CONTRIBUTION OF HEAVY METALS TO STORM WATER FROM AUTOMOTIVE DISC BRAKE PAD WEAR

Prepared for

Santa Clara Valley
Nonpoint Source
Pollution Control Program

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UNDER SEPARATE COVER

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DISCLAIMER

The mass loading results in this report apply only to the Santa Clara Valley and caution should be taken when applying them to other areas. Any mention of trade names, commercial products, or company names does not constitute an endorsement or recommendation for use by the Santa Clara Valley Nonpoint Source Program, its members, the author, or Woodward-Clyde Consultants.

The California State Water Resources Control Board listed South San Francisco Bay as an impaired water body (water quality limited segment) in 1989 under Section 304(1) of the federal Clean Water Act because USEPA water quality criteria for nine heavy metals (cadmium, chromium, copper, lead, mercury, nickel, selenium, silver, and zinc) were periodically exceeded. Individual Control Strategies were required to control heavy metal pollutants from both point and nonpoint sources, including municipal wastewater treatment plants and storm water.

Thirteen cities, the County of Santa Clara, and the Santa Clara Valley Water District jointly formed the Santa Clara Valley Nonpoint Source Pollution Control Program (Program) and obtained a National Pollution Discharge Elimination System (NPDES) permit in June of 1990 in response to the requirements of the 1986 Basin Plan of the California Regional Water Quality Control Board, San Francisco Bay Region (Regional Board), and the Clean Water Act Sections 304(1) and 402(p). The Program's NPDES permit requires the development and implementation of a Source Identification and Control Program to identify sources of heavy metals and assure the implementation of control measure activities desired to prevent releases of such pollutants at their source.

The Program filed a Source Identification and Control Report with the Regional Board on December 1, 1992. The report identified important sources of heavy metals and proposed a range of source control measures. The estimated magnitude of metals sources was based upon regional, state and national data, the Program's previous loads assessment study, and the Program's ongoing monitoring program. The source identification process included several steps in the selection and prioritization of heavy metals, development of source control measures (SCMs), and a proposed strategy for the control of copper. The Source Identification Report looked at five categories of metal sources: 1) air pollution, 2) automotive, 3) industrial, 4) residential, and 5) water supply. From these five categories, it was determined that air pollution (exhaust from diesel and unleaded vehicles and dry/wet deposition), tire wear, and brake pad wear were the most significant sources.

In June of 1993 the Regional Board adopted a waste load allocation for copper in San Francisco Bay and proposed a Basin Plan amendment establishing the waste load allocation. In response, the Program established a South Bay Copper Reduction Dialogue, which included representatives from wastewater treatment plants, storm water dischargers, regulatory agencies, environmental groups, and business/industry. The result of the Dialogue was a joint plan and framework for copper reduction which was submitted to the Regional Board on January 28, 1994.

In December of 1993 the Regional Board issued a Cease and Desist Order (CDO) to the Program to complete the 304(1) process. The CDO requires a plan to reduce copper mass loads and the development of a plan which identifies control measures for heavy metals and assigns responsibilities and time schedules for their implementation.

As a follow-up to the Program's Source Identification Report, this report discusses the contribution of copper, lead, and zinc in automobile disc brake pads to storm water loads to South San Francisco Bay. The study is based on the results of laboratory analyses of heavy metals in 20 different brake pads. Using the laboratory data, a loads model was developed and used to estimate the load of copper, lead and zinc to South San Francisco Bay from brake pads used by seven different automobile manufacturers.

1.0
INTRODUCTION

This report describes the approach and findings of an investigation to evaluate the contribution of heavy metals to storm water by disc brake pad wear. The purpose of the study was to measure metal concentrations in disc brakes, and to estimate the pollutant load contributed by brake pad wear to storm water in Santa Clara Valley. This report includes the results of a literature review, laboratory analyses of brake pad composition, and estimates of pollutant loads contributed by brake pads to storm water in the Santa Clara Valley.

1.1 BACKGROUND

In June of 1990 the San Francisco Bay Regional Water Quality Control Board (Regional Board) issued an NPDES Permit to the Santa Clara Valley Nonpoint Source Pollution Control Program (Program) in fulfillment of the requirements of Section 402(p) of the Clean Water Act. The permit is also an Individual Control Strategy (ICS), which the Program was required to develop because the lower south San Francisco Bay was listed as a water quality limited segment under Section 304(l) of the Clean Water Act. One of the permit provisions required the Program to develop and implement a Source Control Program.

In 1992, the Program completed the "Source Identification and Control Report," which assessed, at a screening level, a large range of potential storm water pollution sources. The pollutant sources were broken into five categories of metal sources: 1) air pollution, 2) automotive, 3) industrial, 4) residential, and 5) water supply. In that report, several automobile-related heavy metal sources were identified, specifically exhaust from vehicles that use diesel and unleaded fuels (air pollution), tire wear, and brake pad wear. Brake pad wear was identified as being a potentially large contributor of copper.

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In response to several of the issues discussed above and as a second phase of the source control effort, the Program has undertaken this study, which is a more detailed study of the contribution of heavy metals to storm water by disc brake wear.

2.0
HISTORY OF BRAKE PADS

There are two basic types of automobile brakes: drum brakes and disc brakes. In drum brakes, the brake shoes are located inside a drum. When the brakes are applied, the brake shoe is forced outward and presses against the drum. Disc brakes consist of two brake pads and a rotor. When the brakes are applied, the two pads squeeze against the rotor. One of the major differences between drum brakes and disc brakes is that drum brakes tend to be enclosed where disc brakes tend to be exposed to the environment.

Jacko et al, (1984) present the evolution of friction materials during the past decade. This section summarizes this evolution in terms of regulations and brake pad formulation.

Until the late 1960's most cars used drum brakes on all 4 wheels. The pads for these drum brakes were organic (i.e., composed of natural materials) and often consisted of resins and asbestos as well as a variety of other materials to help improve braking and wear. In the late 1960's and early 1970's, automobile manufacturers started to incorporate disc brakes, especially for larger motor vehicles, because such brakes had better braking performance. In 1975, the *Federal Motor Vehicle Safety Standard 105*, which required more stringent braking requirements, helped expedite the transition to disc front - drum rear braking systems.

Class A organic disc brake pads were the first used to help make the switch from 4 wheel drum brake to disc front - drum rear systems. Class A organic brake pads were made from asbestos and were effective for low temperatures. As cars started to get smaller in the late 1970's, it became harder to cool the brake pads, so Class B organic brakes were used. Class B organic pads worked better at higher temperatures, but had several problems including durability. As a result, the use of semi-metallic brake pads became more popular. Semi-metallic disc brake pads have lower wear rates and good braking properties at both low and high temperatures.

Brake pad formulation was also influenced by health concerns. In 1972, the Occupational Safety and Health Administration set an airborne asbestos standard of 2 asbestos fibers per cubic centimeter (time weighted average) for manufacturing plants. The U.S. EPA also recognized asbestos as a hazardous material. Although use of asbestos for brake pads has not been banned, much of the brake pad industry is moving away from asbestos brake pads because of concerns regarding airborne particles in the factories and disposal of wastes containing asbestos. There are several patents for asbestos free organic friction materials. Some of these materials were starting to be used in rear drum brakes in 1984.

Changes in brake pad formulation was also driven by the promulgation of the corporate average fuel efficiency requirements in the late 1970's and mid 1980's. These requirements led the automobile industry to switch from rear wheel drive cars to front wheel drive cars. This switch required more front braking which resulted in higher temperatures and a preference for semi-metallic brakes.

This brief history shows that the types and composition of brakes have changed due to regulations regarding worker safety, changes in automobile design and the need for improved brake pad performance.

3.0
LITERATURE REVIEW AND MANUFACTURERS SURVEY

3.1 LITERATURE REVIEW

A literature survey was performed to provide information on the composition of brake pads, and the contribution of heavy metals from brake pads to the environment. This search indicated that in general the information on brake pad composition is fragmented, and specific comprehensive data is not published. The following is a brief summary of the literature that contains information on the composition of brake pads.

Contributions of Urban Roadway Usage To Water Pollution, Shaheen 1975

Shaheen reported a concentration of 30,600 ug/g (or approximately 3%) copper from brake linings. Shaheen's data are for asbestos brakes. Also reported were levels of lead (1,050 ug/g), chromium (2,200 ug/g), nickel (7,454 ug/g) and zinc (124 ug/g).

Multi-Elemental Characterization Of Urban Roadway Dust, Hopke Et Al. 1980

Hopke et al. reported that brake pads contain barium, calcium, cesium, iron, and zinc. However, they did not analyze for copper. Hopke et al. do not specify the type of brake pad, and reference an unpublished Ph.D. Thesis by J.M. Ondov, University of Maryland, 1974.

Steel Fibers Work Way Into Disc Brake Pads, Metal Progress, 1983

Metal Progress reported in 1983 that General Motors passenger cars and light trucks, Ford light trucks, and Chrysler cars and trucks were using steel wool in their disc brake pads.

Automotive Friction Materials Evolution During The Past Decade, Jacko Et Al. 1984

Jacko et al. summarize the composition of 10 typical asbestos-free friction materials from patent information. Of the ten patents, only three identified copper, in the form of brass, at concentrations of 7, 8, and 10 percent by weight.

PM_{10} Source Composition Library For The South Coast Air Basin, Cooper Et Al. 1987

Cooper et al. analyzed a semi-metallic disk brake pad from a 1986 Acura (Radian, 1990) and found iron, copper, molybdenum, tin, and barium. Copper was identified as being approximately 2.3 percent of the composition. Cooper et al. also present concentration data for asbestos brake pads taken from the unpublished PhD Thesis by J.M. Ondov, University of Maryland, 1974. These data show high concentrations (greater than 1 percent composition) of magnesium, silicon, calcium and iron, as well as lesser concentrations (less than 0.1 percent composition) of aluminum, chloride, chromium, and barium.

Honda's Non-Asbestos, Non-Metallic, Non-Glass Brake Pad Composite, Yamaguchi, 1991

In December of 1991, Automotive Engineering reported that Honda developed a new brake pad that was composed of reinforcing fibers, binding plastics, ceramics, metal powders, lubricant, and rubber. The reinforcing fibers are made from carbon fiber, aramid pulp (a synthetic material used in plastics), and chopped ceramic and copper fibers. The metallic powder includes copper, brass, and stainless steel.

3.2 MANUFACTURERS' SURVEY

As part of the literature review, several automobile and brake pad manufacturers were contacted regarding the composition of their brake pads. Companies contacted as part of the manufacturers survey were:

ABEX
Bendix-Allied Signal
Chrysler

Ford
General Motors
Honda
Mercedes Benz
Nissan
Toyota
Volkswagen

Other organizations contacted for information on brake pad composition were:

Midas International
The Friction Material Standards Institute

In all but one case, specific information on the composition of brake pads was either unknown or could not be disclosed due to legal reasons (i.e., proprietary information). The one exception was Mercedes Benz who provided a range of 12 to 22 % copper for their brake pads (Pers. Com. Rick Johnson, Mercedes-Benz, 1993).

Since information on the composition of heavy metals in brake pads could not be acquired through the literature search or from the manufacturers and users, it was necessary to conduct laboratory tests to analyze disc brake pad composition.

4.0
SELECTION OF BRAKE PADS FOR ANALYSIS

There are thousands of different brake pads used on vehicles in the Santa Clara Valley. Different model cars manufactured by the same company may have different brake pads and a particular model car from two different years may have different brake pads. An additional complication is that car owners have several different replacement pad options which include original manufacturer equipment, pads installed by brake specialty shops (i.e., Midas, Acc-U-Tune and Brakes, Brake Doctors, etc.), or do-it-yourself replacement pads purchased from auto supply stores. The following describes the process and criteria used to select the brake pads that were tested.

To assist in the selection process, a data base of automobiles in operation in Santa Clara County (hereafter referred to as Santa Clara automobiles) was obtained from RL Polk & Co. The database provides the make, model and year for Santa Clara automobiles from 1977 to July, 1992. The Polk database is based on July 1989 California Department of Motor Vehicles data. Data later than July 1989 is estimated by Polk by adding new vehicle registrations and deleting vehicles based on scrappage rates.

The data base indicated that the Santa Clara automobile fleet consists of 48 different manufacturers. The top ten manufacturers are:

Ford	12.5%
Toyota	11.3%
Honda	11.0%
Chevrolet	8.6%
Nissan	6.7%
Oldsmobile	4.8%
Buick	4.3%
Mercury	4.2%
Pontiac	3.6%
Volkswagen	3.5%
Total	70%

These top ten manufacturers accounted for approximately 70 percent of the total Santa Clara automobiles. Therefore, it was decided to focus on brake pads from these top ten manufacturers. It was later determined that four of the top 10 manufacturers (Chevrolet, Oldsmobile, Buick, and Pontiac) are subsidiaries of General Motors. These four manufacturers were therefore combined under the General Motors title for the purposes of this study.

As discussed in Section 2.0, most vehicle manufacturers are now using non-asbestos brake pads in their new cars. However, some replacement pads for older cars (and in some cases cars manufactured before 1992) still contain asbestos. Since the older cars will eventually be scrapped, it was decided to focus the study on the newer non-asbestos brake pads.

Another criteria for brake pad selection was the frequency and/or duration of use of the brake pad. If a brake pad was used for several years on a popular model car or was used by several different model cars it had a higher likelihood for selection. In some cases, the desired brake pad was not available and the next most desirable brake pad was chosen. At least one brake pad for each manufacturer was selected.

In summary, the selection criteria for testing brake pads were:

- Non-asbestos brakes on newer models,
- Use on one or more popular models or in multiple years, and
- At least one pad for each of top ten manufacturers.

The twenty brake pads chosen for testing are shown in Table 1, which includes the manufacturer's part number and the models and years of the cars in which the brake pads were used. Note that several of the brake pads, especially the General Motors brake pads, were used on a number of different models.

TABLE 1
BRAKE PADS SELECTED FOR LABORATORY TESTING

Brake Pad Number	Automobile Manufacturer	Brake Pad Part Number	Automobile Year, Make, and Model
1	Ford	F1CZ-2001-A	91 to present Escort
2	Ford	F3DZ-2001-A	93 to present Taurus and Sable
3	Ford	F2DZ-2001-A	86-92 Taurus and Sable
4	Ford	F3ZZ-2001-A	93 to present 2.3L Mustang, 83-88 3.8L Mustang; 86 2.3L Mustang; 84-88 Thunderbird and Cougar (NonTurbo)
5	General Motors	12321455	90-91 Chevrolet Cavalier, Pontiac J2000, Buick Skyhawk; 85-89 Pontiac Grand Am, Oldsmobile Cutlass Calais, Buick Skylark
6	General Motors	12510001	92-93 Buick LeSabre, Pontiac Bonneville, Oldsmobile Royale 88, Chevrolet Caprice Classic
7	General Motors	12510008	87-93 Oldsmobile Cutlass Ciera, Chevrolet Celebrity, Buick Century, Pontiac 6000
8	General Motors	12510005	92 to present Pontiac Grand Am, Oldsmobile Acheiva, Buick Skylark
9	General Motors	12510029	88 to present Oldsmobile Cutlass Supreme, Buick Regal (FRONT)
10	General Motors	12510030	88 to present Oldsmobile Cutlass Supreme, Buick Regal (REAR)
11	Honda	45022-SE0-505	86-89 Accord
12	Honda	45022-SR3-L00	92-93 Civic; 93 Del Sol
13	Honda	45022-SM4-A00	90-93 Accord
14	Masterstop	D465	90 Honda Accord
15	Napa	S-7345	90 Honda Accord
16	Nissan	41060-1E590	89 to present Maxima
17	Nissan	D1060-50Y90	91 to present Sentra
18	Volkswagen	191 698 151 G	85 to present Cabriolet; 90 to present Golf; 85-90 GTI; 89 to present Jetta
19	Toyota	04491-20860	91 to present Celica
20	Toyota	04491-20800	90-92 Corolla

Eighteen of the twenty brake pads are original manufacturer's equipment. Two of the eighteen original manufacturer's equipment brake pads (pad 9: GM 12510029 and pad 10: GM12510030) are for the same car, which has four wheel disc brakes. One of the brake pads (GM12510029) is for the front of the car and the other (GM12510030) is for the rear.

The remaining two brake pads on the list (pad numbers 14: Masterstop D465 and 15: NAPA S-7345) are replacement pads for a 1990 Honda Accord purchased from auto part stores. No brake pads were purchased from brake repair shops because the shops contacted by the author have a policy of not selling parts without service.

The brake pads in Table 1 represent a subset of the brake pad population used in the Santa Clara Valley. It is difficult to estimate what percentage of the population these pads represent because of the uncertainty in what pads are used to replace worn out pads. If we assume that all replacement pads for the makes and model cars in Table 1 are original equipment, the manufacturer's original pads represent about 12 percent of the total brake pad population.

5.0
SAMPLE PREPARATION AND ANALYSIS METHODS

5.1 SAMPLE PREPARATION

Sample preparation consisted of grinding the brake pads then analyzing the dust for total metals and total recoverable metals.

The procedure was as follows:

- A portion of the brake pad (about 50%) was chiseled off the metal backing.
- This material was crushed manually using a mortar and pestle into smaller pieces and screened through a number 16 size sieve (1.2 mm mesh) to obtain a uniform sample that could be acid digested.
- The crushing was continued until about 5 to 10 grams of dust was generated.
- The dust was then analyzed using the methods described below.

5.2 LABORATORY ANALYSIS

Two alternative analysis methods, total metals and total recoverable metals, were used. The total metals analysis is traditionally used for sediment samples. The total recoverable method is usually performed on water samples that contain high concentrations of suspended solids. The total recoverable method was included because it is used to analyze storm water samples and may have been useful for comparison of results.

Total Metals Method:

Approximately one gram of dust was digested using EPA Method 3050 (Acid Digestion of Sediments, Sludges, and Soils). In this method, the dust is dissolved in nitric acid and hydrogen peroxide while being heated, then refluxed with hydrochloric acid. The resulting liquid is then analyzed using an Inductively Coupled Plasma Atomic Emission Spectroscope (ICP) in accordance with EPA Method 6010.

Total Recoverable Metals Method:

Approximately one gram of dust was digested using EPA Method 3005 (Acid Digestion of Waters for Total Recoverable or Dissolved Metals for Analysis by FLAA or ICP Spectroscopy). In this method, the sample is acidified with nitric acid. Then 100 ml of the sample is combined with 2 ml of nitric acid and 5 ml of hydrochloric acid. This mixture is then heated at 90 to 95 degrees C until 15 to 20 ml remain. This solution is then filtered. The resulting liquid is then analyzed using an Inductively Coupled Plasma Atomic Emission Spectroscope (ICP) in accordance with EPA Method 6010.

5.3 PILOT TESTING OF TWO METHODS

Before sending all the brake pads to be tested, four pads (Pad numbers 1: Ford F1CZ-2001-A, 2: Ford F3DZ-2001-A, 11: Honda 45022-SE0-505 and 13: Honda 45022-SM4-A00) were selected as a pilot test to compare the two alternative laboratory analysis methods. The pilot test was conducted for silver, cadmium, chromium, copper, nickel, lead, and zinc.

Figure 1 compares the two digestion methods for copper, lead and zinc for the pilot samples. There is not a significant difference in the metals concentrations for the two digestions. Given the fact that both digestion methods yielded the same result and since method 3005 is theoretically for a water sample, the total recoverable digestion method (method 3005) was discontinued for the remaining 16 brake pads.

The four pilot brake pads were also analyzed for silver, cadmium, chromium, and nickel. None of the four brake pads had detectable levels of silver (detection limit = 0.001%) or cadmium (detection limit = 0.00025%). Chromium was detected in all four of the pads but the concentrations were very low and ranged from 0.003% to 0.016%. Nickel was detected, at very low concentrations (0.006% to 0.014%). Based on these results, the second set of brake pads were only analyzed for three metals (copper, lead and zinc).

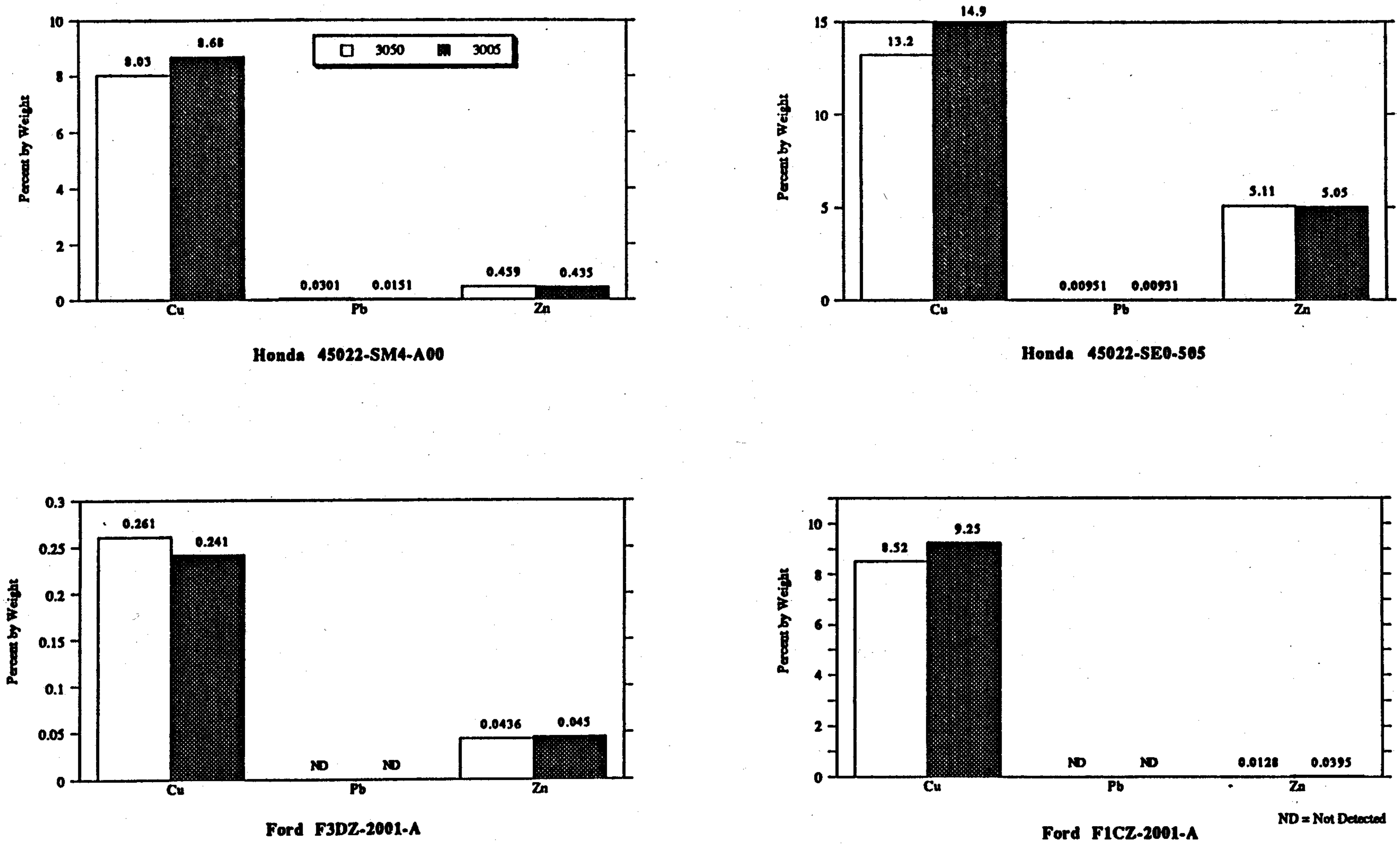


Figure 1: Comparison of Concentration Results using Digestion Methods 3050 and 3005

94001/GMR/6720118M.ALL

6.0
LABORATORY ANALYSIS RESULTS

This section presents the results of laboratory analysis of 20 brake pad and 5 duplicate samples. All the graphs in this section show concentrations as a percent by weight. The actual concentration data (in mg/kg) are presented in the Appendix (published as a separate volume).

6.1 COPPER

The results of the copper analysis of the 20 brake pads tested are presented in Figure 2. The range of copper in brake pads varied from below 0.00625 % (detection limit) for a Ford and General Motors brake pad (Pad 4: Ford F3ZZ-2001-A and Pad 10: GM 12510030) to 20.5% for one of the duplicate Volkswagen brake pads. Of the brake pads tested, the General Motors brake pads had the lowest percentage of copper (<0.02%). Ford, Toyota, and Nissan brake pads had varied results, with some brake pads having a high percentage of copper (8 to 15%) and others having much lower percentage (0.02 to 0.2%). All four of the Honda brake pads tested had relatively high percentages of copper (5 to 13.5%).

Mercedes-Benz brake pads were not tested, but according to Mercedes-Benz, the range of copper content, for all of their brake pads, is 12 to 22 percent.

6.2 LEAD

The results of the lead analysis of the 20 brake pads tested are presented in Figure 3. Only 4 brake pads were found to have a lead content greater than the detection limit of 0.01%. It should be noted that the pilot analyses had a slightly lower detection limit (0.0062% compared to 0.01%) than the main analyses. The lead content in the Volkswagen brake pad was 2.2% (original sample) and 11.9% (duplicate sample). The content in the other three brake pads (Honda 45022-SM4-A00, Masterstop 465, Napa 7345) was less than 0.1%.

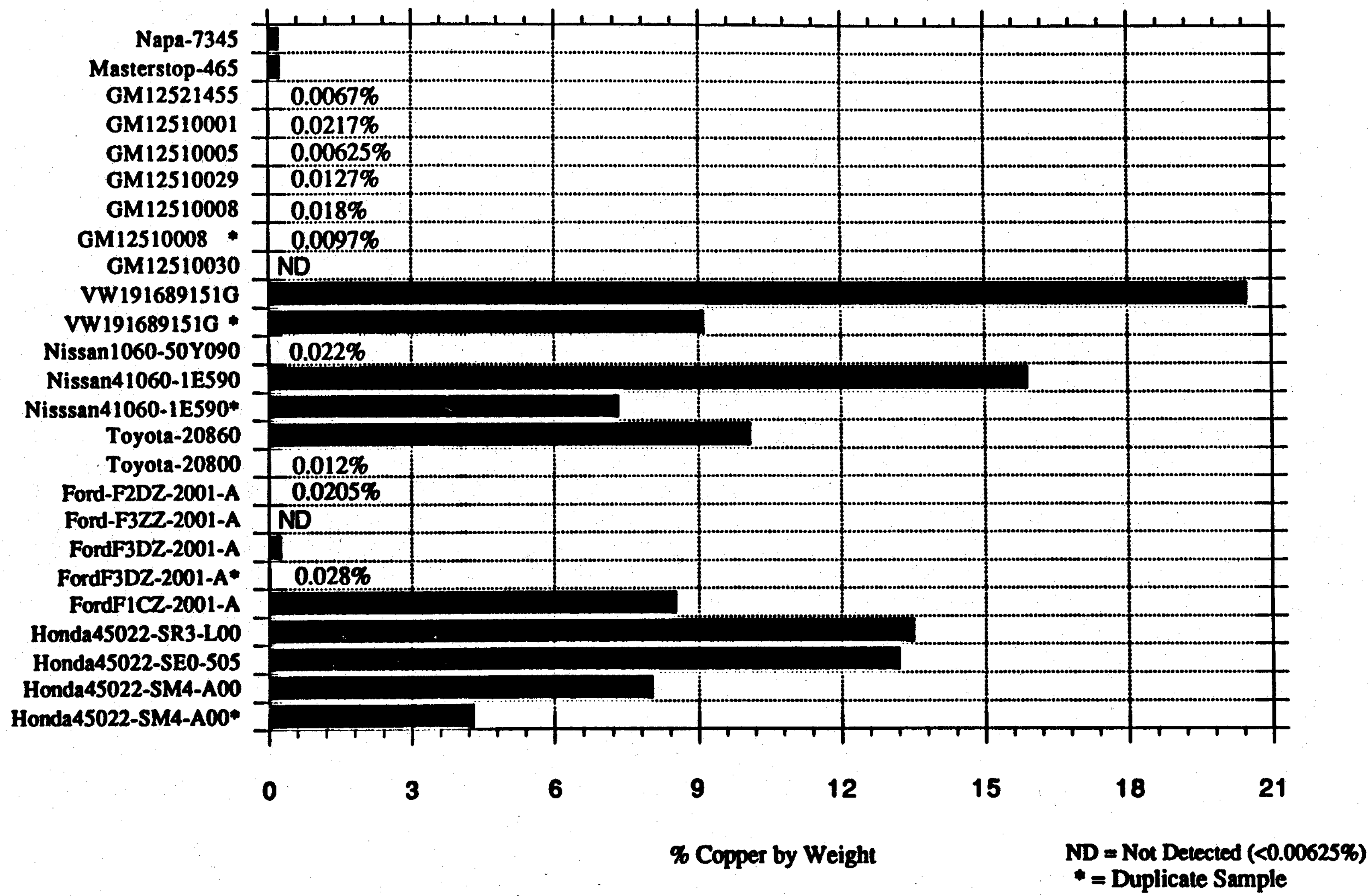


Figure 2: Total Copper in Brake Pads

94001/GMR/8720115M.Cu

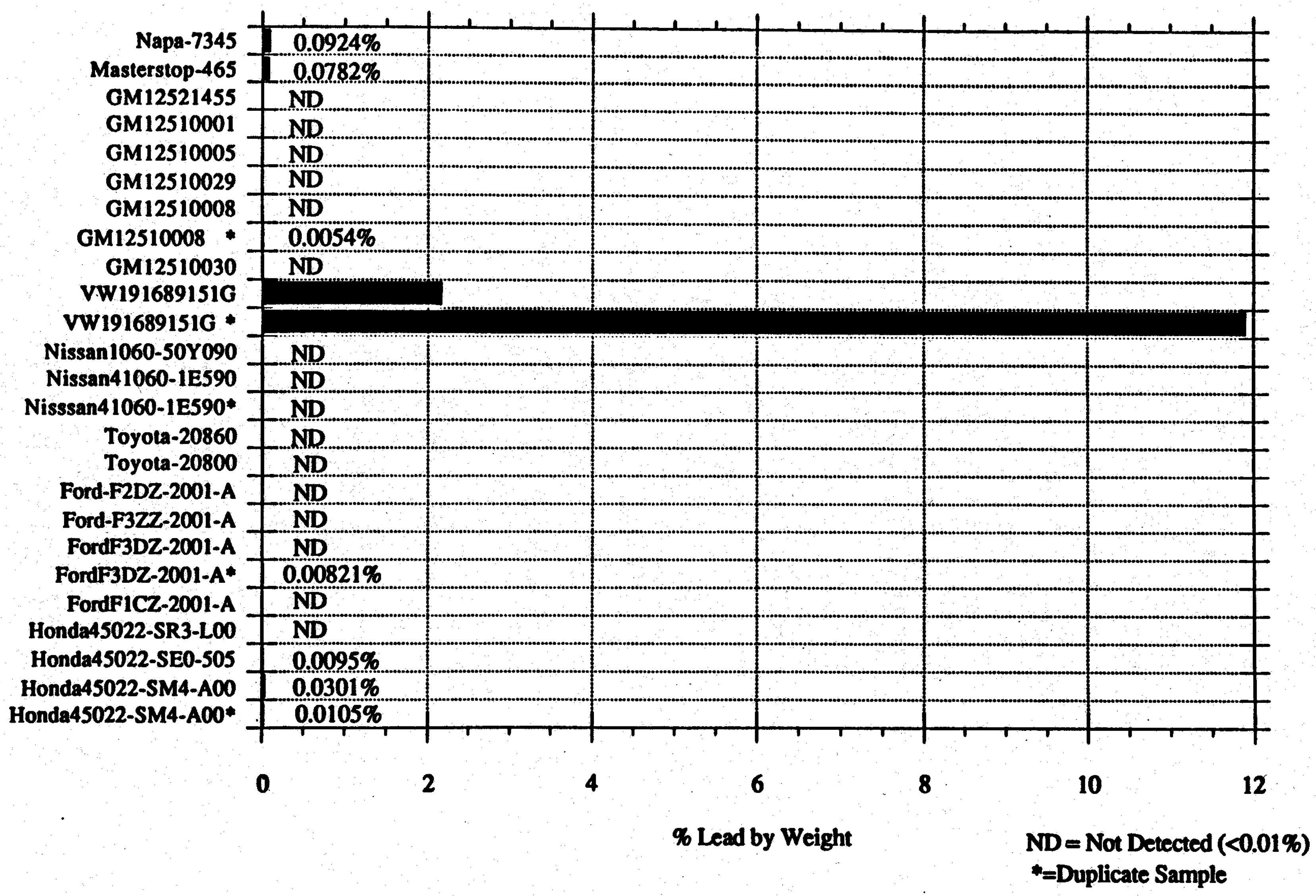


Figure 3: Total Lead in Brake Pads

94001/GMR/8728115M.Pb

6.3 ZINC

The results of the zinc analysis of the 20 brake pads tested are presented in Figure 4. Zinc was found in all the brake pads tested. The zinc content ranged from approximately 0.01% for a Ford brake pad (Pad 1: Ford F1CZ-2001-A) to 18.8% for one of the duplicate Volkswagen brake pads. The Ford and General Motors brake pads had very little zinc (0.04 to 0.28%). Toyota had one brake pad with a low percentage of zinc (0.056%) and one with a moderate percentage (1.21%). Both Nissan and Honda had varied results, each having one brake pad with relatively low zinc content (0.17% and 0.45%) and one with high zinc content (4.9% and 5.1%). Both of the replacement pads had a moderate zinc content (1.49% and 1.78%).

6.4 REPLACEMENT PADS

Figure 5 compares the concentrations between the two do-it-yourself replacement pads (Pad 14: Masterstop D465 and Pad 15: NAPA S-7345) and the manufacturer's original pad (Pad 13: Honda 45022-SM4-A00). The results indicate that the replacement pads have very little copper (<0.2%) compared to the original equipment pads (4 to 6%). The two replacement pads tested had substantially more zinc (1.5 to 1.8%) and lead (0.08 to 0.09%) than the original equipment pad, although the lead content is still quite low.

6.5 REPRODUCIBILITY (ANALYSIS OF DUPLICATE SAMPLES)

As a test of the reproducibility of the analyses, 25% of the brake pads (5 brake pads) were reanalyzed. The companion brake pads were sent to the laboratory and analyzed using the same methods as described in Section 5. The brake pads that were reanalyzed were:

Pad # 2:	Ford F3DZ-2001-A
Pad # 7:	General Motors 1251008
Pad #13:	Honda 45022-SM4-A00
Pad #16:	Nissan 41060-1E590.
Pad #18:	Volkswagen 191689151G

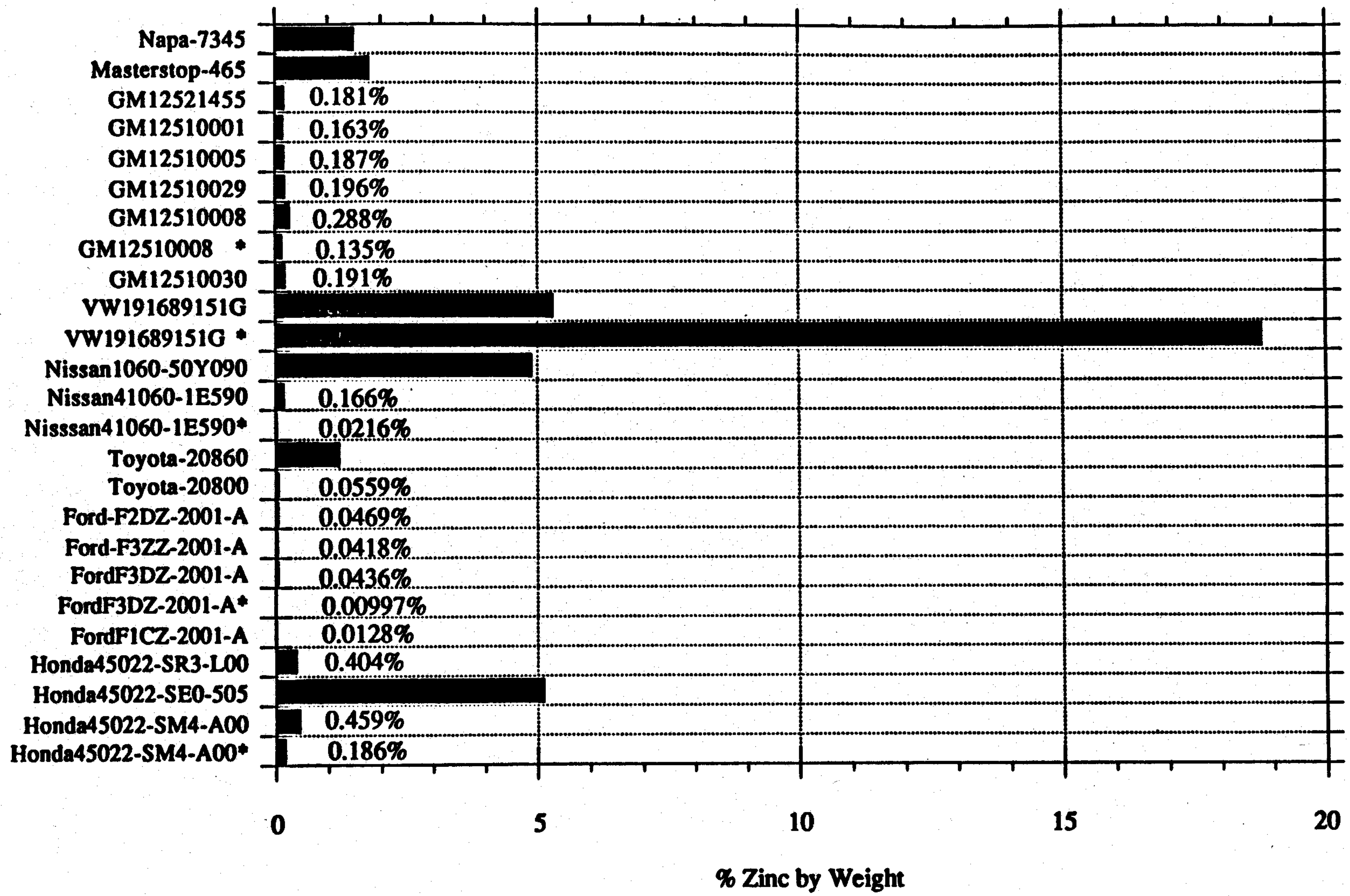
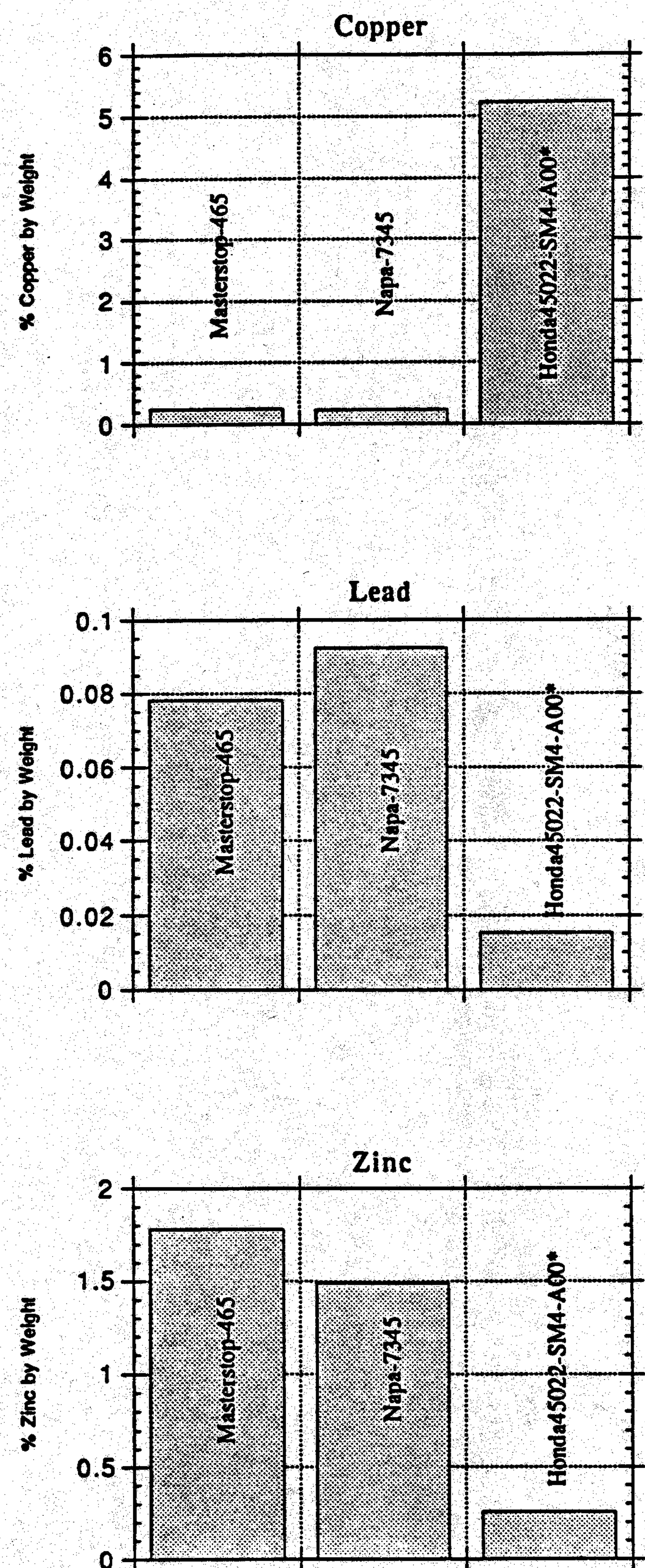


Figure 4: Total Zinc in Brake Pads

94001/GMR/8720115M.Zn



* Average of two brake pad samples

Figure 5: Comparison of Heavy Metal Concentrations for Auto Store Replacement Brake Pads for a 1990 Honda Accord and a Manufacturer's Origianal Brake Pad

The results of the reanalyses show that there is considerable variability in the concentration data (Table 2). This variability may be caused by the variability in the composition between companion brake pads or variability in the concentration within an individual brake pad. Another possible cause of the variability in the brake pad concentration could be the grinding process. Since the crushed brake pads are passed through a sieve, it is possible that the grinding process resulted in a bias toward copper particles of a certain size. Although there are considerable differences in some of the concentrations, it should be noted that the relative ranking of brake pads based on concentration has not changed. In other words, those brake pads with the highest concentration still have the highest concentration and those with the lowest concentration still have the lowest concentration.

Table 2: Comparison of Duplicate Analysis for Heavy Metals

Copper			
Brake Pad	**First Analysis (% by weight)**	**Duplicate Analysis (% by weight)**	**Difference % by weight)**
Honda 45022-SM4-A00	8.03	4.3	-3.73
VW191689151G	20.5	9.13	-11.37
FordF3DZ-2001-A	0.261	0.028	-0.233
GM1251008	0.0183	0.0097	-0.0086
Nissan41060-1E590	15.9	7.34	-8.56
Lead			
Brake Pad	**First Analysis (% by weight)**	**Duplicate Analysis (% by weight)**	**Difference (% by weight)**
Honda 45022-SM4-A00	0.0301	0.0105	-0.0196
VW191689151G	2.17	11.9	9.73
FordF3DZ-2001-A	<0.01	0.00821	<0.00179
GM1251008	<0.01	0.00554	<0.0046
Nissan41060-1E590	<0.01	<0.001	N/A
Zinc			
Brake Pad	**First Analysis (% by weight)**	**Duplicate Analysis (% by weight)**	**Difference (% by weight)**
Honda 45022-SM4-A00	0.459	0.186	-0.273
VW191689151G	5.3	18.8	13.5
FordF3DZ-2001-A	0.0436	0.00997	-0.0336
GM1251008	0.288	0.135	-0.153
Nissan41060-1E590	0.166	0.0216	-0.144

7.0
LOADS ESTIMATES

This section describes how the annual load from brake pad wear to storm water in Santa Clara Valley was estimated. For this purpose a straightforward model was developed. Because of the natural variability and uncertainty in the model inputs, an uncertainty analysis was used so the load could be characterized probabilistically.

7.1 LOADS ESTIMATION MODEL

A model was developed to estimate the contribution of brake pad wear to heavy metals load to storm water. The model is based on the following assumptions:

- Brake pad average mass and wear rate are independent of car manufacturer or pad type.
- Average miles driven are independent of car manufacturer.

Under the above simplifying assumptions, the heavy metal load to storm water for those cars using a given brake pad can be calculated as follows:

$$Load_i = N_{bp} * M_{bp} * Conc_i * (M_{driven} / M_{replace}) * \%_{to\ SW} \qquad (1)$$

where:

$Load_i$	mean annual load to storm water for metal i for a given brake pad [kg]
N_{bp}	number of brake pads in use
M_{bp}	brake pad mass [kg]
$Conc_i$	average concentration of metal i in brake pad [mg/kg]
M_{driven}	average yearly miles driven [miles/year]
$M_{replace}$	average miles driven between pad replacement [miles]
$\%_{to\ SW}$	fraction of load released to the environment that enters storm water

7.1.1 Monte Carlo Simulation

There are two methods of applying the model to estimate loads. The first method is deterministic analysis whereby a single value is used for each variable and a load is calculated. This method can be misleading because it suggests a level of precision that is not justified based on the input data; and therefore was not used. The second method is based on uncertainty analysis. Uncertainty analysis characterizes the variability and uncertainty associated with the input variables, and evaluates these effects on model predictions. Given the range of values for some of the variables associated with the brake pad load model, uncertainty analysis was conducted.

One type of uncertainty analysis is referred to as the Monte Carlo method. In the Monte Carlo method the variability and uncertainty of each input parameter is represented by a frequency distribution. The user provides for each input parameter the distribution type (e.g.,: normal, log-normal, or uniform distribution), with its mean, standard deviation, and minimum and maximum values. Based on the frequency distribution of the inputs, the Monte Carlo program selects a randomly generated input data set, and calculates the corresponding output. This process is repeated in an iterative way until the statistical distribution of the model output converges to a stable distribution, i.e., increasing the number of iterations does not change the shape of the probability distribution of the output. In general, for relatively simple physical models and "well behaved" input frequency distributions, convergence can be reached in a few thousand runs. The result of Monte Carlo analysis is the statistical distribution of the output parameter, defined by parameters such as the mean (the arithmetic average), median (the 50th percentile), or standard deviation.

7.2 MODEL INPUT DATA

Brake Pad Samples used in Model: The model used concentration data from 17 of the 20 brake pads analyzed in this study. Three of the brake pads were not used for the following reasons:

- No data on the number of cars registered in Santa Clara existed for the Ford F3DZ-2001-A brake pad which is for a 1993 Taurus and Sable.

- The two replacement pads (Masterstop, Napa) were not modeled because there is no estimate of the number of cars that use these brake pads.

Number of Brake Pads in Use: The number of brake pads in use is calculated as 4 times the number of automobiles that use the brake pad, because most vehicles use 2 disc brake pads per wheel for the front two wheels. It is assumed that the number of automobiles registered in Santa Clara County is representative of the number of automobiles driven in Santa Clara Valley. There are 2 cities, Morgan Hill and Gilroy, that are in the County but not part of the Valley. However, the population of these 2 cities is less than 4% of the total population of the County. Also, it is estimated that approximately 133,000 people commute to Santa Clara County, and approximately 86,000 commute out of the county (MTC, 1992). The difference between the commuting in and the commuting out is approximately 5% of the total vehicles in Santa Clara County. Therefore, the total number of automobiles registered in Santa Clara County appears to be representative of the total cars driven.

Brake Pad Mass: An average brake pad mass (0.129 kg) was used for the load modeling. It is the average of 9 brake pad mass measurements made in the laboratory. An average mass was used because, due to an inadvertent error in the instructions to the laboratory, the mass of all the brake pads was not measured. Also, the range of mass for the pads that were measured was relatively small (0.082 kg to 0.152 kg).

Concentration of Metals in Brake Pad: The concentration of each metal was assumed to follow a log- normal distribution. A log-normal distribution means that the natural log of the values follow a normal, bell-shaped distribution. This assumption is reasonable, because the distribution of sample concentrations is generally positively skewed, and consists of only positive values, which are characteristics of a log-normal distribution. The log-normal distribution of each metal for each type of brake pad was defined in terms of two parameters: the mean of the log values (M_{ln}) and the variance of the log values ($\_^{2}_{ln}$). The parameter M_{ln} was set equal to the natural log of the measured concentration (if only a single measurement was available) or, when duplicate measurements were available, equal to the average of the log values of the original and duplicate measurements. The second parameter of the log-normal distribution, $\_^{2}_{ln}$ was estimated for each metal based on pooling the duplicate samples. Using $\_^{2}_{ln}$ and M_{1n}, the coefficient of variation can be calculated for each metal. The coefficient of variation is the standard deviation (_) divided by the mean in arithmetic space (i.e., not in log-space). Even though the mean concentration and standard deviation varies for each brake pad, the coefficient of variation remains constant. The calculated coefficient of variation is 1.01 for copper, 0.73 for lead, and 1.24 for zinc.

Annual Miles Driven: There are no direct estimates of total miles driven in Santa Clara County by each car and this number varies significantly for each driver. Therefore, a range of annual miles driven was estimated as 3,000 to 30,000 miles per year with an average of 15,000. A normal distribution was used, which assumes that an equal number of people drive more and less than 15,000 miles per year. The average miles driven per car (15,000) was estimated by taking the California state highway system miles driven in Santa Clara County (California Department of Transportation, 1992) divided by the number of cars registered in Santa Clara County and multiplied by 2. The state highway miles driven was multiplied by 2 because the ratio of non-highway miles driven to highway miles driven in the City of San Jose is approximately 1 to 1 (CalTrans, 1991).

Miles driven until Brake Pad Replacement: Based on the telephone survey of automobile manufacturers, the average miles driven between pad replacement is approximately between 30,000 and 50,000 miles, with an average of 40,000 miles, depending on use and driving conditions (pers com. Garrett Van Camp, Ford; Steve Grafflin, Chrysler; Rick Johnson, Mercedes-Benz). A normal distribution with an average of 40,000 was used for the model input.

Percent of the Load to the Environment that Enters Storm Water: A range of 20 to 90 percent was used for this variable. The low end of this range was estimated by Axtell and Zell, 1977, who performed nationwide literature review of removal processes of dirt from streets. Kobriger and Geinopolos, 1984 used a mass balance approach to estimate the amount of particles smaller than 250 microns that enter storm water from highways. Based on these mass balances, they estimated that 52 to 57% of the particles on highway I-94 in Milwaukee, Wisconsin enter storm water. They also estimated that approximately 89% of the particles on highway I-85 in Efland, North Carolina enter the storm water. A normal distribution with an average of 55% was used for the model input.

7.3 APPLICATION OF MODEL TO ESTIMATE MEAN ANNUAL LOADS

The Monte Carlo uncertainty analysis performed for this study is based on the following probabilistic input parameters:

Parameter	Mean	Standard Deviation	Minimum	Maximum	Distribution
Yearly Miles Driven	15,000	7,000	3,000	30,000	Normal
Miles to Replace Pads	40,000	5,000	30,000	50,000	Normal
Percent Load from Environment to Storm Water	55%	16%	20%	90%	Normal
Copper Concentration	Varies	Varies	--	--	Log-normal
Lead Concentration	Varies	Varies	--	--	Log-normal
Zinc concentration	Varies	Varies	--	--	Log-normal

The mean value for each brake pad was assumed to be the measured concentration or, for the pads with duplicate samples, the average of the original and duplicate samples. For non-detect samples, the detection limit was used.

Once the input values were entered into the model, the following steps were used to estimate the distribution of loads by manufacturer for those automobiles which use brake pads that were tested.

Step 1: For 10,000 iterations, the following were performed:

- Estimate the load for each brake pad using equation 1.

- Sum the load associated with each brake pad by automobile manufacturer (i.e., sum the load for all the Ford pads, Honda pads, etc.). This represents the load for each automobile manufacturer from the specific brake pads analyzed.

This step results in a distribution for each brake pad and for each automobile manufacturer. The model was run for 10,000 iterations to ensure a stable (does not change) output distribution. The output from the model and the distributions are contained in the Appendix.

Step 2: Estimate the load for all cars built by a given automobile manufacturer. In this step, the load distributions calculated for each automobile manufacturer in step 1 are assumed to be representative of all cars built by a given automobile manufacturer and are extrapolated based on the number of Santa Clara Valley automobiles built by a given manufacturer.

To estimate the total Santa Clara vehicles by automobile manufacturer, certain groupings were made. The automobile manufacturer groupings were as follows:

Ford Group includes Ford, Mercury, Lincoln
General Motors includes Chevrolet, Pontiac, Buick, Oldsmobile, Cadillac
Honda Group includes Honda and Acura
Nissan Group includes Nissan and Infinity
Toyota Group includes Toyota and Lexus.

Given these groupings, the load estimate is representative of approximately 79% of the vehicles registered in the Santa Clara Valley. Table 3 presents the mean and range (based on the 20th and 80th percentile load data) of loads for each of the manufacturers.

Table 3: Estimated Total Annual Load to South San Francisco Bay of Copper, Lead, and Zinc from Brake Pads

Manufacturer Group	Copper (pounds/year)		Lead (pounds/year)		Zinc (pounds/year)	
	Mean	Range	Mean	Range	Mean	Range
Ford Group	290	93-411	4.3	2.3-5.9	23	9-32
General Motors	8	4-11	5.5	3.2-7.5	168	80-233
Honda Group	3549	1493-4967	4.2	2.1-5.8	1125	326-1577
Mercedes-Benz	937	291-1352	ND	ND	ND	ND
Nissan Group	1179	371-1687	1.4	0.7-2.0	419	115-597
Toyota Group	435	137-618	2.8	1.3-4.0	74	25-107
Volkswagen	1319	403-1851	421	175-601	1311	325-1843
Total Load from Brake Pads	7717	2792-10897	439	185-626	3120	880-4389
Ave. Total Load $_1$	14600		14600		50000	
Ave. Total Load $_2$	17400					

Ranges are based on 20th and 80th percentile loads estimates.
$_1$Santa Clara Valley Nonpoint Source Study Volume 1: Loads Assessment Report, Woodward-Clyde, 1991
$_2$Wasteload Allocation for Copper for San Francisco Bay, Final Staff Report, Jessica Lacy, SFRWQCB, 1993
ND = No Data
Note: Ford Group includes Ford, Mercury, Lincoln
General Motors includes Chevrolet, Pontiac, Buick, Oldsmobile, Cadillac
Honda Group includes Honda and Acura
Nissan Group includes Nissan and Infinity
Toyota Group includes Toyota and Lexus

7.4 ESTIMATES OF THE PROPORTION OF THE TOTAL LOAD

In 1991, the Program released the Volume 1: Loads Assessment Report (WCC, 1991) which estimated the load to South San Francisco Bay from storm water for several heavy metals. In 1993, the Regional Board, as part of their copper waste load allocation, estimated the load to South San Francisco Bay from storm water for copper (Lacy, 1993). The brake pad load estimates based upon the results presented in this report are compared to these total load estimates in Table 3 and Figure 6. A comparison with WCC, 1991 shows that brake pads contribute between 19% to 75% of the total copper to south San Francisco Bay based on 20th to 80th percentile loads estimates with a mean of 52%. A comparison with Lacy, 1993 shows that brake pads contribute between 16% to 63% of the total copper load to South San Francisco Bay based on 20th to 80th percentile loads estimates with a mean of 44%. Brake pads are also estimated to contribute between 1% to 4% (based on 20th to 80th percentile loads estimates) of the total lead and with a mean of 3% to 9% (based on 20th to 80th percentile loads estimates) of the total zinc with a mean of 6% based on the WCC, 1991 total load estimates.

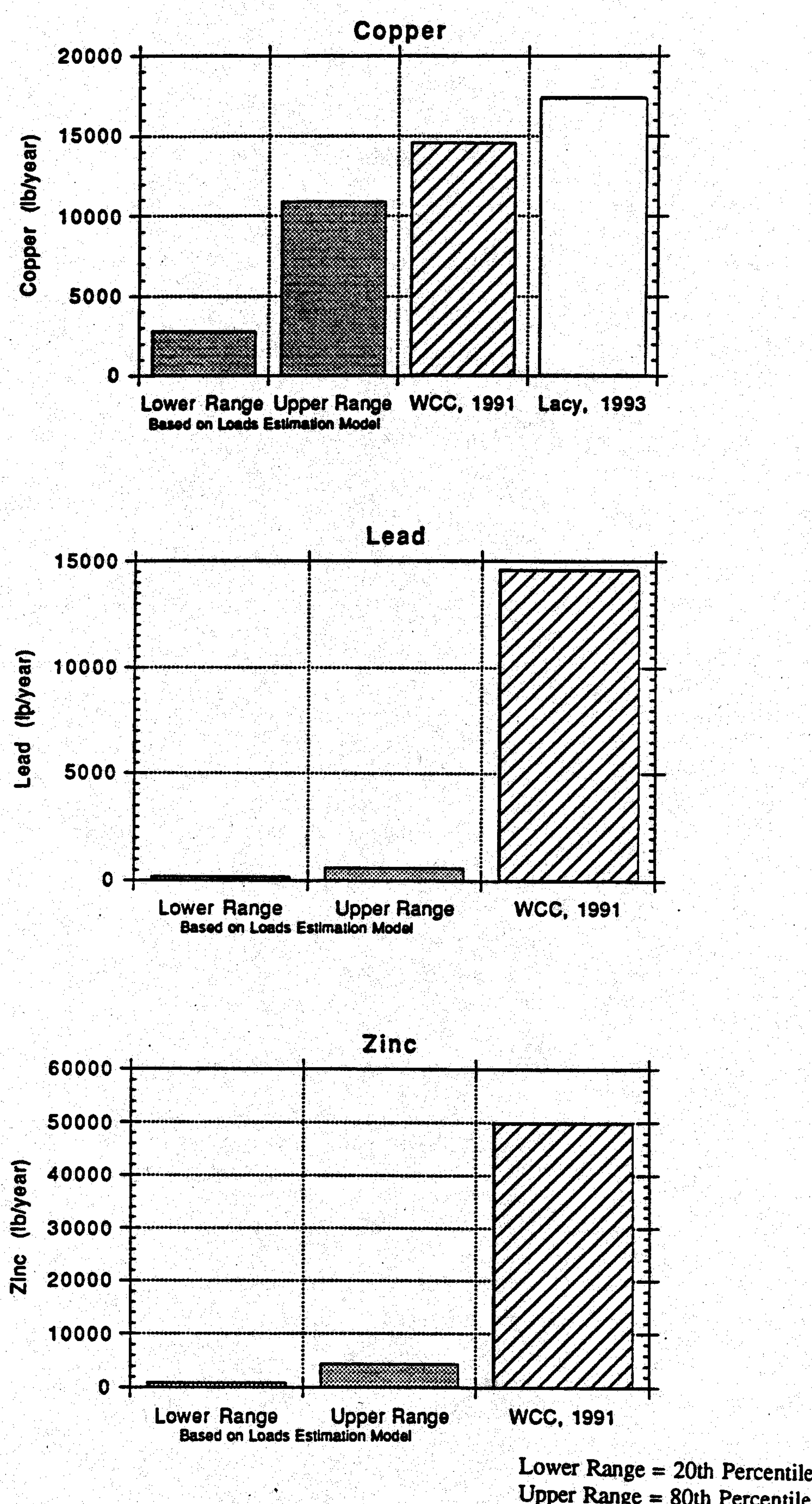


Figure 6: Comparison of Lower and Upper Ranges of Loads from Disc Brake Pads to Total Loads from Storm Water Entering South San Francisco Bay

8.0
CONCLUSIONS

8.1 BRAKE PAD COMPOSITION

Twenty different disc brake pads were purchased for analysis. Eighteen of the brake pads were automobile manufacturer's original equipment. Two brake pads were replacement pads purchased from auto parts stores. In general, the concentration of copper, lead, and zinc varied considerably between each model of brake pad. Five models of brake pads were also duplicate tested. The conclusions from the lab analyses are:

- Brake pads can have high copper content (up to 20%), moderate to high lead content (up to 12%), moderate zinc content (up to 18%), and very low levels of other heavy metals.

- It is possible to make and use brake pads with low copper, lead, and zinc content, such as some of those used by General Motors, Ford, Nissan, and Toyota.

- Some replacement disc brake pads for 1990 Honda Accords have relatively lower copper content, however they have relatively higher lead and zinc content.

- Based on the 18 specific models of brake pads and the laboratory data presented in this report, disc brake pads for some non-domestic cars contain higher copper, lead and zinc content than brake pads for domestic cars.

8.2 BRAKE PAD LOAD ESTIMATE

Using the data collected from the lab analysis, as well as data on disc brake pad wear rates, the number of automobiles in Santa Clara Valley, and average yearly miles driven, a loads model was developed. The conclusions of the loads modeling are:

- Automotive disc brake pads are a significant source of copper to storm water in Santa Clara Valley.

- Automobile disc brakes have lesser contributions of lead and zinc to storm water in Santa Clara Valley.

- Based on 18 specific brake pad models analyzed and 79% of the automobiles in Santa Clara County, brake pads used on non-domestic manufacturer's automobiles appear to contribute a larger load of copper to storm water than brake pads used on domestic manufacturer's automobiles.

8.3 LIMITATIONS

- The load estimates presented in this report are based on the 18 specific brake pads analyzed and are for 79% of the vehicles registered in Santa Clara Valley. Slightly different results would be expected if all of the brake pad models had been analyzed; however, this is not expected to change the conclusion that brake pads are a significant contributor of copper to storm water. The mass loading results in this report apply to the Santa Clara Valley only and caution should be taken when applying them to other areas.

- The comparison of replacement pads to manufacturer's original equipment are based on the two brake pad models tested.

- All of the brake pads tested are assumed to represent the brake pads used in Santa Clara Valley.

9.0
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