual rate of lead deposition, I adjusted the biweekly survey rate to account for the amount of lead worn away by the grinding action of traffic. The "wear adjustment factor" is estimated to be the ratio of lead deposited per kilometer per 14 days to the lead retrieved in the biweekly surveys (0.35 kg/km). From Equation 2, D is estimated to be the amount of lead deposited per kilometer per day, as $D = (1-p)S = (0.0272)(1.094) = 0.0297$ kg/km/day. Thus,

$$\text{Wear adjustment factor} = \frac{(14 \times 0.0297)}{0.35}$$
$$= 1.2.$$

Second, I conducted daily surveys of the southwestern quarter of JTML for 4 weeks, presented as Figure 5, and compared them with the biweekly surveys for this 600-m

segment. From this study, a wear adjustment factor was estimated to be nearly 1.4 by dividing the daily survey rate of 26.0 kg/km/year by the biweekly survey rate of 18.9 kg/km/year. A combined wear adjustment factor of 1.3 was adopted.

To estimate the amount of lead deposited along the outer curb in JTML, I multiplied the annual rate of wheel weight deposition (9.1 kg/km) by the wear adjustment factor of 1.3 and then by 0.95 as a lead adjustment factor to compensate for the 5% antimony content of the weights. The resultant deposition rate does not include lead abraded from the wheel weights between their deposition in the street and the time it takes for them to migrate to the outer curb. No adjustment was made to include lead deposited along the median because that lead would probably not migrate to the outer curb. Accordingly, lead deposition along JTML is conservatively estimated to average 11.8 kg/km/year along the outer curb of both sides of the street along the entire 2.4-km street segment and 24.5 kg/km/year along the southwestern 600-m interval on one side of the street. During the weekly surveys of this southwestern quarter, 15% of the wheel weights found were along a 45-m curb interval at the southernmost intersection; during the steady-state surveys, 22% was found along the same 45 m. Using these percentages, lead deposition is estimated to be 50–70 kg/km/year for this 45-m interval.

Discussion

Although lead weights may be found anywhere motor vehicles go, they most commonly fall off where vehicles rapidly change momentum—for example, when slowing down for a traffic light or turning onto a side street or into a business. Thus, one would expect to find higher deposition of lead weights in these areas.

The federal guideline for the amount of lead needed to create a lead hazard on an outdoor surface such as a sidewalk is 800 µg/ft^2 (*1,12,13*). If accumulated for a year, the lead deposited along the 45 m of outer curb at the southernmost JTML intersection would, using the deposition rates estimated by this study, meet the lead hazard guideline 10,200–13,400 times/year (more frequently than once per hour), which is sufficient to create a continuous hazardous environment. Furthermore, this 45-m curb area at a traffic-light intersection is one where pedestrians are likely to step.

The results of this study can be used to estimate the lead loading of Albuquerque's major thoroughfares by motor vehicle wheel weights. To arrive at this estimate, the geometric mean of lead found along the eight streets included in the steady-state surveys was multiplied by the number of steady

states reached per year, and then multiplied by the number of kilometers of major streets. The geometric mean of lead for the eight streets is 0.50 kg/km. JTML results indicate that wheel weight deposition is equivalent to 10 steady states per year. The city of Albuquerque has 330 km of six-lane principal traffic arteries and 200 km of four-lane minor traffic arteries (*10*). At this time, the wheel weight steady state for minor traffic arteries is not known. However, minor arteries were included by estimating their per-kilometer contribution to be two-thirds that of the principal arteries. The lead deposition rates included the wear adjustment factor of 1.3, the lead adjustment factor of 0.95, and the median adjustment factor of 1.25. Using these factors, lead loading of major Albuquerque thoroughfares by motor vehicle wheel weights is estimated at 3,730 kg/year: 2,650 kg/year for principal traffic arteries and 1,080 kg/year for minor traffic arteries. Similar results should be anticipated wherever lead weights are used to balance motor vehicle wheels.

An estimated 64 million kg/year of lead is consumed worldwide for wheel weights (*14*). The pool of lead rolling over U.S. highways is estimated to be on the order of 25 million kg, based on 200 million automobiles and light trucks (*15*) and assuming 130 g of wheel weights per vehicle. Approximately 15 million kg of the total is urban, because 60% of roadway vehicle-kilometers traveled are urban (*16*). Scaling the estimated Albuquerque deposition to the entire United States indicates that a significant amount of this rolling lead, perhaps 10% (1.5 million kg/year), is deposited in urban streets.

The ramifications of this lead loading are numerous. Small lead particles from abraded wheel weights likely contribute to the lead found in urban runoff. Storm water can sweep this lead into nearby culverts and arroyos, and ultimately washes it into nearby waterways where it can adversely affect water quality and aquatic ecosystems. In Albuquerque the storm-water runoff flows down concrete-lined drainage ditches into the Rio Grande. Such flushing accounts for a large part of the
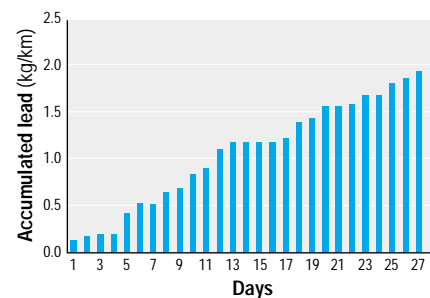

Figure 5. Daily survey results for southwestern JTML showing accumulated metallic lead found along the outer curb on the west side of JTML.

nonpoint urban pollution (*17*). Wheel weight lead can also be dispersed as fugitive dust. In semiarid environments such as that of Albuquerque, dust is common, and the air turbulence that vehicles create as they speed along urban streets can increase the suspension and dispersal of street dust. Finally, lead particles may adhere to pedestrian shoes or the feet of pets. Because contact with exterior leaded soil and dust is a potential hazard wherever it can be easily tracked into the home (*1,12,13*), I propose that wheel weight lead contributes to the lead burden of urban populations. In the absence of leaded gasoline, therefore, lead wheel weights are potentially a major source of lead exposure.

Consistent with U.S. policy to eliminate lead poisoning and protect the environment, the federal government should sponsor research to further document the deposition of wheel weights and evaluate the contribution to total lead exposure and effects on human health and ecosystems. In addition, the federal government should establish performance standards for the attachment of wheel weights to wheels, encourage the manufacture of wheel weights from benign materials, and ultimately phase out the lawful use of lead and other potentially hazardous materials in wheel weights. These findings also indicate that urban streets should be regularly swept and washed, and the street debris taken to a licensed hazardous waste disposal facility. Once motor vehicle wheel weights are no longer made of antimonious lead, the lead hazard in urban streets will subside.

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