EPA-R2-73-283
August 1973

Environmental Protection Technology Series

Toxic Materials Analysis Of Street Surface Contaminants

Office Of Research And Development
U.S. Environmental Protection Agency
Washington, D.C. 20460

RESEARCH REPORTING SERIES

Research reports of the Office of Research and Monitoring, Environmental Protection Agency, have been grouped into five series. These five broad categories were established to facilitate further development and application of environmental technology. Elimination of traditional grouping was consciously planned to foster technology transfer and a maximum interface in related fields. The five series are:

1. Environmental Health Effects Research
2. Environmental Protection Technology
3. Ecological Research
4. Environmental Monitoring
5. Socioeconomic Environmental Studies

This report has been assigned to the ENVIRONMENTAL PROTECTION TECHNOLOGY series. This series describes research performed to develop and demonstrate instrumentation, equipment and methodology to repair or prevent environmental degradation from point and non-point sources of pollution. This work provides the new or improved technology required for the control and treatment of pollution sources to meet environmental quality standards.

For sale by the Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402 - Price $1.55

EPA-R2-73-283
August 1973

TOXIC MATERIALS ANALYSIS OF STREET SURFACE CONTAMINANTS

By

Robert E. Pitt and Gary Amy

Contract No. 14-12-921
Project 11034 FUJ

Project Officer

Francis J. Condon
Municipal Pollution Control Division
Environmental Protection Agency
Washington, D.C. 20460

Prepared for

OFFICE OF RESEARCH AND DEVELOPMENT
U.S. ENVIRONMENTAL PROTECTION AGENCY
WASHINGTON, D.C. 20460

EPA Review Notice

ABSTRACT

Because of the large amounts of toxic materials (especially heavy metals) found associated with street surface particulates during the course of a previous study (Water Pollution Aspects of Street Surface Contaminants), additional work has recently been completed which defines the distribution and range of heavy metals on the nation's city streets.

This project defined the breakdown of the particulates' compositions by having mass spectographic analyses performed on various samples. Using these results, the heavy metals which were determined to have the greatest water pollution potential (As, Cd, Cr, Cu, Fe, Pb, Mn, Hg, Ni, Sr, Ti, Zn and Zr) were analyzed in each of about 75 samples collected nationwide in 10 cities in the previous study.

Other analyses conducted included: size affinities of the metals, solubilities and toxicities of the road surface runoff mixture, and certain organic analyses on selected samples. Additional sampling was conducted on rural road, highway and airport surfaces and particulates were analyzed for the following common water pollution parameters: BOD_5, COD and nutrients, plus selected heavy metals, for comparison with values representative of normal city streets.

This report was submitted in fulfillment of Contract 14-12-921 under the sponsorship of the Water Quality Office, Environmental Protection Agency.

CONTENTS

IGURES

TABLES

TABLES (cont'd)

TABLES (cont'd)

TABLES (cont'd)

TABLES (cont'd)

SECTION I

CONCLUSIONS

1. Possibly the most important metallic elements, from a water pollution standpoint, include: lead, zinc, copper, nickel, chromium, strontium, titanium, and zirconium.
   - Some differences in strength (mg/kg) and loading (lb/curb mile, kg/km) were found between different land use samples. In most cases, the industrial samples had the greatest strength and loading factors, while the commercial sample showed the least. These dissimilarities are most likely due to different activities (for strength) and to different public works practices (for loadings) in each land use.
   - Industrial and commercial land-use areas have the greatest strengths (mg/kg) of heavy metals.
   - Industrial land-use areas have the greatest loading factors (lb/curb mile, kg/km) of heavy metals.
   - Cities with high particulate loadings have high metal loadings.
   - The range of values obtained within one land use or one city is usually within a factor of ten, while the land use and city averages are usually within a factor of 2 to 4 for each metal.

2. When metals associated with street runoff are compared to the metal content of sanitary sewage, most of the runoff metals are 100 to 1000 times greater than the sewage metals on a slug load (lbs/hour, kg/hr) basis, and from 10 to 100 times on a concentration (mg/l) basis.
   - The metal content of street runoff is usually not sufficient to cause noticeable reductions in biological treatment efficiency in plants handling combined sewage/storm drain systems.

3. The solubilities of heavy metals into a simulated receiving water environment are low, most being less than 10% of the available metal.

- Some metals showed decreases in concentration through time after "discharged" to receiving water, possibly being sorbed onto the street surface particulates.
- The highest solubilities were found for larger particle sizes (>246μ).
- Copper, cadmium, lead and zinc are soluble to a sufficient degree to cause toxic effects to certain aquatic organisms under selected conditions (such as soft water).

4. Bioassay tests conducted in aerated, moderately hard water, indicated no short-term (96-hr) toxic effects on stickleback.

- Immediate toxic effects of road surface runoff are most likely due to extreme oxygen demand.
- The most dramatic toxic effects of metals most likely occur when runoff is discharged into quiescent water where it is allowed to accumulate to toxic concentrations.

5. In most cases, more than 50 percent of all the metals are found in size ranges smaller than 495μ.

- The overall removal rate by normal street sweeping practices of heavy metals range from 38% for cadmium to 56% for chromium, with an overall average of 49% for all metals.

6. By comparing city street surface contaminants with those found on rural roads and highways, one finds that the city street particulates have greater pollution potential on a strength (mg/kg) basis. The major difference is

that the BOD_5 strength of the city samples is an order of magnitude greater than the other samples.

- The BOD_5/COD ratio is much less for rural road and highway samples than for city street samples, possibly being caused by an increase in toxicity of these samples, depressing the BOD_5 values.
- On a loading basis (lb/curb mile), the highway surfaces contribute a greater amount of pollutants than any other type of surface tested. This is due to the large amounts of particulates found on the highway surfaces.
- The heavy metal content of airport surface particulates is quite similar to the metal content of road surface particulates. This is probably due to the similarity of paving material and the large volume of gasoline-powered aircraft at the airport that was sampled.
- About 2/3 of the five-day BOD values was found to be exerted during the first day of discharge of the road surface particulates into the receiving water. This, in conjunction with very high BOD_5 values, can cause serious oxygen depletion problems in the receiving water near the time of discharge.

7. Grease and oil were found to be the major organic constituents of major land-use samples. The smaller size ranges of particulates appeared to contain a greater percentage of grease and oil than the larger size ranges, possibly due to greater surface areas per unit weight.

   - There does not appear to be any major differences in organic strengths (mg/kg) of the different land-use samples.

- Samples were analyzed for common pesticides, but the results indicated that the pesticides were unstable during the storage period.

SECTION III
INTRODUCTION

Background

Under the sponsorship of the Office of Research and Monitoring, U.S. Environmental Protection Agency, URS Research Company has conducted a program to determine the water pollution effects of street surface contaminants. During the course of this study, numerous samples were collected from a number of cities throughout the country, representing a wide range of land-use areas. These samples were analyzed for conventional water pollution parameters such as total and volatile solids, coliform bacteria, biochemical oxygen demand, chemical oxygen demand, kjeldahl nitrogen, soluble nitrates and phosphates. Other parameters analyzed on selected samples included certain heavy metals and pesticides. The results of these prior analyses are reported in Water Pollution Aspects of Street Surface Contaminants, EPA-R2-72-081. The amounts of heavy metals and pesticides found on the road surfaces justified further study to determine their distribution, solubilities and toxicities.

This report summarizes and analyzes the results of this effort to obtain the specified additional information. The greatest usefulness of this report will be in the wealth of data presented, enabling the reader to apply these values in a more sophisticated data reduction effort than was possible in this study. Conclusions are presented, but are necessarily based on limited data analysis. To avoid redundancy, this report will only comment on results that are specific to these additional toxic materials analyses. For a complete description of all the test sites and prior discussions of the theory and practice of municipal street sweeping, the reader is referred to the previously mentioned report: Water Pollution Aspects of Street Surface Contaminants. Because of the nature of the toxic materials investigation, this report should be treated as an addition to the Water Pollution Aspects of Street Surface Contaminants report, a brief description of which follows:

URS Research Company was awarded a contract by the Environmental Protection Agency (EPA) relating to the development and evaluation of methods and techniques for reducing water pollution resulting from the water runoff from urban streets and paved areas.

Materials which commonly reside on street surfaces have been found to contribute substantially to urban pollution when washed into receiving waters by storm runoff. The research program focused on the following:

- determining the amount and nature of such contaminants and how their distribution varies with respect to local factors
- establishing the importance of this source, relative to other point and non-point sources
- evaluationg the effectiveness of conventional public works practices in coping with this problem
- proposing potential means of achieving effective control.

The first part of the project was concerned with problem definition; i.e., answering the question, "What are the characteristics of street surface contaminants in terms of potential water pollutants?" Answering this involved a sizable research effort directed toward:

- determining the constituents of street surface materials and their sources
- measuring loading intensities of contaminants on streets
- identifying the significance of factors which affect loading intensities
- defining mechanisms by which contaminants are transported by rainfall runoff
- determining the effects of such contaminants as pollutants in receiving waters.

The second major part of the project was concerned with answering the question, "How effective are current public works practices in controlling this source of pollution?" This involved examining potential control techniques as to their effectiveness and operational characteristics. Primary emphasis was directed toward evaluating conventional street sweeping equipment and practices. Less emphasis was placed on such systems as the newly introduced vacuum sweepers, conventional and special water flushers, catch basins, and specially designed curb and gutter systems.

The third major part of the study was concerned with answering the question, "Is street runoff actually a significant source of water pollution?" This involved comparing its pollutional effects to those attributable to other sources; primarily, treated municipal waste and storm runoff in general. For ease of presentation, much of the discussion centers around the pollutional effects of a hypothetical but rather typical city.

An important aspect of this study is that it provides a basis for evaluating the significance of this source of water pollution relative to other pollution sources. For this reason, the study was designed to include information for communities having a broad range of sizes, geographical locales, and public works practices. Information was developed for major land-use areas within the cities (such as residential, commercial and industrial). A mobile rainmaking device was developed to simulate rainfall conditions on selected city streets. Runoff was analyzed for the following pollutants: BOD, COD, total and volatile solids, kjeldahl nitrogen, nitrates, phosphates, and a range of pesticides and heavy metals.

In an attempt to correlate pollutant loads on receiving waters to discharge from municipal treatment plants, average hourly discharge loadings were compared. In general, street runoff was a greater pollutant than sanitary sewage. Load ratios of street runoff to treated municipal sewage effluents range from a low of about 5:1 for BOD to a high of 1800:1 for lead. The only exception to these ratios occurred in the case of total coliform bacteria where the sanitary sewage contributed greater coliform numbers than did street runoff.

Samples were also analyzed to determine the relation between particle size distribution and specific pollutants. As an example, it was found that approximately 77% of most of the pollutants were associated with particles of 840μ size and smaller. It was also significant to find that many of the pollutants did not go into solution but continued to be identified with particles in the effluent stream. Finally, calculations made to determine the relative efficiency of street sweepers in controlling a street surface pollutant indicated a maximum removal range between 15 and 79 percent of the selected contaminants studied.

Methodology

The analysis program was divided into the following phases:

- Mass spectrographic analyses to determine elemental composition of selected samples
- Selected heavy metal analyses of each sample to determine distribution
- Simulated discharge of road surface contaminants to receiving water to determine solubilities and toxicities
- Heavy metal distribution by particle size to determine removal effectiveness of common street sweeping practices
- Heavy metal and common pollution parameter analyses of grab samples from highway, rural road and airport surfaces
- Organic analyses of selected samples

Phase I - Mass Spectrographic Analyses

Mass spectrographic techniques were used to screen selected street surface contaminant samples to determine their overall elemental composition. The results of this phase helped determine which heavy metals should be analyzed in the subsequent phases.

The samples were combined into three major land-use categories for analysis. These composited samples were representative of residential, industrial and commercial areas. These divisions were chosen because the previous study indicated that this means of dividing samples is the only one which reflects consistent, significant differences. This is largely due to the different activities within each land-use category that contribute to road surface contamination, and to differences in public works practices in each of the land-use categories.

Phase II - Atomic Absorption Analyses of Individual Land-Use Samples

The results from Phase I indicated which heavy metals were most abundant. From this list, those metals having the greatest water pollution potential were selected for detailed investigations. Each sample collected in the previous study was then analyzed for the selected metals. A distribution of each metal was then found by comparing metal loadings from each land use in each city. Ranges of loadings for each metal that could be expected for a specific land-use area were also determined.

Phase III - Solubilities and Toxicities of Heavy Metals Associated With Road Surface Runoff

An overall sample was divided into two size categories ($<246\mu$ and $>246\mu$) which represent material effectively removed by street sweepers and material usually not removed by street sweepers. These two samples, plus an undivided control sample were added to dechlorinated tap water making a solid concentration representative of normal storm water. These samples were aerated for a period of twenty-five days with water samples withdrawn at one, five, and twenty-five day intervals, and analyzed for dissolved heavy metal content and toxicities. The results from this study phase were used to determine the solubilities of the various metals and corresponding toxicities of the mixtures.

Phase IV - Particle Size Distribution Of Heavy Metals Associated With Road Surface Particulates

Material was combined into samples from several cities representative of geographical areas of the country. Metal analyses were then performed on these samples after they were divided into several size ranges. These results enabled predictions to be made on the removal effectiveness of the metals by current street sweeping methods.

Phase V - Additional Analyses on Highway, Rural Road and Airport Surfaces

Additional sampling was conducted on rural roads, freeways and on airport grounds in northern California. Several highways were sampled and the collected material was combined for analyses. The same procedure was used for the rural road and airport samples, except that since only one airport was selected, several different locations on the airport grounds were sampled. The pollution parameters analyzed included: BOD_5, COD, kjeldahl nitrogen, nitrates, phosphates, plus selected heavy metals.

Phase VI - Organic Analyses

Certain organic analyses were performed during the course of this study. In conjunction with the Phase I mass spectrographs, organic analyses were performed on the three major land-use samples. They were also performed on the sized samples Phase III solubility tests. The analyses performed included: tanins and lignins, carbohydrates, organic acids, MBAS (methylene blue active substances), grease and oil, plus the quantities of hydrocarbons and fatty matter in the grease and oil. PCBs (polychlorinated biphenols) and certain pesticides were also analyzed.

SECTION IV

MASS SPECTROGRAPHIC ANALYSES

Objectives

To determine the overall elemental composition of street surface contaminants and compare the respective compositions for residential, industrial and commercial land-use areas.

Background

Before an orderly analytical plan could be devised to further determine the heavy metal composition of the samples, initial screening tests by mass spectrographic techniques were required. These tests resulted in the complete breakdown of the samples to their elemental composition. From these lists, heavy metals that are thought to have water pollution effects, at the detected concentrations, were chosen to be further analyzed in each of the collected samples. These initial samples were combined into major land-use combinations, prior to analyses, in order to detect any major differences in elemental composition possibly caused by different activities in each land-use area.

Methods of Analysis

The samples were combined into three major land-use composites by dividing the previously collected samples into residential, industrial and commercial categories. These categorized samples were then internally mixed by combining identical weights of each sample. The three samples were then shipped to a private laboratory which specializes in mass spectrographic analyses. There the samples were screened and all materials greater than 1/4 in. were removed. The remaining material was ignited at $500^{\circ}C$, crushed, split to 1 gram samples and ground to a <200 mesh (74 μ) powder, then finally subjected to standard mass spectrographic techniques. Because of the uniqueness of the samples, several heavy metal values were verified using atomic absorption techniques.

Table 1

ELEMENTAL COMPOSITION OF STREET SURFACE CONTAMINANTS AS DETERMINED BY MASS SPECTROGRAPH TECHNIQUES

ELEMENT	SYMBOL	RESIDENTIAL (mg/kg)	INDUSTRIAL (mg/kg)	COMMERCIAL (mg/kg)	RESIDENTIAL (lb/curb mi)	INDUSTRIAL (lb/curb mi)	COMMERCIAL (lb/curb mi)	RESIDENTIAL (10^{-3} lb/1000 ft^2)	INDUSTRIAL (10^{-3} lb/1000 ft^2)	COMMERCIAL (10^{-3} lb/1000 ft^2)
Aluminum	Al	M*	M	M	M	M	M	M	M	M
Antimony	Sb	2	5	2	.002	.014	.001	.024	.14	.007
Arsenic	As	20	10	20	.024	.028	.006	.24	.28	.066
Barium	Ba	200	200	200	.240	.56	.058	2.4	5.5	.66
Beryllium	Be	0.2	2	0.2	< .001	.006	< .001	.002	.055	< .001
Bismuth	Bi	0.2	0.2	0.2	< .001	.001	< .001	.002	.006	< .001
Boron	B	10	10	10	.012	.028	.003	.12	.28	.033
Bromine	Br	20	20	50	.024	.056	.015	.24	.55	.17
Cadmium	Cd	< 2	< 2	< 2	< .002	< .006	< .001	.024	< .055	< .007
Calcium	Ca	M	M	M	M	M	M	M	M	[illegible]
Cerium	Ce	20	20	20	.024	.056	.006	.24	.55	.066
Cesium	Cs	1	1	1	.001	.003	< .001	.012	.028	.003
Chlorine	Cl	200	200	200	.24	.56	.058	2.4	5.5	.66
Chromium	Cr	200	500	100	.24	1.4	.029	2.4	14	.33
Cobalt	Co	5	5	5	.006	.014	.001	.06	.13	.017
Copper	Cu	100	100	100	.12	.28	.029	1.2	2.8	.33
Dysprosium	Dy	2	2	2	.002	.006	.001	.024	.055	.007
Erbium	Er	1	1	1	.001	.003	< .001	.012	.028	.003
Europium	Eu	1	1	0.5	.001	.003	< .001	.012	.028	.002
Fluorine	F	1	5	0.5	.001	.014	< .001	.012	.14	.002
Gadolinium	Gd	2	2	2	.002	.006	.001	.024	.055	.007
Gallium	Ga	2	2	2	.002	.006	.001	.024	.055	.007
Germanium	Ge	< 1	< 1	< 1	< .001	< .003	< .001	< .012	< .028	< .003
Gold	Au	< 0.5	< 0.5	< 0.5	< .001	< .002	< .001	< .006	< .014	< .002
Hafnium	Hf	5	10	2	.006	.028	.001	.06	.27	.007
Holmium	Ho	0.5	0.5	0.5	< .001	.002	< .001	.006	.014	.002
Indium	In	< 0.2	< 0.2	< 0.2	< .001	< .001	< .001	.002	< .006	< .001
Iodine	I	0.2	0.2	0.2	< .001	.001	< .001	.002	.006	< .001
Iridium	Ir	< 0.5	< 0.5	< 0.5	< .001	< .002	< .001	< .006	< .014	< .002
Iron	Fe	M	M	M	M	M	M	M	M	M
Lanthanum	La	20	10	10	.024	.028	.003	.24	.27	.033
Lead	Pb	2,000	5,000	5,000	2.4	14	1.4	24	140	17
Lithium	Li	5	5	5	.006	.014	.001	.06	.14	.017
Lutetium	Lu	0.2	0.2	0.2	< .001	.001	< .001	.002	.006	< .001
Magnesium	Mg	M	M	M	M	M	M	M	M	M
Manganese	Mn	200	200	200	.24	.56	.058	2.4	5.5	.66
Mercury	Hg	< 1	< 1	< 1	< .001	.003	< .001	< .012	< .028	< .003
Molybdenum	Mo	20	20	5	.024	.056	.001	.24	.55	.017

Table 1 ELEMENTAL COMPOSITION OF STREET SURFACE CONTAMINANTS AS DETERMINED BY MASS SPECTROGRAPH TECHNIQUES (continued)

ELEMENT	SYMBOL	RESIDENTIAL (mg/kg)	INDUSTRIAL (mg/kg)	COMMERCIAL (mg/kg)	RESIDENTIAL (lb/curb mi)	INDUSTRIAL (lb/curb mi)	COMMERCIAL (lb/curb mi)	RESIDENTIAL (10^{-3} lb/1000 ft^2)	INDUSTRIAL (10^{-3} lb/1000 ft^2)	COMMERCIAL (10^{-3} lb/1000 ft^2)
Neodymium	Nd	20	10	10	.024	.028	.003	.24	.22	.033
Nickel	Ni	100	100	50	.12	.28	.015	1.2	2.8	.17
Niobium	Nb	10	10	10	.012	.028	.003	.12	.28	.033
Osmium	Os	< 0.5	< 0.5	< 0.5	< .001	< .002	< .001	< .006	< .014	< .002
Palladium	Pd	< 0.5	< 0.5	< 0.5	< .001	< .002	< .001	< .006	< .014	< .002
Phosphorus	P	200	100	100	.24	.28	.029	2.4	2.8	.33
Platinum	Pt	< 1	< 1	< 1	< .001	.003	< .001	< .012	< .028	< .003
Potassium	K	M	M	M	M	M	M	M	M	M
Praseodymium	Pr	2	2	2	.002	.006	.001	.024	.055	.007
Rhenium	Re	< 0.5	< 0.5	< 0.5	< .001	< .002	< .001	< .006	< .014	< .002
Rhodium	Rh	< 0.5	< 0.5	< 0.5	< .001	< .002	< .001	< .006	< .014	< .002
Rubidium	Rb	10	10	10	.012	.028	.003	.12	.28	.033
Ruthenium	Ru	< 0.5	< 0.5	< 0.5	< .001	< .002	< .001	< .006	< .014	< .002
Samarium	Sm	2	2	2	.002	.006	.001	.024	.055	.007
Scandium	Sc	5	20	5	.006	.056	.001	.060	.55	.017
Selenium	Se	< 2	< 2	< 2	< .002	< .006	< .001	< .024	< .055	< .007
Silicon	Si	M	M	M	M	M	M	M	M	M
Silver	Ag	< 0.5	< 0.5	< 0.5	< .001	< .002	< .001	< .006	< .014	< .002
Sodium	Na	10,000	10,000	10,000	12	28	2.9	120	280	33
Strontium	Sr	1,000	200	100	1.2	.56	.029	12	5.5	.33
Sulfer	S	500	500	500	.60	1.4	.14	6.0	14	1.7
Tantalum	Ta	2	2	1	.002	.006	< .001	.024	.055	.003
Tellurium	Te	< 2	< 2	< 2	< .002	< .006	< .001	< .024	< .055	< .007
Terbium	Tb	0.5	0.5	0.5	< .001	.002	< .001	.006	.014	.002
Thallium	Tl	< 0.5	< 0.5	< 0.5	< .001	< .002	< .001	< .006	< .014	< .002
Thorium	Th	2	1	1	.002	.003	< .001	.024	.028	.003
Thulium	Tm	0.2	0.2	0.2	< .001	.001	< .001	.002	.006	< .001
Tin	Sn	20	20	20	.024	.056	.006	.24	.55	.066
Titanium	Ti	2,000	2,000	2,000	2.4	5.6	.58	24	55	6.6
Tungsten	W	1	< 0.5	1	.001	< .002	< .001	.012	.014	.003
Uranium	U	2	5	0.5	.002	.014	< .001	.024	.14	.002
Vanadium	V	5	50	50	.006	.14	.015	.062	1.4	.17
Ytterbium	Yb	1	1	1	.001	.003	< .001	.012	.028	.003
Yttrium	Y	5	10	10	.006	.028	.003	.061	.28	.033
Zinc	Zn	100	100	100	.12	.28	.029	1.2	2.0	.33
Zirconium	Zr	500	1,000	200	.60	2.8	.058	6.0	28	.66

* M = major constituent.

Results

Table 1 reports the results of the mass spectrographic analyses. The values are reported for each of the three land-use samples--residential, industrial and commercial--and for each of three units mg/kg, lb/curb mile and lb/1000 ft^2 (in order to be consistent with the previous report). The mg/kg values represent the strengths of the samples, while the lbs/curb mile and lbs/1000 ft^2 represent surface loadings of the material.

The loadings are obviously greatly influenced by the amount of road surface particulates found in a given area. When comparing the characteristics of the particulate material for different land-use areas, the mg/kg values should therefore be used. The surface loading values should be used when rough estimates of the amount of material on the streets is desired. Refer to a later section in this report for a discussion of the amounts of this material removed by normal street sweeping practices.

The values designated by M in Table 1 refer to major components of the street surface material. These elements make up greater than 1% (10,000 ppm) of the material. The corresponding loading values for "M" designations are shown in Table 2.

Table 2

LOADING VALUES FOR "M" DESIGNATED ELEMENTS FROM TABLE 1

(note that all values are "greater than")

	lb/curb mile	10^{-3} lb/1000 ft^2
Residential	> 12	> 120
Industrial	> 28	> 280
Commercial	> 2.9	> 29

Table 3 summarizes the most abundant elements found in the samples. From this list, heavy metals to be analyzed in each individual sample were chosen.

Table 3

ABUNDANT ELEMENTS FOUND IN STREET CONTAMINANT SAMPLES

10,000 mg/kg	500→10,000 mg/kg	100→500 mg/kg
Aluminum	Lead	Barium
Calcium	Sulfur	Chlorine
Iron	Titanium	Chromium
Magnesium	Zirconium	Copper
Potassium		Manganese
Silicon		Nickel
Sodium		Phosphorus
		Strontium
		Zinc

Table 4 lists the metals chosen for further analysis. Most of the elements occurring in concentrations greater than 10,000 mg/kg were not analyzed because they are mostly naturally occurring. Cadmium, arsenic and mercury were also chosen, not because of their abundance, but because of their high toxic potential. The elements of intermediate concentration, except sulfur, were found to be higher in concentration than expected. The concentrations of these three elements--lead, titanium and zirconium--were confirmed by independent methods (atomic absorption).

Table 4

METALS CHOSEN TO BE ANALYZED IN FURTHER DETAIL

Arsenic	Iron	Nickel
Cadmium	Lead	Strontium
Chromium	Manganese	Titanium
Copper	Mercury	Zinc
		Zirconium

Tables 5 and 6 list the elements that were found to have substantial (>10 times) differences in strengths (mg/kg) and loadings (lbs/curb mile) between the different land uses. It is seen that the strengths of the industrial sample is greatest for all elements except strontium, while the strengths of the commercial sample is least for all elements except vanadium. These trends are most likely associated with activity within land uses and not to public works practices. A difference in frequency of cleaning or a difference in cleaning process cannot dramatically change the elemental strengths of the street surface particulates, but will obviously affect the amounts of particulates on the streets.

Table 5

ELEMENTS HAVING SUBSTANTIAL (>10 TIMES) STRENGTH DIFFERENCES BETWEEN DIFFERENT LAND-USE SAMPLES (mg/kg)

ELEMENT	RESIDENTIAL	INDUSTRIAL	COMMERCIAL
Beryllium	0.2	2	0.2
Fluorine	1	5	0.5
Strontium	1000	200	100
Uranium	2	5	0.5
Vanadium	5	50	50

For all elements, the loading values (lbs/curb mile) are least for the commercial sample. All loading values, except for strontium, for the industrial sample are greatest. These trends are most likely due to differences in cleaning frequencies between the land uses. It is common practice for public works departments to clean commercial areas every day, while some industrial areas are only cleaned once every several weeks. The deviations in strengths of the samples also help to amplify these loading differences.

Table 6

ELEMENTS HAVING SUBSTANTIAL (>10 times) LOADING DIFFERENCES BETWEEN DIFFERENT LAND-USE SAMPLES

ELEMENT	LB/CURB MILE		
	RESIDENTIAL	INDUSTRIAL	COMMERCIAL
Antimony	0.002	0.014	0.001
Barium	0.240	0.56	0.058
Chromium	0.240	1.4	0.029
Cobalt	0.006	0.014	0.001
Fluorine	0.001	0.014	<0.001
Hofnium	0.006	0.028	0.001
Lead	2.4	14	1.4
Lithium	0.006	0.014	0.001
Molybdenium	0.024	0.056	0.001
Nickel	0.12	0.28	0.015
Scandium	0.006	0.056	0.001
Strontium	1.2	0.56	0.029
Sulfur	0.60	1.4	0.14
Uranium	0.002	0.014	<0.001
Zirconium	0.60	2.8	0.058

SECTION V

ATOMIC ABSORPTION ANALYSES OF INDIVIDUAL LAND-USE SAMPLES

Objectives

To determine the distribution and range of heavy metal strengths and loadings by analyzing each of the previously collected land-use samples.

Background

By utilizing the results from the previous phase, selected heavy metals were chosen that have high water-pollution potential. These metals were then analyzed in each of about 75 samples which were collected nationwide in the previous study. A good indication of the range of values that can be expected for a specific land use can be acquired by examining the results. A geographical distribution of the metals can also be studied by examining these data. These two objectives are useful when attempting to apply the results of this study to a situation that was not tested, and to determine more accurately the extent of heavy metal pollution resulting from road surface runoff.

Methods of Analysis

A sub-study was conducted to determine the best method to prepare the solid samples prior to atomic absorption analysis. The variables included: sample volume, grinding time (and therefore physical size), digestion solution and digestion time. The samples were not preliminarily ashed in order to keep volatile metal losses to a minimum.

The atomic absorption unit utilized in this study was a Perkin-Elmer Model 306 with automatic burner controls. The hollow cathode lamps were also of Perkin-Elmer manufacture. Multiple-element lamps were used as much as possible to reduce the time required for analyses.

The individual samples were ground in a Pica ball mill for five minutes. One gram of pulverized sample and several glass beads were added to a a reflex condensor apparatus, along with 20 ml of concentrated HCL and 20 ml of distilled water. This mixture was simmered for one hour and then allowed to cool. The sample was then filtered through a 0.45μ membrane filter to remove solid material which may clog the orifice on the atomic absorption unit. The sample volume was then diluted to 50 ml with distilled water. The samples were analyzed for each metal using the procedures recommended in the Perkin-Elmer "Procedures Manual.

These component land uses are defined as follows:

Residential:

LOS low income/old neighborhood/single family residences

MNS medium income/new neighborhood/single family residences

MOS medium income/old neighborhood/single family residences

LOM low income/old neighborhood/multiple family residences

MOM medium income/old neighborhood/multiple family residences

Industrial:

LI light industry

MI medium industry

HI heavy industry

Commercial:

SC suburban shopping center

CBD central business district

The cities sampled include: San Jose, Phoenix, Bucyrus (Ohio), Milwaukee, Baltimore, Tulsa, Atlanta and Seattle. San Jose and Phoenix were sampled twice, once during the winter (first) and once during the summer (second).

Refer to Appendix D for a more complete description of these land uses, along with detailed descriptions of each individual test site. Parameters are recorded such as test date, location, street width, pavement material and condition, gutter and curb material, area type adjacent to parking strip (lawn, etc), sidewalks presence and material, area beyond sidewalks, traffic density, average traffic speed, minimum distance of traffic to curb, days since last major rain, days since last cleaned, and cleaning method utilized.

Results

The results of this phase are reported in Tables 7 through 35. The results are shown for each test site, with numerical averages for each land use and weighted averages for each city. The weighted averages are based on the areas of each land use located within each city. Residential, industrial, commercial and overall averages and ranges are also included. The categorical land-use averages are determined by averaging the component land uses in the following manner:

Residential: $\frac{LOS+MNS+MOS+LOM+MOM}{5}$

Industrial: $\frac{LI+MI+HI}{3}$

Commercial: $\frac{SC+CBD}{2}$

The metals analyzed and reported include: cadmium, chromium, copper, iron, manganese, nickel, lead, strontium and zinc.

Mercury and arsenic were analyzed, but their results are not reported. Mercury values showed substantial reductions due to the storage time to which the samples were subjected. Mercury values obtained when the samples were fresh were between 10 and 300 mg/kg, and after 9 to 12 months' storage the values were between 1 and 20 mg/kg, with an overall average reduction in strength of about 50 fold. The arsenic values were less than the detection limit of the apparatus, with all samples being less than 50 mg/kg arsenic. (The sample preparation procedure diluted all samples 50 to 1; 50 grams of solution for one gram of solid.)

Table 7

Concentration of Cadmium (mg/kg),
Distribution by Land Use

	LOS	MNS	MOS	LOM	MOM	LI	MI	HI	SC	CBD	WEIGHTED AVERAGE
San Jose I	3.5	4.5		3.5		3.4	2.2		5.0	2.6	3.5
Phoenix I	4.0	8.8		5.5	6.0	11	1.7		2.0	6.6	7.2
Milwaukee	4.2	0.60		1.4	2.3		6.3	1.6	2.3	3.9	2.7
Bucyrus	3.0	2.6	1.6				4.7	4.0			2.7
Baltimore		6.1	5.5	8.8	5.2	8.2	8.8	6.8	3.7	25	8.0
San Jose II	6.0	5.4		2.0		3.7	4.0		3.1	4.9	4.3
Atlanta	0.0	0.0				1.5	0.4	6.4	0.0	5.3	1.1
Tulsa	0.95	1.3			2.4	2.8	0.0		9.3	1.6	1.7
Phoenix II	1.1	0.0		0.30	0.8	3.1	0.3		6.4		0.76
Seattle	0.0		1.3	3.4	1.6	1.4			1.5	2.3	1.1
NUMERICAL AVERAGE	2.5	3.3	2.8	3.6	3.1	4.4	3.2	4.7	3.7	6.5	

	AVERAGE	RANGE
RESIDENTIAL	3.1	0 → 8.8
INDUSTRIAL	4.1	0 → 11
COMMERCIAL	5.1	0 → 25
OVERALL	3.8	0 → 25

Table 8

Concentration of Chromium (mg/kg),
Distribution by Land Use

	LOS	MNS	MOS	LOM	MOM	LI	MI	HI	SC	CBD	WEIGHTED AVERAGE
San Jose I	325	295		325		300	285		325	320	304
Phoenix I	203	215		159	238	208	256		168	190	211
Milwaukee	130	153		141	125		179	128	177	190	147
Bucyrus	132	138	178				335	159			180
Baltimore		290	120	210	215	760	290	345	264	356	273
San Jose II	295	245		75		306	194		430	310	245
Atlanta	182	127				162	275	585	100	207	220
Tulsa	186	150			24	138	74		63	135	112
Phoenix II	185	111		165	193	188	310		71		141
Seattle	233		250	239	254	239			247	266	243
NUMERICAL AVERAGE	208	192	183	188	175	288	244	304	205	247	

	AVERAGE	RANGE
RESIDENTIAL	189	24 → 325
INDUSTRIAL	279	74 → 760
COMMERCIAL	226	63 → 430
OVERALL	209	24 → 760

Table 9

Concentration of Copper (mg/kg),
Distribution by Land Use

	LOS	MNS	MOS	LOM	MOM	LI	MI	HI	SC	CBD	WEIGHTED AVERAGE
San Jose I	83	33		96		87	67		80	110	71
Phoenix I	150	140		39	53	100	38		25	69	120
Milwaukee	83	120		170	72		120	170	120	810	160
Bucyrus	91	66	94				120	79			90
Baltimore		120	120	120	190	280	210	150	210	290	160
San Jose II	130	53		34		71	92		96	84	75
Atlanta	150	70				140	38	190	30	300	120
Tulsa	160	71			66	110	64		66	96	91
Phoenix II	99	52		74	46	120	32		99		67
Seattle	80		67	100	48	110			63	210	89
NUMERICAL AVERAGE	110	81	94	90	79	130	87	150	88	250	

	AVERAGE	RANGE
RESIDENTIAL	91	33 → 190
INDUSTRIAL	120	32 → 280
COMMERCIAL	170	25 → 810
OVERALL	120	25 → 810

Table 10

Concentration of Iron (mg/kg),
Distribution by Land Use

	LOS	MNS	MOS	LOM	MOM	LI	MI	HI	SC	CBD	WEIGHTED AVERAGE
San Jose I	27,000	21,000		23,000		24,000	26,000		44,000	16,000	24,000
Phoenix I	23,000	21,000		17,000	23,000	20,000	24,000		15,000	15,000	21,000
Milwaukee	15,000	18,000		14,000	15,000		22,000	15,000	34,000	25,000	18,000
Bucyrus	13,000	15,000	22,000				43,000	20,000			21,000
Baltimore		24,000	15,000	19,000	18,000	31,000	25,000	53,000	23,000	40,000	24,000
San Jose II	48,000	26,000		11,000		17,000	22,000		23,000	30,000	25,000
Atlanta	24,000	13,000				16,000	14,000	72,000	12,000	20,000	24,000
Tulsa	20,000	17,000			1,400	15,000	8,100		8,800	11,000	12,000
Phoenix II	21,000	11,000		20,000	25,000	24,000	22,000		5,000		15,000
Seattle	27,000		23,000	37,000	59,000	27,000			42,000	32,000	29,000
NUMERICAL AVERAGE	24,000	18,000	20,000	20,000	24,000	22,000	23,000	40,000	23,000	24,000	

	AVERAGE	RANGE
RESIDENTIAL	21,000	1,400 → 48,000
INDUSTRIAL	28,000	8,100 → 72,000
COMMERCIAL	24,000	5,000 → 44,000
OVERALL	24,000	1,400 → 72,000

Table 11

Concentration of Manganese (mg/kg),
Distribution by Land Use

	LOS	MNS	MOS	LOM	MOM	LI	MI	HI	SC	CBD	WEIGHTED AVERAGE
San Jose I	450	350		450		500	600		410	470	460
Phoenix I	320	680		280	440	430	330		360	380	540
Milwaukee	280	250		230	290		270	310	390	300	280
Bucyrus	420	370	490				620	470			470
Baltimore		430	150	290	270	830	680	1,600	500	770	480
San Jose II	560	470		230		490	450		540	500	460
Atlanta	210	280				300	240	1,100	290	280	350
Tulsa	430	520			100	440	180		160	250	340
Phoenix II	700	450		370	420	460	400		280		490
Seattle	430		460	490	440	490			440	430	460
NUMERICAL AVERAGE	420	420	370	330	330	490	420	870	370	420	

	AVERAGE	RANGE
RESIDENTIAL	370	100 → 700
INDUSTRIAL	590	180 → 1,600
COMMERCIAL	400	160 → 770
OVERALL	440	100 → 1,600

Table 12

Concentration of Nickel (mg/kg),
Distribution by Land Use

	LOS	MNS	MOS	LOM	MOM	LI	MI	HI	SC	CBD	WEIGHTED AVERAGE
San Jose I	85	100		80		110	93		93	110	96
Phoenix I	0	25		0	5.0	6.0	1.0		7.0	6.0	15
Milwaukee	33	26		0	18		21	30	37	30	22
Bucyrus	13	36	6.5				35	5.5			17
Baltimore		55	2.0	45	18	37	12	14	6.6	51	31
San Jose II	120	75		30		120	93		140	83	87
Atlanta	8.5	7.0				19	12	84	12	18	19
Tulsa	32	1.0			0	24	26		10	29	9
Phoenix II	11	0		2.5	6.5	18	23		170		11
Seattle	39		29	40	39	20			40	39	32
NUMERICAL AVERAGE	38	36	13	28	14	44	35	33	57	46	

	AVERAGE	RANGE
RESIDENTIAL	26	0 → 120
INDUSTRIAL	37	1.0 → 120
COMMERCIAL	52	6.0 → 170
OVERALL	34	0 → 170

Table 13

Concentration of Lead (mg/kg), Distribution by Land Use

	LOS	MNS	MOS	LOM	MOM	LI	MI	HI	SC	CBD	WEIGHTED AVERAGE
San Jose I	2,400	2,100		2,000		2,000	3,500		7,600	3,500	2,700
Phoenix I	1,200	970		3,700	3,600	2,500	1,200		1,600	3,200	1,500
Milwaukee	790	970		580	470		660	360	2,200	2,700	830
Bucyrus	350	430	1,600				780	260			890
Baltimore		1,000	730	1,700	1,500	10,000	1,800	310	2,100	5,700	2,200
San Jose II	5,700	3,900		600		2,700	1,500		10,000	5,100	3,400
Atlanta	280	480				740	1,400	940	2,000	3,900	660
Tulsa	1,100	970			230	1,100	65		2,400	1,300	740
Phoenix II	340	220		2,000	2,900	2,100	1,700		0.0		620
Seattle	1,700		2,500	3,000	2,600	1,100			4,700	3,300	2,100
NUMERICAL AVERAGE	1,500	1,200	1,600	1,900	1,900	2,800	1,400	470	3,600	3,600	

	AVERAGE	RANGE
RESIDENTIAL	1,600	230 → 5,700
INDUSTRIAL	1,600	65 → 10,000
COMMERCIAL	3,600	0 → 10,000
OVERALL	2,000	0 → 10,000

Table 14

Concentration of Strontium (mg/kg),
Distribution by Land Use

	LOS	MNS	MOS	LOM	MOM	LI	MI	HI	SC	CBD	WEIGHTED AVERAGE
San Jose I	19	5.0		17		0	7.5		10	20	8.9
Phoenix I	17	13		13	12	15	12		11	15	14
Milwaukee	21	76		24	20		20	9	7.0	20	28
Bucyrus	33	33	41				24	17			33
Baltimore		23	4.5	24	6.0	34	33	38	33	25	21
San Jose II	28	9.0		21		13	18		13	15	16
Atlanta	2.5	4.0				5.5	14	2.5	5.0	13	4.8
Tulsa	78	110			5.5	93	77		38	37	63
Phoenix II	25	12		23	15	15	10		25		16
Seattle	13		9.0	8.0	10,000*	16			0	15	11
NUMERICAL AVERAGE	26	32	18	19	12	24	24	17	16	20	

	AVERAGE	RANGE
RESIDENTIAL	21	2.5 → 78
INDUSTRIAL	22	0 → 93
COMMERCIAL	18	0 → 37
OVERALL	21	0 → 93

* Not included in average or range.

Table 15

Concentration of Zinc (mg/kg), Distribution by Land Use

	LOS	MNS	MOS	LOM	MOM	LI	MI	HI	SC	CBD	WEIGHTED AVERAGE
San Jose I	320	260		370		350	450		410	600	360
Phoenix I	290	330		210	490	230	210		720	335	340
Milwaukee	300	250		210	210		370	220	320	650	280
Bucyrus	190	110	390				200	140			250
Baltimore		760	730	630	490	780	410	300	510	1,000	640
San Jose II	810	420		210		340	280		380	510	400
Atlanta	270	180				320	310	880	320	1,100	330
Tulsa	350	180			220	360	160		190	420	240
Phoenix II	350	130		250	290	360	150		400		210
Seattle	460		460	660	410	480			390	500	480
NUMERICAL AVERAGE	370	290	530	360	350	400	280	390	400	640	

	AVERAGE	RANGE
RESIDENTIAL	380	110 → 810
INDUSTRIAL	360	140 → 880
COMMERCIAL	520	190 → 1,100
OVERALL	400	110 → 1,100

Table 16

Loading of Total Solids (lb/1,000 ft^2), Distribution by Land Use

	LOS	MNS	MOS	LOM	MOM	LI	MI	HI	SC	CBD	WEIGHTED AVERAGE
San Jose I	6.31	2.17		8.6		12.0	8.4		3.49	2.0	6.88
Phoenix I	5.80	1.36		14.69	2.37	3.43	10.0		4.84	1.60	4.88
Milwaukee	12.36	3.47		9.15	65.56		5.23	155.54	2.66	3.3	35.13
Bucyrus	26.9	6.49	30.69				15.77	25.76			21.01
Baltimore		13.77	23.78	14.21	4.46	16.39	10.86	3.05	.59	1.29	11.99
San Jose II	6.93	2.48		6.27		92.4	8.99		1.51	11.55	46.81
Atlanta	8.55	4.46			.59	43.84	2.27	5.65	7.3	1.03	6.31
Tulsa	1.8	11.77			2.88	13.02	4.4		3.3	2.11	5.67
Phoenix II	21.91	6.02		18.7	6.31	3.85	19.53		2.42	2.97	13.17
Seattle	8.77		4.13	6.77	2.94	14.96			3.65	4.04	7.87
NUMERICAL AVERAGE	11.03	5.77	19.53	11.19	12.15	24.98	10.39	47.5	3.30	3.32	

	AVERAGE	RANGE
RESIDENTIAL	11.93	1.36 → 65.56
INDUSTRIAL	27.62	3.05 → 43.84
COMMERCIAL	3.31	0.59 → 4.84
OVERALL	14.64	0.59 → 65.56

Table 17

Loading of Cadmium (lb/1,000 ft^2), Distribution by Land Use

	LOS	MNS	MOS	LOM	MOM	LI	MI	HI	SC	CBD	WEIGHTED AVERAGE
San Jose I	.00001	.000009		.00003		.00004	.00001		.00001	.000005	.00002
Phoenix I	.00002	.00001		.00008	.00001	.00003	.00001		.000009	.00001	.000035
Milwaukee	.00004	.000002		.00001	.0001		.00003	.0002	.000006	.00001	.000094
Bucyrus	.00008	.00001	.00004				.00007	.0001			.000056
Baltimore		.00008	.0001	.0001	.00002	.0001	.00009	.00002	.000002	.00003	.000095
San Jose II	.00004	.00001		.00001		.0003	.00003		.000004	.0005	.0002
Atlanta	0	0				.00006	.0000009	.00003	0	.000005	.0000069
Tulsa	.000001	.00001			.000006	.00003	0		.00003	.000003	.0000096
Phoenix II	.00002	0		.000005	.000005	.00001	.000005		.00001		.00001
Seattle	0		.000005	.00002	.000004	.00002			.000005	.000009	.0000086
NUMERICAL AVERAGE	.000023	.000014	.000048	.000036	.000024	.000073	.000027	.00008	.0000084	.000071	

	AVERAGE	RANGE
RESIDENTIAL	.000029	0 → .0001
INDUSTRIAL	.00006	0 → .0003
COMMERCIAL	.000039	0 → .0005
OVERALL	.000034	0 → .0005

Table 18

Loading of Chromium (lb/1,000 ft^2), Distribution by Land Use

	LOS	MNS	MOS	LOM	MOM	LI	MI	HI	SC	CBD	WEIGHTED AVERAGE
San Jose I	.002	.00064		.0027		.0036	.0023		.0011	.00064	.002
Phoenix I	.0011	.00029		.0023	.00056	.00071	.0025		.00081	.0003	.001
Milwaukee	.0016	.00053		.0092	.0081		.00093	.019	.00047	.00062	.0051
Bucyrus	.0035	.00089	.0054				.0052	.004			.0037
Baltimore		.0039	.0028	.0029	.00095	.012	.0031	.001	.00015	.00045	.0032
San Jose II	.002	.0006		.00047		.028	.0017		.00064	.0035	.011
Atlanta	.0015	.00053				.0071	.00062	.0033	.00073	.00021	.0013
Tulsa	.00033	.0017			.000069	.0017	.00032		.0002	.00028	.00063
Phoenix II	.004	.00066		.003	.0012	.00072	.006		.00017		.0018
Seattle	.002		.001	.0016	.00074	.0035			.0009	.001	.0019
NUMERICAL AVERAGE	.002	.001	.003	.0031	.0019	.0071	.0025	.0068	.00057	.00087	

	AVERAGE	RANGE
RESIDENTIAL	.0022	.000069 → .0092
INDUSTRIAL	.0054	.00032 → .028
COMMERCIAL	.00072	.00015 → .0011
OVERALL	.0026	.000069 → .028

Table 19

Loading of Copper (lb/1,000 ft^2), Distribution by Land Use

	LOS	MNS	MOS	LOM	MOM	LI	MI	HI	SC	CBD	WEIGHTED AVERAGE
San Jose I	.0005	.00007		.0008		.001	.0005		.0002	.0002	.0004
Phoenix I	.0008	.0001		.0005	.0001	.0003	.0003		.0001	.0001	.0005
Milwaukee	.001	.0004		.001	.004		.0006	.026	.0003	.002	.005
Bucyrus	.002	.0004	.002				.001	.002			.001
Baltimore		.001	.002	.001	.0008	.004	.002	.0004	.0001	.0003	.001
San Jose II	.0009	.0001		.0002		.006	.0008		.0001	.0009	.003
Atlanta	.001	.0003				.006	.00008	.001	.0002	.0003	.0007
Tulsa	.0002	.0008			.0001	.013	.0002		.0002	.0002	.0005
Phoenix II	.002	.0003		.001	.0002	.0004	.0006		.0002		.0008
Seattle	.0007		.0002	.0006	.0001	.001			.0002	.0008	.0007
NUMERICAL AVERAGE	.0010	.00038	.0014	.00072	.00088	.0032	.00067	.0073	.00017	.0006	

	AVERAGE	RANGE
RESIDENTIAL	.00087	.00007 → .004
INDUSTRIAL	.0037	.00008 → .026
COMMERCIAL	.00038	.0001 → .002
OVERALL	.00066	.00007 → .026

Table 20

Loading of Iron (lb/1,000 ft^2), Distribution by Land Use

	LOS	MNS	MOS	LOM	MOM	LI	MI	HI	SC	CBD	WEIGHTED AVERAGE
San Jose I	.170	.045		.197		.288	.218		.153	.032	.165
Phoenix I	.133	.028		.249	.054	.068	.240		.072	.024	.102
Milwaukee	.185	.062		.128	.983		.115	2.33	.090	.082	.632
Bucyrus	.349	.097	.675				.678	.515			.441
Baltimore		.330	.356	.269	.080	.508	.271	.161	.013	.051	.287
San Jose II	.332	.064		.068		1.57	.197		.034	.346	1.17
Atlanta	.205	.057				.701	.031	.406	.087	.020	.151
Tulsa	.036	.200			.040	.195	.035		.029	.023	.068
Phoenix II	.460	.066		.374	.157	.092	.429		.012		.197
Seattle	.236		.094	.250	.173	.403			.153	.129	.228
NUMERICAL AVERAGE	.234	.105	.375	.219	.247	.478	.246	.853	.071	.088	

	AVERAGE	RANGE
RESIDENTIAL	.236	.028 → .983
INDUSTRIAL	.525	.031 → 2.33
COMMERCIAL	.079	.012 → .346
OVERALL	.285	.012 → 2.33

Table 21

Loading of Manganese (lb/1,000 ft^2), Distribution by Land Use

	LOS	MNS	MOS	LOM	MOM	LI	MI	HI	SC	CBD	WEIGHTED AVERAGE
San Jose I	.0028	.00075		.0038		.006	.005		.0014	.00094	.0031
Phoenix I	.0017	.00092		.0041	.001	.0014	.0033		.0017	.0006	.0026
Milwaukee	.0034	.00086		.0021	.019		.0014	.048	.001	.00099	.0098
Bucyrus	.011	.0024	.015				.0097	.012			.021
Baltimore		.0059	.0035	.0041	.0012	.013	.0073	.0048	.00029	.00099	.0057
San Jose II	.0038	.0011		.0014		.045	.004		.00027	.0057	.021
Atlanta	.0017	.0012				.013	.00054	.0062	.0021	.00028	.0022
Tulsa	.00077	.0061			.00028	.0057	.00079		.00052	.00052	.0019
Phoenix II	.015	.0027		.0069	.0026	.0017	.0078		.00067		.0064
Seattle	.0037		.0018	.0033	.0012	.0073			.0016	.0017	.0036
NUMERICAL AVERAGE	.0048	.0024	.0067	.0036	.0042	.011	.0049	.017	.0010	.0078	

	AVERAGE	RANGE
RESIDENTIAL	.0043	.00028 → .019
INDUSTRIAL	.010	.00054 → .048
COMMERCIAL	.0044	.00027 → .0021
OVERALL	.0054	.00027 → .048

Table 22

Loading of Nickel (lb/1,000 ft^2),
Distribution by Land Use

	LOS	MNS	MOS	LOM	MOM	LI	MI	HI	SC	CBD	WEIGHTED AVERAGE
San Jose I	.00053	.00021		.00068		.0013	.00078		.00032	.00022	.00066
Phoenix I	0	.000034		0	.000011	.00002	.00001		.000033	.0000096	.000073
Milwaukee	.0004	.00009		0	.0011		.0001	.0046	.000098	.000099	.00077
Bucyrus	.00034	.00023	.00019				.00055	.00014			.00035
Baltimore		.00075	.000047	.00063	.00008	.0006	.00013	.000042	.0000038	.000065	.00037
San Jose II	.00083	.00018		.00018		.011	.00083		.00021	.00095	.004
Atlanta	.000072	.000031				.00083	.000027	.00047	.000087	.000018	.00011
Tulsa	.000057	.000011			0	.00031	.00011		.000033	.000061	.000051
Phoenix II	.00024	0		.000046	.000041	.000069	.00044		.00041		.00014
Seattle	.00034		.00011	.00027	.00011	.00029			.00014	.00015	.00025
NUMERICAL AVERAGE	.00031	.00017	.00011	.00025	.00022	.00055	.00033	.0013	.00014	.00019	

	AVERAGE	RANGE
RESIDENTIAL	.00021	0 → .00075
INDUSTRIAL	.00072	.00001 → .011
COMMERCIAL	.00016	.0000038 → .00095
OVERALL	.00029	0 → .011

Table 23

Loading of Lead (lb/1,000 ft^2), Distribution by Land Use

	LOS	MNS	MOS	LOM	MOM	LI	MI	HI	SC	CBD	WEIGHTED AVERAGE
San Jose I	.015	.004		.017		.024	.029		.026	.007	.018
Phoenix I	.006	.001		.054	.008	.008	.012		.007	.005	.007
Milwaukee	.009	.003		.005	.03		.003	.055	.005	.008	.029
Bucyrus	.009	.002	.049				.012	.006			.018
Baltimore		.013	.017	.024	.006	.163	.019	0	.001	.007	.026
San Jose II	.039	.009		.003		.249	.013		.015	.058	.159
Atlanta	.002	.002				.032	.003	.005	.014	.004	.004
Tulsa	.001	.011			0	.014	0		.007	.002	.004
Phoenix II	.007	.001		.037	.018	.008	.033		0		.008
Seattle	.014		.01	.02	.007	.016			.017	.013	.016
NUMERICAL AVERAGE	.016	.006	.031	.021	.011	.069	.013	.016	.010	.011	

	AVERAGE	RANGE
RESIDENTIAL	.017	0 → .054
INDUSTRIAL	.032	0 → .249
COMMERCIAL	.010	0 → .058
OVERALL	.018	0 → .249

Table 24

Loading of Strontium (lb/1,000 ft^2), Distribution by Land Use

	LOS	MNS	MOS	LOM	MOM	LI	MI	HI	SC	CBD	WEIGHTED AVERAGE
San Jose I	.00011	.00001		.00014		0	.000063		.000034	.00004	.000061
Phoenix I	.000098	.000017		.00019	.000028	.000051	.00012		.000053	.000024	.000068
Milwaukee	.00025	.00026		.00021	.0013		.0001	.0013	.000018	.000066	.00098
Bucyrus	.00088	.00021	.0012				.00037	.00043			.00069
Baltimore		.00031	.0001	.00034	.000026	.00055	.00035	.00011	.000019	.000032	.00025
San Jose II	.00019	.000022		.00013		.0012	.00016		.000019	.00017	.00074
Atlanta	.000021	.000017				.00024	.000031	.000014	.000036	.000013	.00003
Tulsa	.00014	.0012			.000015	.0012	.00033		.00012	.000078	.00035
Phoenix II	.00054	.000072		.00043	.000094	.000057	.00019		.00006		.00021
Seattle	.00011		.000037	.000054	.029*	.00023			0	.00006	.000086
NUMERICAL AVERAGE	.00025	.00023	.00044	.00021	.00029	.000028	.000021	.00046	.000039	.00006	

	AVERAGE	RANGE
RESIDENTIAL	.0012	.000010 → .029
INDUSTRIAL	.00016	0 → .0013
COMMERCIAL	.000049	0 → .00017
OVERALL	.00093	0 → .029

* Not included in average or range.

Table 25

Loading of Zinc (lb/1,000 ft^2), Distribution by Land Use

	LOS	MNS	MOS	LOM	MOM	LI	MI	HI	SC	CBD	WEIGHTED AVERAGE
San Jose I	.002	.0005		.003		.004	.003		.001	.001	.002
Phoenix I	.001	.0004		.003	.001	.0007	.002		.003	.0005	.001
Milwaukee	.003	.0008		.001	.013		.001	.034	.0008	.002	.009
Bucyrus	.005	.0007	.011				.003	.003			.005
Baltimore		.010	.017	.008	.002	.012	.004	.0009	.0003	.001	.007
San Jose II	.005	.001		.001		.031	.002		.0005	.005	.018
Atlanta	.002	.0008				.014	.0007	.004	.002	.001	.002
Tulsa	.0006	.002			.001	.004	.0007		.0006	.0008	.001
Phoenix II	.007	.0007		.004	.001	.001	.002		.0009		.002
Seattle	.004		.001	.004	.001	.007			.001	.002	.003
NUMERICAL AVERAGE	.0032	.0018	.0096	.0034	.0031	.0092	.0020	.010	.0011	.0016	

	AVERAGE	RANGE
RESIDENTIAL	.0042	.0004 → .017
INDUSTRIAL	.0070	.0007 → .034
COMMERCIAL	.0013	.003 → .005
OVERALL	.0045	.0004 → .034

Table 26

Loading of Total Solids (lb/curb mi),
Distribution by Land Use

	LOS	MNS	MOS	LOM	MOM	LI	MI	HI	SC	CBD	WEIGHTED AVERAGE
San Jose I	835	288		1,138		1,740	1,112		463	265	911
Phoenix I	768	180		1,940	314	454	1,330		640	212	646
Milwaukee	719	275		557	6,940		414	12,300	210	261	2,700
Bucyrus	1,850	410	1,940				997	1,630			1,375
Baltimore		1,240	1,380	1,280	495	1,300	860	242	63	68	1,030
San Jose II	624	197		465		12,200	1,050		161	1,220	6,000
Atlanta	587	329		31		3,710	168	298	425	60	433
Tulsa	115	621			152	1,100	280		25	179	325
Phoenix II	1,620	384		1,090	500	264	1,140		179	204	910
Seattle	463		263	536	141	711			193	193	455
NUMERICAL AVERAGE	842	436	1,194	880	1,424	2,685	817	3,617	262	296	

	AVERAGE	RANGE
RESIDENTIAL	895	31 → 6,940
INDUSTRIAL	2,384	168 → 12,300
COMMERCIAL	281	25 → 1,220
OVERALL	1,188	31 → 12,300

Table 27

Loading of Cadmium (lb/curb mi),
Distribution by Land Use

	LOS	MNS	MOS	LOM	MOM	LI	MI	HI	SC	CBD	WEIGHTED AVERAGE
San Jose I	.0029	.0013		.0040		.0059	.0024		.0023	.0007	.0032
Phoenix I	.0031	.0016		.0107	.0019	.0050	.0023		.0013	.0014	.0047
Milwaukee	.0030	.0002		.0008	.0160		.0026	.0197	.0005	.0010	.0073
Bucyrus	.0056	.0011	.0031				.0047	.0065			.0037
Baltimore		.0076	.0076	.0113	.0026	.0107	.0076	.0016	.0002	.0017	.0082
San Jose II	.0037	.0011		.0009		.0450	.0042		.0005	.0060	.0258
Atlanta	0	0				.0056	.0001	.0019	0	.0003	.0005
Tulsa	.0001	.0008			.0004	.0031	0		.0002	.0003	.0006
Phoenix II	.0018	0		.0003	.0004	.0008	.0003		.0011		.0007
Seattle	0		.0003	.0018	.0002	.0010			.0003	.0004	.0005
NUMERICAL AVERAGE	.0022	.0015	.0037	.0043	.0036	.0096	.0027	.0074	.0007	.0015	

	AVERAGE	RANGE
RESIDENTIAL	.0031	0 → .0160
INDUSTRIAL	.0066	0 → .0450
COMMERCIAL	.0011	0 → .0060
OVERALL	.0037	0 → .0450

Table 28

Loading of Chromium (lb/curb mi),
Distribution by Land Use

	LOS	MNS	MOS	LOM	MOM	LI	MI	HI	SC	CBD	WEIGHTED AVERAGE
San Jose I	.271	.085		.370		.522	.317		.150	.085	.277
Phoenix I	.156	.039		.308	.075	.094	.340		.108	.040	.136
Milwaukee	.093	.042		.079	.868		.074	1.574	.037	.050	.397
Bucyrus	.244	.057	.345				.334	.259			.248
Baltimore		.360	.166	.269	.106	.988	.249	.083	.017	.024	.281
San Jose II	.184	.048		.035		3.733	.204		.069	.378	1.470
Atlanta	.107	.042				.601	.046	.174	.043	.012	.095
Tulsa	.021	.093			.004	.152	.021		.002	.024	.036
Phoenix II	.300	.043		.180	.097	.050	.353		.013		.128
Seattle	.108		.066	.128	.036	.170			.048	.051	.111
NUMERICAL AVERAGE	.165	.090	.192	.196	.198	.789	.215	.523	.054	.083	

	AVERAGE	RANGE
RESIDENTIAL	.168	.004 → .868
INDUSTRIAL	.509	.021 → 3.733
COMMERCIAL	.069	.002 → .378
OVERALL	.231	.002 → 3.733

Table 29

Loading of Copper (lb/curb mi),
Distribution by Land Use

	LOS	MNS	MOS	LOM	MOM	LI	MI	HI	SC	CBD	WEIGHTED AVERAGE
San Jose I	.069	.010		.109		.151	.075		.037	.029	.065
Phoenix I	.115	.025		.076	.017	.045	.051		.016	.015	.078
Milwaukee	.060	.033		.095	.500		.050	2.091	.025	.211	.432
Bucyrus	.168	.027	.182				.120	.129			.124
Baltimore		.149	.166	.154	.094	.364	.181	.036	.013	.020	.165
San Jose II	.081	.010		.016		.866	.097		.015	.102	.450
Atlanta	.088	.023				.519	.006	.057	.013	.018	.052
Tulsa	.018	.044			.010	.121	.018		.002	.017	.030
Phoenix II	.160	.020		.081	.023	.032	.036		.018		.061
Seattle	.037		.018	.054	.007	.078			.012	.041	.040
NUMERICAL AVERAGE	.088	.038	.122	.084	.109	.272	.070	.578	.017	.057	

	AVERAGE	RANGE
RESIDENTIAL	.088	.007 → .500
INDUSTRIAL	.307	.006 → 2.091
COMMERCIAL	.037	.002 → .211
OVERALL	.129	.002 → 2.091

Table 30

Loading of Iron (lb/curb mi),
Distribution by Land Use

	LOS	MNS	MOS	LOM	MOM	LI	MI	HI	SC	CBD	WEIGHTED AVERAGE
San Jose I	22.55	6.05		26.17		41.76	28.91		20.37	4.24	21.86
Phoenix I	17.66	3.78		32.98	7.22	9.08	31.94		9.60	3.18	13.57
Milwaukee	10.79	4.95		7.80	104.1		9.52	184.5	7.14	6.53	48.60
Bucyrus	24.05	6.15	42.68				42.87	32.60			28.88
Baltimore		29.76	20.70	24.32	8.91	40.30	21.50	12.83	1.45	2.72	24.72
San Jose II	29.95	5.12		5.12		207.4	23.1		3.70	36.60	150.00
Atlanta	14.09	4.28				59.36	2.35	21.46	5.10	1.20	10.39
Tulsa	2.30	10.56			0.21	16.50	2.27		0.22	1.97	3.90
Phoenix II	34.02	4.22		21.80	12.50	6.34	25.08		0.90		13.65
Seattle	12.50		6.05	19.83	8.32	19.20			8.11	6.18	13.20
NUMERICAL AVERAGE	18.66	8.32	23.14	19.72	23.54	49.99	20.84	62.85	6.29	7.83	

	AVERAGE	RANGE
RESIDENTIAL	20.24	0.21 → 104.1
INDUSTRIAL	44.56	2.27 → 207.4
COMMERCIAL	7.06	0.22 → 36.60
OVERALL	24.44	0.21 → 207.4

Table 31

Loading of Manganese (lb/curb mi),
Distribution by Land Use

	LOS	MNS	MOS	LOM	MOM	LI	MI	HI	SC	CBD	WEIGHTED AVERAGE
San Jose I	.376	.101		.512		.870	.667		.190	.125	.419
Phoenix I	.246	.122		.543	.138	.195	.439		.230	.081	.349
Milwaukee	.201	.069		.128	2.013		.112	3.813	.082	.078	.756
Bucyrus	.777	.152	.951				.618	.766			.646
Baltimore		.533	.207	.371	.134	1.079	.585	.387	.032	.052	.494
San Jose II	.349	.093		.107		5.978	.473		.087	.610	2.760
Atlanta	.123	.092				1.113	.040	.328	.123	.017	.152
Tulsa	.049	.323			.015	.484	.050		.004	.045	.111
Phoenix II	1.134	.173		.403	.210	.121	.456		.050		.446
Seattle	.199		.121	.263	.062	.348			.085	.083	.209
NUMERICAL AVERAGE	.384	.184	.426	.332	.429	1.274	.382	1.324	.098	.136	

	AVERAGE	RANGE
RESIDENTIAL	.351	.015 → 2.013
INDUSTRIAL	.993	.040 → 5.978
COMMERCIAL	.117	.004 → .610
OVERALL	.468	.004 → 5.978

Table 32

Loading of Nickel (lb/curb mi), Distribution by Land Use

	LOS	MNS	MOS	LOM	MOM	LI	MI	HI	SC	CBD	WEIGHTED AVERAGE
San Jose I	.0710	.0288		.0910		.1914	.1034		.0431	.0292	.0875
Phoenix I	0	.0045		0	.0016	.0027	.0013		.0045	.0013	.0097
Milwaukee	.0237	.0072		0	.1249		.0087	.3690	.0078	.0078	.0594
Bucyrus	.0241	.0148	.0126				.0349	.0090			.0234
Baltimore		.0682	.0028	.0576	.0089	.0481	.0103	.0034	.0004	.0035	.0319
San Jose II	.0749	.0148		.0140		1.464	.0977		.0225	.1013	.5220
Atlanta	.0050	.0023				.0705	.0020	.0250	.0051	.0011	.0082
Tulsa	.0037	.0006			0	.0264	.0073		.0003	.0052	.0029
Phoenix II	.0178	0		.0027	.0033	.0048	.0262		.0304		.0100
Seattle	.0181		.0076	.0214	.0055	.0142			.0077	.0075	.0146
NUMERICAL AVERAGE	.0265	.0157	.0077	.0267	.0240	.2278	.0324	.1016	.0135	.0196	

	AVERAGE	RANGE
RESIDENTIAL	.0201	0 → .1249
INDUSTRIAL	.1206	.0013 → 1.464
COMMERCIAL	.0166	.0003 → .1013
OVERALL	.0400	0 → 1.464

Table 33

Loading of Lead (lb/curb mi),
Distribution by Land Use

	LOS	MNS	MOS	LOM	MOM	LI	MI	HI	SC	CBD	WEIGHTED AVERAGE
San Jose I	2.00	0.60		2.28		3.48	3.89		3.52	0.93	2.46
Phoenix I	0.92	0.17		7.18	1.13	1.14	1.60		1.02	0.68	0.97
Milwaukee	0.57	0.27		0.32	3.26		0.27	4.43	0.46	0.70	2.24
Bucyrus	0.65	0.18	3.10				0.78	0.42			1.22
Baltimore		1.24	1.01	2.18	0.74	13.00	1.55	0.08	0.13	0.39	2.27
San Jose II	3.56	0.77		0.28		32.94	1.58		1.61	6.22	20.40
Atlanta	0.16	0.16				2.75	0.24	0.28	0.85	0.23	0.29
Tulsa	0.13	0.60			0.03	1.21	0.02		0.06	0.23	0.24
Phoenix II	0.55	0.08		2.18	1.45	0.55	1.94		0		0.56
Seattle	0.79		0.66	1.61	0.37	0.78			0.91	0.64	0.96
NUMERICAL AVERAGE	1.04	0.45	1.59	2.29	1.16	6.97	1.32	1.30	0.95	1.25	

	AVERAGE	RANGE
RESIDENTIAL	1.31	0.03 → 7.18
INDUSTRIAL	3.19	0.02 → 32.94
COMMERCIAL	1.10	0 → 6.22
OVERALL	1.66	0 → 32.94

Table 34

Loading of Strontium (lb/curb mi),
Distribution by Land Use

	LOS	MNS	MOS	LOM	MOM	LI	MI	HI	SC	CBD	WEIGHTED AVERAGE
San Jose I	.0159	.0014		.0193		0	.0083		.0046	.0053	.0081
Phoenix I	.0131	.0023		.0252	.0038	.0058	.0160		.0070	.0032	.0090
Milwaukee	.0151	.0209		.0134	.1388		.0083	.1107	.0015	.0052	.0756
Bucyrus	.0611	.0135	.0795				.0239	.0277			.0454
Baltimore		.0285	.0062	.0307	.0030	.0442	.0284	.0092	.0021	.0017	.0216
San Jose II	.0175	.0018		.0098		.1586	.0189		.0021	.0183	.0960
Atlanta	.0015	.0013				.0204	.0027	.0007	.0021	.0008	.0021
Tulsa	.0090	.0683			.0008	.1023	.0216		.0010	.0066	.0205
Phoenix II	.0405	.0046		.0251	.0075	.0040	.0114		.0045		.0146
Seattle	.0060		.0024	.0043	1.410*	.0114			0	.0029	.0050
NUMERICAL AVERAGE	.0200	.0158	.0294	.0183	.0308	.0433	.0155	.0371	.0028	.0055	

	AVERAGE	RANGE
RESIDENTIAL	.0209	.0008 → .1388
INDUSTRIAL	.0320	0 → .1586
COMMERCIAL	.0042	0 → .0183
OVERALL	.0223	0 → .1586

* Not included in average or range.

Table 35

Loading of Zinc (lb/curb mi), Distribution by Land Use

	LOS	MNS	MOS	LOM	MOM	LI	MI	HI	SC	CBD	WEIGHTED AVERAGE
San Jose I	.267	.075		.421		.609	.500		.190	.159	.328
Phoenix I	.223	.059		.407	.154	.104	.279		.461	.071	.220
Milwaukee	.216	.069		.117	1.457		.153	2.706	.067	.170	.756
Bucyrus	.352	.045	.757				.199	.228			.344
Baltimore		.942	1.007	.806	.243	1.014	.353	.073	.032	.068	.659
San Jose II	.505	.083		.098		4.148	.294		.061	.622	2.400
Atlanta	.158	.059				1.187	.052	.262	.136	.066	.143
Tulsa	.040	.112			.033	.396	.045		.005	.075	.078
Phoenix II	.567	.050		.273	.145	.095	.171		.072		.191
Seattle	.213		.121	.372	.058	.341			.075	.097	.218
NUMERICAL AVERAGE	.282	.166	.628	.356	.348	.987	.227	.817	.122	.166	

	AVERAGE	RANGE
RESIDENTIAL	.356	.033 → 1.457
INDUSTRIAL	.677	.045 → 4.148
COMMERCIAL	.144	.005 → .622
OVERALL	.409	.005 → 4.148

The results are reported as mg/kg of metal (strength), pounds per 1000 square feet of street surface (loading) and pounds per curb mile (loading). Only the first and last units will be discussed here as both loading units lead to approximately similar conclusions.

From examining Tables 7 through 15, one finds some trends. The industrial and commercial land uses continually have the most metals on a strength (mg/kg) basis, while the residential land uses usually have the least. This is the same conclusion that was made in the first phase of analyses. On a geographical basis, no clear trends can be established.

Table 14 does demonstrate an interesting anomaly under Seattle MOM. It is seen that a tremendous amount of strontium is associated with this one test site. No other sample even comes to within 1/100 of this value. Because it is associated with only this test site, this must be the result of an accidental spill on the roadway. (The sample was further analyzed and was found to be homogeneous.)

Tables 16 through 25 (lbs/1000 ft^2) show similar trends with Tables 26 through 35 because they all represent the loading of the particulates as the most important defining parameter.

Tables 26 through 35 show more substantial trends based on loading factors. These trends are most likely the result of definite particulate loading patterns as shown on Table 26. The highest loading values for all metals are almost exclusively associated with industrial land use areas, while the lowest values are found in residential and commercial areas. On a geographical basis, it is seen that San Jose, Baltimore and Milwaukee have the highest loading factors, while Tulsa, Seattle and Atlanta have the lowest factors. All these metal loading trends are similar to particulate loading trends as shown in Table 26.

The range of values for each metal in each city and land use is significant. Except for occasional zero values, the ranges of metals are usually limited to less than a factor of ten, with averages about a factor of two to four for mg/kg values. In order to predict amounts of metals on roadways for a specific city, a loading factor is more useful. Because of the added variable of particulate loadings, metal loadings have to be more variable. For loading factors, the range of values often exceeds a factor of 100 within one city or land-use area. The averaged values are much better, with the worst ranges not much greater than a factor of ten, and usually within several fold.

A time element is not included in the results because the sampling program was designed to sample test areas at random, without any regard to when the streets were last cleaned. It can be expected that these amounts of metals will be found whenever a sample is taken. Available city records for the test areas indicated that all areas were cleaned, on the average, about five days prior to the sampling. It can be expected that these amounts of metals will be washed off the streets during the first hour of a rainstorm of moderate intensity, having a peak intensity of at least 0.5 in/hr (1.27 cm/hr).

These amounts of metals can cause significant problems during certain conditions. To help put these metal loadings in perspective, the following discussion compares heavy metal content of road surface runoff to sanitary sewage for a hypothetical city. The metal loadings used are the overall averaged values. Metal contents of sanitary sewage are from Richmond, California sewage treatment plant records for spring 1972 and San Jose-Santa Clara sewage treatment plant records for January 1970. Table 36 defines the hypothetical city parameters, while Tables 37 and 38 compare the metal content of road surface runoff to sanitary sewage (lbs/hr[kg/hr] and mg/1).

Table 36

HYPOTHETICAL CITY PARAMETERS

Population:	100,000 people
Total land area:	14,000 acres
Land-use distribution:	
Residential	75%
Commercial	5%
Industrial	20%
Total street lengths:	400 curb miles
Sanitary sewage flow:	12 MGD

Table 37

METAL LOADING FROM ROAD SURFACE RUNOFF COMPARED TO NORMAL SANITARY SEWAGE*

METAL	ROAD RUNOFF (lb/hr)	SANITARY SEWAGE (lb/hr)	RATIO: RUNOFF/SANITARY
Lead	600	0.13	4,600
Cadmium	1.2	0.0032	380
Nickel	10	0.042	240
Copper	36	0.17	210
Zinc	140	0.84	170
Iron	7,900	54	150
Manganese	150	9.7	15
Chromium	80	12	6.7

* "Hypothetical City" with 0.1 in. rain, lasting for one hour.

Table 38

METAL LOADING FROM ROAD SURFACE RUNOFF COMPARED TO NORMAL SANITARY SEWAGE FLOW

METAL	ROAD RUNOFF (mg/l)	SANITARY SEWAGE (mg/l)	RUNOFF / SEWAGE
Pb	6.2	0.03	210
Cd	0.012	0.00075	16
Ni	0.10	0.01	10
Cu	0.37	0.04	9
Zn	1.4	0.20	7
Fe	83	13	6
Mn	1.6	2.3	0.7
Cr	0.80	2.8	0.3

(from 0.1 in. rain)

It can be seen that during the peak discharge period, runoff contributes a substantially greater portion of metals to a receiving body than a normal sewage treatment plant. If the storm water is collected in a combined system, this metal content can then possibly affect the biological treatment systems. Table 39 summarizes metal concentrations necessary to cause reductions in biological treatment systems. It can be seen that the necessary dosages required are not supplied by storm water runoff.

Table 39

EFFECTS OF HEAVY METALS ON BIOLOGICAL TREATMENT PROCESSES*

	5→10% REDUCTION IN AEROBIC TREATMENT EFFICIENCY	4-HR SLUG DOSE, CAUSING REDUCTION IN COD REMOVAL	HIGHEST ALLOWABLE DOSE FOR SATISFACTORY ANAEROBIC SLUDGE DIGESTION
Cr	10 mg/l	>500 mg/l	>50 mg/l
Cu	1	75	5
Ni	1→2.5	50→200	>10
Zn	5→10	160	10

* "Interaction of Heavy Metals and Biological Sewage Treatment Processes," Environmental Health Series, Water Supply and Pollution Control, USPHS, May 1965.

Table 40 lists the removal efficiencies of various removal techniques used in sewage treatment plants for some of the heavy metals studied in this report. There exists removal techniques to abate almost any heavy metal problem, especially for amounts introduced by road runoff. In most combined systems, the hydraulic capacity of the treatment plant is not sufficient to treat the total flow during periods of high runoff Instead, most of the flow is diverted through overflows without treatment.

Table 40

REMOVAL EFFICIENCIES IN SEWAGE TREATMENT PROCESSES*

METAL	REVERSE OSMOSIS	LINE COAGULATION AND RE-CARBONATION	SAND FILTRATION	CARBON ABSORPTION	PRIMARY SEWAGE TREATMENT	SECONDARY SEWAGE TREATMENT
As		<10%				
Cd		50 → 95	95%	99%	"most"	
Cr^{+3}	72%	99+	77			70%
Cr^{+6}	29	11	3	97		44 → 50
Cu		86 → 99+	60			20 → 85
Fe		40 → 99+				
Hg		<10				
Mn		45 → 96				
Ni		90 → 99+				30 → 60
Pb		90+			"most"	
Ti		90				
Zn		90+	76			60 → 95

* Argo, David G. and Culp, Gordon L. "Heavy Metals Removal in Wastewater Treatment Processes" Two part series. Water and Sewage Works (August and September 1972).

SECTION VI

SOLUBILITIES AND TOXICITIES OF HEAVY METALS ASSOCIATED WITH ROAD SURFACE RUNOFF

Objective

To determine the extent to which heavy metals are in solution in a normal receiving water environment. To determine the toxicity of the road surface particulate mixture in a receiving water environment to a specific aquatic organism (stickleback).

Background

The solution concentrations of heavy metals are important when attempting to determine the toxicity of metals originating from road surfaces. Toxic limits (TLm) reported in the literature are almost exclusively concerned with soluble heavy metal forms. However it would not be realistic to assume that all the metals in road surface runoff are completely soluble in receiving waters without definitive laboratory testing.

Because of the problems of synergism and antagonism associated with heterogenous mixtures such as road surface particulates, it is advisable to measure the effects of the toxicity directly in laboratory toxicity tests.

Methods of Analysis

A quantity of particulate matter from a composite sample combined from nationwide samples was divided into two size ranges. These two size ranges represented material which is effectively removed by street sweeping practices (>246μ) and material usually remaining after sweeping (<246μ). These two sized samples plus an undivided control sample were added to water at a concentration representative of a moderate rain (0.04 inches for one hour). The mixtures were aerated and mixed for 25 days at a temperature of 20°C. After 1, 5 and 25 days, samples were withdrawn and bioassays conducted. Filtered samples, without digestion attempts, were analyzed for heavy metals.

Results

Table 41 shows the results of the laboratory analyses. In addition to the sample analyses, the dilution water heavy metal concentrations were determined to establish a background value. In order to measure the total available heavy metal concentrations, heavy metal analyses were also made on the three dry samples (composite, $< 246\mu$ and $> 246\mu$). By subtracting the heavy metal concentrations of the dilution water from the heavy metal concentrations in the liquid samples, the actual change in heavy metal content of the water column due to the presence of the road surface particulates can be determined. Since the samples were allowed to settle, and then filtered prior to analysis, any additional amounts of heavy metals in the sample, over the initial concentration of the dilution (receiving) water, can be assumed to be due to an amount of the heavy metals associated with particulate fractions becoming soluble. Table 41 lists the results of the analyses, showing the soluble metal concentrations of the dilution water, along with the soluble metal concentrations of the mixture after one, five and twenty-five days of mixing for each of the three samples. Also shown in Table 41 are the results of the bioassays conducted on the mixtures. Tables 42-44 present the results, after correction for the dilution water concentrations for periods of one, five, and twenty-five days of mixing. Values for the percent of available metal in solution are also given. These values were determined by comparing the actual concentrations (after correcting for dilution water values) to theoretical concentrations which would exist if all the available heavy metals (as determined in the analysis of the dry particulates) were in solution. These values are appropriately expressed as percentages. It is seen that several values for metal solubility and increased concentrations are not given. This is because the sample mixture actually had a lower concentration of these metals than the dilution water, as shown in Table 41. These decreases represent a loss of soluble metals in the water column. This may result from a number of processes. The soluble metal in the dilution water may have undergone an ion-exchange process, become sorbed on the roadsurface particulates, or the metal may have become

Table 41

HEAVY METAL CONCENTRATIONS (AS MEASURED) AND
BIOASSAY RESULTS FOR SIMULATED RECEIVING BODY OF WATER

	DILUTION WATER (mg/l)	1-DAY			5-DAY		
		COMPOSITE (mg/l)	<246μ (mg/l)	>246μ (mg/l)	COMPOSITE (mg/l)	<246μ (mg/l)	>246μ (mg/l)
Arsenic (As)	0.0002				0.007	0.000	0.003
Cadmium (Cd)	ND	0.0001	0.00002	0.01	0.00006	0.00003	0.002
Copper (Cu)	ND (<0.001)	0.03	0.03	0.04	0.15	0.005	0.007
Chromium (Cr)	0.002	ND (<.002)	ND	0.002	ND	0.006	ND
Iron (Fe)	0.07	0.09	0.06	0.12	0.10	0.09	0.05
Mercury (Hg)	0.0005	0.0005	0.0005	0.0003	0.0004	0.0002	0.0003
Manganese (Mn)	0.01	0.025	0.02	0.02	0.02	0.04	0.02
Nickel (Ni)	ND (<0.02)	ND	ND	ND	0.03	ND	ND
Lead (Pb)	ND (<0.02)	0.04	0.03	0.03	0.04	0.025	0.04
Strontium (Sr)	ND (<0.01)	0.011	0.011	0.02	0.09	0.10	0.06
Titanium (Ti)	ND (<0.1)	ND	ND	ND	ND	ND	ND
Zinc (Zn)	0.70	0.04	0.02	0.63	0.07	0.08	0.47
Zirconium (Zr)	ND (<1.0)	ND	ND	ND	ND	ND	ND
% survival after 96 hours exposure	100%	100%	100%	100%	100%	100%	100%

Table 41

HEAVY METAL CONCENTRATIONS (AS MEASURED) AND
BIOASSAY RESULTS FOR SIMULATED RECEIVING BODY OF WATER (continued)

		25-DAY		
	DILUTION WATER (mg/l)	COMPOSITE (mg/l)	≤246μ (mg/l)	≥246μ (mg/l)
Arsenic (As)	0.002	0.005	0.0001	0.002
Cadmium (Cd)	ND	≤0.001	≤0.001	≤0.001
Copper (Cu)	ND (≤0.001)	0.011	0.016	0.120
Chromium (Cr)	0.002	0.005	0.002	0.003
Iron (Fe)	0.07	0.10	0.012	0.06
Mercury (Hg)	0.0005	0.0005	0.0003	0.0002
Manganese (Mn)	0.01	0.04	0.04	0.04
Nickel (Ni)	ND (≤0.02)	0.01	0.01	0.01
Lead (Pb)	ND (≤0.02)	0.04	ND	ND
Strontium (Sr)	ND (≤0.01)	0.40	0.26	0.20
Titanium (Ti)	ND (≤0.1)	ND	ND	ND
Zinc (Zn)	0.70	0.10	0.15	0.17
Zirconium (Zr)	ND (≤1.0)	ND	ND	ND
% survival after 96 hours exposure	100%	100%	100%	100%

TABLE 42

HEAVY METAL CONCENTRATIONS AND SOLUBILITIES
IN SIMULATED RECEIVING BODY OF WATER

1-DAY SAMPLE	OVERALL COMPOSITE		< 246 μ COMPOSITE		> 246 μ COMPOSITE	
	CONC. mg/l	PERCENT OF AVAILABLE METAL IN SOLUTION	CONC. mg/l	PERCENT OF AVAILABLE METAL IN SOLUTION	CONC. mg/l	PERCENT OF AVAILABLE METAL IN SOLUTION
Arsenic (As)	--	--	--	--	--	--
Cadmium (Cd)	0.0001	0.13%	0.0002	0.2 %	0.01	14 %
Copper (Cu)	0.03	2.7	0.03	4.3	0.04	12
Chromium (Cr)	--	--	--	--	--	--
Iron (Fe)	0.02	0.01	--		0.05	0.02
Mercury (Hg)	--	--	--	--	--	--
Manganese (Mn)	0.015	0.38	0.01	0.31	0.01	0.53
Nickel (Ni)	--	--	--	--	--	--
Lead (Pb)	0.02	0.37	0.01	0.23	0.01	0.77
Strontium (Sr)	--	--	--	--	0.01	1.7
Titanium Ti)	--	--	--	--	--	--
Zinc (Zn)	--	--	--	--	--	--
Zirconium (Zr)	--	--	--	--	--	--
BIOASSAY (% survival)	100%		100%		100%	

TABLE 43

HEAVY METAL CONCENTRATIONS AND SOLUBILITIES
IN SIMULATED RECEIVING BODY OF WATER

5-DAY SAMPLE	OVERALL COMPOSITE		< 246 μ COMPOSITE		> 246 μ COMPOSITE	
	CONC. mg/l	PERCENT OF AVAILABLE METAL IN SOLUTION	CONC. mg/l	PERCENT OF AVAILABLE METAL IN SOLUTION	CONC. mg/l	PERCENT OF AVAILABLE METAL IN SOLUTION
Arsenic (As)	0.007	--	--	--	0.003	--
Cadmium (Cd)	0.00006	0.08%	0.00003	0.03%	0.002	2.9 %
Copper (Cu)	0.014	1.3	0.004	0.58	0.006	1.8
Chromium (Cr)	--	--	0.004	0.29	--	--
Iron (Fe)	0.03	0.01	0.02	0.01	--	--
Mercury (Hg)	--	--	--	--	--	--
Manganese (Mn)	0.01	0.25	0.03	0.94	0.01	0.53
Nickel (Ni)	0.03	1.0	--	--	--	--
Lead (Pb)	0.04	0.74	0.025	0.58	0.04	3.1
Strontium (Sr)	0.09	10	0.10	10	0.06	9
Titanium (Ti)	--	--	--	--	--	--
Zinc (Zn)	--	--	--	--	--	--
Zirconium (Zr)	--	--	--	--	--	--
BIOASSAY (% survival)	100%		100%		100%	

TABLE 44

HEAVY METAL CONCENTRATIONS AND SOLUBILITIES
IN SIMULATED RECEIVING BODY OF WATER

25-DAY SAMPLE	OVERALL COMPOSITE		< 246 μ COMPOSITE		> 246 μ COMPOSITE	
	CONC. mg/l	PERCENT OF AVAILABLE METAL IN SOLUTION	CONC. mg/l	PERCENT OF AVAILABLE METAL IN SOLUTION	CONC. mg/l	PERCENT OF AVAILABLE METAL IN SOLUTION
Arsenic (As)	0.005	--	--	--	0.002	--
Cadmium (Cd)	< 0.001	< 1.3 %	< 0.001	< 1.0 %	< 0.001	< 1.4 %
Copper (Cu)	0.011	0.91	0.016	2.2	0.12	36
Chromium (Cr)	0.003	0.17	--	--	0.001	0.10
Iron (Fe)	0.03	0.01	0.05	0.03	--	--
Mercury (Hg)	--	--	--	--	--	--
Manganese (Mn)	0.03	0.75	0.03	0.94	0.03	1.6
Nickel (Ni)	0.01	2.9	0.01	7.1	0.01	5.0
Lead (Pb)	0.04	0.74	--		--	
Strontium (Sr)	0.40	50	0.26	26	0.20	34
Titanium (Ti)	--	--	--	--	--	--
Zinc (Zn)	0.10	2.5	0.15	7.9	0.17	8.0
Zirconium (Zr)	--	--	--	--	--	--
BIOASSAY (% survival)	100%		100%		100%	

volatilized due to the aerating and mixing action (especially for mercury), and the metal may have precipitated. Causes of precipitation are usually due to either a pH change or the solubility of salts from a solid which form a precipitate with the metal. A pH change could have been caused by the increase in dissolved oxygen due to aeration causing a striping of the CO_2 in the water, which in turn would lower the pH value. Another possible cause for a pH change would be the naturally low buffer capacity of the dilution water, along with increasing concentrations of soluble salts forming alkaline or acidic ions in the mixture. The solubilities of the metals are low, most being less than 10% but the extreme being as high as 50%.

Figure 1 relates solubilities with time. Because only three time frames were analyzed (1, 5 and 25 days), some of the figures necessarily show inflection points at these times. In reality, it is not known what occurred between these dates, but it is assumed that the trends were continued. A comparison of curves of the same metal (e.g. Cu) show some disparities where the trend of the composite sample was different from the trends of both the sized samples. These disparities are difficult to explain, but one probably due to the heteregeneous character of the samples.

About half of the metals showed a decrease in solution concentration with time. These decreases were caused by a loss of metal from the soluble state at a faster rate than the solubility of the metals from the solid state, as shown by a continuously decreasing curve. As stated previously, the loss of metals could be caused by ion-exchange, sorption, volatility, precipitation, or a combination of all four. If the curve shows an increasing trend it can be assumed that the metal is solubilizing at a faster rate than the soluble form is being lost. Combinations of these two curve types would reflect a situation where the rates of loss and gain are not constant because of some other factor. It is reasonable to expect that the solubilities would reach an equilibrium after sufficient time. As an example, the cadmium curves are steadily decreasing for all size ranges, even though the solubilities are widely different. Strontium and manganese are steadily increasing. The copper and iron curves are combinations of

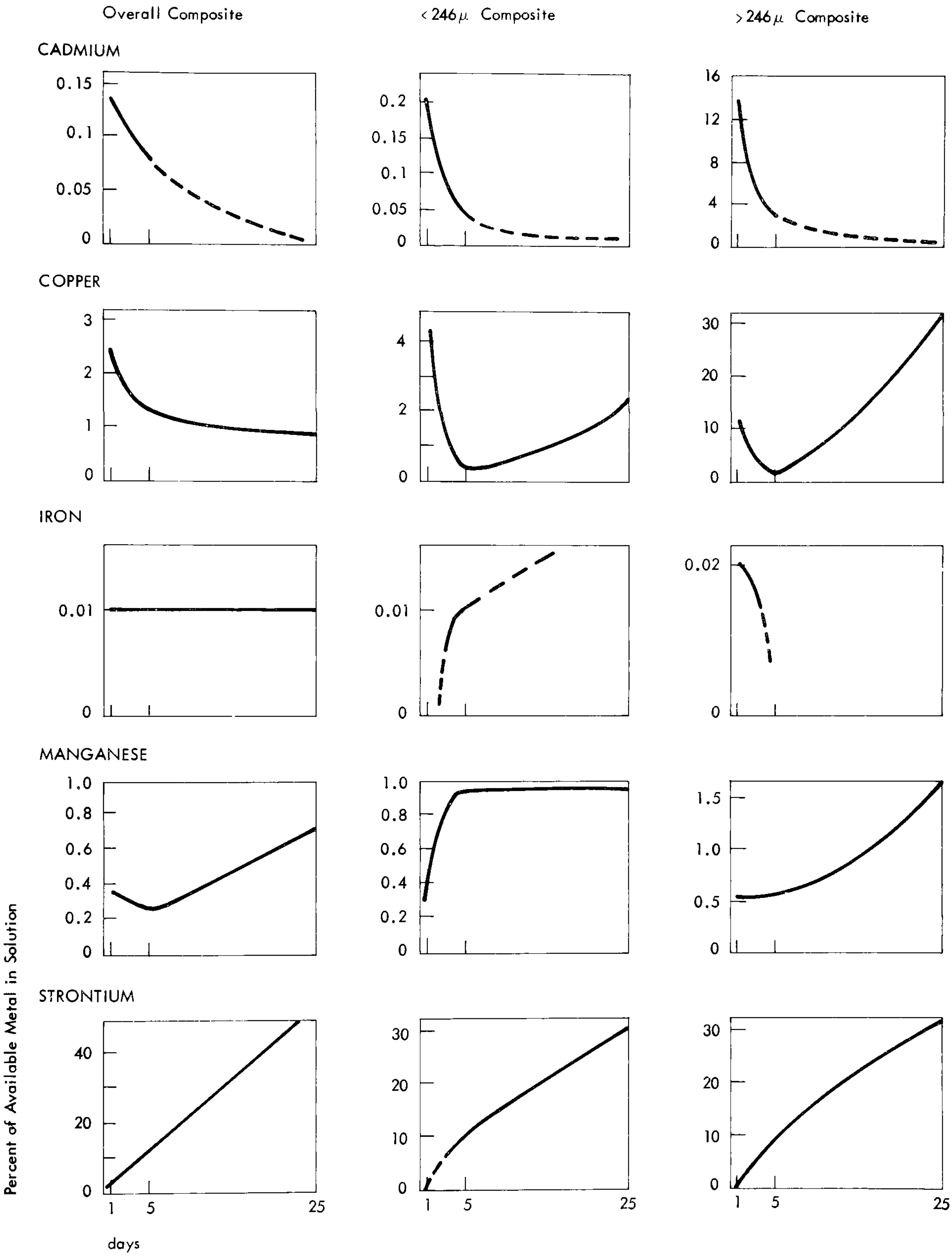


Fig. 1. Solubility Curves for Selected Heavy Metals

these two types, either reaching a maximum or a minimum value at an intermediate point.

Table 45 compares standard solubility data of simple metallic salts and metallic elements with the concentration increases of the heavy metals in the laboratory tests. In all cases, the elemental form of the metals are insoluble, except for strontium, which decomposes in water. For any one element the solubilities of the different salt forms are highly variable. It is therefore not possible to compare the test solubilities with this data to determine the salt form in which the metal exists. Whenever any soluble forms exist, the solubilities from the tests are much lower than the literature values. This is reasonable, considering the length of time the street surface particulate material resides on the streets before being removed. During this time, leaching action caused by normal atmospheric moisture probably removes some fraction of the more soluble forms of the metals.

For all metals, it is found that the maximum solubilities occur in association with the larger particle size fraction. This phenomena may be attributed to several factors. The first of these may reflect the relative distribution of surface energy. Particles in the smaller size fraction have a significantly large total surface area than found in the larger sizes. Surface attraction and adherance can be expected to be greater with the finer distribution permitting greater quantities of metal salts to be available for solution in the larger fraction.

The second and probably most significant explanation lies with the mineralogical composition associated with the two fractions. The larger particles tend to be relatively fresh rock fragments or monomineralic grains, most commonly quartz and feldspar. Chemical or physical processes of metal salt accumulation can be expected to be low for such grains.

The mechanical abrasion processes such as found on street surfaces tend to grind the larger particles into smaller sizes having greater surface areas.

Table 45

COMPARISON OF STANDARD SOLUBILITIES OF SIMPLE METALLIC SALTS AND METALLIC ELEMENTS WITH RANGES OF SOLUBILITY INCREASES FOUND IN TESTS

Compound	Cold Water Solubilities g/100 ml	Cold Water Solubilities mg/l	Range Found in Tests, mg/l increase
Arsenic (As)	Insoluble	-	0.003 - 0.007
$AsCl_3$	Decomposes	-	
As_2O_5	150	1.5×10^6	
As_2O_3	3.7	3.7×10^4	
AsOCl	1.2	1.2×10^4	
As_2S_3	0.00005	0.5	
Cadmium (Cd)	Insoluble	-	< 0.001 → 0.01
$CdCl_2$	140	1.4×10^6	
$Cd(OH)_2$	0.00026	2.6	
$Cd(NO_3)_2$	109	1.1×10^6	
CdO	Insoluble	-	
$CdSO_4$	75.5	7.6×10^5	
CdS	0.00013	1.3	
$CdSO_3$	Slightly soluble	-	
Copper (Cu)	Insoluble	-	0.004 → 0.12
Cu_2CO_3	Insoluble	-	
Cu_2Cl_2	70.6	7.1×10^5	
$Cu(OH)_2$	Insoluble	-	
Cu_4O	Insoluble	-	
Cu_2SOx	Decomposes	-	
$CuSO_4$	14.3	1.4×10^5	
Cu_2S	1×10^{-14}	1×10^{-10}	

Table 45 (Cont'd)

COMPARISON OF STANDARD SOLUBILITIES OF SIMPLE METALLIC SALTS AND METALLIC ELEMENTS WITH RANGES OF SOLUBILITY INCREASES FOUND IN TESTS

Compound	Cold Water Solubilities g/100 ml	mg/l	Range Found in Tests mg/l increase
Chromium (Cr)	Insoluble	-	0.001 → 0.004
$CrCl_2$	Very soluble	-	
$Cr(OH)_2$	Decomposes	-	
CrO_2, CrO, Cr_2O_2, CrS	Insoluble	-	
Iron (Fe)	Insoluble	-	0.02 → 0.05
$FeCl_3$	74.4	7.4×10^5	
$Fe(OH)_2$	0.00015	1.5	
FeS_2	0.00049	4.9	
Mercury (Hg)	Insoluble	-	ND
Hg_2CO_3	0.0000045	0.045	
$Hg(ClO_3)_2$	25	2.5×10^5	
Hg_2Cl_2	0.0002	2	
$HgCl_2$	6.9	6.9×10^4	
$Hg_2(NO_2)_2$	Decomposes	-	
Hg_2O	Insoluble	-	
$HgSO_4$	Decomposes	-	
Hg_2S	Insoluble	-	
Manganese (Mn)	Decomposes	-	0.01 → 0.03
$MnCO_3$	0.0065	65	
$Mn(OH)_2$	0.0002	2	
Mn_3O_4	Insoluble	-	
Mn_2O_7	Very soluble	-	
$MnSO_4$	52	5.2×10^5	

Table 45 (Cont'd)

COMPARISON OF STANDARD SOLUBILITIES OF SIMPLE METALLIC SALTS AND METALLIC ELEMENTS WITH RANGES OF SOLUBILITY INCREASES FOUND IN TESTS

Compound	Cold Water Solubilities g/100 ml	Cold Water Solubilities mg/l	Range Found in Tests mg/l increase
Nickel (Ni)	Insoluble	-	0.01 → 0.03
$NiCO_3$	0.0093	93	
$NiCl_2$	64.2	6.4×10^5	
NiO	Insoluble	-	
$NiSO_4$	29.3	2.9×10^5	
NiS	0.00036	3.6	

The greater surface area exposes more of the material to the weathering-decomposition process. Weathering of many mineral species such as feldspars is extremely rapid under such circumstances. Various clay minerals are the end result of this action. The sorptive properties of many clay minerals, with open lattice structures, has been well documented, thus providing a mechanism for metal salt tie-up in the finer size ranges. This size range also contains a larger amount of organic material on a surface area basis. Organic material take-up of metal salts is also thought to be a significant process.

Other factors which may plan a role in this process include biologic action such as particle-surface bacterial assimilation. This process is again related to the increased available surface area associated with the finer particles. It also appears that most of the solubilities of the composite samples have a random distribution between the solubilities of the large and small sized samples, as expected. This probably results from the overall heterogeneity of the samples which make accurate predictions of causes and effects difficult.

Table 46 compares maximum values of heavy metals measured in the simulated receiving water environment with values in the literature that have been shown to be harmful. Maximum arsenic concentrations found are about 1/10 the USPHS drinking water standard and about 1/500 of concentrations shown to have no effect on the "self purification" of streams. The maximum copper values are within the range that can be toxic to aquatic organisms, depending on the water's chemistry, but are about 1/8 the USPHS drinking water standard. The values of cadmium are less than 1/3 the values required to be toxic to certain aquatic organisms, but are about equal to the USPHS drinking water standard.

Lead values are less than 1/2 the concentration that has been shown to be "very toxic" in soft water, and less than 3/4 the USPHS drinking water standard. Maximum zinc concentrations are within the range that has been shown to be lethal for certain aquatic organisms in soft water, but are about 1/30 the USPHS drinking water standard.

Table 46

COMPARISON OF MAXIMUM CONCENTRATIONS OF HEAVY METALS FOUND IN SIMULATED RECEIVING WATER TEST WITH VALUES THAT HAVE BEEN SHOWN TO HAVE EFFECTS ON AQUATIC ORGANISMS*
(not intended to be a complete list)

HEAVY METAL AND MAXIMUM VALUE INCREASES IN SIMULATED RECEIVING WATER	CONCENTRATION (mg/l)	NOTES
Arsenic	3 → 20	No harm to certain aquatic insects
(0.003 mg/l)	2 → 4	No interference with "self-purification" of streams
	0.05	USPHS drinking water standard
Copper	0.015 → 3.0	Toxic to variety of aquatic organisms, depending on water chemistry
(0.12 mg/l)	1.0	USPHS drinking water standard
Cadmium	5	Toxic to Daphnia
(0.01 mg/l)	0.037	No effect on fathead minnows for exposure to complete generation
	0.03+0.15 mg/lZn	Mortal to salmon fry
	0.01	USPHS drinking water standard
Lead	0.1	"Very toxic" in soft water
(0.04 mg/l)	3.0	Found in drinking water in Germany, 1933 and the Netherlands, 1953 for short period of time after water was in pipes for 24 hours
	0.05	USPHS drinking water standard
Zinc	0.1 → 1.0	Toxic to aquatic organisms in soft water
(0.63 mg/l)	5.0	USPHS drinking water standard

* Impact of Various Metals on the Aquatic Environment, EPA, Water Quality Office, Tech. Report No. 2, 1971

The bioassay tests conducted with the simulated receiving water showed 100% survival of stickleback for 96-hour exposure in all instances. The receiving water used for the tests was dechlorinated tap water, having moderate hardness (about 50 mg/l $CaCO_3$). If the receiving water was soft water, more like normal river water into which the runoff usually is discharged, the copper, lead and zinc concentrations as shown in Table 45 should be sufficient to cause mortality of certain more sensitive aquatic organisms.

The lethal effects of the mixture are enhanced by the extremely high oxygen demand of the road surface particulates. Because the test solutions were continuously aerated, the dissolved oxygen in the samples did not reach critically low levels because the oxygen demand was met. In all cases, low dissolved oxygen is synergistic to other lethal mechanisms. The immediate toxic effects of road surface runoff that have been reported are most likely due to this high oxygen demand. The metals have their most probable toxic effect when road surface runoff is discharged into a quiescent body of water where the metals can be accumulated in the bottom muds and benthic organisms until lethal limits are reached.

SECTION VII

PARTICLE SIZE DISTRIBUTION OF HEAVY METALS ASSOCIATED WITH ROAD SURFACE PARTICULATES

Objective

To measure the heavy metal content of selected city samples which have been divided into size categories, to determine the removal efficiencies of these metals by normal street sweeping practices.

Background

During the course of the previous study, Water Pollution Aspects of Street Surface Contaminents, studies were made on the removal effectiveness of normal street sweeping practices. It was determined that the most important parameter which affects particulate removal was particle size (assuming dry conditions). Removal effectivenesses for different particulate sizes were determined. By analyzing the heavy metal content in specific size ranges to determine the percent of total heavy metal associated with each size range, and by applying the results from the previous study, heavy metal removal rates can be determined.

Methods of Analysis

Composite samples of four cities distributed in different parts of the country were divided into four size ranges. The cities tested included Tulsa, Seattle, San Jose II and Baltimore, and the size ranges were $<104\mu$, $104 \rightarrow 246\mu$, $246 \rightarrow 495\mu$ and $>495\mu$. These 16 samples were analyzed for heavy metals after undergoing sample preparation procedures described elsewhere in this report.

Results

The direct results of this phase are reported in Tables 47 through 55. These tables report the metal concentrations as mg/kg for each sample. These values were combined with particulate loading values for each city and size range and were recalculated as percentages of the metal found in each size range sample. These values are shown in Tables 56 through 60. These values are also shown in bar graph form in Figures 2 through 10.

By examining the bar graphs, trends can be established which determine in what size ranges the metals are most abundant. Cadmium is only found in two cities, and in both cases it is found only in the size ranges less than 495μ. In most cases, more than 50% of the total metals are found in size ranges smaller than 495μ. The exceptions are all for Tulsa, where strontium, manganese, iron and chromium are mostly (55→75%) associated with size ranges greater than 495μ.

Table 61 lists removal rates of particulates for specific size ranges. Most of the material is not removed unless it is greater than 246μ. Table 62 shows the theoretical removal rates for each of the samples. The overall removal rate, averaged for all metals is 49%. The values for each metal range from 38% for cadmium to 56% for chromium, while the individual rates range from 17% for strontium in San Jose II to 69% for chromium in Baltimore. Therefore, barely more than one-half of the heavy metals found on the streets remain after the streets have been cleaned by normal street sweeping practices.

TABLE 47

PARTICLE SIZE DISTRIBUTION FOR CADMIUM
(mg/kg)

	< 104 μ	104 to 246 μ	246 to 495 μ	> 495 μ
Tulsa	0	0	0	0
Seattle	0	0	0	0
San Jose II	9	6	5	0
Baltimore	8	8	0	0

TABLE 48

PARTICLE SIZE DISTRIBUTION FOR CHROMIUM
(mg/kg)

	< 104 μ	104 to 246 μ	246 to 495 μ	> 495 μ
Tulsa	220	75	105	85
Seattle	400	220	200	215
San Jose II	700	750	450	220
Baltimore	1,100	650	250	700

TABLE 49

PARTICLE SIZE DISTRIBUTION FOR COPPER
(mg/kg)

	< 104 μ	104 to 246 μ	246 to 495 μ	> 495 μ
Tulsa	137	1,500	182	160
Seattle	228	75	69	50
San Jose II	137	111	46	50
Baltimore	500	200	200	100

TABLE 50

PARTICLE SIZE DISTRIBUTION FOR IRON
(mg/kg)

	< 104 μ	104 to 246 μ	246 to 495 μ	> 495 μ
Tulsa	18,000	66,000	83,000	72,000
Seattle	0	32,000	29,000	32,000
San Jose II	35,000	33,000	30,000	29,000
Baltimore	65,000	35,000	26,000	37,000

TABLE 51

PARTICLE SIZE DISTRIBUTION FOR MANGANESE
(mg/kg)

	< 104 μ	104 to 246 μ	246 to 495 μ	> 495 μ
Tulsa	303	170	260	280
Seattle	540	350	300	380
San Jose II	450	370	330	340
Baltimore	890	600	650	380

TABLE 52

PARTICLE SIZE DISTRIBUTION FOR NICKEL
(mg/kg)

	< 104 μ	104 to 246 μ	246 to 495 μ	> 495 μ
Tulsa	0	0	0	0
Seattle	15	0	30	5
San Jose II	80	100	70	40
Baltimore	100	30	30	55

TABLE 53

PARTICLE SIZE DISTRIBUTION FOR LEAD
(mg/kg)

	< 104 μ	104 to 246 μ	246 to 495 μ	> 495 μ
Tulsa	1,100	3,200	6,100	1,500
Seattle	5,000	4,000	1,900	950
San Jose II	7,000	7,500	6,000	1,500
Baltimore	2,450	1,700	1,300	750

TABLE 54

PARTICLE SIZE DISTRIBUTION FOR STRONTIUM
(mg/kg)

	< 104 μ	104 to 246 μ	246 to 495 μ	> 495 μ
Tulsa	280	55	100	150
Seattle	130	80	150	170
San Jose II	50	0	0	0
Baltimore	50	55	50	50

TABLE 55

PARTICLE SIZE DISTRIBUTION FOR ZINC
(mg/kg)

	< 104 μ	104 to 246 μ	246 to 495 μ	> 495 μ
Tulsa	500	1,000	1,400	600
Seattle	600	400	300	300
San Jose II	600	500	200	100
Baltimore	800	500	400	500

TABLE 56

PERCENT OF HEAVY METALS IN
VARIOUS PARTICLE SIZE RANGES

SEATTLE	< 104 μ	104 to 246 μ	246 to 495 μ	> 495 μ
Zinc	24%	26%	17%	33%
Copper	38	21	18	23
Lead	5	27	46	22
Iron	4	24	27	45
Cadmium	--	--	--	--
Chromium	24	22	18	36
Manganese	21	22	17	40
Nickel	20	0	60	20
Strontium	14	14	23	49

TABLE 57

PERCENT OF HEAVY METALS IN
VARIOUS PARTICLE SIZE RANGES

TULSA	< 104 μ	104 to 246 μ	246 to 495 μ	> 495 μ
Zinc	2%	13%	36%	49%
Copper	2	53	11	34
Lead	2	13	48	37
Iron	1	10	24	65
Cadmium	--	--	--	--
Chromium	9	9	22	60
Manganese	4	7	20	69
Nickel	--	--	--	--
Strontium	8	4	15	73

TABLE 58

PERCENT OF HEAVY METALS IN
VARIOUS PARTICLE SIZE RANGES

SAN JOSE II	< 104 μ	104 to 246 μ	246 to 495 μ	> 495 μ
Zinc	34%	37%	14%	15%
Copper	29	31	11	29
Lead	25	35	25	15
Iron	18	22	19	41
Cadmium	39	35	26	0
Chromium	25	35	19	21
Manganese	19	22	18	41
Nickel	21	33	21	25
Strontium	100	0	0	0

TABLE 59

PERCENT OF HEAVY METALS IN
VARIOUS PARTICLE SIZE RANGES

BALTIMORE	< 104 μ	104 to 246 μ	246 to 495 μ	> 495 μ
Zinc	22%	27%	16%	35%
Copper	34	28	20	18
Lead	24	36	20	20
Iron	23	26	14	37
Cadmium	32	68	0	0
Chromium	23	29	8	40
Manganese	21	30	24	25
Nickel	29	17	12	42
Strontium	14	31	20	35

TABLE 60

PERCENT OF HEAVY METALS IN
VARIOUS PARTICLE SIZE RANGES

AVERAGE OF FOUR CITIES: TULSA, BALTIMORE, SAN JOSE II, SEATTLE	< 104 μ	104 to 246 μ	246 to 495 μ	> 495 μ
Zinc	20%	26%	21%	33%
Copper	26	33	15	26
Lead	14	28	35	23
Iron	11	21	21	47
Cadmium	36	52	12	0
Chromium	20	24	17	39
Manganese	16	20	20	44
Nickel	23	17	31	29
Strontium	34	12	15	39

Table 61

AVERAGE STREET SWEEPER REMOVAL EFFICIENCY

PARTICLE SIZE	PERCENT REMOVAL
< 104 μ	17%
104 to 246 μ	48
246 to 495 μ	55
> 495 μ	67

Table 62

PERCENT HEAVY METAL REMOVAL BY AVERAGE STREET SWEEPER

METAL	PERCENT REMOVED BY CITY				
	TULSA	SEATTLE	SAN JOSE II	BALTIMORE	AVERAGE
Zinc	59%	48%	41%	49%	49%
Copper	55	42	45	42	46
Lead	58	54	45	46	51
Iron	62	57	52	49	55
Cadmium	--	--	38	38	38
Chromium	58	49	46	69	56
Manganese	61	50	51	48	53
Nickel	--	50	48	48	49
Strontium	61	55	17	52	46

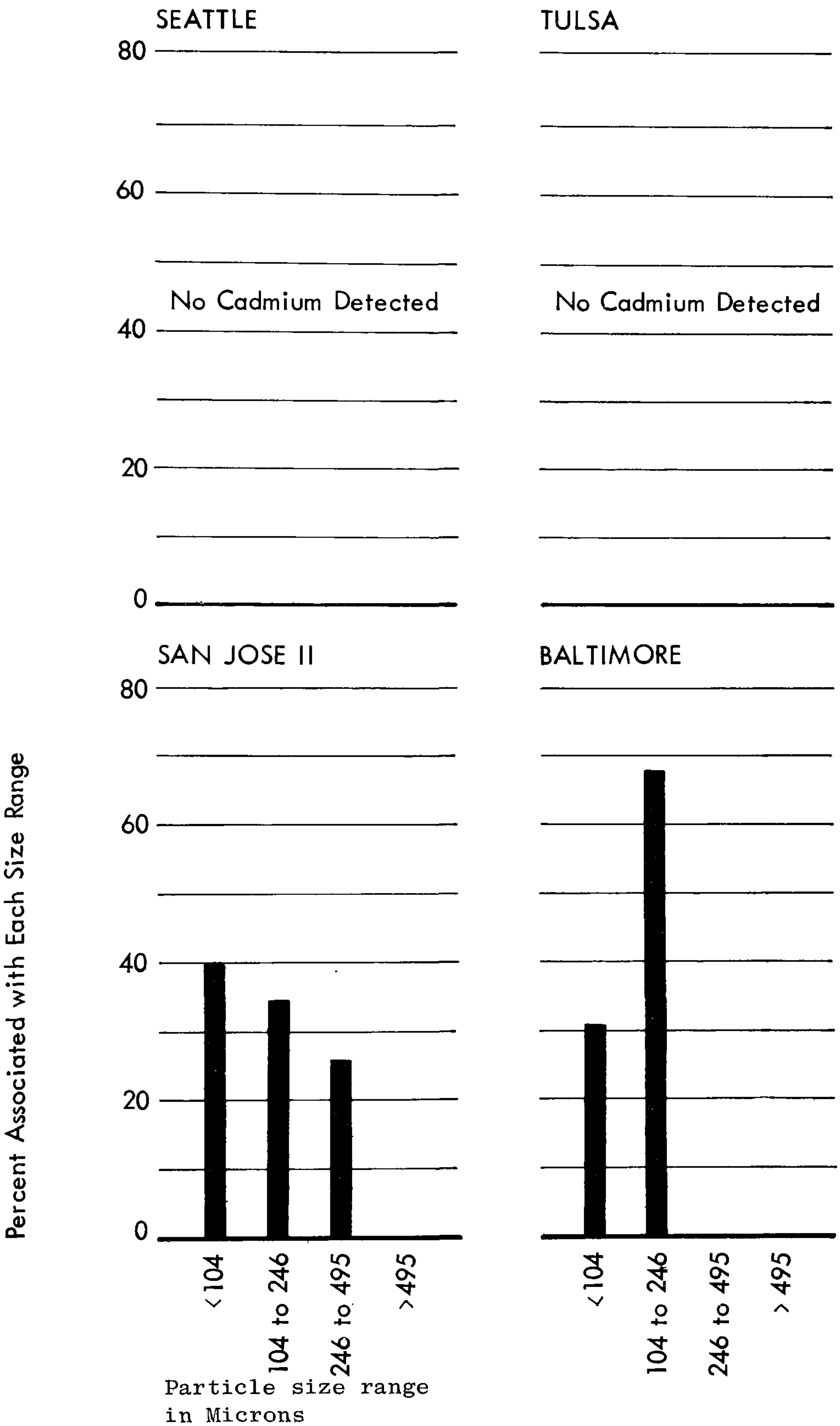


Fig. 2. Particle Size Distribution of Cadmium.

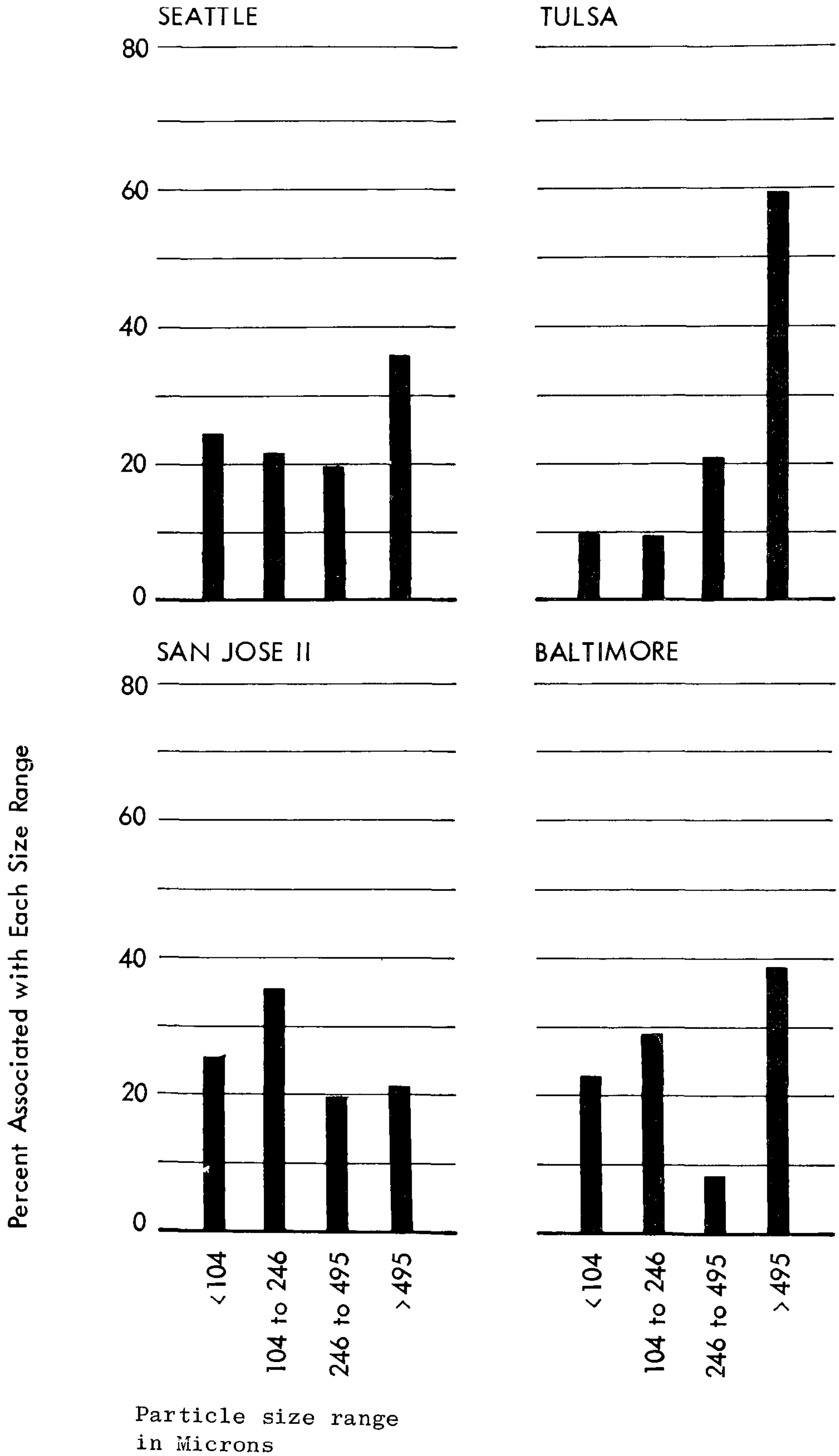
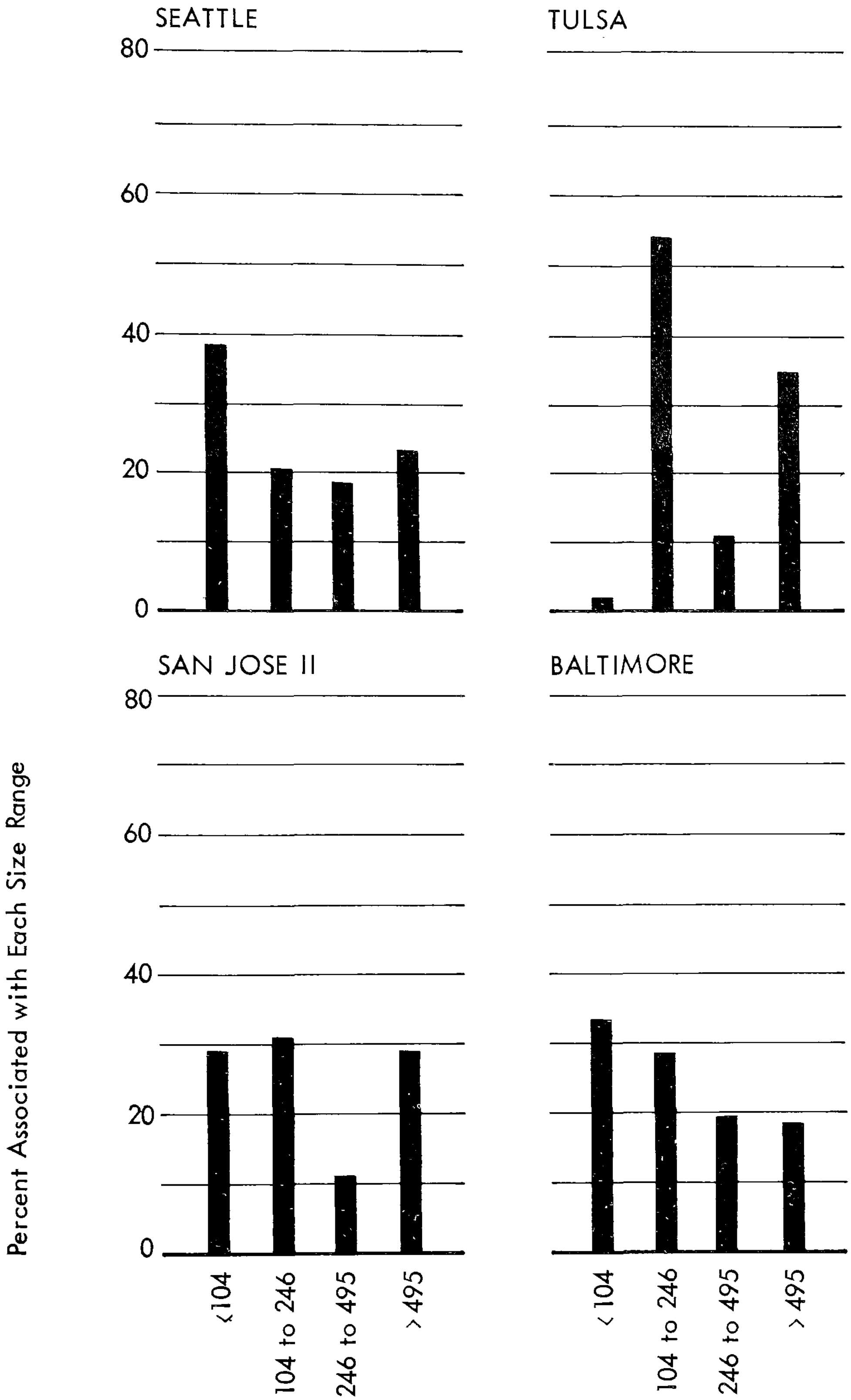
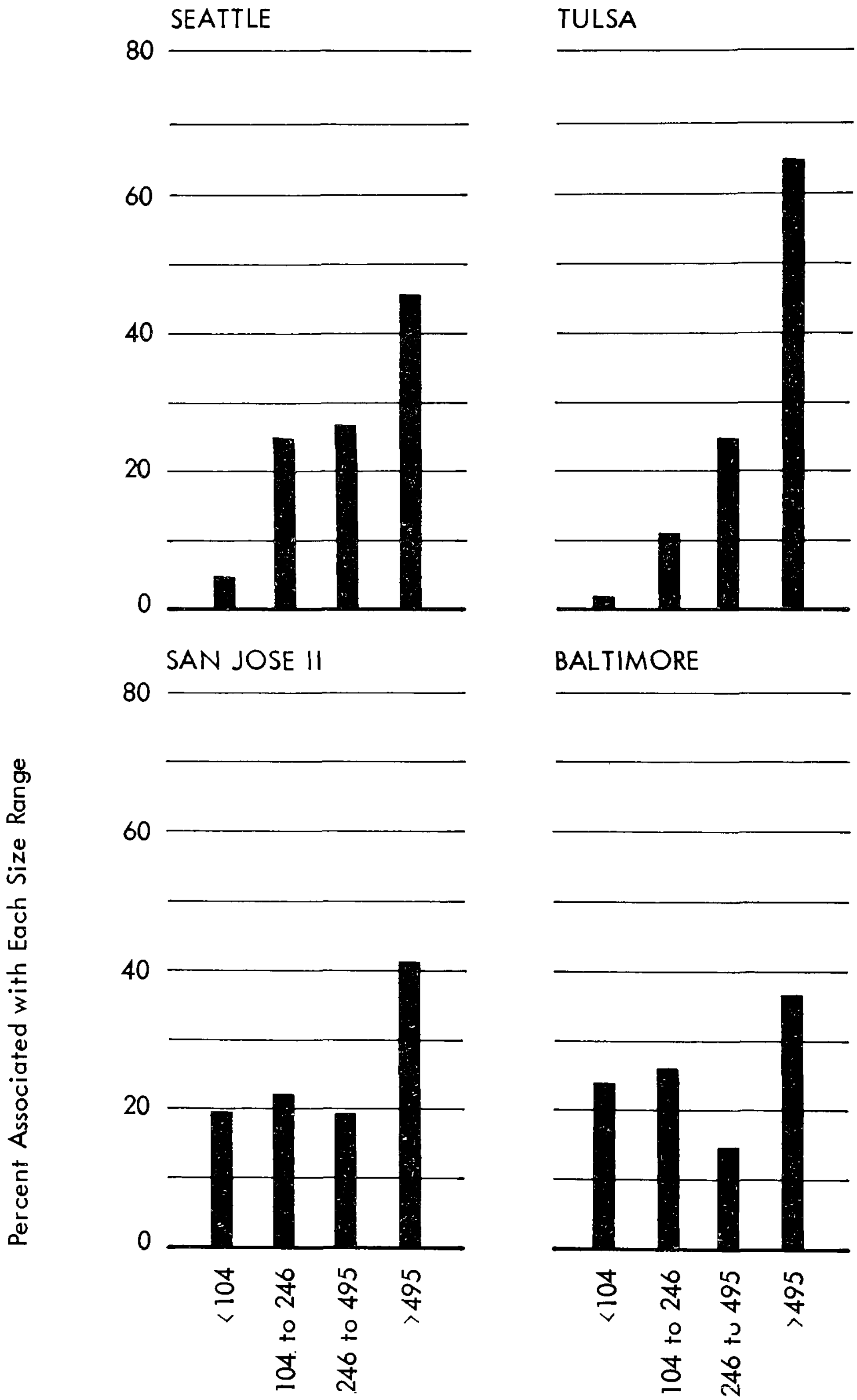


Fig. 3. Particle Size Distribution of Chromium.



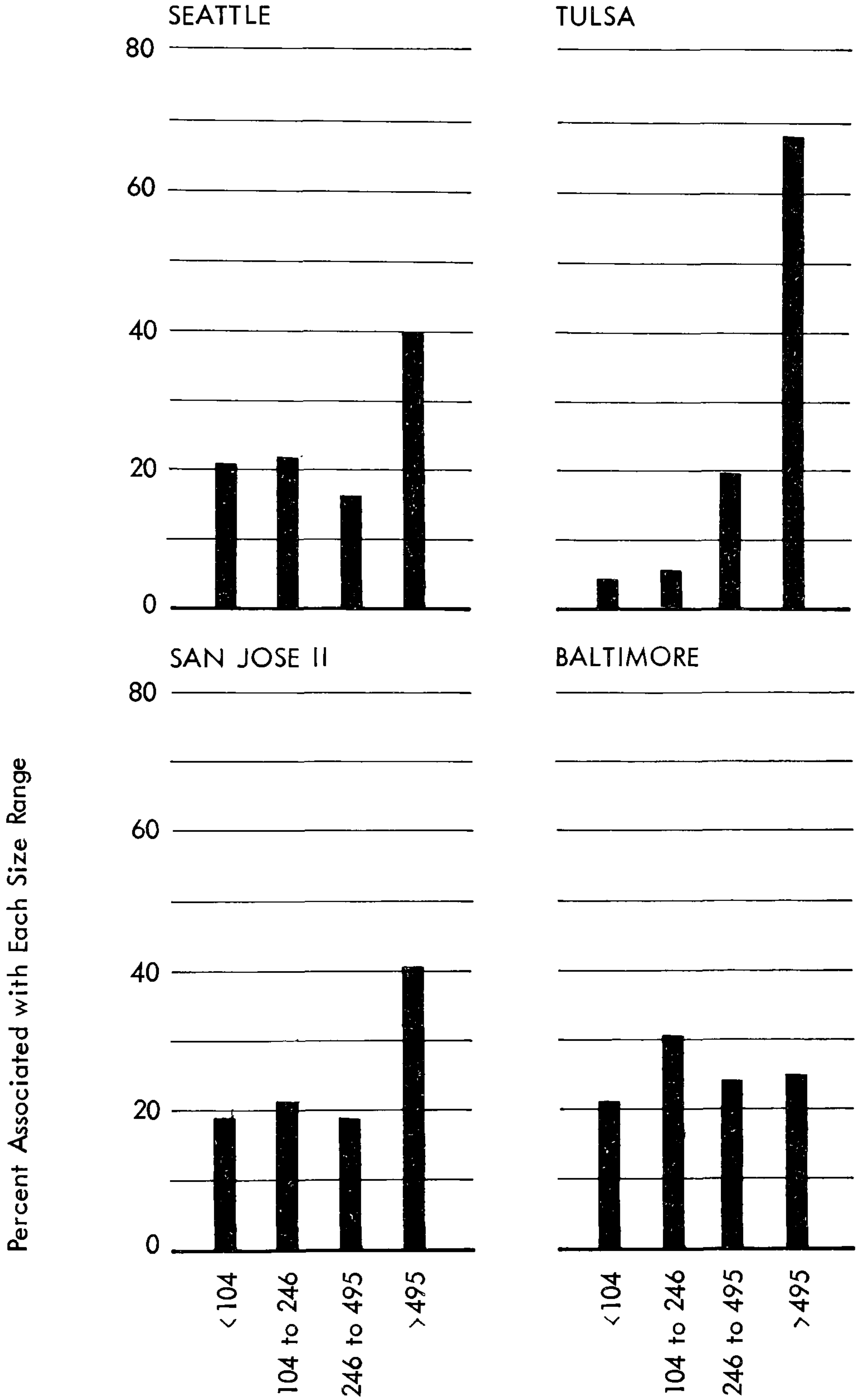
Particle size range
in Microns

Fig. 4. Particle Size Distribution of Copper.



Particle size range
in Microns

Fig. 5. Particle Size Distribution of Iron.



Particle size range
in Microns

Fig. 6. Particle Size Distribution of Manganese.

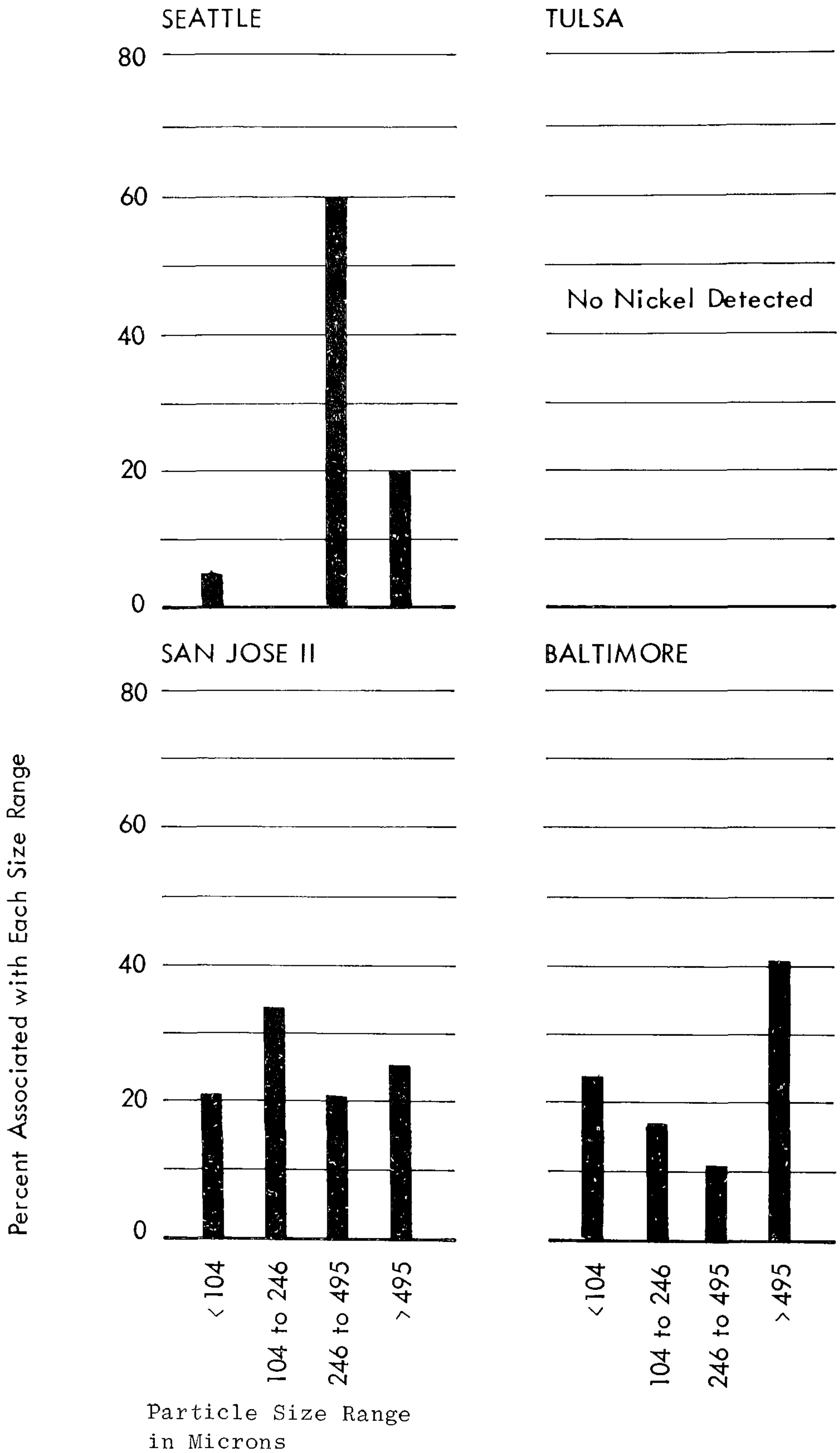


Fig. 7. Particle Size Distribution of Nickel.

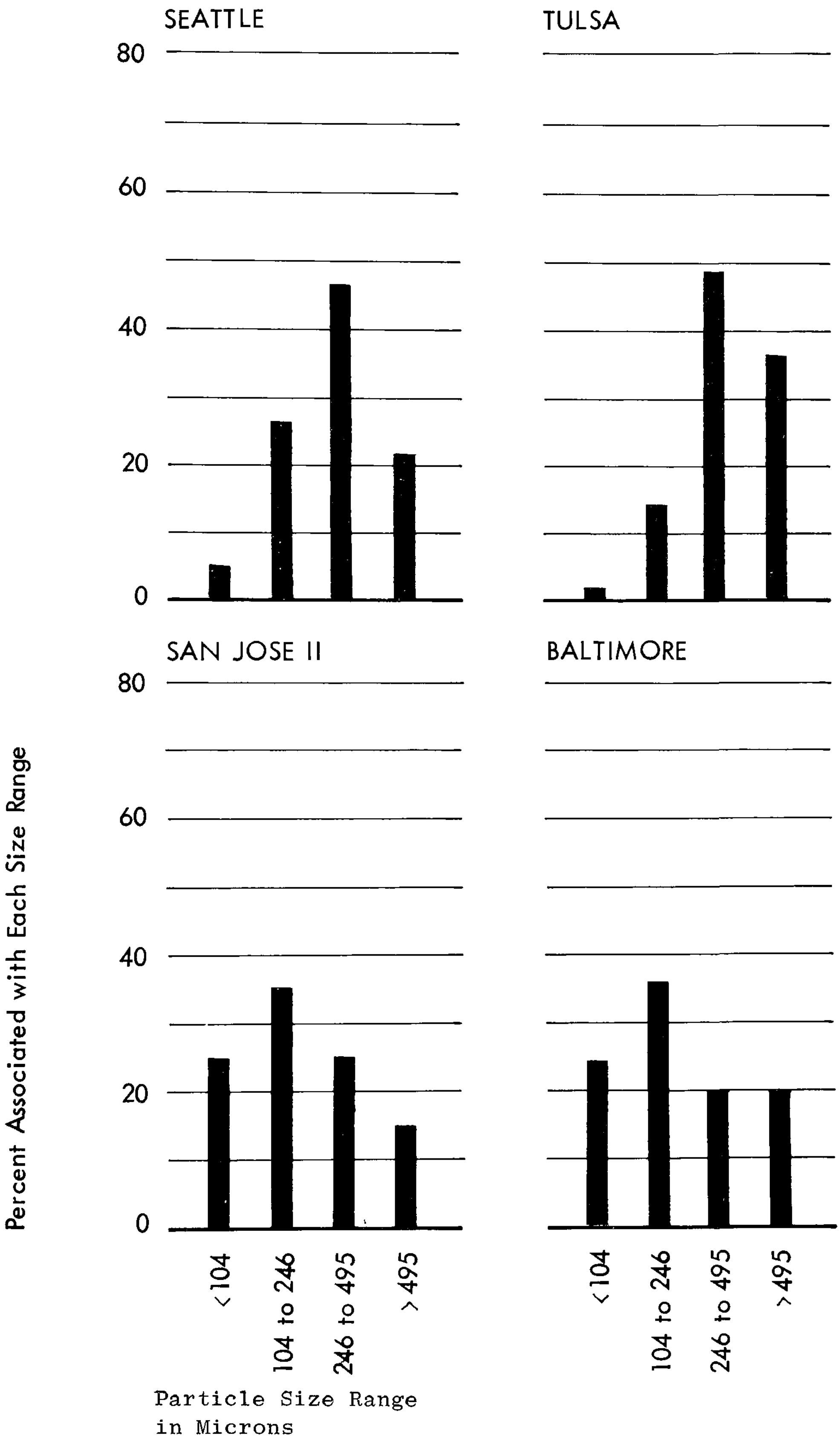


Fig. 8. Particle Size Distribution of Lead.

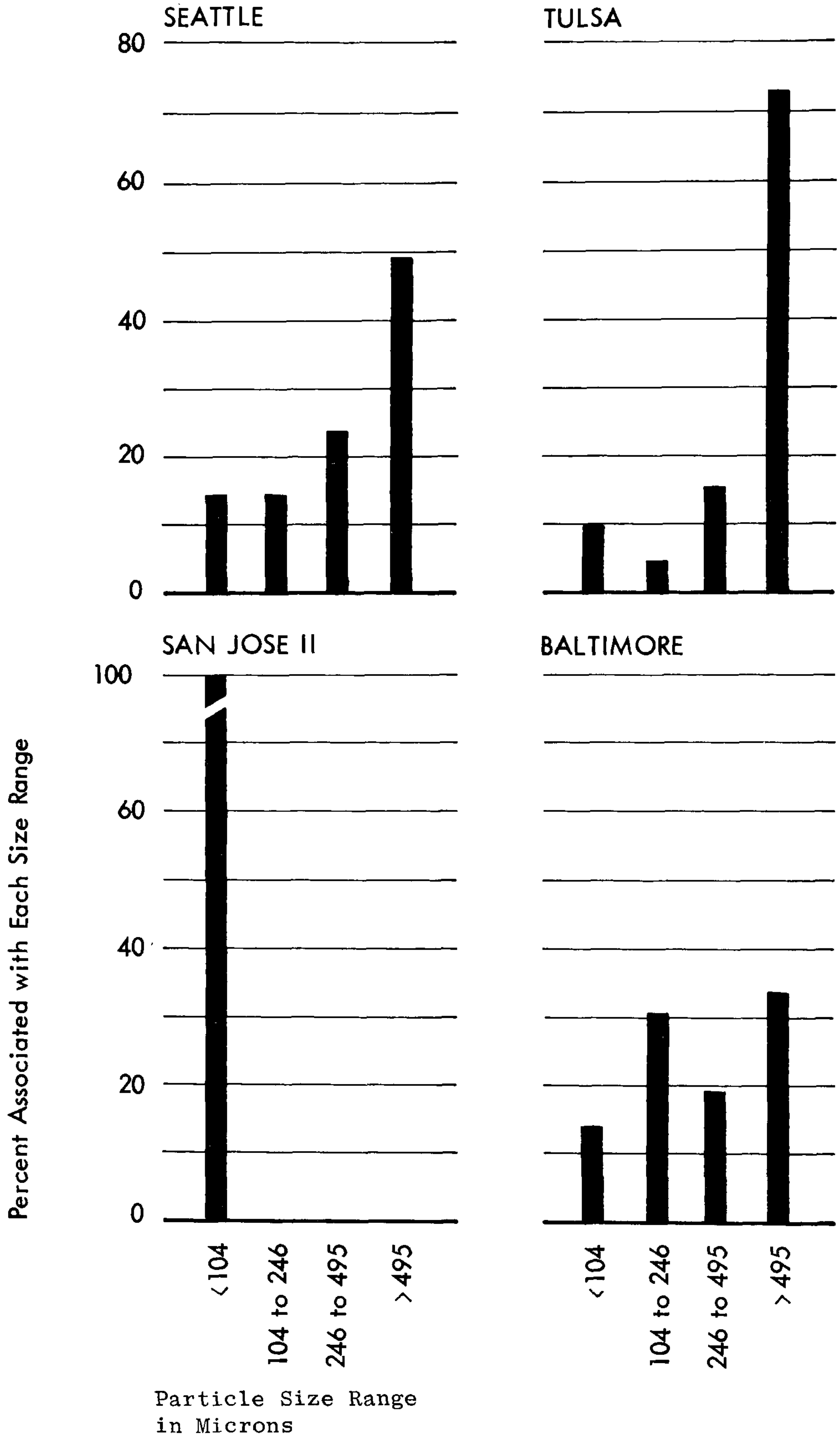
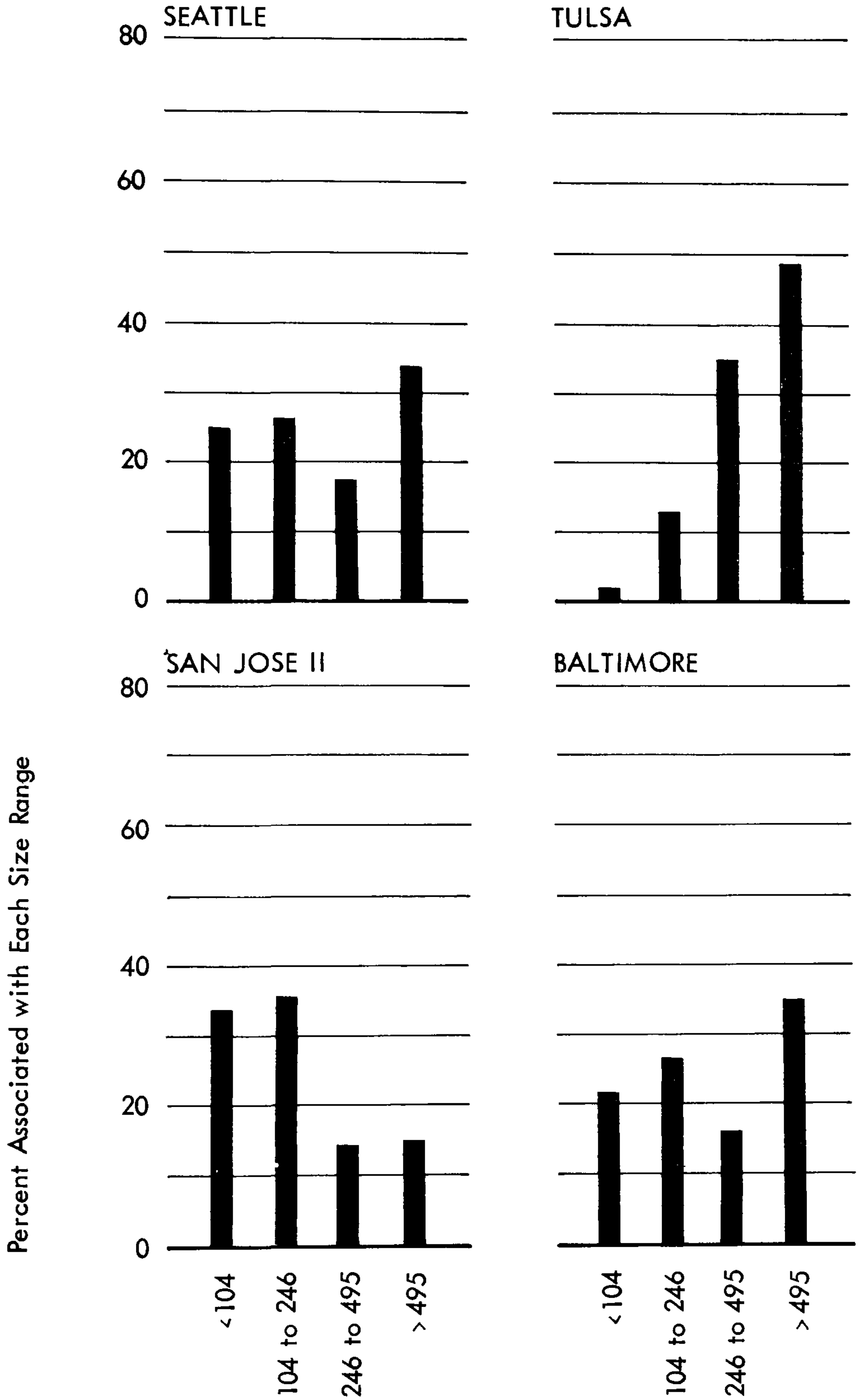


Fig. 9. Particle Size Distribution of Strontium.



Particle Size Range
in Microns

Fig. 10. Particle Size Distribution of Zinc.

SECTION VIII

ADDITIONAL ANALYSES ON HIGHWAY, RURAL ROAD AND AIRPORT SURFACES

Objective

To compute concentrations of common water pollution parameters and heavy metals of road surface particulates collected from a series of rural road, highway and airport surfaces. To compare these values with those obtained from analyzing samples collected previously from a variety of city streets.

Background

There exists little information concerning the water pollution aspects of rural road and highway particulates. Because these types of roadways make up a significant portion of the streets in most of the country, this type of information is extremely valuable in order to assess the total pollution potential from road surface runoff. Airports account for large areas of paved surfaces in comparatively small areas. Consequently, airport runoff can cause serious problems if the large volume of runoff generated has a high pollution potential.

Method of Analysis

A modest sampling effort was conducted to gather particulates from rural road, highways, and airport surfaces in the San Francisco Bay Area. Five rural roads were sampled and the collected particulates were combined for analysis. The same procedure was used for the highway sample. Test sites were chosen that represent as many different types of roadways and surrounding areas as possible.

All the airport sampling was conducted at the San Jose Municipal Airport Several areas were sampled at the airport, including runway and taxiway surfaces, soil on the side of the runway, and soil on the side of the taxiway.

The following list describes the roadway sampling areas:

Rural road sampling locations:

a) "Highway" 9, six miles west of Saratoga, California; 2 lanes, moderate auto traffic, 35→50 mph.

b) Skyline Boulevard, near Alpine Road, 5 miles west of Los Altos Hills, California; 2 lanes, light to moderate auto traffic, 35→50 mph.

c) Skyline Boulevard, near Highway 84, three miles west of Woodside, California; 2 lanes, light to moderate auto traffic, 35→50 mph.

d) Tunitas Creek Road, near Kings Mountain Park; 2 lanes, light auto traffic, 30 mph.

e) Labitos Creek Cutoff, near Highway 1, five miles south of Half Moon Bay, California; 2 lanes, very light auto traffic, 30 mph.

Highway sampling locations:

a) Highway 92, San Mateo, California; 4 lanes, heavy auto and truck traffic, 60 mph.

b) Cañada Road, near Pulgas Water Temple; 2 lanes, very heavy auto traffic, 40 mph.

c) Highway 280, near Palo Alto; 6 lanes, moderate auto traffic, 70 mph.

d) Highway 85, near Los Altos; 4 lanes, very heavy auto and truck traffic, 60 mph.

e) Highway 101, near San Jose; 6 lanes, very heavy auto and truck traffic, 60 mph.

All the sampled areas experienced heavy rainfall about five days prior to sampling. The roadway samples were analyzed for BOD_5, COD, phosphates, nitrates, kjeldahl nitrogen, and selected metals. The airport samples were only analyzed for heavy metal content. The heavy metal analyses were conducted as described elsewhere in this report, and the other tests were conducted as per "Standard Methods."

Results

The results are presented in Tables 63 and 64. There are major differences in strengths of pollutants between the different samples as shown in Table 63.

- the city street sample has the highest values of BOD_5, COD, NO_3^-, N, Cr, Fe, Pb and Zn;
- the rural road sample has highest $PO_4^{\equiv}$, and Mn strengths;
- the highway sample has highest Cd concentrations;
- the runway side sample has highest Cu and Ni strengths;
- the taxiway side sample has highest Fe and Sr concentrations.

The major differences are the higher street surface values; the BOD values are an order of magnitude greater than for the other samples. The BOD_5/COD ratio is much less for the rural road and highway samples, possibly caused by increased toxicity of these samples depressing the BOD_5 values. Lead and zinc city street values are about 4 times the highway values and 6 to 30 times the rural road values. This is probably caused by the inefficiency of heavy stop-and-go traffic on the city streets, and lower vehicle volumes on rural roads.

The airport values are surprisingly similar to the road surface values, reflecting similar pavement composition and heavy gasoline powered general aviation use. (San Jose Municipal Airport has one of the heaviest general aviation traffic loads in the country.) The soil to the side of the paved airport surfaces has metallic compositions similar to the paved surfaces' particulates. Very little particulate material (<0.1 lb/10^3ft^2) was found on the runways, reflecting high ground turbulence caused when the large aircraft take off or land. The taxiways did show larger amounts of surface particulates (about 1 lb/10^3ft^2) but not as much as roadway surfaces. The airport surfaces are only swept when the particulate material poses a safety hazard to the aircraft.

Table 64 compares the loading of different street surfaces. This table reflects particulate loadings on the surfaces. The highway surfaces

Table 63

COMPARISON OF STRENGTHS (mg/kg) OF DIFFERENT PAVED SURFACE PARTICULATES FOR COMMON POLLUTION PARAMETERS AND CERTAIN HEAVY METALS

PARAMETERS (mg/kg)	CITY STREET	RURAL ROAD	HIGHWAY	AIRPORT TAXIWAY AND RUNWAY	SIDE OF RUNWAY / AIRPORT	SIDE OF TAXIWAY / AIRPORT
BOD_5	17,000	1,500	2,300	-	-	-
COD	73,000	49,000	46,000	-	-	-
$PO_4^{\equiv}$	980	1,900	203	-	-	-
NO_3^-	460	140	35	-	-	-
N	1,900	500	650	-	-	-
Cd	3.8	0	9	6	7	0
Cr	209	215	185	125	100	155
Cu	120	39	40	18	214	54
Fe	24,000	23,000	21,000	21,000	22,000	26,000
Mn	440	860	370	310	220	560
Ni	34	105	105	85	140	85
Pb	2,000	65	490	110	75	190
Sr	21	50	50	0	80	95
Zn	400	70	190	75	175	98

Table 64

COMPARISON OF LOADINGS OF DIFFERENT TYPES OF ROADWAYS FOR COMMON POLLUTION PARAMETERS AND CERTAIN HEAVY METALS

PARAMETER	POUNDS PER CURB MILE		
	CITY STREET	RURAL ROAD	HIGHWAY
BOD_5	18	2.4	15
COD	95	77	299
$PO_4^{\equiv}$	1.1	3.0	1.32
NO_3^-	0.043	0.22	0.23
N	2.4	0.79	4.22
Cd	0.0037	0	0.058
Cr	0.231	0.34	1.20
Cu	0.129	0.06	0.26
Fe	24.4	36	136
Mn	0.468	1.35	2.39
Ni	0.040	0.16	0.68
Pb	1.66	0.10	3.17
Sr	0.022	0.078	0.32
Zn	0.409	0.11	1.24

therefore have the greatest loadings for most of the parameters. The only exceptions are that the city street surfaces have slightly greater BOD_5 loadings, and the rural road sample showed greater phosphate loadings. This would be caused by the greater number of cars on the freeways and the infrequency of freeway sweeping. The freeway loading results are perhaps too low because only the curbs were sampled; material in the traffic lanes was not collected or analyzed.

BOD rate experiments were conducted on the rural road and highway samples. Normal rate constants could not be computed because the results are actually expressed as milligrams oxygen consumed per kilogram solid sample, and not as milligram oxygen consumed per liter of waste. It was shown that about 2/3 of the 5-day BOD was exerted during the first day of discharge. This substantiates the immediate toxic effects caused by fast oxygen depletion of the receiving water.

SECTION IX
ORGANIC ANALYSIS

Objective

The objective of this particular phase of the study was to investigate the concentrations of organic material found in street surface contaminants.

Background

Organic material may be found on street surfaces in a variety of forms:

- Cellulose from paper, wood, bark, leaves and grasses
- Tannins from tree bark and vegetation
- Lignins from wood fibers
- Grease and oil from automobile drippings
- Hydrocarbons from automobile exhaust emissions
- Carbohydrates from food-type litter
- Bird and animal droppings

Both the composition and amount of organic material found on street surfaces are important. Large amounts of organic material can exert a high BOD in receiving waters which may reduce the level of dissolved oxygen below that required to maintain aquatic or marine life. Certain organic substances such as lignins are very resistant to biological oxidation. The grease and oil characteristics of organic material can seriously impair the aesthetic value of receiving waters by creating taste and odor problems. Due to its poor solubility, grease and oil can complicate the transportation or storm water runoff by fouling the surfaces of the storm drains.

Methods of Analysis

Both land-use and particle-size composites were prepared for organic analysis by using the original samples collected for the initial study, Water Pollution Aspects of Street Surface Contaminants.

These composite samples were analyzed for tannins and lignins, carbohydrates, organic acids, MBAS (methylene blue active substances), grease and oil, PCBs (polychlorinated biphenols) and various pesticides. MBAS is a measure of anionic-type surface active materials, or detergents. The relative amounts of hydrocarbons and fatty matter in the grease were also determined. The methods of analysis were those described in Standard Methods for the Examination of Water and Wastewater.

Results

The results of the organic analysis are shown in Tables 65, 66, and 67. Significant amounts of carbohydrates were detected in the samples. Tannins, lignins, and MBAS were detected in moderate amounts, while organic acids were below the detection limits.

Grease and oil were the major organic constituents found in the samples. The smaller particle-size composite ($<246\mu$) appeared to contain a greater percentage of grease and oil than the larger particle-size composite ($<246\mu$). Also, except for the residential composite, there was a greater amount of hydrocarbons than fatty matter detected in the grease.

There does not appear to be any great difference in the organic strengths (mg/kg) of the material collected from different land-use areas, except for the proportions of hydrocarbons and fatty matter in the grease and oil. Industrial and commercial samples appear to contain mostly (>90%) hydrocarbons in the grease and oil, while the residential sample contains about 70% fatty matter in the grease and oil. The street loadings (lb/curb mile and lb/1000 ft^2) are highly influenced by the amount of street surface particulates and, therefore, one finds that the industrial areas contain the greatest amounts of all organic materials, except fatty matter, per unit surface area or length.

The samples were tested for the presence of PCBs and various pesticides. However, the results were significantly lower than the results obtained in the initial study, Water Pollution Aspects of Street Surface Contaminants. This discrepancy is probably due to the instability of these

Table 65

ORGANIC ANALYSIS OF SELECTED SAMPLES

ITEM	LOADING INTENSITIES (mg/kg)					
	OVERALL COMPOSITE	< 246 μ COMPOSITE	> 246 μ COMPOSITE	RESIDENTIAL COMPOSITE	INDUSTRIAL COMPOSITE	COMMERCIAL COMPOSITE
Tanins and lignins	65	120	115	105	150	113
Carbohydrates	490	1,000	480	1,270	1,100	740
Organic acids	--*	--	--	--	--	--
MBAS	36	57	23	49	33	38
Grease and oil	11,025	14,551	10,052	15,526	11,699	16,882
Hydrocarbon in grease	10,259	13,802	9,288	4,677	11,236	15,097
Fatty matter in grease	766	749	764	10,849	463	1,785

* Below detection limit.

Table 66

ORGANIC ANALYSIS OF SELECTED SAMPLES

ITEM	LOADING INTENSITIES (lb/curb mile)					
	OVERALL COMPOSITE	< 246 μ COMPOSITE	> 246 μ COMPOSITE	RESIDENTIAL COMPOSITE	INDUSTRIAL COMPOSITE	COMMERCIAL COMPOSITE
Tanins and lignins	.098	.078	.098	.126	.420	.038
Carbohydrates	.735	.651	.408	1.52	3.08	.215
Organic acids	--*	--	--	--	--	--
MBAS	.054	.037	.020	.059	.092	.011
Grease and oil	16.5	9.47	8.53	18.6	32.8	4.90
Hydrocarbon in grease	15.4	8.99	7.89	5.60	31.5	4.38
Fatty matter in grease	1.10	.480	.640	13.0	1.30	0.52

* Below detection limit.

Table 67

ORGANIC ANALYSIS OF SELECTED SAMPLES

ITEM	LOADING INTENSITIES (lb/1,000 ft^2)					
	OVERALL COMPOSITE	< 246 μ COMPOSITE	> 246 μ COMPOSITE	RESIDENTIAL COMPOSITE	INDUSTRIAL COMPOSITE	COMMERCIAL COMPOSITE
Tanins and lignins	9.5×10^{-4}	7.6×10^{-4}	9.5×10^{-4}	1.2×10^{-3}	4.1×10^{-3}	3.7×10^{-4}
Carbohydrates	7.1×10^{-3}	6.3×10^{-3}	3.9×10^{-3}	.015	.030	2.4×10^{-3}
Organic acids	--*	--	--	--	--	--
MBAS	5.2×10^{-4}	3.6×10^{-4}	1.9×10^{-4}	5.8×10^{-4}	9.1×10^{-4}	1.2×10^{-4}
Grease and oil	.161	.092	.083	.185	.323	.055
Hydrocarbon in grease	.150	.087	.076	.055	.310	.049
Fatty matter in grease	.011	4.7×10^{-3}	6.3×10^{-3}	.129	.012	5.9×10^{-3}

* Below detection limit.

materials since the original samples were stored for about 9 months between the initial study and the current study.

The most significant point to evolve from the organic analysis is the amount of grease and oil found on street surfaces. As much as 32.8 lbs/curb mi. of grease and oil was detected. This large amount of grease and oil could have an adverse effect upon a receiving body of water by exerting a high BOD_5 and creating taste and odor problems.

A greater percentage of grease and oil was found in the smaller particle-size composite than in the larger particle-size composite. This is possibly due to sorption of grease and oil by clay and silt particles. Industrial samples appear to contain greater surface loadings of organics, except fatty matter, than other land-use categories, reflecting greater particulate loadings in the industrial areas. The strengths (mg/kg) of the organic content by land use does not seem to vary significantly, except that the residential areas contain a greater portion of fatty matter (in grease and oil) than the other land-use categories.

SECTION X

ACKNOWLEDGMENTS

This report summarizes research conducted by URS Research Company for the Water Quality Office, Environmental Protection Agency, under Contract No. 14-12-921. The Project Officer was Francis J. Condon. The work was performed under the direction of Dr. Franklin J. Agardy, Executive Vice President and Director of the Environmental Systems Division. Robert Pitt served as Project Manager. The laboratory analyses were performed with the help of Gary Amy and Charles Brennen.

SECTION XI

APPENDICES

Page No.

APPENDIX A

BIBLIOGRAPHY

The publications included in this list relate to the analyzing and significance of toxic materials, primarily heavy metals and pesticides. This list is not intended to be inclusive.

Included in this list are several bibliographies that should supply the reader with additional information.

One should also refer to the bibliography included in the related report, Water Pollution Aspects of Street Surface Contaminants, EPA-RZ-72-081.

Altshuller, A.P.; Lonneman, William A.; Sutterfield, Frank D.; and Kopczynski, Stanley L. "Hydrocarbon Composition of the Atmosphere of the Los Angeles Basin - 1967." Environmental Science and Technology: Vol. 5, no. 10 (Oct. 1971), pp. 1009-1016.

Argo, David G., and Culp, Gordon L. "Heavy Metals Removal in Wastewater Treatment Processes: Part 2 - Pilot Plant Operation." Water and Sewage Works (Sept. 1972), pp. 128-132.

Baker, Robert A., and Luh, Ming-Dean. "Mercury Analyses and Toxicity: A Review." Industrial Wastes (May-June 1971), pp. 21-28.

Barrett, Bruce R. "Monitors Solve Fish-Kill Mystery." Civil Engineering-ASCE (Jan. 1971), pp. 40-42.

Bazell, Robert J. "Lead Poisoning: Combating the Threat from the Air." Science: Vol. 174 (Nov. 5, 1971), pp. 574-576.

Becacos-Kontos, T. "Pollution in Greek Waters." Marine Pollution Bulletin: Vol. 2, no. 10 (Oct. 1971), pp. 158-160.

Bowman, Harry R.; Conway, John G.; and Asaro, Frank. "Atmospheric Lead and Bromine Concentration in Berkeley, Calif. (1963-70)." Environmental Science and Technology: Vol. 6, no. 6 (June 1972), pp. 558-560.

Breidenbach, A.W.; Lichtenberg, J.J.; Henke, C.F.; Smith, D.J.; Eichelberger, J.W., Jr.; and Stierli, H. The Identification and Measurement of Chlorinated Hydrocarbon Pesticides in Surface Waters. U.S. Dept. of Interior, Federal Water Pollution Control Administration. Nov. 1966.

Brown, B., and Ahsanullah, M. "Effect of Heavy Metals on Mortality and Growth." Marine Pollution Bulletin: Vol. 2, no. 12 (Dec. 1971), pp. 182-187.

Cairns, John, Jr., et al. The Use of Fish Movement Patterns to Monitor Zinc. Virginia Polytechnic Institute and State U., Blacksburg, Center for Environmental Studies. Dec. 1971.

California Dept. of Public Health, Bureau of Sanitary Engineering. Mercury Analyses of California Water Supplies. Informational Circular SE 70-4. Oct. 14, 1970.

Campbell, Irene R., et al. Biological Aspects of Lead: An Annotated Bibliography: Part II - Literature from 1950 Through 1964. Ohio: U. of Cincinnati, Kettering Lab., May 1972.

Cheremisinoff, Paul N., and Habib, Yousuf H. "Cadmium, Chromium, Lead, Mercury: A Plenary Account for Water Pollution: Part 1 - Occurrence, Toxicity and Detection." Water and Sewage Works (July 1972), pp. 73-86.

Collinson, Charles, and Shimp, Neil F. Trace Elements in Bottom Sediments from Upper Peoria Lake, Middle Illinois River A Pilot Project. Illinois State Geological Survey, Environmental Geology Notes, No. 56. Sept. 1972.

Dean, John G.; Bosqui, Frank L.; and Lanouette, Kenneth H. "Removing Heavy Metals from Waste Water." Environmental Science and Technology: Vol. 6, no. 6 (June 1972), pp. 518-522.

Dunlap, Lloyd. "Mercury: Anatomy of a Pollution Problem." Chemical and Engineering News (July 5, 1971), pp. 22-34.

Eshleman, Alan; and Siegel, S.M. "Metals in the Ecosystem; Leaded Grass and Other Abominations." U. of Hawaii, Dept. of Botany. Rev. Dec. 1970.

Faber, Raymond A.; Risebrough, Robert W.; and Pratt, Helen M. "Organochlorines and Mercury in Common Egrets and Great Blue Herons." Environmental Pollution: Vol. 3 (1972), pp. 111-122.

Frost, Justin. "Earth, Air, Water." Environment: Vol. 11, no. 6 (July-Aug. 1969), pp. 15-33.

Goerlitz, Donald F., and Brown, Eugene. Techniques of Water-Resources Investigations of the U.S. Geological Survey: Chapt. A3 - Methods for Analysis of Organic Substances in Water. U.S. Dept. of Interior, Geological Survey. 1972.

Hsu, Deh Y., and Pipes, Wesley O. "Modification of Techniques for Determination of Aluminum in Water by Atomic Absorption Spectrophotometry." Environmental Science and Technology: Vol. 6, no. 7 (July 1972), pp. 645-647.

Interdepartmental Task Force on PCBs. Polychlorinated Biphenyls and the Environment. NTIS No. COM-72-10419. May 1972.

Jeffries, D.J.; and French, M.C. "Lead Concentrations in Small Mammals Trapped on Roadside Verges and Field Sites." Environmental Pollution: Vol. 3 (1972), pp. 147-156.

John, Matt K.; Chuah, Hong H.; and VanLaerhoven, Cornelis J. "Cadmium Contamination of Soil and Its Uptake by Oats." Environmental Science and Technology: Vol. 6, no. 6 (July 1972), pp. 555-557.

Johnson, Richard E.; Rossano, August T., Jr.; Sylvester, Robert O. "Dustfall as a Source of Water Quality Impairment." Proceedings, ASCE: Journal of Sanitary Engineering Division: Vol. SA1 (Feb. 1966), pp. 245-267.

Kahn, Herbert L. "Principles and Practices of Atomic Absorption." Reprint from Advances in Chemistry Series, No. 73, Trace Inorganics in Water, pp. 183-229. 1967.

Klein, David H. "Mercury and Other Metals in Urban Soils." Environmental Science and Technology: Vol. 6, no. 6 (June 1972), pp. 560-562.

_____, and Goldberg, Edward D. "Mercury in the Marine Environment." Environmental Science and Technology: Vol. 4, no. 9 (Sept. 1970), pp. 765-768.

Lanford, Charles E. "Trace Minerals Affect Stream Ecology." Oil and Gas Journal: Vol. 16, no. 13 (Mar. 31, 1969), pp. 82-84.

Lehman, G.S., and Wilson, L.G. "Trace Element Removal from Sewage Effluent by Soil Filtration." Water Resources Research: Vol. 7, no. 1 (Feb. 1971), pp. 90-99.

Morrow, Norman L., and Brief, Richard S. "Elemental Composition of Suspended Particulate Matter in Metropolitan New York." Environmental Science and Technology: Vol. 5, no. 10 (Oct. 1971), pp. 786-789.

Palmer, J.S. Toxicity of 45 Organic Herbicides to Cattle, Sheep, and Chickens. U.S. Dept. of Agriculture, Agricultural Research Service, Production Research Rept. No. 137. Mar. 1972.

Perkin-Elmer. Technique and Applications of Atomic Absorption. Perkin-Elmer Corp., 1971.

Perkin-Elmer Corp. Analytical Methods in Atomic Absorption Spectroscopy.

Peterson, Frank L., et al. Effect of Storm Runoff Disposal and Other Artificial Recharge to Hawaiian Ghyben-Herzberg Aquifers. U. of Hawaii, Water Resources Research Center. Nov. 1971.

Portmann, J.E., and Wilson, K.W. The Toxicity of 140 Substances to the Brown Shrimp and Other Marine Animals. 2nd ed. Ministry of Agriculture, Fisheries and Food. Shellfish Information Leaflet, No. 22. Dec. 1971.

Purves, David. "Consequences of Trace-Element Contamination of Soils." Environmental Pollution: Vol. 3 (1972), pp. 17-24.

Rothschild, E.; Buxbaum, J.; Mauss, E.; Paulson, G.; Emerman, S.; and Cantwell, A.M. Childhood Lead Poisoning: An Analysis of Current State and Municipal Programs. New York: N.Y. Scientists' Comte. for Public Information, Inc., 1971.

Sartor, James D., and Boyd, Gail B. Water Pollution Aspects of Street Surface Contaminants. EPA, Municipal Pollution Control Branch. 1972.

Schmidt, Timothy T.; Risebrough, Robert W.; and Gress, Franklin. "Input of Polychlorinated Biphenyls into California Coastal Waters from Urban Sewage Outfalls." Bulletin of Environmental Contamination and Toxicology: Vol. 6, no. 3 (1971), pp. 235-243.

Schneider, Robert F. The Impact of Various Heavy Metals on the Aquatic Environment. EPA, Water Quality Office, Technical Rept. No. 2. Denver: Feb. 17, 1971.

Schroeder, Henry A. "Metals in the Air." Environment: Vol. 13, no. 8 (Oct. 1971), pp. 18-32.

Sinha, Evelyn. Metals as Pollutants in Air and Water; An Annotated Bibliography. OEI Series, Vol. 6. La Jolla, Calif.: Ocean Engineering Information Service, 1972.

Södergren, A.; Svensson, B.; and Ulfstrand, S. "DDT and PCB in South Swedish Streams." Environmental Pollution: Vol. 3 (1972), pp. 25-36.

Stiff, M.J. "The Chemical States of Copper in Polluted Fresh Water and a Scheme of Analysis to Differentiate Them." Water Research: Vol. 5 (1971), pp. 585-599.

Taras, Michael J.; Greenberg, Arnold E.; Hoak, R.D.; and Rand, M.C.; eds. Standard Methods for the Examination of Water and Wastewater. 13th ed. Washington, D.C.: American Public Health Association, 1971.

U.S. Dept. of Agriculture. Soil Conservation Service. Soil Survey Laboratory Methods and Procedures for Collecting Soil Samples. Soil Survey Investigations Rept. No. 1. Rev. April 1972.

U.S. EPA. Water Quality Standards Criteria Digest; A Compilation of Federal/State Criteria on -- Mercury and Heavy Metals. Aug. 1972.

_____. Water Quality Standards Criteria Digest; A Compilation of Federal/State Criteria on -- Nitrates. Aug. 1972.

_____. Water Quality Standards Criteria Digest; A Compilation of Federal/State Criteria on -- Dissolved Oxygen. Aug. 1972.

_____. Water Quality Standards Criteria Digest; A Compilation of Federal/State Criteria on -- Dissolved Solids. Aug. 1972.

_____. National Environmental Research Center. Methods for Organic Pesticides in Water and Wastewater. 1971.

_____. _____. Analytical Quality Control Laboratory. Handbook for Analytical Quality Control in Water and Wastewater Laboratories. June 1972.

_____. _____. _____. Methods for Chemical Analysis of Water and Wastes. 1971.

_____. Office of Air Programs and National Environmental Research Center. Div. of Health Effects Research. Corrections and Additons to "Health Hazards of Lead (Rev. April 11, 1972). April 27, 1972.

_____. Office of Water Programs. Div. of Water Quality Standards. Phosphate Criteria. June 1971.

"USGS Completes Nationwide Reconnaissance of Metals in Streams." Water and Sewage Works (June 1971), pp. 174-175.

U.S. Tariff Commission. Synthetic Organic Chemicals; U.S. Production and Sales of Pesticides and Related Productivity, 1970. Preliminary. Sept. 1971.

Warnick, Stephen L., and Bell, Henry L. "The Acute Toxicity of Some Heavy Metals to Different Species of Aquatic Insects." Journal of Water Pollution Control Federation: Vol. 41, no. 2, part 1 (Feb. 1969), pp. 280-284.

Wurster, Charles F. "Aldrin and Dieldrin." Environment: Vol. 13, no. 8 (Oct. 1971), pp. 33-45.

Yeager, David W.; Cholak, Jacob; and Henderson, Ethel W. "Determination of Lead in Biological and Related Material by Atomic Absorption Spectrophotometry." Environmental Science and Technology: Vol. 5, no. 10 (Oct. 1971), pp. 1020-1022.

APPENDIX B

MAJOR COMPONENTS OF STREET SURFACE POLLUTION POTENTIAL

This outline lists the theoretically possible components of street surface pollution-causing material. It is based on theoretical considerations and does not imply to be inclusive. It should be helpful when determining probable sources of the measured street surface constituents.

I Major Components of Street Pollution

A. Large sized/biologically insignificant

1. bulk cellulosic matter

   a. tree limbs, twigs, leaves, shrubs

   b. lumber

   c. paper

   d. cotton materials

   e. rayon

   f. cellophane

2. bulk metals and alloys of construction and containerization

   a. steel

   b. iron

   c. aluminum

   d. magnesium

   e. copper and bronze

   f. zinc

   g. tin

3. fabric, packaging and construction plastics

4. natural processed animal fibers

B. Variable sized/biologically insignificant

1. soil conditioners

2. basic soil constituents

3. inorganic dustfalls from air pollutants

C. Variable sized/biologically nutritive /water soluble

1. natural and compounded fertilizers

   a. nitrogen compounds (ammonium, nitrate, urea, cyanates, etc.)

   b. phosphates

   c. potassium compounds

   d. secondary growth elements (Ca, Mg, Fe, Cu, Zn, Mn, B, Mo, S)

2. de-icing compounds

   a. sodium hexametaphosphate

   b. urea

   c. ammonium nitrate

   d. potassium pyrophosphate

3. soluble air pollutants

   a. sulfur oxides (as SO_4)

   b. nitrogen oxides (as NO_3)

   c. ash

4. phosphate based detergents

5. lawn and garden ash

D. Variable sized solids or solutions/biologically inhibiting/ water soluble

1. de-icing compounds

   a. sodium chloride

   b. calcium chloride

   c. ferric ferrocyanide

   d. sodium ferrocyanide

   e. sodium chromate

2. air pollutants

   a. carbon monoxide

   b. sulfides, sulfites

   c. nitrites

   d. ozone

3. anti-freeze compounds

   a. diacetone alcohol

   b. methanol

   c. ethylene glycol

4. roadway hydrocarbons

   a. some highly oxygenated bitumens

5. water base paint solutions

E. Variable sized, immiscible or suspendable biologically inhibiting/ water insoluble

1. vehicular and roadway hydrocarbons
    a. oils
    b. greases
    c. tetraethyl lead and decomposition products
    d. bitumens

2. hydraulic fluids
    a. propylene glycol diricinoleate
    b. tri-N-butylamine

3. water insoluble air pollutants
    a. hydrocarbons

4. pesticide/herbicide carriers

F. Variable sized solids or solutions/biologically toxic/water soluble

1. common pesticides, herbicides, etc.
    a. arsenic (acetoarsenites, arsenites, arsenates)
    b. copper (arsenites, etc.)
    c. lead (arsenites, etc.)
    d. thallium compounds
    e. chloropicrin
    f. dinitro-o-cresol
    g. furfural
    h. malathion
    i. nicotine
    j. phenol

G. Variable sized solids, liquids or suspensions/biologically toxic/ water insoluble

1. common pesticides, herbicides, etc.
    a. benzene hexachloride
    b. chlordane

c. dichlorodiphenyltrichloroethane (DDT)
d. dichloroethylene
e. dichloroethyl ether
f. 2-4 dichlorophenoxyacetic acid (2,4-D)
g. dinitro-o-cresol
h. methoxychlor
i. parathion
j. tetramethylthiuram disulfide
k. toxaphene
l. trichloroethylene
m. dichlorobenzenes (ortho and para)
n. pyrethrins
o. aldrin
p. dieldrin
q. organo-mercury compounds

H. Variable sized culture media/biologically active/water suspendable life forms

1. animal excretions
   a. fecal coliforms
   b. fecal streptococci
   c. biological nutrient source
2. human excretions
   a. fecal coliforms
   b. fecal streptococci
   c. biological nutrient source
3. dead animals
   a. fecal coliforms
   b. non-fecal coliforms
   c. fecal streptococci
   d. biological nutrient source
4. vegetation
   a. biological nutrient source

5. food wastes
   a. biological nutrient source
6. soil
   a. biological nutrient source

APPENDIX C

PROBABLE CHEMICAL COMPOUNDS ASSOCIATED WITH HEAVY METALS

A study was originated in an attempt to determine in what ionic forms were the heavy metals. In close to neutral pH conditions, most metals are restricted to two ionic forms. Table C-1 describes these ionic forms and possible associated chemical compounds for some of the metals.

TABLE C-1

IONIC FORMS AND POSSIBLE CHEMICAL COMPOUNDS FOR SEVERAL HEAVY METALS

METAL	IONIC FORMS	PROBABLE COMPOUNDS
Pb	+2, +4	PbS, $PbCO_3$, $PbSO_4$ $PbCrO_4$, PbO, $Pb(OH)_2$, $PbCl_2$, PbI_2
Cu	+1, +2	Cu_2S, Cu_2O, $Cu(OH)_2$, CuCN, $CuSO_4$, CuO, CuI
Zn	+2	ZnS, ZnO, $ZnSO_4$, $Zn(OH)_2$
Fe	+2,+3	Fe_2O_3, FeO, $Fe(OH)_3$, $FeSO_4$, $Fe_2(SO_4)_3$, $Fe(NO_3)_2$, $Fe(NO_3)_3$, $Fe(OH)_2$, $FeCO_3$

The analytical method attempted (extraction at different pH values to obtain solubility constants) was not sophisticated enough to allow a complete description of the ionic forms of the metals. The pH values of all the street surface particulates was within the range of 6.5 to 7.8.

APPENDIX D

SUMMARY OF CHARACTERISTICS OF TEST SITES IN SELECTED CITIES

GLOSSARY OF TERMS USED IN TABLES D-1 through D-11
(Self-explanatory terms omitted)

Street • Pavement:	Type of surfacing
• Condition:	Excellent - Very smooth surface, no cracks, essentially new condition.
	Good - Few cracks, near new condition.
	Fair - Cracks, some pavement deterioration.
	Poor - Many cracks, moderate to extensive deterioration.
Volume of Water:	The amount of water utilized for collecting street surface sample (in gallons).
Parking Density:	Heavy - Parking mostly continuous.
	Moderate - Around half of available areas filled.
	Light - Very few vehicles parked.
Traffic:	Predominantly automobile, trucks, or mixed.
Density:	Heavy - $>$ 10,000 AADT (annual average daily traffic).
	Moderate - 500-10,000 AADT
	Light - $<$ 500 AADT
Minimum distance from curb (ft):	The distance between the curb and traffic flow.

Table D-1

DESCRIPTIONS OF TEST SITES IN SAN JOSE DURING FIRST TEST SERIES

	LOW / OLD		MED / NEW	MED / OLD		INDUSTRY			CENTRAL BUSINESS DISTRICT	SUBURBAN SHOPPING CENTER
	single	multi	single	single	multi	light	medium	heavy		
CODE NUMBER	SJ-I-1	SJ-I-2	SJ-I-3			SJ-I-6	SJ-I-7		SJ-I-9	SJ-I-10
SITE LOCATION	BERKELEY & DOBERN	E WILLIAM & 18TH	CAMUS & LOMBARD			COMMERCIAL & 10TH	MISSION & 10TH		SAN FERNANDO & 3RD	RACE & AUZERIAS
PERCENT LAND USE	13.25	13.25	26.5			19.0	19.0		4.5	4.5
DATE	12-14-70	12-14-70	12-14-70			12-15-70	12-15-70		12-15-70	12-15-70
STREET • pavement	ASPHALT	ASPHALT	ASPHALT			ASPHALT	ASPHALT		ASPHALT	ASPHALT
• condition	GOOD	FAIR	GOOD			FAIR	GOOD		FAIR	GOOD
• width (ft) (crown to gutter)	18	15	16			25	24		20	20
GUTTER	CONCRETE	CONCRETE	CONCRETE			CONCRETE	CONCRETE		ASPHALT	CONCRETE
CURB	CONCRETE	CONCRETE	CONCRETE			CONCRETE	CONCRETE		CONCRETE	CONCRETE
PARKING STRIP	GRASS	GRASS	GRASS			ASPHALT	DIRT		DIRT	CONCRETE
SIDEWALK	CONCRETE	CONCRETE	CONCRETE			NONE	NONE		CONCRETE	CONCRETE
AREA BEYOND SIDEWALK	LAWN	LAWN	LAWN			DIRT	BUILDINGS		PARK. LOT	PARK LOT
SIZE OF TEST AREA (ft^2)	680	560	600			1000	880		800	800
VOLUME OF WATER (gal)	18	27	27			30	25		40	40
PARKING DENSITY	LIGHT	LIGHT	MOD.			LIGHT	MOD.		MOD.	LIGHT
TRAFFIC • main types of vehicles	AUTO	AUTO	AUTO			MIXED	MIXED		AUTO	AUTO
• density	LIGHT	LIGHT	LIGHT			MOD.	HEAVY		HEAVY	MOD.
• average speed (mph)	10	10	10-15			25	30-40		30-35	20
• min. distance from curb (ft)	4	5	4			10	6-8		5-6	5
DAYS SINCE LAST RAIN	12	13	12			13	18		13	18
DAYS SINCE LAST CLEANED	n.a.	n.a.	n.a.			n.a.	n.a.		n.a.	n.a.
CLEANING METHOD	SWEPT	SWEPT	SWEPT			SWEPT	SWEPT		SWEPT	SWEPT

Table D-2

DESCRIPTIONS OF TEST SITES IN PHOENIX DURING FIRST TEST SERIES

	LOW / OLD		MED / NEW	MED / OLD		INDUSTRY			CENTRAL BUSINESS DISTRICT	SUBURBAN SHOPPING CENTER
	single	multi	single	single	multi	light	medium	heavy		
CODE NUMBER	PI-1	PI-2	PI-3		PI-5	PI-6	PI-7		PI-9	PI-10
SITE LOCATION	14TH & POLK	1931 E. POLK	59TH & CAMPBELL		3RD & CULVER	800 N. 21ST	7TH ST. NEAR I-10			3900 N. 33RD A
PERCENT LAND USE	18.5	2.6	56.7		5.8	6.3	2.5		3.8	3.8
DATE	1-15-71	1-14-71	1-15-71		1-14-71	1-16-71	1-16-71		1-17-71	1-17-71
STREET • pavement • condition	ASPHALT FAIR	ASPHALT FAIR	ASPHALT EXCEL.		ASPHALT FAIR	ASPHALT GOOD	ASPHALT EXCEL.		ASPHALT FAIR	ASPHALT GOOD
• width (ft) (crown to gutter)	18	12	14		14	20	25		24	15
GUTTER	CEMENT	CEMENT	CEMENT		CEMENT	CEMENT	CEMENT		ASPHALT	CEMENT
CURB	CEMENT	CEMENT	CEMENT		CEMENT	CEMENT	CEMENT		CEMENT	CEMENT
PARKING STRIP	DIRT	CEMENT	CEMENT		DIRT	DIRT	CEMENT		CEMENT	CEMENT
SIDEWALK	CEMENT	CEMENT	CEMENT		CEMENT	NONE	CEMENT		CEMENT	CEMENT
AREA BEYOND SIDEWALK	LAWN	LAWN	LAWN		LAWN	DIRT	ASPHALT PARKING LOT		BUILDINGS	ASPHALT LOT
SIZE OF TEST AREA (ft^2)	1000	1000	1000		1000	1000	1000		1000	1000
VOLUME OF WATER (gal)	48	199	120		233	48	48		48	48
PARKING DENSITY	LIGHT	LIGHT	LIGHT		HEAVY	MOD.	V. LIGHT		HEAVY	LIGHT
TRAFFIC • main types of vehicles	AUTO	AUTO	AUTO		AUTO	MIXED	AUTO		AUTO	AUTO
• density	LIGHT	LIGHT	LIGHT		LIGHT	MOD.	HEAVY		HEAVY	MOD.
• average speed (mph)	15-20	20.	15-20		15-20	30	40		25-30	25-30
• min. distance from curb (ft)	6-8	8	8		6	8	8		6-8	6-8
DAYS SINCE LAST RAIN	12	12	12		12	12	12		12	12
DAYS SINCE LAST CLEANED	8	1	7		3	10	8		1	13
CLEANING METHOD	SWEPT	SWEPT	SWEPT		SWEPT	SWEPT	SWEPT		SWEPT	SWEPT

Table D-3

DESCRIPTIONS OF TEST SITES IN MILWAUKEE DURING FIRST TEST SERIES

	LOW / OLD		MED / NEW	MED / OLD		INDUSTRY			CENTRAL BUSINESS DISTRICT	SUBURBAN SHOPPING CENTER
	single	multi	single	single	multi	light	medium	heavy		
CODE NUMBER	Mi-1	Mi-2	Mi-3		Mi-5		Mi-7	Mi-8	Mi-9	Mi-10
SITE LOCATION	6th & E LLOYD	5th & W. VINE	23rd & BRIDGES		LATHAM & S. 10th		BECHER & ALLIS	GREENFIELD & BARCKY	MASON & BROADWAY	27th & PARNELL
PERCENT LAND USE	16.3	16.3	16.3		16.3		12.5	12.5	4.7	4.7
DATE	4-28-71	4-28-71	4-29-71		4-28-71		4-28-71	4-29-71	4-27-71	4-29-71
STREET • pavement	ASPHALT	ASPHALT	CONCRETE		ASPHALT		ASPHALT	ASPHALT	ASPHALT	CONCRETE
• condition	GOOD	POOR	GOOD		FAIR		FAIR	FAIR	EXCEL.	FAIR
• width (ft) (crown to gutter)	12	10	18		18		16	16	25	25
GUTTER	ASPHALT	CONCRETE	CONCRETE		CONCRETE		ASPHALT	ASPHALT	ASPHALT	CONCRETE
CURB	CONCRETE	CONCRETE	CONCRETE		CONCRETE		CONCRETE	CONCRETE	CONCRETE	CONCRETE
PARKING STRIP	DIRT	DIRT	LAWN		DIRT		CONCRETE	DIRT	CONCRETE	DIRT
SIDEWALK	CONCRETE	CONCRETE	CONCRETE		CONCRETE		CONCRETE	CONCRETE	CONCRETE	CONCRETE
AREA BEYOND SIDEWALK	GRASS	DIRT	LAWN		LAWN		BUILDINGS	DIRT	BUILDINGS	PARK LOT
SIZE OF TEST AREA (ft^2)	440	460	600		800		600	600	600	600
VOLUME OF WATER (gal)	10	8	13		15		8	17	8	25
PARKING DENSITY	LIGHT	NO PARK.	LIGHT		NO PARK.		NO PARK	NO PARK.	NO PARK.	LIGHT
TRAFFIC • main types of vehicles	AUTO	AUTO	AUTO		AUTO		MIXED	TRUCK	AUTO	AUTO
• density	LIGHT	LIGHT	LIGHT		LIGHT		MOD	HEAVY	HEAVY	MOD
• average speed (mph)	15-20	15-25	20-25		20-25		15-20	15-20	30-35	25-30
• min. distance from curb (ft)	4	2-3	6-8		6		4-6	4-6	8	8
DAYS SINCE LAST RAIN	0	0	0		0		0	0	0	0
DAYS SINCE LAST CLEANED	7	6	7		9		8	8	1	7
CLEANING METHOD	SWEPT	SWEPT	SWEPT		SWEPT		SWEPT	SWEPT	SWEPT	SWEPT

Table D-4

DESCRIPTIONS OF TEST SITES IN BUCYRUS DURING FIRST TEST SERIES

	LOW / OLD		MED / NEW	MED / OLD		INDUSTRY			CENTRAL BUSINESS DISTRICT	SUBURBAN SHOPPING CENTER
	single	multi	single	single	multi	light	medium	heavy		
CODE NUMBER	Bu-1		Bu-3	Bu-4			Bu-7	Bu-8	Bu-9	
SITE LOCATION	SCHABERT & MONNETT		VICTORIA & MARTHA	WALLACE & EAST			AUTO & WAYNE	SOUTHERN & HARRIS	W. WARREN & SANDUSKY	
PERCENT LAND USE	18		18	36			12	8	8	
DATE	4-30-71		4-30-71	4-30-71			4-30-71	4-30-71	4-30-71	
STREET • pavement	ASPHALT		ASPHALT	ASPHALT			ASPHALT	ASPHALT	ASPHALT	
• condition	POOR		EXCEL.	EXCEL.			EXCEL.	POOR	FAIR	
• width (ft) (crown to gutter)	15		14	14			14	14	17	
GUTTER	CONCRETE		CONCRETE	ASPHALT			ASPHALT	CONCRETE	ASPHALT	
CURB	CONCRETE		CONCRETE	CONCRETE			CONCRETE	CONCRETE	CONCRETE	
PARKING STRIP	LAWN		LAWN	LAWN			LAWN	GRASS	CONCRETE	
SIDEWALK	CONCRETE		NONE	CONCRETE			NONE	NONE	CONCRETE	
AREA BEYOND SIDEWALK	LAWN		LAWN	LAWN			LAWN	GRASS	BUILDINGS	
SIZE OF TEST AREA (ft^2)	520		480	480			480	480	600	
VOLUME OF WATER (gal)	15		14	20			11	11	12	
PARKING DENSITY	LIGHT		LIGHT	NO PARK.			LIGHT	NO PARK.	MOD.	
TRAFFIC • main types of vehicles	AUTO		AUTO	AUTO			AUTO	AUTO	AUTO	
• density	LIGHT		LIGHT	LIGHT			LIGHT	MOD.	MOD.	
• average speed (mph)	15-20		15-20	15-20			20-25	25-30	20-25	
• min. distance from curb (ft)	3-5		6	5-7			4	4	6-8	
DAYS SINCE LAST RAIN	2		2	2			2	2	2	
DAYS SINCE LAST CLEANED	n.a.		n.a.	n.a.			n.a.	n.a.	n.a	
CLEANING METHOD	SWEPT		SWEPT	SWEPT			SWEPT	SWEPT	SWEPT	

Table D-5

DESCRIPTIONS OF TEST SITES IN BALTIMORE DURING FIRST TEST SERIES

	LOW / OLD		MED / NEW	MED / OLD		INDUSTRY			CENTRAL BUSINESS DISTRICT	SUBURBAN SHOPPING CENTER
	single	multi	single	single	multi	light	medium	heavy		
CODE NUMBER		Ba-2	Ba-3	Ba-4	Ba-5	Ba-6	Ba-7	Ba-8	Ba-9	Ba-10
SITE LOCATION		MILTON & LANVALE	SEKOIS & PICKWICK	34th & HICKORY	BANK & ELWOOD	S. CAROLINE & FLEET	EASTERN & EAST FALLS	KEY HIGHWAY & McMANUS	MARION & CATHEDRAL	ATHOL & EDMONDSON
PERCENT LAND USE		28.2	14.1	14.1	14.1	6.6	6.4	6.4	5.8	4.0
DATE		5-4-71	5-4-71	5-4-71	5-4-71	5-4-71	5-5-71	5-5-71	5-5-71	5-5-71
STREET • pavement		ASPHALT	CONCRETE	ASPHALT	ASPHALT	ASPHALT	ASPHALT	CONCRETE	ASPHALT	ASPHALT
• condition		GOOD	GOOD	EXCEL.	EXCEL	FAIR	FAIR	EXCEL	EXCEL	EXCEL.
• width (ft) (crown to gutter)		16	16	10	18	18	20	30	25	20
GUTTER		ASPHALT	CONCRETE	CONCRETE	ASPHALT	GRANITE	BRICK	CONCRETE	ASPHALT	ASPHALT
CURB		CONCRETE	CONCRETE	CONCRETE	CONCRETE	CONCRETE	CONCRETE	CONCRETE	CONCRETE	CONCRETE
PARKING STRIP		CONCRETE	LAWN	CONCRETE	CONCRETE	GRANITE	CONCRETE	CONCRETE	CONCRETE	DIRT
SIDEWALK		CONCRETE	NONE	CONCRETE	CONCRETE	GRANITE	CONCRETE	CONCRETE	CONCRETE	CONCRETE
AREA BEYOND SIDEWALK		BUILDINGS	LAWN	SHRUBS	GRASS	BUILDINGS	PARK. LOT	GRASS	BUILDINGS	SHRUBS
SIZE OF TEST AREA (ft^2)		680	680	440	840	600	600	600	400	800
VOLUME OF WATER (gal)		13	15	14	15	18	17	19	17	
PARKING DENSITY		HEAVY	LIGHT	MOD.	NO PARK.	NO PARK.	NO. PARK.	LIGHT	NO PARK.	LIGHT
TRAFFIC • main types of vehicles		AUTO	AUTO	AUTO	AUTO	TRUCK	MIXED	MIXED	AUTO	AUTO
• density		MOD.	LIGHT	LIGHT	MOD.	HEAVY	HEAVY	MOD.	HEAVY	MOD.
• average speed (mph)		25	20-25	15-20	25-30	25-30	25-30	40-45	30-35	25 30
• min. distance from curb (ft)		8	6-8	4-6	6	6-8	6-8	12	2-3	6-8
DAYS SINCE LAST RAIN		26	26	26	26	26	26	26	26	26
DAYS SINCE LAST CLEANED		1	13	5	4	3	4	4	1	4
CLEANING METHOD		SW. & FLUSH	SW. & FLUSH	SW. & FLUSH	SW. & FLUSH	SW. & FLUSH	SW. & FLUSH	SW. & FLUSH	SW. & FLUSH	SW. & FLUSH

Table D-6

DESCRIPTIONS OF TEST SITES IN SAN JOSE DURING SECOND TEST SERIES

	LOW / OLD single	LOW / OLD multi	MED / NEW single	MED / OLD single	MED / OLD multi	INDUSTRY light	INDUSTRY medium	INDUSTRY heavy	CENTRAL BUSINESS DISTRICT	SUBURBAN SHOPPING CENTER
CODE NUMBER	SJII-1	SJII-2	SJII-3			SJII-6	SJII-7		SJII-9	SJII-10
SITE LOCATION	BERKLEY & DOBERN	18TH & WILLIAMS	CAMOS & LOMBARD			COMMERCIAL & 10TH	10TH & MISSION		E. 3RD & SAN FERNANDO	AUZEUAIS & RACE
PERCENT LAND USE	13.25	13.25	26.5			19.0	19.0		4.5	4.5
DATE	6-15-71	6-15-71	6-15-71			6-15-71	6-15-71		6-15-71	6-15-71
STREET • pavement	ASPHALT	ASPHALT	ASPHALT			ASPHALT	ASPHALT		ASPHALT	ASPHALT
• condition	GOOD	FAIR	GOOD			FAIR	GOOD		FAIR	GOOD
• width (ft) (crown to gutter)	18	15	16			25	24		20	20
GUTTER	CONCRETE	CONCRETE	CONCRETE			CONCRETE	CONCRETE		ASPHALT	CONCRETE
CURB	CONCRETE	CONCRETE	CONCRETE			CONCRETE	CONCRETE		CONCRETE	CONCRETE
PARKING STRIP	GRASS	GRASS	GRASS			ASPHALT	DIRT		DIRT	CONCRETE
SIDEWALK	CONCRETE	CONCRETE	CONCRETE			NONE	NONE		CONCRETE	CONCRETE
AREA BEYOND SIDEWALK	LAWN	LAWN	LAWN			DIRT	BUILDINGS		PARK. LOT	PARK LOT
SIZE OF TEST AREA (ft^2)	680	560	600			1000	880		800	800
VOLUME OF WATER (gal)	18	27	27			30	25		40	40
PARKING DENSITY	LIGHT	LIGHT	MOD.			LIGHT	MOD.		MOD.	LIGHT
TRAFFIC • main types of vehicles	AUTO	AUTO	AUTO			MIXED	MIXED		AUTO	AUTO
• density	LIGHT	LIGHT	LIGHT			MOD.	HEAVY		HEAVY	MOD.
• average speed (mph)	10	10	10-15			25	30-40		30-35	20
• min. distance from curb (ft)	4	5	4			10	6-8		5-6	5
DAYS SINCE LAST RAIN	59	59	59			59	59		59	59
DAYS SINCE LAST CLEANED	n.a.	n.a	n.a			n.a.	n.a		n.a.	n.a
CLEANING METHOD	SWEPT	SWEPT	SWEPT			SWEPT	SWEPT		SWEPT	SWEPT

Table D-7

DESCRIPTIONS OF TEST SITES IN ATLANTA DURING FIRST TEST SERIES

	LOW / OLD single	LOW / OLD multi	MED / NEW single	MED / OLD single	MED / OLD multi	INDUSTRY light	INDUSTRY medium	INDUSTRY heavy	CENTRAL BUSINESS DISTRICT	SUBURBAN SHOPPING CENTER
CODE NUMBER	At-1	At-2	At-3		At-5	At-6	At-7	At-8	At-9	At-10
SITE LOCATION	WALNUT & THURMOND	DREW & CLARRILLA	FERNLEAF Ct & FERNLEAF Rd		BOLTON Dr.	n.a.	SEABOARD INDUST RD.	16th & HOLLY	MERIETTA & GRADY	PIEDMONT
PERCENT LAND USE	19.3	19.3	19.3		19.3	7.4	7.4	7.4	.2	.2
DATE	6-22-71	6-22-71	6-22-71		6-22-71	6-22-71	6-22-71	6-22-71	6-22-71	
STREET • pavement	ASPHALT	CONCRETE	ASPHALT		ASPHALT	ASPHALT	ASPHALT	ASPHALT	ASPHALT	ASPHALT
• condition	GOOD	GOOD	GOOD		POOR	FAIR	POOR		GOOD	EXCEL
• width (ft) (crown to gutter)	18	20	15		15	16	14	18	16	20
GUTTER	ASPHALT	CONCRETE	ASPHALT		CONCRETE	ASPHALT	ASPHALT	ASPHALT	CONCRETE	CONCRETE
CURB	CONCRETE	CONCRETE	GRANITE		CONCRETE	CONCRETE	GRANITE	GRANITE	CONCRETE	CONCRETE
PARKING STRIP	GRASS	GRASS	LAWN		GRASS	GRASS	GRASS	GRASS	CONCRETE	CONCRETE
SIDEWALK	NONE	CONCRETE	NONE		CONCRETE	NONE	NONE	CONCRETE	CONCRETE	CONCRETE
AREA BEYOND SIDEWALK	GRASS	LAWN	LAWN		LAWN	GRASS	GRASS	GRASS	BUILDINGS	STONE WALL
SIZE OF TEST AREA (ft^2)	520	640	560		400	640	400		440	440
VOLUME OF WATER (gal)	16	13	30		20	24	27	14	9	20
PARKING DENSITY	LIGHT	LIGHT	LIGHT		LIGHT	NO PARK.	NO PARK.	NO PARK.	NO PARK.	NO PARK
TRAFFIC • main types of vehicles	AUTO	AUTO	AUTO		AUTO	TRUCK	MIXED	TRUCK	MIXED	MIXED
• density	LIGHT	LIGHT	LIGHT		LIGHT	MOD.	MOD.	MOD.	HEAVY	HEAVY
• average speed (mph)	10	15	10		20-25	40	30	30	20	20-30
• min. distance from curb (ft)	4	6	5		8	8	4	6	6	4
DAYS SINCE LAST RAIN	2	2	2		2	2	2	2	2	2
DAYS SINCE LAST CLEANED	14	1	21		28	30	7	10	1	14
CLEANING METHOD	SW & FLUSH	SW & FLUSH	SW & FLUSH		SW & FLUSH	SW & FLUSH	SW & FLUSH	SW & FLUSH	SW & FLUSH	SW & FLUSH

Table D-8

DESCRIPTIONS OF TEST SITES IN TULSA DURING FIRST TEST SERIES

	LOW / OLD		MED / NEW	MED / OLD		INDUSTRY			CENTRAL BUSINESS DISTRICT	SUBURBAN SHOPPING CENTER
	single	multi	single	single	multi	light	medium	heavy		
CODE NUMBER	TU-1		TU-3		TU-5	TU-6	TU-7		TU-9	TU-10
SITE LOCATION	EATON & GREENWOOD		45TH & BRADEN		ST. LOUIS & E. 14TH	44TH & 68TH	CATIMER & OWASSO		3RD & BOSTON	CANTON & E. 43RD
PERCENT LAND USE	24.0		35.0		35.0	2.0	2.0		.7	.7
DATE	6-28-71		6-25-71		6-25-71	6-25-71	6-25-71		6-25-71	6-25-71
STREET • pavement	ASPHALT		CONCRETE		CONCRETE	CONCRETE	ASPHALT		ASPHALT	CONCRETE
• condition	POOR		FAIR		FAIR	GOOD	FAIR		FAIR	FAIR
• width (ft) (crown to gutter)	14		14		14	18	16		20	16
GUTTER	ASPHALT		CONCRETE		CONCRETE	CONCRETE	CONCRETE		ASPHALT	CONCRETE
CURB	CONCRETE		CONCRETE		CONCRETE	CONCRETE	CONCRETE		CONCRETE	CONCRETE
PARKING STRIP	GRASS		GRASS		GRASS	GRASS	GRASS		CONCRETE	LAWN
SIDEWALK	CONCRETE		NONE		CONCRETE	NONE	NONE		CONCRETE	NONE
AREA BEYOND SIDEWALK	BUILDINGS				STONEWALL	GRASS	BUILDINGS		PARK. LOT	LAWN
SIZE OF TEST AREA (ft^2)	480		400.		400	640	480		640	440
VOLUME OF WATER (gal)	16		17		20	30	20		19	17
PARKING DENSITY	MOD.		LIGHT		NO. PARK.	LIGHT	NO PARK.		BUS STOP	NO PARK.
TRAFFIC • main types of vehicles	AUTO		AUTO		AUTO	TRUCK	TRUCK		MIXED	AUTO
• density	MOD.		LIGHT		MOD.	LIGHT	MOD.		HEAVY	MOD.
• average speed (mph)	15		15		20	20	20		30	25
• min. distance from curb (ft)	5		5		3	6	6		8	3
DAYS SINCE LAST RAIN	9		9		9	9	9		9	9
DAYS SINCE LAST CLEANED	na		na		na.	na.	na.		na	na
CLEANING METHOD	SW & FLUSH		SW. & FLUSH		SW. & FLUSH	SW. & FLUSH	SW & FLUSH		SW & FLUSH	SW. & FLUSH

Table D-9

DESCRIPTIONS OF TEST SITES IN PHOENIX DURING SECOND TEST SERIES

	LOW / OLD		MED / NEW	MED / OLD		INDUSTRY			CENTRAL BUSINESS DISTRICT	SUBURBAN SHOPPING CENTER
	single	multi	single	single	multi	light	medium	heavy		
CODE NUMBER	PII-1	PII-2	PII-3		PII-5	PII-6	PII-7		PII-9	PII-10
SITE LOCATION	W POLK & 18TH	E. POLK & 19TH	59TH & CAMBELL		CULVER & 3RD	N. 21ST & FILLMORE	57TH ST.		MONROE & 1ST	33RD & GRAND
PERCENT LAND USE	18.5	2.6	56.7		5.8	6.3	2.5		3.8	3.8
DATE	6-24-71	6-28-71	6-28-71		6-28-71	6-28-71	6-28-71		6-29-71	6-28-71
STREET • pavement	ASPHALT	ASPHALT	ASPHALT		ASPHALT	ASPHALT	ASPHALT		ASPHALT	ASPHALT
• condition	POOR		GOOD		FAIR	GOOD	GOOD		FAIR	GOOD
• width (ft) (crown to gutter)	18	12	14		14	20	25		24	15
GUTTER	CONCRETE	CONCRETE	CONCRETE		CONCRETE	CONCRETE	CONCRETE		ASPHALT	CONCRETE
CURB	CONCRETE	CONCRETE	CONCRETE		CONCRETE	CONCRETE	CONCRETE		CONCRETE	CONCRETE
PARKING STRIP	DIRT	CONCRETE	CONCRETE		GRASS	DIRT	ASPHALT		CONCRETE	CONCRETE
SIDEWALK	CONCRETE	CONCRETE	CONCRETE		CONCRETE	NONE	ASPHALT		CONCRETE	CONCRETE
AREA BEYOND SIDEWALK	LAWN	LAWN	LAWN		LAWN	DIRT LOT	PARK. LOT		BUILDING	PARK LOT
SIZE OF TEST AREA (ft^2)	560	440	480		600	520	440		520	560
VOLUME OF WATER (gal)	22	20	18		18	17	15		20	24
PARKING DENSITY	MOD.	HEAVY	LIGHT		HEAVY	MOD.	NO PARKING		TOWAWAY	LIGHT
TRAFFIC • main types of vehicles	AUTO	AUTO	AUTO		AUTO	MIXED	MIXED		MIXED	AUTO
• density	LIGHT	MOD.	LIGHT		LIGHT	MOD.	HEAVY		HEAVY	LIGHT
• average speed (mph)	15	20	10		15	20	40 - 50		20	20
• min. distance from curb (ft)	6	8	4		6	8	8		8	6
DAYS SINCE LAST RAIN	60+	60+	60+		60+	60+	60+		60+	60+
DAYS SINCE LAST CLEANED	na	na	na		na	na	na		na	na
CLEANING METHOD	SWEPT	SWEPT	SWEPT		SWEPT	SWEPT	SWEPT		SWEPT	SWEPT

Table D-10

DESCRIPTIONS OF TEST SITES IN SEATTLE DURING FIRST TEST SERIES

	LOW / OLD		MED / NEW	MED / OLD		INDUSTRY			CENTRAL BUSINESS DISTRICT	SUBURBAN SHOPPING CENTER
	single	multi	single	single	multi	light	medium	heavy		
CODE NUMBER	Se-1	Se-2		Se-4	Se-5	Se-6	Se-6-2		Se-9	Se-10
SITE LOCATION	16TH & FIR	21ST & YESLER		12ST & E. THISTLE	SUNNYSIDE & GREEN LAKE WAY	106TH AVE.	WALKER & 6TH		3RD & VIRGINIA	110TH & N. 5TH
PERCENT LAND USE	30.0	9.0		35.0	5.0	20.0			.5	1.0
DATE	7-8-71	7-8-71		7-7-71	7-8-71	7-8-71	7-8-71		7-8-71	7-8-71
STREET • pavement	ASPHALT	ASPHALT		CONCRETE	ASPHALT	CONCRETE	CONCRETE		ASPHALT	ASPHALT
• condition	POOR	GOOD		GOOD	FAIR	FAIR	FAIR		FAIR	FAIR
• width (ft) (crown to gutter)	12	16		16	10	12	10		10	12
GUTTER	ASPHALT	ASPHALT		CONCRETE	ASPHALT	CONCRETE	CONCRETE		ASPHALT	ASPHALT
CURB	CONCRETE	CONCRETE		CONCRETE	CONCRETE	CONCRETE	CONCRETE		CONCRETE	CONCRETE
PARKING STRIP	GRASS	CONCRETE		GRASS	CONCRETE	DIRT	DIRT		CONCRETE	CONCRETE
SIDEWALK	CONCRETE	CONCRETE		CONCRETE	CONCRETE	NONE	NONE		CONCRETE	CONCRETE
AREA BEYOND SIDEWALK	LAWN	BUILDINGS		LAWN	PLANTS	DIRT	DIRT		PARK. LOT	BUILDINGS
SIZE OF TEST AREA (ft^2)	400	600		560	360	400	320		360	400
VOLUME OF WATER (gal)	13	16		15	25	17	23		10	15
PARKING DENSITY	LIGHT	NO PARK.		LIGHT	MOD.	MOD.	MOD.		BUS STOP	NO PARK
TRAFFIC • main types of vehicles	AUTO	AUTO		AUTO	AUTO	MIXED	MIXED		AUTO	AUTO
• density	LIGHT	HEAVY		LIGHT	HEAVY	HEAVY	HEAVY		HEAVY	HEAVY
• average speed (mph)	15	30		10	30	30	30		25-30	30
• min. distance from curb (ft)	4	8		6	5	8	8		6	8
DAYS SINCE LAST RAIN	12	12		12	12	12	12		12	12
DAYS SINCE LAST CLEANED	na	na		na	n.a	na	na.		na.	n.a
CLEANING METHOD	SW. & FLUSH	SW & FLUSH		SW. & FLUSH	SW. & FLUSH	SW & FLUSH	SW. & FLUSH		SW. & FLUSH	SW & FLUSH

Table D-11

DESCRIPTIONS OF TEST SITES IN MERCER ISLAND, WASH.; DECATAUR, GA.; OWASSO, OKLA.; AND SCOTTSDALE, ARIZ. DURING FIRST TEST SERIES

	LOW / OLD		MED / NEW	MED / OLD		INDUSTRY			CENTRAL BUSINESS DISTRICT	SUBURBAN SHOPPING CENTER
	single	multi	single	single	multi	light	medium	heavy		
CODE NUMBER			MIs-3	De-4	Ow-4	Sc-4				
SITE LOCATION			MERCER IS.	WINTER AVE & LARK PL	W. 3RD & BEAMONT	E. 74TH & ROOSEVELT				
PERCENT LAND USE			n.a	n.a	n.a	n.a.				
DATE			7-7-71	6-23-71	6-26-71	6-29-71				
STREET • pavement			ASPHALT	ASPHALT	ASPHALT	ASPHALT				
• condition			GOOD	FAIR	FAIR	GOOD				
• width (ft) (crown to gutter)			16	14	15	20				
GUTTER			CONCRETE	ASPHALT	CONCRETE	CONCRETE				
CURB			CONCRETE	CONCRETE	CONCRETE	CONCRETE				
PARKING STRIP			GRASS	GRASS	GRASS	CONCRETE				
SIDEWALK			GRASS	CONCRETE	CONCRETE	CONCRETE				
AREA BEYOND SIDEWALK			GRASS	LAWN	LAWN	LAWN				
SIZE OF TEST AREA (ft^2)			560	440	480	680				
VOLUME OF WATER (gal)			21	18	23	30				
PARKING DENSITY			MOD.	MOD.	LIGHT	LIGHT				
TRAFFIC • main types of vehicles			AUTO	AUTO	AUTO	AUTO				
• density			LIGHT	LIGHT	LIGHT	LIGHT				
• average speed (mph)			15	10	10	20				
• min. distance from curb (ft)			6	5	5	10				
DAYS SINCE LAST RAIN			12	2	9	30+				
DAYS SINCE LAST CLEANED			n.a.	n.a	n.a	n.a				
CLEANING METHOD			n.a.	n.a.	n.a	n.a.				

APPENDIX E

CONVERSION TO METRIC UNITS

ENGLISH UNIT	CONVERSION FACTOR		METRIC UNIT
lb/curb mi	x 0.28	=	kg/curb km
lb/1000 ft^2	x 4.88	=	g/m^2
lb/hr	x .454	=	kg/hr
inch	x 2.54	=	cm
foot	x .3	=	meter
mile	x 1.609	=	km
mph	x 1.609	=	kph
acre	x 4.05×10^{-3}	=	km^2
ft^2	x 9.29×10^{-2}	=	m^2
gallon	x 3.79	=	liter

☆U.S. GOVERNMENT PRINTING OFFICE: 1973- 546-309/58

SELECTED WATER RESOURCES ABSTRACTS

INPUT TRANSACTION FORM

1. Report No.	2.	3. Accession No.
		W

4. Title
Toxic Materials Analysis of Street Surface Contaminants
EPA-R2-73-283

5. Report Date

6.

8. Performing Organization Report No.

7. Author(s)
Pitt Robert E., Amy Gary

10. Project No.
11034 FUJ

9. Organization
URS Research Company
155 Bovet Road
San Mateo, California 94402

11. Contract/Grant No.

13. Type of Report and Period Covered

12. Sponsoring Organization

15. Supplementary Notes
Environmental Protection Agency report number,
EPA-R2-73-283, August 1973.

16. Abstract

Because of the large amounts of toxic materials (especially heavy metals) found associated with street surface particulates during the course of a previous study (Water Pollution Aspects of Street Surface Contaminants), additional work has recently been completed which defines the distribution and range of heavy metals on the Nation's city streets.

This project defined the breakdown of the particulates' compositions by having mass spectographic analyses performed on various samples. Using these results, the heavy metals which were determined to have the greatest water pollution potential (As, Cd, Cr, Cu, Fe, Pb, Mn, Hg, Ni, Sr, Ti, Zn, and Zr) were analyzed in each of about 75 samples collected nationwide in 10 cities in the previous study.

17a. Descriptors

Storm Runoff, Surface Runoff, Urban Runoff, Pollution (Water)
BOD, COD, solids, heavy metals

17b. Identifiers

Street cleaning, street surface contaminants

17c. COWRR Field & Group

18. Availability	19. Security Class. (Report)	21. No. of Pages	Send To:
	20. Security Class. (Page)	22. Price	WATER RESOURCES SCIENTIFIC INFORMATION CENTER U.S. DEPARTMENT OF THE INTERIOR WASHINGTON, D. C. 20240

Abstractor	Institution

WRSIC 102 (REV. JUNE 1971)