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Water Pollution Aspects of Street Surface Contaminants

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November 1972

WATER POLLUTION ASPECTS
OF STREET SURFACE CONTAMINANTS

By

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Contract No. 14-12-921
Project 11034 FUJ

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ABSTRACT

Materials which commonly reside on street surfaces have been found to contribute substantially to urban pollution when washed into receiving waters by storm runoff. In fact, runoff from street surfaces is similar in many respects to sanitary sewage. Calculations based on a hypothetical but typical U.S. city indicated that the runoff from the first hour of a moderate-to-heavy storm would contribute considerably more pollutional load than would the same city's sanitary sewage during the same period of time.

This study provides a basis for evaluating the significance of this source of water pollution relative to other pollution sources and provides 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). 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.

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Section I

CONCLUSIONS

Under the sponsorship of the Office of Research and Monitoring, U.S. Environmental Protection Agency, research was conducted to investigate and define the water pollution impact of urban storm water discharge and to develop alternate approaches suitable for reducing pollution from this source. At the start of this study, a comprehensive literature search was conducted to collect existing data regarding the sources, quantities, and pollutional properties of street surface contaminants and refuse. It revealed the following:

- a considerable amount of data and information exists relating to pollutional loads associated with storm water and combined storm and sewer systems
- the data available on storm water pollutional loads are not directly relatable to the materials contributed by street surface contaminants
- information was lacking on relationships between street surface contaminants, their pollutional characteristics and the manner in which they are transported during storm runoff periods.

This study, therefore, focused on three principal areas:

- determining the amounts and types of materials which commonly collect on street surfaces
- determining the effectiveness of conventional public works practices in preventing these materials from polluting receiving waters
- evaluating the significance of this source of water pollution relative to other sources.

The research led to the following conclusions:

1. *Runoff from street surfaces is generally highly contaminated.* In fact, it is similar in many respects to sanitary sewage. Calculations based on a hypothetical but typical U.S. city indicate that the runoff from the first hour of a moderate-to-heavy storm (brief peaks

to at least 1/2 in./hr) would contribute considerably more pollutional load than would the same city's sanitary sewage during the same period of time , as indicated in the following table.

CALCULATED QUANTITIES OF POLLUTANTS WHICH WOULD ENTER RECEIVING WATERS - HYPOTHETICAL CITY

	STREET SURFACE RUNOFF (following 1 hr storm) (lb/hr)	RAW SANITARY SEWAGE (lb/hr)	SECONDARY PLANT EFFLUENT (lb/hr)
Settleable plus Suspended Solids	560,000	1,300	130
BOD_5	5,600	1,100	110
COD	13,000	1,200	120
Kjeldahl nitrogen	880	210	20
Phosphates	440	50	2.5
Total coliform bacteria (org/hr)	4000×10^{10}	$460{,}000 \times 10^{10}$	4.6×10^{10}

Source: Tables 37 and 38.

The hypothetical city has the following characteristics:

- Population - 100,000 persons
- Total land area - 14,000 acres
- Land-use distribution:
  - residential - 75%
  - commercial - 5%
  - industrial - 20%
- Streets (tributary to receiving waters) - 400 curb miles
- Sanitary sewage - 12×10^6 gal/day.

It should be noted that these calculations are for a situation in which streets are cleaned (intentionally or by rainfall) on the average of about once every five days. Thus, the above discharge of contaminated runoff could conceivably occur many times in a year. On the basis of this information, there is little question that street surface contaminants warrant serious consideration as a source of receiving water pollution, particularly in cases when such discharges of contaminants coincide with times of low stream flow or poor dispersion.

2. *The major constituent of street surface contaminants was consistently found to be inorganic; mineral-like matter, similar to common sand and silt.*

This inorganic material, most of which is probably blown, washed, or tracked in from surrounding land areas, does not constitute a serious water pollutant by itself. However, along with this material is organic matter, a small fraction of the total on the basis of mass. At a given location, both fractions (organic and inorganic) increase in loading intensity (lb/curb mile) with increasing time since the last cleaning. Data indicate, however, that the organic fraction tends to accumulate at a faster rate than the inorganic fraction. However, within the time frame of interest here (i.e., a few days to a few weeks), the organic fraction is still much smaller than the inorganic.

The quantity and character of contaminants found on street surfaces is summarized in the following table. The tabulated values are for all cities tested. They are weighted averages in which data for larger cities are allowed to bias the reported loading intensities.

MEASURED CONSTITUENTS	WEIGHTED MEANS FOR ALL SAMPLES (lb/curb mile)
Total Solids	1400
Oxygen Demand	
BOD_5	13.5
COD	95
Volatile Solids	100
Algal Nutrients	
Phosphates	1.1
Nitrates	.094
Kjeldahl Nitrogen	2.2
Bacteriological	
Total Coliforms (org/curb mile)	99×10^9
Fecal Coliforms (org/curb mile)	5.6×10^9
Heavy Metals	
Zinc	.65
Copper	.20
Lead	.57
Nickel	.05
Mercury	.073
Chromium	.11
Pesticides	
p,p-DDD	67×10^{-6}
p,p-DDT	61×10^{-6}
Dieldrin	24×10^{-6}
Polychlorinated Biphenyls	1100×10^{-6}

Source: Tables 40, 41, 42 and 43

Note: The term "org" refers to "number of coliform organisms observed."

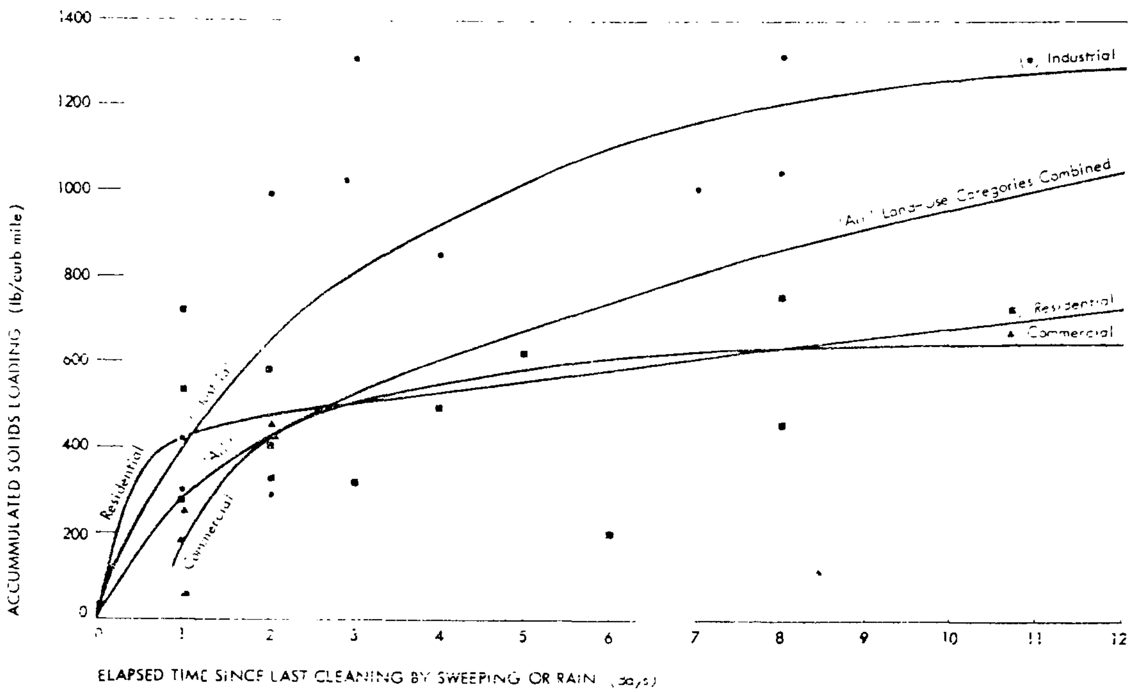
Significant amounts of heavy metals were detected in the contaminant materials collected from street surfaces; zinc and lead being the most prevalent, as indicated in the previous table.

Heavy metal compounds have the potential of being highly detrimental to biological systems, depending upon their specific chemical form. The samples collected in this study have been analyzed only so far as to indicate the total quantities of each metal present, not their specific chemical form. The Office of Research and Monitoring of the U.S. Environmental Protection Agency intends to develop more definitive information from the samples collected in this study.

Substantial quantities of organic pesticides and related compounds were found in the street surface contaminants. On the order of 0.001 lb/curb mile total was found for the cities tested, although the data showed considerable variation from site to site. The chlorinated hydrocarbons p,p-DDD and p,p-DDT were found rather consistently, as were polychlorinated biphenyl (PCB) compounds (see Table 12 in Section IV). Although these have repeatedly been associated with adverse environmental effects in recent controversies, the actual significance of these findings cannot yet be stated since the environmental consequences of such materials have not yet been established with any degree of certainty.

3. The quantity of contaminant material existing at a given test site was found to depend upon the length of time which had elapsed since the site was last cleaned; intentionally (by sweeping or flushing) or by rainfall. The field sampling program focused on collecting materials from street surfaces at single points in time (i.e., no attempts were made to repeatedly sample a given site to develop information on how contaminants accumulate with time). However, information was collected for each site to define the elapsed time since the last substantial rain storm and/or cleaning.

Computer analyses of such data revealed correlations between antecedent cleaning time and loading intensity. In general, industrial land-use areas tend to accumulate contaminants faster than commercial or residential areas. Accumulation patterns as calculated here are shown in the figure below (See Appendix I for details).



Source: Appendix I

4. *The quantity of contaminant material existing on street surfaces was found to vary widely, depending upon a range of factors.* However, loading intensities averaged on the order of 1400 lb/curb mile of street for the cities tested. The total solid loading intensities for the various land-use areas tested are tabulated below.

LAND USE	NUMERICAL MEAN (lb/curb mi)	WEIGHTED MEAN (lb/curb mi)
Residential		1,200
low/old/single	850	
low/old/multi	890	
med/new/single	430	
med/old/single	1,200	
med/old/multi	1,400	
Industrial		2,800
light	2,600	
medium	890	
heavy	3,500	
Commercial		290
central		
business district	290	
shopping center	290	
Overall		1,400

Source: Table 2

The principal factors affecting the loading intensity at any given site include the following: surrounding land-use, the elapsed time since streets were last cleaned (either intentionally or by rainfall), local traffic volume and character, street surface type and condition, public works practices, season of the year, etc.

Contaminant loading intensities were found to vary with respect to land-use patterns in the surrounding locale. In general, industrial areas have substantially heavier than average loadings. All industrial test sites (20 of them) taken together have an average loading of some 2800 lb/curb mile; twice the mean for cities on the whole. This is probably because industrial areas tend to be swept less often and because generation rates of dust and dirt tend to be high (e.g., "fallout," spillage from vehicles, unpaved dirt areas, streets in poor condition, etc.). Of these, heavy industrial areas showed the heaviest loadings, medium industrial the lightest. The loadings varied so widely between individual sites that it would be speculative to state why one type of industrial area is dirtier than another.

Commercial areas have substantially lighter loading intensities than the mean for cities on the whole (290 lb/curb mile average vs 1400). This is probably because they are swept so often; typically several times weekly, daily in prime areas.

Residential areas were found to have an average loading intensity comparable to the average for all land uses of all cities taken together: 1200 lb/curb mile. Here again, the loadings varied widely from site to site, and it would be speculative to state why one city is more heavily loaded than another or why one type of residential neighborhood is cleaner than another. The data in Table 2 (Section IV) implies, however, that there is some tendency for newer, more affluent neighborhoods to be cleaner; possibly because they are better maintained by residents and/or are further from sources of contamination.

5. *Perhaps one of the most important findings of this study is that such a great portion of the overall pollutional potential is associated with the fine solids fraction of the street surface contaminants.* Further, these fines account for only a minor portion of the total loading on street surfaces. As shown in the following table, the very fine, silt-like material (< 43 microns) accounts for only 5.9 percent of the total solids but about one-fourth of the oxygen demand and perhaps one-third to one-half of the algal nutrients. It also accounts for over one-half of the heavy metals and nearly three-fourths of the total pesticides. This concentration of pollutants in a small amount of very fine matter is of particular importance, considering that conventional street sweeping operations are rather ineffective in removing fines (sweepers were observed to leave behind 85 percent of the material finer than 43 microns; 52 percent of the material finer than 246 microns).

<table>
<tr><th colspan="4">FRACTION OF TOTAL CONSTITUENT ASSOCIATED
WITH EACH PARTICLE SIZE RANGE (% by weight)</th></tr>
<tr><th></th><th>$< 43\mu$</th><th>$43\mu \rightarrow 246\mu$</th><th>$> 246\mu$</th></tr>
<tr><td>TOTAL SOLIDS</td><td>5.9</td><td>37.5</td><td>56.5</td></tr>
<tr><td>BOD_5</td><td>24.3</td><td>32.5</td><td>43.2</td></tr>
<tr><td>COD</td><td>22.7</td><td>57.4</td><td>19.9</td></tr>
<tr><td>Volatile Solids</td><td>25.6</td><td>34.0</td><td>40.4</td></tr>
<tr><td>Phosphates</td><td>56.2</td><td>36.0</td><td>7.8</td></tr>
<tr><td>Nitrates</td><td>31.9</td><td>45.1</td><td>23.0</td></tr>
<tr><td>Kjeldahl Nitrogen</td><td>18.7</td><td>39.8</td><td>41.5</td></tr>
<tr><td>Heavy Metals (all)</td><td colspan="2">51.2</td><td>48.7</td></tr>
<tr><td>Pesticides (all)</td><td colspan="2">73</td><td>27</td></tr>
<tr><td>Polychlorinated Biphenyls</td><td colspan="2">34</td><td>66</td></tr>
</table>

Source: Table 47, 48 and 49.

6. *Chemical Oxygen Demand (COD) tests provide a better basis for estimating the oxygen demand potential.* It was found that due to the presence of toxic materials in street surface contaminants seriously interfered with BOD measurements. Such materials (particularly heavy metals) were found to be present in many samples at levels far in excess of those known to cause substantial interference.

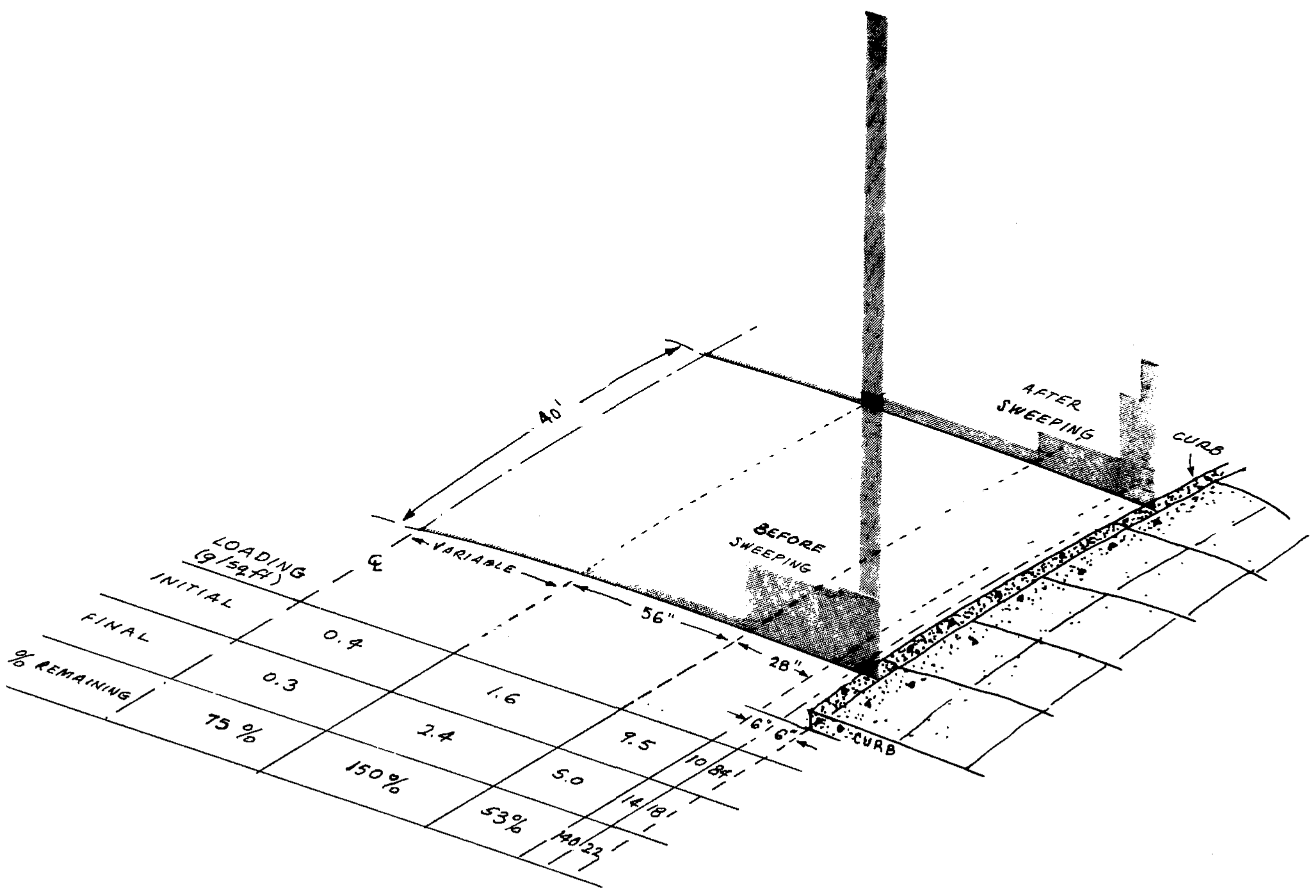
7. *Street surface contaminants are not distributed uniformly across the streets.* The solids loading intensity across a typical street is given below.

STREET LOCATION (Distance from Curb)	SOLIDS LOADING INTENSITY (% of Total)
0 - 6 in.	78
6 -12 in.	10
12 -40 in.	9
40 -96 in.	1
96 to center line	2

Source: Table 4

Typically, 78 percent of the material was found within 6 in. of the curb; over 95 percent within the first 40 in. Presumably this is due to transport by traffic (direct impact plus air currents) and because the curb is a physical barrier, the gutter a protected zone.

The distribution of debris across a street after sweeping results in the gutter being much cleaner; however, the sweeping operation moves much of the material out of the gutter and redistributes it on areas which were somewhat cleaner prior to sweeping. The redistribution is shown below.



Source: Fig. 42

The present design of gutter brooms is such that they tend to redistribute the dust and dirt fraction (< 2000 μ) over the surface of the street, and indeed are not particularly efficient in moving the dust and dirt fraction out of the gutter.

8. The rate at which rainfall washes loose particulate matter from street surfaces depends upon three primary factors: rainfall intensity, street surface characteristics, and particle size. Computer-assisted analysis of data from a special series of field experiments revealed that the wash-off phenomenon can be simulated by a simple, exponential equation:

$$N_c = N_o(1 - e^{-krt})$$

where N_c is the weight of material of a given particle size washed off a street initially having a loading of N_o after t minutes of rainfall at an intensity of r inches per hour. The proportionality constant k (units of hr/in. min) depends upon street surface characteristics but was found to be almost independent of particle size (at least within the range of sizes of particular interest here; i.e., 10 to 1000 microns).

Street surface characteristics were found to have an effect on the contaminant loadings observed at a given site. For example, asphalt streets had loadings about 80 percent heavier than all concrete streets. Streets paved partially with asphalt and partially with concrete were intermediate (their loadings were about 65 percent heavier than for all concrete streets). The condition of street pavement is also important. Streets in fair-to-poor condition had loadings about 2-1/2 times as high as streets in good-to-excellent condition.

The design of future systems for controlling pollutional effects of street runoff should take into account the fact that particulate contaminants arrive at point of entry to the sewer system in a manner which is quite regular and predictable on the basis of a few, easily measured parameters descriptive of the site and the design rainstorm. Further studies should be conducted to develop design procedures which can assure that the performance of such pollution control facilities is consistent with their cost.

9. Current street cleaning practices are essentially for aesthetic purposes and even under well-operated and highly efficient street sweeping programs, their efficiency in the removal of the dust and dirt fraction of street surface contaminants is low. The removal efficiency of conventional street sweepers was found to be dependent upon the particle size range of street surface contaminants as follows:

PARTICLE SIZE (Microns)	SWEEPER EFFICIENCY (%)
2000	79
840→2000	66
246→ 840	60
104 → 246	48
43 →104	20
< 43	15
Overall	50

Source: Table 32

The overall removal effectiveness for the dust and dirt fraction is 50 percent (that is, one-half of the dirt and dust fraction remains on the street). The removal effectiveness for litter and debris, however, (i.e., paper, wood, leaves, etc.) ranges from 95 to 100 percent.

10. Street cleaning effort, in terms of equipment minutes per 1000 sq ft of area swept, required to achieve a greater removal effectiveness of the dust and dirt fraction of street surface contaminants is several times the effort normally expended in sweeping operations as indicated below.

EFFECTIVENESS (%)	EFFORT (equip min/ 1000 sq ft)	INCREASE OVER NORMAL (0.237)
95	1.5	6.3
90	.85	3.6
70	.50	2.1

Source: Table 34

Increased effort can be achieved by operating at a slower speed (normal effort based on operating speed of 6 mph) or conducting multiple passes. To achieve an overall effectiveness of 70%, two cleaning cycles would be required. Effectiveness values greater than 90% are probably not achievable with present state-of-the-art street sweepers.

11. The technique of measurement of the effectiveness of street cleaning practices, as related to the pollutional properties of street surface contaminants, was adequately demonstrated in this study. Additionally, the following mathematical relationship was utilized to calculate the removal effectiveness of the dust and dirt fractions by particle size range:

$$M = M^* + (M_o - M^*)e^{-kE}$$

where M is the amount of street surface contaminants remaining after sweeping, M_o is the initial amount and E is the amount of sweeping effort involved in equipment minutes per 1000 sq ft (M^* and k are dimensionless empirical constants dependent upon sweeper characteristics, particle size of contaminants and street surface).

12. One of the most serious problems encountered in street sweeping concerns vehicle parking. Increases in the use of vehicles and unavailability of offstreet parking result in the occupancy of the gutters by parked vehicles. In congested areas it is not unusual to find the entire curb sides of streets occupied by parked vehicles. In some large cities, "no parking" regulations have been instituted during scheduled street sweeping hours.

13. The state-of-the-art regarding management information systems for public works is not very far advanced. Existing cost accounting, work reporting and equipment maintenance recording systems are fragmentary and produce disparate comparative statistical data. There is need for a system which will aid in providing public works with accurate cost data associated with street cleaning practices.

14. Specially conducted field studies indicate that catch basins (as they are normally employed) are reasonably effective in removing coarse inorganic solids from storm runoff (coarse sand and gravel) but are ineffective in removing fine solids and most organic matter. This is of considerable importance because it is these latter materials which contribute most heavily to water pollution effects. The material which collects in catch basins comes from sources other than surface runoff. Sample analyses indicated that much of the material found in urban and suburban catch basins consisted of litter, leaves, used oil, etc. Upon decomposition, the contents of catch basins become even more threatening to receiving water quality.

Section II

RECOMMENDATIONS

Section II

RECOMMENDATIONS

OPERATOR TRAINING

- Street cleaning operations are generally focused on controlling those types of contaminants and debris which are a nuisance from the standpoint of aesthetics or public safety. The finer matter, shown here to be of importance as a water pollutant, is seldom pursued. Although conventional street sweeping equipment is not particularly effective in collecting fines, with special attention on the part of operators a considerable amount of the material normally "missed" could be collected.

It is recommended that street cleaning equipment operators be trained not only in how their equipment can best be operated (i.e., vehicle speed, broom speed, broom position, etc.) but also in what material needs to be removed and where this is commonly located. Much of the fine material which normally lays in the gutters could be picked up if the operators had an appreciation for its importance relative to water pollution effects.

EFFORT

- This study has shown that the removal effectiveness of the dust and dirt fraction of street surface contaminants is a function of the effort expended in street cleaning operations, and to achieve a greater removal effectiveness requires several times the effort normally expended in sweeping operations. Effort is measured in equipment min/1000 sq ft and effort can be increased by operating at a lower speed or sweeping more often.

It is recommended that increased effort be expended on street cleaning operations. Operating speeds should not exceed 5 miles per hour unless operating on high-speed arterials. Additional cleaning cycles should be scheduled on streets that are the principal vehicular arterials.

DATA COLLECTION

- Acceptable methods of planning and evaluating the efficiency of street cleaning programs are not available at the present time. The adequacy and overall economy of street cleaning programs largely depend upon the effective utilization of currently available street cleaning equipment. An effective program planning technique requires accounts and detailed reporting on manpower and equipment utilization and equipment maintenance and operating costs.

It is recommended that public works departments maintain accurate and detailed records of street cleaning operations, including manpower utilization, equipment utilization, and equipment maintenance. The American Public Works Association, in their Special Reports No. 36 and No. 37, have created guidelines for developing standard procedures to be used in collecting and reporting statistics and for measuring and evaluating equipment performance. The procedures outlined in these reports should be utilized in providing the necessary input data to a cost-effective street cleaning program.

STREET MAINTENANCE

- Pavement type and condition were both found to have a substantial effect on the total amount of loose particulate matter found on streets. All-concrete streets were typically much cleaner than all-asphalt streets; mixed concrete/asphalt streets were intermediate. Streets in good condition were substantially cleaner than those in fair or poor condition. These findings are as one might expect, although the specific reasons (cause/effect relationships) have not been established, i.e., the streets could be cleaner because they are easier to sweep or because they themselves generate less material. Whatever the reason, it appears as though there are distinct benefits to keeping streets in good condition.

It is recommended that public works departments pay increased attention to maintaining pavements in good condition. When the material for paving is being selected, it is recommended that this difference in asphalt and concrete be taken into consideration, along with the factors normally included in such decisions.

AUTO PARKING CONTROLS

- The field tests conducted in this study indicate that the bulk of the material of primary concern (at least from the standpoint of water pollutional effects) tends to accumulate near the curb. This is particularly true where on-street parking is heavy. Discussions with public works personnel revealed that no satisfactory means have been found for effectively cleaning streets while cars are parked densely along the curb.

It is recommended that cities give special consideration to ways of restricting on-street parking on the days that sweepers or flushers make their regular rounds. An effective approach (employed in Baltimore) was to pass an ordinance restricting on-street parking, send *public works crews out to educate local residents as to their street cleaning program (a high degree of public support developed, with neighbors reminding each other of the need to move their cars on sweeping days), post signs along the streets, and enforce the ordinance through citations and/or tow-away of vehicles. The program has allowed the city to achieve substantially better control of all forms of street contaminants and debris.*

EQUIPMENT ADJUSTMENTS

- A survey of equipment parameters (i.e., main broom speed, strike or patterns, main broom pressure, gutter broom position, etc.) in various cities showed a wide range of operational characteristics. The effectiveness of sweeping can be improved by proper adjustments of main broom, gutter broom, hydraulic systems, dust deflectors, elevator mechanisms, hopper operations, etc.

It is recommended that routine maintenance schedules include proper adjustments to sweeper operating parameters as specified in Manufacturer's, Owner's, and Operating Manuals.

GUTTER BROOMS

- Gutter brooms were found to redistribute the dust and dirt fraction ($<2000\mu$) over the surface of the street, and in fact were not particularly efficient in moving the dust and dirt fraction out of the gutter.

It is recommended that the role of gutter brooms in street cleaning be further evaluated and research directed towards the development of new techniques for the efficient cleaning of gutters.

CATCH BASINS

- Controlled field tests conducted on catch basins indicate that they are relatively ineffective in preventing pollutant materials washed off streets from entering the sewer system. Thus they serve little constructive function. Further, they tend to accumulate large quantities of organic matter (from a variety of sources) which subsequently decompose and constitute a threat of massive slug pollution on being flushed out during storms.

It is recommended that public works departments give serious consideration to how necessary catch basins are in their particular systems. Where a simple stormwater inlet structure would suffice, it is probably desirable to get rid of the catch basin (either by replacing it or by filling it in).

An interim response which would be of considerable value in most communities would be to clean out dirty catch basins on a regular basis. This would be particularly effective if they were cleaned just before periods of major rainfall.

SEPARATION OF STORM AND SANITARY SEWERS

• Modern sewer design practice has been influenced by the assumption that storm runoff is quite clean, relative to sanitary sewage. Thus, separate systems have been provided; one to convey the storm runoff to direct discharge into receiving waters, the other to convey the sanitary sewage to a treatment plant before it is discharged. This study along with other recent information indicates that storm runoff is far from being "clean" and probably warrants being treated in many instances. Many older cities in this country were built with combined systems where storm and sanitary sewage are not kept separate. There has been some pressure for several years to encourage cities with combined systems to separate their sewers (a very extensive operation, from the standpoint of practicality and economics). The fact that both types of sewage have been found to be important pollutant sources casts some doubt as to whether sewer separation is warranted or treatment of all sewage is required.

It is recommended that further consideration be given to the desirability of separating storm and sanitary sewers.

FREEWAY RUNOFF

• This study focused on the contaminant materials which reside on urban and suburban street surfaces. It intentionally omitted consideration of freeways, even though these are a common element in most cities and are surely heavily loaded. They were omitted because they are typically subject to a somewhat different spectrum of contaminant sources and because they cannot be cleaned by the same techniques as conventional surface streets. Also, the techniques for studying them are necessarily somewhat different.

It is recommended that special studies be conducted to determine the amount and nature of materials which can wash off of urban freeways during storms and identify means for controlling this source of water pollutants. It would be important to conduct this study on well-defined test areas having exclusive existing drainage systems. Since traffic characteristics and aerial transport of fine solids both have a pronounced effect on contaminant loadings, it is imperative that these be studied concurrently with the freeway surface itself.

VACUUM WANDS

• Recent developments in street maintenance equipment have provided public works operations with a new type of equipment for collecting loose leaves and litter via manually guided, truck-mounted, vacuum "wands." Such devices or modifications thereof may be applicable to collecting street surface contaminants from areas normally rendered inaccessible by parked cars.

It is recommended that special tests be conducted to evaluate the feasibility (technical, operational, and economic) of vacuum wand units in collecting street surface contaminants.

SPECIAL CURB SYSTEM

- Field tests conducted in this study indicate conclusively that the bulk of the material of primary concern is located near the curb. This area is often swept only sporadically or missed completely. It is clear that flusher units could be designed to wash materials over to the curb with a high degree of effectiveness. If the water and contaminants could then flow along the gutter to a pickup point, a great improvement could be made in the control of subsequent street runoff. However, with parked cars present, the flow of water down the gutter is seriously impaired by curbed tires. Hence, with conventional curb/gutter construction, the potential benefits of specially designed flushing systems cannot be realized.

It is recommended that research and development be conducted to explore special curb/gutter configurations which would allow free flow of water and flushed debris to a pickup point, even in the presence of parked cars. Other aspects of this study would be to develop special mobile flushers (probably evolutionary extensions of the low volume/ high velocity units developed by the U.S. Naval Radiological Defense Laboratories for removing radioactive fallout materials from street surfaces), as well as special equipment and techniques for picking up the water and contaminants after flushing.

COST EFFECTIVENESS

- A cost-effectiveness program for street cleaning operations was presented in this study which would assist public works directors in evaluating the efficiency of street cleaning operations. However, insufficient information was obtained during this study to adequately prooftest the proposed model program.

It is recommended that a full-scale test program be conducted, in cooperation with a municipal public works department, to examine the overall effectiveness of street cleaning operations and the feasibility of a cost-effectiveness model that could be utilized by municipalities to upgrade current street cleaning practices. The full-scale test program should include the evaluation of newly developed street cleaning equipment such as vacuumized sweepers, and broom sweepers, and the general feasibility of adopting special public works practices involving the use of special flushing units, modified gutter and inlet designs, catch basins, and extra cleaning cycles for both catch basins and urban streets.

SNOW AND ICE

- The sampling program in this study was conducted in several cities - Seattle, Milwaukee, and Baltimore - that receive considerable amounts of snow at various times of the year.

It is recognized that considerable quantities of water pollution are associated with the enormous quantities of snow removed from urban streets and dumped into nearby bodies of water or onto water supply watersheds. However, no attempt was made in this study to conduct a sampling program to measure such pollution.

In addition, large quantities of de-icing agents are applied to urban streets during winter months for removal of ice and snow. There has been growing concern over the environmental effects resulting from these practices.

It is recommended that a study be conducted in several snow-belt cities located near bodies of water to determine the extent and severity of this problem. The results of such a study should serve to define possible requirements for modifying current snow dumping practices and developing safer means of ultimate snow disposal.

Section III

INTRODUCTION

Section III

INTRODUCTION

BACKGROUND

During the past few years, it has become increasingly obvious that runoff from storms in urban areas is by no means "rainwater" in terms of quality. Rather, storm runoff typically contains substantial quantities of impurities; so much so that it is a more serious source of pollutants than municipal sewage in many areas. Numerous studies have been and are being conducted to help define this problem; to determine the amounts of pollutant substances involved, their sources, their practical significance, and possible means of control.

Urban runoff can contribute to a variety of problems, including direct pollution of receiving waters, overloading of treatment facilities, and impairment of sewer and catch basin functions. These problems are caused in part by hydraulic overloading, but also by the various pollutants contained within the runoff.

Previous studies by the American Public Works Association (Ref. 1) and AVCO Corporation (Refs. 2 and 3) provide much valuable information on the total problem of water pollution resulting from urban runoff. They both point out the shock pollution loads which storm runoff from urban areas can place on receiving waters. Among the sources of pollution in urban runoff water are debris and contaminants from streets, contaminants from open land areas, publicly used chemicals, air-deposited substances, ice control chemicals, and dirt and contaminants washed from vehicles. The APWA report (Ref. 1) suggested various means of reducing the pollution problem created by urban runoff and emphasized the need for more definitive investigations as to the source, cause, and extent of the pollutants; the interrelationships and significance of the variables; and the development of standard procedures, methods and/or techniques for measuring the street surface contaminants. Among the concepts proposed for limiting storm water pollution was the improvement of street cleaning methods and operations.

URS Research Company recently conducted a comprehensive literature search (see Bibliography) to collect existing data regarding the sources, quantities, and pollutional properties of street surface contaminants and refuse, which has revealed the following:

- a considerable amount of data and information exists relating to pollutional loads associated with storm water and combined storm and sewer systems

- the data available on storm water pollutional loads are not directly relatable to the materials contributed by street surface contaminants
- information is lacking on relationships between street surface contaminants, their pollutional characteristics and the manner in which they are transported during storm runoff periods.

OBJECTIVES

The broad objectives of this study were to investigate and define the water pollution impact of urban storm water discharge and to develop alternate approaches suitable for reducing pollution from this source. The study focused on three principal areas:

- determining the amounts and types of materials which commonly collect on street surfaces
- determining the effectiveness of conventional public works practices in preventing these materials from polluting receiving waters
- evaluating the significance of this source of water pollution, relative to other sources.

METHOD OF APPROACH

The above objectives were accomplished in nine major tasks, as follows:

Task 1. Develop a planning and control technique for the entire study (this Section)

Task 2. Establish a project review panel (this Section)

Task 3. Determine the current state of the art related to street cleaning practices, specifically as they relate to water pollution control (Section V)

Task 4. Determine the characteristics of street surface contaminants and refuse (Section IV)

Task 5. Develop means of determining extent and significance of pollutional materials not usually captured in normal sampling techniques (Section IV)

Task 6. Develop standard techniques or procedures which can be utilized for evaluating the performance of equipment and street cleaning practices (Section V)

Task 7. Identify the variables involved, their interrelationships and their relative significance in water pollution terms under most likely real-world conditions (Sections IV, V and VI)

Task 8. Determine the feasibility of developing a mathematical model and, if possible, the degree of sophistication required (Section V)

Task 9. Prepare a final report.

Brief descriptions of the specific task units conducted to meet the objectives of each major task are given in Table 1. Figure 1 presents a systems network showing the interrelationships between the various task units. The systems network also served as a scheduling tool which allowed feedback and evaluation as the project proceeded.

PROJECT OVERVIEW AND SCOPE

The study, which required some eighteen months to conduct, involved a broad range of research techniques, including:

- field measurements and sample collection
- sample analyses
- experimental studies
- literature reviews
- surveys (by questionnaires and interviews).

The major efforts of the study centered around three elements:

- collecting contaminant materials from street surfaces all over the country
- analyzing those materials to determine their physical, chemical, and biological properties (insofar as these pertain to source identification, evaluating pollutional potential, and/or possible means of control)
- observing and evaluating various street cleaning practices in several cities throughout the country.

In this study we have defined street surface contaminants as being those materials found on street surfaces which are capable of being washed off during common rain storms. Street surfaces are defined as being the paved traffic lanes, any parking lanes, and the gutter; i.e., the area typically bounded by curbs. In urban areas the total contribution of contaminants comes from a much larger area than just this "street surface." For instance, there are surely substantial contributions from sidewalks, planter strips, yards, driveways, parking lots, roofs of buildings, etc. Thus, the quality of the water entering the storm sewer inlet is only partly a function of the contaminants washed from the street, per se.

The overall problem of controlling urban runoff pollution is complex indeed. The general approach involves dividing the overall problem into discrete segments which can be studied first separately and then in relationship to each other. This project is but a part of that overall approach; our "segment" is the "street surface." As the overall problem becomes understood, effective control measures can be developed and implemented.

The rationale for selecting the "street surface" as the study area and excluding various adjacent contributing areas is twofold:

- the street surface receives contaminants from sources which do not contaminate surrounding areas (particularly vehicular traffic)
- several of the potential control measures can be applied to street surfaces but not to surrounding areas (e.g., street sweeping).

Table 1

STUDY TASKS

WATER POLLUTION EFFECTS OF STREET SURFACE CONTAMINANTS

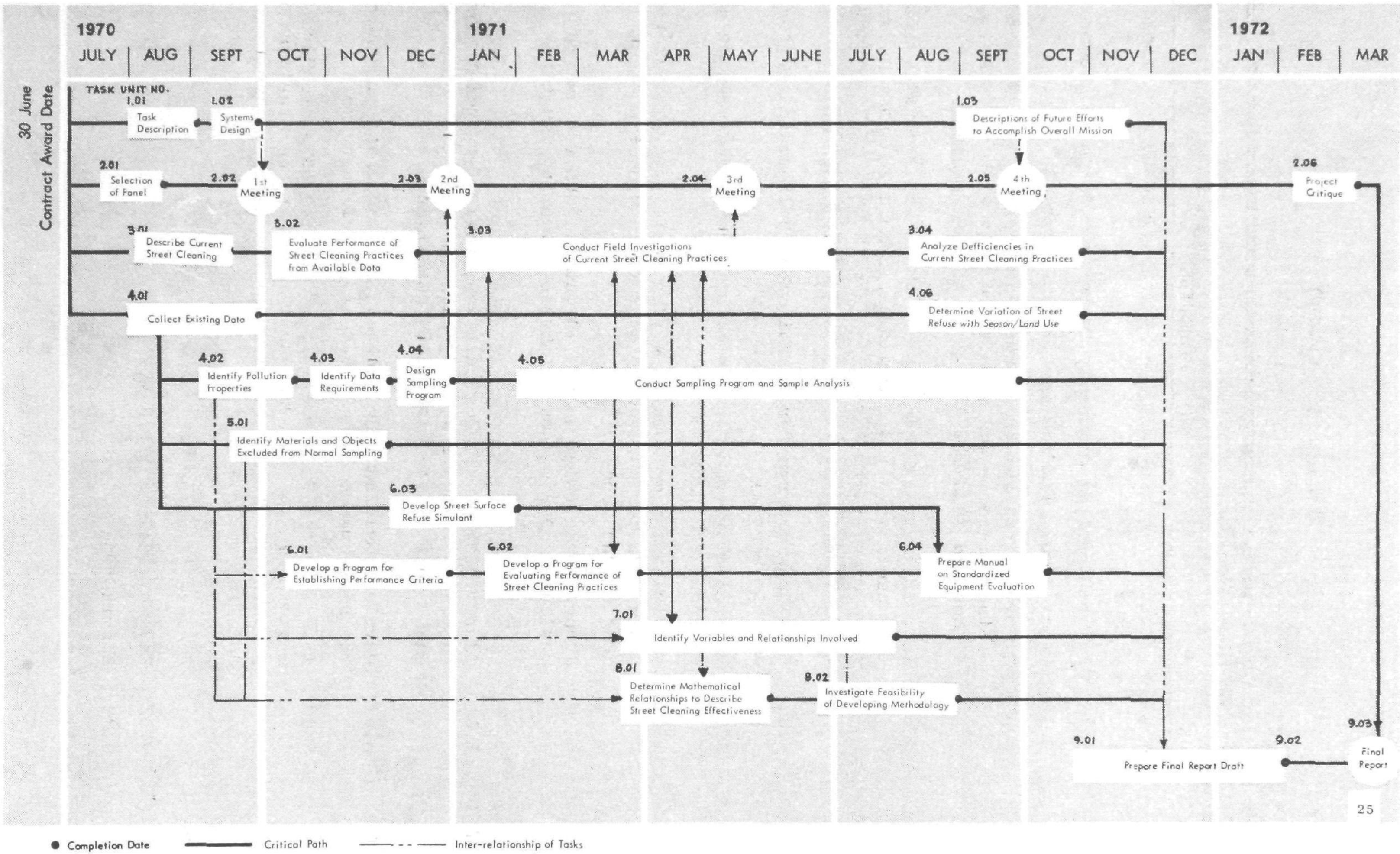
MAJOR TASK	TASK UNIT	OBJECTIVE
1	1.01	Describe the requirements for each major task and specific task unit comprising this study
	1.02	Design a systems network for accomplishing those tasks
	1.03	Describe future efforts required to accomplish the overall mission
2	2.01	Select review panel members
	2.02	Conduct 1st review panel meeting
	2.03	Conduct 2nd review panel meeting
	2.04	Conduct 3rd review panel meeting
	2.05	Conduct 4th review panel meeting
	2.06	Prepare project critique
3	3.01	Describe current street cleaning practices including the descriptions and specifications of equipment
	3.02	Determine from available data the performance (effectiveness and cost) of current street cleaning practices as these relate to water pollution control
	3.03	Conduct field evaluations of current street cleaning practices to supplement the data found to be available in task unit 3.02
	3.04	Identify and analyze the deficiencies in existing street cleaning practices as they relate to water pollution control
4	4.01	Collect existing data regarding the sources, quantities and pollutional properties of street surfaces contaminants and refuse
	4.02	Identify, on a preliminary basis, those physical, chemical and biological properties of street surface contaminants and refuse which are believed to be pertinent to street cleaning operations, transport of the material by runoff, and the action of the material as a pollutant

Table 1 (Continued)

MAJOR TASK	TASK UNIT	OBJECTIVE
	4.03	Identify requirements for additional or more reliable information
	4.04	Design sampling and analysis program to obtain required data
	4.05	Conduct sampling and analysis program
	4.06	Determine the manner in which the properties of street surface contaminants and refuse vary with factors such as season and land use
5	5.01	Identify materials or objects which are generally excluded from usual sampling techniques, including those materials whose undesirable impact is related primarily to factors such as aesthetics, hazards, or nuisances
6	6.01	Develop a program for establishing performance criteria for street cleaning in a given area
	6.02	Develop a program for evaluating the performance of street cleaning equipment and/or practices
	6.03	Develop a set of simulants (synthetic street refuse) for evaluating performance of street cleaning equipment and/or practices
	6.04	Prepare results of task 6 in manual form for use in evaluating performance of street cleaning equipment and/or practices
7	7.01	Identify the variables involved, their interrelationships and their relative significance in water pollution terms under most likely real world conditions
8	8.01	Develop empirical mathematical relationships to describe the performance of selected street cleaning methods
	8.02	Investigate the feasibility of developing a standardized methodology for determining least-cost acceptable street cleaning practice from alternatives using mathematical modeling techniques
9	9.01	Prepare final report draft
	9.02	Review final report draft
	9.03	Submit final report

Figure 1

THE SYSTEMS NETWORK



Section IV

CHARACTERISTICS OF STREET SURFACE CONTAMINANTS

Section IV

CHARACTERISTICS OF STREET SURFACE CONTAMINANTS

This section deals with answering the basic question, "What are the characteristics of street surface contaminants in terms of being potential water pollutants?" This involves the discussion of:

- common sources and constituents
- observed loading intensities
- transport mechanisms.

COMMON SOURCES AND CONSTITUENTS

In this study we have defined street surface contaminants as being those materials found on street surfaces which are capable of being washed off during common rain storms. Street surfaces are defined as being the paved traffic lanes, any parking lanes, and the gutter; i.e., the area typically bounded by curbs. Excluded, therefore, are sidewalks, planter strips, yards, driveways, roofs of buildings, etc. All of these surfaces contribute both water and contaminants. However, as discussed in Section III, they have been excluded here because they are not subject to the same array of sources and because the means of controlling contaminants from street surfaces would generally not apply in these other areas.

Street surface contaminants are comprised primarily of particulate matter but also include non-particulate soluble and suspendable matter which are capable of being washed off the streets by rainfall (i.e., oils, salts, saps, etc., are included even though they represent a minor loading on a mass basis).

The sources of materials found on street surfaces are greatly varied. However, the bulk of the contaminants commonly found comes from the sources described in the following paragraphs. Obviously, the material observed at any given location will be a composite of several sources; the actual "mix" being a function of such factors as land use, geographical locale, season, weather, traffic volume and character, local public works practices, etc.

Pavement

The street surface itself is a source of the materials we have defined as being contaminants. Included here are asphaltic and Portland cement, their various products of decomposition, and aggregate materials. In addition, there are typically small amounts of road marking paints, crack fillers, and expansion joint compounds. On a weight basis, aggregate materials account for the largest contribution of contaminants from this source. Observation of photomicrographs was of particular value here. The amounts found at any given location vary substantially and cannot be predicted on the basis of information developed here. Three important factors have been identified which appear to correlate with observed generation rates of such materials:

- the age and condition of street surfaces (old, worn, cracked streets seem to generate more in the way of contaminants)
- the local climate (cold winters accelerate degradation through freeze-thaw cycling, the use of studded tires, and the use of sand, ash, and chemicals for skid control)
- leaks and spills of fuels and oils which hasten the degradation of asphaltic pavements.

Motor Vehicles

This source of street surface contaminants contributes a broad range of materials and in numerous ways. Although the contributions cannot be quantified, they can be listed by general category:

- leakage of fuel, lubricants, hydraulic fluids, and coolants
- fine particles worn off of tires and clutch and brake linings
- particulate exhaust emissions
- dirt, rust, and decomposing coatings which drop off of fender linings and undercarriages
- vehicle components broken by vibration or impact (glass, plastic, metals, etc.).

The generation rates of these materials have not been determined but probably correlate with season, geographic locale, and local traffic conditions.

Their importance as water pollutants varies substantially from material to material. Fuel, lubricants, and hydraulic fluids degrade asphaltic pavements, thereby increasing the amount of inorganic solids loadings on receiving waters. Further, they float, causing films which are unsightly and hinder oxygenation. Like many other petrochemicals, they are damaging to biological forms. The lead, nickel, and zinc compounds used in their formulation are also harmful but to an undetermined extent.

The purpose of this discussion is not to define the extent to which motor vehicles contribute to water pollution. That is a complex subject in itself. Rather, we have listed a number of ways in which they affect the amount and nature of the street surface contaminants investigated in this study.

Atmospheric "Fallout"

This category has been included to establish a relationship between street surface contaminants and air pollution. A large fraction of the particulate matter contributing to the water pollution effects of street surface contaminants are of a size fine enough that they could have been transported by air currents prior to being deposited on the street surface. The extent to which this actually occurs is not known, of course, for the contaminants as a whole. However, certain contaminants surely arrived on the street surface following air transport.

Major sources of such materials would be industrial stacks and vents, construction and excavation projects, agricultural operations, and exposed vacant land areas. Automotive traffic and heavy commercial air traffic are also sources of fine airborne particles.

Many such forms of "fallout" are virtually inert and would add only turbidity and suspended solids loadings to receiving waters. Others are surely reactive and would impose loadings of oxygen demand, algal nutrients, toxic metals, and pesticides.

Vegetation

This source includes leaves and other plant materials (pollen, bark, twigs, seeds, fruiting bodies, grasses, etc.) which fall onto the street surface, are blown there by wind, or are dumped or raked there. In any given location, the generation rates are clearly a function of season, land use, local landscaping, and public works practices. However, such materials are distributed widely; substantial amounts of fragmented vegetative matter were found in virtually all street surface contaminant samples, irrespective of season or locale.

These materials are of interest in this study for several reasons. They contribute to oxygen demand (immediate demand if they are allowed to accumulate and decompose in catch basins, long-term demand after they sink to form bottom deposits). Algal nutrients and pesticides are also generally associated with vegetation.

Runoff From Adjacent Land Areas

A significant amount of both organic and inorganic matter found in street surface contaminant samples originates in adjacent land areas and is transported to the streets by runoff (some also blows there and is tracked onto the streets by vehicles). The amount and nature of material so imported varies widely as a function of topography, land use, season, public works practices, etc. The major sources are, of course, areas where soil is exposed rather than protected by vegetative cover, paving, or other means (e.g., vacant lots and fields, unprotected cuts and fills, ongoing construction and demolition projects).

In addition to particulate matter and soil-like material, oils and greases from parking areas, service stations, and commercial/industrial operations are transported onto street surfaces by runoff.

Litter

This category of street surface contaminants is notable even though it is probably not a major source of water pollution in the usual sense of the term. Included here is the myriad of refuse items which are discarded (intentionally or otherwise) by the public at large. Two major components of this litter are packaging materials of all sorts (paper, plastic, metal, glass, etc.) and printed matter (newspapers, magazines, advertising flyers, etc.). Another source of litter is the intentional disposal of waste material into the street when nearby occupants sweep sidewalks and driveways or rake up plant debris and dispose of it in the street.

As would be expected, litter exists on the street surface intact and in various degrees of decomposition (photomicrographs of street surface contaminant samples typically reveal the presence of dust-size fragments of glass, clearly recognizable as ground-up soft drink and beer bottles).

Litter is of particular importance to this study because of its relationship to conventional street cleaning operations. Most street sweepers are employed for the primary purpose of cleaning up visible litter and like-size materials, the intent being to maintain aesthetically pleasing community streets. Section V of this report discusses the effectiveness of such operations in controlling the pollutional aspects of street surface contaminants.

The fact that many components of litter float in receiving waters makes them a particular nuisance from the standpoint of visual aesthetics (e.g. styrofoam cups, plastic bags, waxed paper cups, cigarette packages, etc., all float well and tend to be concentrated at the surface by eddy currents, wind, and quiescent water). Because such conditions impair the receiving water's suitability for certain uses, they are considered here to be a pollutional effect of street surface contaminants.

Another effect of litter on water pollution is that litter tends to collect in catch basins where its organic fractions gradually decompose, causing increased oxygen demand, suspended solids, and turbidity in receiving waters, once there is sufficient storm flow to flush them out. Further, litter mechanically interferes with a catch basin's ability to pass leaves, grass, and fine solids; hence, these also tend to be stored and to decay, adding to the pollutional shock load on receiving waters.

Organics (food, animal droppings), another source of litter, are generally present in substantially smaller quantities (on a weight basis) than the dust and dirt fraction component of street litter and debris. Organics could affect BOD readings; however, they are generally considered a source of nuisance rather than a serious water pollutant. Most of the fecal coliform bacteria observed in samples of street surface contaminants are probably associated with bird and animal droppings.

Spills

This category of street surface contaminants is well known but virtually impossible to describe quantitatively, either in amount or character. The major source of spills is vehicular transport. The types of materials vary widely, but include primarily: dirt, sand, gravel, cement, various bulk commercial and industrial raw materials and products, agricultural products, and various types of wastes. Although a minor source in most areas, discharges from backed-up, broken, or overloaded sewers also contribute contaminants to street surfaces.

Anti-Skid Compounds

These include common salts ($NaCl$ and $CaCl_2$) plus a host of specially formulated organic and inorganic compounds which are applied with the intent of melting ice or inhibiting its formation during cold weather. Included also are various types of relatively inert materials (e.g., sand and ash) which are applied to act as abrasives in reducing skid hazards. The total amount of anti-skid compounds applied during cold weather in northern communities is considerable. This subject has been covered in detail in two recent reports (Refs. 4,5) and therefore will be mentioned superficially here and discussed further in Section V.

OBSERVED LOADING INTENSITIES

The major field sampling efforts conducted under this study were directed toward determining the amount and nature of contaminants actually residing on street surfaces at the time of sampling. The matter collected corresponds quite closely with that matter which would wash off of a typical street during a moderate-to-heavy rain of about an hour's duration (the specifics of the field sampling techniques are presented and discussed in Appendix A). It is important to note that the values reported herein are observed loading densities (in weight per unit curb length or weight per unit street surface area) rather than rates of accumulation, except where specified. For each sample collected, the data concerning the elapsed time since prior sweeping and the time since prior substantial rainfall was recorded. This information, plus a description of each test area, is given in Appendix B.

At the outset of the study it was recognized that the amount of contaminant material residing on the street surface would vary considerably from place to place and from time to time, depending upon a number of dominant factors. Much of this study has been devoted to identifying those factors and establishing their relative importance.

These dominant factors can be grouped into three major categories:

- time since last cleaning or rainfall
- season of the year
- locale (actually, the activities that go on at the particular location).

Before getting into the details as to how contaminant loadings vary in response to these factors, it is important to discuss the issue of generation rate vs observed loading intensity. Consider a hypothetical area of street surface which is (for the purposes of discussion) subjected to a continual and uniform loading of contaminants (uniform with respect to both time and spatial distribution). If there were no other activities to disturb the contaminants, the loading intensity would increase linearly with respect to time, as shown in Fig. 2a.

If the street were cleaned periodically but the cleaning operation were unable to remove all of the deposit, the curve would be cyclic as shown in Fig. 2b.

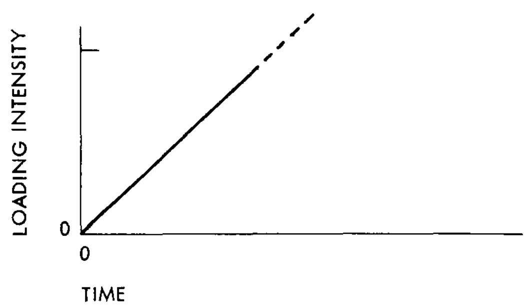


Fig. 2a. Accumulation of Contaminants - Hypothetical Case (linear buildup, no sweeping, no rainfall)

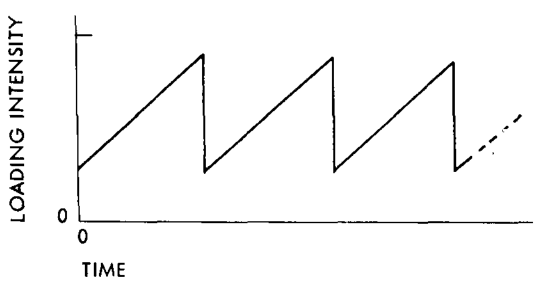


Fig. 2b. Accumulation of Contaminants - Hypothetical Case (linear buildup with periodic sweeping but no rainfall)

In any actual situation it is clear that the plot cannot be linear but rather would curve over and gradually approach a limit (see Fig. 3a). If this were not the case, an unswept street would become impassable with accumulated debris. While the mechanisms of removal cannot be described quantitatively, they surely include wind, displacement by moving traffic, and the like. Where periodic cleaning is practiced, the plot looks like Fig. 3b. Note that this represents a case of uniform, continuous loading and a regular cleaning (with the same degree of efficiency each time and a uniform frequency).

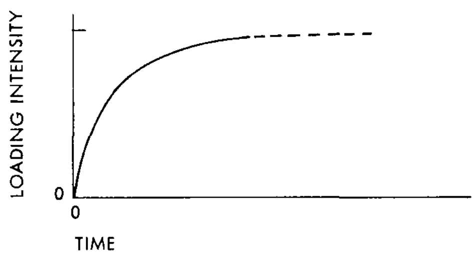


Fig. 3a. Accumulation of Contaminants - Hypothetical Case (natural buildup, no sweeping, no rainfall)

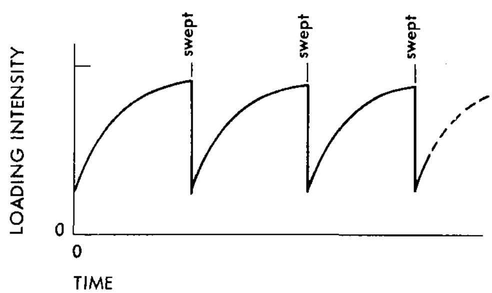


Fig. 3b. Accumulation of Contaminants - Hypothetical Case (natural buildup with periodic sweeping but no rainfall)

Figure 4 depicts the effect that intermittent rains would give. Large storms would remove more than sweepers; small storms, less.

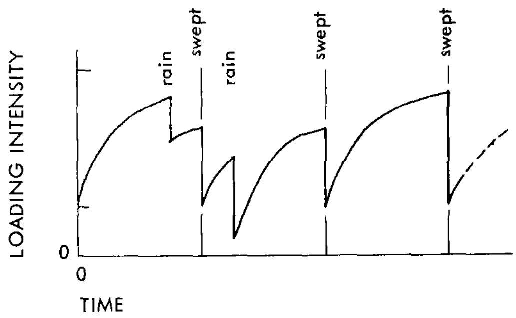


Fig. 4. Accumulation of Contaminants - Typical Case (natural buildup with periodic sweeping and intermittent rainfall)

The final task here is to consider how the plot would look if all of these factors (i.e., sweeping efficiency, sweeping frequency, rainfall frequency, etc.) were allowed to vary randomly throughout their normal range. Its shape would be very complex indeed, looking very little like the simplistic curves of Figures 2b or 3b.

The purpose for discussing this situation is to place into context the meaning of the "observed loading intensities" reported herein. Streets were sampled to determine their contaminant loading intensities. At each sampling location, historical information was obtained as to when the street had last been swept and when the last rain of considerable magnitude (one hour minimum, peaks to one-half in./hr). The thing to note here is that, while these data are of some value, they are by no means sufficient to describe the shape of the overall curve. As a matter of fact, it is impossible to derive the rate of accumulation (the slope at any point along the rising portion of the curve) on the basis of these data. However, such was not the intent in this study; that point should be made clear. What we are interested in is the answer to the question: "How much material resides on a typical street which is subject to being washed off by rainfall occurring at a random point in time?" To answer that, it was necessary to look at streets in every stage representative of the entire curve; streets which had not been cleaned recently, those which had just been swept or had just been flushed by rain, etc.

A limited sub-study was conducted to determine if any consistent trends could be found to relate the amount of contaminants found on streets with the elapsed time since the last sweeping or substantial rainfall. Since areas with widely differing overall characteristics were included in the study, it was difficult to discern any dominant or repetitive trends. The efforts involved in this sub-study are reported in Appendix C.

General Observations

Total solids loading intensities were determined by collecting contaminant materials from street surfaces by a combination of dry sweeping and flushing with a jet of water. Sample areas of 800 to 1000 sq ft of street were used (see Appendix A for a complete description of field procedures and rationale for their selection). The total dry weight of solids sample divided by the size of the area sampled is reported here as the "loading intensity." Two means of reporting such values have been adopted:

- the average loading intensity over the entire area sampled (lb/1000 sq ft)
- the average loading intensity along the length of the area sampled (lb/curb mile).

At the outset of the study, it was assumed that the loading intensities would vary from location to location in response to such factors as land-use category, season of the year, geographic locale, size of the city, etc. For this reason, sampling sites were selected to represent a broad range of all of these factors. In summary, we collected samples in some ten land-use categories in twelve cities (large and small) throughout the country. The overall solids loading intensities observed are reported in Tables 2 and 3. (A summary of data on all observed pollutant characteristics is presented in Appendix C along with an analysis of accumulation rates.)

A review of the data reveals that solid loading intensities vary significantly from city to city and from land use to land use. While it is presumptive to report a single value representative of such a widely varying population, the calculated means (weighted over both land uses and cities) are: 16 lb/1000 sq ft and 1500 lb/curb mile. Obviously, they should be used only with some caution.

At the outset of the study, it was hoped that trends could be identified to help relate the amount of street surface contaminants present with certain local characteristics; in particular, parking, traffic, and pavement.

The conclusions, after review of all the data collected here, are that pavement composition and condition have a fairly consistent effect on the amount of total solids present as street surface contaminants. Specifically, streets paved entirely with asphalt have loadings about 80 percent heavier than all-concrete streets (streets paved partly with concrete, partly with asphalt, are about 65 percent heavier than all concrete). Streets whose pavement condition was rated "fair-to-poor" were found to have total solids loading about 2-1/2 times as heavy as those rated "good-to-excellent."

The other factors considered: traffic speed, traffic density, and parking density, all surely have an influence, but no consistent trends could be identified. It is probable that other, more dominant, factors had greater effects (e.g., land use, season, etc.).

The following paragraphs deal with the factors which influence the loading intensities observed at any given test site.

Table 2

TOTAL SOLIDS, LOADING INTENSITIES (lb/curb mi)

	RESIDENTIAL					INDUSTRIAL			COMMERCIAL		
	LOW/OLD/ SINGLE	LOW/OLD/ MULTI	MED/NEW/ SINGLE	MED/OLD/ SINGLE	MED/OLD/ MULTI	LIGHT	MEDIUM	HEAVY	CENTRAL BUSINESS DISTRICT	SHOPPING CENTER	*Weighted Mean*
San Jose I	840	1,100	290			1,700	1,100		270	460	910
Phoenix I	770	1,900	180		310	450	1,300		210	640	650
Milwaukee	720	560	280		6,900		410	12,000	260	210	2,700
Bucyrus	1,900		410	1,900			1,000	1,600			1,400
Baltimore		1,300	1,200	1,400	500	1,300	860	240	68	63	1,000
San Jose II	620	470	200			12,000	1,100		1,200	160	6,000
Atlanta	590	31	330			3,700		300	60	430	430
Tulsa	120		620		150	1,100	280		180		330
Phoenix II	1,600	1,100	380		500	260	1,100		200	180	910
Seattle	470	540		260	140	710			190	190	460
Decatur				1,200							
Scottsdale				1,200							
Mercer Island			93								
Owasso			250								
Numerical Mean	850	890	430		1,400	2,600	890	3,500	290	290	
Weighted Mean			1,200				2,800		290		1,500

Note: Tabulated values are the average loading intensities one would find if the contaminants were spread uniformly across the full width of the street. The fact that they are distributed quite non-uniformly means that these figures must be used with caution.

Table 3

TOTAL SOLIDS, LOADING INTENSITIES
(lb/1000 sq ft)

	RESIDENTIAL					INDUSTRIAL			COMMERCIAL		
	LOW/OLD/ SINGLE	LOW/OLD/ MULTI	MED/NEW/ SINGLE	MED/OLD/ SINGLE	MED/OLD/ MULTI	LIGHT	MEDIUM	HEAVY	CENTRAL BUSINESS DISTRICT	SHOPPING CENTER	*Weighted Mean*
San Jose I	6.3	8.6	2.2			13.0	8.4		2.0	3.5	8.6
Phoenix I	5.8	14.0	1.4		2.4	3.4	10.0		1.6	4.8	8.5
Milwaukee	12.0	9.2	3.5		66.0		5.2	160.0	3.3	2.7	32
Bucyrus	27.0		6.5	31.0			16.0	26.0			18
Baltimore		14.0	14.0	24.0	4.5	16.0	11.0	3.1	1.3	0.6	11
San Jose II	69.0	6.3	2.5			92.0	9.0		12.0	1.5	56
Atlanta	8.6		4.5		0.6	44.0		5.7	1.0	7.3	4.7
Tulsa	1.8		12.0		2.9	13.0	4.4		2.1	3.3	4.6
Phoenix II	22.0	19.0	6.0		6.3	3.9	20.0		3.0	2.4	12
Seattle	8.8	6.8		4.1	2.9	15.0			4.0	3.7	6.4
Decatur				20							
Scottsdale				13							
Mercer Island			1.3								
Owasso			3.9								
Numerical Mean	12	11	5.6		15	25	11	47	3.3	3.3	
Weighted Mean											16

Note: Tabulated values are the average loading intensities one would find if the contaminants were spread uniformly across the full width of the street. The fact that they are distributed quite non-uniformly means that these figures must be used with caution.

Land Use

At the outset of this study the assumption was that the amounts and types of materials on street surfaces vary as a function of surrounding land use. This was based on the knowledge that numerous related factors (e.g., sweeping practices, traffic volume and type, parking patterns, vegetation, etc.) all vary with respect to land use. Thus, the sampling and analysis program employed here was designed to develop information on a range of land uses. Ten categories were selected. While these ten are not comprehensive (i.e., there are areas typical of many communities which are not included), they do account for a gross majority of the land area comprising most non-rural communities. Furthermore, these particular categories are easily recognized in most communities (in the sense that they can be identified and readily distinguished from other land-use categories).

The purpose for collecting samples in a variety of land-use categories was two-fold: to provide a rational basis for characterizing an entire city (samples from all land-use areas were combined to yield "city composites") and to allow any significant trends between land-use categories to be identified. (Photographs depicting the general, overall appearance of the areas comprising each of these land-use categories are included in Appendix D to help orient the reader.)

Figure 5 depicts variations in total solids loadings from one land-use category to another. The data plotted are from the eight cities listed in Table 3.

Three major land-use "groupings" which are used throughout the remainder of the report are introduced here: residential, industrial, and commercial.

One conclusion that can be drawn from this information is that, although there is considerable variation between land-use categories, when taken all together, streets in industrial areas generally tend to be more heavily loaded than residential streets; commercial streets, less heavily loaded. These conclusions are consistent with expectations. Commercial areas are commonly swept weekly (often daily); industrial areas often rather infrequently and irregularly (details regarding common municipal sweeping practices are given in Section V).

It was noted earlier that this study focuses primarily upon existent solids loadings intensities (i.e., the solids one observes at a given point in time rather than their accumulation rate over time). This approach is essential if one is to predict the amount of contaminant which will run off during a storm. For example, consider the trends plotted on Fig. 5. A curb-mile of "residential" street will contribute more contaminants than a curb-mile of "commercial" street even though the commercial streets receive more contaminants per unit time. The fact that commercial streets are cleaned so frequently (to maintain

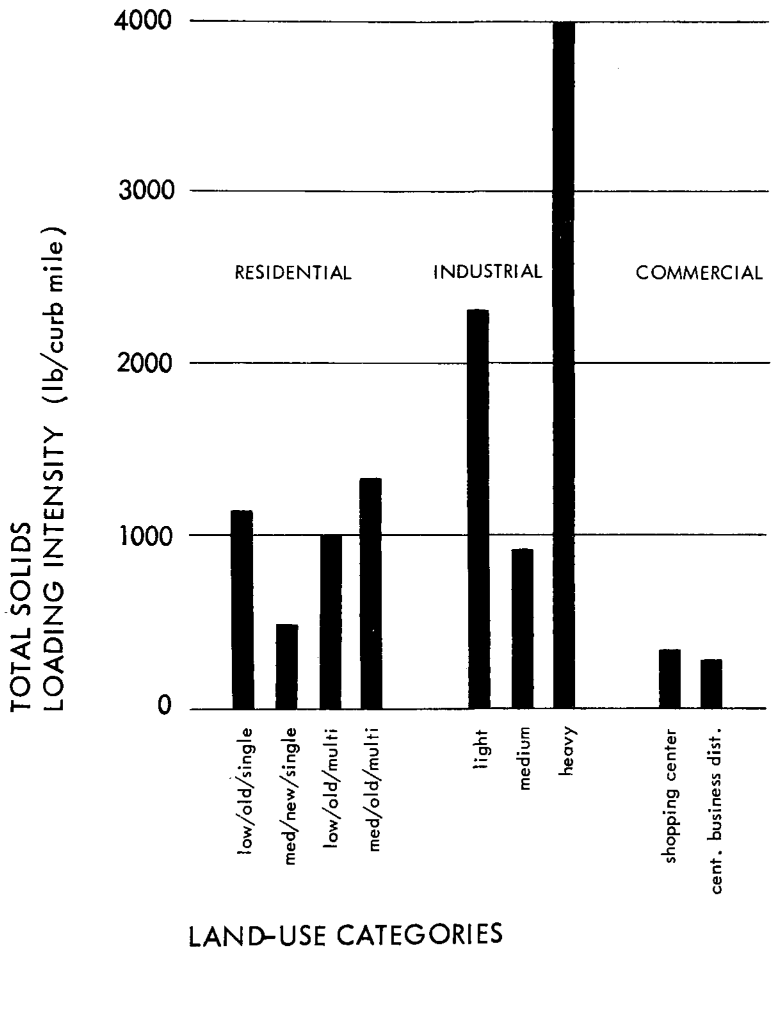


Fig. 5. Total Solids Loading on Street Surfaces - Variation with Land Use

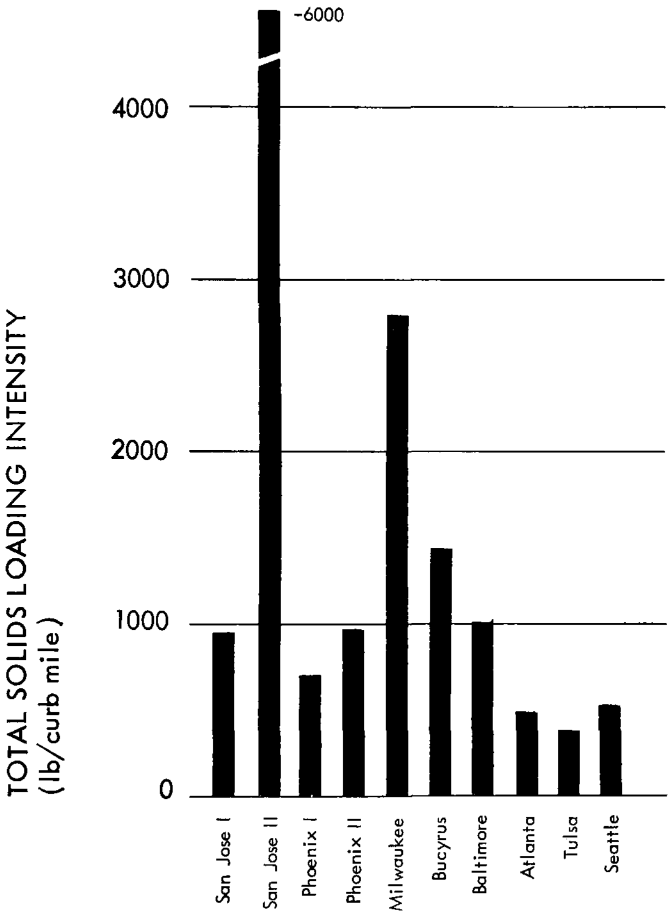
high aesthetic standards) tends to mask the fact that the accumulation rate between sweepings is quite high.

Cities

Another factor expected to affect the amount and nature of contaminants (observable at any location) was the particular city. There is little doubt that the following factors affect contaminant loadings and that they differ from city to city:

- geographical locale - a factor with a substantial but ill-defined effect on climatic conditions (seasonality of snow, rainfall, wind, etc.), the community's proximity to fixed area sources of airborne particulates (deserts, plains, tilled fields, etc.), the amount and type of vegetation (and associated leaf-fall), etc.
- activities within the community - a generalized factor which refers to the presence of point sources of airborne particulates from residential, commercial, institutional, and industrial activities (incinerators, power plants, industrial stacks, construction projects, etc.)
- public works practices and controls - a composite of factors including street cleaning practices, street maintenance practices, snow and ice control practices, and control over such activities as refuse collection, litter abatement, use of studded tires, etc.
- non-specific characteristics of the community including land area, population, land-use patterns, population density and distribution, traffic density and patterns, general overall air pollution, and the important factor of public attitude regarding public cleanliness and aesthetics (a factor which is often reflected in terms of the size of the public works department budget).

While it is plausible to assume that loadings would vary from city to city, it had to be established that they do. Figure 6 shows graphically how these loadings vary. However, the information developed in this study does not provide a basis for predicting their value for a given city (nor was that the intention of the study). The purpose for including several cities of different types, sizes, and locations was to be sure that a broad enough range of conditions was represented in the "sample population" to assure the reliability and credibility of the research findings. The eight principal cities studied were selected on the basis of differences in their age, size, geographical locale, land-use patterns, population and industrial growth patterns, topography, and types of receiving waters.



NOTE: The unusually high value for San Jose II may be an anomaly caused by an unrepresentative sample.

Fig. 6. Total Solids Loading on Street Surfaces - Variations between Cities

Likewise, the purpose for repeating tests in some cities was not to ascertain the exact variation in conditions from time to time during the year. Rather, it was to determine if there are any seasonal effects (obviously, there are marked effects) which should be given special consideration in any subsequent studies of this type.

The dates of the samplings are listed below (further details of individual sites are presented in Appendix B).

San Jose I	Dec. 1970
San Jose II	June 1971
Phoenix I	Jan. 1971
Phoenix II	June 1971
Milwaukee	Apr. 1971
Bucyrus	Apr. 1971
Baltimore	May 1971
Atlanta	June 1971
Tulsa	June 1971
Seattle	July 1971

Distribution on Street Surfaces

Contaminant materials are not distributed uniformly on street surfaces; neither across them nor along them. Most of the material (especially particulate solids) is concentrated toward the curb. This is as expected considering the tendency of traffic to "blow" material out of the traffic lanes. A cross section taken of the full width of a typical street would show some accumulation down the very center, little in the traffic lanes, quite a bit in the curb lane (especially if cars are allowed to park there; not so much because they are the source but rather because their presence arrests and fosters the accumulation of moving material). The highest concentration of solids is in the gutter, as would be expected, since the curb forms a barrier to any particles moving transversely. At grade median strips are generally zones of accumulation for particulate street surface contaminants. Raised medians are generally relatively clean but, at points where breaks are provided, considerable accumulation is common.

It is important to note that the distributions described above are for particulate solids. Substances like oils, greases, and various liquids which spill or leak onto the street surface are generally found in heaviest concentration along the center of each traffic lane and down the center of parking lanes.

It is important to recognize the distinct non-uniformity of distribution. For one, this non-uniformity makes it somewhat risky to discuss loading intensities on the basis of weight per unit area unless such values are carefully explained as to meaning (i.e., it is important to stress that these are "average" loadings over reasonably large areas which include most of the street's width). For this reason, most values reported here are in terms of lb/curb mile rather than lb/1000 sq ft.

Another important aspect of this distinct non-uniformity has to do with the potential for cleaning streets. The fact that most of the particulate matter is concentrated in a relatively narrow zone along the curb (typically, on the order of 70 or 80 percent is located within 6 in. of the curb) means that cleaning efforts focused there could be highly effective. On the other hand, since this is the very location where cars park, it is virtually impossible to achieve desired cleanliness when cars are present.

Figures 7a through 7d show the distributions measured on streets in several of the cities tested. The distributions are not identical from site to site, but the trends described above are generally substantiated. The data are plotted in these figures and given in Table 4.

Contaminant materials are not distributed uniformly along the length of the streets. Features which tend to cause major variations are intersections, bus stops, special turning lanes, and even driveways. As noted previously, any variations in parking patterns will also cause variations in loadings. Field sampling results indicate that intersections are loaded on the order of one-third as heavy as the normal run of street (these tests focused on the particulate solids loading within the first 7 ft of the curb - the path covered by a conventional street sweeper). Further, driveways were found to be less heavily loaded than the spaces between driveways although the variation was only about 30 percent.

POLLUTIONAL PROPERTIES

The preceding discussion presented data concerning the amounts and distribution of contaminant materials found on street surfaces. The following discussions are concerned with the nature of those materials, particularly their potential to act as pollutants in receiving waters. Six principal aspects are covered:

- suspended and settleable solids
- oxygen demand
- algal nutrients
- coliform bacteria
- heavy metals
- pesticides.

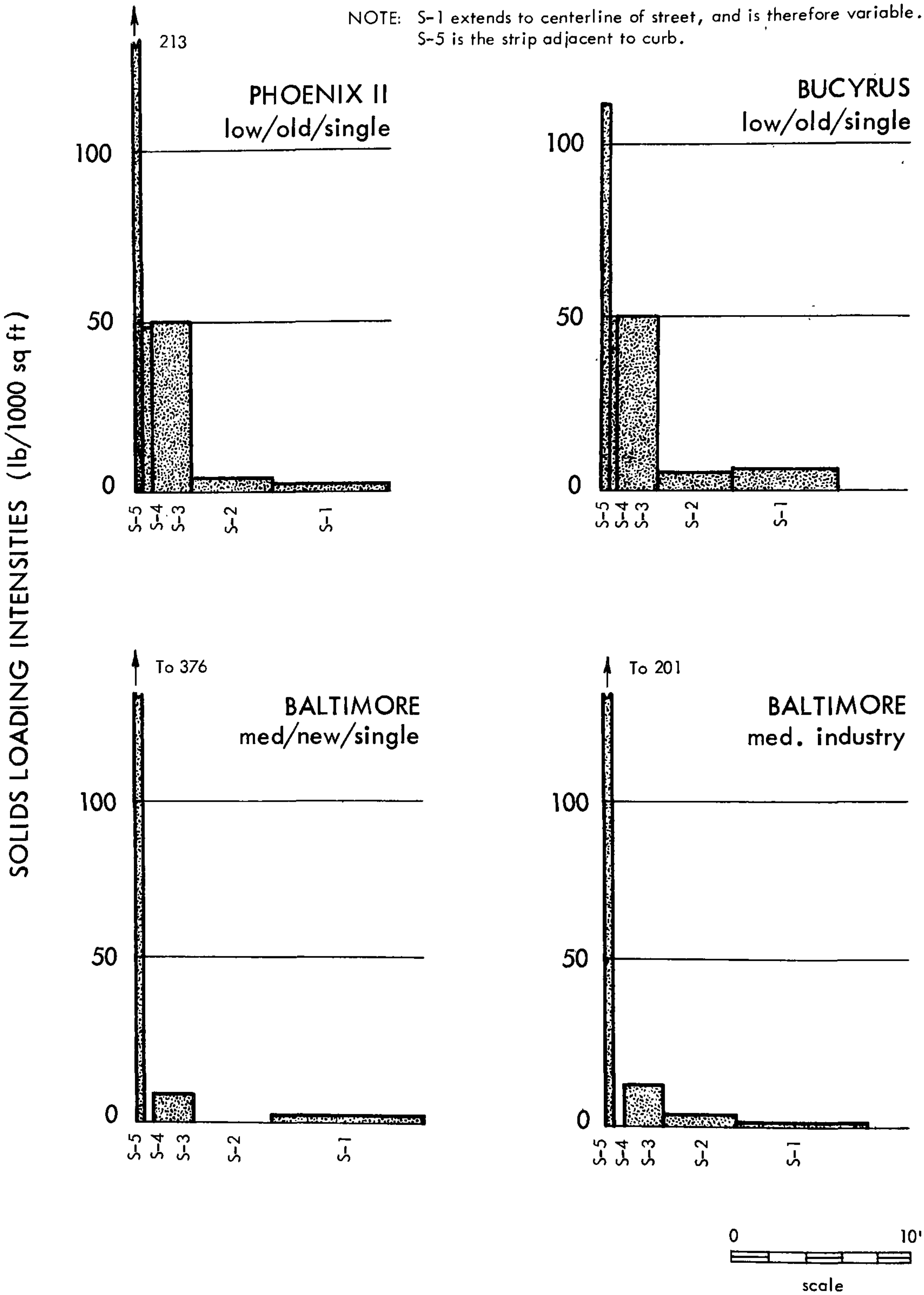
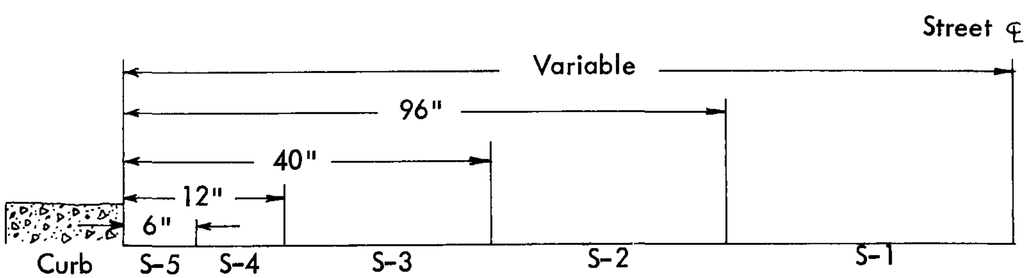


Fig. 7. Distribution of Solids Across Streets (Based on Table 4)

Table 4

SOLIDS LOADING INTENSITIES
Distribution Across Streets

CITY AND LAND USE	S-1 lb/ $10^3 ft^2$	S-1 lb/ curb mi	S-2 lb/ $10^3 ft^2$	S-2 lb/ curb mi	S-3 lb/ $10^3 ft^2$	S-3 lb/ curb mi	S-4 lb/ $10^3 ft^2$	S-4 lb/ curb mi	S-5 lb/ $10^3 ft^2$	S-5 lb/ curb mi
Baltimore med/new/single	.79	64.2	.37	30.1	9.3	755	8.8	713	376	30600
Baltimore medium industry	.73	59.4	1.7	136	15.4	1250	9.3	755	201	16300
Baltimore heavy industry	.10	8.1	.35	28.4	2.2	179	2.0	162	54	4360
Milwaukee med/new/single	.11	8.9	.35	28.4	0.4	28.4	1.5	122	69	5610
Bucyrus low/old/single	6.7	545	6.4	520	51.4	4180	41.4	3360	112	9100
Tulsa light industry	18.4	1500	2.0	162	7.5	610	19.8	1610	21	1690
Seattle light industry	--	--	.66	53.6	2.7	220	19.7	1600	33	2660
Phoenix-II low/old/single	2.0	162	3.8	309	48.6	3950	47.4	3850	213	17300
Atlanta heavy industry	.02	1.6	.06	4.9	0.6	50.5	1.2	97.6	105	8540
Percentage of total loading found in each strip (average values)	2%		1%		9%		10%		78%	



These were selected for study because of their potential for impairing receiving water quality and because they are commonly used in characterizing pollutants from other sources (this obviously facilitates evaluating the importance of street surface contaminants, relative to other sources of pollution).

Another important characteristic of street surface contaminants is their particle size distribution. This is because the size of solids determines their transport on the street (by wind, water, and traffic effects) and the ease with which they are removed by various cleaning techniques (sweepers, vacuum sweepers, flushers, even catch basins). Furthermore, particle size is important in terms of pollutional aspects (i.e., where the particles end up and what types of effects they will have). In the following pages information is reported as to the tendency for certain pollutional aspects to be associated with certain particle size ranges.

Data to support the issues are presented along with the discussion in most cases. However, for convenience, the bulk of the data for the study has been reduced and summarized, with pertinent excerpts presented in Appendix C.

Suspended and Settleable Solids

Microscopic examination has revealed that the bulk of materials, loose contaminants found on street surfaces, consist of "inert" minerals of various types (quartz, feldspar, etc.) which reflect components of street paving compounds and local geology. This inert portion of the total contaminant loading is similar in size, shape, and composition to the materials geologists classify as "sediments" and will henceforth be referred to simply as sediments.

Sediments entering receiving waters fall into two major categories on the basis of size; both categories have environmental effects associated with them. Depending upon local flow patterns and velocities, a portion of the sediments will be suspended, while the remainder, by virtue of size and weight, will enter receiving waters by saltation, traction or decreased transport energy (reduced flow velocity). The mechanisms by which these materials act as pollutants may be direct, indirect, or both.

The indirect effects of high sediment loadings on biologic systems can be very great. Such mechanisms include the physical burial of plants and animals and changes in the nature of the substrata causing alteration of fauna and flora. High suspended sediment concentrations reduce water transparency, inhibiting the transmission of light required for photosynthesis. This also interferes with predator/prey hunting relationships. High sediment loads increase the probability of transporting pesticides, nutrients, various organic pollutants and many microbiological forms by acting as a mobile substrate on which they adsorb, absorb, or otherwise adhere.

The direct effect of sediments includes actual damage to biological structures, burial of organisms, and the clogging of respiratory, feeding and digestive organs. High sediment loadings can also contribute to the possibility of clogging sewer lines, increased solids loadings at treatment facilities, and the shoaling of waterways.

Table 5 presents data on the particle size distributions of composite samples from representative cities. The data were determined by summing values obtained by dry sieving, wet sieving, and sedimentation pipette analyses. (This is a common method used for determining particle size on the basis of settling velocity, via Stoke's Law relationships.) Analytical procedures utilized are described in Appendix E.

The classifications "sand," "silt," and "clay" have been included here to help communicate the general properties of street surface contaminants. These classifications also roughly correspond to the behavior of the materials in water; that is, sand will generally settle out at low current velocities, clay will remain suspended, and silt will be intermediate (some will settle, some will not).

It seems likely that the materials in suspension will have a long-range environmental effect; the coarser materials, a short-range effect (they will be removed locally by sedimentation). Although the percentages of suspended material are small compared to the total loading, their actual weight on a curb-mile basis may be of some significance in increasing the suspended sediment concentration of the receiving waters. For example, consider the case of Milwaukee. By estimating the amount of runoff for a 0.5 in. rain of 1 hour duration over a distance of 1 mile, the loading per size range data for Milwaukee (from Table 5) has been employed to develop an estimate of the concentration of suspended material in the runoff. Runoff velocities are assumed to be high enough to suspend most silt and all clay-size material. The greatly reduced flow rates that this material will subsequently be exposed to will still probably be high enough to maintain a state of transport. Complete suspension will result in an average runoff concentration of around 100 ppm. Several case studies are presented in Section VI to help put the pollutional potential of street surface contaminants into perspective.

In reality, the initial sediment slug may be many times higher. This concentration will be diluted substantially by the receiving water through a factor governed by its volume and initial suspended sediment concentration. Depending on circumstances, the concentration may be elevated to levels which could interfere with various organisms.

In the interest of helping orient the reader, we can compare the information in Table 5 with street sweeper performance data (details of which are discussed in Section V). The thing to note here is that given a conventional sweeper operating at maximum efficiency, on the order of 70 percent of material sand-size and larger can be removed. Smaller materials are not removed well at all, however. From the standpoint of normal public works objectives (i.e., keeping the street relatively free of large aesthetically displeasing debris), conventional sweepers do an effective job. However, from the standpoint of controlling the fine particulate matter which contributes so heavily to water pollution, conventional sweeping is relatively ineffective. This is especially true, of course, when sweepers are poorly operated. Photographs showing street surface contaminants after dry sieving into particle size ranges are shown in Fig. 8.

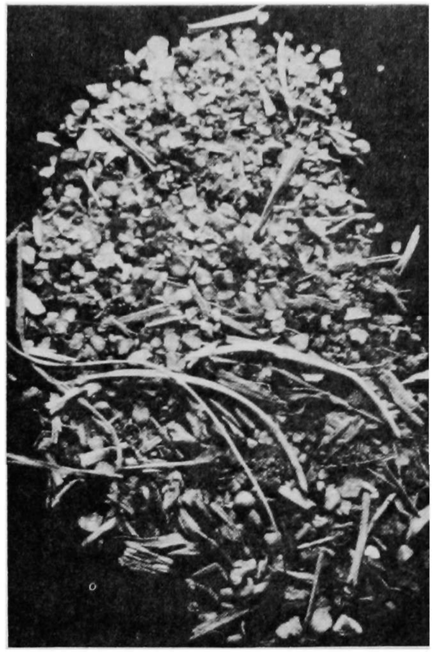
Table 5

PARTICLE SIZE DISTRIBUTION OF SOLIDS
SELECTED CITY COMPOSITES

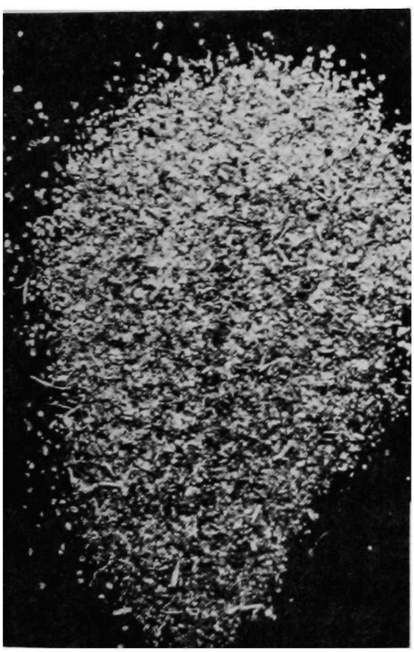
SIZE RANGES	MILWAUKEE	BUCYRUS	BALTIMORE	ATLANTA	TULSA
> 4,800 μ	12.0%	%	17.4%	%	- %
2,000-4,800 μ	12.1	10.1	4.6	14.8	37.1
840-2,000 μ	40.8	7.3	6.0	6.6	9.4
246-840 μ	20.4	20.9	22.3	30.9	16.7
104-246 μ	5.5	15.5	20.3	29.5	17.1
43-104 μ	1.3	20.3	11.5	10.1	12.0
30-43 μ	4.2	13.3	10.1	5.1	3.7
14-30 μ	2.0	7.9	4.4	1.8	3.0
4-14 μ	1.2	4.7	2.6	0.9	0.9
< 4 μ	0.5	-	0.9	0.3	0.1
Sand %, 43-4,800 μ	92.1	74.1	82.1	91.9	92.3
Silt %, 4-43 μ	7.4	25.9	17.1	7.8	7.6
Clay %, < 4 μ	0.5	-	0.9	0.3	0.1
Lb Sand/curb mi	2,480	1,020	845	394	300
Lb Silt/curb mi	200	356	176	33.5	30
Lb Clay/curb mi	13.5		9.3	1.3	0.3

Note: μ = microns.

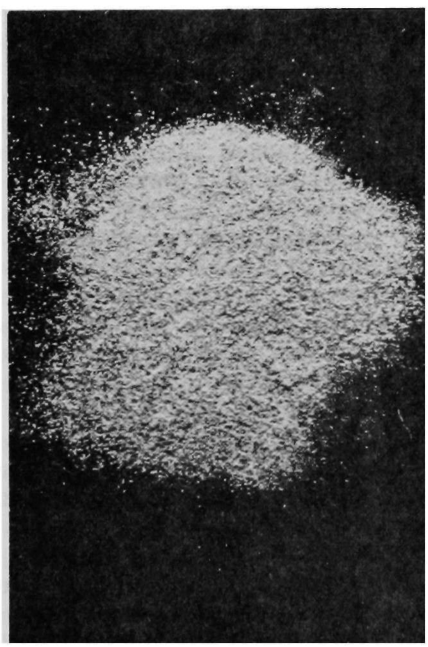
840-2000 microns (3X)



246-840 microns (3X)



104-246 microns (3X)



104 microns (3X)

Fig. 8. Street Surface Contaminants After Dry Sieving

Oxygen Demand

One of the most significant detrimental effects a pollutant can have on receiving waters is to depress the dissolved oxygen level. Minor depressions can usually be tolerated by a free flowing, relatively unpolluted stream without any serious effects, although some shift in the aquatic ecological balance will result. However, in many situations where receiving waters are already subject to the physical and chemical effects imposed by urban areas, the ambient or "usual case" oxygen resource is only marginal to begin with. Therefore, substantial loads of oxygen-demanding substances often lead to undesirable conditions; perhaps the most notorious being fish kills, foul odors, unsightly discoloration, and slime growths.

In short, then, materials which depress receiving water oxygen resources are considered pollutants. For the most part, such pollutants are organic substances which are consumed by the stream biota as food. Concurrent with their consumption, the biota (primarily aerobic bacteria) "breathe in" oxygen that was initially dissolved in the water. This has the effect of stabilizing the organic matter (which is a "plus") but leaves the rest of the aquatic life with less oxygen to fill their needs (this being the "minus").

The amount of such organic matter present in polluted water or in a waste can be measured and is broadly described in terms of "oxygen demand." Three indices of such demand or waste strength which are in relatively common use are BOD, COD, and volatile solids. BOD stands for biochemical oxygen demand and is a reasonably direct measure of what goes on in the receiving water (actually the test employs conditions which are quite similar to what happens in nature, i.e., the waste is "fed" to bacteria and the oxygen "breathed" during a 5-day test period is measured). COD stands for chemical oxygen demand, an index which is measured by reacting the sample at high temperature with strong chemicals (a boiling mixture of concentrated sulphuric acid and potassium dichromate) to determine how much oxidizable matter is present. The COD test is rapid, precise, and less subject to certain interferences than the BOD test, and was therefore indicated here. A third index of waste strength is the volatile solids test which involves merely "burning" a dried portion of waste solids at very high temperature (600°C) under controlled conditions. This test is rapid, even simpler and less subject to the factors which interfere with the BOD or COD tests. It has been included here for that reason.

Oxygen demand loadings on street surfaces were found to vary over a very wide range depending upon the city, the land use, time since last rainfall or sweeping, etc. This, of course, was expected. Loading intensities varied from a high of over 60 to less than 2 lb/curb mile for BOD and from 400 to 13 for COD (see Table 6). While the importance of this is difficult to judge directly, the case studies developed in Section VI should help put the findings in perspective. In summary, they indicate that the oxygen demand attributable to street runoff is quite substantial indeed. This source contributes large quantities of oxygen-demanding materials in "slugs" which unquestionably causes a short-term impairment of receiving water quality in perhaps a majority of locations. These conditions have been substantiated by actual observations (see Refs. 6 and 7). Perhaps the most notable case would be where the Sandusky River, loaded with street runoff, has turned a murky black and lost most of its fish life as it flows past Bucyrus, Ohio.

Table 6

OXYGEN DEMAND LOADING INTENSITIES ON STREETS

	SAN JOSE-I	PHOENIX-I	MILWAUKEE	BUCYRUS	BALTIMORE	SAN JOSE-II	ATLANTA	TULSA	PHOENIX-II	SEATTLE
BOD (lb/curb mi)	16	6.5	12	2.9	61	53	1.9	14	10	4.8
COD (lb/curb mi)	310	30	48	29	20	400	13	30	54	17

Note: Tabulated values are computed average extrapolated from observed loading intensities in several land-use areas having different antecedent accumulation periods. For this reason, the values should be used with caution.

It should be noted that while BOD tests were run for many samples collected from street surfaces, the data should be viewed with some skepticism. This is primarily due to the fact that the presence of toxic materials can seriously interfere with measured BOD results. Such materials (particularly heavy metals) have been found to be present in many samples at levels far in excess of those known to cause substantial interference. Note that the interference is in the direction of yielding low results, so that our measurements should probably all be raised somewhat (by how much we would not speculate).

The COD test provides a better basis for estimating the oxygen demand potential, primarily because it is not subject to interference by toxic materials. COD tests were run on the bulk of the samples collected.

Oxygen demand values were measured to evaluate the pollution potential of street runoff but also to reflect suspected differences and trends with respect to such factors as land use, geographic locale, particle size range, etc. For the most part, the data are not very informative (i.e., differences are notable but rather inconsistent). Numerous cross-checks were run to verify test data and point up any errors in procedure and/or computation, but to little avail. Apparently, even though many large samples were collected in many areas and multiple tests run on each, the heterogeneous nature of the material collected inherently yields high deviations.

This lack of regularity is particularly evident in comparing oxygen demand loading from city to city. Figures 9, 10, and 11 plot the loading intensities for the same ten tests in terms of three indices of organic matter (or oxygen demand); e.g., BOD, COD, and volatile solids.

Some trends are apparent where loading intensities are compared on the basis of land-use category, as shown in Figs. 12 and 13. Specifically, over the ten city samples included, light industry tends to be heavily loaded with both BOD and COD and the commercial areas (suburban shopping centers and central business districts) only lightly loaded. The reason for this pattern is not understood. However, there is a tendency for public works departments to concentrate sweeping efforts in commercial areas. Spillage of loads from trucking operations could account for the high values in light industrial areas (these are often dominated by warehousing operations, bulk materials storage, and light manufacturing). It is of interest to note that, on a total solids basis (organic plus inorganic solids), heavy industry is far dirtier than light industry (see Fig. 5 and Table 7). Obviously, the dirt from heavy industry contains far less organic matter (as would be expected).

Table 7

LOADING INTENSITIES ON STREETS - VARIATION BY LAND USE

	LOW/OLD/ SINGLE	LOW/OLD/ MULTI	MEDIUM/ NEW/ SINGLE	MEDIUM/ OLD/ MULTI	LIGHT INDUSTRY	MEDIUM INDUSTRY	HEAVY INDUSTRY	CENTRAL BUSINESS DISTRICT	SUBURBAN SHOPPING CENTER
BOD (lb/curb mi)	8.6	20	5.1	10	39	10	13	2.4	2.5
COD (lb/curb mi)	27	23	17	34	190	53	58	8.7	6.0
Total Solids (lb/curb mi)	1000	1000	480	1300	2300	900	3900	280	290

As reported later in this section, it was found that rainfall washes streets fairly clean, removing a substantial fraction of the contaminants. Following a rain, contaminants build up, increasing with respect to time. A subject of interest here was to determine the manner in which oxygen demand loadings build up following a rain. BOD and COD loadings in lb/curb mile were first plotted vs time since last rainfall. These increased rather steadily, as would be expected. Of more interest, however, are the plots of Fig. 14 which show how the oxygen demand strengths of unit amounts of solids samples increase with time [i.e., percent by

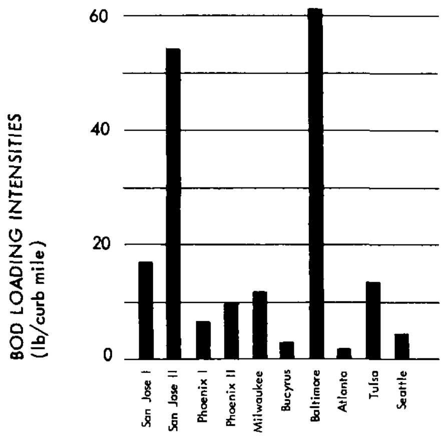


Fig. 9. BOD Loading Intensities on Streets - Variation Between Cities

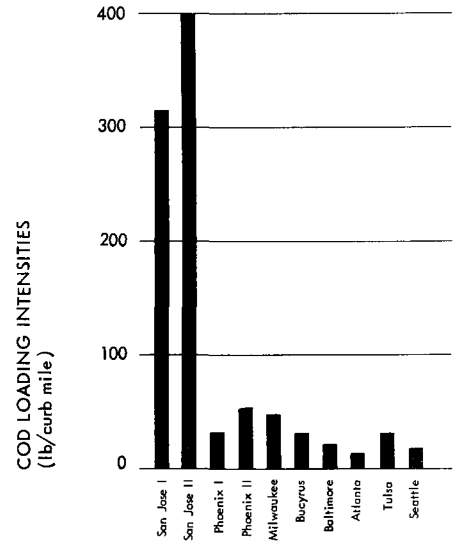


Fig. 10. COD Loading Intensities on Streets- Variation Between Cities

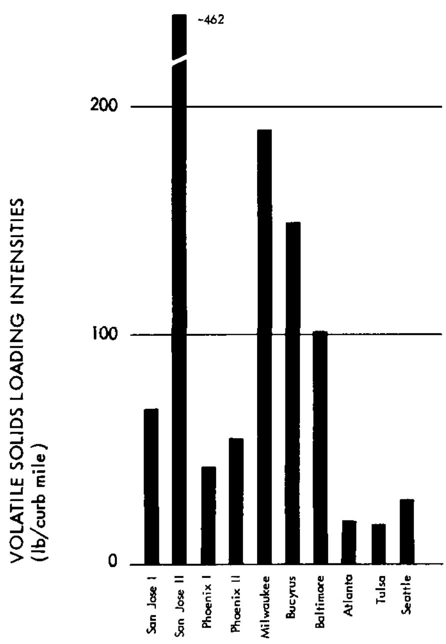


Fig. 11. Volatile Solids Loading Intensities on Streets - Variation Between Cities

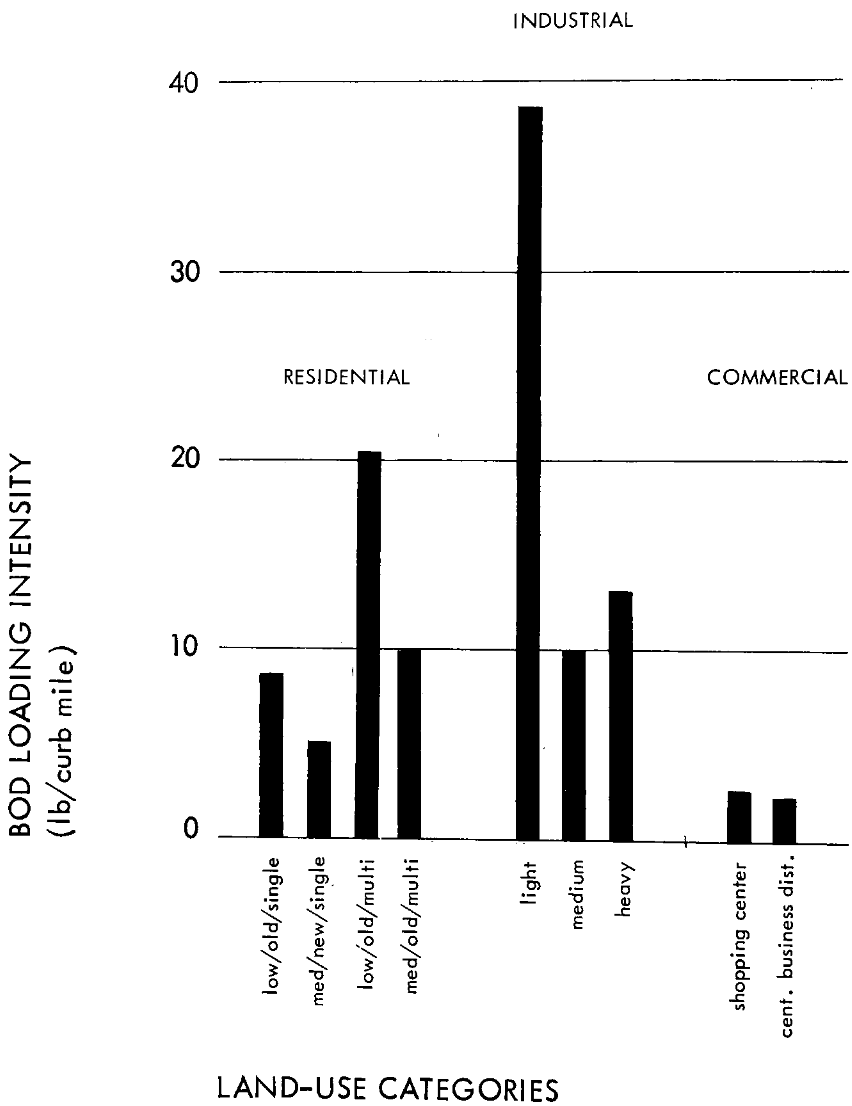


Fig. 12. BOD Loading Intensities on Streets - Variation with Land Use

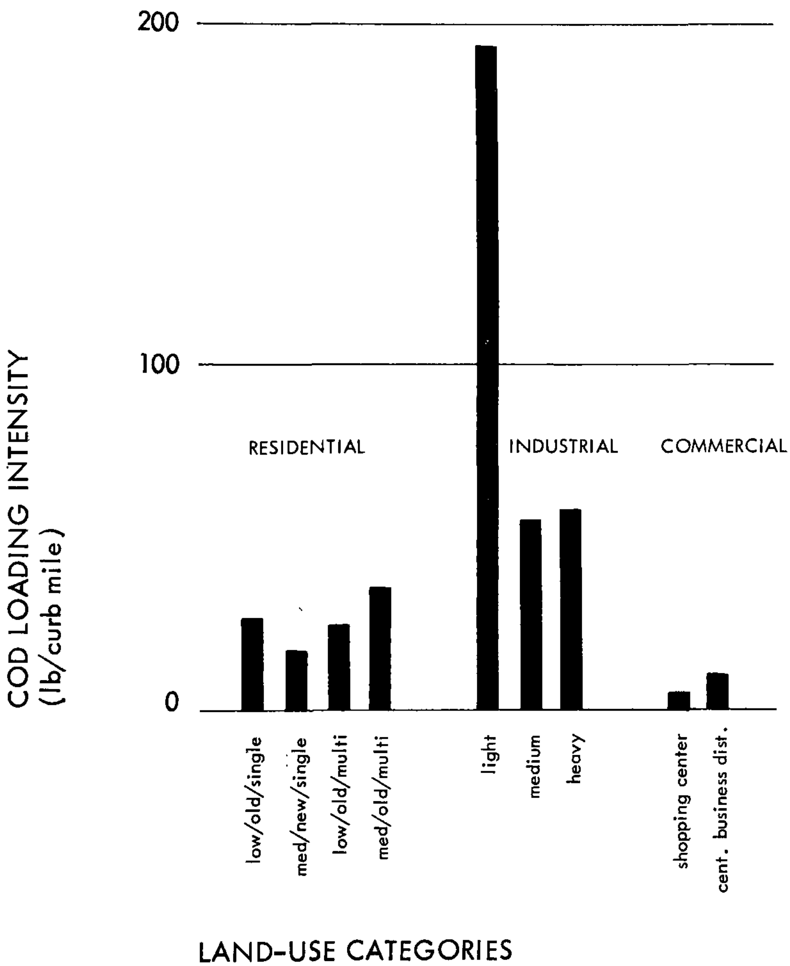


Fig. 13. COD Loading Intensities on Streets - Variation with Land Use

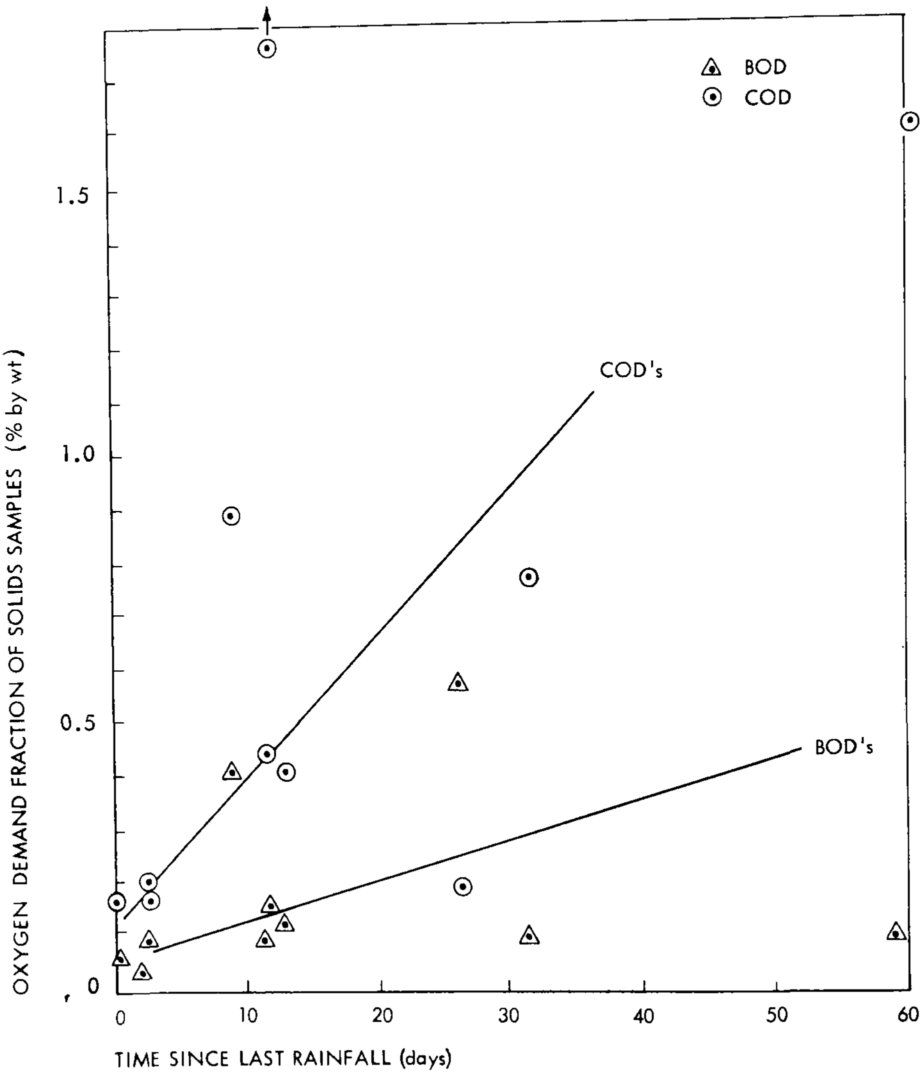


Fig. 14. Increase of BOD and COD Concentrations in Solids Samples with Increased Elapsed Time Since Last Rainfall

weight of total solids, not pounds per curb mile (percent by weight equivalent to pounds of BOD per 100 lb of total dry solids)]. The trend is that the oxidizable fraction of the contaminants continually increases; COD at a greater rate than BOD. Recognizing that the data are limited and quite scattered, we refrain from speculating on the exact shape of these curves (other than to say that they probably level out somewhat, given sufficient time). The conclusion to be drawn here is that the data support our initial assumption that organic materials (the oxidizable fraction) tend to accumulate on the streets faster than inorganic materials (otherwise the curves would have a negative slope). This conclusion leads back to the issue of the sources of street surface contaminants. Whatever the sources, it is clear that they must be contributing organic matter more rapidly than inorganic matter. Another way to say this is that vehicular inputs, leaves, litter, etc. are dominant over sand and dust-like material. Further, these data seem to indicate that fixed, constant sources of material containing both organics and inorganics (the street surface itself is the prime example) must be insignificant contributors to the total load since their curve (if considered alone) would plot as a straight horizontal line on Fig. 14. Note also that there is no evidence that the pollution strength of the solids decreases with time of exposure (through weathering) even up through as much as 60 days.

As discussed previously, an important characteristic of street surface contaminants is their particle size distribution. This is because the size of solids determines their transport on the street (by wind, water, and traffic effects) and the ease with which they are removed by various cleaning techniques (sweepers, vacuum sweepers, flushers, even catch basins). Furthermore, particle size is important in terms of pollutional aspects (i.e., where the particles end up and what types of effects they will have).

Figure 15 shows how the organic matter in street surface contaminants is distributed between particle size ranges (here, volatile solids is being used as an indicator of organic matter). Composites representative of various cities and groups of cities were analyzed. Note that in all cases the finer sizes tend to contain more organic matter than the coarser sizes. This is reasonable since organic matter is typically low in structural strength and can easily be ground into fine particles. Furthermore, since non-particulate organic matter often adheres to the surface of particles, the finer the particles involved the more organic matter will adhere (because fine particles have greater unit surface areas than coarse particles). This association of higher volatile solids with fine particle size ranges is quite consistent from composite to composite as shown by the shaded zones for each plot in Fig. 15.

BOD and COD were also analyzed to identify any relationships between oxygen demand and particle size. The resulting trends (the data are tabulated in Appendix C) are similar to Fig. 15, although somewhat less consistent (presumably due to interferences in the chemical interactions in the analyses).

Differentiation into size ranges is important because it allows comparison with the efficiency of street cleaning devices, as determined in Section V. The size ranges at which sweepers are essentially ineffective (< 246 microns) are observed to contain 33.9 to 99.5 percent of the total BOD and COD loading. In other words, the majority of the oxygen demand observed will run off the street with rainfall.

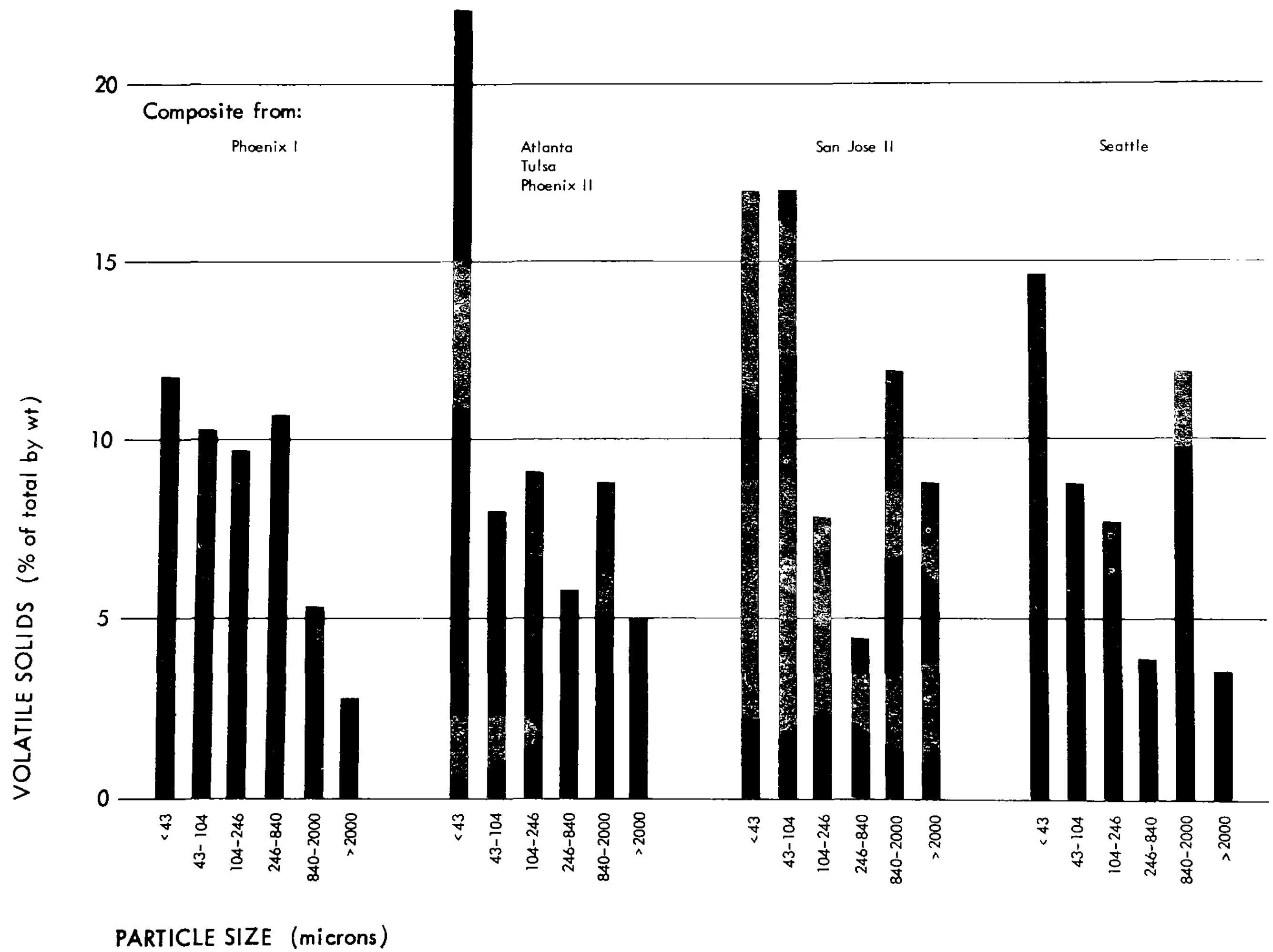


Fig. 15. Volatile Fraction of Street Surface Contaminant Solids - Distribution between Particle Size Ranges

Algal Nutrients

An important aspect of water quality is its aesthetic appeal. Any visual evidence of pollution therefore limits a water's beneficial uses. While algal nutrients generally do not in themselves affect the appearance of water, the aquatic growths which they stimulate do by increasing color, turbidity, objectionable floating matter, and slimes. The ultimate effect of nutrient discharges to receiving waters is eutrophication. This is the term used to describe waters in which there is a high level of phytoplankton activity, the results often being highly turbid, colored waters having objectionable tastes and odors. When significant amounts of nutritents are present in the water system, it is virtually impossible to reverse the process and lower the nutrient level. This is due in part to the fact that plant activity results in the conversion of nutrients into plant matter and proteins, but, upon decomposition, the nutrients are released back into the water system in a closed cycle. With phytoplankton activity, the surface layers become supersaturated in dissolved oxygen during periods of photosynthesis. Then, during periods of low illumination, the algae consume oxygen. Eutrophied bodies of water can therefore exhibit marked fluctuations in oxygen content, a situation which is unfavorable to most aquatic life. Possibly the most notorious aspect of eutrophic waters is the occasional occurrence of an algae "bloom," wherein the waters become loaded with tremendous amounts of algae. Natural byproducts of algae metabolism often include substances which can produce tastes and odors along with possible toxic substances. Normally, such substances are too dilute to be of much concern. During a bloom, however, they become a problem. Further, when the bloom dies out, large quantities of decomposing algae can exert tremendous oxygen demand, possibly leading to anaerobic conditions and stratification of relatively quiescent waters.

Nitrogen and phosphorous compounds are generally considered to be the most important common algal nutrient compounds in receiving waters. In this study these were measured as total Kjeldahl nitrogen, soluble nitrates, and total phosphates. Phosphate compounds exist in several chemical forms in nature. The most available form is orthophosphate (organically bound), while polyphosphate is of only minor consideration. Polyphosphates are converted with orthophosphates in aqueous environments within several days (usually within several hours). Therefore, total phosphates is a valuable measure of phosphorous nutrient impact. Nitrogen also exists in several forms in nature, but the forms of primary interest in terms of availability are nitrates and ammonium nitrogen. Again, since the nitrogen in an aqueous system can be converted in various ways to one of these two forms, the total nitrogen test is indicative of nitrogen nutrient availability.

Limitations on nutrient levels of receiving waters are established to prevent concentrations from building up which would

- lead to uncontrollable algal activity
- cause harmful physiological effects among consumers
- interfere with certain water treatment systems.

While there is much controversy as to how much nutrient is too much, the following maximum levels have been recommended by the Committee on Water Quality Criteria (Ref. 8) to prevent eutrophication:

Phosphates - 0.015 mg/ℓ (ppm)

Nitrogen - 0.3 mg/ℓ (ppm)

The U.S. Public Health Service (Ref. 9) recommends the following limit on nitrogen in surface and drinking waters:

10 mg/ℓ of nitrate nitrogen

It has been found that the consumption of water having nitrate levels exceeding this limit by infants may lead to a serious blood disease: methemoglobinemia ("blue babies"). The Committee on Water Quality Criteria (Ref. 8) points out that difficulties with coagulation in water treatment plants often result when concentrations of complex phosphates exceed 0.1 mg/ℓ . (mg/ℓ = milligrams of substance per liter of water, on a dry weight basis.)

The eutrophication and methemoglobinemia problems are usually encountered when pollutants enter the water system constantly (assuming the system is not quiescent). Shock loadings (as might occur from street runoff) would be of less consequence in well mixed, free-flowing rivers. In the case where street runoff enters lakes or swamps, however, nutrients could accumulate, eventually reaching and passing recommended levels.

Data on loading intensities of nutrients found on street surfaces are summarized in Table 8. Percent-by-weight values can be thought of conveniently as the "strength" of the dry solids collected from the street surface. These strength values vary somewhat from one land-use category to another, but only over a moderate range. This is evident from the plots in Fig. 16. These data, based on the analysis of samples from numerous cities, imply that all street surface contaminants are similar in composition from site to site (at least from the standpoint of phosphates, nitrates and Kjeldahl nitrogen). It would be pure speculation to extend this conclusion very far, but it is interesting. It was assumed at the outset of the study that algal nutrients would probably be found in greatest concentration in residential areas because of the use of fertilizer in domestic gardening. The data here do not support this hypothesis.

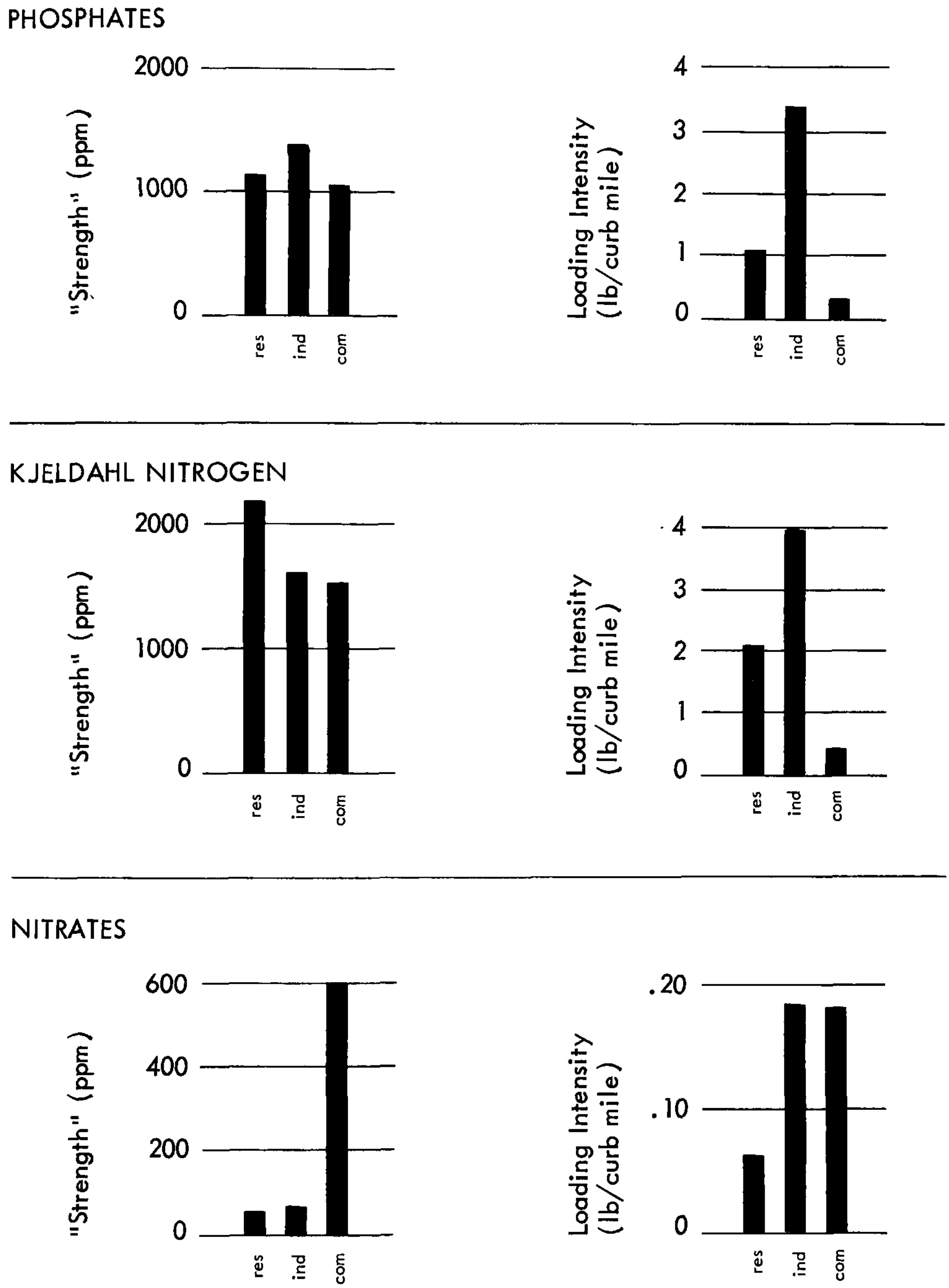


Fig. 16. Nutrient Loading Intensities and Waste "Strengths" - Variation with Land Use

Table 8

NUTRIENTS IN STREET SURFACE CONTAMINANTS - VARIATION WITH LAND-USE CATEGORY

	STRENGTH (% by weight)	LOADING INTENSITY (lb/curb mi)	(lb/1,000 sq ft)
Phosphates			
Residential	0.113	1.07	12.3
Industrial	0.142	3.43	39.4
Commercial	0.103	0.29	3.41
Kjeldahl Nitrogen			
Residential	0.218	2.04	23.8
Industrial	0.163	3.94	67.1
Commercial	0.157	0.45	5.17
Nitrates			
Residential	0.0064	0.063	0.70
Industrial	0.0072	0.178	2.00
Commercial	0.0600	0.172	1.96

Note: The term "strength," as used here, refers to the amount of contaminant contained in the dry solids collected from the street surface (on a weight basis), i.e., a phosphate value of 0.1 percent would be equivalent to 1 lb of phosphate per 1,000 lb of sample.

Table 8 reports information on nutrient loading intensities as well as strength. These values, expressed in terms of both pounds per curb mile and pounds per 1000 sq ft, vary considerably with respect to land use. However, the variations are due primarily to differences in total solids loading intensities. Figure 16 indicates the range over which values of loading intensity differ.

The distribution of nutrients by particle size is shown in Figs. 17, 18, and 19. Note that phosphates exhibit a distinct pattern, most being in the smaller size ranges. The values for total nitrogen vary widely, exhibiting no definite pattern. Nitrates show a pattern similar to phosphates but less pronounced. The discrepancy between total nitrogen and nitrates may be due to the presence of other nitrogen species which were not measured.

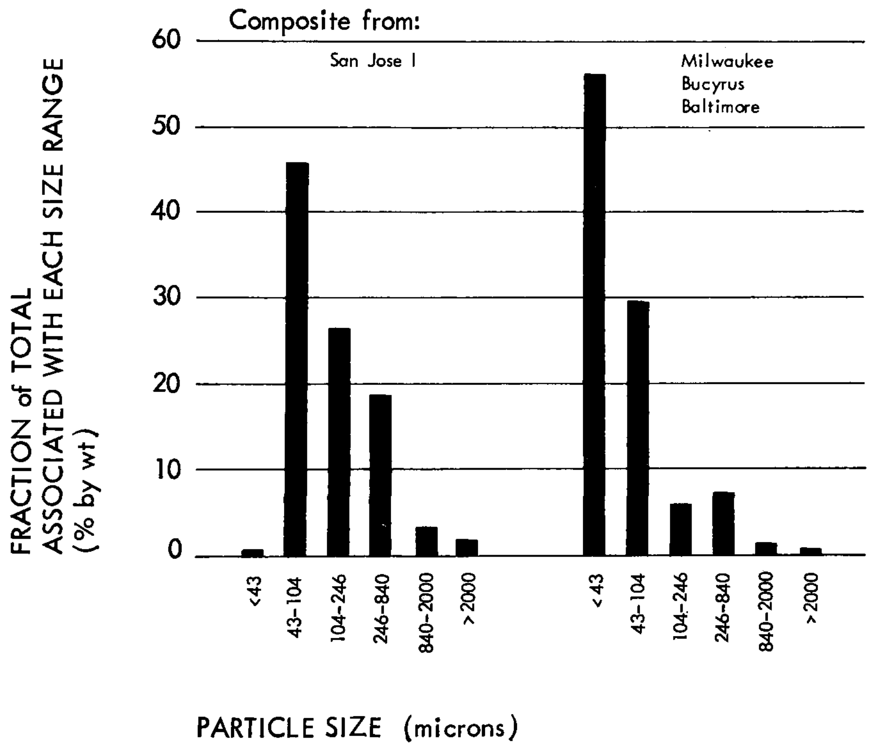


Fig. 17. Variation of Total Phosphates with Particle Size

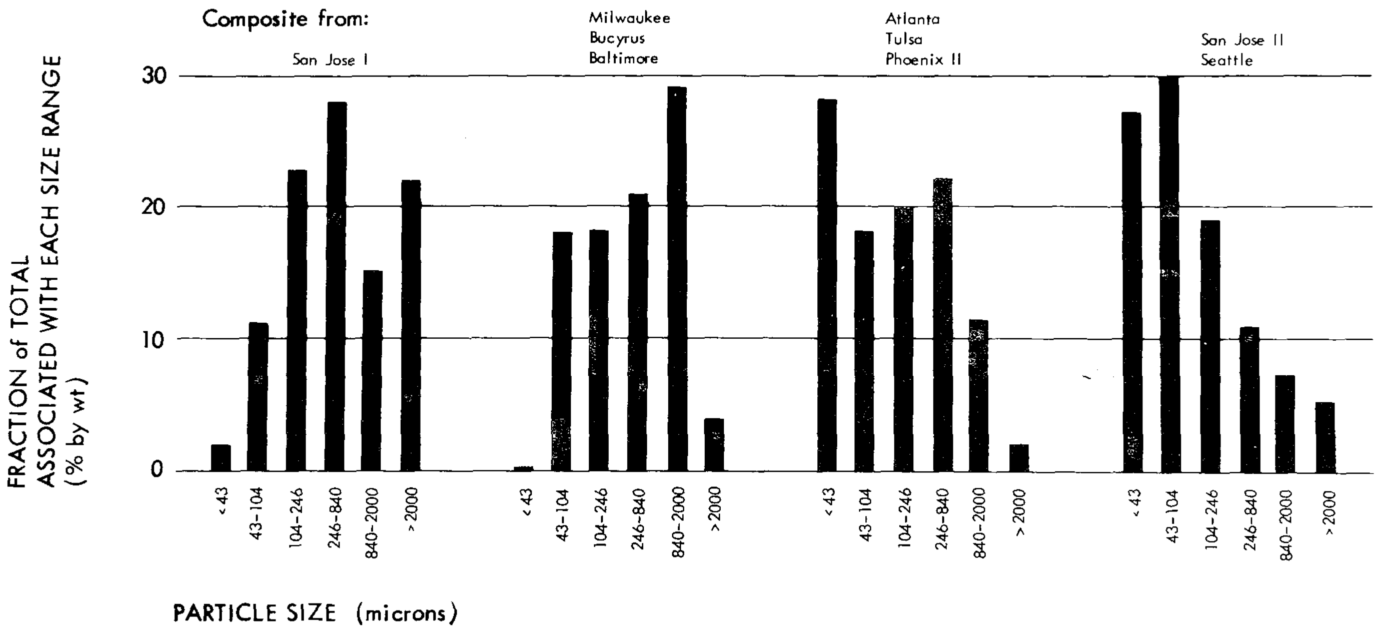


Fig. 18. Variation of Kjeldahl Nitrogen with Particle Size

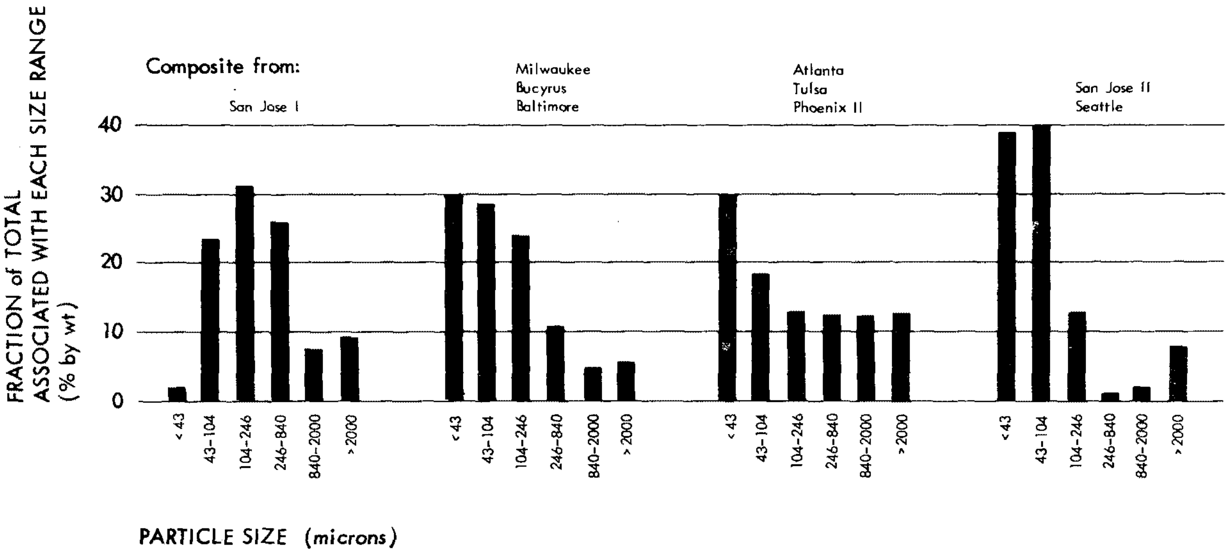


Fig. 19. Variation of Nitrates with Particle Size

Coliform Bacteria

The presence and quantity of pathogenic bacteria in natural waters are difficult to determine by routine analytical methods. It has, therefore, become common practice to test for other bacteria which are known to be associated with pathogens. The coliform group of organisms is widely used for this purpose. These "indicator organisms" are found naturally in the intestines of warm-blooded animals. Thus, when analysis of water reveals the presence of these indicators, it is assumed that contamination by feces has likely occurred. However, coliform organisms also live naturally in common solids, although the particular type of coliform is different. This difference can be determined readily through routine bacteriologic analyses.

Two terms commonly used in describing the bacteriologic quality of water are "total coliforms" and "fecal coliforms." These terms are actually descriptive of test procedures rather than classes of organisms, but are often used to describe both. "Fecal coliforms" are those types which are found in warm-blooded animals and do not include soil bacteria. Their presence has been found to correlate quite consistently with the presence of various pathogenic organisms. "Total coliforms," on the other hand, include both fecal coliforms and common soil bacteria. They are not, therefore, considered to be as reliable an indicator of pathogenic bacteria, given a water contaminated by an unknown source.

It is generally assumed that the presence of fecal coliform bacteria in a water supply signifies contamination by sewage and, therefore, the possible presence of pathogens. It has been shown (Ref. 10) that swimming in water containing high total coliform counts increases the probability of contracting paratyphoid, diarrhea-enteritis, minor gastro-intestinal disturbance, and eye, ear, nose and throat infections. Drinking from a water supply which has a high total coliform count obviously increases the likelihood of contracting any of these illnesses.

The Public Health Service has established drinking water standards which are accepted by many state and local regulatory agencies. The standards for bacteriological quality are expressed as the maximum permissible number of total coliform organisms measured per volume of water sample. If the supply has less than 2.2 total coliforms/100 ml it is considered generally acceptable. If greater than 4 per 100 ml, immediate remedial action is required (Ref. 9).

In this study, both total and fecal coliforms were measured during the field test series using standard membrane filter techniques almost immediately after samples were collected. Table 9 summarizes the total and fecal coliform counts observed on street surfaces, expressing them by land-use categories.

Table 9

COLIFORM BACTERIA IN STREET SURFACE CONTAMINANT - VARIATION WITH LAND-USE CATEGORY

	STRENGTH[a] (10^6 org/lb)	LOADING INTENSITY (10^6 org/curb mi)	(10^6 org/1,000 sq ft)
Fecal Coliforms			
Residential	15.4	6,100	70
Industrial	1.82	2,600	30
Commercial	175	34,000	390
Total Coliforms			
Residential	80.8	60,000	696
Industrial	187	150,000	1,760
Commercial	79.9	116,000	1,300

Note: The term "strength," as used here, refers to the number of coliforms observed in street surface samples, related to the amount of sample collected (on a dry-weight basis). Standard membrane filter techniques were used throughout for identifying and enumerating coliform organisms. The abbreviation "org" refers to "number of coliform organisms" observed in the analysis.

The distribution of coliforms by particle size was not determined because the heterogeneous character of the material, the necessity of performing the tests in the field to restrict any growth and reproduction of the coliforms, and the chance of physically disturbing the clumps of fecal matter which would change the size distribution.

Comparing the coliform counts obtained from the dry swept samples and from the flushed liquid sample indicates that the coliforms do not associate preferentially with either the liquid or the solids. This may imply that the coliforms are distributed randomly throughout the size ranges. The cleaning efficiency for the coliforms would therefore closely resemble the cleaning efficiency of the solid material.

Note that the data for total coliforms are more consistent than those for fecal (by land use as well as the spread of values found). This may be because the fecal coliform test is more complex or because fecal matter tends to be located in high concentrations in small areas (thereby reducing sampling reliability). The strengths of the street dirt may be the most important issue here. The observed strengths vary with land use for both total and fecal coliform counts. The total counts show little variation by land use, with the residential and commercial areas showing the lowest counts. The fecal coliform counts show a wider spread, with the industrial being the lowest and commercial the highest. The loading intensities per unit area or length of curb reflect the total amount of dirt collected.

It should be noted that these values cannot be used as a basis for estimating the coliform levels in the receiving waters. In most instances, coliforms die off rather rapidly in receiving waters (although notable exceptional cases have been observed where rapid regrowth has occurred). For this reason, given data for the amounts found on streets, it is unwise to speculate at all as to the coliform levels in receiving waters.

Heavy Metals

Heavy metals are of concern because of their high potential toxicity to various biological forms. Samples collected from street surfaces in many cities were analyzed for the following metals: zinc, copper, lead, nickel, mercury, and chromium (samples were preconcentrated before analyzing for mercury). Atomic absorption techniques were used. Early in the sampling program tests were run for arsenic and cadmium but, since only insignificant amounts were detected, these tests were discontinued.

The samples were composited in various ways and analyzed to reflect trends of particular interest. Table 10 reports the heavy metals loading intensities (in pounds per curb mile) found in each of the cities tested. Figures 20 and 21 show how the heavy metals are distributed between major land-use categories (considering all cities together). Figure 22 shows distributions by particle size (for composites prepared from samples collected in several cities).

The thing to note here is that, from the standpoint of concentration alone, zinc and lead have the heaviest loadings, chromium and nickel the lightest. These trends are borne out in all of the cities tested. It should not be concluded, however, that these metals are necessarily the worst polluters; they may be, but this cannot be stated at the present time. The toxic effect of a given metal on an aquatic environment is dependent upon a number of complex and rather poorly understood factors. One of the most important factors is the form of the particular metal. The data reported here are the total amounts of such metals present, without regard to their chemical/physical states (i.e., their valence, whether they are tied up into complex inorganic or organic compounds, etc.). Analyses of such materials should be performed as part of a more definitive future study. At this time it is possible only to consider the significance of finding such metals in their most toxic form, recognizing the dangers inherent in making such speculations. It is strongly urged that the conclusions drawn below be adequately qualified if ever quoted out of context.

Table 10

HEAVY METALS LOADING INTENSITIES (lb/curb mile)

	ZINC	COPPER	LEAD	NICKEL	MERCURY	CHROMIUM
San Jose-I	1.4	.49	1.85	.19	.20	.10
San Jose-II	.28	.020	.90	.085	.085	.14
Phoenix-II	.36	.058	.12	.038	.022	.029
Milwaukee	2.1	.59	1.51	.032	-	.047
Baltimore	1.3	.33	.47	.077	-	.45
Atlanta	.11	.066	.077	.021	.023	.011
Tulsa	.062	.032	.030	.011	.019	.0033
Seattle	.37	.075	.50	.028	.034	.081
Arithmetic Means	.75	.21	.68	.060	.080	.12

Before proceeding to a discussion of the potential significance of each heavy metal, consider their distribution by land use and particle size. Figure 20 shows how heavy metals are distributed by major land-use category. For all metals except mercury, loading intensities (in lb/curb mi) are heaviest in industrial areas and lightest in commercial areas. Before any conclusions are drawn regarding the implications of these data, it is well to consider Fig. 21 which expresses the distribution in terms of the "unit strength" of the street surface materials (percent by weight; i.e., pounds of metals per 100 pounds of dry solids). Here the distinct trends as to land use disappear. This is probably because the dominant patterns in total solids loadings overshadow patterns in concentration levels of metals.

Figures 22 and 23 show the distribution of heavy metals between particle size ranges. The plots, which are based on data for samples collected from five cities, show little trend except for lead. There seems to be a distinct tendency for lead to be associated with fine particles. If it is assumed that antiknock gasoline additives are the principal source of lead found on street surfaces, then these results are as would be expected, since particulate exhaust emissions would be very fine indeed.

The following paragraphs provide specific information on each of the heavy metals found here.

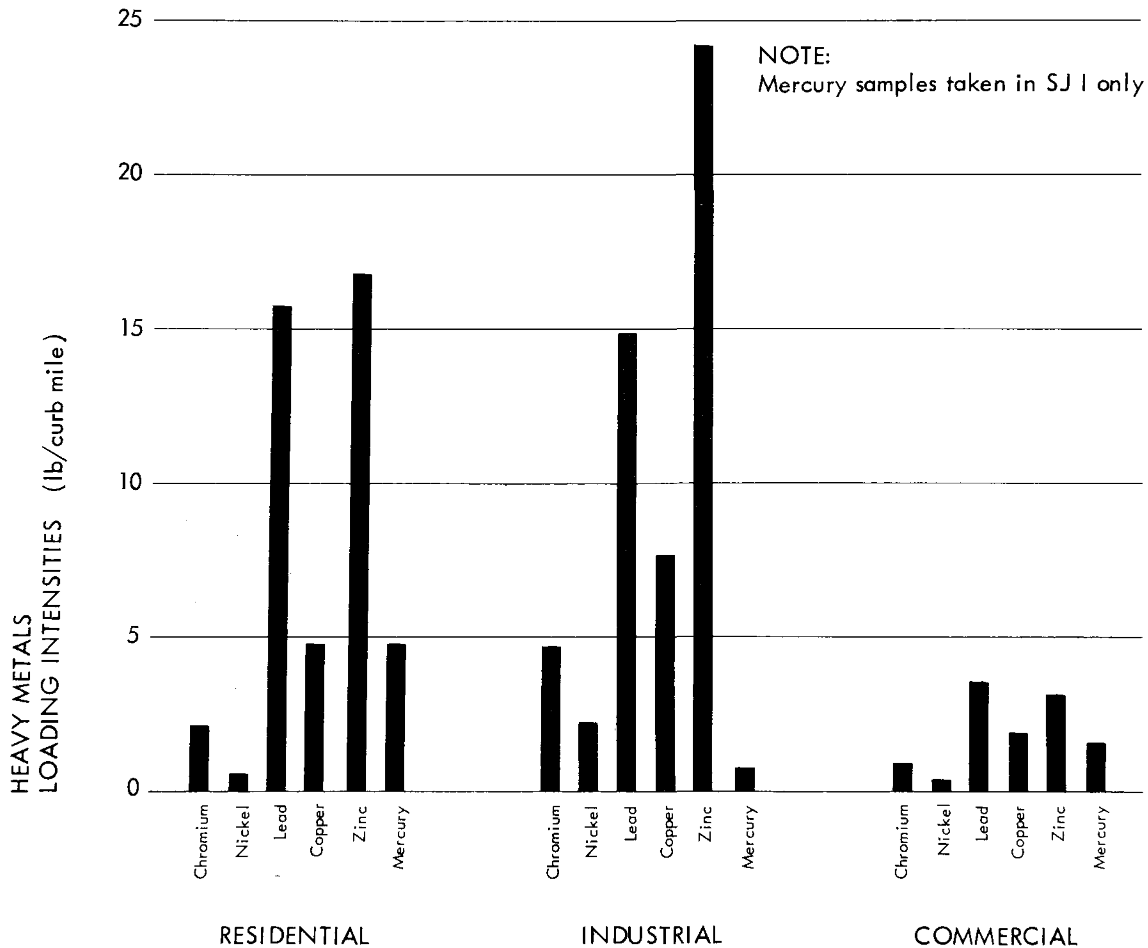


Fig. 20. Heavy Metals Loading Intensities on Street Surfaces - Variation with Land Use

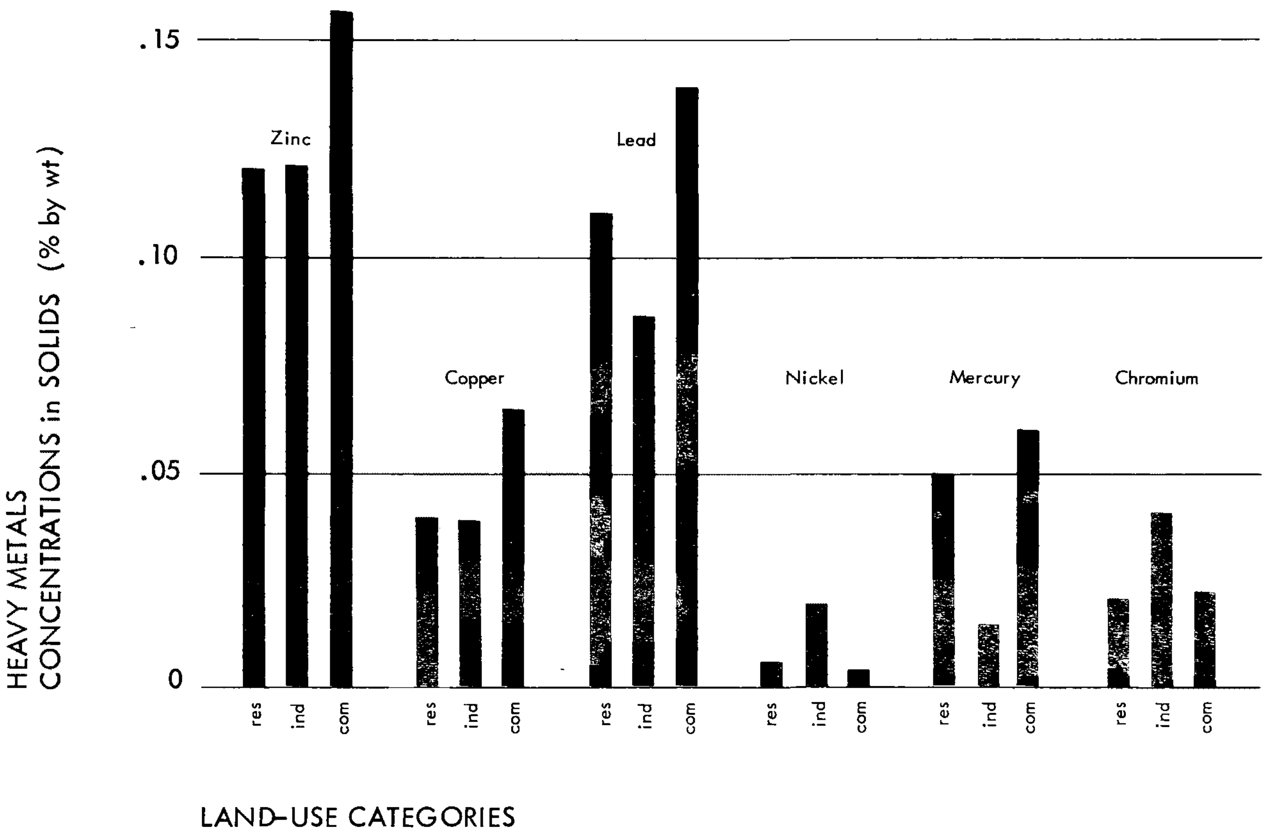


Fig. 21. Heavy Metals Concentrations - Variation with Land Use

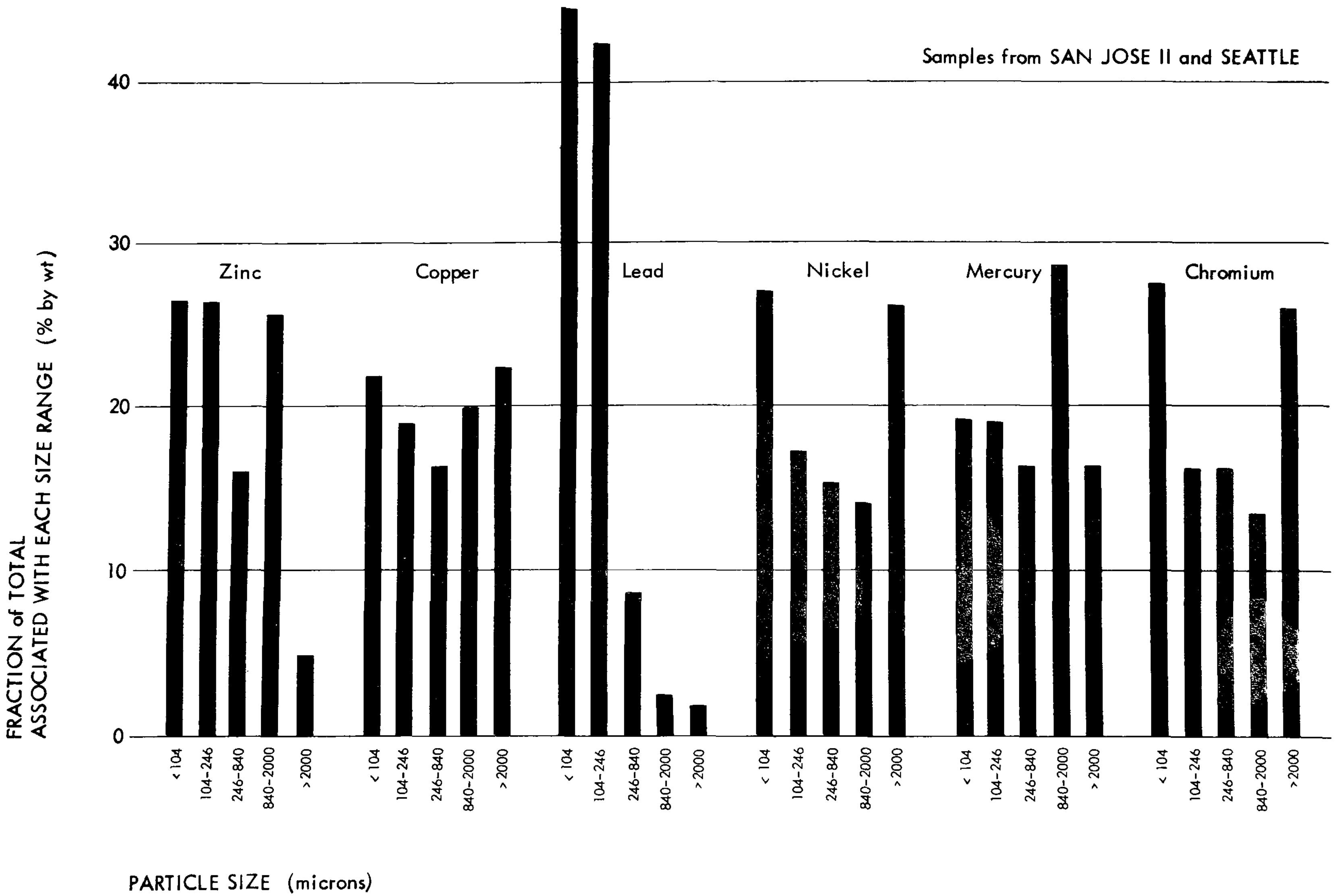


Fig. 22. Heavy Metals Concentrations - Variation with Particle Size

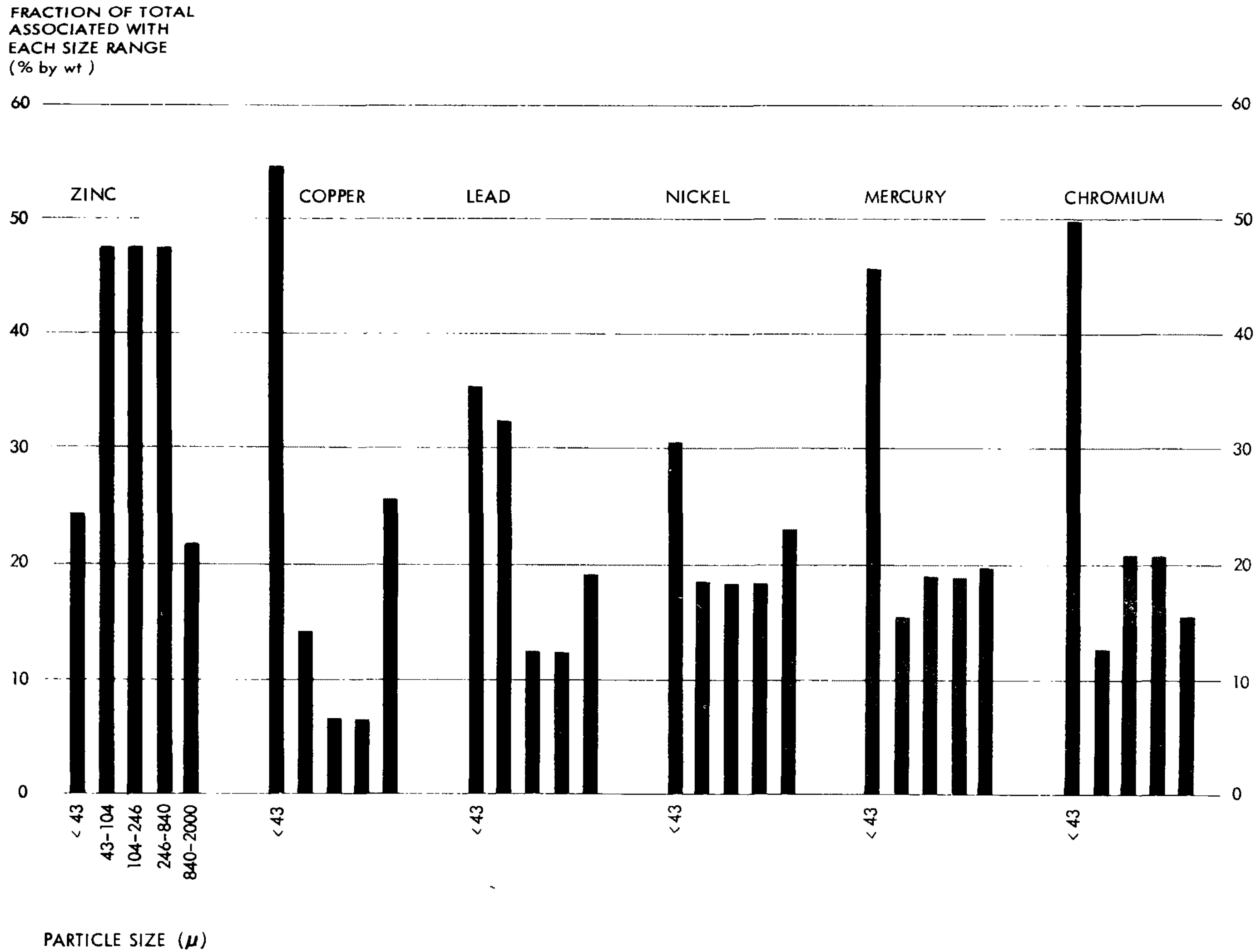


Fig. 23. Heavy Metals in Street Surface Contaminants - Variation by Particle Size for Bucyrus, Atlanta, Tulsa, and Phoenix II

ZINC - Most common zinc compounds are not particularly toxic in low-to-moderate concentrations; nor are they particularly soluble in water. It is estimated that people consume on the order of 10 to 15 mg of zinc daily in their diets (Ref. 11). From the standpoint of water supplies, 5 ppm is the USPHS drinking water limit (Ref. 9) (Concentrations of 25 to 30 ppm have an objectionable taste and appear milky.) Aquatic organisms are more sensitive than humans to zinc. Concentrations as low as 0.1 to 1.0 ppm have been found lethal to fish and other aquatic animals (Ref. 10). Copper is reported to have a synergistic effect with zinc toxicity (i.e., a given concentration of zinc becomes more toxic to certain species when copper is present in the solution).

Analysis of street surface contaminant samples indicates that zinc is present in higher loading intensities than other heavy metals (see Table 10). Observed values range from a low of 0.062 lb/curb mile (Tulsa) to a high of 2.1 (Milwaukee); the mean for all cities tested was 0.75 lb/curb mile. Zinc was not found to associate with any particular size range of particles. Sources of zinc in street surface contaminants have not been identified specifically; however, substantial quantities of zinc are used in formulating tire rubber compounds.

COPPER - In humans and other higher organisms, copper is not particularly toxic. It does not exhibit cumulative effects, as do many other heavy metals. USPHS drinking water standards limit copper to 1.0 ppm (Ref. 9). Recommended limits for irrigation water are 0.1 ppm, 0.05 ppm for salt water organisms, and only 0.02 ppm for fresh-water organisms. These values recognize the fact that copper is toxic to lower biological forms (indeed, copper compounds are typically used in low concentrations to control aquatic weeds and algae).

Loading intensities for copper on street surfaces loadings of zinc and lead and the light loadings of chromium and nickel (see Table 10). Observed loadings range from a low of 0.02 lb/curb mile (San Jose II) to a high of 0.59 (Milwaukee); the mean for all cities tested was 0.21 lb/curb mile. Copper was not found to associate with any particular range of particle sizes. The sources of the copper in street surface contaminants have not been identified.

LEAD - The effects of lead on biological forms are also quite varied. In vertebrate animals, lead is a cumulative poison which typically concentrates in bone. It is estimated that humans consume on the order of 0.33 mg daily in their diets. USPHS drinking water standards limit lead to 0.05 ppm. At somewhat higher concentrations, it has been reported to be moderately toxic to fish and other aquatic organisms (Ref. 10).

Loading intensities for lead in street surfaces were quite high, second only to zinc (Table 10). They ranged from a low of 0.030 lb/curb mile (Tulsa) to a high of 2.0 (San Jose II); the mean for all cities tested was 0.68 lb/curb mile. Figure 22 reflects the very strong tendency lead has for being preferentially associated with small particle size range solids (nearly 90 percent of the total lead found was with particles smaller than 246 microns, the size of a fine, silty sand). The term "associated" is used here because it is not known whether the lead exists in a compound whose particles are this size or if the lead is somehow adhering to particles of this size. Probably both situations exist. If the primary source of lead is gasoline antiknock compounds (a plausible speculation, but one that should be investigated), then it is consistent that the bulk of material found would be associated with very fine particles.

NICKEL - This heavy metal is not considered harmful to man in normal concentrations; no USPHS limit for nickel in drinking water has been established. It is, however, moderately toxic to aquatic organisms and can be very toxic to plant life, depending on the chemical form (Refs. 12,13).

Of all the heavy metals tested here, nickel was found to have the lowest loading intensities, ranging from a low of 0.011 lb/curb mile (Tulsa) to a high of 0.19 (San Jose I); the mean for all cities tested was only 0.060 lb/curb mile. Nickel was not found to be concentrated appreciably in any particular size range of particles. The sources of nickel in street surface contaminants have not been identified.

MERCURY - In both its free state and in many of its combined forms, mercury can be highly toxic to a broad range of biological forms. Indeed, this element has recently been the subject of much controversy, in public as well as technical circles. Many studies are presently underway to develop a better understanding of mercury's role in various environmental problems. Thus, a definitive discussion at this point would probably be of little long-term value. However, it is probably safe to state that mercury can be expected to be detrimental to aquatic ecosystems at concentrations as low as 0.005 ppm.

Mercury was found to have only moderate loading metals (Table 10). Observed values ranged from a low of 0.019 lb/curb mile (Tulsa) to a high of 0.30 (San Jose I); the mean value for all cities tested was .081 lb/curb mile. Mercury was not found to associate with any particular size range of particles. The source of mercury in street surface contaminants has not been identified.

CHROMIUM - The toxicity of chromium is distinctly dependent upon its chemical form. The metal form Cr^{o} is extremely common but virtually inert, whereas the hexavalent ion Cr^{+6} is extremely toxic. USPHS drinking water standards limit hexavalent chromium to 0.05 ppm but state no limit for trivalent forms (Ref. 9). While its physiological effects are poorly understood, chromium is not known to be a cumulative poison to humans (Ref. 10). Toxic effects on lower biological forms are variable. Limits of 100 ppm for fisheries and 5 ppm for irrigation water have been recommended.

Chromium was not found in substantial quantities in street surface contaminants (only nickel was lower). Observed loading intensities ranged from 0.0033 lb/curb mile (Tulsa) to 0.45 (Baltimore), the mean value for all cities tested being only 0.12 lb/curb mile. These values were for total chromium (i.e., all chemical forms taken together). Considering the fact that vehicle bumpers and trim are typically plated with chromium, these low values would suggest that the amounts of trivalent and hexavalent chromium present on street surfaces are probably very low indeed.

Pesticides

The widespread presence of pesticides in the environment has recently caused much public and private concern because of their potential for upsetting ecological balances. Gas chromatographic techniques have revealed the presence of various combinations and concentrations of organic pesticides in all the street surface samples tested. Organic pesticides in particular were examined because of their high persistence in the environment (Ref. 14). The specific substances analyzed for are listed in Table 11 along with their respective detection limits (i.e., the lowest concentrations which can be measured quantitatively by the gas chromatographic methods employed here). Not all, however, were found to be present in street surface samples. Tables 12 and 13 report the loading intensities for all pesticides found in the samples tested. In the interest of obtaining maximum benefit from available funds, samples collected from land-use areas of several cities were combined into composite samples prior to analysis (the analytical costs for pesticide determinations are quite substantial). Several conclusions can be drawn from the data in Table 12. First, the chlorinated hydrocarbons: p,p-DDD, p,p-DDT, and dieldrin are typically found in highest concentration. Also, PCB's (polychlorinated biphenyls) are present in higher concentrations than pesticides per se. Finally, the amount of these materials (taken all together, pesticides and PCB's) is really rather high, being on the order of 0.00125 lb/curb mile for the cities tested.

It is well to discuss the role of PCB's here. While these industrial chemical compounds are not used as pesticides, they do share many of their properties. They are included here because they, like the chlorinated hydrocarbons, are the subject of much controversy. They have repeatedly been found to correlate with detrimental environmental effects (primarily birth defects in wildlife). They have also been found to be extremely long-lived and are believed to be widely distributed throughout domestic and worldwide ecosystems (Ref. 15). Another important reason for including PCB's here is that their presence can cause interference with analyses for other pesticides. The magnitude or significance of that interference cannot be estimated, however.

Samples from Milwaukee, Bucyrus, and Baltimore were analyzed to show variation with respect to land use and particle size. Table 14, which reports the concentration of each pesticide by major land-use category, reveals no consistent patterns. Figure 24 indicates that DDD, DDT and dieldrin all tend to associate with finer particles but that PCB's associate with coarser particles. The association of pesticides with fine particles supports the speculations made at the outset of the study. No explanation is given for why the PCB's favor the larger particles.

The interpretation of observed pesticide levels is difficult indeed. It should be appreciated that, at the present state of the art, acceptable levels of pesticides in the environment at large are very much a matter of speculation (i.e., no one can say how much is too much). Further, it should be understood that while we conducted many tests and had many analyses run, this effort should be still considered as "spot-checks" rather than an accurate representation of situations in the country as a whole. The important factor, however, is that these materials are present in rather significant quantities. Organic pesticides are normally measured in parts per billion by weight (values

Table 11

DETECTION LIMITS FOR PESTICIDE ANALYSES

Chlorinated Hydrocarbons

	Liquid Samples (ppb)	Dry Samples (ppm)
DDE	0.1	0.01
p,p-DDD	0.1	0.01
o,p-DDT	0.1	0.01
p,p-DDT	0.1	0.01
Chlordane	0.5	0.05
Dieldrin	0.1	0.01
Endrin	0.2	0.02
Lindane	0.1	0.01
α-BHC	0.1	0.01
Heptachlor	0.1	0.01
Aldrin	0.1	0.01
Kelthane	0.2	0.02
Heptachlorepoxide	0.1	0.01
Methoxychlor	1.0	0.10
Toxaphene	2.0	0.20
Thiodan	0.1	0.01
Polychorinated biphenyl	1.0	0.10

Organic Phosphates (Methyl Parathion)

Liquid = 0.01 - 0.001 ppm

Dry = 0.05 - 0.005 ppm

Table 12

PESTICIDE LOADING INTENSITIES
(10^{-6} lb/curb mi)

	p,p-DDD	p,p-DDT	DIELDRIN	ENDRIN	LINDANE	METHOXY-CHLOR	METHYL PARATHION	PCB's	TOTAL OF ALL PESTICIDES AND PCB's
San Jose I	67	110	11	2	17	0	20	1,200	1,427
San Jose II and Seattle	120	170	27	0	0	0	0	1,100	1,417
Phoenix II, Atlanta and Tulsa	34	13	24	0	0	0	0	65	136
Milwaukee	0.5	1.0	10	0	3.1	8500	0	3400	12,000
Bucyrus	83	60	17	0	0	1600	0	650	2,451
Baltimore	100	30	3.0	0	0	170	0	1000	1,300

Table 13

PESTICIDE CONCENTRATIONS
(10^{-9} lb of pesticide/lb of dry solids)

	p,p-DDD	p,p-DDT	DIELDRIN	ENDRIN	LINDANE	METHOXY-CHLOR	METHYL PARATHION	PCB's
San Jose I	73	120	12	2.2	19	0	22	1,300
San Jose II	20	28	4.4	0	0	0	0	180
Phoenix I								
Phoenix II	37	14	26	0	0	0	0	71
Milwaukee	0.19	0.38	3.8	0	1.2	3,100	0	1,300
Bucyrus	61	43	12	0	0	1,200	0	470
Baltimore	100	30	3.0	0	0	170	0	1,000
Atlanta	79	20	55	0	0	0	0	150
Tulsa	100	39	74	0	0	0	0	200
Seattle	270	380	59	0	0	0	0	2,300

Table 14

PESTICIDE CONCENTRATIONS IN TOTAL SOLIDS (ppm)

	p,p-DDD	p,p-DDT	DIELDRIN	ENDRIN	LINDANE	METHOXY-CHLOR	METHYL PARATION	PCB's
Residential								
San Jose I	0.082	0.15	0	0	0	0	0	0.81
Milwaukee	0	0	0.009	0	0	2.5	0	2.0
Baltimore	0.11	0.030	0	0	0	0.19	0	0.99
Industrial								
San Jose I	0.060	0.091	0.031	0	0.031	0	0.037	1.5
Milwaukee	0.	0	0	0	0.001	3.6	0	2.0
Baltimore	0.020	0.020	0.018	0	0	0	0	1.0
Commercial								
San Jose I	0.040	0.030	0	0.058	0	0	0	0.60
Milwaukee	0.020	0.031	0	0	0	1.8	0	0.99
Baltimore	0.020	0.031	0	0	0	0	0	0.51

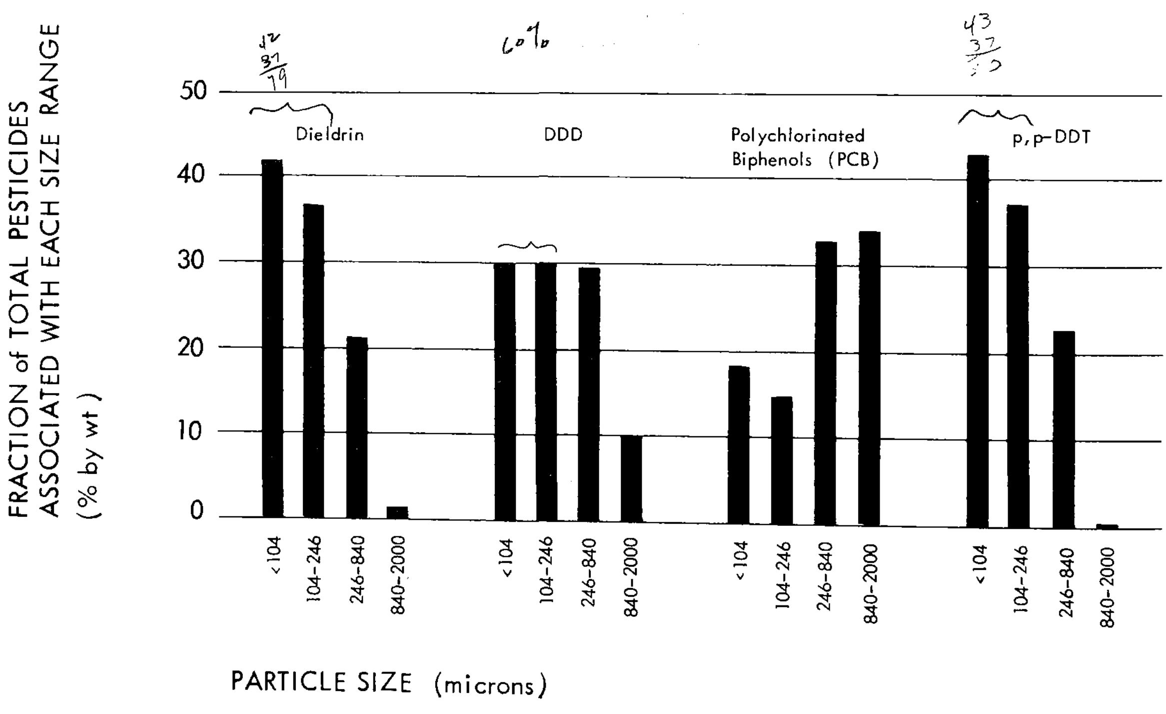


Fig. 24. Pesticide Concentrations - Variation with Particle Size

of several ppb are not uncommon but are cause for some concern when found in the environment). Street surface concentrations, when present, all range in parts per million (on the order of a thousand times higher).

The fate and relative significance of the various pesticides must be considered both in terms of residence on the street surfaces and ultimately in the receiving waters. While pesticides' effects in soil systems have received considerable study, aquatic mechanisms have not been well documented to date.

While they reside on street surfaces (the site of net accumulation), pesticides are subject to a number of degrading actions. Among these are volatilization, decomposition by ultraviolet light and other radiation, chemical degradation, microbial degradation, and sorption and desorption by soil particles. Thus, depending on resident time and the above factors, a certain amount of in situ decomposition will occur on the street surface. The importance of all this on the pollutional effects of street runoff is questionable. When pesticides enter receiving waters, the mechanisms listed above can apply to reduce their effect. However, at the same time, biological "magnification" can occur. Degrading effects are overshadowed by concentrating effects. Chlorinated hydrocarbons are increasingly concentrated by many types of organisms with successive steps up the food chain. This is especially true in the upper trophic levels. Numerous cases of fish kills and damage to invertebrate populations have been reported (Refs. 16, 17, 18, 19). In addition, pesticides tend to concentrate in sediments by adsorption, concentrating them in regions containing additional biologic communities.

TRANSPORT OF CONTAMINANTS

Street surface contaminants are washed into receiving waters via the route illustrated in Fig. 25. Contaminants are

- freed from the street surface itself
- carried transversely across the surface to the gutter by the overland sheet-like flow
- carried parallel to the curb line to the storm sewer inlet by the gutter flow
- dropped through a stormwater inlet and transported to the receiving waters via storm or combined sewers (where catch basins are present, some of the denser particulates are caught by simple sedimentation).

The fact that contaminants move through this sequence is well known. However, the relationships between the contaminants and the various mechanisms involved are only poorly understood. Given this as a

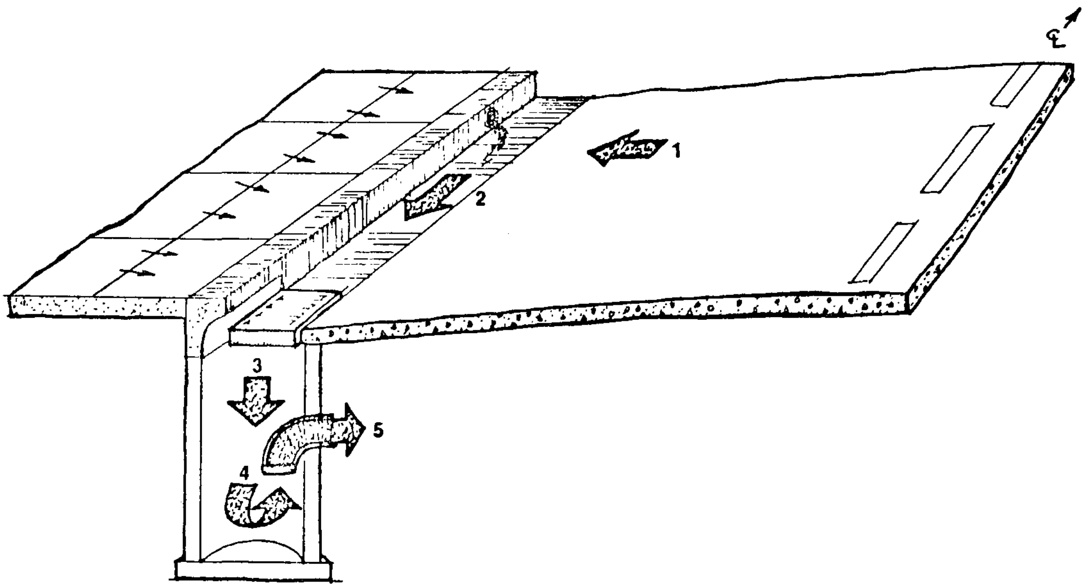


Fig. 25. Transport of Street Surface Contaminants by Runoff

starting point for this study, it was necessary to conduct a series of substudies which would provide a basis for understanding (at least empirically) what happens to elements of street surface contaminants on their way to receiving waters.

The first such substudy was designed to experimentally determine the manner in which contaminants are flushed from the street surface by typical rainfall. A portable rain simulator was designed and built (see Figs. 26 and 27). The simulator applies water uniformly over a fixed section of street at various controlled flow rates. The water, supplied from nearby hydrants, sprays vertically (4 to 8 ft) through hundreds of small jets (0.018 in. dia), which break up into discrete droplets about the size of common raindrops before they fall to the street. The device produces a pattern on the street surface which has the appearance of a moderate-to-heavy rainfall.

It was found that contaminant materials are removed via two mechanisms which operate simultaneously:

- Soluble fractions go into solution; the impacting raindrops and the horizontal sheet-flow provide good mixing turbulence and a continuously replenished clean "solvent."

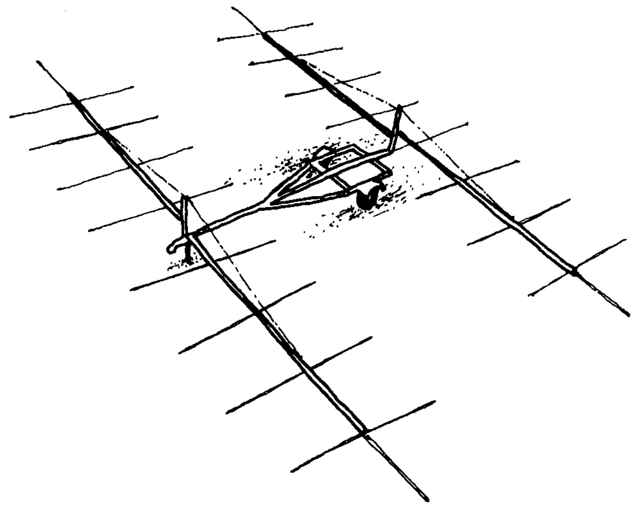
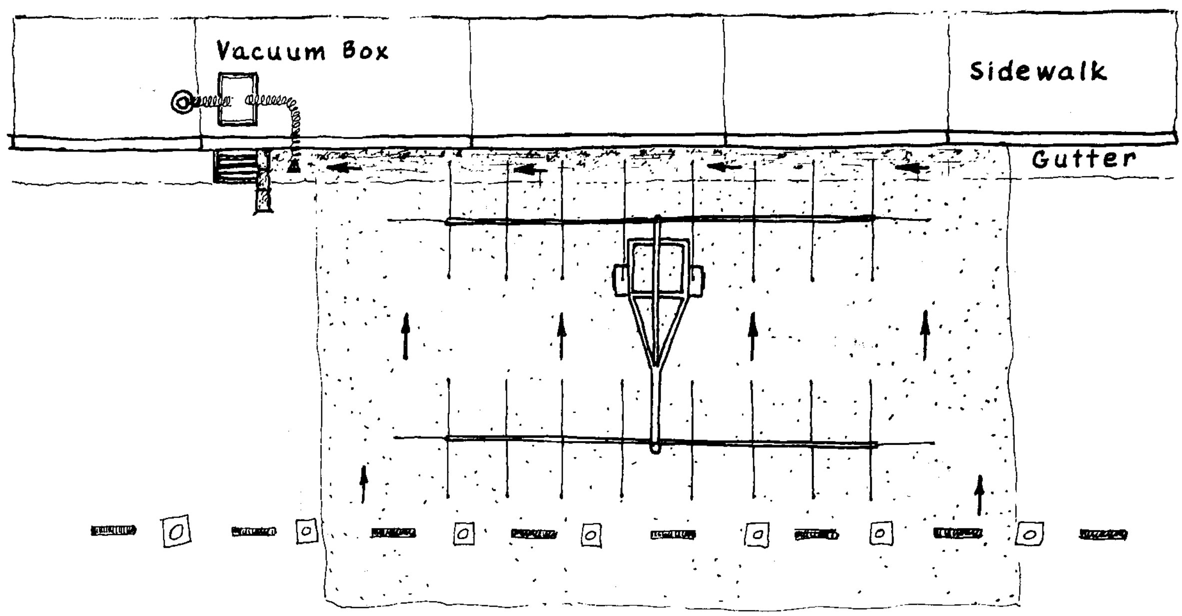


Fig. 26 . Mobile Rain Simulator

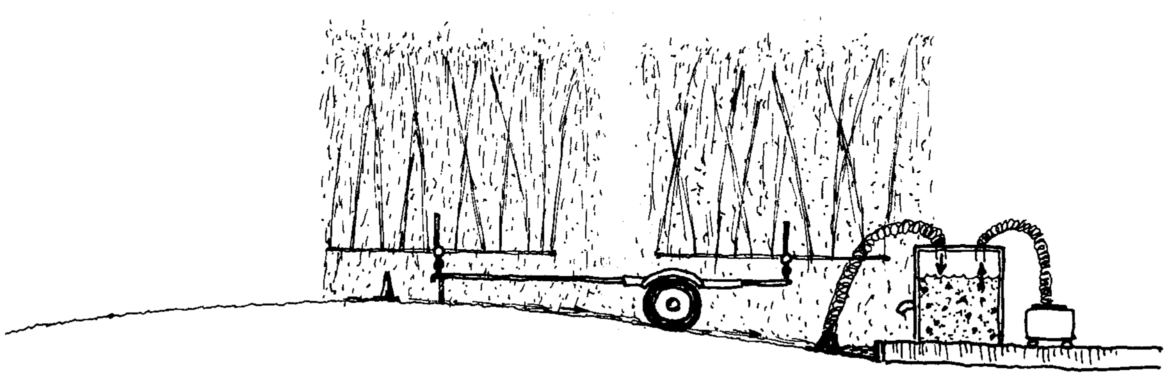
- Particulate matter (from sand size to colloidal size) is dislodged from its resting place by the impact of falling drops. Once dislodged, even reasonably heavy particles will be maintained in a state of "pseudo-suspension" by the repeated impact of adjacent drops creating a reasonably high general level of turbulence. (A substantial amount of the contaminants was found to be located down inside small pits, cracks, and other irregularities in the street surface.)

The sheet-like flow of water across the surface carries the contaminant materials to the gutter. These mechanisms are easily discussed and understood, but only on a qualitative basis.

Experimental studies were conducted in Bakersfield (California) to determine the rate at which contaminants are washed off of streets, given various levels of rainfall intensity. (Bakersfield was selected as a site for the field tests because it was the nearest sizable city which had not experienced any significant rainfall since the preceding summer and therefore had a moderate-to-heavy loading of solids of all sizes available to observe.) The influences of street surface characteristics were also of interest here. Field tests were conducted wherein three typical street areas (two asphalt and one concrete) were flushed by a simulated rainfall for a period of 2-1/4 hours. Every 15 min during that period, samples of liquids and particulates were taken for subsequent analysis. At the end of the period, the streets were flushed



Plan View



Side View

Fig. 27. Rain Simulator and Sample Collection System

thoroughly with a firehose to wash off any remaining loose or soluble matter. Samples of this remaining material were also collected. Two rainfall rates, 0.2 in./hr and 0.8 in./hr, were used. (The lower intensity - 0.2 in./hr - is typical of a heavy rainfall. The high intensity - 0.8 in./hr - would be an unusually high sustained value for any area of the country. However, since such values commonly occur for at least short periods during ordinary storms, it was important to observe how this very high rate removes contaminants.)

The preliminary flushing tests in Bakersfield provided much valuable information. On the basis of that experience, we were able to make several important modifications to our equipment and field testing procedure. An important reason for conducting the tests was to determine an appropriate sprinkling time and rate to be used as fixed parameters in subsequent test series.

Samples were fractionated in Imhoff cones to separate settleable and floatable matter from the water which contained dissolved, colloidal and suspended matter. Each of these fractions was analyzed; the settleable solids were also separated into six particle size ranges by dry sieving. The results of this test series are presented in Figs. 28 through 32.

The thing to note here is that, while the first runoff to reach the curb was quite dirty, the subsequent runoff got clearer and clearer as time went on. Admittedly this observation was predictable; yet it was necessary to be established in terms of meaningful parameters. Stated another way, it was observed that of the total amount of material which could conceivably be flushed off by a given rainfall intensity, the amount flushed off during each successive time period decreased in a regular pattern. Likewise, the cumulative amount increased, approaching the total loading as an asymptote. This pattern is shown clearly in Figs. 28 through 32. The thing to note in these figures is that the runoff patterns shown in the plots are remarkably uniform in shape and vary little from test to test (even though a range of rainfall intensities and street surface types were used). It is also interesting to note the similarity between curves of all particle sizes.

Mathematical analyses of the data plotted have revealed that the transport of particles across street surfaces fits an exponential function quite well, as shown in the following discussion.

It was assumed that the rate of removal of particles of a given size from a unit area of street surface is proportional to the number of particles of that size contained within the unit area, as well as to the rate of water deposition on the area. These assumptions are expressed

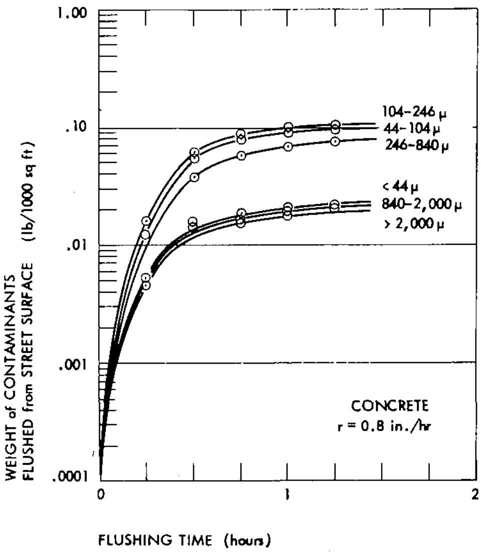


Fig. 28. Particle Transport Across Street Surfaces - Variation by Particle Size

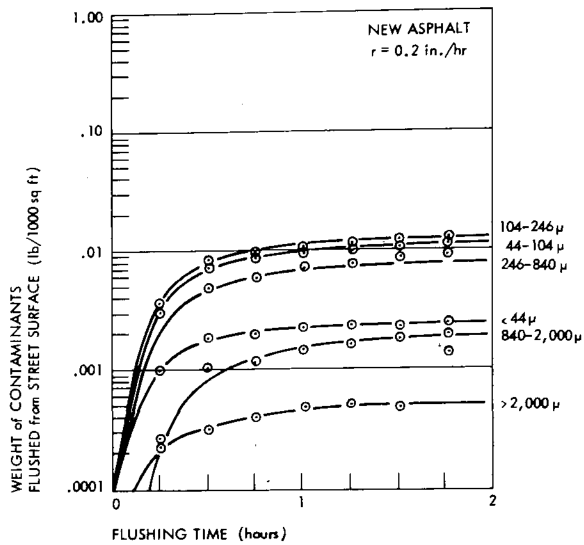


Fig. 29. Particle Transport Across Street Surfaces - Variation by Particle Size

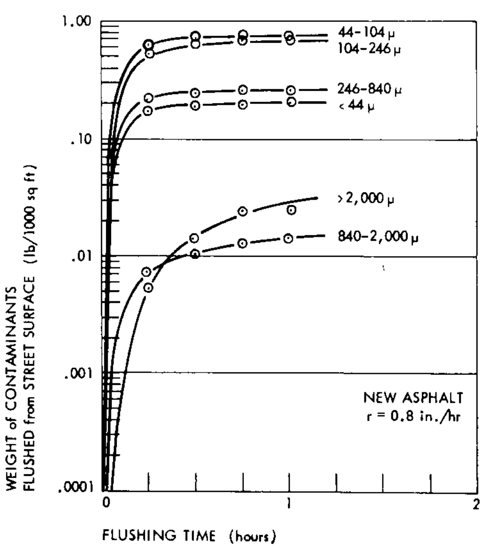


Fig. 30. Particle Transport Across Street Surfaces - Variation by Particle Size

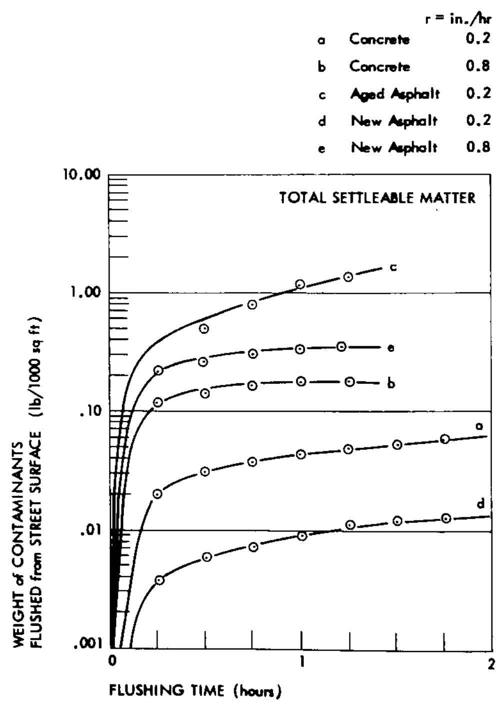


Fig. 31. Particle Transport Across Street Surfaces - Variation by Street Character and Rainfall Intensity

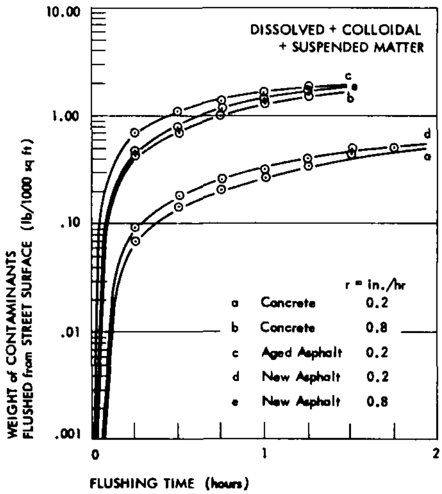


Fig. 32. Particle Transport Across Street Surfaces - Variation by Street Character and Rainfall Intensity

in mathematical terms as:

$$\frac{dN}{dt} = krN$$

where:

N is the amount of particles of the given size which remain on the street surface at time t (expressed in g/sq ft)

r is the rainfall intensity over the area (expressed in in./hr)

t is time (in min)

k is a proportionality constant (having the units of hr/in.min)

With the mobile rain simulator, the intensity r is uniform with respect to time and space (at least within the bounds of the test site). The above can then be treated as an ordinary differential equation whose solution is:

$$N = N_o e^{-krt}$$

In the experiments, we measured the amount of matter removed with time, rather than the amount remaining (indeed, the total amount, N_o, was never measured directly. The equation then becomes:

$$N_c = N_o(1-e^{-krt})$$

where:

N_c is the amount of material of a given particle size which has been removed during time interval t by a rainfall of intensity r

N_o is the initial loading intensity of that material of that particle size which could ever be washed from the street by rain of intensity r (even as t approaches infinity)

k is a proportionality constant dependent on street surface characteristics.

The experiments carried out in Bakersfield were of sufficient duration to establish the asymptotic values of N_o. These experiments established the appropriateness of the developed relationship as shown in Figs. 28 through 32.

Based on the exponential function that was derived from the preliminary flushing data, certain conclusions can be drawn on the rate and amount of material that could be removed from a street by a given rainfall.

- The proportionality constant k for material removed from a street surface by rainfall is dependent on street surface properties but is not dependent upon rainfall intensity. This means that the type of street (e.g., asphalt or concrete, coarse or fine surface, roughness, etc.), and the condition of the street (i.e., old and cracked or new and smooth) is a major controlling factor on how fast such material would enter a storm drainage system.
- The amount of material (N_O) which is capable of being removed from a street varies with the rainfall intensity r. This means that for a given rainfall intensity on a street surface for which the proportionality constant k is known, the relative amount of material flushed into the sewer over a given time period could be predicted.

It appears from the data that all particles of the size ranges examined are removed from the street at approximately the same rate, given the same rainfall conditions. Therefore, the street surface constant k is virtually independent of particle size (i.e., dN/dt is not a function of particle size). This is substantiated by the fact that the plot in Fig. 33 is essentially a horizontal line. Analyses of the liquid samples showed that soluble, colloidal, and suspended materials removed from a street surface show the same functional behavior as the settleable solids. However, since no further separation of these fractions was made, it was not determined if this is true for each of these fractions independently.

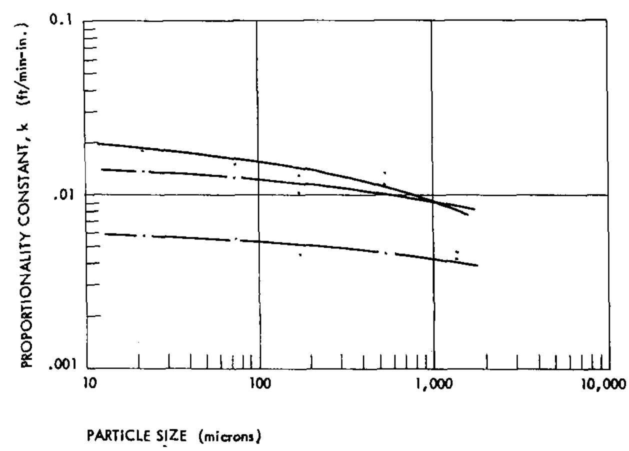


Fig. 33. Relationship between Particle Size and Proportionality Constant

Runoff carrying street surface contaminants flows across the street, reaches the gutter, and moves down the gutter toward the storm sewer inlet, as shown in Fig. 25. While moving down the gutter, it mixes with runoff from other sources (i.e., off sidewalks, driveways, surrounding land area, building drains, etc.). Thus, the runoff which arrives at the storm sewer inlet is not street surface runoff, per se. This study focuses on street surface contaminants only. The field techniques employed here were carefully designed to include only those contaminants which reside on street surfaces.

Since street surface contaminants are but a single source of all contributions to storm runoff, we have attempted to determine how important they are. Their "importance" can only be expressed relative to all sewered storm runoff since the myriad of other contributions have not yet been isolated for study (nor has unsewered storm runoff been studied to any great extent). Table 37 in Section VI compares the street surface runoff (calculated for a hypothetical city) with storm sewer discharges observed in several U.S. cities.

Section V

EFFECTIVENESS OF CURRENT PUBLIC WORKS PRACTICES

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EFFECTIVENESS OF CURRENT PUBLIC WORKS PRACTICES

Current public works practices may, in some instances, result in a reduction of pollution of receiving waters from storm water runoff. Practices that may influence the pollution of receiving waters include:

- street cleaning
- catch basin cleaning
- refuse and litter collection
- street maintenance
- sewer cleaning
- snow and ice control
- air pollution control
- open area maintenance
- construction
- parking regulations.

Of the above mentioned practices, the role of street cleaning and the role of catch basins in controlling or reducing the pollutional effects of street surface contaminants were included within the scope of this study.

This section, therefore, deals with answering the question "How effective are current public works practices in controlling pollution of receiving waters from street surface contaminants?" More specifically, this involves the discussion of:

- existing street cleaning practices
- street sweeping effectiveness
- catch basin effectiveness.

EXISTING STREET CLEANING PRACTICES

Street cleaning practices throughout the nation were evaluated through a review of the literature, and by conducting a detailed survey of current practices in several sample cities. The effectiveness of current street cleaning practices was also determined in each of the test cities and a series of control tests was conducted utilizing a street surface contaminant simulant. (A description of the test areas utilized in each city is given in Appendix B.) Effectiveness data from previously conducted street sweeping tests were evaluated and correlated with data obtained in this study.

Present methods of cleaning streets fall into two categories: sweeping and flushing. These methods, for the most part, are carried out by machines specifically designed for that purpose - street sweepers and street flushers. As an ancillary function, most municipal street cleaning departments are also responsible for catch basin cleaning and leaf collection in the fall. In most northern cities a spring clean-up of streets which have been snowbound all winter is common. Because the bulk of accumulated trash and sand can be very great, this clean-up often utilizes front end loaders, trucks, and hand crews which are followed by sweepers and/or flushers. The following paragraphs will describe the procedures and the equipment used for the above-mentioned functions.

Street Sweeping

Machine sweeping accounts for the great majority of street cleaning performed in most communities. This effort may be assisted by a limited amount of manual sweeping in areas that machines cannot reach. Hand cleaning is primarily used to clean those streets where the presence of cars prevents the use of mechanical equipment. It is most often employed in business districts where the emphasis is placed on keeping "visible" pollution (such as papers, tin cans) under control. Manual methods are also useful in supporting mechanical operations. For example, a hand crew can follow a street sweeper and clean out catch basin inlets, sweep up missed debris or assist in transferring debris from the sweeper to trucks.

Motorized street sweepers are designed to loosen dirt and debris from the street surface (this debris is normally most concentrated in the gutter area), transport it onto a moving conveyor and deposit it temporarily in a storage hopper; the sweeper also typically contains a dust control system. Three basic types of sweepers are in use; as shown in Table 15, the most common is a design which utilizes a rotating gutter broom to move materials from the gutter area into the main pickup broom which rotates to carry the material onto a belt and into the hopper. This type of sweeper relies upon water spray to control the dust problem. A wide variety of sweepers of this type is available. Included are those which are self-dumping and those which have 3 wheels or 4 wheels. Three-wheel sweepers are generally considered more maneuverable while 4-wheel sweepers can generally travel at higher road speeds when not sweeping.

The second class of sweepers includes those which use a regenerative air system. These sweepers are designed to "blast" the dirt and debris from the road surface into the hopper with a portion of the air being recycled. A portion of the air is vented through the dust separation system. Such sweepers may also use water spray for dust control.

Table 15

SOME COMMONLY USED STREET SWEEPERS

TYPE	MANUFACTURER	MODEL	NO. WHEELS	NO. ENGINES	MAIN BROOM WIDTH (in.)	SIDE BROOM DIAMETER (in.)	SWEEPING PATH[b]	SWEEPING SPEED (mph)	MAX. TRAVEL SPEED (mph)	WATER SPRAY	HOPPER CAPACITY (3 cu yd)	COMMENTS
Pickup Broom	BLH Austin-Western	70	3	1	60	36	9 ft	1-10	25	yes	4½	Model 40-B has 2-cu yd hopper
	Elgin	475 (White Wing)	3	1	68	36	8 ft	1-15	22	yes	4½	Model 375 has 3½-cu yd hopper
	Elgin	Pelican	3	1	68	36	8 ft	1-15	22	yes	2½	Self-dumping (8ft 6 in. lift)
	MB	Cruiser	4	1	60	47	n.a.	3/4 & up	50	yes	4-1/3	Dumps from rear
	Mobil	TE 4	4	2	60	42	7 ft 6 in.	1-12	55	yes	4	Model TE-3 has 3-cu yd hopper
	Wayne	984	3	1	58	45	9 ft	2-8	25	yes	4	Model 973 has 3-cu yd hopper
	Wayne	945	4	2	58	45	8 ft	1-15	55	yes	4	
	Wayne	933	3	1	58	45	8 ft	1-15	55	yes	3	Self-dumping (94 in lift)
	Murphy	4032	4	2	58	45	10 ft	1-12	55	yes	3	Self-dumping (side dump)
	Murphy	4042	4	2	58	45	10 ft	1-12	55	yes	4	Self-dumping (side dump)
	Murphy	4062	4	2	58	45	10 ft	1-12	55	yes	6	Self-dumping (side dump)
Air	Tymco	300	4	2	80	Optional	6 ft 8 in.	1-8	55	Optional	3	Uses "regenerative" air system
	Tymco	600	4	2	96	Optional	8 ft	1-10	55	yes	6	Uses "regenerative" air system
Vacuum	Tennant	100	3	1	42	32	6 ft	0-12	15	no	1-3/4	Uses vacuum system for dust control
	Elgin	Whirlwind	4	2	60	28	87 in.	n.a.	55	yes	5.5	Has auxiliary pickup nozzle
	Ecolotec	Vacu-Sweep	6	2	60	20	72 in	n.a.	55	yes	6.3	Has auxiliary pickup nozzle
	Coleman	Metro-Vac	6	2	-	20	94 in.	n.a	55	yes	11½	

NOTE: This list is not comprehensive but does include the most commonly used sweepers. Sweeping path data are using 1 side broom. The Tymco sweepers have no broom; the broom width specified is actually the width of the pickup head

A third type, vacuum sweepers, has been in use in Europe for many years and in limited use in this country for some time. Considerable interest has recently been generated by the introduction of new models. These vacuum sweepers operate using both a broom for loosening and moving street dirt debris and a vacuum system to pick up the debris. All material picked up by the vacuum nozzle is saturated with water on entry and passes into a vacuum chamber where the water-laden dust and dirt drop out of the air stream.

Small, industrial-type sweepers may be considered as a subclass to the vacuum sweepers since they generally utilize an enclosed vacuum system for dust control. These small sweepers are most useful for cleaning parking lots and parking garages. In industry they are used to sweep factory floors and sidewalks. Since these machines are of very limited use on city streets, no data are included here.

The basic procedure used when operating a street sweeper is for the sweeper to travel next to the curb, cleaning one swath along the length of the street and then returning on the other side. (Litter normally accumulates in the gutter because of currents created by passing traffic obviating the need to sweep the center portion of the street.) In some cases, a second pass is made by the street sweeper along the curb to increase the effectiveness of sweeping.

When the hopper of a street sweeper is filled, the material must be dumped. It can be taken in the sweeper to a storage or disposal site or, as is the more common practice, simply dropped in a convenient place along the street sweeping route, preferably an inconspicuous side street. In the latter case, the dirt and debris is later collected by truck crews and usually a front-end loader. The majority of street sweepers dump their hoppers from the bottom. However, several manufacturers make street sweepers in which the hopper swings up on arms and can be dumped into a truck directly, thus negating the necessity for a separate pickup crew.

The operating speed of most street sweepers falls in the range of 4 to 8 mph. This is an acceptable speed for performing sweeping operations in residential and commercial areas where a sweeper has to maneuver around cars which are blocking access to the curb. However, for cleaning main arterial streets or freeways, an operating speed of 4 to 8 mph is not only dangerous to the driver in the vehicle but can cause severe traffic tieups. Therefore, several manufacturers offer a 4-wheel street sweeper with an auxiliary engine to drive the brooms that can be used in sweeping arterials (streets or freeways) at speeds up to 15 mph, thereby reducing the danger somewhat.

Auxiliary engines provide constant speed and power to brooms and elevators thus allowing the operator to vary sweeper speed as necessary for street conditions (i.e., traffic, debris type and loading, etc.) and maintaining broom speed. This is advantageous in minimizing debris left on streets at intersections.

One of the most serious problems encountered in street sweeping concerns vehicle parking. Increases in the use of vehicles and unavailability of off-street parking result in the occupancy of the gutters by parked vehicles. In congested urban areas, it is not unusual to find virtually the entire curb sides of streets occupied by parked vehicles. The City of Baltimore has instituted a no-parking regulation during scheduled street sweeping hours and has found that public acceptance (especially residents of the street in question) has been encouraging.

Street Flushing

Street flushing as presently conducted serves only to displace dirt and debris from the street surface to the gutter. The volume of water utilized is insufficient to transport the accumulated litter to the nearest drain. Most public works agencies use flushers for: (1) aesthetic purposes or (2) moving material out of travel lanes quickly.

A street flusher consists of a water supply tank mounted on a truck or trailer, a gasoline engine driven pump for supplying pressure, and three or more nozzles for spreading the water as directional sprays. The large nozzles on the flusher are individually controlled and are usually placed so that one is directed across the path of the flusher and one on each side is pointed out toward the gutters. This arrangement makes it possible to flush an entire street and also provides flexibility in operation.

The capacity of the water tank on a street flusher varies from 800 to 3500 gallons. The nozzle pressure of the water usually is between 30 and 55 psi. The amount of water delivered must be proportional to the speed of the vehicle and the pumps must be capable of supplying sufficient water at suitable pressures. Specifications of street flushers are given in Table 16.

During normal operation, a street flusher will travel to its assigned route, fill its tank at a fire hydrant, and proceed along the length of a street flushing material into the gutter. On narrow streets, the whole street can be flushed in one pass. However, on wider streets (those wider than about 22 ft) multiple passes are needed.

Catch Basin Cleaning

The major purpose of a catch basin is to intercept grit and other materials which, if allowed to enter the sewer system, could form deposits and clog the sewer. Catch basins, which are typically located under the inlet structures, act as sedimentation basins and collect large objects that enter the inlet structure. Over a period of time, these catch basins become full and have to be cleaned. The material in a catch basin then has to be periodically removed and hauled off to a selected dump site.

Table 16

COMMONLY USED STREET FLUSHERS AND EDUCTORS

COMPANY	MODEL	TANK CAPACITY (gal)	FLUSHING WIDTH (ft)	PUMP SIZE (gpm)	COMMENTS
Etnyre	Leader	800-3,000	Variable	750	Flusher only.
Etnyre	Clipper	800-3,000	Variable	750	Flusher only.
Etnyre	Superliner	800-3,000	Variable	750	Flusher only.
Rosco	MTA	1,200, 1,600 2,100	Variable	750	Flusher only.
M S	Vactor	2,500	42	650	Used as a vacuum truck.
Wayne	Sanivac 1600	3,300	45	600	Used as a vacuum truck, capacity - 16 cu yd.
Wayne	Sanivac 1300	2,600	45	600	Used as a vacuum truck, capacity - 13 cu yd.
Central Eng. Co.	VAC-ALL	1,700-2,200	42	650	Used as a vacuum truck, capacity - 10-16 cu yd.

There are three principal methods used to clean catch basins: manual, eductor, and a clam-shell or orange-peel bucket. The most common manual method is to bail out the water and then dip out the material deposited in the catch basin, piling it on the pavement so it can be hauled away. Long-handled dippers are generally used for lifting the material. The catch basin material is then shoveled into trucks and hauled to dumps and sanitary landfills.

The eductor method of cleaning catch basins consists of using a large vacuum truck with a sewer jet hose which is lowered into the catch basin from the inlet. The vacuum pump on the truck is utilized to suck the catch basin material up into a large watertight tank on the truck. Most of these trucks can serve a double purpose in that when they are not being used for catch basin cleaning, their tanks can be filled with water so they can be used as street flushers. The vacuum method is the most sanitary of those in general use as there is little leakage and the catch basin material does not run on the street; however, some material, such as very large rocks and boards, cannot be picked up by the vacuum hose and has to be removed manually. Specifications of eductors are given in Table 16.

The second mechanical method employs a bucket machine or hoist. The process consists of lifting the solid catch basin material with an "orange-peel" or clam-shell bucket operated by a hydraulic crane which dumps the material into a truck. This operation is comparatively fast. However, some catch basin inlets are too small to allow the passage of the bucket through them and the loose, runny catch basin material tends to run out of the bucket as it is transferred to a waiting truck, thereby dirtying the street.

Special Problems

Keeping streets clean also involves various ancillary operations, including leaf pickup, snow removal, and, in some cases, removal of abandoned automobiles and the disposal of dead animals. The following paragraphs will present brief descriptions of these various operations as they are generally practiced.

Leaf Collection. In parts of the country where deciduous trees abound, street cleaning departments have the seasonal problem of collecting the fallen leaves. The collection and removal of leaves is important for several reasons: wet leaves on a pavement surface impair vehicular traction and create slippery conditions that may be almost as dangerous as icy pavements. Also, leaves clog catch basins and inlet gratings and, unless removed, impede the transport of runoff and can cause major flood damage.

The collection and disposal of leaves is done by a variety of methods, depending on the job conditions and equipment vailable to the municipality. Municipal collection schedules also vary widely. Some cities clean frequently during the leaf season so that a relatively small amount of leaves is picked up during each cleaning period. Other cities will pick up leaves at regular intervals throughout the leaf season, while still others will collect the leaves only once at the end of the season.

The methods of collecting leaves include manual and several types of machine collection. In the manual method, street crews simply sweep the leaves into a pile and load the pile on a truck. Machine methods for leaf collection include using a street sweeper alone, a street sweeper with a trash screen mounted on the front to push the leaves ahead of it, and front-end loaders either to load collected leaves or to gather leaves in their buckets. The method used by a front-end loader or a street sweeper with a leaf blade in front to collect leaves is for the vehicle to proceed down the street pushing the leaves in a pile ahead of it until the leaves begin to overlap the front of the blade. At this point the vehicle leaves the pile, proceeds around it, and starts pushing up a second pile for collection. When the machine is operating as a sweeper, it collects leaves (the same as it does other street debris) in a hopper and dumps the hopper in a convenient location when full. Collection of the piled-up leaves can be done using either a front-end loader or a vacuum truck. In the case of the front-end loader, the leaves are picked up by the front-end loader bucket and deposited into an accompanying truck which hauls the leaves off for disposal. The vacuum truck uses a suction hose to suck the leaves into the body of the truck where they are further compacted, then proceeds to a dumping place when the turck is filled.

Snow Removal. The presence of snow on streets, of course, prevents normal cleaning operations. This suspension of normal cleaning operations over the winter months can in itself lead to the buildup of heavy deposits on streets. However, snow and ice control procedures can also add to the presence of pollutants on streets. Most highway authorities in the United States have a policy of maintaining "bare pavement" to protect lives and promote safety. Thus, ice and snow are removed as quickly as possible from roads and highways. Deicing compounds (road salts) are usually applied at rates of 400 to 1,200 lb per mile of highway per application. Over the winter season, many roads and streets commonly receive on the order of 20 tons of deicers per lane mile. This is equivalent to 100 tons of salt or more applied per mile of roadway for multiple-lane highways.

The reported use of sodium chloride (Refs. 4 and 5), calcium chloride and abrasives in the United States for the winter of 1966-1967 amounted to 6,320,000 tons sodium chloride, 247,000 tons calcium chloride and 8,400,000 tons of abrasives.

While most of the deicing salts applied in urban areas will eventually be channeled into the sewer system with the runoff water in the spring thaws, insoluble abrasive materials tend to remain on the streets and gutters. Thus, the spring cleanup is a routine practice in many northern cities and may involve the use of manual crews and front-end loaders to help in digging out the heavy deposits.

Another concern, however, is the presence of dirt and debris and particularly deicing compounds which are incorporated into the snow, slush and ice which is picked up and removed. Ultimately, this finds its way into local receiving waters. Usually this is done by carting the snow directly to a body of water, dumping it in, and allowing it to melt. Some cities, however, use snow melting machines which melt the snow as it is collected. The melt water, including any salt, then flows directly into the sewer system.

Abandoned Cars. Abandoned or "junk" cars are a problem in most cities, but the problem is most obvious in those communities where parking regulations are used in support of street cleaning operations. However, the problem of parked cars, in general, is a major deterrent to street cleaning so that the inclusion of the additional junk cars normally is not of major concern. A survey conducted as part of this study indicated that, in most cities, the police are responsible for removal of "junkers" once notified by the street cleaning department.

Disposal of Animals. Although many small animals and a few larger ones are killed on streets and highways in the course of a year (thereby creating a concentrated source of pollution) they are generally not dealt with as part of the street cleaning program. Rather, some organization, either within the city government or under contract to the city, is responsible for removing such bodies and ultimately disposing of them. Hence, although such a function is found within some city governments under the street cleaning program, it will not be considered further in this report.

Survey of Street Cleaning Practices in Selected Cities

One of the subtasks in this study was to determine the type and extent of various street cleaning practices across the nation. To this end a 9-page questionnaire (see Appendix F) based on one used by the American Public Works Association was prepared and used as the basis for interviews in selected cities. The sample includes most of the cities where the street surface sampling program was conducted (in a few instances questionnaires were not returned) plus a few cities which were selected for special characteristics (such as extreme winter conditions). The cities for which data were obtained are listed in Table 17. The table includes the miles of streets which are regularly swept, population data and climatological data. A summary of the data obtained is given in Tables 18 through 22. Although the cities selected generally fall in the moderately large population category, they do represent a wide spectrum of climatic conditions and street cleaning programs.

This survey of street cleaning practices was not intended to be comprehensive, since other excellent data sources are available. These include a recent survey undertaken by The American City magazine (Refs. 20 and 21) and the Western Pennsylvania Chapter of the APWA and Institute for Urban Policy and Administration, University of Pittsburgh (Ref. 22). In the following analysis of street cleaning practices, these sources will be referenced where appropriate.

Table 23 lists cleaning practices in selected cities. All cities were found to have a comprehensive sweeping program. About one-half of the cities also had a flushing program; most of the remainder used flushers to some small extent. Several cities relied heavily upon manual cleaning programs (which includes both gang and "white wing" crews), and all but one city used manual crews to some extent. Normally the use of manual crews is restricted to downtown areas or small business areas and to daytime hours on a daily basis. One interesting exception is San Francisco where manual crews are used in many of the residential areas, the reason being that parking is extremely limited in the city. In many neighborhoods sweepers can never get to the curb (this also accounts for the high use of flushers in San Francisco).

Table 17

CHARACTERISTICS OF CITIES SURVEYED

	MAP-MILES SWEPT STREETS	% ASPHALT	POPULATION (1970)	AREA (1960) (sq mi)	ANNUAL RAINFALL (in.)	ANNUAL SNOWFALL (in.)	NO. DAYS/YEAR WITH PRECIPITATION	NO. DAYS/YEAR BELOW 33°F
San Jose	1,165	95	536,965	138	12	T	62	20
Phoenix	1,450	100	580,275	187	7	0	51	7
Milwaukee	1,701	75	709,537	90	33	30	124	162
Bucyrus	n.a.	n.a.	13,200	n.a.	37	29	135	123
Baltimore	2,000	75	895,222	75	43	23	102	108
Atlanta	1,750	85	487,553	136	44	2	107	73
Tulsa	n.a.	n.a.	328,219	49	30	12	82	95
Seattle	1,280	16	524,263	82	34	45	150	28
Minneapolis	1,000	50	167,685	53	19	74	127	152
St. Paul	896	67	107,848	52	25	44	133	160
San Francisco	850	80	704,217	45	28	0	69	0
Lawrence, Ka.	150	28	45,143	n.a.	34	20	98	98

NOTE:

Source of Population data: Statistical Abstract of U.S., 1970, Bureau of Census.

Source of Weather data: National Climatological Summary of Data, U.S. Weather Bureau, Vol. 20, 1969

In San Jose the area has increased from 56 sq mi in 1960 to 138 sq mi in 1970.

The information for Lawrence, Kansas, is from Ref. 23.

T = trace.

n.a. = not available.

Table 18

STREET SWEEPING EQUIPMENT IN SELECTED CITIES

	3-WHEEL	4-WHEEL	SELF-DUMPING (3-Wheel)	VACUUM TYPE	AVERAGE LIFE (yr)	AVERAGE DOWNTIME (%)
San Jose	1	14	-	-	9	15
Phoenix	-	21	-	-	7-8	17-22
Milwaukee	13	9	-	-	12-15	Varies w/season
Baltimore	-	26	-	-	5	25
Atlanta	-	-	24	-	7	10
Seattle	-	18	-	-	8	20
Minneapolis	1	17	-	-	5	25
St. Paul	2	5	7	-	5	25
San Francisco	11	3	-	-	10	25
Lawrence	3	-	-	-	4	5

Note: Ref. 20 indicates that of some 250 cities surveyed, 68 percent use 3-wheel sweepers, 27 percent use 4-wheel sweepers, while 5 percent use "others" (either 3- or 4-wheel) which include air- or vacuum-type sweepers.

Table 19

OPERATING SPECIFICATIONS FOR SWEEPERS IN CITIES SURVEYED

	OPERATING SPEED (mph)	MAIN BROOM MATERIAL	MAIN BROOM LIFE	PATTERN WIDTH (in.)	GUTTER BROOM MATERIAL	GUTTER BROOM LIFE	MAXIMUM ROUTE (curb mi/shift)
San Jose	6-10	P-P	800-900 mi	6-8	Wire	300 mi	34
Phoenix	5-7	Wire	927 mi	6	Wire	1-2 wk	32
Milwaukee	5-6	P-P	80-120 hr	4-6	Wire	140-160 hr	22
Baltimore	5-6	P-P	1,200-1,500 mi	6-8	Wire	50-60 mi	32
Atlanta	6	P-P	4-6 wk	7	Wire	2 wk	30
Seattle	7-8	P-P	1,000 mi	5-7	Wire	600 mi	33
Minneapolis	2-15	P-P	500-800 hr	5-6 in.	Wire	2 wk	28
St. Paul	2-15	P-P	4-6 wk	4-6	Wire	1-2 wk	30
San Francisco	4-8	P-P	1,000-1,200 mi	6	Wire	350 mi	35
Lawrence	4½-5	P-P	1,300 mi	2-6	Wire	350 mi	30

NOTE: P-P polypropylene or other plastics.

Table 20

FLUSHERS IN CITIES SURVEYED

	TOTAL FLUSHERS	AVERAGE LIFE (yr)	AVERAGE DOWNTIME (%)	ROUTE (curb mi/shift)
San Jose	0	-	-	-
Phoenix	1	6-8	5	-
Milwaukee	2		Phasing Out	
Baltimore	11	8	25	5-6
Atlanta	3	7	3	-
Seattle	8	8	3	30
Minneapolis	3	n.a.	n.a.	5
St. Paul	7	10	5	n.a.
San Francisco	10	9	20	45-night 35-day
Lawrence	2	10	5	-

NOTE: n.a. = not available.

Table 21

CATCH BASIN CLEANING IN CITIES SURVEYED

	TOTAL NO. CATCH BASINS	FREQUENCY OF CLEANING	NUMBER CLEANED/ YEAR	METHOD	NUMBER OF EDUCTORS	NUMBER OF CREWS	MEN/ CREW	COST, $/CATCH BASIN
San Jose	n.a.	as required	3,600	Eductor	1	1	2	9.52
Phoenix	3,100	6/yr	18,600	Hand Eductor	 1	12 2	2 2	
Baltimore	32,200	1/yr or as required	about 68,000	Hand Eductor	 4	6 2	4 3	15.00 3.00
Seattle	20,000	1/yr	20,000	Eductor	8	7	2	5.64
Minneapolis	35,000	as required	n.a.	Eductor	1	1	2	n.a.
St. Paul	10,000	as required	n.a.	Hand Eductor	- 2	1 1	2 1	15.00 n.a.
San Francisco	50,000	as required	12,000	Eductor	10	8	3	9.12

NOTE: n.a. not available.

Table 22

SWEEPER DEBRIS COLLECTED, BY MONTH, FOR FOUR CITIES
(as reported by City Public Works Departments)

Month	Curb Miles Cleaned				Debris Removed cu/yd				% Total Debris			
	Baltimore	San Francisco[a]	San Jose	Phoenix	Baltimore	San Francisco	San Jose	Phoenix[b]	Baltimore	San Francisco	San Jose	Phoenix
Jan	4826	3514	6263	17445	3000	660	1266	5282	7.5	7.5	8.9	8.2
Feb	4539	4251	5708	14533	2884	786	1292	3804	7.2	8.9	9.1	5.9
Mar	4982	3633	6857	14300	3228	636	1350	4553	8.0	7.2	9.5	7.1
Apr	5476	4444	6557	16490	3068	813	1187	3838	7.6	9.2	8.4	6.0
May	5536	4563	6168	14928	3180	783	1067	4120	7.9	8.9	7.5	6.4
June	7475	5572	6409	14462	3792	879	1238	3781	9.4	10.0	8.7	5.9
July	7880	4672	6584	14043	4292	729	1327	3841	10.7	8.2	9.4	6.0
Aug	6575	4182	6165	13625	3716	702	1242	3600	9.2	8.0	8.8	5.6
Sept	8129	3263	5241	13796	4132	627	1061	8497[c]	10.3	7.1	7.4	13.2
Oct	5897	3903	7138	15201	3008	714	1064	9708	7.5	8.1	7.5	15.1
Nov	5270	4360	5443	12243	2968	795	878	6586	7.4	9.0	6.2	10.2
Dec	5317	3953	5773	13986	2936	696	1220	6683	7.3	7.9	8.6	10.4
Total	71,902	50,310	74,296	175,052	40,204	8,820	14,192	64,293	100.0	100.0	100.0	100.0

a Curb miles/mo for flushers follow a similar pattern with a yearly total of 67,511 curb-miles.
b In tons (weighed at landfill); a conversion factor of 1.0 tons = 1.0 cu yd can be used for comparative purposes.
c The sharp rise in September is due to the initiation of a street sealing program; residual chips are picked up by sweeping operations.

Table 23 also lists the number of sweepers and flushers in the various cities; from these data has been calculated the number of sweepers and flushers per 1000 miles of street. In all cases sweepers are more numerous than flushers. Since the results of the URS survey indicate that route miles per shift covered are about the same for the two types of equipment, then it certainly follows that sweepers provide the major portion of street cleaning programs. Reference 21 indicates that in a survey of 152 cities virtually all cities with a population in excess of 500,000 use flushers extensively with the percentage dropping with decreasing city size, ultimately reaching an average of 16 percent for cities of under 25,000 population. This same study also shows that a significant number of cities (estimated at about 20 percent of all cities) use street flushing in direct support of sweeping operations. This operation is usually performed only on selected streets (i.e., streets located in central business districts) during selected times of the year.

Table 23

CLEANING PRACTICES IN SELECTED CITIES

	MAJOR CLEANING PROGRAMS			EQUIPMENT		EQUIPMENT/1,000-mi STREET	
	SWEEPER	FLUSHER	MANUAL	SWEEPER	FLUSHER	SWEEPER	FLUSHER
San Jose	x	0	0	15	0	12.9	
Phoenix	x	M	M	21	1	14.5	0.7
Milwaukee	x	M	x	22	2	12.9	1.2
Baltimore	x	x	x	26	11	13.0	5.5
Atlanta	x	M	x	24	3	13.7	1.7
Seattle	x	x	x	18	8	14.1	6.3
Minneapolis	x	M	M	18	3	18.0	3.0
St. Paul	x	x	M	14	7	15.6	7.8
San Francisco	x	x	x	14	10	16.5	11.8
Lawrence	x	x	M	3	2	20.0	13.3

NOTE:

Manual cleaning normally used in business districts only.

x major use.

0 none.

M - minor use.

Reference 21 also shows that smaller cities have, on the average, more sweepers per thousand miles of streets than do larger cities; the median value for cities under 25,000 population is 20 sweepers/1,000 miles of streets whereas for the cities of over 500,000 population the equivalent value is 15. This, of course, is not to imply that smaller cities necessarily have cleaner streets since both the loading on streets and the frequency of sweeping must be taken into account. In fact, an interesting area for research would be to ascertain how effectively various cities do utilize their sweepers; that is, what fraction of the time does the sweeper actually engage in sweeping. For example, cities which utilize their sweepers for both day and night operations show better utilization than those that sweep only at night.

Another variable is downtime, which the URS survey indicated to average about 25 percent; however, some cities reported downtime as low as 10 percent. This variation is partly attributable to the life expectancy of the equipment which was found to range from 5 to 15 years. (Downtime does increase with equipment age and presents an interesting problem in optimization: that is, when does downtime rise to the point where replacement becomes the desired mode?). Not surprisingly, flushers have a considerably longer average life span than sweepers, and their downtime is much lower, averaging about 5 percent.

In the cities that URS surveyed, 4-wheel sweepers were predominant; however, in Ref. 21 the reverse is true. As will be discussed later, no appreciable differences appear to exist between the cleaning effectiveness of the two types of sweeper, although the supposedly better maneuverability of the 3-wheel sweeper might improve overall effectiveness somewhat. The admitted advantage of the 4-wheel sweeper is higher traveling speed which normally allows off-street dumping of collected debris. Two interesting trends were also encountered. The first is that self-dumping sweepers seem to be gaining wider acceptance, possibly because they eliminate the need for street-side dumping and subsequent transfer. The other even more recent trend is the development and acceptance of vacuum-type sweepers. Several major manufacturers are now marketing such sweepers and, based upon tests conducted previously (Ref. 24, which will be discussed later), vacuum sweepers do indeed pick up more dirt and debris than conventional sweepers. However, because such sweepers were not available in the test cities, they were not evaluated during this research study.

Variables in sweeper characteristics and operations which are known to affect sweeping effectiveness include main broom fiber, strike or pattern, and sweeping speed. Main broom fiber as found in the URS survey was predominantly polypropylene. However, a number of cities (25 percent as reported by Ref. 21), do use steel bristle main brooms and about 16 percent of the cities use natural fiber brooms. Broom life, even for the same type broom, is extremely variable and is difficult to compare since it may be reported in different units. Steel wire bristles are generally used in gutter brooms (all cities in the URS survey utilized steel wire gutter brooms). Gutter brooms last somewhat longer than main brooms, with cities reporting gutter broom life averaging from 300-600 curb miles swept.

Strike (i.e., that fraction of broom circumference which touches the pavement) averaged about 5 in. However the range was from 2 in. to 8 in. and seemed to vary with both sweeping conditions and broom wear. Sweeping speed was reported to range from 2 to 15 mph (the latter for sweeping of main arterial streets during daylight hours). The average operating speed was closer to 6 mph. Reference 21 also found that the median operating speed was between 5 and 5-1/2 mph.

Sweeping costs have been long reported in dollars/curb mi swept. Reported costs range widely. For example, The American City survey (Refs. 20 and 21) found average costs, by city class, to range from a low of $2.18 to a high of $8.42. Variations for individual cities can be even greater than this. This very wide range is partly attributable to labor rates and labor utilization. For example, the URS survey revealed that equipment operator's pay scales range from a minimum of $2.60 to a maximum of $7.00 per hour. Another variable is equipment costs, with depreciation and maintenance costs likely to differ considerably between cities. Finally, cities typically use different overhead rates and accounting procedures. The final result then is that attempts to compare costs between cities is difficult and may lead to erroneous conclusions. For this reason, we did not pursue the dollar costs per curb mile. Rather, the URS survey focused on information relating to the number of miles swept and the amount of debris picked up.

The most pertinent information found in the URS survey includes:

- the average number of sweepers in use
- the number of miles of city streets swept
- the number of curb miles swept per unit time (usually per month)
- the quantity of debris collected per unit time.

The manner in which these four factors can be assessed is shown in Fig. 34 (data are shown in Table 22). Figure 34a shows the sweeper utilization, based on the curb miles swept (per year) by each sweeper (that is, the

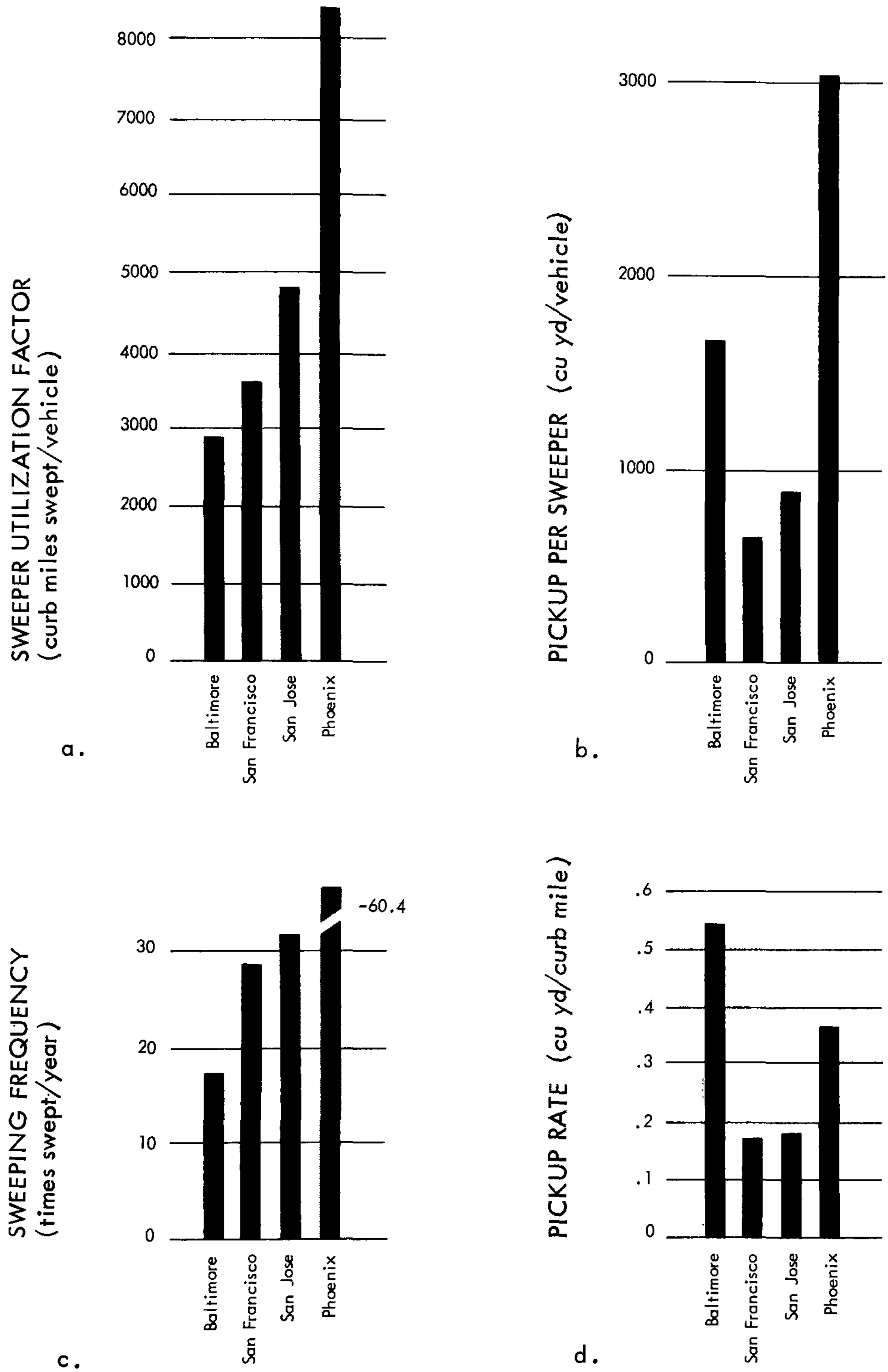


Fig. 34. Comparison of Sweeper Performance in Four Cities

total number of curb miles swept was divided by the number of sweepers in active use). The variation is considerable and shows that Phoenix utilizes its sweepers more effectively than Baltimore. Figure 34b illustrates the unit pickup per sweeper, determined by dividing the total quantity of debris collected (per year) by the number of sweepers. Again, Phoenix is much higher than the other cities. The reason can now be deduced by considering Fig. 34c which shows the average number of times streets in the city are swept each year. This value is obtained by dividing the curb miles swept per year by the total number of miles of swept street in the city multiplied by 2 to approximate total curb miles. It must be pointed out that this average includes streets that are swept daily along with some that are swept only occasionally. Figure 34c then shows that Phoenix sweeps its streets much more frequently than any of the other cities; consequently, the number of curb miles swept per sweeper is higher. More importantly, the amount of debris picked up per sweeper is higher. Data presented in Table 21 show that street cleaning operations in Phoenix remove the largest quantity of debris.

Another way in which the data may be expressed is shown in Fig. 34d which shows the pickup rate for debris (determined by dividing the total quantity of debris collected by the total curb miles swept). Again, there exists considerable variation, but in this case Phoenix is in the middle of the group. While the pickup rate does not constitute an absolute measure of effectiveness(because it does not consider the debris loading on the street surface) it might well provide a valuable comparative measure for similar neighborhoods and land uses. For example,the output of two sweepers and operators over an extended period of time could be recorded and assessed to determine any relative differences. However, if pickup rate could be used as an absolute measure of effectiveness, it would be simple to say that the sweeping operation that picked up the most debris per mile of curb was the most effective.

At this point we are not attempting to impute any great significance to any one of these particular forms of expressing sweeper utilization, but we do believe that with a sufficiently broad data base from a number of cities such a presentation would be most useful to an individual city in determining the efficiency of its sweeper performance. As suggested in a recent APWA publication (Ref. 25), frameworks for performance evaluation need to be developed for street cleaning which will allow the public works engineer to maximize performance and to minimize cost.

STREET SWEEPING EFFECTIVENESS

The effectiveness of existing street cleaning practices, as related to water pollution control, was researched in the following manner:

- published data were reviewed and information obtained from street cleaning equipment manufacturers

- *in situ* evaluation tests of street sweepers were conducted in cities where the street surface sampling program was conducted
- controlled tests were done utilizing a simulant of street surface contaminants.

The results of each investigation are described in the following paragraphs.

Review of Pertinent Literature

Information needed to establish the effectiveness of existing street cleaning practices as related to water pollution control was obtained from a review of published data and interviews with street cleaning equipment manufacturers. The primary sources of data containing pertinent information are in a series of reports (Refs. 26 through 29). These describe a comprehensive series of tests conducted to determine the effectiveness of street cleaning practices when utilized to remove dry particulate matter from paved areas (synthetic fallout material). The particle size range of the material utilized in these tests approximated the dust and dirt fraction of street surface contaminants found to constitute the major portion of the street pollution load.

Little or no data relating to cleaning effectiveness were obtained from the major manufacturers of street cleaning equipment. References 30, 31 and 32 were provided by the Newark Brush Co., which has conducted tests on the performance of various broom types. Reference 33 reports the results of the sweeper efficiency study conducted by the Wayne Manufacturing Co. for the American Public Works Association in connection with the APWA study (Ref. 1) on urban runoff.

A considerable amount of data relating to the cost of street cleaning is available; however, the data are usually dependent upon the street cleaning practices followed by the reporting city, the accounting practices followed by the city and the prevailing labor rates, fuel costs, etc. As indicated previously, a recent APWA report (Ref. 25) describes procedures for determining costs for street cleaning operations. A summary of the pertinent findings obtained from the various sources follows.

The usefulness of street sweepers and street flushers to decontaminate paved areas was evaluated in a number of full-scale test programs conducted by the U. S. Naval Radiological Defense Laboratory (NRDL) during the 1960's. The tests were designed to:

(a) determine the effectiveness of motorized and vacuumized street sweepers and conventional street flushers when removing dry particulate matter of various particle size ranges and initial mass levels

(b) establish the limitations of existing street cleaning equipment with respect to the removal of dry particulate matter

(c) reveal equipment design or operational improvements which would increase their effectiveness.

The various test parameters included:

- Machine type
  - motorized sweeper (Wayne 450)
  - vacuumized sweeper (Tennant 100)
  - motorized flusher (Etnyre Nozzles)
- Operational procedures
  - forward speed (1st, 2nd and 3rd gear)
- Mass loading
  - 20-600 g/sq ft (44-1300 lb/1000 sq ft)
- Particle size
  - six particle size ranges (44 micron to 2000 micron)
- Surface type
  - asphalt
  - concrete

The measurement techniques for determining mass loadings in these studies utilized a radioactive tracer which allowed the direct measurement of residual mass levels of less than 1 percent of the initial mass. This technique is much preferred over a material weight-balance technique which is subject to error when the residual mass levels are low.

The NRDL studies are perhaps of most interest because a theoretical explanation of street sweeper performance has evolved from them. In the studies undertaken at Camp Stoneman (Ref. 27), an equation was evolved based upon results such as those shown in Fig. 35. The equation, which is found to express well the variables under consideration, is:

$$M = M^* + (M_o - M^*)\, e^{-kE}$$

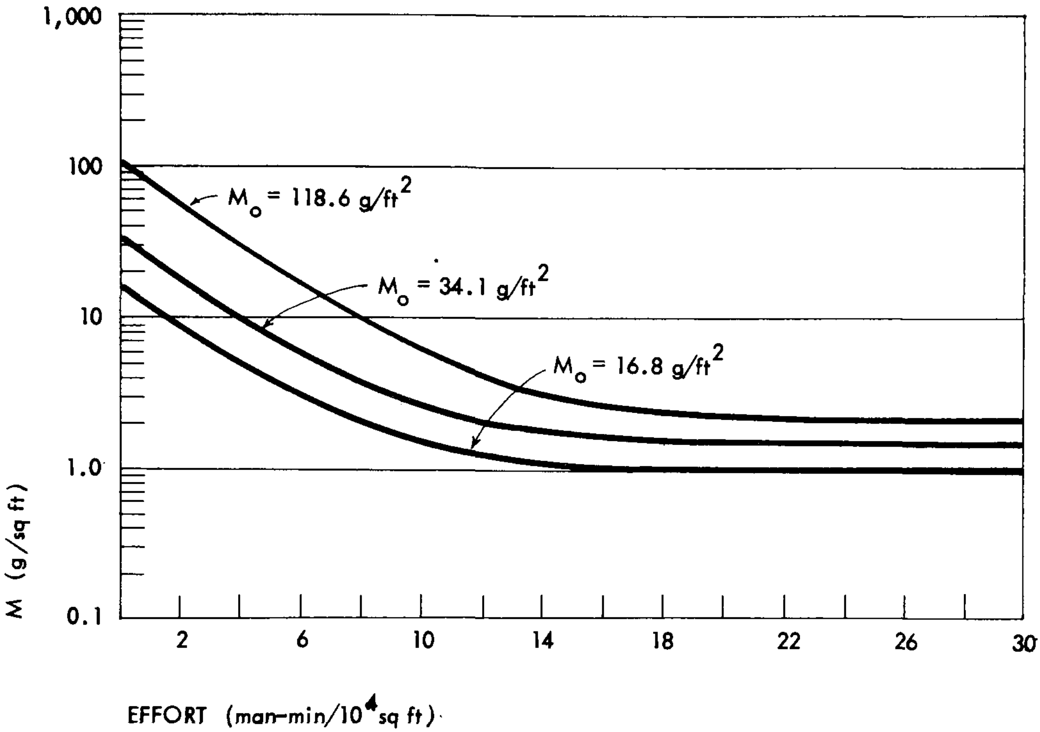
where M = the mass remaining after sweeping (g/sq ft)

M_o = the initial mass before sweeping (g/sq ft)

M^* = an irreducible mass remaining after any amount of sweeping (and dependent upon the type sweeper, the surface, and particle size)

k = a dimensionless empirical constant dependent upon the sweeper characteristics

E = the amount of sweeping effort involved (equipment minutes/1000 sq ft swept)



SOURCE: Ref. 27

Fig. 35. Effectiveness of Conventional Motorized Street Sweeping on Portland Cement Concrete at Three Mass Levels

This study showed that the amount of mass remaining on the street can be effectively reduced by making repeated passes over the same area with the sweeper. Also, certain operational changes can improve performance. For example, it was found that a sweeper moving at 2-1/2 mph removed almost as much dirt in one pass as a sweeper moving at 5 mph removed in 2 passes. This initial NRDL study gave rise to other similar studies which, for economy, were of the strip test variety (Refs. 24 and 29).

A series of strip tests conducted by NRDL to evaluate the effectiveness of vacuumized and motorized street sweepers revealed that, for a given level of effort, vacuumized sweeping was more effective than motorized sweeping. Table 24 compares the effectiveness for motorized sweeping and vacuumized sweeping for a range of initial mass levels and particle sizes and for similar levels of effort.

Table 24

COMPARISON OF REMOVAL EFFECTIVENESS FOR MOTORIZED SWEEPING AND VACUUMIZED SWEEPING

MACHINE TYPE	RELATIVE EFFORT	GEAR	20 g/ft^2 177-300μ (%)	100 g/ft^2 74-177μ (%)	600 g/ft^2 74-177μ (%)
Motorized	2.17	2	92.5	58.0	46.0
Vacuumized	2.88	2	95.0	94.5	89.5
Motorized	4.32	1	94.5	-	62.6
Vacuumized	5.83	1	98.5	-	91.4

NOTE: Tests conducted on asphaltic concrete. Results are for 1 pass in 2nd gear and 1 pass in 3rd gear. Reference 24.

g/ft^2 = Initial mass level.
μ = Particle size range of simulant.
% = Removal effectiveness = Mo-M*/Mo x 100.

Effort as applied by a street sweeper is not a continuous function which can be truly represented by curves or mathematical equations. This is because sweepers are designed to operate at the governed engine speed which produces the most effective broom operation. The series of discrete forward speeds obtained with a set of transmission gears combine with integral numbers of passes over the surface swept to produce distinct levels of effort that can be applied.

Effort is defined as a factor which is inversely proportional to the forward speed and directly proportional to the time spent covering a given area. Its units are equipment minutes per 1000 sq ft of area swept.

$$\text{Relative Effort} = \frac{1200}{\text{Forward Speed (ft/min)}}$$

The constant factor 1200 was chosen arbitrarily so that none of the sweepers had a RE < 1.0 at the fastest speed (3rd gear) tested. Unit relative effort corresponds to a forward speed of 1200.

Area coverage rates for unit relative effort are dependent upon broom widths and can be directly calculated from the relationship

$$\text{Area Coverage Rate (sq ft/min)} = \frac{\text{broom width(in.)}}{\text{12 (in./ft)}} \times 1200 \text{ (ft/min.)}$$

The area coverage rates do not account for the overlap of sweeper passes or the turn around or dump cycle time. As defined, RE values are additive.

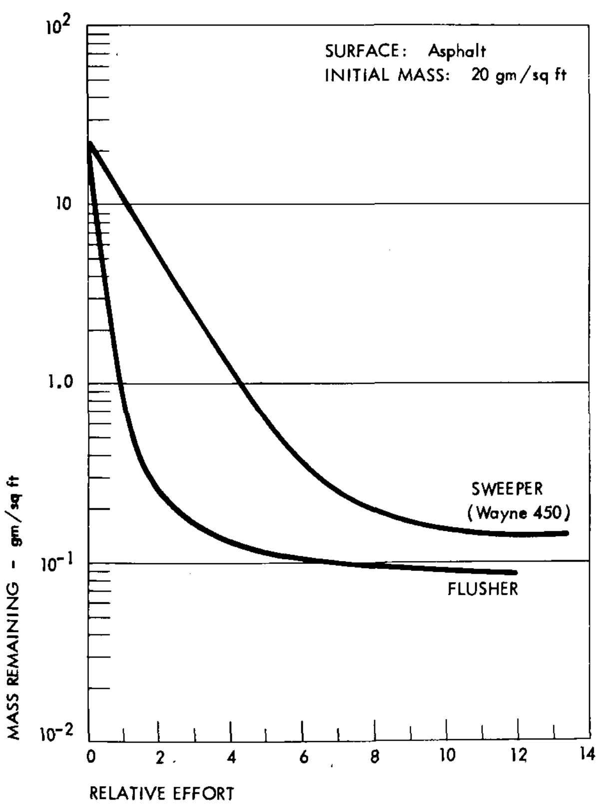


Fig. 36. Comparison of Cleaning Performances of Motorized Street Sweeping and Motorized Street Flushing

Figure 36 compares the relative performance of street flushing with street sweeping methods. The results were taken for similar test conditions, i.e., mass loading, particle size and surface type. For the test conditions, it can readily be seen that a flusher can be a much superior method for moving street contaminants in the dust and dirt fraction. (Note that the mobile flushing units employed in these tests were specially designed with high pressure pumps and highly effective nozzles.) Conventional street flushers would not be nearly as effective. It should also be noted that a street flusher does not pick up contaminants but transports material to and along the curb.

In Refs. 30 and 31 the Newark Brush Co. summarizes a series of tests designed to measure the cleaning efficiency of various types of main brooms on several types of street surface contaminants. The reports conclude that:

- It is more difficult to pick up fine road debris than coarse material; sweeping pattern and broom speed are critical factors.
- A worn broom sweeps all types of debris better than a new one.
- Crimped wire and fiber brooms proved more efficient in these tests than plastic or plastic-wire mixtures for all debris at the broom patterns used. (Plastic-fiber brooms used substantially smaller patterns as the subsequent text will explain.)
- The sweeping pattern contributes greatly to cleaning efficiency; small patterns leave uncleaned streaks in depressions on irregular road surfaces.
- At faster road speeds, proportionally higher broom rotation speeds should be employed.

Figure 37 shows the quantitative effect of sweeping patterns on the efficiency of debris removal and Fig. 38 shows the effect of increasing broom speeds on residual debris with the pattern and sweeper speed maintained constant. Figure 39 shows the effect of sweeper speed on the residual debris.

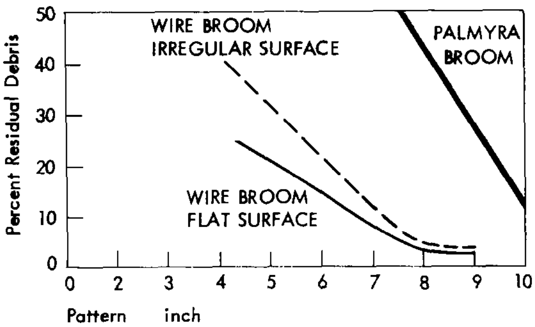


Fig. 37 The Effect of Pattern on Residual Debris

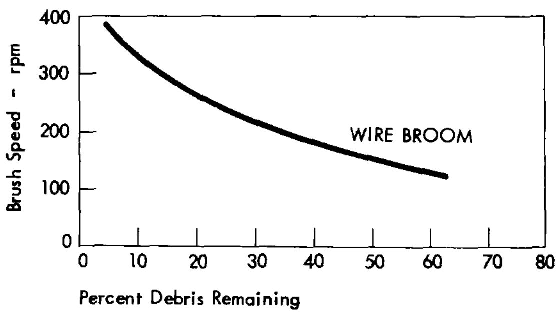


Fig. 38 Debris Pick-up vs Brush Speed

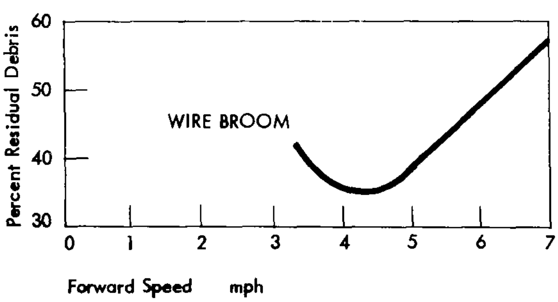


Fig. 39 The Effect of Sweeper Speed on the Residual Debris

A factor to be considered in the relationships shown in Figs. 38 and 39 is that these tests were conducted with a single engine sweeper. Thus, within the limitations of several gear ratios, higher broom speeds result from higher engine speeds. Higher forward speeds also result in a problem of maintaining contact between the broom and the pavement; this reduces sweeping effectiveness. Thus, the desirability of an auxiliary engine to maintain a constant broom speed at the most efficient broom rpm is apparent. A conclusion one can reach when examining Figs. 38 and 39 is to sweep at a forward speed of approximately 4 mph with a broom speed of 100 rpm.

These tests have indicated the importance of establishing performance requirements for street cleaning practices and in particular, operational guidelines, i.e., broom patterns, broom rpm, sweeper speeds, etc., to achieve the desired effectiveness.

In Situ Sweeper Evaluation Tests

Field evaluations of current street sweeping practices were conducted in a number of the cities included in the street surface sampling program. A description of the test sites is given in Appendix B. Briefly, the test procedure used was as follows:

- A street was selected and two adjacent test areas were cordoned off. The first area was used to determine initial loading; the latter, sweeping effectiveness.
- Initial loading was determined by hand sweeping the test area and picking up the accumulated debris, then flushing with a water jet, collecting the runoff, and determining the solid content. Material so collected was then analyzed to determine the initial loading. (See Appendix A for details on sampling procedure.)
- The street sweeper (furnished and operated by the local public works department) passed over the second test area. The surface was again swept and flushed to ascertain the remaining solids. All test areas were 40 ft in length and 8 ft wide.
- The removal effectiveness, in percent, was determined by the formula:

$$\text{Removal Effectiveness} = \frac{(\text{initial loading})-(\text{final loading})}{(\text{initial loading})} \times 100\%$$

Table 25 summarizes the tests conducted and gives information on sweeper type and other operating parameters. Table 26 summarizes the street cleaning effectiveness obtained in each test. Table 27 summarizes the particle size distribution of street surface loadings before and after sweeping and Table 28 summarizes the effectiveness of removal by loading location across the street. The uniformity of the initial loading on the adjacent test areas proved to be quite good. In a series of replicate tests, 50 percent of the adjacent test areas had initial loadings which did not vary more than ± 5 percent. In only one case (out of 8) did the non-uniformity of the loading exceed ± 20 percent.

Table 25
SUMMARY OF STREET CLEANING EFFECTIVENESS TESTS

CITY	TEST NO.	LAND USE	STREET TYPE	STREET CONDITION	EQUIPMENT TYPE	PICKUP BROOM CONDITION	PICKUP BROOM SPEED (rpm)	PICKUP BROOM STRIKE (in.)	VEHICLE SPEED (Gear)	VEHICLE SPEED (mph)
Milwaukee	Mi-3	3	Concrete	Good	Wayne 945	Fair	2,000	8	3rd	5.5
Milwaukee	Mi-10	10	Concrete	Fair	Mobil TE-4	Fair	1,200	7	2nd	3.4
Baltimore	Ba-7	7	Asphaltic	Fair	Wayne 945	New	2,000	5½	2nd	4.0
Scottsdale	Sc-4	4	Asphaltic	Good	Wayne 985	Worn (50%)		5	2nd	5.5
Atlanta	At-9	8	Asphaltic	Good	Elgin Pelican	Fair	n.a.	6	2nd	3.4
Tulsa	Tu-6	6	Concrete	Good	Elgin Pelican	Worn (50%)	n.a.	4	2nd	4.1
Phoenix	PII-2	2	Asphaltic	Poor	Mobil TE-3	Fair	1,700	5	2nd	5.5

NOTE:
See Table 2 for land-use identifiers.
See Appendix B for information on parking and traffic conditions.
All sweepers equipped with polypropylene main pickup brooms and steel gutter brooms. Gutter brooms left operating in all tests. Spray bar used on all tests.
n.a. not available.

Table 26
SUMMARY OF STREET CLEANING EFFECTIVENESS

TEST NO.	INITIAL LOADING (g/sq ft)	INITIAL LOADING ($lb/1000\ ft^2$)	RESIDUAL LOADING (g/sq ft)	RESIDUAL LOADING ($lb/1000\ ft^2$)	REMOVAL EFFECTIVENESS (%)
Mi-3	1.69	3.72	0.89	1.96	47
Mi-10	1.07	2.36	1.31	2.88	
Ba-7	4.93	10.86	4.37	9.62	11
At-9	2.58	5.68	1.75	3.85	32
Tu-6	6.01	13.24	3.89	8.57	35
PII-2	10.03	22.09	3.78	8.32	62
Sc-4	3.36	7.40	1.49	3.28	56

NOTE: Removal effectiveness is for dirt and dust fraction. Could not determine residual mass on Mi-10 due to wet street conditions.

Table 27

REMOVAL EFFECTIVENESS VERSUS PARTICLE SIZE DISTRIBUTION

PARTICLE SIZE RANGE (micron)	ATLANTA INITIAL LOADING (g)	ATLANTA RESIDUAL LOADING (g)	TULSA INITIAL LOADING (g)	TULSA RESIDUAL LOADING (g)	PHOENIX INITIAL LOADING (g)	PHOENIX RESIDUAL LOADING (g)	SCOTTSDALE INITIAL LOADING (g)	SCOTTSDALE RESIDUAL LOADING (g)
> 2,000	175	76	1,438	142	535	240	217	43
840-2,000	103	14	418	181	308	107	439	124
246-890	375	56	690	588	2,190	224	915	415
104-246	231	29	544	595	1,273	381	421	287
43-104	66	136	415	549	425	614	213	134
< 43	43	187	324	431	175	498	87	14
Total (g)	993	498	3,829	2,486	4,906	2,064	2,292	1,017
Overall Eff. (%)		50		35		62		56

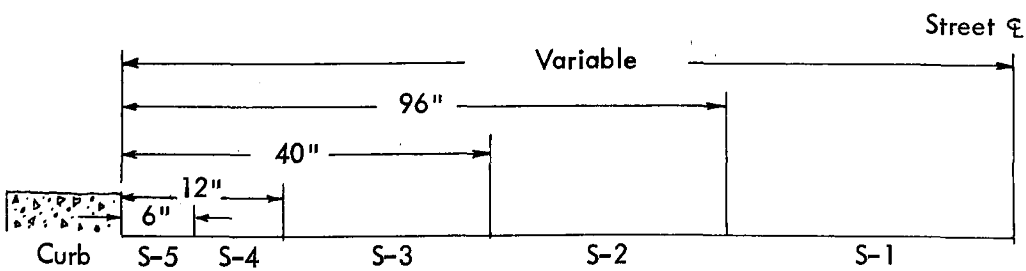
Table 28

REMOVAL EFFECTIVENESS ACROSS STREET SURFACE

STREET SECTION	ATLANTA INITIAL LOADING (g)	ATLANTA RESIDUAL LOADING (g)	TULSA INITIAL LOADING (g)	TULSA RESIDUAL LOADING (g)	PHOENIX INITIAL LOADING (g)	PHOENIX RESIDUAL LOADING (g)	SCOTTSDALE INITIAL LOADING (g)	SCOTTSDALE RESIDUAL LOADING (g)
S-1	2	2	191	188	216	62	56	88
S-2	4	24	271	1,040	324	56	614	286
S-3	24	18	391	387	2,261	944	694	180
S-4	11	8	279	283	72	469	500	256
S- 5	952	446	2,697	588	2,033	533	428	207
Total (g)	993	498	3,829	2,486	4,906	2,064	2,292	1,017

NOTE: See Appendix B for parking and traffic conditions. In Scottsdale, street sloped toward centerline to facilitate runoff.

Street layout as follows:



Controlled Sweeper Evaluation Tests

A series of controlled sweeper evaluation tests was conducted to proof-test procedures for establishing performance criteria for street sweepers Test parameters included:

- debris loading density
- sweeper type
- forward speed of sweeper
- broom type
- rotational speed of broom.

Other variable parameters, such as broom pattern (strike) and pressure, were set at the manufacturer's recommended specifications. The tests were conducted in the City of San Jose on a newly constructed asphalt paved street with concrete gutters and curbing.

Test areas, 50 ft by 8 ft, were delineated on the test street and each test area was cleaned thoroughly by vacuum cleaning and hose flushing. After the surface was dry, a synthetic street surface contaminant (described in Appendix G) was spread on the street surface utilizing a calibrated lawn fertilizer spreader. Several sampling pans (1 sq ft in area) were placed on each test area during dispersal of the simulant for use in determining the initial loading density. Table 29 summarizes the initial loading density for each of the tests conducted.

Street sweepers, provided by the City of San Jose and a commercial street sweeping organization (San Jose Commercial Sweeping Co., Inc.) were utilized in the test areas. Table 30 summarizes the test results and gives information on sweeper type and operating conditions utilized during each test. A single pass was made over the test area, and the residual synthetic street contaminant loading was determined by following the procedures (see Appendix A) utilized in the street surface sampling program.

The test procedures developed in this series of tests proved worthwhile and effective for use in establishing performance criteria of street sweepers.

DISCUSSION OF SWEEPING EFFECTIVENESS

Three general types of tests have been conducted: <u>in situ</u> street tests, controlled tests in which paved areas are artifically given a variable or uniform loading, and strip tests in which a narrow path of material is laid down to be removed by the pickup broom (the gutter broom is normally disengaged). Since the latter type of test is easily run and readily reproducible, most of the data generally available on street

Table 29

INITIAL LOADING DENSITY OF SIMULANT

TEST NO.	ACROSS STREET LOCATION (g/sq ft) S-1	S-2	S-3	TOTAL LOADING (g)
1	0.76	1.58	13.5	1,584
2	1.89	5.00	23.7	3,059
3	3.50	12.20	40.4	5,610
4	1.40	5.50	12.5	1,940
5	3.10	14.30	49.6	6,700
6	1.20	4.80	15.7	2.170

Street layout as follows:

℄ of street - Test areas average 50 ft long

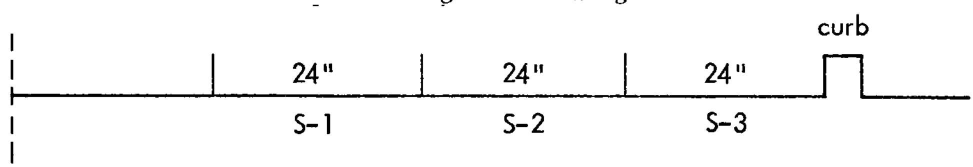


Table 30

SUMMARY OF RESULTS
CONTROLLED SWEEPER EVALUATION TESTS

TEST NO.	SWEEPER TYPE	SWEEPER SPEED (mph)	PUB ENGINE (rpm)	SIMULANT LOADING INITIAL (g)	RESIDUAL (g)	REMOVAL EFFECTIVENESS (%)
1	Mobil-TE-3	4.8	1,750	1,584	629	60.3
2	Mobil-TE-3	5.6	1,200	3,059	682	77.7
3	Mobil-TE-3	6.4	1,750	5,610	2,334	58.4
4	Mobil-TE-3	6.4	1,750	1,940	1,425	26.5
5	Tymco-300	1.0	-(b)	6,700	3,735	44.2
6	Tymco-300	1.0	-(b)	2,170	1,388	36.0

NOTE: PUB - Main pickup broom. Polypropelene utilized in Tests 1-4 , strike measured 6-1/2 in. Tymco sweepers not equipped with pickup broom.

sweeping has been developed in this way. Since the strip test provides nearly ideal operating conditions, it is not surprising that results from such tests result in removal effectiveness of greater than 90 percent, as shown in Fig. 40. Controlled tests prove somewhat less effective, and in situ street tests fall even lower in measured effectiveness. However, street tests represent real-world conditions.

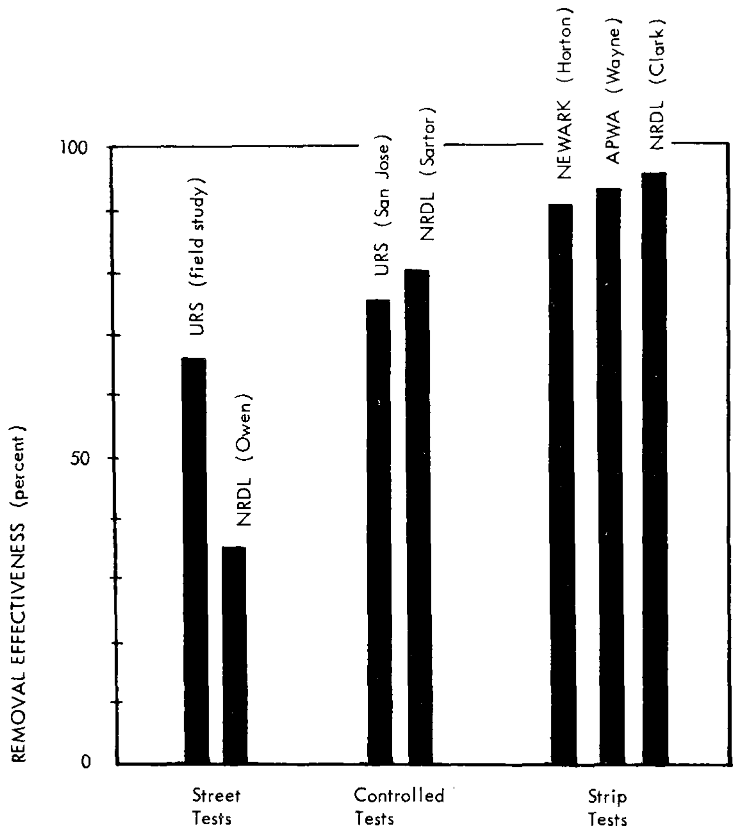


Fig. 40. Comparison of Results from Sweeping Effectiveness Tests Conducted Under Various Conditions: For Dirt/Dust Fraction

The sources of data for these various tests (Refs. 24 through 33) include the present study, some work undertaken by the APWA, evaluations by manufacturers of street cleaning equipment, and finally the series conducted by the Naval Radiological Defense Laboratory (NRDL).

Now let us turn to the consideration of parameters which have been identified as most important to street sweeping effectiveness. Table 31 lists fixed, controllable and untested parameters. "Fixed" parameters refer to those with which the Public Works Engineer is "stuck." For the purposes of assessing removal effectiveness of the dirt and dust fractions, we will consider the unit mass level (expressed in grams/sq ft), the particle size, and the uniformity of material across the street. Initial loading, the first of the fixed parameters, is dependent upon the land-use category, the season of the year, and frequency of cleaning. The NRDL studies and the results obtained in the controlled tests have shown that removal effectiveness increases with increasing mass levels.

Table 31

PARAMETERS WHICH AFFECT STREET SWEEPING PERFORMANCE

Fixed	Loading:	Mass level Particle size Uniformity
	Surface:	Type Condition
	Sweeper:	Type
Controllable	Sweeper Operation:	PUB type PUB rpm PUB diameter PUB strike Forward speed Number of passes Gutter broom Debris deflector
Untested	Operator skill	

NOTE: Other fixed parameters which have been discussed elsewhere include: land-use category, frequency of cleaning, and seasonal variations.
PUB - Main Pickup Broom

The present URS study provides some pertinent data on the effect of particle size on street sweeping effectiveness. Our results indicate an overall removal effectiveness of 50 percent (that is, half the dirt and dust fraction was picked up by the sweeper and half remained on the street). However, when considering the removal effectiveness in terms of particle size, the results are far different. Our analysis, done by sieving the solid sample through standard Tyler sieves, indicated that initially the middle-size fractions (i.e., the 104-840 micron fraction) were predominant, as shown in Fig. 41. (For comparative purposes, the less than 43 micron material has a consistency of flour, the 104 to 246 micron grouping is equivalent to fine sand, the 246 to 840 micron fraction is equivalent to a coarse sand, while the greater than 2000 micron grouping consists of small pebbles, shards of glass, cigarette butts, etc. (Large gravel and rocks were not included in the sample and when present were rejected.) However, after sweeping, this proportional distribution was found to change, with the smaller fractions (i.e., the 43 104 micron range) showing an increase (see Table 27) while other size

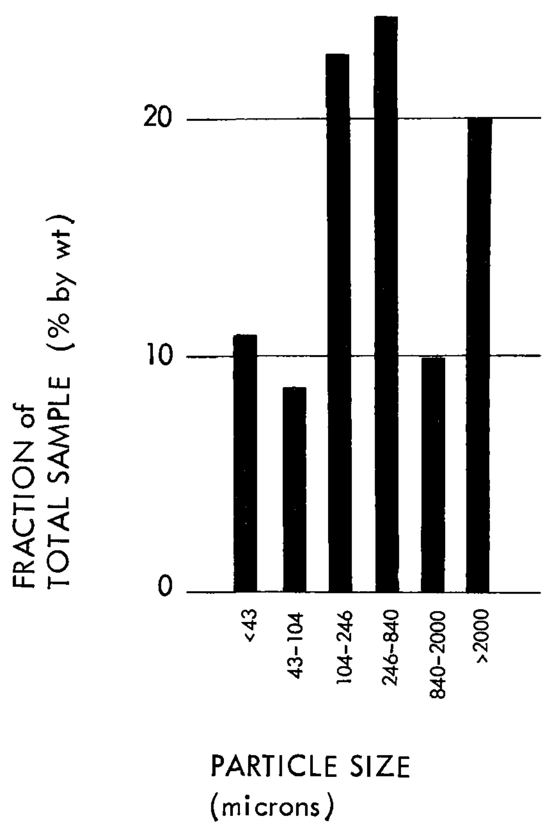


Fig. 41. Particle Size Distribution Initially: For a Composite Sample

ranges decreased somewhat. The results indicate that removal effectiveness is actually greater than 70 percent for the larger fractions (greater than 246 microns), dropping somewhat for the middle-size fraction and decreasing to an insignificant amount for the smallest fractions. This finding, which was corroborated by the NRDL studies, has serious implications; namely, that the smallest fractions are the most poorly removed by conventional street sweeping procedures. This is particularly significant since the principal pollutant materials have been found in highest concentrations in association with the fine fractions.

Table 32 summarizes the removal efficiency of the dust and dirt fractions by particle size range as determined by the in situ tests and as determined through utilization of the NRDL equation:

$$M = M^{*} + (M_{o} - M^{*})e^{-kE}$$

The following assumptions were utilized in calculating the removal efficiencies:

1. Paved surface - asphaltic concrete, fair condition
2. Equipment - conventional motorized street sweeper with three or four wheels, utilizing a polypropylene main pickup broom and steel bristle gutter brooms
3. Effort - Based on average operating speed of 6 mph and an 8 ft wide swath:

$$(8\ \text{ft}) \times \left(\frac{6\ \text{miles}}{\text{hr}}\right) \times \left(\frac{1\ \text{hr}}{60\ \text{min}}\right) \times \left(\frac{5280\ \text{ft}}{\text{mile}}\right) = 4224\ \text{sq ft/min}$$

or E = 0.237 equipment min/1,000 sq ft

Table 32

ESTIMATED STREET SWEEPER EFFICIENCY

PARTICLE SIZE (μ)	REMOVAL EFFICIENCY, (%) IN SITU TEST	EQUATION	COMPOSITE (estimate)
> 2,000	78.8	-	79
840 - 2,000	66.4	-	66
246 - 840	69.5	49.2	60
104 - 246	47.7	48.7	48
43 - 104	< 0	22.2	20
< 43	< 0	15.8	15

NOTE: In-situ tests are average removal efficiencies from test results given in Table 25. The equation utilizes the relationship:

$$M = M^* + (M_o - M^*)\, e^{-KE}$$

4. Proportionality constant, k, is dependent upon sweeper characteristics. For conventional sweepers, k = 0.330 (see Ref. 27)

5. M^* is the irreducible mass which would theoretically remain after an infinite amount of sweeping (dependent upon sweeper type, surface and particle size of contaminant). For particles of 43 to 104 μ, $M^* = .75$ g/sq ft and for particles of 104 to 840 μ, $M^* = .14$ g/sq ft (estimated from data in Refs. 26 through 29)

6. M_o = the initial mass loading before sweeping in g/sq ft

   Average loading from selected cities = 7.26 g/sq ft

   Note that 1 g/sq ft = 2.20 lb/1000 sq ft

   From Table 5, average particle size distribution of solids in selected city composites:

Particle Size Range (μ)	Distribution (%)	Loading (g/sq ft)
> 2000	20.1	1.46
840 - 2000	6.8	.49
246 - 840	20.2	1.46
104 - 246	19.8	1.44
43 - 104	18.0	1.31
< 43	15.1	1.06

Table 33 summarizes the calculated removal effectiveness values for particle size ranges for which equation constants were available.

Table 33

SUMMARY OF CALCULATED REMOVAL EFFECTIVENESS VALUES

$$\text{Based on: } M = M^* + (M_o - M^*)e^{-kE}$$

$$\text{Efficiency} = \frac{M_o - M}{M_o} \times 100\%$$

PARTICLE SIZE (μ)	(1) M_o	(2) M^*	(3) (M_o-M^*)	(4) e^{-KE}	(5) (3)x(4)	M (2)+(5)	EFFECTIVENESS (%)
246-840	1.46	0.14	1.32	0.457	0.604	0.744	49.2
104-246	1.44	0.14	1.30	0.457	0.594	0.734	48.7
43-104	1.31	0.75	0.56	0.457	0.266	1.016	22.2
< 43	1.06	0.75	0.31	0.457	0.142	0.892	15.8

The URS in situ tests also show the nonuniform distribution of debris across streets. Figure 42 shows the variations in mass loadings (g/sq ft) found across the street both before and after sweeping. As might be predicted, the gutter was found to be the most heavily loaded zone on unswept streets. Loading then drops rapidly moving out from the curb. However, after sweeping, the gutter is much cleaner; this is not so for some of the other areas. In short, it appears that the sweeping operation has moved much of the material out of the gutter but has tended to redistribute it on areas which were somewhat cleaner prior to sweeping. The function of gutter brooms on conventional motorized sweepers is to move material out of the gutter into the path of the main pickup broom. Dirt deflectors are utilized to assist in directing the material for pickup. Since the distribution of material on streets is such that a large portion (70-80 percent) of the material is located within 6 in. of the curb, a device such as a gutter broom is required for efficient street debris and litter removal. However, the present design of gutter brooms is such that they tend to redistribute the dust and dirt fraction (< 2000 μ) over the surface of the street, and indeed are not particularly efficient in moving the dust and dirt fraction out of the gutter.

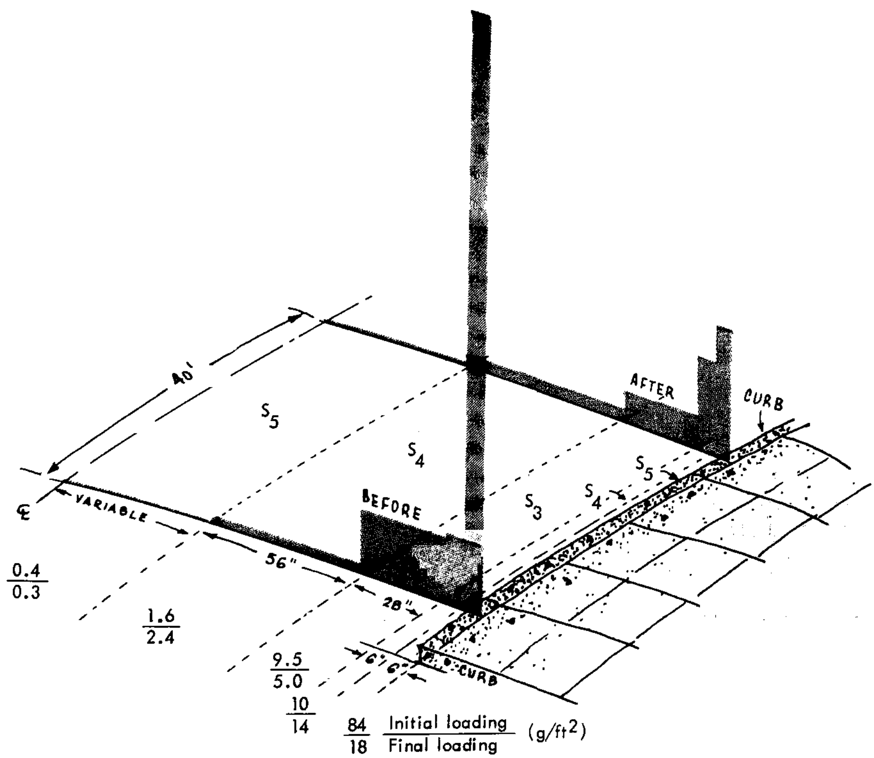


Fig. 42. Initial and Final Loading Across Swept Streets: Composite Sample

Consider now surface type as a "fixed" parameter. Only the NRDL and URS studies have attempted to differentiate between asphaltic concrete and Portland cement surfaces. Relatively small differences were found. However, surface condition, which was an important factor in the present tests, does affect removal effectiveness. We have been unable to quantitatively describe surface conditions although it is obvious that surfaces in poor condition, with large cracks, depressions, etc., are more difficult to sweep and removal effectiveness suffers. Likewise, it is difficult to assess the effect of curb type, street slope and street contour. Further studies should probably be undertaken so that this parameter can be considered in the design of new streets.

The final "fixed" parameter is sweeper type. A variety of tests conducted on conventional 3-wheel and 4-wheel sweepers does not indicate great differences between various models or types. Vacuum and airsweepers have been evaluated only on controlled tests and strip tests. Sweepers of this type were not available in the test cities for in situ tests.

Moving now to "controllable" parameters, we find a variety of machine characteristics which can be varied by the operator to change the cleaning characteristics of the machine. Historically, considerable study has been done on the parameters listed in Table 30. Cited literature indicates that best cleaning performance is obtained with a steel pickup broom, followed closely by the natural fiber brooms and finally by plastic pickup brooms. However, despite the apparent superiority of the steel-type and natural fiber-type pickup broom in removal effectiveness, the trend is definitely toward the adoption of plastic-type brooms, since they do perform satisfactorily (at least on litter and larger dust and dirt fractions).

The effect of broom diameter (that is, wear) has been studied by several investigators, but results are ambiguous. One claim is that a new broom sweeps cleanest whereas another claim is that shorter fibers are better. In either case, the evidence suggests that the differences in performance are rather small (perhaps the point is academic since brooms are generally used until worn out anyway).

Pickup broom strike has been found by all investigators to be an important consideration in cleaning efficiency. The greater the strike, the better the cleaning efficiency. However, increasing the strike also increases the wear on the broom.

The rotational speed of the pickup broom has not been demonstrated to be a highly critical aspect of cleaning performance. However, for sweepers with auxiliary engines, increasing the rpm of the pickup broom does seem to improve pickup efficiency somewhat. Forward speed of the sweeper, especially when it is geared directly to the rpm of the main broom, does seem to have an important effect on cleaning performance. As previously noted, the slower the machine moves, the better the cleaning performance appears to be. However, for machines in which the pickup broom rotational speed is geared to forward speed, it appears possible that effectiveness may actually drop since at the slower speed the main broom speed also drops.

A final variable which has not been assessed by any researchers is that of operator performance and competence. However, the URS test team did conclude from a subjective evaluation of operations in various cities that the skill and competency of the operator is a very crucial factor. While it is difficult to conceive of a test procedure that would identify and quantify the skills required of a good operator, perhaps at some point in the future such an index may be developed.

Turning again now to the equation developed by NRDL to explain removal effectiveness, we see in Fig. 43 how such a curve would look for the conditions that are normally encountered in street sweeping. The first pass removed approximately 50 percent of material on the surface, the second pass removed about 50 percent of that remaining for a total removal effectiveness of 75 percent. Subsequent passes remove effectively less of the remaining mass, although the overall effectiveness does approach 100 percent with increasing number of passes, so we see that one procedure for increasing removal effectiveness is to sweep the same area two or more times.

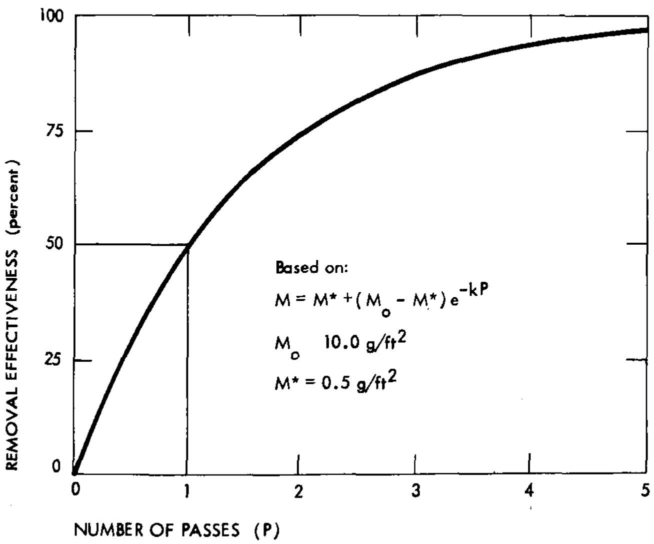


Fig. 43 Removal Effectiveness with Number of Passes

A comparison of the effort required to achieve lower residual mass levels and increasing removal effectiveness, as compared to the effort expended during typical street cleaning operations, can be illustrated by utilizing the NRDL equation and the sweeper parameters assumed in deriving the calculations given in Table 33.

Table 34 compares the effort required, as determined from the NRDL equation, to achieve different degrees of effectiveness at several initial mass levels for a motorized sweeper on asphaltic concrete. It can readily be seen that the amount of effort required to obtain greater than 90 percent effectiveness is several times the effort normally expended in sweeping operations.

Table 34

EFFORT REQUIRED TO ACHIEVE RESIDUAL MASS LEVELS

M_o (g/sq ft)	M (g/sq ft)	EFF %	E (equip min/1,000 sq ft)	INCREASE OVER NORMAL (.237)
20	1.0	95	1.50	6.3
	2.0	90	.85	3.6
	5.0	75	.50	2.1
50	2.0	96	1.35	5.7
	5.0	90	.80	3.4
120	2.0	98	2.00	8.4
	5.0	96	1.10	4.6

CATCH BASIN EFFECTIVENESS

Although most of this study is focused on street surface contaminants and various means for removing them from street surfaces, a special substudy was directed toward catch basins. The primary goal here was to develop an understanding of how catch basins affect the quality of the runoff water which passes through them. It should be noted that the study was quite limited in scope and should not be viewed as being comprehensive in breadth or depth. Nonetheless, some of the information developed should prove valuable in understanding the pros and cons of catch basins as they relate to the pollutional aspects of street runoff discharged to receiving waters.

To summarize our conclusions based on field testing and laboratory analysis, we found that catch basins can be reasonably effective in protecting sewers from loadings of coarse granular material but have a definite potential for contributing to water pollution problems. The following paragraphs describe the catch basins we studied, our test procedures, and the rationale for these conclusions.

In the way of background, it is of interest to note that catch basins became quite popular appurtenances in sewerage systems during the years before sound, well-engineered, paved streets were common and before mechanical trenching made it practical to lay sewers on reasonably steep grades. Catch basins were included in sewer design as a means of preventing sewers from becoming clogged by the rocks and gravel-like material which commonly entered the sewer system. Another function was to provide a waterseal to control the escape of sewer odors and gases. In recent years, public works and design engineers have questioned the merit of routinely including catch basins in modern systems.

The subject of catch basins is included here not so much in the sense of what their eventual fate should be, but rather to determine what effect those currently in use might have on receiving water quality. Note that the term "catch basin" is rather nonspecific; devices of a very broad variety of sizes and shapes are in general use. Their primary common feature is that they act as miniature settling basins for removing dense solids via simple sedimentation. The catch basins which were studied here are located in a residential area of San Francisco. They are true catch basins in that they were specifically designed and installed for this purpose (many are not). They are of a standard design, minor variations of which are found in urban and suburban areas throughout the country.

The experimental program can best be understood after considering that two phenomena occur simultaneously in a typical catch basin during periods of storm runoff:

- Dissolved and particulate solids initially contained in the catch basin (as a result of prior deposit) are stirred up and swept out by the water flowing through
- Particulate solids carried in the influent settle out and are retained in the catch basin.

Clearly, the relative balance between these two phenomena determines whether the unit is a benefit or a detriment. The fact that these act simultaneously accounts for why so little quantitative information on performance is available. Our study approach involved separating the two phenomena so they could be examined independently. Two types of tests were employed:

- Clean water was run under controlled conditions into several previously "dirty" catch basins (ones which had not been cleaned for several months). The discharge from these was sampled and analyzed. Several flow rates were used to cover the conditions of light, moderate, and heavy storm intensities

- Dirty water was run under controlled conditions into a "clean" catch basin and the discharge sampled and analyzed to establish the unit's removal efficiency under different flow rates. The "dirty" water was made up by carefully introducing solids which had previously been collected from street surfaces. (This "dirt" was mixed with water from a fire hydrant supply with a time-varying concentration to simulate the variation in storm water solids content with time from the onset of a storm.)

During the course of the tests, numerous water samples were collected; most of them shortly after the onset of the simulated storm to reflect the "shock" loading effect. Subsequent analysis was directed primarily toward determining the amounts and size distribution of solids.

Test results on the initially clean catch basins indicate that they are reasonably effective treatment units for removing heavy solids from storm runoff. The curves of Fig. 44 show that virtually all of the solids larger than 246μ diameter were removed. On the other hand, only a small portion of the fine solids was removed. These curves were for a test wherein a heavy rainfall intensity (1/2 in./hr) was applied over a rather sizable catchment area (25,000 sq ft). (A word of caution is in order here regarding the subsequent use of reported values. It must be recognized that these catch basins are of a standard design and are used routinely in a broad variety of situations. This means that virtually no consideration is given toward sizing them to be appropriate to the expected flow [i.e., the same unit is used to receive runoff from both large catchment areas and very small areas]. The net result of this practice is that retention times vary tremendously from basin to basin; likewise, turbulence levels vary and removal efficiencies vary.) Other tests indicate that higher flow rates through the same basin result in lower removal efficiencies, and lower rates give higher efficiencies (as would be expected). Catch basins function as very simple sedimentation units and are, therefore, limited by the same factors that limit any sedimentation process: turbulence and retention time. The catch basins tested have no turbulence-controlling baffles at either their inlets or outlets and operate under complete mixing during all but the lowest flows. The retention time is extremely short, less than a minute even for rather low flows. These facts explain why catch basins are effective only in removing coarse materials. Since other phases of this research project have identified the fine particle size ranges as being most relevant to receiving water pollution, we conclude that even the best conventional catch basins are ineffective in reducing pollution.

The curves of Fig. 44 show that removal efficiencies varied during the test, generally decreasing with respect to time. Presumably this is due to unstable conditions of hydraulic turbulence and resuspension (although further tests would be required to support this speculation).

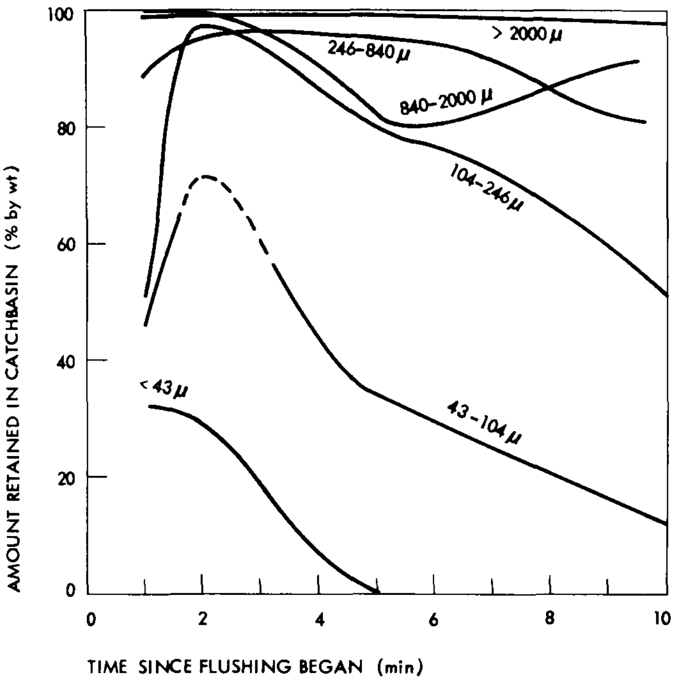


Fig. 44. Removal of Street Surface Contaminant Solids - Variation with Particle Size

The other issue examined in this substudy has to do with catch basin potential for adding pollutants to the flow passing through them. This was studied by running clean water at prescribed flow rates through several catch basins which had not been cleaned for several months. The discharge was sampled repeatedly over a period of about an hour (with most of the samples taken shortly after the "storm" onset). The catch basins all had several thousand pounds of solids in them, with a layer of water (and floating debris) up to the outlet level. The water first discharged was very dirty; composed primarily of this supernatant water, some of the floating matter, plus particulate matter suspended by the turbulence flow. Within a few minutes, the water became reasonably clear but still contained particulates. Even after nearly an hour's flushing, the discharge contained much particulate matter. At the end of an hour, inflow was stopped and the volume of basin contents was measured.. It was found that only about 1 percent of the initial solids in the basin was removed by the flushing action of any of the simulated storms (light, moderate, or heavy). On the other hand, the material which was flushed out as the initial slug would have a substantial pollutional impact on the receiving waters. This is borne out by analyses of catch basin contents.

The City of San Francisco Public Works staff provided URS with data developed as part of their studies of combined storm/sanitary sewers. URS sampled and analyzed the content of several catch basins in Baltimore and Milwaukee. Pertinent data on these catch basin contents are reported in Tables 35 and 36. While these data reflect conditions during winter and spring months, the "catch basin operation" can be considered essentially uniform during all seasons of the year. In terms of operational mode, the catch basin acts as a short-term sedimentation basin and its efficiency, measured in terms of solids removal and retention, is generally constant. A recent study (Ref. 34) indicates that the sedimentation process does show improved efficiency when operated at elevated temperature, but, in the case of short term detention systems, such as catch basins, this effect must be considered negligible. However, recognizing that pollutant loads (in terms of specific constituents) do vary seasonally, it would be expected that during summer months the pollutant load on catch basins and the resultant effluents from them will be higher in nitrates and phosphates due to increased use of fertilizers. It should be stressed that this change in pollutant character and quantity is not a function of catch basin efficiency but rather a function of increased pollutant load to the environment.

Table 35

SUMMARY OF DATA ON CATCH BASIN CONTENT ANALYSIS
(from City of San Francisco)

CATCH BASIN LOCATION	FIRST SAMPLING SERIES				SECOND SAMPLING SERIES			
	COD (mg/ℓ)	BOD (mg/ℓ)	TOTAL N (mg/ℓ)	TOTAL P (mg/ℓ)	COD (mg/ℓ)	BOD (mg/ℓ)	TOTAL N (mg/ℓ)	TOTAL P (mg/ℓ)
Plymouth and Sadowa	3,860	190	10.9	< 0.2	8,610	122	2.8	0.3
7th and Hooper	15,000	430	33.2	< 0.2	2,570	170	2.0	< 0.2
Yosemite	739	11	1.8	< 0.2	21,400	120	4.6	< 0.2
40th and Moraga	9,060	40	16.1	< 0.2	51,000	130	12.0	< 0.2
Mason and O'Farrell	8,100	130	29.7	< 0.2	7,720	85	16.5	< 0.2
32nd and Taraval	153	5	0.5	< 0.2	708	15	1.4	< 0.2
Haight and Ashbury	37,700	1,500	1.4	< 0.2	143,000	420	14.6	< 0.2
Marina Area	701	100	7.0	< 0.2	8,600	40	< 0.5	< 0.2
Montgomery Street	6,440	390	18.8	< 0.2	8,160	300	3.9	< 0.2
Webster and Turk	1,440	44	14.0	< 0.2				
Lower Selby	288	6	1.4	< 0.2				
Upper Mission	5,590	50	12.0	0.3				

NOTE: Both sampling series were conducted in winter 1970. All values based on analysis of total basin contents after complete mixing.

Table 36

ANALYSIS OF CATCH BASIN CONTENTS

TEST SITE CODE	LIQUID SAMPLES (Supernatant)			SOLID SAMPLES (Sediments)		
	COD (mg/ℓ)	PHOSPHATES (mg/ℓ)	NITRATES (mg/ℓ)	COD (mg/g)	PHOSPHATES (mg/g)	NITRATES (mg/g)
			Baltimore			
BA-6	150	1.10	4.0	31.0	0.60	0.50
BA-8	-	-	-	12.0	0.17	0.90
BA-2	175	2.2	5.5	-		-
			Milwaukee			
Mi-5	8,250	1.5	9.0	7,750	3.0	16.0
Mi-8			-	11.75	0.09	0.70

NOTE: See Appendix B for site code key, giving cities and land-use categories. Both sampling series were conducted in April/May 1971.

The successful operation of a catch basin, as a sedimentation process, is a function of the solids retention capacity of the system. Basins which are frequently cleaned have the capacity for operating at design efficiency and retaining solids (with associated pollutants); however, effluents from dirty catch basins (most basins in urban and suburban areas are cleaned less than once per year and are categorized as "dirty") exert a significant pollutional load on receiving waters and/or waste treatment plants. A portion of the solids found in catch basins is not deposited there by runoff. Rather, catch basins may act as convenient receptacles for litter, leaves and garden cuttings, crankcase drainings, etc.

Section VI

SIGNIFICANCE OF STREET SURFACE RUNOFF AS A SOURCE OF WATER POLLUTION

Section VI

SIGNIFICANCE OF STREET SURFACE RUNOFF AS A SOURCE OF WATER POLLUTION

The intent of this section is to place the information obtained in this study in perspective and to help answer the question of how important street surface contaminants are, relative to other common sources of water pollution. To accomplish this, we have compared a city's street runoff with both its treated sanitary sewage discharge and its storm water discharge. In the interest of simplicity we have made these comparisons using a hypothetical city, rather than a real one. This city's street surface contaminants have the properties determined in this study (means of the values actually observed have been employed in the comparisons). The hypothetical city has the following characteristics:

- Population - 100,000 persons
- Total land area - 14,000 acres
- Land-use distribution:
  - residential - 75%
  - commercial - 5%
  - industrial - 20%
- Streets (tributary to receiving waters) - 400 curb miles
- Sanitary sewage - 12 x 10^6 gal/day.

The comparisons made here are for the first hour of a moderate-to-heavy rainstorm; one which involves brief peak rates of at least 1/2 in./hr during that first hour.

Table 37 compares the pollutants in street runoff (generated by that 1-hr storm) with the pollutants which the city's municipal sewage treatment plant would contribute during a typical hour's discharge (the plant is assumed to be a well-operated secondary facility). Obviously, the street runoff is a much greater source of short-term "slug" loadings. It should be noted that, if this comparison were to be recomputed using the total pollutant loading over an annual cycle, the street runoff would likely be less than the treated sewage load. We have not made such comparisons because of the difficulty of establishing meaningful weather patterns for a hypothetical city.

Table 37

COMPARISON OF POLLUTIONAL LOADS
FROM HYPOTHETICAL CITY -
STREET RUNOFF vs GOOD SECONDARY EFFLUENT

	CONTAMINANT LOAD ON RECEIVING WATERS STREET SURFACE RUNOFF (lb/hr)	EFFLUENT FROM GOOD SECONDARY TREATMENT PLANT (% removal)[(a)]	(lb/hr)[(b)]	RATIO (STREET/SEWAGE)[(c)]
Settleable + Suspended Solids[(d)]	560,000	90	130	14,300
BOD[(d)]	5,600	90	110	51
COD[(d)]	13,000	90	120	110
Total Coliform Bacteria	40×10^{12} Organisms/hr	99.99	4.6×10^{10} Organisms/hr	870
Kjeldahl Nitrogen[(d)]	880	90	20	44
Phosphates[(d)]	440	95	2.5	180

(a) Typical removal efficiencies for waste treatment plants.
(b) Loadings discharged to receiving waters (average hourly rate).
(c) Ratio of loadings: street runoff/sanitary discharge.
(d) Weighted averages by land use, all others from numerical means.

This type of comparison involves a number of assumptions as to raw sewage loading and treatment plant performance (all of which affect the computed relative importance of the street runoff).

A similar type of comparison has been made using raw sanitary sewage as the base. Table 38 gives the properties of the raw sewage used in this example, along with computed ratios of how the street surface contaminants compare. Note that even raw sewage contributes less pollutants than street runoff during the first hour (coliform bacteria being a notable exception).

By using storm runoff data collected in a number of cities throughout the United States, it was possible to develop at least an approximate idea of the relationship between street surface runoff and the discharge from actual (i.e., not hypothetical) storm sewers. This information, presented in Table 39, is not particularly consistent, however, so any conclusions drawn therefrom would be speculative, at best.

SUMMARY OF CONTAMINANT LOADS

Investigations of the characteristics and quantities of urban and suburban street surface contaminants included conventional parameters of water pollution such as total and volatile solids, biochemical oxygen demand,

Table 38

COMPARISON OF POLLUTIONAL LOADS FROM HYPOTHETICAL CITY -

Street Runoff vs Raw Sanitary Sewage

	CONTAMINANT LOADS ON RECEIVING WATERS STREET SURFACE RUNOFF (lb/hr)	RAW SANITARY SEWAGE		RATIO STREET/SEWAGE [b]
		(mg/ℓ)	(lb/hr) [a]	
Settleable + Suspended Solids [c]	560,000	300	1,300	430
BOD_5 [c]	5,600	250	1,100	5.1
COD [c]	13,000	270	1,200	11
Total Coliform Bacteria	40×10^{12} Organisms/hr	250×10^{6} [e] Organisms/liter	4.6×10^{14} Organisms/hr	0.0087
Kjeldahl Nitrogen [c]	880	50 [f]	210	4.2
Phosphates	440	12 [d]	50	8.8
Zinc	260	0.20 [h]	0.84	310
Copper	80	0.04 [h]	0.17	470
Lead	230	0.03 [h]	0.13	1,800
Nickel	20	0.01 [h]	0.042	480
Mercury	29	0.07 [g]	0.27	110
Chromium	44	0.04 [h]	0.17	260

(a) Loadings discharged to receiving waters (average hourly rate).
(b) Ratio of loadings: street runoff/sanitary discharge.
(c) Weighted averages by land use, all others from numerical mean.
(d) Ref. 10.
(e) Ref. 35.
(f) Ref. 36.
(g) Ref. 37.
(h) San Jose-Santa Clara Water Pollution Control Plant, averages for January 1970, personal communication.

chemical oxygen demand, Kjeldahl nitrogen, soluble nitrates and phosphates. Also included are less common parameters; e.g., heavy metals (including chromium, copper, zinc, nickel, mercury, lead and cadmium) and both chlorinated hydrocarbon and organic phosphate pesticide compounds. However only the following were found: dieldrin, DDD, DDT, methoxychlor, endrin, methylparathion, and lindane. Polychlorinated biphenyls (PCB's) were also sought and found in significant quantities in all cities studied. Additionally, studies were conducted concerning the presence of both total and fecal coliform bacteria on the streets.

Table 39

COMPARISON OF STREET SURFACE CONTAMINANTS WITH STORM SEWER DISCHARGES

SOURCES OF POLLUTANTS		BOD (% by wt)[a]	COD (% by wt)	KJELDAHL NITROGEN (% by wt)	PHOSPHATES (% by wt)	TOTAL COLIFORM BACTERIA (10^6 org/lb)[b]
Storm Sewer Samples (reported by others)	East Bay Sanit. Dist. (c)	6.2				4
	Cincinnati (c)	4.6	42.3			
	Tulsa (d)	2.2	16	.16	.21	73
	Bucyrus (e) (a combined system storm/ sanitary)	11	40	1	.93	4,400
Street Surface Contaminants (collected in this study)	Tulsa	4.2	8.8	.2	.17	200
	Bucyrus	.21	2.1	.087	.018	
	Average over ten cities	1.7	8.4	.18	.092	104
Street Surface Contaminants (reported by others)	Chicago (c)	.5	4.0	.048		

(a) Concentrations of pollutant as a percent of total solids (dry weigh base).
(b) Concentrations of viable organisms associated with total solids (dry weight basis).
(c) Ref. 1.
(d) Ref. 2.
(e) Ref. 35.

Tables 40 through 43 summarize the quantity of pollutants identified in the investigation in terms of the parameters cited above. Reviewing the information in Table 40 reveals the rather extensive potential problem posed by these pollutants. As an example, the weighted average of 5-day BOD is shown in Table 40 to be 13.5 pounds per curb mile. In a typical (hypothetical) community of 100,000 population having 400 curb miles of streets, this would represent a potential load on the receiving water of 5,400 pounds of BOD estimated from an average 2- to 10-day buildup period since last sweeping or rain. The same city with a well-run municipal sewage treatment plant would have a daily BOD discharge of only about 1/30 this figure. While this is, of course, a hypothetical calculation and does not reflect the time span over which the street contaminant would be discharged to the receiving water, it nevertheless reflects serious concern over the non-point pollutant described.

Table 40

POLLUTION LOADS BY SELECTED COMMUNITIES
(lb/curb mi)

CITY	CURB MILES	TOTAL SOLIDS	VOLATILE SOLIDS	BOD_5	COD	KJELDAHL NITROGEN	SOLUBLE NITRATE	PHOSPHATES
San Jose I	2,300	910	66	16	(310)	2.1		0.70
San Jose II	2,300	6,000	460	53	(400)	11.0	0.27	4.5
Phoenix I	2,900	650	40	7	30	1.5	0.29	0.22
Phoenix II	2,900	910	92	10	54	2.9	0.12	2.8
Milwaukee	3,400	2,700	180	12	48	1.4	0.052	0.27
Baltimore	3,900	1,000	96	-		1.9	0.038	1.0
Seattle	2,600	460	29	5	17	0.9	0.027	0.49
Atlanta	3,500	430	18	2	13	0.5	0.024	0.26
Tulsa	3,600	330	19	14	30	0.7	0.012	0.54
Bucyrus	200	1,400	150	3	29	1.2	0.12	0.25
Weighted Average	27,600	1,400	100	13.5	95 32[a]	2.2	0.094	1.1

[a]Excluding San Jose I and II

Table 41

HEAVY METALS LOADS BY SELECTED COMMUNITIES
(lb/curb mile)

CITY	CHROMIUM	COPPER	ZINC	NICKEL	MERCURY	LEAD	CADMIUM	TOTAL HEAVY METALS
San Jose I	0.20	0.50	1.4	0.13	0.30	1.9	0.0033	4.5
San Jose II	0.14	0.02	0.28	0.085	0.085	0.90	(0.0031)	1.5
Phoenix I	-	-	-	-	-	-	-	-
Phoenix II	0.029	0.058	0.36	0.038	0.022	0.12	(0.0031)	0.63
Milwaukee	0.047	0.59	2.1	0.032	(0.082)[a]	1.5	0.0032	4.5
Baltimore	0.45	0.33	1.3	0.077	(0.082)[a]	0.47	0.0026	2.8
Seattle	0.081	0.075	0.37	0.028	0.034	0.50	(0.0031)	1.09
Atlanta	0.011	0.066	0.11	0.021	0.023	0.077	(0.0031)	0.31
Tulsa	0.0033	0.032	0.062	0.011	0.019	0.030	(0.0031)	0.16
Bucyrus	-	-	-	-	-	-	-	-
Weighted Average	0.11	0.20	0.65	0.05	0.073	0.57		1.6

Note: Except for San Jose I, Phoenix I, Milwaukee, Baltimore, and Bucyrus, cadmium estimates were based on other observations.

Table 42

PESTICIDE LOADS BY SELECTED COMMUNITIES
(lb/curb mile)

CITY	DIELDRIN	PCB	BP-DDD	METH-OXYCHLOR	P,P-DDT	ENDRIN	METHYL PARATHION	LINDANE	TOTAL PESTICIDES
San Jose I	11	1,200	67	0	110	2.0	20	17	1,460
San Jose II	27	1,100	120	0	170	0	0		1,417
Phoenix I									
Phoenix II	24	65	34	0	13	0	0		136
Milwaukee	10	3,400	0.5	8,500	1.0	0	0	0	11,910
Baltimore	3	3,400	100	170	30	0	0		3,700
Seattle	27	1,100	120	0	170	0	0		1,420
Atlanta	24	65	34	0	13	0	0		136
Tulsa	24	65	34	0	13	0	0		136
Bucyrus	17	650	83	1,610	61				2,410
Median	24	1,100	67		61				1,420

NOTE: All values by 10^{-6}.

Table 43

TOTAL AND FECAL COLIFORM LOADING DISTRIBUTION BY LAND-USE CATEGORY

AREA	TOTAL COLIFORMS (10^9 org/ curb mile)	TOTAL COLIFORMS (number/ gram solids)	FECAL COLIFORMS (10^9 org/ curb mile)	FECAL COLIFORMS number/ gram solids)
Residential	60	160,000	5.8	16,000
Industrial	150	82,000	1.6	4,000
Commercial	120	110,000	18.	5,900
Combined (Total)	99	130,000	5.6	14,000

Note: The per curb mile ratio is not equal to the per gram solids ratio because extreme values in each matrix were eliminated prior to determining the weighted averages for each land-use area. The eliminated values from each matrix were not always representing the same city and land use, hence the discrepancy.

Based on information available concerning antecedent street cleaning and rainfall patterns, an attempt was made to calculate accumulation rates in terms of pounds of pollutant per curb mile per day. These summary figures are shown in Table 44. It should be appreciated that these "daily" values are somewhat artificial in that there was no way to account for either the effectiveness of street cleaning operations or the extent of the rainfall and associated pollutant runoff prior to the street sampling procedures. Nevertheless, it is apparent from Table 44 that the relative pollutant load is significant, although the relationship between specific pollutants does change. In the case of BOD, the mean value of 4.5 lb/curb mi/day (or 1800 lb for 400 curb miles for the hypothetical city) is roughly equivalent to the amount of BOD discharged to the receiving waters daily by the sewage treatment plant.

Table 44

AVERAGE RATE OF ACCUMULATION OF POLLUTANTS
(lb/curb mi/day)

CITY	TOTAL SOLIDS	VOLATILE SOLIDS	BOD_5	COD	KJEDAHL NITROGEN	NITRATES	PHOSPHATE	TOTAL HEAVY METALS	TOTAL PESTICIDES
San Jose I	70	5.3	1.2	24	0.16	-	0.054	0.34	110×10^{-6}
San Jose II	860	65	7.6	56	1.5	0.038	0.64	0.22	200
Phoenix I	92	5.9	0.93	4.3	0.21	0.041	0.031		
Phoenix II									
Milwaukee	2,700	180	12	48	1.4	0.052	0.27	4.3	12,000
Baltimore	260	24			0.48	0.0095	0.25	0.68	940
Seattle									
Atlanta	220	9.3	0.95	6.5	0.24	0.012	0.13	0.21	68
Tulsa							-		
Bucyrus	690	74	1.4	25	0.60	0.060	0.12		
Weighted Average	730	51	4.5	26	0.66	0.029	0.37	1.3	200

Note:

1. No sweeping data available for Phoenix II, Seattle, and Tulsa.
2. Based on number of days since cleaned, either by rain or by sweeping, whichever occurred closest to the test date.
3. Heavy metals include chromium, copper, zinc, nickel, mercury, lead, and cadmium.
4. Pesticides include dieldrin, PCB, DDD, methoxychlor, DDT, endrin, methyl parathion, and lindane.

In summary, all other identified characteristics exhibit similar relationships in terms of wastes emanating from domestic treatment plants.

The information in Table 41 deals specifically with heavy metals. The metals included here were found in sufficient concentration to be detectable in all cities of the study. This of itself is not a surprise due to the sensitivity of the analytical procedures. However, the fact that the weighted average of the total heavy metals is as high as 1.6 pounds per curb mile is rather alarming.

Considering that the subject of individual heavy metal's effects on the environment is only slightly understood at best, and considering further that so little conclusive work has been done regarding the synergistic effects of combinations of metals, there is every reason for concern over the high quantities found in this investigation.

Information concerning pesticides is presented in Table 42. The concern over pesticides has reached such proportion that many states have banned their use and sale and the Federal government has taken an active role in prohibiting extensive use of DDT and other long-lived synthetic pesticides. The information in Table 42 is significant on two counts. First, the fact that the median value for total pesticides found in the study is high enough to be reported in terms of pounds (albeit a rather small number - 0.0014 lb/curb mile). For the hypothetical community of 100,000 population, the calculated pesticide loading was in excess of 1/2 lb per precipitation incident, which represents approximately 0.1 lb/day. Secondly, about three-fourths of the total weight of such materials were found to be polychlorinated biphenyls, a class of compounds over which there has been much recent concern due to the high incidence of wildfowl deaths correlatable with high PCB levels. It is premature at this point to speculate on the implications of how PCB are being introduced to the environment or why there is such a high incidence of PCB identified. However, recent studies have shown PCB concentrations as high as 0.2 ppm in soft-shelled clams taken from Chesapeake Bay and as high as 1.5 ppm in Atlantic Ocean zooplankton. Based on an estimated 42,500 tons of PCB commercially produced in the U.S. in 1970 and assuming a closed system use of approximately 60 percent, the accumulation on urban and suburban streets, as reported in this study, represents 0.15 percent of the total PCB production.

Table 43 summarizes the total and fecal coliform distribution found in the study. For purposes of summary, values are given for the three major land-use classifications within a community (i.e., residential, industrial, and commercial), as well as a combined figure representative of the average municipality. Two observations can be made here. The first concerns the overall magnitude--more than 100 billion total coliforms and over 1 billion fecal coliforms per curb mile. The second concerns the relative magnitude of total to fecal counts.

The number of fecal coliforms found in the street samples is about a thousand-fold less than densities commonly associated with the discharges from domestic animals. The figures in Table 43 indicate that fecal coliforms range from 4,000 to 16,000 per gram of solids. Comonly accepted figures for animals are in the range of 8 to 23 million fecal coliforms per gram of feces.

Data reported in Table 43 indicates that the highest ratio occurs in the industrial areas, the lowest in central business districts (which are typically swept daily). On a comparative basis, reported ratios of total to fecal coliform in raw sewage have been found to range from 2.1 to 12, while ratios for storm runoff (uninfluenced by domestic sewage discharges) range from 10 to 300. Studies concerning the relationship between total and fecal coliforms as a function of time indicate that the fecal coliforms exhibit a more rapid die-off (they are much more sensitive). Therefore, the greater the ratio of total to fecal, the greater the time interval since deposition. In other words, the high ratios exhibited in industrial areas may well be attributed to a longer residence time on the streets. In any case, all of the ratios seem to indicate that the bacteria have resided in the test sites for some time and are probably not indicative of fresh bacterial discharge.

However, the total impact of the non-point pollutants must be assessed in terms of the product of the pollutant load per land-use category and the actual amount of land area represented by the designated land-use category. Thus, although Table 45 and 46 show the industrial category to have the highest loading of pollutants per curb mile, there may be no problems in a small community with minimal industry.

Table 45

DISTRIBUTION OF CONTAMINANT LOAD BY LAND-USE CATEGORY
(lb/curb mile)

	RESIDENTIAL	INDUSTRIAL	COMMERCIAL
Total Solids	1,200	2,800	360
Volatile Solids	86	150	28
BOD_5	11	21	3
COD	25	100	7
Kjeldahl Nitrogen	2.0	3.9	0.4
Nitrates	0.06	0.18	0.18
Phosphates	1.1	3.4	0.3
Total Heavy Metals	0.58	0.76	0.18
Total Pesticides	--	--	--

Table 46

DISTRIBUTION OF CONTAMINANT LOAD BY LAND-USE CATEGORY
(lb/curb mile/day)

	RESIDENTIAL	INDUSTRIAL	COMMERCIAL
Total Solids	590	1,400	180
Volatile Solids	44	77	14
BOD_5	3.6	7.2	0.99
COD	20	81	5.7
Kjeldahl Nitrogen	0.60	1.2	0.12
Nitrates	0.019	0.055	0.055
Phosphates	0.37	1.1	0.10
Total Heavy Metals	1.2	1.6	0.34

Note: Based on number of days since cleaned, either by rain or by sweeping, whichever occurred the closest to the test date.

The figure reported here as "Residential" was computed by combining all of the observed data for the four residential land-use categories sampled in each city. "Industrial" and "Commercial" figures were computed similarly.

Normally, pollutants are associated with liquid discharge and are, therefore in terms of concentration (e.g., mg/ℓ or ppm). This is both reasonable and proper in that treatment facilities operate in physical, chemical, and/or biological modes to remove pollutants from the liquid stream so as to minimize their concentration and total impact on the receiving water. However, the pollutants associated with street surface comtaminants are, by and large, in the dry state until such time that they are hydraulically conveyed to and through storm or combined sewer systems to the receiving water. Treatment of this type of pollutant can take place either at the source, at the point of discharge, or more typically, not at all. If treatment (and in the broad context this means removal of constituents) is attempted at the point of origin, then it is apparent that it is most appropriate to characterize the pollutants in the dry state. For this reason, extensive studies were conducted to establish relationships. A review of Table 47, 48, and 49 summarizes these relationships. A review of Table 47 clearly indicates that efforts to control or remove particles larger than 2,000 microns from streets will generally remove no more than 10 percent of a broad spectrum of pollutants, even if the removal of these large-size particles were 100 percent effective. Putting it in somewhat different terms, approximately 75 to 100 percent (depending on the specific pollutant) of the pollutants are associated with particles smaller than 2,000 microns; perhaps of even more significance, between 40 and 90 percent of the pollutants are associated with particles of less than 246 microns in diameter. Clearly then, the design of any treatment method for controlling street surface pollutants must necessarily be effective at removing a rather broad spectrum of particle sizes.

Table 47

FRACTION OF POLLUTANT ASSOCIATED WITH EACH PARTICLE SIZE RANGE (% by Weight)

	PARTICLE SIZE (μ)					
	> 2,000	840 → 2,000	246 → 840	104 → 246	43 → 104	< 43
Total Solids	24.4	7.6	24.6	27.8	9.7	5.9
Volatile Solids	11.0	17.4	12.0	16.1	17.9	25.6
BOD_5	7.4	20.1	15.7	15.2	17.3	24.3
COD	2.4	4.5	13.0	12.4	45.0	22.7
Kjeldahl Nitrogen	9.9	11.6	20.0	20.2	19.6	18.7
Nitrates	8.6	6.5	7.9	16.7	28.4	31.9
Phosphates	0	0.9	6.9	6.4	29.6	56.2
Total Heavy Metals	16.3	17.5	14.9	23.5	27.8 (43 → 104 and < 43 combined)	
Total Pesticides	0	16.0	26.5	25.8	31.7 (43 → 104 and < 43 combined)	

Table 48

FRACTION OF HEAVY METALS ASSOCIATED WITH EACH PARTICLE SIZE RANGE (% by Weight)

	PARTICLE SIZE (μ)				
	> 2,000	840 → 2,000	246 → 840	104 → 246	< 104
Chromium	26.1	13.6	16.3	16.3	27.7
Copper	22.5	20.0	16.5	19.0	22.0
Zinc	4.9	25.9	16.0	26.6	26.6
Nickel	26.2	14.2	15.3	17.2	27.1
Mercury	16.4	28.8	16.4	19.2	19.2
Lead	1.7	2.6	8.7	42.5	44.5
Average	16.3	17.5	14.9	23.5	27.8

Table 49

FRACTION OF PESTICIDES ASSOCIATED WITH EACH PARTICLE SIZE RANGE (% by Weight)

	PARTICLE SIZE (u)			
	840→ 2,000	246 → 840	104 → 246	< 104
Dieldrin	0.9	21.3	36.0	41.8
PCB	33.5	32.4	15.7	18.4
DDD	10.7	29.3	30.3	29.7
Methoxychlor	35.0	27.0	11.0	27.0
DDT	0	22.3	36.1	42.1
Average	16.0	26.5	25.8	31.7

Table 48 shows the distribution of heavy metals relative to particle size, and Table 50 shows how these heavy metals are distributed by land-use category. A review of Table 50 indicates that chromium, nickel, and cadmium are probably of less concern than the other heavy metals, at least on the basis of total quantities. However, as stated earlier, the lack of definitive information concerning the individual toxic effects of these metals (and particularly their synergistic effects with each other or other compounds) precludes the assumption that, although chromium, nickel, and cadmium represent an insignificant amount of total heavy metals, they have no serious impact on receiving waters.

Table 50

DISTRIBUTION OF HEAVY METALS BY LAND-USE CATEGORY (% by Weight)

METAL	RESIDENTIAL	INDUSTRIAL	COMMERCIAL	TOTAL
Chromium	5	8	5	7
Copper	10	14	20	11
Zinc	38	44	24	40
Nickel	1	5	3	3
Mercury	10	4	20	4
Lead	36	25	28	35
Cadmium	--	--	--	--
	100%	100%	100%	100%

Note: The figure reported here as "Residential" was computed by combining all of the observed data for the four residential land-use catagories sampled in each city. "Industrial and Commercial" use were computed similarly.

The results of the investigation to date emphasize several points. The data presented here indicate rather clearly that a broad spectrum of pollutants exists in significant quantities in all of the cities investigated and in each of the land-use areas designated therein. Further, these data provide a basis for estimating the anticipated uncontrolled pollutant discharge to the receiving waters of other communities. Finally, it is now possible to make realistic and meaningful comparisons concerning the relative impact of this non-point pollutant source on a comparative basis with discharges from municipal and industrial sources as well as other non-point pollutant sources as they become quantified. The study reveals, for the first time, the dominant relationships between pollutant properties and the particle size distributions with which they are associated. This is an extremely important relationship because it allows a sound engineering evaluation to be made concerning the value of various means of street litter control in reducing this non-point pollution source. It also allows quantification of the pollutant load to a receiving water under a wide variety of water pollution control technologies. In fact, the identified relationships give perspective to the impact of street cleaning practices in terms of controlling street surface pollution runoff.

THE EFFECTIVENESS OF STREET CLEANING PRACTICE

It is apparent from the preceding discussion and supporting tables that conclusive evidence now exists confirming not only the wide spectrum of pollutants present on urban and suburban streets, but also the order of magnitude of the loading intensities of these pollutants. This section concerns means of controlling the quantity of pollutants which actually reach the receiving water. This is clearly a function of the daily accumulation of pollutants on the streets and their transport, by runoff, to streams, lakes, bays, etc. The daily accumulation, in turn, is determined in part by street cleaning operations. Obviously, if cleaning removed all pollutants on the streets daily then this non-point pollution source would be reduced to insignificance.

Street sweepers (brush or vacuum) are intended to remove those types of materials which are of concern to the public, primarily because they are aesthetically objectionable. Almost by coincidence, street sweepers also remove particle-related pollutants. Studies were conducted in the 1950's and early 1960's on sweeper efficiencies (using sweepers which still represent the current state of technology). Those studies are valuable in that they allow estimates to be made concerning sweeper effectiveness in removing pollutants. Using information developed in those prior studies, it was possible to establish relationships between sweeper performance and particle removal. With these data it is possible to calculate the hypothetical maximum removal of selected pollutants for any given community. As an example, consider the hypothetical community described earlier in this section for which it is possible to compute the resultant pollution load after sweeping. The initial step involves calculating sweeper effectiveness using data in Section V.

The resulting calculations are shown in Table 51. It is significant to note that the range of removal efficiencies is from a high of only 79 percent to a low of 15 percent. These figures are of particular interest when it is realized that these efficiencies represent optimum operation of carefully adjusted equipment and are probably seldom achieved with municipally operated sweepers. Even assuming these relatively high efficiencies, there would still remain a residual street surface contaminant loading of about 3200 lb of BOD on the city's streets (this assumes that the contaminants have had about 5 days to accumulate since the last sweeping or rain). This is equivalent to about three times the daily output from a well-run municipal treatment plant.

A limited sub-study was conducted to determine if any consistent trends could be found to relate the amount of contaminants found on streets with the elapsed time since the last sweeping or substantial rainfall. Since areas with widely differing overall characteristics were included in the study, it was difficult to discern any dominant or repetitive trends. The efforts involved in this sub-study are reported in Appendix I.

SIGNIFICANCE TO STREET CLEANING PROGRAMS

The conclusion is inescapable: even under well-operated and highly efficient street sweeping programs, the broad spectrum of pollutants accumulated in urban and suburban streets represent a non-point pollution potential well in excess of the presently allowable discharge from municipal treatment plants. Either more efficient street cleaning equipment must be developed and put into operation or storm water must be treated prior to discharge to the receiving waters.

Attempts to treat storm water at the point of discharge have been made in certain instances, such as in Chicago, New York City, Washington, D.C., etc,; generally by storing the storm water in ponds, lakes, or underwater bladders, removing floating and suspended matter by screening and sedimentation, then releasing the water at a controlled rate. Where the storm water contains large quantities of suspended silt and sediment, this approach is effective. The enormous volume of water which can originate in an urban watershed in a single storm, however, requires extremely large and expensive storage facilities.

The cleaning of urban streets has long been a routine function of municipal government. The operation was developed to meet relatively subjective cleanliness criteria, based on individual perceptions of satisfactorily cleaned streets. Urban sociologists have observed that this perception is subject to large variations, in part related to socio-economic status. Even when the goal of an adequately clean street is defined and accepted, municipal street cleaning operations differ in their ability to achieve that goal.

Table 51

SELECTED POLLUTANT REMOVAL PROJECTIONS - BY STREET SWEEPERS

PARTICLE SIZE (u)	SWEEPER EFFICIENCY (%)	TOTAL SOLIDS Size Distribution (%)	TOTAL SOLIDS Removal (%)	BOD_5 Size Distribution (%)	BOD_5 Removal (%)	COD Size Distribution (%)	COD Removal (%)	KJELDAHL NITROGEN Size Distribution (%)	KJELDAHL NITROGEN Removal (%)	PHOSPHATES Size Distribution (%)	PHOSPHATES Removal (%)	TOTAL HEAVY METALS Size Distribution (%)	TOTAL HEAVY METALS Removal (%)	TOTAL PESTICIDES Size Distribution (%)	TOTAL PESTICIDES Removal (%)
> 2,000	79	24.4	19.3	7.4	5.8	2.4	1.9	9.9	7.8	0	0	16.3	12.9	0	0
840 → 2,000	66	7.6	5.0	20.1	13.3	4.5	3.0	11.6	7.7	0.9	0.6	17.5	11.6	16	10.1
246 → 840	60	24.6	14.8	15.7	9.4	13.0	7.8	20.0	12.0	6.9	4.1	14.9	8.9	26.5	15.9
104 → 246	48	27.8	13.3	15.2	7.3	12.4	6.0	20.2	9.7	6.4	3.1	23.5	11.3	25.8	12.4
43 → 104	20	9.7	1.9	17.3	3.5	45.0	9.0	19.6	3.9	29.6	5.9	27.8	5.6	31.7	6.3
< 43	15	5.9	0.9	24.3	3.6	22.7	3.4	18.7	2.8	56.2	8.4	--	--	--	--
Total Removal Efficiency			55.2		42.9		31.1		43.9		22.1		50.3		44.7

Effective methods of planning and evaluating the efficiency of street cleaning practices are not available at the present time to assist those public works personnel responsible for street cleaning programs.

Figure 45 presents a cost effectiveness program which would assist public works officials in evaluations and/or selecting the combination of equipment and operational procedures which will provide the desired cleaning effectiveness.

As shown in Fig. 45, cost-effectiveness indices should be derived for each street cleaning practice and for the important particle size ranges of street surface contaminants. For each combination of equipment and operational practice there is associated:

- A total cost, including fixed and variable costs
- A level of effectiveness represented by a particle size removal efficiency for specific particle size ranges
- A relationship between the particle size range and the the pollutional properties of street surface contaminants.

Operational practice is composed of two elements: the operator and the equipment type being utilized. Operator skill and training and crew size are important inputs to operational practice. Equipment parameters include:

- Equipment type
  - broom
  - vacuum
  - air
  - combination
- Number of cleaning cycles
- Speed of operation
- Broom parameters
  - type of bristle
  - rotation speed
  - contact pattern (strike)
  - broom pressure
  - condition of broom
- Pickup mechanisms
  - hopper size
  - gutter brooms
- Auxiliary systems
  - vacuum
  - air spray
  - water spray
  - filtration system

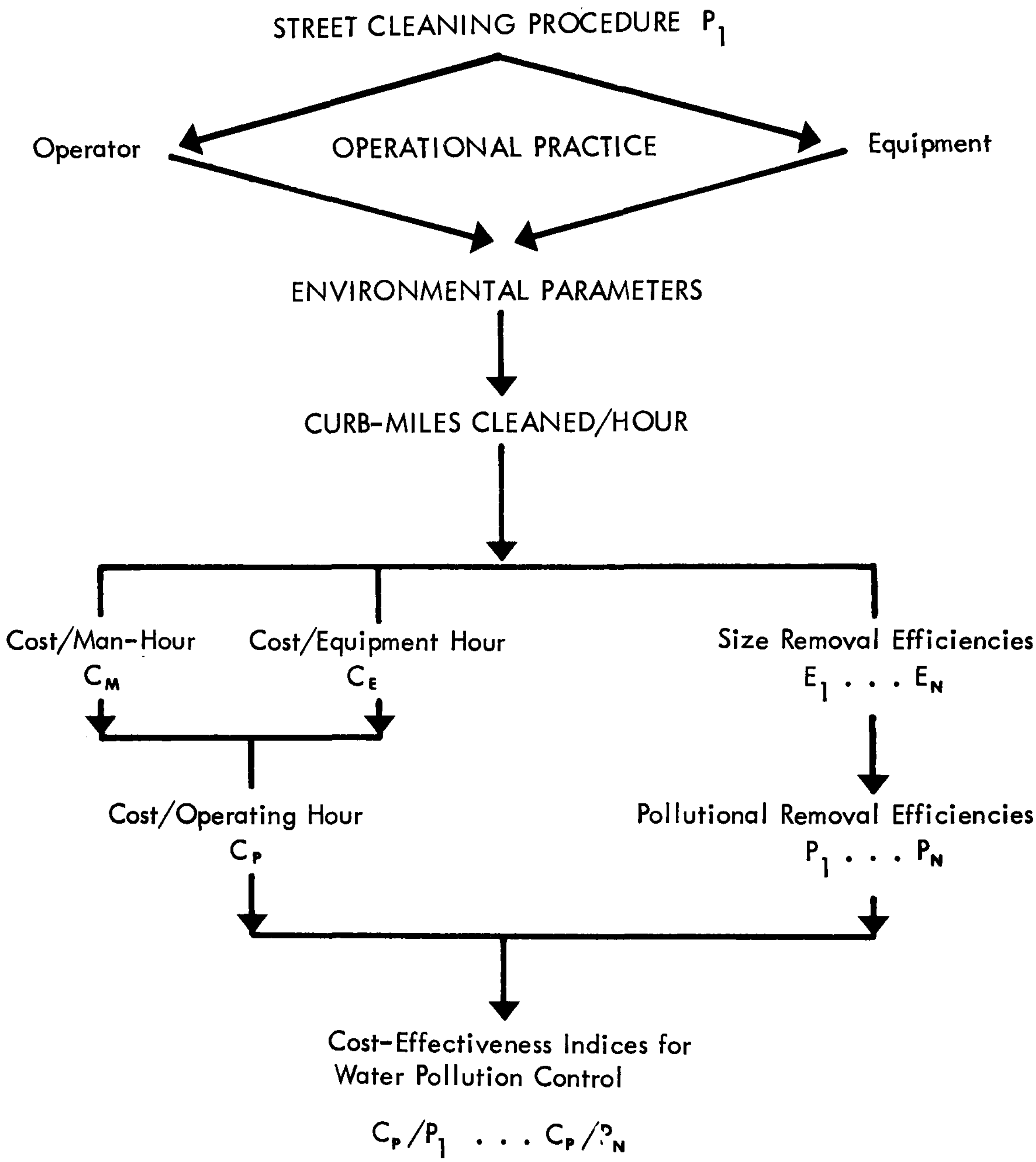


Fig. 45. Cost Effectiveness Program for Street Cleaning

Environmental parameters include:

- Quantity and amount of contaminants and refuse on street surface
- Pollution potential of the various components (dust, dirt, litter, leaves, etc.) of comtaminants and refuse
- Particle size distribution of the dust and dirt fraction
- Street type, surface characteristics
- Curb and gutter configuration
- Pavement type and condition
- Street repair practices
- Catch basin design.

As discussed in the previous section, the state of the art regarding management information systems for public works is not very far advanced. Existing cost accounting, work reporting, and equipment maintanence recording systems are fragmentory and produce disparate comparative statistical data. There is a need for a system which will aid in providing public works personnel with accurate cost data associated with street cleaning practices.

The technique of measurement of street cleaning effectiveness as related to the pollutional properties of street surface contaminants was adequately demonstrated in this study. The techniques described in Appendix A for collection of street surface samples could be utilized to determine the size removal efficiencies and corresponding pollutional removal required to determine the overall cost-effectiveness indices for each street cleaning practice evaluated.

Section VII

ACKNOWLEDGMENTS

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ACKNOWLEDGMENTS

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A Project Review Panel met quarterly during the conduct of the study to suggest direction and evaluate work progress. The panel was comprised of the following:

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Public Works organizations in the cities selected for the street surface sampling program and the in situ street cleaning tests were most cooperative in providing assistance in

- selection of test areas
- provision of street cleaning equipment and operators
- provision of traffic control during testing.

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Milwaukee, Wisconsin	Mr. Joe Alberti Mr. Jasper Harwood
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Atlanta, Georgia	Mr. Richard Respress Mr. O. A. Powers Mr. Ralph Hulsey Mr. Jack Campron

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Baltimore, Maryland	Mr. Gene Neff Mr. Leonard Folio Mr. Lou Votta
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Section VIII

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Appendix A

SAMPLE COLLECTION METHODS

APPENDIX A

SAMPLE COLLECTION METHODS

The goals of the sampling program were fourfold:

- To determine the manner in which contaminants are flushed from street surfaces by rainfall runoff
- To determine the quantity as well as the physical/chemical/biological characteristics of street surface contaminants which are removed from street surfaces by rainfall runoff and/or by sweeping
- To determine how these quantities and characteristics vary with respect to factors such as land use, geographical locale, and season
- To examine correlations between pollutants and the physical fractions with which they are associated.

To fulfill these goals required the development of several sampling and testing programs. The first conducted was the simulation of rainfall removal effects. From the results of these early tests, progressively simpler and more efficient procedures were evolved. The following is a summary of the sample collection techniques and test procedures utilized during the study:

Test Procedures

Initial field tests were conducted wherein three typical street areas (two asphalt and one concrete) were flushed by a simulated rainfall. (Bakersfield, California, was selected as a site for the field tests because it was the nearest sizeable city which had not yet experienced any significant rainfall since the preceding summer.) The system designed and built by URS to accomplish this is shown in Figures 26 and 27. It sprinkles fine sprays of water which cover an area approximately 40 x 25 ft (1000 sq ft) and is constructed of four 16-pipe manifolds mounted on a small trailer. Each manifold has four 8 ft sprinkler booms attached at 4-ft intervals plus a 4 ft boom at the outer end of the manifold.

The rainfall simulator is wheeled into position over the designated sample area and connected by firehose to a nearby fire hydrant; a flow-meter, pressure gage, and valve system controlling and measuring water flow rate were also connected into the system. The rainfall simulator was calibrated experimentally to relate rainfall intensity to pressure. Simulated rainfall flushing was conducted for a period of 2-1/4 hr at each test site. Every 15 min during that period, samples of liquids and particulates were taken for subsequent analysis. At the end of the period, the streets were flushed thoroughly with a firehose to wash off any remaining loose or soluble matter. Samples of this remaining material were also collected. Two rainfall rates, 0.2 in./hr and 0.8 in./hr, were used.

The runoff collection system consists of several watertight vacuum boxes of 160 gal capacity, a large industrial vacuum cleaner, two vacuum hoses and several sandbags. The sandbags are used to make a small dam in the gutter a short distance downstream of the test area. The vacuum cleaner is connected to one of the vacuum boxes, drawing a vacuum on the box. A pickup hose from the box is placed in the gutter in front of the dam and picks up all the water runoff coming down the gutter. When one box is filled the vacuum cleaner and pickup hoses are switched to another box and the runoff collection is continued. The box is fitted with a cloth filter bag to collect all but the finest particulate matter to be saved for subsequent analysis; the water in the box was discarded after noting its volume. A smaller (5 gal) vacuum can was used to collect liquid samples for analysis; the inlet nozzle was withdrawn periodically from the gutter to assure that the 5 gal were obtained throughout the 15 min period.

In addition, dry samples were collected with an industrial-type vacuum sweeper (Tennant Mfg. Co. Model HD-42, Figure A-1). The dust collection system on the sweeper has been modified somewhat to simplify

Fig. A-1. Motorized Vacuum Sweeper

sample handling. This was done by removing the dust filter collector and substituting a special replaceable dust filter bag. Note that the unit is not intended to simulate the effect of cleaning strets using conventional municipal sweepers; rather, it is intended to simulate the results which could be attained by advanced state-of-the-art equipment employing a combination of brush sweeping and vacuum. Tests to date have shown the small unit to be quite effective in removing all visible debris and all but a small amount of the very fine particulate matter.

The preliminary flushing tests in Bakersfield provided much valuable information. On the basis of that experience, we were able to make several important modifications on our equipment and field testing procedure. A primary reason for conducting the tests was to determine an appropriate sprinkling time and rate to be used as fixed parameters in subsequent test series.

Results of initial testing in Bakersfield allowed improvement of the sampling technique. The following program was developed:

<u>Test A</u>: Sprinkling unswept street area with simulated rainfall

<u>Test B</u>: Vacuum sweeping an unswept street area

<u>Test C</u>: Sprinkling a previously vacuum swept street area by simulated rainfall

<u>Test B'</u>: Hand sweeping an unswept street area

<u>Test C'</u>: Flushing a previously hand swept street area using a jet of water.

All tests were conducted on adjacent sections of street using the following standardized procedure:

<u>Test area</u>: 25 ft x 40 ft of level street oriented parallel to curb

<u>Rainfall intensity</u>: 1/2 in./hr uniformly for one hour

<u>Vacuum sweeping</u>: Two passes with Tennant HD-42 (8 to 10 min)

<u>Hand sweeping</u>: Two passes with a stiff-bristle street broom

<u>Flushing</u>: Water applied in a high-intensity jet until street surface foaming ceases.

In San Jose only Tests A, B and C were conducted. These tests were carried out on streets representing seven different preselected land-use areas. In Phoenix all five tests were conducted on each of the streets representing each of the eight land-use areas.

Routine Sampling Procedures

Modifications of the preceding sampling program were developed since it was found impractical to transport the rain-simulation and other bulky equipment across country. The standard sampling routine was essentially reduced to a combination of Tests B' and C', that is, hand-sweeping and hose flushing combined with a small-scale vacuum recovery system. The procedure consisted of three phases, locality data taking, hand-sweeping, and flushing-vacuum recovery of remaining material.

Locality Data Collection

After setting up traffic control in the chosen test area, information was gathered as to: location, date, land use, parking and traffic characteristics; street, gutter, and curb composition, condition and texture, test area and description of the adjoining area. At this time photographs of the area were taken.

Hand Sweeping

Hand sweeping, or dry solids collection, utilized a standard stiff bristled broom sweeping towards the curb while moving laterally along the street. After concentration in the gutter, samples were collected by whisk broom and dustpan and normally placed in clean paint cans.

Hose Flushing

Flushing was conducted after sweeping to remove adherent soluble films and otherwise nonsweepable material. The downslope gutter was dammed with sandbags to create a collection area for flushing water. A small vacuum collector was constructed using 5 gal paint cans and connected to a rented industrial wet/dry vacuum cleaner. The test area was first slightly wetted to facilitate removal of soluble materials. Flushing was then commenced at the road crown using a garden hose and spray nozzle connected to fire hydrants. All water used was collected by vacuum box and measured. The samples were then mixed by vigorous stirring and split to 1 gal volume. If pesticide analysis was to be conducted, an additional sample was taken in quart size glass containers. Plastic gallon bottles were used for all other samples.

Across the street sampling and sweeper testing were conducted in conjunction with routine sampling as required.

Distribution of Street Surface Contaminants Across a Street

The test procedure involved dividing a one hundred ft long section of street into swaths from the center line to the curb. Widths of the parallel swaths were as follows:

S-5 6 in. (nearest to curb)

S-4 6 in.

S-3 28 in.

S-2 56 in.

S-1 remaining distance to street centerline (variable from site to site)

The width of swaths varied, decreasing from the center line to the curb, in order to more closely define contaminant loading in the areas where heavy accumulations of contaminants are known to exist. Each swath was vacuum swept twice with the Tennant HD-42 Vacuum Sweeper to collect the samples in San Jose I and Phoenix I, while remaining collections were by hand sweeping. With the exception of very large samples which were split, all of the material collected in each swath was returned to the laboratory in plastic bags. Analyses were for total dry solids.

Equipment Performance Tests

Two methods were employed to determine the performance of street cleaning equipment. The first relies on measuring the amount of a street refuse simulant left on a clean street after the passage of the equipment to be tested. The second method compares before and after sweeping loadings of adjacent dirty streets.

Simulant Test

Test areas 50 ft by 8 ft were laid out at the test site. Each test area was vacuum swept twice and then hosed down until all foaming ceased. These test areas were then allowed to dry.

A street refuse simulant (see Appendix G) of realistic specific gravity, size distribution and shape was applied to test areas at a prescribed loading density for each specific test. A pre-weighed amount of simulant was placed in a calibrated lawn fertilizer cart and dispersed over the test area. Several shallow pans of 1 sq ft area were placed on the test area, collected after distributing the simulant, and weighed to check the initial loading density. The street sweeper tested made one pass over the test area, operating under the conditions designated for the specific test. Following each test, the test area was again hose flushed and all the water collected. Solids were separated by settling and subsequent decantation and weighed to determine yield.

Routine Tests

Routine equipment evaluation tests were usually conducted in conjunction with across street sampling as previously described. To conduct a sweeper test, two areas were used. The first was swept (usually using across the street methods) and hosed to determine the total initial loadings. The second area, adjacent to the first, was swept using a street sweeper. It was then hand swept, using across the street procedures to determine any change in distribution of loadings, and then hose flushed with vacuum collection.

Sample Handling and Preparation Procedures

All solids and liquid samples (except for San Jose) were shipped by air from the test sites to the laboratory. Upon receiving the shipment, the laboratory technicians placed the samples in a cold room maintained at $5^{\circ}C$, and placed the dry samples in a room at ambient temperature (about $20^{\circ}C$). The solids were stored in new unlined metal paint cans, while the liquids were stored in plastic containers. All samples designated for pesticide analysis were collected and stored in glass containers.

All individual solid samples were dried under heat lamps (less than $100^{\circ}F$) and weighed.

A composite solid and liquid sample for each city was then prepared by the following technique:

> Solid Composite - Each individual land-use sample for a given city was thoroughly mixed and an aliquot of a given weight removed. The aliquot size was based on the land-use percentage of the city multiplied by the amount of material found on the sample street in that land use.
>
> Liquid Composite - Each individual land-use sample was thoroughly mixed and an aliquot taken based on the land-use percentage of each city.

Size classification of solid sample was performed by standard sieve analysis. Sieve analysis was run on all city, land-use and area composites and on all street sweeper evaluation tests. The dried solid sample to be analyzed was placed on top of the 2000 micron screen in the nest of 5 screens (sizes 2000 microns, 840 microns, 246 microns, 104 microns, 43 microns and the pan). The screens were then placed in a roto tap unit and agitated for 1/2 hr. The screens were then removed and the material on each screen weighed.

Special sample preparation was used for the heavy metal analysis of the liquid samples. All liquid samples were cotton filtered prior to analysis to remove large settleable solids.

Solid Sample Preparation

Prior to chemical analysis aliquots of each solid composite sample were taken and placed in a blender with a known amount of distilled water (varied according to strength of pollutant) and homogenized.

Appendix B

SUMMARY OF CHARACTERISTICS OF TEST SITES IN SELECTED CITIES

Appendix B

SUMMARY OF CHARACTERISTICS OF TEST SITES IN SELECTED CITIES

GLOSSARY OF TERMS USED IN TABLES B-1 through B-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 B-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 B-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. [illegible]			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	ASPHALT	ASPHALT	ASPHALT		ASPHALT	ASPHALT	ASPHALT		ASPHALT	ASPHALT
• condition	FAIR	FAIR	EXCEL.		FAIR	GOOD	EXCEL.		FAIR	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 B-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 B-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. WARRENT & 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 B-5

DESCRIPTIONS OF TEST SITES IN BALTIMORE 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		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 B-6

DESCRIPTIONS OF TEST SITES IN SAN JOSE 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	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 B-7

DESCRIPTIONS OF TEST SITES IN ATLANTA 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	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 B-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	n.a		n.a.		n.a	n.a.	n.a		n.a	n.a.
CLEANING METHOD	SW.& FLUSH		SW.& FLUSH		SW.& FLUSH	SW.& FLUSH	SW.& FLUSH		SW & FLUSH	SW.& FLUSH

Table B-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	n.a	n.a	n.a.		n.a	n.a	n.a.		n.a.	n.a
CLEANING METHOD	SWEPT	SWEPT	SWEPT		SWEPT	SWEPT	SWEPT		SWEPT	SWEPT

Table B-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 SINCF LAST RAIN	12	12		12	12	12	12		12	12
DAYS SINCE LAST CLEANED	n.a	n.a		n.a	n.a.	n a	n a		n a	n.a
CLEANING METHOD	SW. & FLUSH	SW. & FLUSH		SW. & FLUSH	SW & FLUSH	SW. & FLUSH	SW & FLUSH		SW. & FLUSH	SW & FLUSH

Table B-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 C

DATA SUMMARY AND INVESTIGATION OF ACCUMULATION RATES

APPENDIX C

DATA SUMMARY AND INVESTIGATION OF ACCUMULATION RATES

During the course of this study, it was suggested that an attempt be made to determine the relationship between the amount of contaminant material at a given site and the period of time which had elapsed since that site had been cleaned by either rainfall or sweeping. This appendix describes the attempts made to determine such accumulation rates.

In the way of background, it is important to reflect back upon the discussion of Figs. 2, 3, and 4 in Section IV. The field sampling programs carried out in this study were directed toward collecting materials which exist on street surfaces at a given point in time. At some prior point in time, these sites had been cleaned, by sweeping and/or rainfall. Thus, we have two points on a curve but know virtually nothing about the shape of the curve between those points. The discussion in Section IV suggests that the curve is surely not linear. Clearly, a study could be conducted to develop basic data on accumulation rates, but this would require making numerous repetitive field measurements on the same sites.

Recognizing the above, it was still decided that a sub-study should be conducted to investigate the possibility of establishing some type of correlation between time and loading intensity.

The data employed were of three types:

- the solids loadings intensities measured at each of the sampling sites (in lb/curb mile)
- the elapsed time since the street was last swept (these data from public works department records)
- the elapsed time since rainfall had last cleaned the streets (NOAA weather records were scanned to determine the antecedent period for a 1/2 in. rain storm).

Only solids data were included in this sub-study. This grossly simplified data manipulation does not introduce any appreciable error (primarily because the total contaminant loading correlates so well with just the solids loading).

OVERVIEW

Various numerical analysis techniques were employed, using digital computer solutions. Analyses were conducted in five parts:

Table C-1

QUANTITIES OF POLLUTANTS FOUND ON STREETS (lb/1000 sq ft)

POLLUTANT	SAN JOSE-I	PHOENIX I	MIL-WAUKEE	BUCYRUS	BALTI-MORE	SAN JOSE-II	ATLANTA	TULSA	PHOENIX II	SEATTLE	NUMERICAL MEAN
BOD_5	0.15	0.085	0.14	0.038	0.67	0.50	0.021	0.20	0,13	0.067	0.20
COD	2.9	0.39	0.58	0.38	0.22	3.8	0.14	0.42	0.70	0.24	0.98
$PO_4^{\equiv}$	0.0066	0.0029	0.0033	0.0033	0.011	0.042	0.0029	0.0076	0.036	0.0069	0.012
NO_3^-	0.031	0.0038	0.00062	0.0016	0.00042	0.0025	0.00026	0.00017	0.0016	0.00038	0.0042
N	0.020	0.020	0.017	0.016	0.021	0.10	0.0053	0.0092	0.038	0.013	0.026
Solids	8.6	8.5	32	18	11	56	4.7	4.6	12	6.4	16
Cd	$28x10^{-6}$	-	$38x10^{-6}$	-	$29x10^{-6}$	-	-	-	-	-	$32x10^{-6}$
Ni	0.0018	-	0.00038	-	0.00085	0.00080	0.00023	0.00015	0.00049	0.00039	0.00064
Pb	0.018	-	0.018	-	0.0052	0.0085	0.00085	0.00042	0.0016	0.007	0.0074
Zn	0.013	-	0.052	-	0.014	0.0026	0.0012	0.00087	0.0047	0.0052	0.012
Cu	0.0046	-	0.0071	-	0.0036	0.00019	0.00073	0.00045	0.00075	0.0011	0.0023
Cr	0.0019	-	0.00056	-	0.0050	0.0013	0.00012	0.000046	0.00038	0.0011	0.0013
Hg	0.0028	-	-	-	-	0.00080	0.00025	0.00027	0.00029	0.00048	0.00082
Endrin	$.019x10^{-3}$	-	0	0	0	0	0	0	0	0	-
Dieldrin	$.10x10^{-3}$	-	$0.12x10^{-3}$	$0.22x10^{-3}$	$0.033x10^{-3}$	$0.25x10^{-3}$	$0.26x10^{-3}$	$0.34x10^{-3}$	$0.31x10^{-3}$	$0.38x10^{-3}$	
PCB	$11x10^{-3}$	-	$41x10^{-3}$	$8.5x10^{-3}$	$11x10^{-3}$	$10x10^{-3}$	$0.72x10^{-3}$	$0.91x10^{-3}$	$0.85x10^{-3}$	$15x10^{-3}$	
Methoxychlor	0	-	$100x10^{-3}$	$21x10^{-3}$	$1.9x10^{-3}$	0	0	0	0	0	-
p,p-DDT	$1.0x10^{-3}$	-	$0.012x10^{-3}$	$0.78x10^{-3}$	$0.33x10^{-3}$	$1.6x10^{-3}$	$0.14x10^{-3}$	$0.18x10^{-3}$	$0.17x10^{-3}$	$2.4x10^{-3}$	
Lindane	$0.16x10^{-3}$	-	$0.037x10^{-3}$	0	0	0	0	0	0	0	-
Methyl Parathion	$0.19x10^{-3}$	-	0	0	0	0	0	0	0	0	-
DDD	$0.63x10^{-3}$	-	$0.006x10^{-3}$	$1.1x10^{-3}$	$1.1x10^{-3}$	$1.1x10^{-3}$	$0.37x10^{-3}$	$0.48x10^{-3}$	$0.44x10^{-3}$	$1.7x10^{-3}$	

Table C-2

QUANTITIES OF POLLUTANTS FOUND ON STREETS (lb/curb mi)

POLLUTANT	SAN JOSE-I	PHOENIX I	MIL-WAUKEE	BUCYRUS	BALTI-MORE	SAN JOSE-II	ATLANTA	TULSA	PHOENIX II	SEATTLE	NUMERICAL MEAN	AVERAGE DEVI-ATION	AD/	WEIGHTED AVER-AGE
BOD_5 lb/curb mi	16	6.5	12	2.9	61	53	1.9	14	10	4.8	18	16	0.86	14
COD lb/curb mi	310	30	48	29	20	400	13	30	54	17	95	100	1.1	95
$PO_4^{\equiv}$ lb/curb mi	0.70	0.22	0.27	0.25	1.0	4.5	0.26	0.54	2.8	.49	1.1	1.0	0.92	1.1
NO_3^- lb/curb mi	3.3	0.29	0.052	0.12	0.038	0.27	0.024	0.012	0.12	0.027	0.043	0.040	0.93	0.094
N lb/curb mi	2.1	1.5	1.4	1.2	1.9	11	0.48	0.66	2.9	0.90	2.4	1.8	0.74	2.2
Solids lb/curb mi	910	650	2700	1400	1000	6000	430	330	910	460	1500	1200	0.78	1400
Cd lb/curb mi	0.0030	-	0.0032	-	0.0026	-	-	-	-	-	0.0029	0.0002	0.069	-
Ni lb/curb mi	0.19	-	0.032	-	0.077	0.085	0.021	0.011	0.038	0.028	0.060	0.043	0.72	0.05
Pb lb/curb mi	1.9	-	1.5	-	0.47	0.90	0.077	0.030	0.12	0.50	0.68	0.60	0.88	0.57
Zn lb/curb mi	1.4	-	2.1	-	1.3	0.28	0.11	0.062	0.36	0.37	0.75	0.63	0.85	0.65
Cu lb/curb mi	0.49	-	0.59	-	0.33	0.020	0.066	0.032	0.058	0.075	0.21	0.20	0.95	0.20

Table C-2 (Continued)

QUANTITIES OF POLLUTANTS FOUND ON STREETS (lb/curb mi)

POLLUTANT	SAN JOSE-I	PHOENIX I	MIL-WAUKEE	BUCYRUS	BALTI-MORE	SAN JOSE-II	ATLANTA	TULSA	PHOENIX II	SEATTLE	NUMERICAL MEAN	AVERAGE DEVI-ATION	AD/NM	WEIGHTED AVER-AGE
Cr lb/curb mi	0.20	-	0.047	-	0.45	0.14	0.011	0.0033	0.029	0.081	0.12	0.11	0.92	0.11
Hg lb/curb mi	0.30	-	-	-	-	0.085	0.023	0.019	0.022	0.034	0.081	0.075	0.93	0.073
Total heavy Metals lb/curb mi	4.4	-	4.3	-	2.6	1.5	0.31	0.16	.63	1.1	1.9	-	-	1.7
Total Coliforms Billion/curb mi	-	-	49	-	46	72	32	170	48	160	82	46	0.57	99
Fecal Coliforms Million/curb mi	-	-	7.0	-	12000	590	2900	31,000	2400	1900	7200	8000	1.1	5600 median value
Endrin 10^{-6} lb/curb mi	2.0	-	0	0	0	0	0	0	0	0	-	-	-	-
Dieldrin 10^{-6} lb/curb mi	11	-	10	17	3.0	27	24	24	24	27	-	-	0	24
PCB 10^{-6} lb/curb mi	1200	-	3440	650	1000	1000	65	65	65	1100	-	-	-	1100
Methoxychlor 10^{-6} lb/curb mi	0	-	8500	1600	170	0	0	0	0	0	-	-	-	-
p,p-DDT 10^{-6} lb/curb mi	110	-	1.0	60	30	170	13	13	13	170	-	-	-	61
Lindane 10^{-6} lb/curb mi	17	-	3.1	0	0	0	0	0	0	0	-	-	-	-
Methyl Parathion 10^{-6} lb/curb mi	20	-	0	0	0	0	0	0	0	0	-	-	-	-
DDD 10^{-6} lb/curb mi	67	-	0.5	83	100	120	34	34	34	120		-	-	67
Total Pesticides and PCB	1400	-	12000	2400	1300	1400	140	140	140	1400	-	-	-	1300

Table C-3

ESTIMATED QUANTITIES OF CONTAMINANTS WHICH WOULD WASH OFF STREETS IN A RAINSTORM

POLLUTANT	SAN JOSE-I	PHOENIX-I	MILWAUKEE	BUCYRUS	BALTIMORE	SAN JOSE-II	ATLANTA	TULSA	PHOENIX-II	SEATTLE
BOD (lb)	38,000	17,000	43,000	610	300,000	130,000	3,200	50,000	26,000	23,000
COD (lb)	748,000	78,000	180,000	6,100	98,000	960,000	22,000	110,000	140,000	82,000
$PO_4^{\equiv}$ (lb)	1,700	580	1,000	53	4,900	11,000	440	1,900	7,300	2,400
NO_3^- (lb)	7,900	800	200	23	190	650	36	43	710	130
N (lb)	5,000	3,900	5,000	250	9,300	26,000	820	2,400	7,500	4,300
Solids (lb)	2,200,000	1,700,000	10,000,000	290,000	4,900,000	14,000,000	730,000	1,200,000	2,400,000	2,200,000
Cd (lb)	7.2	-	12	-	13	-	-	-	-	-
Ni (lb)	460	-	110	-	380	200	36	40	99	130
Pb (lb)	4,600	-	5,400	-	2,300	2,200	130	110	310	2,400
Zn (lb)	3,400	-	7,600	-	6,400	670	190	220	940	1,800
Cu (lb)	1,200	-	2,100	-	1,600	48	110	120	150	360
Cr (lb)	480	-	170	-	2,200	340	19	12	75	390
Hg (lb)	720	-	-	-	-	200	39	68	57	160
Number Total Coliforms x 10^{14}	-	-	1.8	-	2.2	1.7	.54	6.1	1.2	7.7
Number Fecal Coliforms x 10^{12}	-	-	25	-	59	1.4	4.9	110	6.2	9.1
Endrin (grams)	3.6	-	0	0	0	0	0	0	0	0
Dieldrin (grams)	20	-	16	1.6	7	29	19	39	28	59
PCB (grams)	2,100	-	5,600	62	2,200	1,200	50	110	77	2,400
Methoxychlor (grams)	0	-	14,000	150	380	0	0	0	0	0
p,p-DDT (grams)	200	-	1.6	5.7	67	190	10	21	15	370
Lindane (grams)	30	-	5.1	0	0	0	0	0	0	0
Methyl Parathion (grams)	36	-	0	0	0	0	0	0	0	0
DDD (grams)	120	-	0.82	7.9	220	130	26	56	40	260

NOTE: Figures in the table are estimates, calculated on the basis of loading intensities measured in several land-use areas in each city. A rainfall of at least 0.1 in./hr with peak intensity of 0.5 in./hr would wash off these amounts of contaminants.

Table C-4

QUANTITY OF POLLUTANTS FOUND ON STREETS PER DAY SINCE LAST SWEEPING

POLLUTANT	SAN JOSE-I Swept 13 Days Prior	PHOE-NIX-I Swept 7 Days Prior	MIL-WAUKEE Swept 6 Days Prior	BU-CYRUS	BALTI-MORE Swept 4 Days Prior	SAN JOSE-II Swept 7 Days Prior	ATLANTA Swept 16 Days Prior	TULSA	PHOE-NIX-II	SEATTLE	NUMERI-CAL MEAN	AVER-AGE DEVI-ATION	AD/NM
BOD_5 lb/mi/day	1.2	0.93	2.0	No response to inquiry.	15	7.6	0.12	No records kept.	No response to inquiry.	No records kept.	4.5	4.6	1.0
COD lb/mi/day	24	4.3	8.0		5.0	57	0.81				16	15	0.96
$PO_4^{\equiv}$ lb/mi/day	0.054	0.031	0.045		0.25	0.64	0.016				0.17	0.18	1.1
NO_3^- lb/mi/day	0.25	0.041	0.0087		0.0095	0.038	0.0015				0.058	0.064	1.1
N lb/mi/day	0.160	0.21	0.23		0.48	1.5	0.03				0.44	0.38	0.85
Solids lb/mi/day	70	93	450		250	860	27				300	240	0.82
Cd lb/mi/day	0.0002		0.0005		0.0007						0.0005	0.0002	0.40
Ni lb/mi/day	0.015		0.0053		0.019	0.012	0.0013				0.01	0.0056	0.54
Pb lb/mi/day	0.15		0.25		0.12	0.13	0.0048				0.13	0.054	0.42
Zn lb/mi/day	0.11		0.35		0.33	0.04	0.0069				0.17	0.14	0.83
Cu lb/mi/day	0.038		0.098		0.083	0.003	0.0041				0.045	0.037	0.82
Cr lb/mi/day	0.015		0.0078		0.11	0.020	0.0007				0.031	0.032	1.0
Hg lb/mi/day	0.023					0.012	0.0014				0.012	0.007	0.58
Total Coliforms 10^9/mi/day			8.2		12	10	2.0				8.0	3.0	0.38
Fecal Coliforms 10^6/mi/day			1.2		3000	84	180				800	1100	1.3
Endrin 10^{-6} lb/mi/day	0.15		0		0	0	0						
Dieldrin 10^{-6} lb/mi/day	0.85		1.7		0.75	3.9	1.5						
PCB 10^{-6} lb/mi/day	92		570		250	160	4.1				-		
Methoxychlor 10^{-6} lb/mi/day	0		1400		43	0	0				-		
p, p-DDT 10^{-6} lb/mi/day	8.5		0.17		7.5	24	0.81				-		
Lindane 10^{-6} lb/mi/day	1.3		0		0	0	0				-		
Methyl Parathron 10^{-6} lb/mi/day	1.5		0		0	0	0						
DDD 10^{-6} lb/mi/day	5.2		0.083		25	17	2.1						

Table C-5

QUANTITY OF POLLUTANTS FOUND ON STREETS PER DAY SINCE LAST MAJOR RAINFALL

POLLUTANT	SAN JOSE-I Rain 14 Days Prior	PHOENIX-I Rain 12 Days Prior	MIL-WAUKEE Rain 1 Day Prior	BUCYRUS Rain 2 Days Prior	BALTI-MORE Rain 26 Days Prior	SAN JOSE-II Rain 59 Days Prior	AT-LANTA Rain 2 Days Prior	TULSA Rain 9 Days Prior	PHOENIX II Rain 30+ Days Prior	SE-ATTLE Rain 12 Days Prior	NU-MERI-CAL MEAN	AVER-AGE DEVI-ATION	AD/NM
BOD_5 lb/mi/day	1.1	0.54	12	1.5	2.3	0.90	0.95	1.6	.33	0.40	2.1	1.9	0.90
COD lb/mi/day	22	2.5	48	15	0.77	6.8	6.5	3.3	1.8	1.4	11	10	0.91
$PO_4^{\equiv}$ lb/mi/day	0.050	0.018	0.27	0.13	0.038	0.76	0.13	0.060	0.093	0.041	0.090	.29	3.2
NO_3^- lb/mi/day	0.24	0.024	0.052	0.06	0.002	0.0046	0.012	0.0013	0.004	0.0023	0.040	0.047	1.2
N lb/mi/day	0.15	0.13	1.4	0.60	0.073	0.19	0.24	0.073	0.097	0.075	0.30	0.31	1.0
Solids lb/mi/day	65	54	2700	700	38	100	220	37	30	38	400	520	1.3
Cd lb/mi/day	0.0002		0.0032		0.0001						0.0012	0.0010	0.83
Ni lb/mi/day	0.014		0.032		0.003	0.0014	0.011	0.0012	0.0013	0.0023	0.0078	0.0074	0.95
Pb lb/mi/day	0.14		1.5		0.018	0.015	0.039	0.0033	0.004	0.012	0.22	0.31	1.5
Zn lb/mi/day	0.10		2.1		0.05	0.0047	0.055	0.0069	0.012	0.031	0.30	0.46	1.5
Cu lb/mi/day	0.035		0.59		0.013	0.0003	0.033	0.0036	0.019	0.0063	0.086	0.13	1.5
Cr lb/mi/day	0.014		0.047		0.017	0.0024	0.055	0.0004	0.00097	0.0068	0.018	0.017	0.94
Hg lb/mi/day	0.021					0.0014	0.012	0.0021	0.00073	0.0028	0.0065	0.0063	0.97
Total Coliforms 10^9/mi/day			49		1.8	1.2	16	19	1.6	13	15	12	0.79
Fecal Coliforms 10^6/mi/day			7.0		460	10	1500	3400	80	160	800	940	1.2
Endrin 10^{-6} lb/mi/day	0.14		0	0	0	0	0	0	0	0	0.016	0.028	1.8
Dieldrin 10^{-6} lb/mi/day	0.79		10	8.5	.12	0.46	12	2.7	0.80	2.3	4.2	4.0	0.95
PCB 10^{-6} lb/mi/day	86		3400	330	38	19	33	7.2	2.2	92	460	660	1.4
Methoxychlor 10^{-6} lb/mi/day	0		8500	800	6.5	0	0	0	0	0	1000	1700	1.7
p, p-DDT 10^{-6} lb/mi/day	7.9		3.1	30	1.2	2.9	6.5	1.4	0.43	14	7.2	6.7	0.93
Lindane 10^{-6} lb/mi/day	1.2		0	0	0	0	0	0	0	0	0.13	0.23	1.8
Methyl Parathion 10^{-6} lb/mi/day	1.4		0	0	0	0	0	0	0	0	0.16	0.28	1.8
DDD 10^{-6} lb/mi/day	4.8		0.5	42	3.8	2.0	17	3.8	1.1	10	9.4	9.1	0.97

Table C-6

QUANTITY OF POLLUTANTS FOUND ON STREETS PER CURB MILE PER DAY SINCE LAST SWEEPING OR LAST MAJOR RAINFALL

POLLUTANT	SAN JOSE-I Swept 13 Days Prior	PHOE-NIX-I Swept 13 Days Prior	MIL-WAUKEE Swept 1 Day Prior	BUCYRUS Rain 2 Days Prior	BALTI-MORE Swept 4 Days Prior	SAN JOSE-II Swept 7 Days Prior	ATLANTA Rain 2 Days Prior	TULSA	PHOENIX-II	SEATTLE	NU-MERI-CAL MEAN	AVER-AGE DEVI-ATION	AD/NM	WEIGHTED AVER-AGE
BOD_5 lb/mi/day	1.2	0.93	12	1.5	15	7.6	0.95				5.5	5.0	0.91	4.5
COD lb/mi/day	24	4.3	48	15	5.0	57	6.5				22	17	0.77	26
$PO_4^{\equiv}$ lb/mi/day	0.054	0.031	0.27	0.13	0.25	0.64	0.13				0.21	0.15	0.71	0.37
NO_3^- lb/mi/day	0.25	0.041	0.052	0.06	0.0095	0.038	0.012				0.066	0.053	0.80	0.029
N lb/mi/day	0.16	0.21	1.4	0.60	0.48	1.6	0.24		[illegible]	[illegible]	0.67	0.47	0.70	0.66
Solids lb/mi/day	70	93	2700	700	250	860	220				700	620	0.89	730
Cd lb/mi/day	0.0002		0.0032		0.0007						0.0014	0.0012	0.86	
Ni lb/mi/day	0.015		0.032		0.019	0.012	0.011				0.018	0.006	0.33	
Pb lb/mi/day	0.15		1.5		0.12	0.13	0.039				0.38	0.44	1.2	
Zn lb/mi/day	0.11		2.1		0.33	0.04	0.055				0.53	0.63	1.2	
Cu lb/mi/day	0.038		0.59	-	0.083	0.003	0.033	[illegible]		[illegible]	0.15	0.18	1.2	
Cr lb/mi/day	0.015		0.047		0.11	0.020	0.055				0.050	0.027	0.54	
Hg lb/mi/day	0.023					0.012	0.012				0.016	0.005	0.31	
Total Heavy Metals lb/mi/day	0.35		4.3	[illegible]	0.66	0.22	0.21				1.1			1.3
Total Coliforms 10^9/mi/day			49		12	10	16				22	14	0.63	
Fecal Coliforms 10^6/mi/day			7.0		3000	84	1500				1100	1100	1.0	
Endrin 10^{-6} lb/mi/day	0.15		0	0	0	0	0				6.0			
Dieldrin 10^{-6} lb/mi/day	0.85		10	8.5	0.75	3.9	12				820			
PcB 10^{-6} lb/mi/day	92		3400	330	250	160	33				710			
Methoxychlor 10^{-6} lb/mi/day	0		8500	800	43	0	0		[illegible]		13			
p, p-DDT 10^{-6} lb/mi/day	8.5		3.1	30	7.5	24	6.5							
Lindane 10^{-6} lb/mi/day	1.3		0	0	0	0	0							
Methyl Parathion 10^{-6} lb/mi/day	1.5		0	0	0	0	0							
DDD 10^{-6} lb/mi/day	5.2		0.5	42	25	17	17				18			
Total Pesticides and PCB 10^{-6} lb/mi/day	110		12000	1200	330	200	69				2400			200

Table C-7

STRENGTH OF SOLID MATERIAL

POLLUTANT	SAN JOSE-I	PHOENIX-I	MILWAUKEE	BUCYRUS	BALTIMORE	SAN JOSE-II	ATLANTA	TULSA	PHOENIX-II	SEATTLE	NUMERICAL MEAN	AVERAGE DEVIATION	AD/NM
BOD_5 ppm	17,000	10,000	4,400	2,100	61,000	8,900	4,500	43,000	11,000	10,000	17,000	13,000	0.76
COD ppm	340,000	46,000	18,000	21,000	20,000	68,000	30,000	91,000	58,000	38,000	73,000	68,000	0.93
$PO_4^{\equiv}$ ppm	770	340	100	180	1,000	750	620	1,700	3,000	1,100	980	610	0.62
NO_3^- ppm	3,600	450	20	89	38	45	55	37	130	59	460	630	1.4
N ppm	2,300	2,300	530	890	1,900	1,800	1,100	2,000	3,200	2,000	1,900	570	0.32
Cd ppm	3.3	-	1.2	-	2.6	-	-	-	-	-	-	-	-
Ni ppm	210	-	12	-	77	14	49	33	41	61	54	34	0.63
Pb ppm	2,100	-	560	-	470	150	180	91	130	1,100	530	510	0.96
Zn ppm	1,500	-	1,600	-	1,300	46	260	190	390	810	760	450	0.59
Cu ppm	540	-	220	-	330	3.4	160	98	39	172	200	130	0.65
Cr ppm	220	-	18	-	450	23	25	10	32	172	120	130	1.1
Hg ppm	330	-	-	-	-	14	53	59	24	75	93	120	1.3
Endrin 10^{-3} ppm	2.2	-	0	0	0	0	0	0	0	0	-	-	-
Dieldrin 10^{-3} ppm	12	-	3.8	12	3.0	4.4	55	74	26	59	28	-	-
PCB 10^{-3} ppm	1,300	-	1,300	470	1,000	100	150	200	71	2,300	780	-	-
Methoxychlor 10^{-3} ppm	0	-	3,100	1,200	170	0	0	0	0	0	500	-	-
p,p-DDT 10^{-3} ppm	120	-	0.38	43	30	28	30	39	14	380	75	-	-
Lindane 10^{-3} ppm	19	-	1.2	0	0	0	0	0	-	-	-	-	-
Methyl Parathion 10^{-3} ppm	22	-	0	0	0	0	0	0	0	0	-	-	-
DDD 10^{-3} ppm	73	-	0.19	61	100	20	79	100	37	270	82		
Number Total Coliforms/ gram solids	-	-	40,000	-	100,000	26,000	160,000	1,110,000	120,000	770,000	330,000	-	-
Number Fecal Coliforms/ gram solids	-	-	5.7	-		200	15,000	210,000	5,800	9,100	38,000	-	-

Table C-8

OXYGEN DEMAND OF STREET SURFACE CONTAMINANTS - VARIATION BY PARTICLE SIZE

POLLUTANT			Particle Size, (μ)					
			<43μ	43-104μ	104-246μ	246-840μ	840-2000μ	>2000μ
	BOD_5*	SJI	24.7%	14.4%	18.2%	26.4%	13.4%	2.9%
		Mi, Bu, Ba	30.3	14.0	13.3	17.9	21.2	3.3
		At, Tu, PII	19.8	11.6	13.3	19.9	32.9	2.5
		SJII, Se	22.7	26.4	18.9	9.3	6.3	16.4
	COD*	SJI	1.4%	22.7%	23.6%	38.4%	9.2%	4.7%
		At, Tu, PII	38.3	43.1	9.0	6.9	2.7	-
		Mi, Bu, Ba	5.2	2.8	1.5	0.4	0.1	0.0
		SJII and Se	45.7	26.5	15.4	6.2	6.2	-
	Volatile portion of solids in specific size range	PI	11.5%	10.0%	9.5%	10.4%	5.1%	2.8%
		Mi, Bu, Ba	13.3	13.3	9.4	7.9	10.9	5.5
		SJII	16.7	16.5	7.8	4.2	11.8	8.6
		At, Tu, PII	21.4	7.6	8.6	5.3	8.1	4.7
		Se	14.1	8.5	7.6	3.9	11.7	3.5

* Tabulated values are percents of total pollutant associated with each size range (% by weight).

Part 1. The solids loading intensity data were grouped into residential, industrial, and commercial land uses, plus all land uses combined. The following curve forms were fitted by the least squares method to determine loading intensity/unit time.

$$Y = A + BX \qquad \text{Eq. (a)}$$

$$Y = AB^X \qquad \text{Eq. (b)}$$

$$Y = A \exp(BX) \qquad \text{Eq. (c)}$$

$$Y = A + B/X \qquad \text{Eq. (d)}$$

$$Y = 1/(A + BX) \qquad \text{Eq. (e)}$$

$$Y = X/(A + BX) \qquad \text{Eq. (f)}$$

Part 2. Data on loading intensities for all land-use categories were grouped by particle size categories ($<246\mu$ for small and $>246\mu$ for large) and compared to days since last swept, days since last rain, and days since last cleaning by either sweeping or rain. The same curves used in Part 1 were then fitted.

Part 3. The solids loading data were again grouped by land-use category (as in Part 1) and the following analysis was performed:

- Mean, variance, standard deviation, standard error, coefficient of variation, minimum, 10th percentile, 1st quartile, median, 3rd quartile, 90th percentile, maximum, quartile deveation, average deviation, moment coefficient of skewness, and Pearson coefficient of skewness were computed
- Histograms were plotted
- Cumulative histograms were plotted.

Part 4. Using the data obtained from Part 3 with the loadings grouped by land-use categories, values less than the 10th percentile and greater than the 90th percentile were rejected. The same curves used in Part 1 were then fitted.

Part 5. Additional computer runs were made to determine any difference between cleaning by sweeping or by rain without dividing the data by land use. Only the mid-80 percent of the rates were used. The same curves used in Part 1 were then fitted.

RESULTS

The results of the five-part analysis of observed data are presented in the following paragraphs, tables, and figures.

PART 1

This analysis (Table C-9) deals with the influence of land-use category on the correlation between solids loading and elapsed time since streets were last cleaned by either sweeping or by rainfall (whichever occurred first).

Table C-9

LOADING INTENSITIES/UNIT TIME FOR DIFFERENT LAND-USE AREAS

1. RESIDENTIAL LAND USE

EQUATION	CURVE FORM	INDEX OF DETERMINATION
a.	$Y = 1306 - 62X$	3.5×10^{-2}
b.	$Y = 654 \left(X^{-8.29 \times 10^{-2}}\right)$	5.7×10^{-3}
c.	$Y = 603 \exp (-2.08 \times 10^{-3}X)$	7.0×10^{-5}
d.	$Y = 435 + 1200/X$	0.10
e.	$Y = 1/(4.44 \times 10^{-3} - 2.43 \times 10^{-4}X)$	2.6×10^{-2}
f.	$Y = X/(3.88 \times 10^{-3} + 1.42 \times 10^{-3}X)$	5.1×10^{-2}

2. COMMERCIAL LAND USE

EQUATION	CURVE FORM	INDEX OF DETERMINATION
a.	$Y = 306 + .54X$	1.0×10^{-4}
b.	$Y = 212 \left(X^{6.82 \times 10^{-2}}\right)$	6.4×10^{-3}
c.	$Y = 215 \exp (7.03 \times 10^{-3}X)$	2.2×10^{-3}
d.	$Y = 354 - (59.7/X)$	5.5×10^{-3}
e.	$Y = 1/(6.44 \times 10^{-3} - 6.71 \times 10^{-5}X)$	5.3×10^{-3}
f.	$Y = X/(4.93 \times 10^{-4} + 5.83 \times 10^{-3}X)$	1.3×10^{-3}

3. INDUSTRIAL LAND USE		
EQUATION	CURVE FORM	INDEX OF DETERMINATION
a.	$Y = 1450 + (-67.8X)$	4.9×10^{-2}
b.	$Y = 957 \left(X^{-5.24 \times 10^{-2}}\right)$	2.3×10^{-3}
c.	$Y = 998 \exp(-2.50 \times 10^{-2}X)$	9.2×10^{-3}
d.	$Y = 1070 + 255/X$	4.9×10^{-3}
e.	$Y = 1/(1.55 \times 10^{-3} - 1.25 \times 10^{-5}X)$	9.8×10^{-4}
f.	$Y = X/(4.95 \times 10^{-4} + 1.29 \times 10^{-3}X)$	1.1×10^{-2}

4. ALL LAND USES COMBINED		
EQUATION	CURVE FORM	INDEX OF DETERMINATION
a.	$Y = 948 - 24.1X$	9.3×10^{-3}
b.	$Y = 429 \left(X^{0.144}\right)$	1.6×10^{-2}
c.	$Y = 470 \exp(1.20 \times 10^{-2}X)$	2.4×10^{-3}
d.	$Y = 756 + 169/X$	3.3×10^{-3}
e.	$Y = 1/(4.40 \times 10^{-3} - 1.70 \times 10^{-4}X)$	1.9×10^{-2}
f.	$Y = X/(3.88 \times 10^{-3} + 1.60 \times 10^{-3}X)$	7.1×10^{-2}

X = elapsed time since last clean (days)

Y = solids loading on streets (lb/curb mile)

PART 2

This analysis (Table C-10) deals with the influence of particle size on the correlation between solids loading and elapsed time since street was last cleaned (by rainfall, by sweeping, or by whichever occurred first). Data for all land-use categories were combined here.

Table C-10

LOADING INTENSITIES/UNIT TIME BY PARTICLE SIZE

STREETS LAST CLEANED BY RAINFALL

LARGE PARTICLES (>246μ) CURVE FORM	INDEX OF DETERMINATION	SMALL PARTICLES (<246μ) CURVE FORM	INDEX OF DETERMINATION
a. $Y = 321 + 5.46X$	0.24	a. $Y = 167 + 13.6X$	0.37
b. $Y = 314 \left(X^{8.29 \times 10^{-2}}\right)$	3.9×10^{-2}	b. $Y = 210 \left(X^{0.16}\right)$	6.9×10^{-2}
c. $Y = 316 \exp (9.34 \times 10^{-3}X)$	0.16	c. $Y = 202 \exp (2.02 \times 10^{-2}X)$	0.28
d. $Y = 446 - 42.5/X$	1.1×10^{-3}	d. $Y = 504 - 284/X$	3.4×10^{-2}
e. $Y = 1/(3.32 \times 10^{-3} \quad 1.98 \times 10^{-5}X)$	0.11	e. $Y = 1/(5.51 \times 10^{-3} - 5.55 \times 10^{-5}X)$	0.13
f. $Y = X/(-1.18 \times 10^{-3} + 3.07 \times 10^{-3}X)$	3.0×10^{-2}	f. $Y = X/(-1.69 \times 10^{-3} + 4.83 \times 10^{-3}X)$	2.6×10^{-2}

STREETS LAST CLEANED BY SWEEPING

LARGE PARTICLES (>246μ) CURVE FORM	INDEX OF DETERMINATION	SMALL PARTICLES (<246μ) CURVE FORM	INDEX OF DETERMINATION
a. $Y = 586 - 18.2X$	0.35	a. $Y = 137 + 18.1X$	0.25
b. $Y = 832 \left(X^{-0.347}\right)$	0.39	b. $Y = 113 \left(X^{0.411}\right)$	0.15
c. $Y = 551 \exp (-3.46 \times 10^{-2}X)$	0.26	c. $Y = 159 \exp (5.77 \times 10^{-2}X)$	0.20
d. $Y = 221 + 1420/X$	0.64	d. $Y = 412 - 824/X$	0.15
e. $Y = 1/(2.00 + 6.50 \times 10^{-5}X)$	0.17	e. $Y \quad 1/(6.28 \times 10^{-3} \quad 2.24 \times 10^{-4}X)$	0.14
f. $Y = X/(-6.03 \times 10^{-3} + 3.43 \times 10^{-3}X)$	0.44	f. $Y \quad X/(6.65 \times 10^{-3} + 3.35 \times 10^{-3}X)$	3.4×10^{-2}

LAST CLEANED BY EITHER SWEEPING OR RAINFALL

LARGE PARTICLES (>246μ) CURVE FORM	INDEX OF DETERMINATION	SMALL PARTICLES (<246μ) CURVE FORM	INDEX OF DETERMINATION
a. $Y = 528 - 13.8X$	0.29	a. $Y = 267 + 12.3X$	0.13
b. $Y = 564 \left(X^{-0.182}\right)$	0.28	b. $Y = 299 \left(X^{-175 \times 10^{-2}}\right)$	9.2×10^{-4}
c. $Y = 513 \exp (-2.99 \times 10^{-2}X)$	0.27	c. $Y = 266 \exp (1.94 \times 10^{-2}X)$	2.6×10^{-2}
d. $Y = 356 + 301/X$	0.21	d. $Y = 338 \quad 28.2/X$	3.9×10^{-3}
e. $Y = 1/(2.02 \times 10^{-3} + 6.62 \times 10^{-5}X)$	0.25	e. $Y = 1/(3.85 \times 10^{-3} + 1.20 \times 10^{-5}X)$	4.8×10^{-4}
f. $Y = X/(-1.72 \times 10^{-3} + 2.92 \times 10^{-3}X)$	0.25	f. $Y = X/(-1.86 \times 10^{-3} + 4.68 \times 10^{-3}X)$	6.5×10^{-2}

X = elapsed time since last clean (days)

Y = solids loading on streets (lb/curb mile)

The following four equations were found to have the best fit to measured data regarding method of cleaning versus particle size:

Streets Last Cleaned by Rain

Large Particles

Curve	Index of Determination
Y = 321 + 5.46X	0.24

Small Particles

Curve	Index of Determination
Y = 167 + 13.6X	0.37

Streets Last Cleaned by Sweeping

Large Particles

Curve	Index of Determination
Y = 221 + 1420/X	0.64

Small Particles

Curve	Index of Determination
Y = 137 + 18.1X	0.25

By comparing the indexes of determination and, therefore, the regularity of the data for specific groupings, it is possible to compare effectiveness. It is seen that the effectiveness of removal of particles by the rain is about the same for large particles as it is for small particles; whereas for street sweeping large particles are removed better than small particles.

PART 3

This analysis dealt with determining the nature of the statistical distribution of all of the observed data (for use in Parts 4 and 5). Figure C-1 shows the computed histograms comparing frequency of rates of accumulation. Table C-11 presents the results of the statistical analysis.

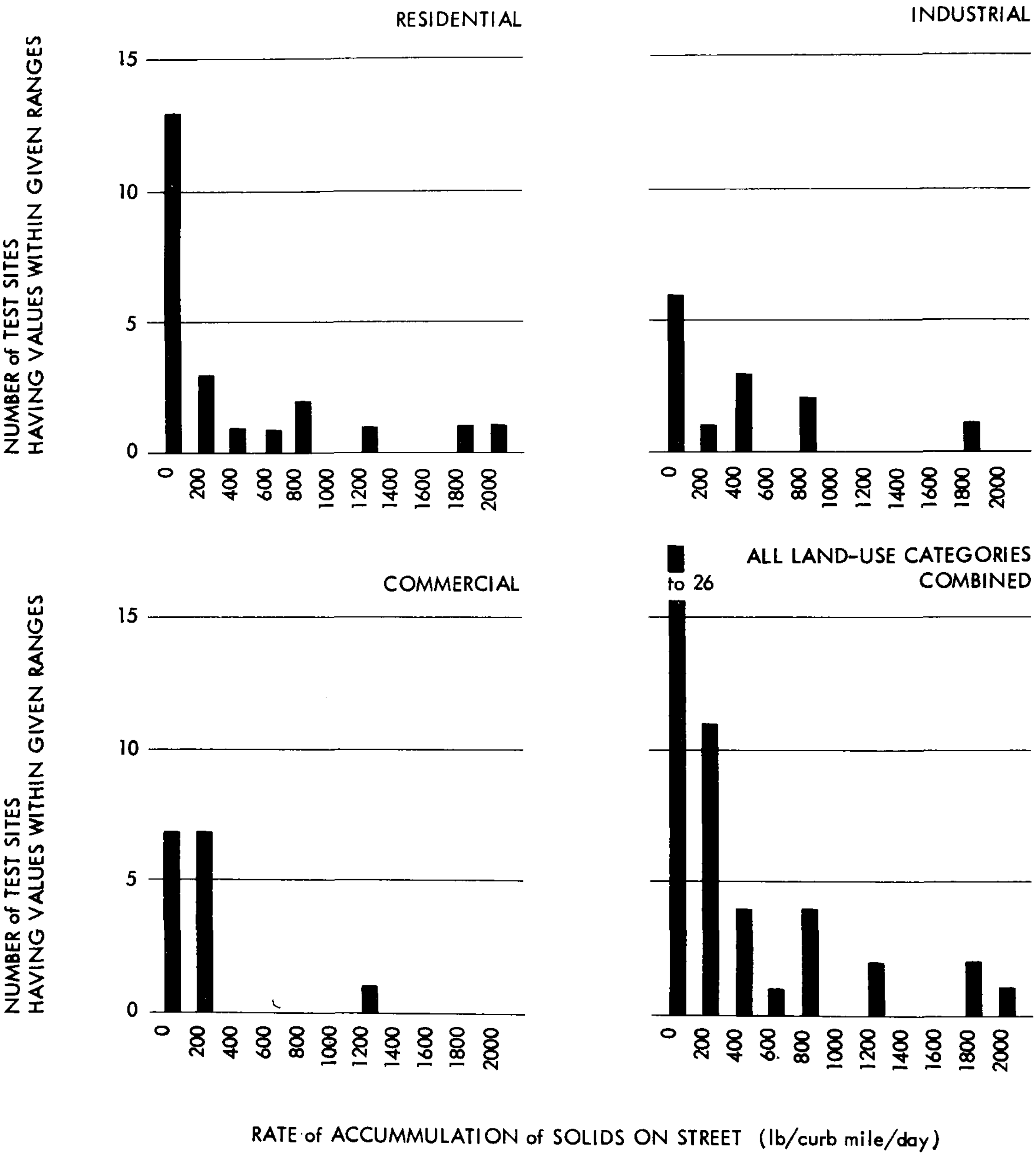


Fig. C-1. Computed Histograms of Accumulation Rate of Solids on Street

Table C-11

STATISTICAL ANALYSIS OF ACCUMULATION DATA

STATISTICAL PARAMETER	RESIDENTIAL LAND-USE (lb/mi/day)	INDUSTRIAL LAND-USE (lb/mi/day)	COMMERCIAL LAND-USE (lb/mi/day)	ALL LAND-USE CATEGORIES COMBINED (lb/mi/day)
Mean	373	447	226	348
Variance	0.251×10^6	0.250×10^6	0.835×10^5	0.200×10^6
Standard Deviation	501	500	289	447
Standard Error	107	139	74.6	63.3
Coefficient of Variation	1.34	1.12	1.28	1.29
Minimum	24.0	45.0	8.00	8.00
10th Percentile	31.2	75.0	30.8	32.8
1st Quartile	74.5	149	64.0	74.5
Median	125	215	204	186
3rd Quartile	491	499	223	384
90th Percentile	966	859	263	930
Maximum	1940	1850	1220	1940
Range	1920	1800	1210	1930
10-90 Percentile Range	934	784	233	897
Quartile Deviation	208	175	79.3	155
Average Deviation	378	346	143	319
Moment Coefficient of Skewness	1.69	1.63	2.62	2.03
Pearson Coefficient of Skewness	1.49	1.39	0.23	1.09

PART 4

This analysis deals with the influence of land-use category on the correlation between solids loading and elapsed time since streets were last cleaned by either sweeping or by rainfall (whichever occurred first). It is quite similar to the analysis performed in Part 1 but does not include any data lower than the 10th percentile or higher than the 90th percentile (see Part 3). Table C-12 shows the best fitting equa ions for the standard curve types.

Table C-12

LOADING INTENSITIES/UNIT TIME SINCE LAST CLEANED

1. RESIDENTIAL LAND-USE

EQUATION	CURVE FORM	INDEX OF DETERMINATION
a.	$Y = 495 + 34.8X$	0.12
b.	$Y = 446\left(X^{0.194}\right)$	9.1×10^{-2}
c.	$Y = 426 \exp(5.65 \times 10^{-2}X)$	0.17
d.	$Y = 773 - 244/X$	3.6×10^{-2}
e.	$Y = 1/(5.27 \times 10^{-4} + 1.84 \times 10^{3}X)$	0.13
f.	$Y = X/(5.27 \times 10^{-4} + 1.84 \times 10^{-3}X)$	2.2×10^{-2}

2. COMMERCIAL LAND-USE

EQUATION	CURVE FORM	INDEX OF DETERMINATION
a.	$Y = 174 + 41.6X$	0.61
b.	$Y = 170\left(X^{0.648}\right)$	0.46
c.	$Y = 162 \exp(0.126X)$	0.32
d.	$Y = 694 - 519/X$	0.88
e.	$Y = 1/(7.19 \times 10^{-3} - 5.28 \times 10^{-4}X)$	0.12
f.	$Y = X/(7.84 \times 10^{-3} - 4.32 \times 10^{-4}X)$	0.25

3. INDUSTRIAL LAND-USE

EQUATION	CURVE FORM	INDEX OF DETERMINATION
a.	$Y = 772 + 55.1X$	0.13
b.	$Y = 556\left(X^{0.397}\right)$	0.27
c.	$Y = 617 \exp(8.91 \times 10^{-2}X)$	0.20
d.	$Y = 1300 - 777/X$	0.26
e.	$Y = 1/(1.96 \times 10^{-3} - 1.55 \times 10^{-4}X)$	0.22
f.	$Y = X/(1.87 \times 10^{-3} + 6.01 \times 10^{-4}X)$	0.32

EQUATION	4. ALL LAND USES COMBINED CURVE FORM	INDEX OF DETERMINATION
a.	$Y = 480 + 43.5X$	0.12
b.	$Y = 296 \left(X^{0.511}\right)$	0.31
c.	$Y = 329 \exp (9.85 \times 10^{-2}X)$	0.21
d.	$Y = 994 - 652/X$	0.25
e.	$Y = 1/(4.29 \times 10^{-3} - 3.25 \times 10^{-4}X)$	0.14
f.	$Y = X/(5.09 \times 10^{-3} + 3.38 \times 10^{-4}X)$	0.30

X = elapsed time since last clean (days)

Y = solids loading on streets (lb/curb mile)

Figure C-2 illustrates the best fitting curves for each land-use category when the extreme 10 percent values are disregarded. The appropriate equations and indexes of determination are:

Residential land-use category:

$Y = 426 \left(e^{0.0565X}\right)$; index of 0.17

Industrial land-use category:

$Y = X/(0.00187 + 0.000601X)$; index of 0.32

Commercial land-use category:

$Y = 694 - 519/X$; index of 0.88

All land-use areas combined:

$Y = 296 \left(X^{0.511}\right)$; index of 0.31

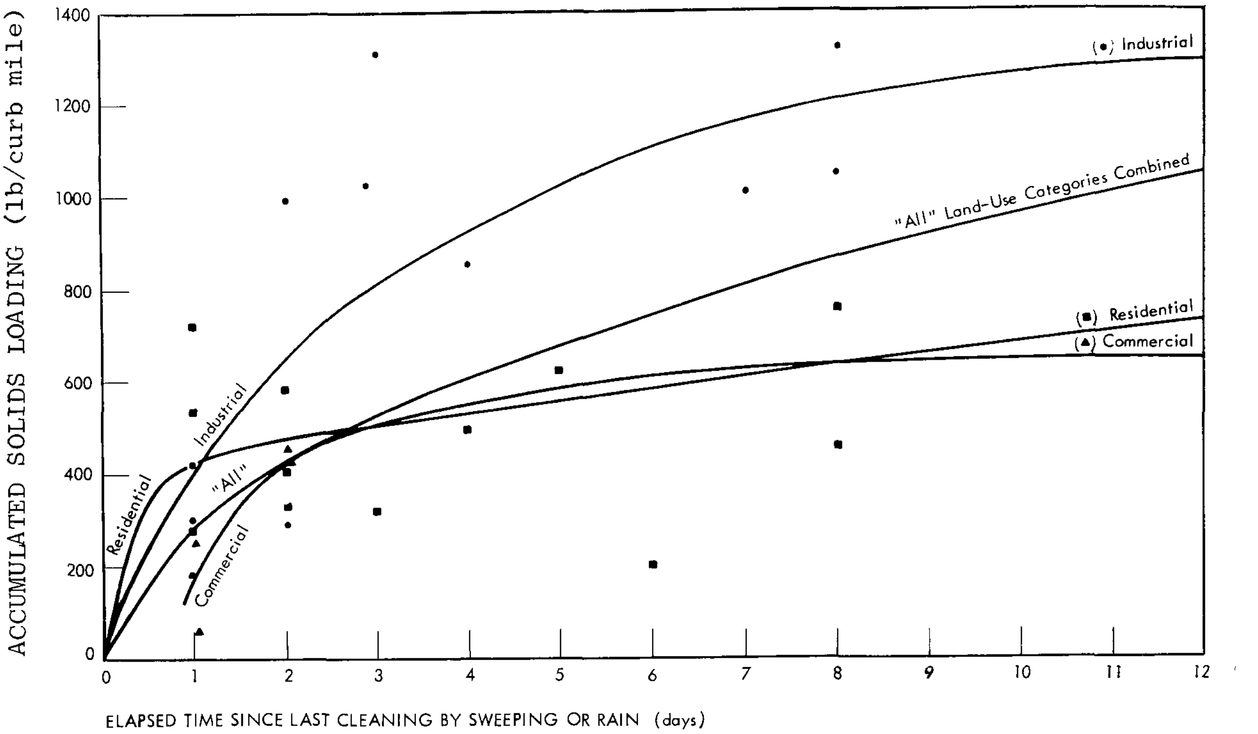


Fig. C-2. Time Since Last Cleaning vs Solids Loading

It can be seen that the slopes of the straight line portions of the commercial and residential land-use area curves are both smaller than the slope of the industrial land-use regeneration curve. These slopes were found to be as follows:

LAND-USE CATEGORY	SLOPE (lb/curb mile/day)
residential	28
industrial	60
commercial	10
all combined	57

Part 5

This analysis (Table C-13) deals with the influence of cleaning method (i.e., rainfall vs sweeping) on the correlation between solids loading and elapsed time since last cleaning. Here too, only data between the 10th and the 90th percentile were included.

Table C-13

LOADING INTENSITIES/DAYS SINCE LAST CLEANED BY RAINFALL OR SWEEPING

STREETS LAST CLEANED BY RAINFALL

EQUATION	CURVE FORM	INDEX OF DETERMINATION
a.	$Y = 587 + 26.9X$	0.057
b.	$Y = 435 \left(X^{0.317}\right)$	0.19
c.	$Y = 460e^{(5.46 \times 10^{-2}X)}$	0.13
d.	$Y = 1028 - 577/X$	0.17
e.	$Y = 1/(2.56 \times 10^{-3} - 1.18 \times 10^{-4}X)$	0.17
f.	$Y = X/(1.97 \times 10^{-3} + 9.58 \times 10^{-4}X)$	0.30

STREETS LAST CLEANED BY SWEEPING

EQUATION	CURVE FORM	INDEX OF DETERMINATION
a.	$Y = 324 + 68.0X$	0.24
b.	$Y = 191 \left(X^{0.739}\right)$	0.51
c.	$Y = 214 \left(e^{0.162X}\right)$	0.37
d.	$Y = 986 - 768/X$	0.37
e.	$Y = 1/(6.32 \times 10^{-3} - 6.13 \times 10^{-4}X)$	0.26
f.	$Y = X/(7.56 \times 10^{-3} + 6.27 \times 10^{-5}X)$	0.47

= elapsed time since last clean (days)

Y = solids loading on streets (lb/curb mile)

Figure C-3 illustrates the best fitting curves for the above two groups of data (b and f, respectively), and the curve for all land-use areas combined for days since cleaned, from the preceding study. It can be seen that difference between cleaning by sweeping and by rain is negligible on a total weight basis. See preceding computer study for differences in cleaning effectiveness for small and large particle sizes because of cleaning method.

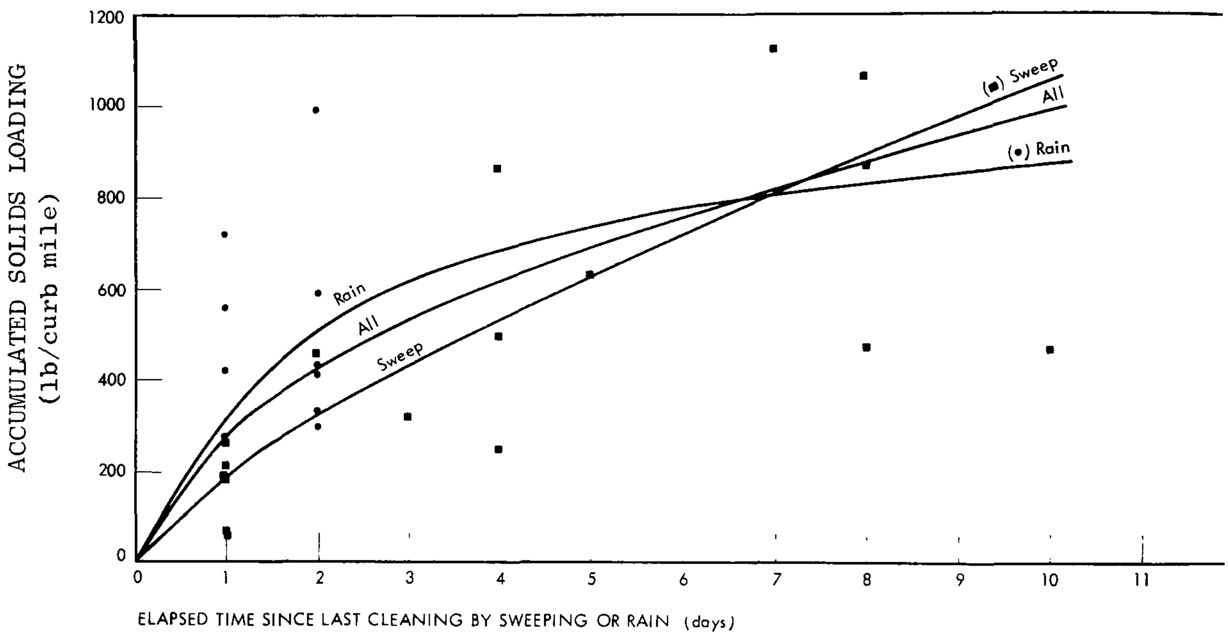
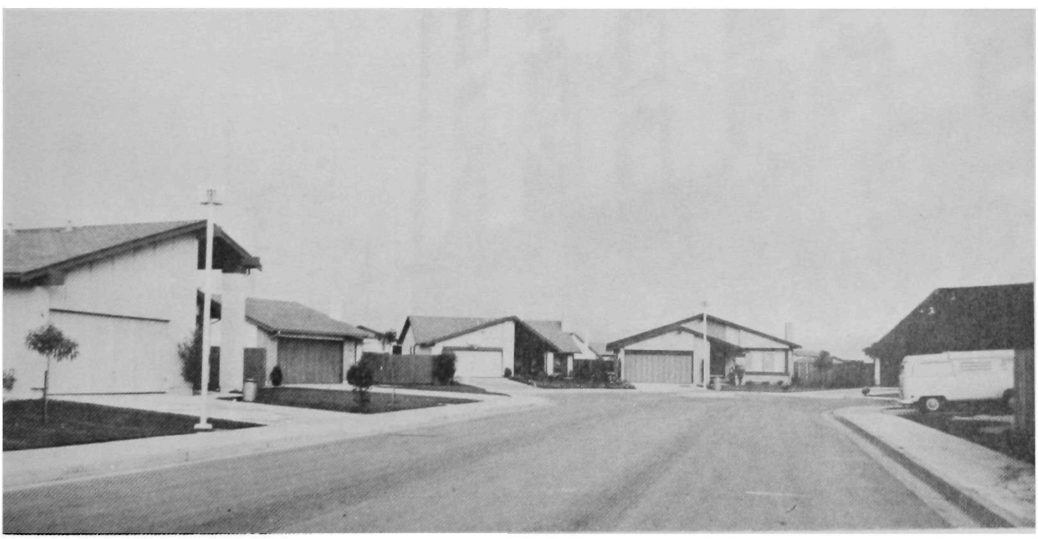


Fig. C-3. Time Since Last Cleaning vs Solids Loading

Appendix D

TYPICAL LAND-USE CATEGORIES

RESIDENTIAL: low/old/single



RESIDENTIAL : med/new/single

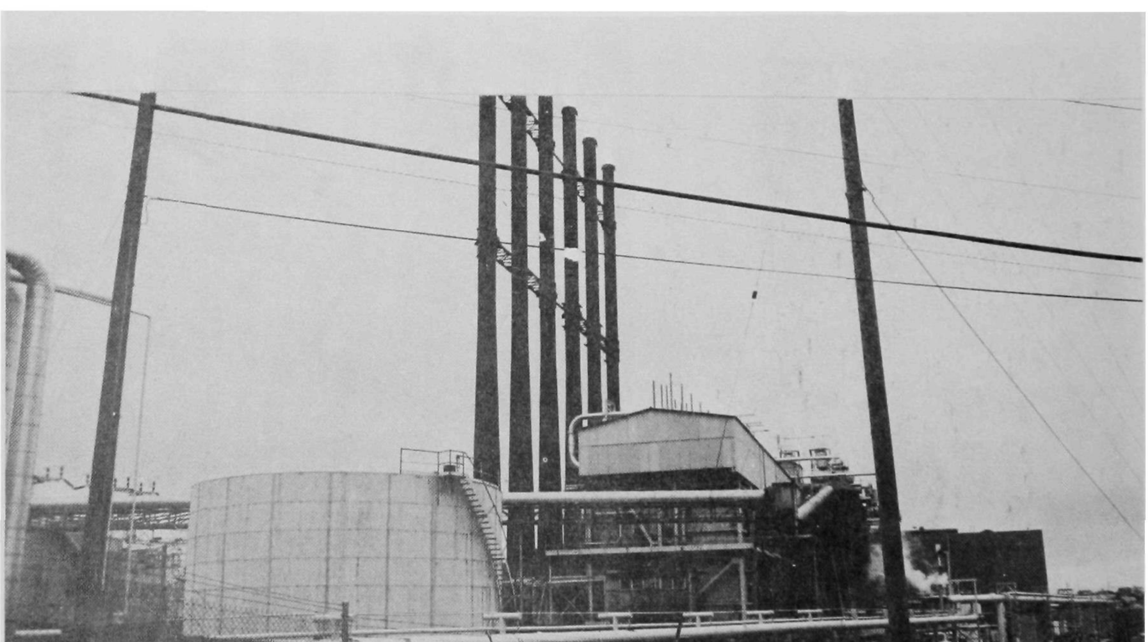
RESIDENTIAL : low/old/multi

RESIDENTIAL : med/old/multi

RESIDENTIAL : med/old/single

INDUSTRIAL : light

INDUSTRIAL : medium



INDUSTRIAL : heavy

COMMERCIAL : shopping center

COMMERCIAL : central business district

Appendix E

METHODS USED FOR ANALYSIS

Appendix E

METHODS USED FOR ANALYSIS

The heavy metals were analyzed using standard atomic absorption (Ref. E-1) methods by Metallurgical Laboratories, Inc. of San Francisco. The metals analyzed included cadmium, nickel, lead, zinc, copper, chromium and mercury. All valence states were measured combined.

The pesticide and PCB analyses were performed by Morse Laboratories of Sacramento, using standard gas chromatograph (Ref. E-1) methods. All chlorinated hydrocarbons were tested for in each sample, but only those found were listed. All organic phosphates were tested for in selected samples, and again, only those found were listed. PCB's were run separately because of their interference on the pesticide analyses.

The soluble nitrate analyses were performed by Cook Research Laboratories, Inc. of Menlo Park, using tentative methods (Ref. E-1). Total Kjeldahl nitrogen includes ammonia and organic nitrogen, but not nitrite and nitrate nitrogen. The total Kjeldahl nitrogen analyses were also performed by Cook Laboratories, using standard methods (Ref. E-1).

The five day biochemical oxygen demand tests (BOD_5) were performed by Cook Laboratories, using the standard (Ref. E) five day bottle technique. The chemical oxygen demand (COD) tests were run by URSRC personnel. The liquid samples were treated in the usual manner, and a slurry was made from the solid materials. The selected samples were boiled with potassium dichromate and sulfuric acid in reflex condensors, as per "Standard Methods" (Ref. E-1), and the values were determined colorimetrically using HACH (Ref. E-2) chemicals and a "spec-20" (Ref. E-3) colorimeter. The samples were centrifuged before readings were taken to reduce background turbidity.

Total phosphates were determined by URSRC laboratory personnel, using the standard (Ref. E-1) colorimetric procedure for ortho phosphates using HACH (Ref. E-2) chemicals and a "spec-20" (Ref. E-3) colorimeter. The samples were boiled for 90 minutes in an acid mixture to convert the polyphosphates to ortho phosphate, and centrifuged, before analysis. Again, the liquid samples were handled normally, and a slurry was made from the dry samples.

Total and fecal coliform counts were determined by URSRC personnel, using the standard (Ref. E-1) (as of 1971) membrane technique. Millipore apparatus was used along with their Endo and MFC broths for the total and fecal coliform determinations, respectively. The liquid samples were determined in the usual way, by passing a known amount of the sample through the membrane filter. The solid samples were made into a liquid slurry of known concentration, and mixed in a high speed blender. Several different "dilutions" were made of each sample in order to get the coliform density reading within the desired range.

The total solids were determined by URSRC personnel. The liquid sample from hosing each test area was analyzed for solids as per "Standard Methods" (Ref. E-1) and computed as amount of solids per unit area. The solids swept were weighed and added to the amount obtained from the liquid analysis to get the total solids for the test area. The solids were also ashed in a muffle furnace according to "Standard Methods" (Ref. E-1) to determine the volatile fraction.

The time lapse between collection of the samples and running the tests was kept to a minimum. The coliform determination of the liquid samples was made the evening the samples were collected, while the "solid" coliform counts were made immediately upon the return of the testing personnel from the field trips. All other tests were also run as close to the receiving date of the material as possible.

The results of the tests were all handled in a similar fashion: All tests were run on liquid (hosed) and solid (swept) samples. Results were reported as ppm of solids or as mg/ℓ of the liquid. These values were converted to amount of material per sq ft hosed and swept, which were then combined to total amount of pollutant per sq ft. By knowing the street and test site width, total amount of pollutant per curb mile was determined. The strength of the solids in terms of each pollutant was determined by dividing the total amount of pollutant per sq ft by the total solids per sq ft.

Table E-1 lists the pollutants, methods used for analysis, and test samples analyzed for these pollutants.

Table E-1

SAMPLES TESTED FOR EACH POLLUTANT

Pollutant	Analytical Method	Samples Tested
Lead, nickel, zinc, copper chromium	Atomic Absorption	R, I and C of SJ-1, Mil and Balt. City composites of SJ-2, Atl, Tul, Pho-2, and Sea. Southern and Western composites broken into particle size ranges including < 43 microns, 43 → 104 microns, 104 → 246 microns, 246 → 840 microns, 840 → 2000 microns, and > 2000 microns.
Mercury	Atomic Absorption	same as lead, except R, I and C on SJ-1 only.
Cadmium	Atomic Absorption	R, I and C of SJ-1, Mil and Balt.
Soluble Nitrates	Tentative Method	Nine land-use composites. Ten city composites. SJ-1, Northern, Southern, and Western composites broken into particle size ranges including < 43 microns, 43 → 104 microns, 104 → 246 microns, 246 → 840 microns, 840 → 2000 microns, and > 2000 microns.
Kjeldahl Nitrogen	Standard Method	
Phosphates	Standard Colorimeter Method	Same as Nitrates, except size analysis on SJ-1 and Northern composites only
BOD_5	Standard 5-day Bottle Method	Same as Nitrates.
COD	Dichromate-Colorimetric	Same as Nitrates.
Chlorinated Hydrocarbons PCB	Gas Chromatography	R, I and C of SJ-1, Mil and Balt. Northern, Southern and Western composites broken into particle size range: < 104, 104 → 246 microns, 246 → 840 microns, 840 → 2000 microns.
Organic Phosphates	Gas Chromatography	SJ-1 city composite
Total Coliforms Fecal Coliforms	Membrane filter. Standard Method (as of 1971)	Every land use tested in each of the ten cities.
Total Solids	Standard Method	Same as coliforms, plus the analysis of all ten cities (< 43 microns, 43 → 104 microns, 104 → 246 microns, 246 → 840 microns, 840 → 2000 microns, > 2000 microns.
Volatile Solids	Standard Method	Nine land-use composites, ten city composites, plus on standard size ranges of Pho-1, Northern composite, SJ-2, Southern composite, and Seattle.

Note: List of abbreviations used in table are as follows:

- R: residential major land-use composite
- I: Industrial major land-use composite
- C: commercial major land-use composite
- Southern composite: made up of Atlanta, Tulsa and Phoenix-2
- Western composite: made up of San Jose-2 and Seattle
- Northern composite: made up of Milwaukee, Bucyrus and Baltimore
- SJ-1: San Jose, winter test
- SJ-2: San Jose, summer test
- Pho-1: Phoenix, winter test
- Pho-2: Phoenix, summer test
- Mil: Milwaukee
- Balt: Baltimore
- Buc: Bucyrus
- Atl: Atlanta
- Tu: Tulsa
- Sea: Seattle

Standard Methods for the Examination of Water amd Wastewater. American Public Health Association, 12 ed, 1965. (13 ed also, 1971).

Appendix E

References

E-1. Standard Methods for the Examination of Water and Wastewater, American Public Health Association, 12th ed., 1965.

E-2. HACH Chemical Company, Ames, Iowa.

E-3. Product of Bausch and Lomb, New York, N.Y.

Appendix F

QUESTIONNAIRE

This questionnaire was patterned after one utilized by the American Public Works Association in a similar survey.

Appendix F

QUESTIONNAIRE

Street Cleaning Practices Utilized in City

GENERAL

Streets	Condition (miles) Good	Fair	Poor	Gutter (%) Std.	Round	None	% Swept
Concrete							
Asphalt							
Other							
Paved alleys							

Other agencies responsible for street cleaning -

Contractor ___________

County/State ______________

Name of responsible city department _____________________

Head _____________________________ URS Contact __________________

____

PERSONNEL

No. supervisory personnel ________________

Average salary ________________

No. nonsupervisory personnel ______________

Operators ______________ Salary ________

Nonoperators ______________ Salary ________

PROCEDURES

Frequency of cleaning (by neighborhood)

	Frequency			Time		Parking Controls?
AREA	Sweeper	Flusher	Hand	Day	Night	
Downtown						
Industrial						
Arterial						
Market						
Residential Lo income						
Hi income						

Extent of cleaning (by neighborhood)

	Route miles		
	Sweeper	Flusher	Hand
Downtown			
Industrial			
Arterial			
Market			
Residential Lo income			
Hi income			

EQUIPMENT		Number	Expected Life	% Down Time
	Sweepers			
	# 1			
Specify	# 2			
Type	# 3			
	# 4			
	Flushers			
Specify Type				
	Trucks			
Specify Type				
	Loaders			
Specify Type				
	Eductors			
Specify Type				
	Others			
Specify				

SWEEPERS -- Operating Specs

	# 1	# 2	# 3	# 4
Average operating speed, mph				
Main broom fiber				
Main broom strike				
Main broom pressure				
Main broom life				
Main broom rotation speed				
Gutter broom material				
Gutter broom life				
Hopper size				

Sweeper performance by neighborhood

	Length Shift	Curb Mi per Shift	Water per Shift Gal	Cu yd per Shift	Crew Size per Shift	Type debris (wt-%)			
						Wood/ paper	Glass/ metal	Dirt/ dust	Other
Downtown									
Industrial									
Arterial									
Market									
Residential									
Lo income									
Hi income									

Collection of sweeper debris

No. of trucks: ____ Loaders: ________________

How covered: __________________________________

Average size of pickup (yds): ___________________________

Ultimate dump site: ____________________________

SPECIAL PROBLEMS

Leaves

Schedule

Method

Equipment

Quantity (per season)

Disposal

Dead Animals (if pertinent)

Abandoned cars (if pertinent)

Chemical Use (by city)

Quantity each season: Herbicides _________

Pesticides/insecticides _________

Fertilizers ______________

Snow

Amount of chemicals used each season ________________

Type chemical(s) ________________

Amount of sand/cinders used each season ____________

Snow disposal site ________________

Estimated chemical load in snow disposed of __________

Is spring cleanup scheduled ?

____

Procedure: ____

____

Disposal site for spring cleanup debris: _____________

____

Catch basins

Total number ______________ Times oiled per gear __________

Times cleaned per year _____________

Method of cleaning :

	No. of Crew	Man/ Crew	Cost, $/ basin	Cost, $/cu yd	Disposal Site
Hand					
Bucket					
Eductor					
AVERAGE					X

Sidewalks/parking lots

Frequency and procedure. ________________________

Extent of area involved: ____________________

Refuse Collection

	Frequency	Collection Curb	Collection Backyard	Contract	Litter Baskets	Annual Amount
Downtown						
Industrial						
Arterial						
Market						
Residential						
Lo income						
Hi income						

Source of miscellaneous litter and debris:*

	Downtown	Industrial	Arterial	Market	Residential Hi	Residential Lo
Spillage from trucks						
Litter from parades						
Disintegration of streets						
Yard refuse						
Animal droppings						
Wind pockets/storms						
Trash receptacles						
Demolition						
Streetside dumping						
Street construction						
Poor refuse collection practices						
Street trees						
Lack of catch basin inlets						
Air pollution						
Droppings from vehicles						

* Rate Importance as: H (high), M (medium) or L (low)

COST

	Yearly Costs, $			
	Labor	Equipment	Other	Total
Hand cleaning				
Motor sweeping				
Flushing				
Disposal of sweepings				
Snow removal				
Leaf removal				
Dead animals				
Catch basin clng.				
Other				
Total				

Cost per unit cleaned, $

Hand cleaning	(curb mile)
Motor sweeping	(curb mile)
Flushing	(mile)
Catch basins	(per catch basin)

EFFECTIVENESS

In your judgement what is the effectiveness of your street cleaning practices?

	Large Visible	Dirt & Dust	Glass & Metal	Organic
Good				
Fair				
Poor				

Sweeper Operations by Month

		Loads*	Curb-Miles
January	________		
February	________		
March	________		
April	________		
May	________		
June	________		
July	________		
August	________		
September	________		
October	________		
November	________		
December	________		

*Specify conversion factor to cubic yards

Appendix G

STREET SURFACE CONTAMINANT SIMULANT

Appendix G

STREET SURFACE CONTAMINANT SIMULANT

In developing standardized equipment and/or cleaning practice evaluation methods, a street surface contaminant simulant was prepared for use in test programs. This approach was used to enhance the reliability of evaluating equipment parameters and various practices under standardized street contamination conditions.

Requirements for such a simulant have been long recognized. In Operation STREETSWEEP (Ref.G-1), ferromagnetic particles of two size ranges were utilized to simulate weapons fallout particles; however, it became apparent that the use of this simulant was inappropriate for ordinary street dirt. In Operation SUPERSWEEP (Ref.G-2) three sizes of radiotantalum-tagged particles were utilized to simulate fallout particles. In both of these experiments it was shown that small particles were the most difficult to remove. In operation STONEMAN (Ref.G-3) and STONEMAN II (Ref.G-4) a simulant covering a broad particle-size range was used. This simulant consisted of a loam-type soil and several grades of sandblasting sand.

Results from the street surface sampling program in this URS study indicate that the bulk of street surface contaminants is made up of particles ranging from 43 to 2000 microns. Figure G-1 shows the cumulative particle size distribution derived from the sampling program in the cities of San Jose and Phoenix. Since the distribution of particle sizes was found to be fairly similar in each city, the particle size distribution selected for the simulant to be utilized in the controlled street sweeping evaluation tests was made an average of the two cities (shown by the dotted line in Figure G-1). The composition by weight of the simulant for each size range is given in Table G-1.

The synthetic simulant represents the dust, dirt and gravel fraction of the street litter. An average of 92 percent by weight of the street litter collected in the sampling program passed through a 200 micron screen (10 mesh) and was mainly composed of dust, dirt, sand and gravel.

The material used for the simulant consisted of two grades of commercially available Del Monte Sand, #60 mesh and #1 ground. These two grades of river bottom sand contain a large percentage of the size fractions found in the street surface samples. The sieve analysis for these two grades are in Table G-2. The particles were separated into the required size ranges on a commercial sieving machine (manufactured by Novo Corporation). This machine (a vibratory type) feeds the raw material from a storage hopper onto a screen where two fractions are obtained; one greater and one smaller than the screen mesh opening. Selected screens are used to produce the various size ranges required.

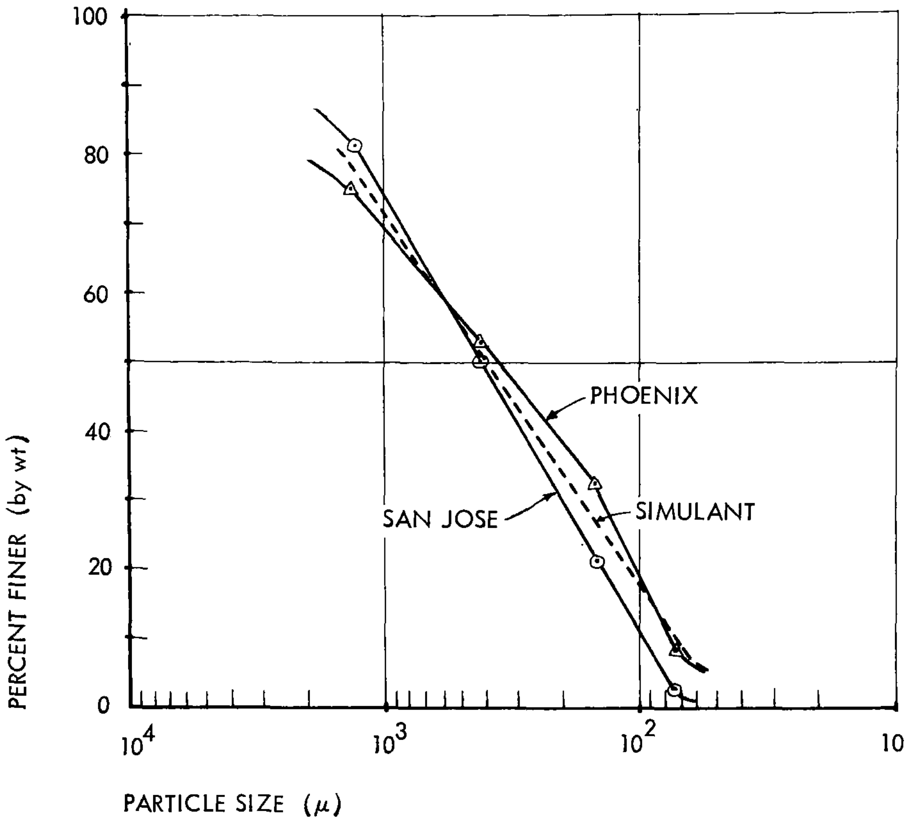


Fig. G-1. Simulant Compared to Street Surface Contaminant Samples, Tests B and C

Table G-1

SIMULANT PROPERTIES

Particle Size (μ)	Composition (% by weight)
2000	8
840-200	20
246-840	30
104-246	20
43-104	16
43	6

Several hundred pounds of each size range were produced for use as the street surface contaminant simulant.

The simulant was formulated by combining the desired weights (Table G-1) of each particle size group. If necessary, the simulant combination can be changed by varying the weight composition of each particle size range. Some important geometrical properties of the various size ranges are given in Table G-3.

Table G-2

ANALYSIS OF SANDS USED IN FORMULATING SIMULANT

	Mesh Opening (μ)	Percent Retained	Cumulative Percent Less Than Stated Size
No. 1 Ground Del Monte Sand	297	3.8	96.3
	177	20.8	75.5
	149	13.4	62.1
	74	32.2	29.9
	53	12.2	17.7
	43	7.2	10.5
	43	10.5	
Nominal 60 mesh Ground Del Monte Sand	420	8.2	91.8
	297	48.4	43.4
	250	21.3	22.1
	177	19.9	2.2
	149	1.3	0.9
	105	0.9	
	105	0	

Table G-3

GEOMETRIC PROPERTIES OF PARTICLES

Size Range (μ)	Number of Particles (per gram)	Average Surface Area per Particle (cm^2)	Average Particle Diameter (μ)
43- 88	6.98×10^6	6.69×10^{-5}	47
88-175	6.20×10^5	3.21×10^{-4}	101
175-350	7.54×10^4	1.39×10^{-3}	210
350-750	7.09×10^2	7.85×10^{-3}	500

Appendix G

References

G-1. R. A. Laughlin, J. Howell, et al. Operation STREETSWEEP. Naval Radiological Defense Laboratory Report ADX-39, 2 December 1948.

G-2. F. R. Holden, R. A. Laughlin, et al. Operation SUPERSWEEP. Naval Radiological Defense Laboratory Report ADZ-42, 4 October 1948.

G-3. J. D. Sartor, H. B. Curtis, et al. Cost and Effectiveness of Decontamination Procedures for Land Targets. Naval Radiological Defense Laboratory Report USNRDL-TR-196, 27 December 1957.

G-4. H. Lee, J. D. Sartor and W. H. Van Horn. Performance Characteristics of Dry Decontamination Procedures. Naval Radiolocal Defense Laboratory Report, USNRDL-TR-336, 6 June 1959.

Appendix H

CATCH BASIN TEST PROCEDURES

Appendix H

CATCH BASIN TEST PROCEDURES

Determination of the changes in street runoff resulting from passage through a catch basin followed two approaches. The first of these involved investigation of the hydraulic flushing effect of inlet water on antecedent basin contents. This essentially consisted of discharging fresh water into dirty catch basins under controlled conditions and sampling the effluent. The second approach was the determination of the solids removal effectiveness of catch basins. This was investigated by discharging water and street litter simulant into a clean catch basin and sampling the effluent.

The sampling site (in San Francisco at 40th and Moraga Avenues) is believed to be as typical an urban catch basin installation as might be found. It contains three similar catch basins, all draining into a central interceptor, which in turn drains into the sewer system (actually a combined storm/sanitary sewer system). The installation is shown in Fig. H-1. The central interceptor allowed a common sampling point for all

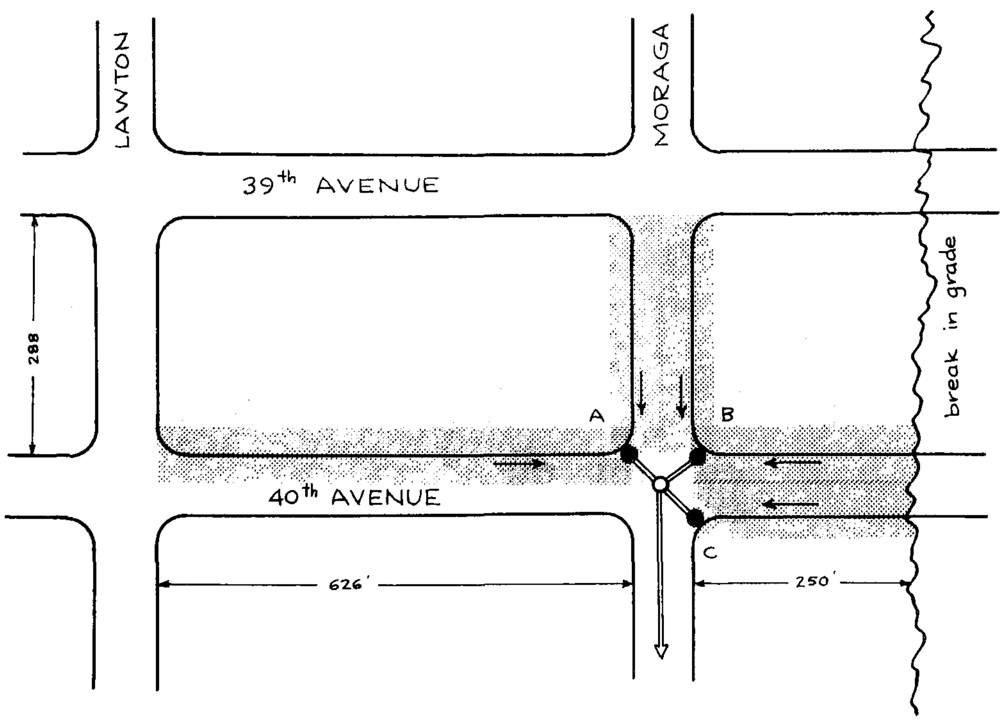


Fig. H-1. Map of Test Site for Catch Basin Tests (San Francisco) the tests. The intersection is on a slight grade, allowing rapid and efficient drainage of water and sediment and an accurate determination of individual drainage areas. The catch basins are of a standard, rather conventional design: concrete with curb inlets and cast iron gratings (a cross section is shown in Figure H-2).

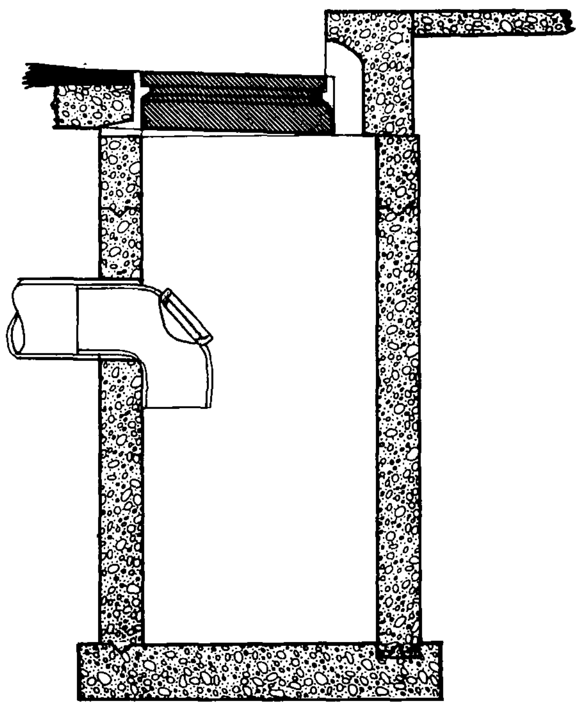


Fig. H-2. Cross-Section Through Catch Basin

Computation of a number of factors was necessary prior to the start of testing. The amount of runoff for each of the three drainage areas was calculated at several rainfall intensities. These amounts were then converted to flow rates (cubic feet per second) to allow use of a flow meter to regulate the supplying fire hydrant. Using previously collected street loading data for the land use encountered (i.e., residential), the amount of material that would be expected to wash off the street was determined. The amount of water for each rainfall intensity, and the drainage basin loadings are shown in Table H-1. Using this information (along with information on the rate at which rain removes street surface loadings derived from previous studies), the percentages of the total loading washed off the street were calculated on a time basis and sample introduction amounts and times were established (as shown in Table H-2).

Table H-1

PARAMETERS USED IN CATCH BASIN STUDY

CATCH BASIN	DRAINAGE AREA (sq ft)	RAINFALL INTENSITY (in./hr)	FLOW RATE INTO CATCH BASIN (gal/min)	SOLIDS INPUT RATE at 2 g/sq ft (lb/40 min)
A	41,700	0.07	32.1	144
B	25,000	0.49	126.1	88
C	11,050	0.72	82.2	38

Table H-2

QUANTITIES OF SIMULANT USED

TIME SINCE BEGINNING OF TEST (min)	AMOUNT OF SIMULANT MIXED WITH FLOW INTO EACH CATCH BASIN (lb)		
	A	B	C
0			
	36	22	9-1/2
2			
	18	11	5
5			
	27	16-1/2	7
6			
	27	16-1/2	7
20			
	36	22	9-1/2
40			
Total in 40-min Intervals	144	88	38

The actual sampling procedure consisted of starting the flow of water into a catch basin and then lowering a bucket into the central interceptor to take a series of samples (one at each predetermined time interval). For example, during the time interval 0 to 1 min, approximately five 1-gal samples were collected and composited on the spot in the interceptor. Other samples were taken in a similar manner for the intervals 1 to 2 min, 2 to 5 min, 5 to 10 min, and 10 to 20 min. In the laboratory, total settleable solids and dissolved and suspended solids were determined for all samples. In addition, samples from the "clean" catch basin tests and the representative samples of the street simulant were analyzed by dry sieving to determine size distribution.

DIRTY CATCH BASINS

Clean water was introduced to catch basins A, B, and C (one at a time, in three separate tests) at measured flow rates of 0.29, 0.51, and 0.81 in./hr, respectively. Sample compositing intervals were 2, 5, 10, and 20 min in Test A, with 1 min sample added in Test B and a 40 min sample added in Test C. The measured output of each catch basin and the flow rate are shown in Table H-3. The results indicate that most of the material originally contained in a catch basin tends to remain there, regardless of runoff flowing through it.

Table H-3

TEST OF "DIRTY" CATCH BASINS

CATCH BASIN	CATCHMENT AREA SIZE (ft)	INFLOW RATE IN TERMS OF EQUIVALENT RAINFALL OVER CATCHMENT AREA (in./hr)	WEIGHT OF SOLIDS IN CATCH BASIN AT OUTSET (lb)	WEIGHT OF SOLIDS REMOVED BY "STORM" (lb)	SOLIDS REMOVAL EFFICIENCY (% by weight of original)
A	41,700	0.29	2,047	26.6	1.2
B	25,000	0.51	2,559	30.0	1.1
C	11,050	0.81	3,481	21.6	0.6

Observed, but not measured in the sampling, was the general quality of the water above and mixed with the sediments. Before testing, the non-settleable contents were septic with an observable percentage of plant material, oil and grease. Initial flows into the catch basin removed this very quickly.

CLEAN CATCH BASINS

Catch Basin B was cleaned out by a combination of water-jet blasting and wet vacuuming for this series of tests. The simulant material was introduced by dumping a pre-weighed amount of material (pre-calculated for each time interval) into the gutter several feet above the catch basin grate and gradually eroding it with water supplied by a fire hydrant. This proved to be an accurate method of introducing solids uniformly. Sampling at the central interceptor was accomplished as described for the dirty catch basin tests.

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16. Abstract

Materials which commonly reside on street surfaces have been found to contribute substantially to urban pollution when washed into receiving waters by storm run-off. In fact, runoff from street surfaces is similar in many respects to sanitary sewage. Calculations based on a hypothetical but typical U.S. city indicated that the runoff from the first hour of a moderate-to-heavy storm would contribute considerably more pollutional load than would the same city's sanitary sewage during the same period of time.

This study provides a basis for evaluating the significance of this source of water pollution relative to other pollution sources and provides 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). 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.

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

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