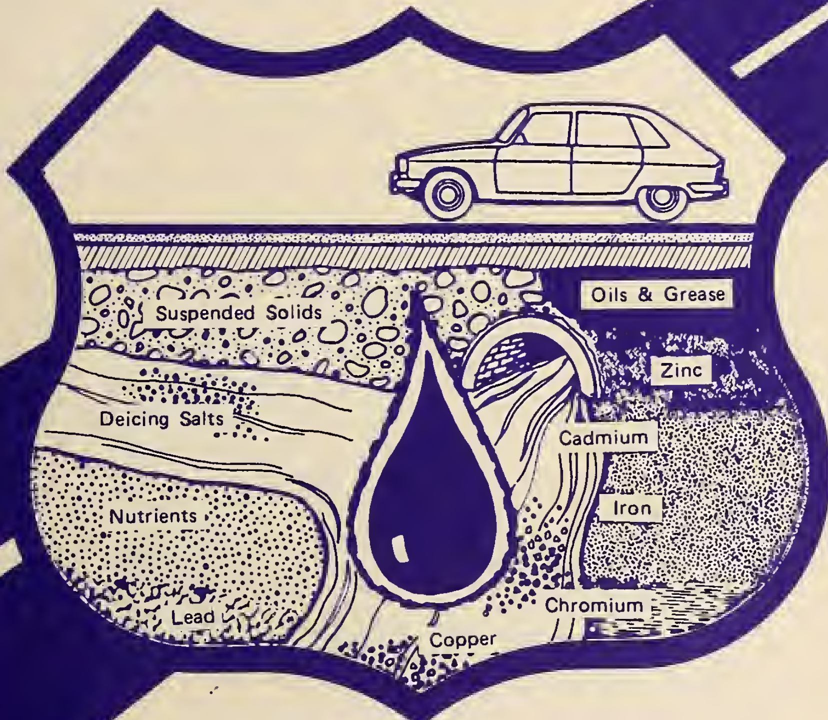
No. FHWA/RD-81/042

STITUENTS OF HIGHWAY RUNOFF

Vol. I. State-of-the-Art Report
February 1981
Final Report



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Prepared for
FEDERAL HIGHWAY ADMINISTRATION
Offices of Research & Development
Environmental Division
Washington, D.C. 20590

FOREWORD

This report is composed of six volumes; Volume I documents the constituents of highway stormwater runoff and their pollutional effects; Volume II contains detailed procedures for conducting a monitoring and analysis program for highway runoff pollutant data; Volume III describes a simple predictive procedure for estimating runoff quantity and quality from highway systems; Volume IV is the research report discussing research approach and findings; Volume V contains the computer users manual for a highway runoff data storage program and Volume VI is an executive summary. The report will be of interest to planners, designers and researchers involved in evaluation of highway stormwater runoff contributions to non-point sources of water pollution.

Research in Water Quality Changes due to Highway Operations is included in the Federally Coordinated Program of Highway Research and Development as Task 3 of Project 3E, "Reduction of Environmental Hazards to Water Resources to the Highway System". Mr. Byron N. Lord is the Project and Task Manager.

Sufficient copies of the report are being distributed to provide a minimum of one copy to each FHWA Regional office, Division office and State highway agency. Direct distribution is being made to the Division offices.

D. Solomon
for Charles F. Scheffey
Director, Office of Research
Federal Highway Administration

NOTICE

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16. Abstract

This state-of-the-art report documents the constituents of highway runoff and their pollutional effects. It provides a general background about the problem, its recognition and the emerging emphasis to address the problem and its solutions. It discusses highway design and drainage characteristics and their relationship to runoff quantity. An extensive review of the available literature on the quality of stormwater runoff from urban areas in general and from highway drainage areas in particular, has been made.

The titles of the volumes of this report are:

FHWA-RD-	Subtitle	
81/042	Vol. I	State-of-the-Art Report
81/043	Vol. II	Procedural Manual for Monitoring of Highway Runoff
81/044	Vol. III	Predictive Procedure for Determining Pollutant Characteristics in Highway Runoff
81/045	Vol. IV	Characteristics of Runoff from Operating Highways. Research Report.
81/046	Vol. V	Highway Runoff Data Storage Program and Computer User's Manual
81/047	Vol. VI	Executive Summary

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METRIC CONVERSION FACTORS

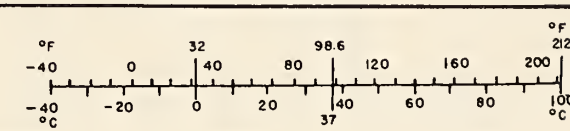
Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

*1 in = 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures. Price $2.25, SD Catalog No. C13.10:286.

Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



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SECTION I
INTRODUCTION

The United States Public Health Service (1) published a report in 1964 which focused attention on the pollutional impact of storm generated discharges. Together with additional studies conducted over the past decade, this report dispelled any thoughts that the only sources of water quality degradation were domestic sewage and industrial wastewaters. Urban runoff, as well as all nonpoint sources are now considered as sources of pollutional materials (2). Environmental quality can be preserved only by determining and controlling where necessary, pollution emanating from these sources. Indeed, environmental impact statements (EIS) have as one of their prime objectives the quantification of possible pollutants emanating from the operation and maintenance of highway facilities, so that sound judgements can be made as to the overall "usefulness" of the facility.

The National Environmental Policy Act of 1969 (PL91-190) mandates that for all projects affecting the environment, all government agencies shall utilize a systematic, interdisciplinary approach to minimize the impact of the proposed project on the environment. Charged with this responsibility, the Federal Highway Administration (FHWA) has recognized the importance of developing analytical methods for quantifying the impact of highway facilities on the surrounding environment.

Highway operation and maintenance contributes a variety of pollutants to surface and subsurface water. Solids, nutrients, heavy metals, oil and grease, pesticides and bacteria can all be associated with highway runoff. However, the extent to which the runoff from highways affects the quality of the surrounding waters is not well defined. Indeed, all the components of this runoff have not been identified nor has their origin, movement within the highway system and quantities been clearly established. This information is needed if the impact of the highway facility on the environment is to be evaluated.

The last decade has seen increased efforts in research and development to abate contaminant discharges from storm sewer and combined sewer overflows. Over 100 million dollars have already been expended for research and development efforts and investigation of alternate feasible solutions to this problem. Projects were conducted to determine the quality of storm sewer and nonsewered urban runoff along with investigation of feasible methods for the handling/treatment of combined sewer overflows. The results of the stormwater and combined sewer overflow projects are being carefully monitored, evaluated, revised, and inventoried by the Office of Research and Monitoring, U.S. Environmental Protection Agency (3, 4). However, the objectives of most of the previous and ongoing stormwater characterization research have not been directed, specifically towards the effects from operation and maintenance of highway systems. Techniques employed for sampling, sweeping and flushing are open to serious question. Standardized procedures do not exist and the compatibility and reproducibility of research is most difficult. Such information as the effects on water quality of sediments, deicing chemicals, street runoff, urban freeway runoff and other related activities have been or are being investigated to varying degrees by FHWA and EPA sponsored programs.

Urban runoff and stormwater pollution literature and information have been sorted out selectively and combined with existing highway runoff quality data in order to prepare this state-of-the-art report on the constituents of highway runoff and their pollutional impact on the surrounding environment. This report includes a comprehensive survey of the literature to evaluate the following:

1. Identification of the roadway contaminants and their potential sources.

2. Identification of the highway design and maintenance practices that affect the drainage and quality of highway runoff.

3. Identification of the constituents of runoff emanating from highway facilities.

4. Quantification of highway runoff constituents and comparison with other stormwater runoff loadings.

5. Status of present knowledge with regard to the pollutional effects of highway systems.

SECTION II
ROADWAY CONTAMINANTS, THEIR POTENTIAL SOURCES AND IMPACTS

Roadway Contaminants

Materials accumulate on highway surfaces, median areas and adjoining right-of-ways as a result of highway use, maintenance, natural contributions and air pollution fallout. These materials accumulate within the highway system between precipitation periods and roadway sweepings, and are scoured due to wind, rainfall or snowmelts.

Table 1 contains a listing and description of the contaminants generally found on the roadway and its appurtenances. This table also lists the standard analytical determinations used for identifying the various contaminants and the primary sources which contribute these contaminants to the roadway environment. The magnitude of these contaminants on roadways is in turn a result of variables such as:

1. Traffic characteristics (speed, volume, braking, etc).
2. Climatic conditions (intensity and form of precipitation, wind, temperature).
3. Maintenance policies (sweeping, mowing, repair, deicing, etc).
4. Surrounding land use (residential, commercial, industrial, rural).
5. Percent pervious and impervious areas.
6. Age of car and its maintenance.
7. Littering laws and regulations covering car emissions and delivery trucks.
8. Use of special additives in vehicular operation.
9. Vegetation type on the highway right-of-way.
10. Accidental spills.

Many sources of the important pollutants in highway runoff are adequately documented in the literature while several others require further study. For example, the sources of solids deposition on highways is well known, i.e., tire and pavement wear, brake shoe drum wear, rust, car exhaust, mud and dirt accumulated on vehicle bodies, sanding/salting for roadway deicing, atmospheric fallout, erosion from highway right-of-way, pavement maintenance, extraneous litter and spilled loads such as sand, gravel, grains, etc.

Many sources of heavy metals are well documented. Much of the lead is deposited principally through the use of leaded fuels and some

Table 1. Listing of common contaminants on roadways.

Classification	Examples	Analytical determination	Primary sources
Particulates	Dust and dirt, stones, sand, gravel, grain, glass, plastics, metals, fine residue.	SS, settleable solids.	Pavement, vehicle, atmosphere, litter, maintenance.
Heavy metals	Lead, zinc, iron, copper, nickel, chromium, mercury.	Specific heavy metal via atomic absorption.	Vehicle, atmospheric washout.
PCB, pesticides	Chlorinated hydrocarbons, organo-phosphorus.	Gas chromatography.	Spraying of highway right-of-way vegetation.
Inorganic salts	$CaCl_2$, NaCl, SO_4, Br.	Cl, SO_4, Br, non vol. solids, conductivity.	Deicing salts, atmospheric washout, vehicle.
Organic matter	Vegetation, dust and dirt, humus, roadway accumulations, oil, fuels.	Volatile fraction, hexane extractables (oil and grease) BOD, COD, TOC.	Roadside vegetation, vehicle, litter, aerosols.
Nutrients	Nitrogen, phosphorus.	TKN, NO_2, NO_3, PO_4.	Fertilizer.
Pathogenic bacteria (indicators)	Coliforms.	TC, FC, FS, and other specific indicators.	Soil, litter, excreta, bird droppings.
Other	Asbestos, rubber, special compounds.	Chemical diffraction and electron microscopy, special techniques.	Vehicle, specific additives.

by tire wear where lead oxide is used as a filler material (5, 6). Zinc is also used as a filler material in tires and as a stabilizing additive in motor oil. The majority of iron enters the highway drainage system from the rusting of vehicular bodies and other steel (such as guard rails, etc) normally incorporated in the construction of the highway system. For example, stabilized slag (from steel production) is sometimes used in the construction of highways (used commonly in the state of Pennsylvania). As a result, higher heavy metal loadings, particularly iron, may be experienced. Heavy metals such as copper, nickel and chromium, although found in much smaller quantities in runoff are present due to the wear of metals from metal plating, bearings, bushings and other moving parts within the engine. Some copper may be deposited as a result of wear of brake linings which have copper added (5).

The PCB's and specific pesticides originate mostly from the use of the weed killer compounds on the highway right-of-way. Some PCB's may be a result of the breakdown of other additives used in vehicle operation. Similarly, the wear of clutch and brake linings has been reported to be the primary source of asbestos in highway runoff (5). Tire wear is the source of traffic related rubber found in roadways (5, 7, 8).

High concentrations of chlorides, sodium and calcium in highway runoff can be attributed to the use of salt and other deicing agents on highways (9, 10, 11). The anti-knock fluid added to leaded gasoline contains lead alkalis and organic scavengers, ethylene dichloride and dibromide whose function is to combine with the lead to form inorganic lead salts, chiefly bromochloride. These inorganic lead salts are mostly retained in the exhaust system at low speeds and then discharged in increasing quantities as the vehicle speed increases.

Much of the oil and grease and related petroleum compounds found in highway runoff result from spills or leaks of motor vehicle lubricants, antifreeze and hydraulic fluids. Some oil and grease may also be contributed by the road bed leachate from asphalt paved highway systems.

<u>Pollutant Transport and Impact on Receiving Waters</u>

Physical movement of the pollutants from the highway surface is seen to occur via two important mechanisms: washoff via rainfall or snowmelt and blow-off by wind and/or vehicle turbulence. It has been determined (12) that the rate at which rainfall washes loose particulate matter from street surfaces depends on three primary factors:

1. Rainfall intensity.
2. Street surface characteristics.
3. Particle size.

A sizable percentage of the pollution potential of street debris was found to be contained in the very fine silt like fraction (<43μ). Although this material accounted for only 5.9%, by weight, of the total solids on the street surface, it contained approximately one fourth of the total oxygen demand and one third to one half of the algal nutrients. This material also accounted for more than half of the heavy metals and nearly three fourths of the total pesticides. These concentrations of the pollutants in the material are of particular importance because conventional street sweeping operations are rather ineffective in removing this material. It was also found that the street surface contaminants are not distributed uniformly across the streets. Approximately 85-90% of the pollutants were found to accumulate within 12 inches (30 cm) of the curb.

Vehicle induced reentrainment is a mechanism by which larger non-suspendable dirt and dust are ground into smaller particles by the vehicle wheels, enabling these particles to become airborne. The moving action of the wheels of the vehicle breaks up the cohesive bonds on the dust and imparts kinetic energy to these particles.

The pollutants contained in highway runoff may cause water quality impacts on receiving waters through two mechanisms; (i) their shock or acute loadings and (ii) their long term accumulation within the waterbody as well as associated sediments. Both mechanisms may result in levels of water quality impairment outside the limits of general water quality criteria for aquatic life, water supply and recreational uses of receiving water. However, receiving water impacts are often very site specific and the extent of the problems will depend heavily on conditions such as rainfall quantities, point sources of pollution and their treatment, land use and the sensitivity of the receiving waters. There is very little information documented in available literature pertaining to impacts on receiving waters from highway runoff. However, some literature dealing with urban runoff may be applicable to potential impacts from highway runoff in varying degrees. For example, the following broad classes of problems have been categorized for urban runoff in terms of associated impacts on receiving waters (13):

-Aesthetic deterioration - Either general appearance (dirty, turbid, cloudy) or the actual presence of specific, objectionable conditions (odors, floating debris, oil films, scum or slimes, etc) may make the receiving water unattractive or repugnant.

-Dissolved oxygen depletion - Organic materials stimulate the growth of bacteria which may consume oxygen faster than natural processes can replenish. This condition may or may not be visually apparent. In the extreme, discloration, gas formation and odors may be apparent - however, well before this extreme is reached, conditions suitable for a balanced aquatic population of fish and lower species in the food chain may be destroyed. The presence of unoxidized nitrogen compounds (e.g., ammonia) is in some cases a significant element in water quality problems related to low dissolved oxygen levels.

-Pathogen concentrations - The presence of excessive concentrations of objectionable microorganisms can prevent the receiving water from being used for certain water supply and recreational purposes.

-Suspended solids - Particulate matter may contribute to a variety of problems, such as objectionable aesthetic consideration, formation of sediment deposits which smother bottom dwelling aquatic organisms, impeded navigation or restricted river flow contributing to flooding potential.

-Nutrients - The discharge of materials which fertilize or stimulate excessive or undesirable forms of aquatic growth can create significant problems in some receiving water systems. Overstimulation of aquatic weeds or algae (eutrophication) can be aesthetically objectionable, cause dissolved oxygen problems, and in extreme cases can interfere with recreational uses, creating odors, and heavy mats of floating material at shorelines.

-Toxicity - Toxicity problems can fall into either of two categories: Metals or pesticides/persistent organics. Toxicants may exhibit a subtle, long term effect on the environment in areas well removed from the area under consideration, by the discharge of small quantities which gradually accumulate in sensitive areas.

Highway runoff may cause similar impacts on receiving waters depending upon local conditions and receiving water characteristics. Such contributions of the highway runoff pollutant loads to total receiving water loads may become increasingly important as new control measures are adopted to reduce the impact of other nonpoint and point sources.

SECTION III
HIGHWAY DESIGN AND DRAINAGE CHARACTERISTICS AND THEIR RELATIONSHIP TO RUNOFF QUANTITY

Maintaining adequate drainage is one of the most important aspects of the location and design of highways. Drainage design generally involves controlling and removing the surface and groundwater within the limits of the right-of-way and adjacent territory, thereby preventing water from pooling on the pavement surface and accumulating within the roadway area. With the increase in freeway usage, greater roadway pavement width is required and the geometrics become more complex. Also, the emphasis on highway safety has increased. A substantial increase in paved areas has increased the volume of stormwater to be removed and has made removal itself more difficult.

To provide for minimum disruption to natural drainage along a roadway, an extensive drainage system is generally required. The structures (inlets and storm sewers) and drainage channels for the system must be adequate to handle the runoff, yet not present a potential hazard to vehicles (14, 15). These drainage structures and channels are designed based upon hydrologic conditions to a hydraulic capacity not to exceed a certain design year, such as a 50 year storm.

Through the years, the design of roadway drainage and the facilities to handle the water has improved. Many of the improvements are directly related to safety, including the removal of hazards and obstructions from the vehicle path. The reduction in use of curb sections has changed the drainage characteristics of the roadway and adjacent areas. In urban areas, the installation of median barriers and paved medians has changed drainage patterns. These and other factors have and will continue to affect drainage design.

Drainage Design

Today's highway planning provides for the most advanced form of roadway design available. There are three basic profiles in roadway construction. Any one or a combination of the designs are used for today's roads. They include ground level, depressed, and elevated roadways. The use of any of these design types is dependent on several factors, such as area topography, development, soil conditions, drainage, economics and aesthetics.

<u>Ground Level (At-Grade) Roadway</u> - This type of design as illustrated in Figure 1 is generally used in areas of flat terrain and in suburban and rural areas where cross streets are widely spaced (16 17). Areas to be drained by inlets for this type of roadway profile consist mainly of the median, shoulder, roadside and paved areas

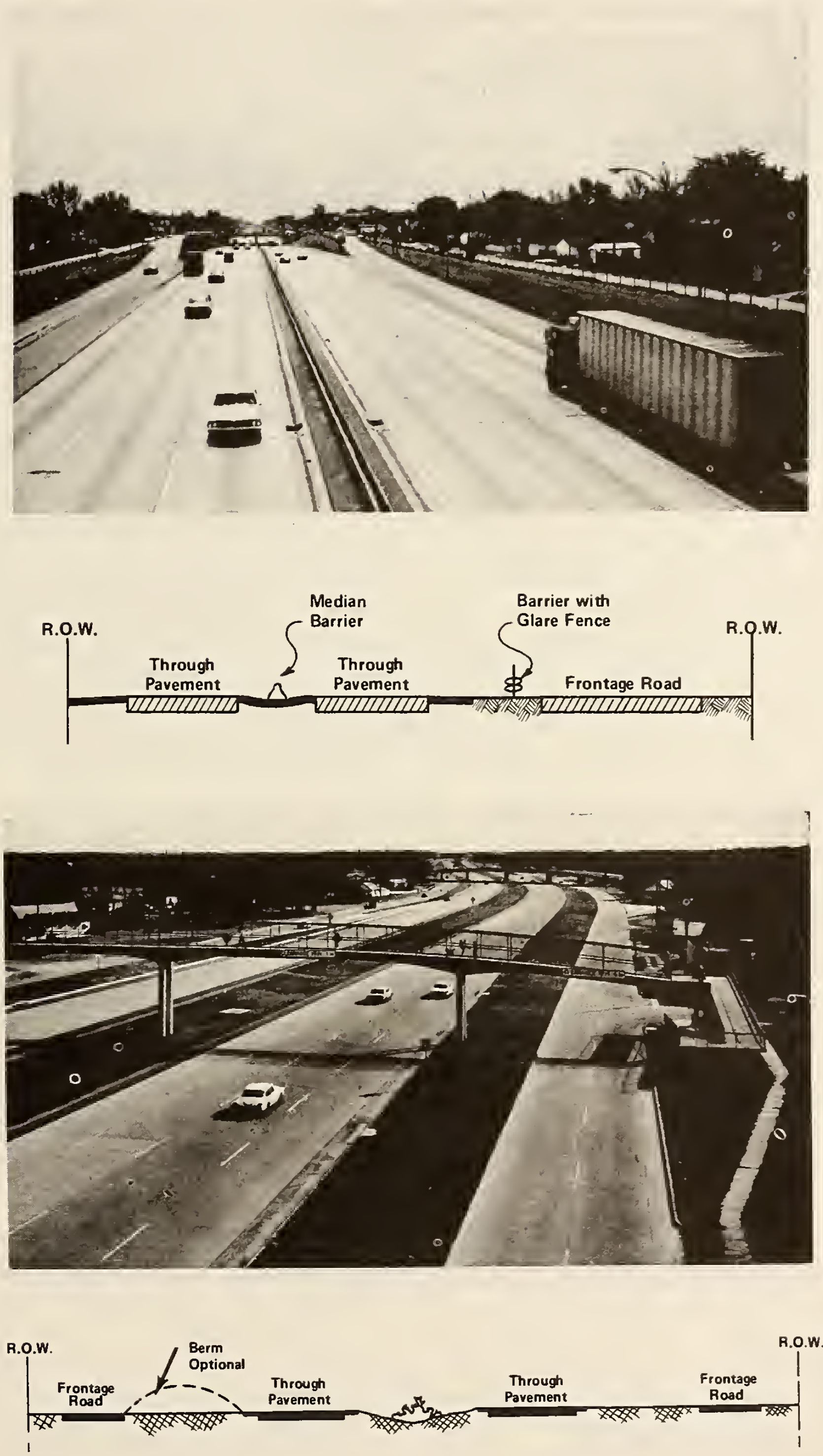

Figure 1. Typical ground level roadway (16).

within the right-of-way. The drainage of the inlets may be via an existing sewer system or a trunk sewer designed specifically to handle the new roadway. Because the roadway is at ground level, drainage by means of a ditch system is not practical for extended areas unless it can drain to natural drainage channels.

Depressed (Below-Grade) Roadway - In urban areas especially, freeways are designed to be below the surface of the adjacent streets, as illustrated in Figures 2 and 3 (16), thereby allowing major streets to pass over the through roadway (16, 17). Unless vertical retaining walls are used along this type of design, the right-of-way necessary for this roadway section must be wider to allow the grade slopes necessary to reach the ground level. The surface drainage for this type of section is accomplished by crowning the roadway and sloping the shoulders to side ditches or gutters and collecting the stormwater in inlets. Surface runoff from adjacent lands can also be collected in these ditches. In deep cut sections, additional ditches are provided at the top of the slope to intercept the surface flow and to prevent excessive erosion of the cut slope. These ditches lead into natural water courses or into storm sewers. In addition to the roadway and surface drainage, subsurface drainage may be needed where the ground water level is likely to be near the surface at any time. In some deep cuts pumping stations are necessary to bring the stormwater into existing higher level storm sewers. The monitoring of runoff for pollution measurement is very difficult at outfalls with pumping stations.

Elevated Above Ground Roadway - The use of an elevated roadway may be appropriate in areas of restricted right-of-way, high groundwater table, flooding, traffic congestion or other circumstances which make a depressed or at-grade roadway undesirable or uneconomical (16, 17). The elevated roadway, as illustrated in Figure 4 (16) can consist of roadway bridge structures in areas of restricted right-of-way or earth embankments where right-of-way permits.

The drainage for an elevated roadway or structure is provided by inlets in the structure itself. The inlets are then drained by downspouts to an existing storm sewer or drainage system in the area, as shown in Figure 5.

On high embankment roadways without curbs, a drainage channel can be built along the top edge of the fill to keep surface runoff from multilane freeways close to the top of the embankment. In areas of bridge structures, a channel can be provided at the end of structures to carry the water down the embankment to the side ditches. Lower embankment roadways without curbs and with two or three lanes of traffic simply drain the stormwater off the roadway and down the embankment to the side ditches. The side ditches drain into natural channels, as illustrated in Figure 6 (17) or into inlets to storm sewers. The ditch sections and top of slopes are usually rounded, which provides safety for errant vehicles (15), reduces erosive

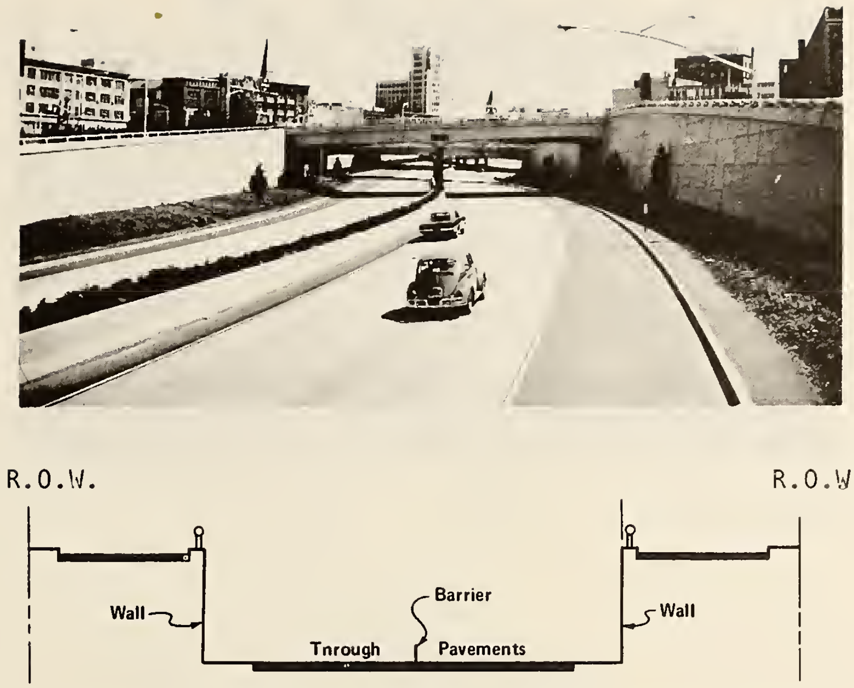

Figure 2. Typical depressed roadway, retaining walls (16).

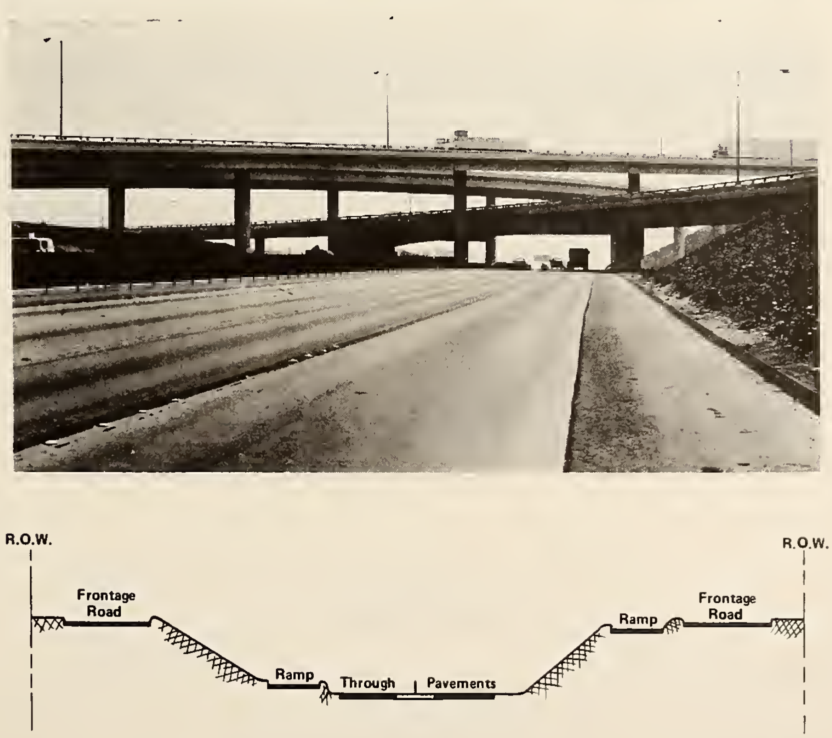

Figure 3. Typical depressed roadway, sloped outer separation (16).

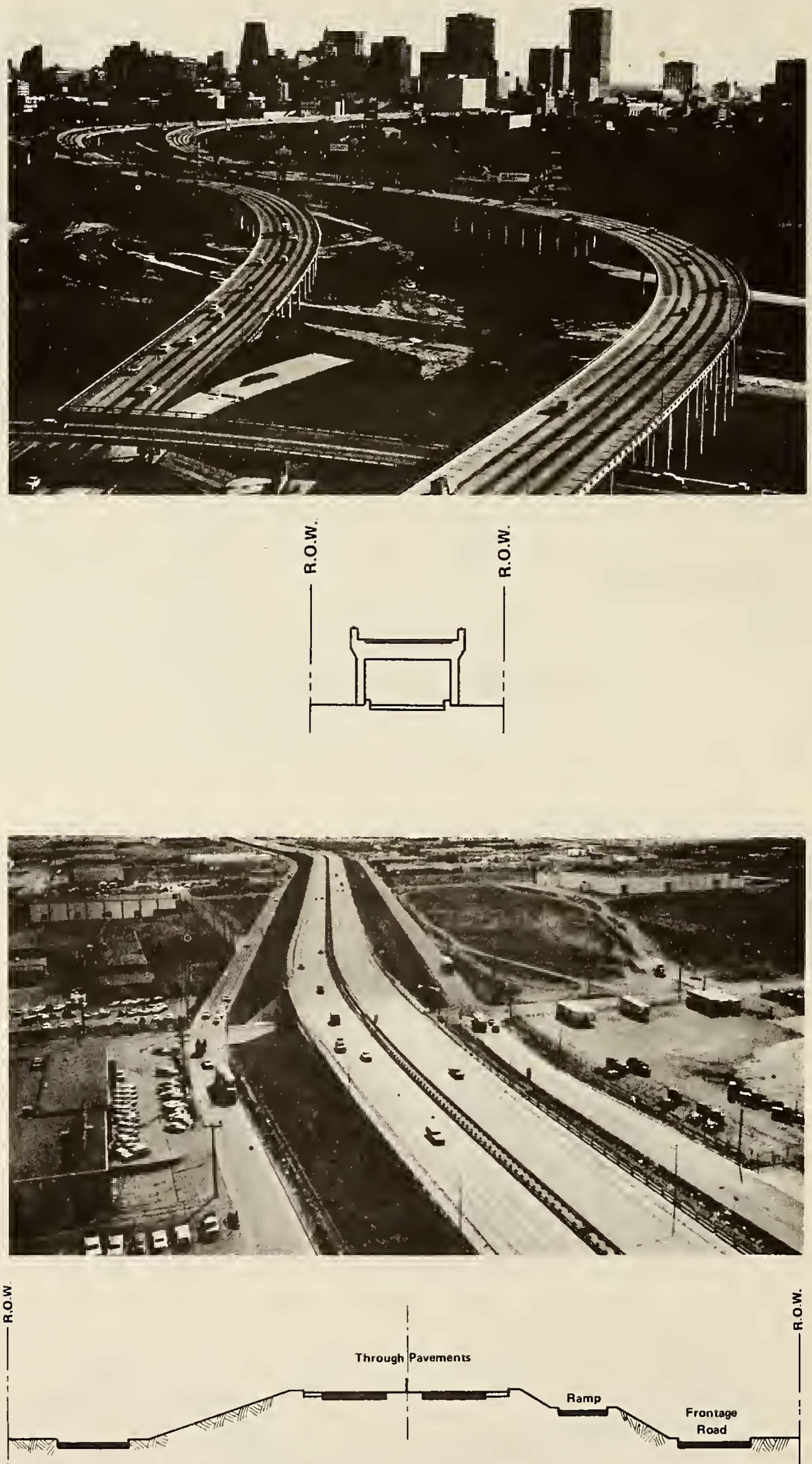

Figure 4. Typical elevated roadway on structure (above) and embankment (below) (16).

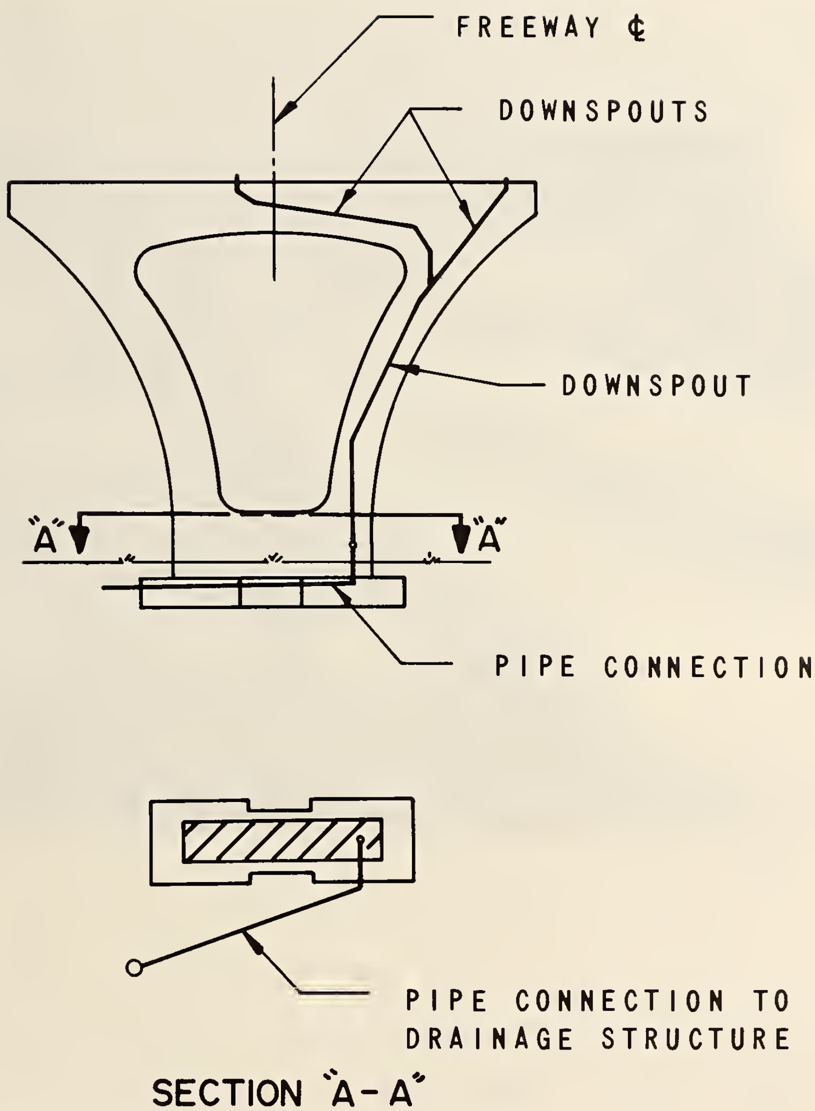

Figure 5. Typical structure downspout design.

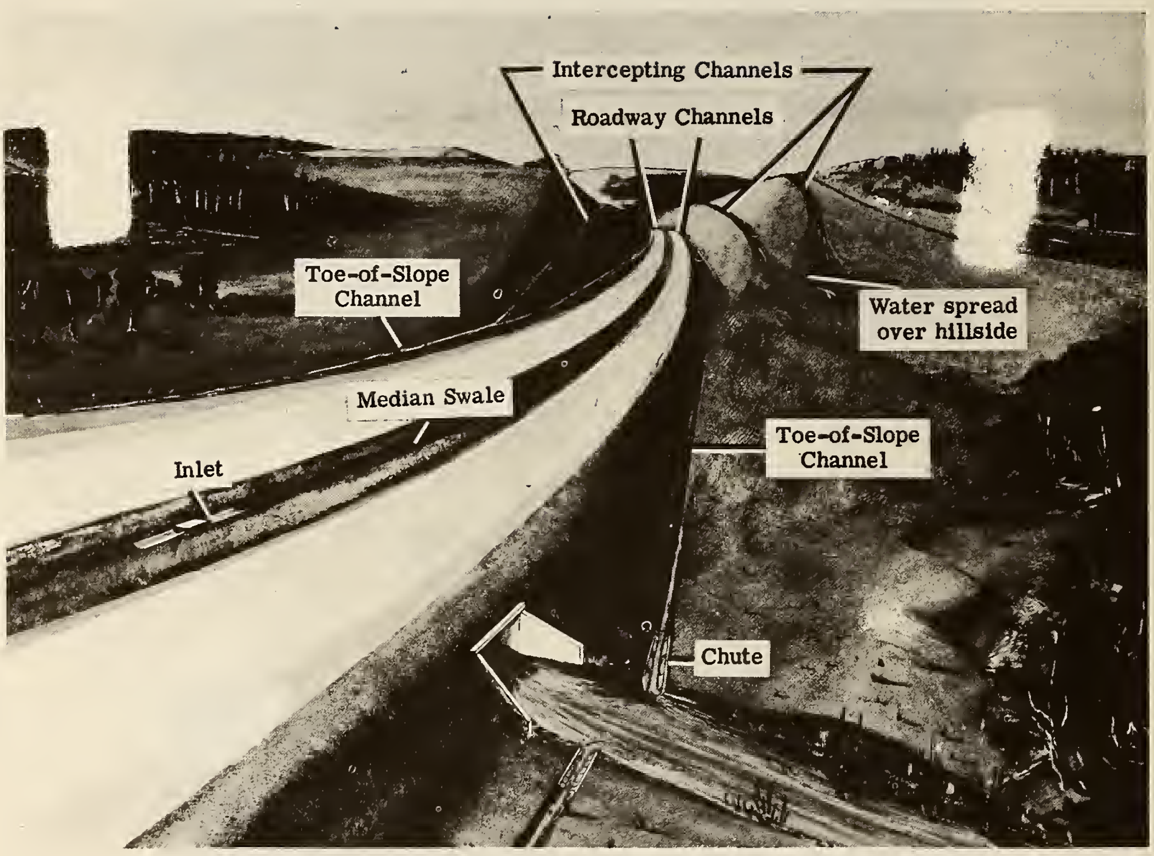

Figure 6. Typical roadside drainage channels and structure (17).

potential, facilitates planting, and improves the appearance. In urban areas, paved gutters may be provided at the outer edges of the pavement which drain into inlets and storm sewers.

Pavement Surfaces

The type of pavement for highways is determined by a number of factors, the most important of which is the volume and composition of the anticipated traffic (16, 17). Two types of pavements, rigid and flexible are used in freeway design:

Rigid Pavement - The rigid type pavements, such as concrete, are used for high volume areas and generally have good riding and nonskid qualities during all weather. Because of its stiff qualities, the surface retains its shape and ability to drain under normal use. The smoothness of the surface offers little frictional resistance to the flow of surface water.

Flexible Pavement - The flexible pavements, such as bituminous, are used especially in areas of unstable subbase. When compared to a rigid pavement, the initial cost of an intermediate flexible pavement is somewhat less, the life of the pavement is less, and the maintenance cost higher. Because of the flexible qualities, constant or heavy use tends to change the pavement shape and its ability to drain as designed.

Elements of Design

Every element in the design of a roadway has a direct or indirect effect on the drainage of the facility. For example, roadway surfaces are normally crowned or sloped to speed drainage of surface water (19). A typical cross section slope on a straight aligned roadway is given in Table 2. The slope varies with the type of pavement surface, the more pervious surfaces having greater slopes.

Table 2. Typical pavement cross slopes.

Surface type	In./ft	Cm/m	Ft/ft (m/m)
Rigid	1/8 - 1/4	1.0 - 2.0	0.01 - 0.02
Flexible	3/16 - 3/8	1.5 - 3.0	0.015 - 0.03

On divided roadways, the choice is between crowning the pavement to drain in both directions or sloping the pavement to drain in one direction. In the northern climates, it is preferable to prevent snowmelt water from crossing the pavement and becoming a hazard by freezing. Thus, a crowned section is desirable. This type of section requires drainage structures on both sides of the pavement.

Roadway Cross Sections - Two basic freeway sections are used in design. The oldest section most commonly found in urban areas, uses curb along the outside travel lanes (Figure 7). This configuration utilizes edge-of-the-road drainage with inlets located along the curb, and spacing based upon roadway geometrics and gutter flow characteristics. Inadequate inlet capacity or poor inlet location may result in flooding of the travel way which creates a hazard to traffic. Another inadequacy which may occur with this type of drainage is partial or complete clogging of the drainage structures by water-borne debris and trash if it is not properly maintained.

The latest trend in design is to eliminate the curb sections to improve safety (15) (Figure 7). The elimination of the curb and the creation of flush shoulders adjacent to the roadway alters drainage characteristics. Runoff from this design configuration flows over the shoulders to side ditches which are provided along the roadway to supplement the natural drainage channels. The design of these side ditches, which are located a minimum of 30 ft (9 m) from the travel way, is critical to improve safety, appearance, and prevent erosion. Generally, the side slopes adjacent to the ditches are as flat as possible for safety considerations and still consistent with the drainage requirements. The side ditches provide open channels for the removal of surface water from within the right-of-way, and in certain circumstances, from non-highway areas adjacent to the right-of-way.

Water flow in the ditches is generally parallel to the roadway centerline. The grades approximate those of the highway except where a steep grade may cause erosion. Ditches must be hydraulically capable of handling the anticipated flow of surface water in such a way that the roadway is not endangered or the safety of the motorist threatened.

Highway shoulders vary from 2 to 10 ft (0.6 - 3 m) in width and are either paved or unpaved. Shoulder pavement has a bearing on the cross slope to be used. The shoulders are normally sloped away from the roadway to improve drainage. In the case of a gravel or earth shoulder, a portion of the runoff enters the soil and becomes part of the ground water supply. Typical shoulder cross slopes for various pavement surfaces are shown in Table 3.

Paved shoulders tend to direct the flow of water into roadway drainage channels in cut sections, or down the grassed slopes on embankment sections. Mountable shoulder curbs with inlets, or a concrete surface drain flume can be used at the outer edge of the shoulder when the water cannot be discharged over the shoulder edge because of erosion or other reasons. On this type of section, paved gutters and inlets usually become necessary.

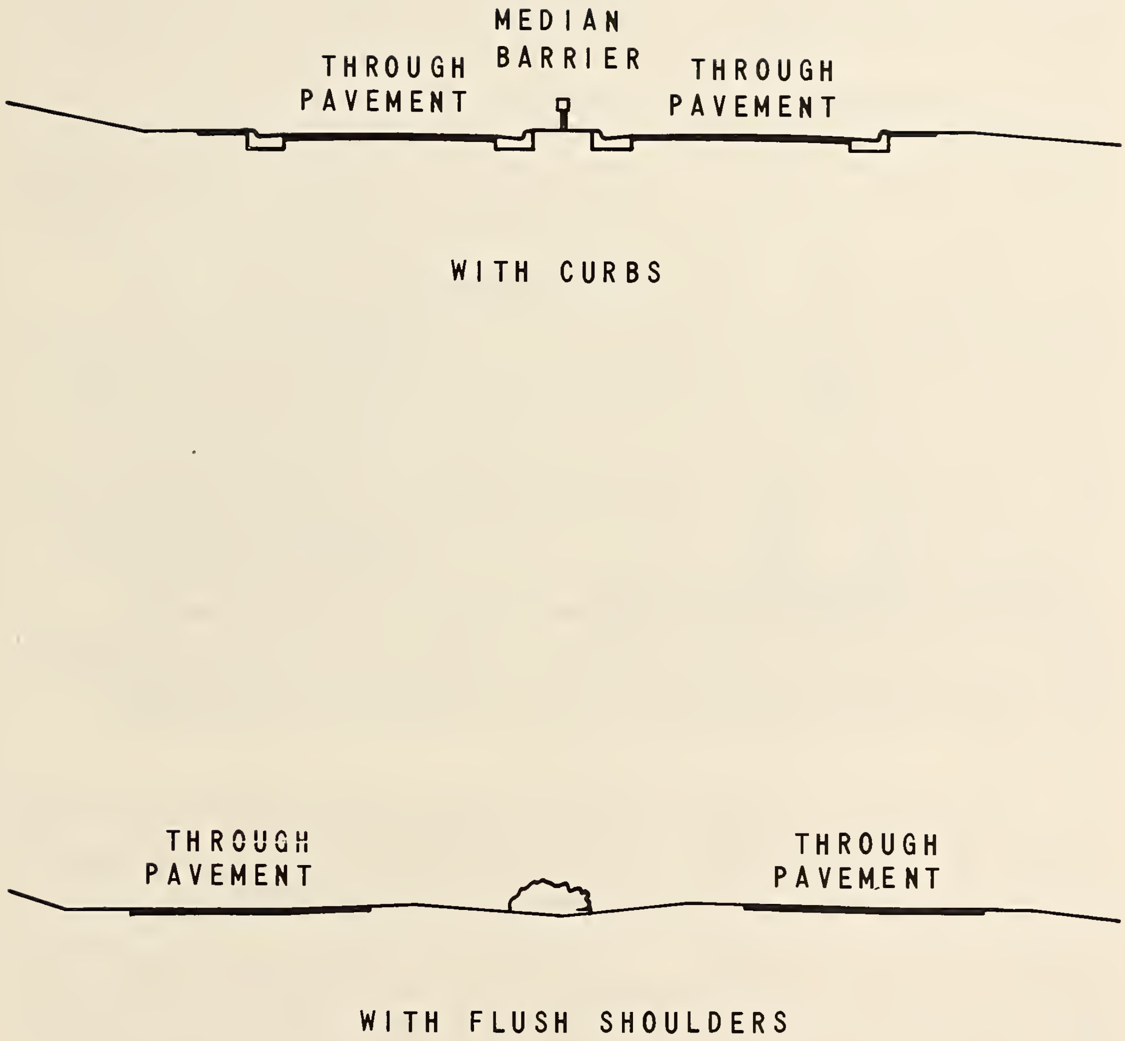

Figure 7. Typical roadway sections.

Table 3. Shoulder cross slopes (16, 17).

	Shoulder cross slope		
	In./ft	Cm/m	Ft/ft
No pavement edge curbs			
Bituminous	3/8 - 5/8	3 - 5	0.03 - 0.05
Gravel or crushed stone	1/2 - 3/4	4 - 6	0.04 - 0.06
Turf	1	8	0.08
With curbs at pavement edge			
Bituminous	1/4	2	0.02
Gravel or crushed stone	1/4 - 1/2	2 - 4	0.02 - 0.04
Turf	3/8 - 1/2	3 - 4	0.03 - 0.04

Median Drainage Design - The primary purpose of the median is to separate opposing lanes of traffic (16, 17) for safety reasons. Portions of the adjacent pavement and the shoulders where the medians have sufficient width to not require a barrier will be drained into the median. Medians with sufficient width are sloped to a center swale for drainage (Figure 7). Side slopes to the ditch should be 6:1 or flatter to provide adequate opportunity for safe recovery when vehicles leave the pavement (15). The swale is sloped longitudinally for drainage to inlets or transverse channels which discharge into storm drains or culverts. If the drainage is such that a paved channel is required, it should be made safe for vehicles out of control. In areas where the opposing roadways are at great distances apart, it is preferred to discharge the stormwater over the shoulder and allow it to run down a protected embankment, with as little concentration of flow as practicable.

Inlets are spaced in grassed medians to remove water before its volume or velocity exceeds allowable limits to prevent erosion and flooding of street surfaces. Some ponding of the water is allowable but water levels should not raise above the roadway surface.

In urban areas where freeway right-of-way is limited, median barriers (Figure 8) are used where the roadways are less than 60 ft (18 m) apart. Median and roadside barriers are also used where obstructions such as light standards or bridge appurtenances are found. When concrete median barriers are used, the entire median is usually paved to eliminate future maintenance. Frequent drainage structures and storm sewers are needed to intercept the stormwater and channel it to a local outfall.

Embankment Slope Design - Erosion prevention is one of the major factors in the design and construction of highways today (20). Erosion can be controlled to a degree by the geometric design, especially the

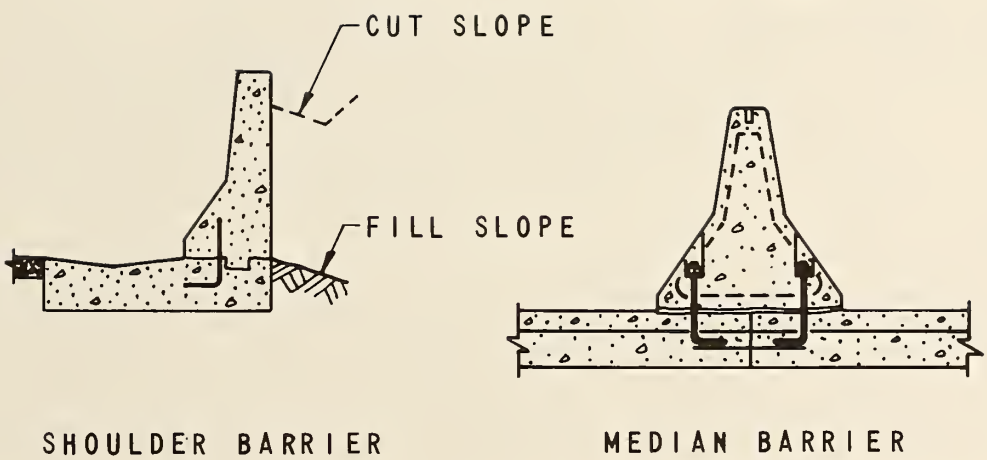

Figure 8. Typical concrete barriers.

cross section. The inslope design which extends from the edge of the shoulder to the ditch line is sloped at 6:1. The main purpose for the design is to provide a safety section flat and free of obstructions for at least 30 ft (9.1 m) from the edge of the pavement. This also slows the runoff, thus reducing the erosion potential.

The sideslopes which continue beyond the 30 ft (9.1 m) safety section may vary from flat to 3:1 or 4:1. The 3:1 or 4:1 sideslopes are easily stabilized by grass. In some cases, steeper grade slopes may be needed but such slopes increase the erosion potential. Often, in such cases, a combination of 3:1 slope and a retaining wall may be used. To prevent erosion in the toe of slope drainage channels, it will become necessary to pave the channel if the velocities of the runoff become excessive. Energy dissipation is also used to reduce runoff velocity.

Curbed Roadway Inlets - Freeways are developed to move vehicles at high speeds with complete safety. The vertical geometric design therefore, must be as flat as possible. For roadway sections with curbs, flat vertical slopes slow the flow of stormwater over the pavement increasing the spread of water and decreasing the velocity of flow along the curb. Therefore, inlet spacing becomes a critical design feature on roadways using curbed sections. In general, inlets are placed at all low points in the curb grade. On a continuous grade section, inlets must be spaced to limit the spread of the water onto the pavement. Inlets are also placed at curbed ramp noses to prevent the spread of water beyond the nose pavement area. The capacity of a curb opening inlet varies with the depth of water at the inlet entrance and the length of opening. The spacing of the inlets is equal to the length of pavement needed to generate the discharge corresponding to the allowable spread on the pavement. The flow bypassing each inlet must be included in the flow arriving at the next inlet.

In a low point sag vertical curve section or sump, inlets are placed upgrade from the low point and at the low point. The upgrade inlets are used to provide a safety factor if the low point inlet becomes clogged. These inlets also help to reduce the deposit of sediment on the pavement caused by the low velocities associated with flat grades which may occur near the low point. Pollutant washoff of the paved area for curbed roadways will be complete depending on the amount of rainfall and can be monitored at the outfall.

Flush Shoulder Inlets - In roadway sections without curbs, ditch or open channel drainage may be used. Where sufficient right-of-way is available, this type of drainage may be used in lieu of storm sewers to convey storm runoff. The water can also be ponded in the ditches, thereby reducing the inlets which may otherwise be required. Inlets to natural drainage channels or storm sewers may be placed in critical areas such as low points or along continuous grades where the flow velocities exceed such a level that erosion is possible. In such cases, it may be necessary to protect the ditch with pavement or flexible channel lining. Pollutant washoff of the paved area will flow into grass areas along the roadway and then to inlets. This will require more time and rainfall to monitor complete washoff since some of the pollutant material will become trapped in the grass.

Freeway Landscaping - Landscaping along freeways serves many purposes and is considered through all stages of planning and construction. A well planned landscape development which blends the new roadway design into the existing environment is not only pleasing to the motorist and surrounding community but also aids in controlling erosion and pollution. Flat slopes are effective for controlling erosion by supporting vegetation which reduces the flow rate of runoff. Shrubs or small trees may be used in selected areas to reduce noise pollution, headlight glare, and reduce the erosion potential on steeper slopes.

Erosion must be controlled during and after construction. Slopes are designed considering the soil and erosion limitations. The soil is protected with vegetation cover, mulch or erosion resistant material as soon as possible. During construction, sediment traps or temporary barriers are used. Where feasible, areas of existing vegetation may be left in place.

Landscape Planting - Proper plant selection and early planting during and after construction is the best way to control erosion. The establishment of vegetation can be achieved at any time of the year by using various seed mixtures and planting methods. Temporary or quick growing species can be planted with the perennial species as a means of establishing early plant growth. In areas where the weather prolongs the germination process, the area can be stabilized with mulch or chemical stabilizers.

The new plant growth along the freeways is watered periodically for at least two years or until the plants are established with a root system able to survive on natural moisture. Water can be provided by truck or, as in the case of newer freeways that include larger amounts of valuable plants, with a permanently installed sprinkler system. Arid areas of the United States also use sprinkler systems to maintain freeway landscaping.

Landscape Maintenance - Once plant growth has started, a continual maintenance program must be established. This involves regular inspections which include weed control, disease and insect control, and routine checking of physical damage to grass, ground cover, shrubs, vines and trees.

In recent years, highway agencies have been doing selective cutting, such as a reduction in the mowing of grass, mostly for economic reasons. This allows plants to grow for unspecified lengths of time in areas where there is no problem to the motorist. The selective method of landscaping and maintenance has further helped to control erosion and minimize runoff.

Roadway Maintenance - A continual roadway maintenance program is also necessary. The routine work includes such items as drainage structure and culvert cleaning and flushing. Storm sewers (especially structure downspouts) also require routine cleaning and flushing.

Other roadway maintenance includes road sweeping, cleaning of spills, repair or improvement of pavement, and lane marking. Snow removal and application of salt and sand is routine in cold climate locations.

Estimation of Stormwater Runoff Rates

There are several methods of estimating stormwater runoff rates. Kohler and Paulus (21), Chow (22) and Gray (23) present reviews of mathematical methods which are aimed at developing sewer design for the runoff from urban areas based on flood peaks from urban watersheds. Izzard (24) developed a method to simulate overland flow across plane surfaces. The Rational Method (17) was developed late in the 19th century and is still the most widely used model for determining peak runoff.

The Rational Method is one of two methods recommended by FHWA (14, 18) for estimating stormwater runoff rates. For drainage areas greater than about 200 acres (81 ha) in size, they recommended using the methods developed by Potter (25). The Rational Method is used by more than 90 percent of the engineering agencies in the United States (18).

The Rational Method converts rainfall intensity for the design frequency storm to runoff by the formula $Q = CiA$

Where Q = peak rate of runoff, in cubic feet per second (m^3/min)

C = Weighted runoff coefficient (average of the coefficients) assigned to the different types of contributing areas)

i = Average rainfall intensity, in inches (cm) per hour, for the selected frequency and for duration equal to the time of concentration.

A = Drainage area in acres (ha) tributary to the point under design.

This formula is not dimensionally correct, however, a one inch (2.54 cm) depth of rainfall applied at a uniform rate in one hour to an area of one acre (0.4 ha) will produce 1.008 cubic foot per second (0.03 m^3/sec) of runoff if there are no losses (18). This makes the numerical value of Q nearly equal to the product of i and A. The coefficient C accounts for the losses.

The Rational Method is based on the thesis that if a uniform rainfall of intensity (i) were falling in an impervious area of size A, the maximum rate of runoff at the outlet to the drainage area would be reached when all portions of the drainage area were contributing; the runoff rate would then become constant (18).

Many refinements have been suggested in the application of the Rational Method. The suggested refinements in the method probably improve the runoff estimate, but the additional data requirements and the increased work involved for refinements do not appear warranted in the design of drainage channels and inlets (14,18).

The runoff coefficient values vary from 0.80 to 0.95 for concrete or asphalt to 0.10 to 0.70 for grassed areas (26). Tables are available to use for exact values and if several different values of C are used, a weighted C value should be computed. Typical runoff coefficients for various land uses and soil types are shown in Table 4. Soil types are divided into two groups; sandy soils, loess (consists of clay and silt particles) (27) and clay, shallow soils.

The rainfall intensity (i) is usually obtained from the National Oceanic and Atmospheric Administration, U.S. Department of Commerce intensity-frequency charts which contain curves for 2, 5, 10, 25, 50 and 100 year storms (or return periods). To use the intensity charts, it is necessary to compute the time required for runoff from the most remote point (point from which the time of flow is greatest) of the drainage area to arrive at the drainage structure. This is called the time of concentration. BPR Hydraulic Design Series No. 4 (18) contains a chart to compute the time of concentration.

In general, freeway drainage design uses return periods from 10 to 100 years. Frequency values are used that will insure against flooding of the highway and adjacent areas. The American Association of State Highway and Transportation Officials recommends the following (16, 17): For inlets and connections in nondepressed freeways - 10 years; in depressed freeways - 50 years; and for storm sewers - 50 to 100 years. Typical intensities using this criteria in Milwaukee, Wisconsin would be approximately 8.1 in. (20.6 cm) per hour, for a 50 year storm of 5 minutes duration and 6.4 in. (16.3 cm) per hour for a 10 year storm.

Table 4. Runoff coefficients (26).

(Range of values for use in Rational formula)

Soil group	Sandy soils, loess			Clay, shallow soils		
Slope range	0-2%	2-6%	6%+	0-2%	2-6%	6%+
Land Use						
Industrial	0.68 0.85	0.68 0.85	0.69 0.86	0.69 0.86	0.69 0.86	0.70 0.87
Commercial	0.71 0.88	0.71 0.88	0.72 0.89	0.72 0.89	0.72 0.89	0.72 0.90
Dense residential	0.33 0.58	0.39 0.61	0.44 0.64	0.38 0.60	0.44 0.63	0.51 0.69
Suburban, with yards	0.22 0.33	0.27 0.39	0.30 0.44	0.30 0.40	0.34 0.44	0.43 0.54
Agricultural & woods	0.08 0.18	0.13 0.21	0.16 0.28	0.14 0.24	0.19 0.29	0.26 0.41
Row crops	0.08 0.22	0.16 0.30	0.22 0.38	0.19 0.34	0.28 0.41	0.38 0.56
Open space, lawns, parks, meadows	0.05 0.14	0.10 0.19	0.14 0.24	0.12 0.21	0.17 0.26	0.24 0.35
Median strips - turf	0.19 0.24	0.20 0.26	0.24 0.30	0.20 0.27	0.25 0.32	0.30 0.40
Side slopes - turf			0.25 0.32			0.30 0.38
Freeways & expressways in general	0.57 0.71	0.59 0.72	0.60 0.74	0.59 0.73	0.61 0.75	0.63 0.78
Pavement: asphalt			0.70 to 0.95			
concrete			0.80 to 0.95			
brick			0.70 to 0.80			
Gravel roads & shoulders			0.40 to 0.60			

SECTION IV
URBAN RUNOFF QUALITY DATA

A great deal of research concerning runoff from a variety of land use activities has been conducted. These studies have primarily been carried out on urban lands which drain either to storm sewers or drainage ditches. Although there is a difference in quality between urban stormwater runoff and highway drainage, the sources, factors affecting the runoff, and the reported data are similar. Because of the extensive literature on urban stormwater runoff, the following discussion is applicable, at least in part, to highway runoff studies.

From the time rainwater falls on an urban area until it is ultimately discharged to a receiving body of water, it encounters and conveys contaminants from many different sources. Rainwater, itself, has been found to become contaminated as it falls through the atmosphere. In a 1966 study, the suspended solids and COD loadings in lb/acre/day (kg/ha/day) from rainwater were found to be higher than sanitary sewage during some periods of precipitation (28). During the flow of water over different urban surfaces and through drainage channels, various contaminants are transported, transformed and eventually deposited. The pollutional effect from these contaminants is measured by the presence of pathogenic bacteria, oxygen demanding materials, toxic substances, nutrients, inorganic salts, and particulates.

Earlier runoff studies were usually concerned with only the quality characteristics without regard to the hydraulic data. The research was generally limited to collection and analysis of water samples within the storm sewers or at the outfall. In many cases, flow measurements were not taken and pollutant concentrations (mg/l) could not be converted to pollutant loadings (lb, kgs) and the time significance of such pollutional impacts to receiving waters could not be determined. One of the earliest (1950) and most often cited studies in this country was conducted by Palmer in downtown Detroit, Michigan (29). The BOD value of storm water samples at street catch basins ranged between 96 and 234 mg/l and coliform counts up to 930,000 MPN/100 ml were recorded. About the same time, results of several similar studies in other countries were published. A

1956 study on stormwater runoff in Moscow, USSR, reported BOD's as high as 285 mg/l and suspended solids up to 3,500 mg/l (30). Leningrad, USSR has BOD's of 36 mg/l and suspended solids of 14,541 mg/l in stormwater runoff from cobblestone streets. In a 1950 study on runoff from streets and parks during summer weather in Stockholm, Sweden BOD's were as high as 80 mg/l, COD's reaching 3,100 mg/l and coliform counts up to 200,000/100 ml (31). This Swedish study concluded that significant shock loadings may be exerted by such runoff pollutants on the receiving stream.

In 1956, stormwater runoff samples taken from a 611 acre (247 ha) site in Oxhey, England, contained BOD's up to 100 mg/l and suspended solids up to 2,045 mg/l (32). This study also showed that the BOD tended to increase with the length of the antecedent dry weather period. The first flushes of runoff were found to be significant in terms of pollution potential, only when the runoff occurred after a long antecedent dry period. An analysis of stormwater runoff from residential, park, school, and sports-ground areas in a 1961 Pretoria, South Africa study, showed BOD's of 30 mg/l, COD's of 29 mg/l, total organic nitrogen of 5.4 mg/l and coliform counts of 240,000/100 ml (33).

To fill the gap left by the earlier studies which were concerned primarily with the water quality characteristics, a more comprehensive study on the quality of stormwater runoff was conducted by Weibel et.al., in Cincinnati, Ohio in 1964 (34). This study was conducted on a 27 acre (11 ha) residential and light commercial urban area of Cincinnati having a population density of nine persons/acre. The study area was served by a separate storm sewer system. Thirty-seven percent of the area was impermeable. The runoff coefficient and time of concentration were estimated to be about 0.37 and 15 minutes, respectively. Stormwater runoff samples collected from this area showed average pollutant concentrations of 227 mg/l suspended solids, 57 mg/l volatile suspended solids, 111 mg/l COD, 17 mg/l BOD, 1.0 mg/l inorganic nitrogen, 1.1 mg/l total hydrolyzable phosphate, and 1.7 μg/l organic chlorine. The average coliform density in 90 percent of the samples was 2,900/100 ml, but individual samples varied widely. The BOD and COD values were generally comparable to typical secondary sewage treatment effluent, while suspended solids concentrations paralleled raw sewage values. The nutrient concentrations significantly exceeded the indicated threshold levels for algal blooms (0.3 mg/l inorganic nitrogen and 0.03 mg/l inorganic phosphate). If the measured organic chlorine concentration of 1.7 μg/l were derived entirely from chlorinated-hydrocarbon type insecticides, it would amount to about 3.9 μg/l of pesticide as a group average (25 compounds). The coliform density significantly exceeded the criterion of 1,000/100 ml commonly used as a maximum for swimming waters in the United States. The constituent loads, calculated on an annual basis as a percentage of sanitary sewage production are shown in Table 5.

Table 5. Comparison of urban stormwater runoff loads in Cincinnati, Ohio with domestic sewage loads (34).

Constituents	Domestic sewage		Urban runoff loads as percentage of sewage loads,%	
	lb/day/acre[a]	lb/yr/acre[b]	During runoff	Annually
Suspended solids	1.5	540	2400	160
COD	2.6	960	520	33
BOD_5	1.5	540	110	7
Total PO_4	0.19	68	70	5
Total N	0.23	82	200	14

[a]To obtain metric units of kg/day/ha, multiply by 1.12.

[b]To obtain metric units of kg/yr/ha, multiply kg/day/ha by 365.

Bryan (35) reported in 1971 on a stormwater sampling program in Durham, North Carolina. The 1067 acre (431 ha) drainage basin studied comprised a mixture of land uses with a population density of nine persons per acre. The runoff quality data from this site was compared to the data reported by others in various studies mentioned earlier. The water quality data, as shown in Table 6, were in general agreement with the findings of the other studies. It was concluded that the total (annual) contribution of BOD by stormwater was about equal to the sanitary wastewater effluent from secondary treatment at 85-95 percent efficiency. The total solids contribution of the urban runoff was substantially larger than the expected average raw sewage contribution from the same basin. The COD load was estimated to be higher than the raw sewage load expected from an average residential urban area. The contribution of phosphates was found to be nominal in comparison with domestic wastewater. The yield of lead presumed to originate from internal combustion engines operating on and near the basin was determined to be 1.9 lb/acre/yr (2.13 kg/ha/yr) - representing measured lead concentrations in the range of 0.1 to 1.9 mg/l and flow weighted lead concentration of 0.67 mg/l. The concentration of total pesticides (Dieldrin, p, p'DDE, o,p'DDT, p,p'DDD and p,p'DDT) weighted for flow significance was estimated to be 1.2 µg/l.

Results of a 1970 urban runoff study conducted in Tulsa, Oklahoma are shown in Table 7.

Table 6. Comparison of stormwater quality from an urban drainage basin in Durham, NC (35) with results reported by others.

Location		BOD, mg/l	COD, mg/l	Total solids, mg/l	Volatile solids, mg/l	Suspended solids, mg/l	Total phosphate, mg/l	Fecal coliforms, per 100 ml	Chloride as NaCl, mg/l
Durham, N.C. (urban stormwater)	Mean	14.5	179	2730	298	--	0.58	30,000	12.6
	Range	2->232	40-600	274-13,800	20-1110	--	0.15-2.50	7000-86,000	3.0-390
Cincinnati, Ohio (urban stormwater)	Mean	17	111	--	--	227	1.1	--	19.8
	Range	1- 173	20-610	--	--	5-1200	<0.02-7.3	500-76,000	5.0-705
Cincinnati, Ohio (rainfall)	Mean	--	16	--	--	13	0.24	--	--
Coshocton, Ohio (rural stormwater)	Mean	7	79	--	--	313	1.7	--	--
	Range	0.5-23	30-159	--	--	5-2074	0.25-3.3	<2-56,000	--
Coshocton, Ohio (rainfall)	Mean	--	9.0	--	--	11.7	0.08	--	--
Detroit, Mich. (1949) (urban stormwater)	Range	96-234	--	310-914	--	--	--	--	--
Seattle, Wash. (urban stormwater)		10	--	--	--	--	4.3 max	16,100 max	--
Stockholm, Sweden (urban stormwater)	Median	17	188	300	90	--	--	4,000	--
	Maximum	80	3100	3000	580	--	--	200,000	--
Pretoria, S. Africa (residential/park/school)		30	29	--	--	--	--	240,000	--
(business and flat area)		34	28	--	--	--	--	230,000	--
Oxney, England	Maximum	100	--	--	--	2045	--	--	--
Leningrad, USSR		36	--	--	--	14,541	--	--	--
Moscow, USSR	Range	18-285	--	--	--	1000-3500	--	--	--

Table 7. Estimated daily load of pollutants entering the Tulsa, Oklahoma area receiving streams (36).

Parameter	Average daily pollution load, lb: Stormwater[a]	Sewage treatment plant effluents	Total	Relative contribution of stormwater, %
BOD	4,455	19,370	23,825	20
COD	30,803	67,180	97,983	31
Suspended solids	107,200	18,400	125,600	85
Organic Kjeldahl-N	355	760	1,115	31
Sol. PO_4-P	469	11,020	11,489	4

[a]The reported values for stormwater were calculated from the total load on a yearly basis averaged over each day of the year.

Note: To obtain metric units of kg, multiply by 0.454.

These results again demonstrate that urban runoff contributes a significant pollution load on receiving waters. The major sources of pollutants were considered to be the material deposited on impervious surfaces and the material eroded or picked up from drainage channels. The largest amounts of pollutants were generated during the season of greatest runoff (36). The data presented in Table 8 from another 1970 study conducted in Tulsa, Oklahoma (37) shows seasonal variation in pollutant loadings and supports the fact that the season of greatest runoff generates the largest pollutant loadings. The land surface characteristics which showed the highest correlation with stormwater pollutant concentrations (36) were:

1. Environmental conditions.
2. Geomorphic characteristics that affect drainage.
3. The degree of land development.

BOD_5 concentrations decreased with increasing runoff flow, but the total amount of BOD increased with the increasing flow.

In residential areas, the runoff pollution per unit area increased with population density and/or the number of developed parcels. In commercial and industrial areas, runoff pollution per unit area actually decreased with the number of persons visiting the area. This

Table 8. Summary of average stormwater pollutant loadings by season (loadings per street area) average 1967 - 1968 (37).

Parameter	Season	Pounds/acre/season[a] Min.	Avg.	Max.	Precipitation inches[b]	No. of events over 0.1 inch
BOD_5	Fall	5.1	9.7	17.1	7.0	10
	Winter	2.2	6.4	15.1	5.2	9
	Spring	10.2	22.2	44.5	13.2	19
	Summer	3.0	15.4	40.1	8.7	14
COD	Fall	22.1	44.5	127.6	7.0	10
	Winter	24.3	55.3	101.7	5.2	9
	Spring	88.9	155.8	280.6	13.2	19
	Summer	33.7	93.3	123.4	8.7	14
Organic nitrogen	Fall	1.02	2.03	4.68	7.0	10
	Winter	0.92	1.80	3.10	5.2	9
	Spring	3.10	5.11	12.28	13.2	19
	Summer	1.35	2.57	3.91	8.7	14
PO_4	Fall	1.33	3.37	4.59	7.0	10
	Winter	1.06	2.56	5.96	5.2	9
	Spring	1.99	5.03	15.06	13.2	19
	Summer	1.95	3.03	4.89	8.7	14
Total solids	Fall	445	1051	4001	7.0	10
	Winter	439	766	1150	5.2	9
	Spring	1117	2400	3965	13.2	19
	Summer	536	1188	2000	8.7	14

[a]To convert lb/acre to kg/ha multiply by 1.12.

[b]To convert inches to centimeters multiply by 2.54.

was explained by suggesting that, as the number of daily visitors increased, the degree and frequency of maintenance operations increased.

The American Public Works Association (APWA) conducted a study (1969) in the Chicago metropolitan area to determine the factors in the urban environment which contribute to the pollution of stormwater runoff (38). Street refuse-litter coming in contact with rainfall or snow thaws was found to create a water pollution potential, in direct proportion to the amount and nature of these urban environment wastes. Street litter accumulation rates for various land uses were calculated. These rates ranged from 0.5 to 8 lb/day/100 ft (0.8 - 12 kg/day/100 m) of curb length. Average loadings varied from 2.4 lb/day/100 ft (3.6 kg/day/100 m) of curb in single family residential areas to 4.7 lb/day/100 ft (7.1 kg/day/100 m) of curb in commercial areas. In general, this study found that urban runoff amounts to 1% by volume of the raw sewage for that particular area. However, the pollutional impact of these urban runoff discharges occurs only during rainfall or snow thaw. It was estimated that during these periods, the shock pollution load on the receiving waters would be 160% of the raw sewage BOD and 800% of the secondary treatment effluent BOD load.

Studies on stormwater qualities differ widely in pattern and background conditions. For example, the above mentioned APWA study showed the significance of the shock loading impact of urban runoff while another study (1971) conducted in Atlanta, Georgia showed that stormwater drainage constitutes 65% of the annual pollution load in terms of BOD contributed by the metropolitan area (39). This study found that a storm of two week frequency caused anaerobic conditions to exist in the receiving water 19 miles (30.6 km) below the study area.

In 1972, Kothanadaraman (40) summarized the data obtained from several other studies pertaining to the quality of combined sewer overflows and separate storm sewer overflows. The summarized data with the corresponding references is shown in Table 9. The author also presents brief descriptions of the drainage areas contributing to these widely varying qualities of the combined sewer overflows for the Ann Arbor and Detroit, Michigan areas is shown in Table 10 (44). For storm sewers the suspended solids values were 2,080 mg/l, compared to 274 mg/l for combined sewers.

However, the BOD in the storm sewers was only 28 mg/l, compared to 153 mg/l in the combined sewers. Also, the storm sewer values for ammonia nitrogen, organic nitrogen and total PO_4 were much less than that of the combined sewer, but the nitrate nitrogen was 3 times higher in the separate than in the combined.

Table 9. Summary of characteristics of combined and separate storm sewer discharges (40).

Location	pH	Suspended solids, mg/l	Volatile suspended solids, mg/l	COD, mg/l	BOD, mg/l	Nitrogen, mg/l	Total phosphorus, mg/l	Total coliform, MPN/100 ml
			Combined Sewer Discharges					
Baltimore, MD(41)	--	396-2509	26.3-57.9[b]	--	--	--	--	--
Bucyrus, OH (42)	--	306-675	96-390	--	31-177	0.5-16.9[c]	2.0-15.1	--
Cincinnati, OH (43)[(a)]	--	450-1460	30-280	96-2000	130-7000	--	--	--
Detroit, MI (44)	--	250	50-200	--	50	--	-- --	$4.3x10^6$
Detroit, MI (44)	--	260-510	92-310	--	92-410	6.0-9.9	10.1-34.0	--
Philadelphia, PA (45)	--	1-15	--	--	36-148	--	--	$1x10^7-1x10^8$
Portland, OR (46)	4.5-6.0	70-325	57-166	138-324	57-155	3.7-7.0	--	--
Sacramento, CA (47)	6.5-7.5	30-500	30-311	59-431	75-328	--	--	$1.2x10^5-8.6x10^6$
Washington, D.C.(48)	5.6-6.7	135-2000	10-1280	80-1760	10-470	1.0-16.5	0.8-9.4	$4.2x10^5-5.8x10^6$
			Separate Storm Sewer Discharges					
Ann Arbor, MI (44)	--	470-4400	31-530	--	24-49	--	1.2-9.4	--
Cincinnati, OH (34)	5.3-8.7	5-1200	1-290	20-610	1-173	0.3-7.5	0.0-7.3	$2.9x10^3-4.6x10^5$
Detroit, MI (28)	--	310-914	136-370	--	96-234	--	--	$25x10^3-9.3x10^5$
Sacramento, CA (47)	--	19-211	3-211	21-176	24-283	--	--	$5.5x10^3-1.0x10^6$
Washington, D.C.(48)	5.6-6.7	130-11,280	0-880	29-1514	3-90	0.5-6.5	0.2-4.5	$1.2x10^3-3.2x10^6$

a. Data from May 12, 1970 storm
b. Volatile suspended solids in percent
c. Nitrogen as NO_3

Table 10. Comparison of annual mean values for Detroit (combined) and Ann Arbor (separate) sewer overflows (44).

Analyses	Combined	Separate
Phenols, μg/l	312	16
BOD, mg/l	153	18
NH_3N, mg/l	12.6	1.0
Organic N, mg/l	3.7	1.0
NO_3N, mg/l	0.5	1.5
Total PO_4, mg/l	14.6	5.0
Soluble PO_4, mg/l	7.7	0.8
SS, mg/l	274	2,080
VSS, mg/l	117	218
Sett. solids, mg/l	238	1,590
Vol. sett. solids, mg/l	97	140

In a 1966 study which compared combined and storm sewer discharges in the Detroit, Michigan area (49), it was shown that the ratio of suspended solids in storm sewers to combined sewers was 9.5 to 1.0 (1280 mg/l to 150 mg/l), organic nitrogen two to one (0.74 - 0.37 mg/l), ammonia nitrogen 0.15 to one (0.5 to 3.3 mg/l) and total phosphates 1.0 to 3.2 (2.9 to 9.0 mg/l).

The seasonal differences in bacterial counts for total coliform (TC), fecal coliform (FC), and fecal streptotococcus (FS) were compared for sites in Cincinnati and Coshocton, Ohio (50). Three urban locations, (a wooded hillside next to a city park, a suburban business district storm drain, city street gutters), and one rural location were chosen as sample sites. Total coliform peak densities occurred for urban locations in autumn, as did fecal coliform and fecal streptococcus densities in street gutters and the business district. However, fecal coliform and fecal streptococcus reached their peak during the summer for the wooded hillside runoff. The rural site exhibited peak densities in the summer and winter seasons. Total results from this 1968 study are shown in Table 11.

In a 1974 study in Durham, North Carolina (51), the organic concentration in urban land runoff was found to be approximately one-half that for typical raw municipal wastewater where the concentrations of

Table 11. Runoff characteristics for urban and rural locations (50).

Site	Date	Total samples	Season	Total coliform, ml	Fecal coliform, ml	Fecal streptococcus, ml
Wooded hillside	2/62-12/64	278	Spring	2,400	190	940
			Summer	79,000	1,900	27,000
			Autumn	180,000	430	13,500
			Winter	260	20	950
Street gutters	1/62-1/64	177	Spring	1,400	230	3,100
			Summer	90,000	6,400	150,000
			Autumn	290,000	47,000	140,000
			Winter	1,600	50	2,200
Business district	4/62-7/66	294	Spring	22,000	2,500	13,000
			Summer	172,000	13,000	51,000
			Autumn	190,000	40,000	56,000
			Winter	46,000	4,300	28,000
Rural	1/63-8/64	94	Spring	4,400	55	3,600
			Summer	29,000	2,700	58,000
			Autumn	18,000	210	2,100
			Winter	58,000	9,000	790,000

metals and solids were two to fifty times greater in urban runoff. Table 12 shows the average concentration for all storms sampled and the computed annual urban runoff pollutant yield during the 1972 calendar year from each acre drained.

Table 12. Average pollutant concentration in stormwater runoff and annual pollutant yield in Durham, NC - 1972 (51).

Pollutant	Mean concentration, mg/l	Pollutant yield, lb/acre[b]
COD	170	938
TOC	42	187
Total solids	1440	7700
Volatile solids	205	1458
Total suspended solids	1223	6691
Volatile suspended solids	122	797
Kjeldahl nitrogen as "N"	0.96	6.1
Total phosphorus as "P"	0.82	4.7
Fecal coliform	230[a]	-
Aluminum	16	64
Calcium	4.8	52
Cobalt	0.16	1.9
Chromium	0.23	1.6
Copper	0.15	1.6
Iron	12	102
Lead	0.46	2.9
Magnesium	10	71
Manganese	0.67	4.9
Nickel	0.15	1.2
Zinc	0.36	2
Alkålinity	56	-

[a]Number per ml.

[b]To convert lb/acre to kgms/ha multiply by 1.12.

Two EPA studies discussing microorganisms in urban stormwater were published in 1976 (52) and 1977 (53). Data in Table 13 shows that coliform counts ranged from the order of magnitude found in domestic wastewater to a few orders less. The data shows the variation between the minimum and maximum values to be orders of magnitude apart at each stormwater runoff site. These variations are probably attributable to differences in flow volume and intensity, quantity of rainfall, number of dry days preceding the storm event, and portion of the flow drainage sampled (first flush, mid-storm, tail)(52). High coliform counts can come from sources such as soils and animals, other than humans. A FC/FS ratio of 4.0 or greater is believed to be indicative of human feces and a ratio of 1.0 or less is believed to be indicative of animal feces.

For the stormwater runoff sites in Table 13, it was reported (52) that FC/TC ratios for the majority of samples from each site were between 0.1 and 1.0. At the Stoney Run, Glen Avenue, Bush Street and Northwood sites, more than 90% of the samples had FC/FS ratios less than 4.0, and more than 80% of the samples had FC/FS ratios of 1.0 or less. At the Howard Park site only 18% of the samples had FC/FS ratios of 4.0 or greater, while 41% of the samples had FC/FS ratios of 1.0 or less. At the Jones Falls site only 12% of the samples collected had FC/FS ratios of 4.0 or greater, while 76% of the samples had FC/FS ratios of 1.0 or less.

Table 14 shows that samples collected at these sites (53) also contained different viruses, and that animal virus was detected in the majority of samples.

Although the data from the above studies, and others (54 through 60), vary considerably for each location and for each storm, it is apparent that urban runoff is a significant source of pollution, both in terms of shock load and fraction of the total water pollution entering a body of water, serving an urban drainage area. In general, these waters all have a high turbidity, contain high solids concentrations, have a high COD, have a very low BOD/COD ratio, are significant in nutrient levels, and contain high bacterial counts. Depending upon the exact geographic location, the runoff may be very high in other specific pollutant concentrations (oil, chlorides, lead, etc). These findings make it apparent that stormwater runoff must be reduced or treated prior to discharge if water quality of the receiving waters is to be protected. In order to devise cost-effective systems for handling this problem, information is required concerning the quality and quantity of urban runoff. Also, information on the temporal distributions of these parameters in relation to rainfall intensity during runoff periods should be known.

The Change in Stormwater Runoff Quality with Time

The change in stormwater runoff quality with time is due to:

Table 13. Comparison of levels of microorganisms in stormwater runoff and raw sewerage Baltimore metropolitan area (52).

Station	Number of samples	Total coliform, MPN/100ml	Fecal coliform, MPN/100ml	Fecal streptococci, MPN/100ml	Pseudomonas aeruginosa, MPN/100ml	Staph. aureus, MPN/100ml	Salmonella sp., MPN/10 liters	FC/TC	FC/FS
Stoney run	17								
min.		$5.4x10^3$	$1.3x10^3$	$5.3x10^2$	$2.3x10^2$	$<3.0x10^0$	$2.9x10^0$	<.07	.06
max.		$1.6x10^6$	$5.4x10^4$	$3.0x10^5$	$2.4x10^5$	$7.9x10^1$	$>1.3x10^3$	1.0	92.5
Glen ave.	17								
min.		$7.9x10^3$	$1.4x10^3$	$9.2x10^3$	$1.3x10^2$	$<3.0x10^0$	$1.7x10^0$	.06	.02
max.		$1.6x10^6$	$2.3x10^5$	$2.8x10^6$	$2.6x10^5$	$1.5x10^2$	$>1.1x10^4$	1.0	5.9
Howard park	17								
min.		$4.9x10^3$	$2.3x10^3$	$<1.0x10^3$	$7.9x10^2$	$6.0x10^0$	$3.9x10^0$	.02	.05
max.		$2.8x10^7$	$2.9x10^6$	$1.4x10^6$	$5.4x10^4$	$9.2x10^2$	$>1.3x10^3$	1.0	32.7
Jones falls	17								
min.		$3.3x10^4$	$5.0x10^3$	$2.6x10^3$	$9.4x10^2$	$4.0x10^0$	1.7x10	.01	.06
max.		$>2.4x10^6$	$>1.6x10^6$	$8.0x10^5$	$1.6x10^6$	$1.1x10^1$	2.7x10	1.0	4.4
Bush street	17								
min.		$7.9x10^3$	$1.7x10^3$-	$2.5x10^3$	$1.1x10^2$	$<3.0x10^0$	$<1.7x10^0$	.05	.02
max.		$2.4x10^6$	$2.4x10^6$	$1.9x10^6$	$7.5x10^4$	$4.6x10^3$	$2.7x10^3$	1.0	12.9
Northwood	14								
min.		$1.3x10^3$	$8.0x10^1$	$1.7x10^3$	$1.7x10^1$	$<3.0x10^0$	$<1.7x10^0$	.01	.01
max.		$1.7x10^5$	$7.9x10^4$	$3.0x10^5$	$9.2x10^3$	$4.6x10^2$	$4.3x10^1$	.65	4.6
Raw sewage	34								
min.		$1.3x10^6$	$3.3x10^5$	$2.0x10^4$	$3.3x10^3$	$4.3x10^1$	$2.6x10^1$	.03	1.2
max.		$1.6x10^9$	$9.2x10^8$	$3.3x10^6$	$5.4x10^7$	$4.6x10^3$	$2.7x10^4$	1.0	25.0

Table 14. Occurrence of selected viruses in stormwater samples - Baltimore Metropolitan Area (52).

Sample site	Occurrence, %				
	Animal virus	Poliovirus	Coxsackie virus B	Echovirus	Other
Stoney run	100	73	73	27	9[a]
Glen Avenue	92	75	42	17	8[b]
Howard Park	100	42	58	8	8[b]
Jones Falls storm drain	83	67	50	33	8[a]
Bush Street	75	25	42	25	8[c]
Northwood	83	42	50	33	8[a]

[a]Not identified.

[b]Reovirus.

[c]Adenovirus.

1. The availability of contaminants from the drainage area, i.e., more contaminants are available for washoff at the beginning of a storm than at the end.

2. The variation in runoff intensity, volume and the drainage area characteristics.

Pollutographs, like those in Figure 9, can be constructed from flow and quality data. The pollutographs for BOD and suspended solids show pollutant concentration (mg/l) and pollutant loadings (lb/day) on the vertical axis varying with time (hrs) on the horizontal axis. The solid lines on the pollutographs represent pollutant concentration. Knowing the concentration and flow over a specified time interval the pollutant load (lb) can be calculated. These pollutant loading rates can then be expressed over any appropriate time interval, for example lb/day (the solid lines on the pollutographs). The hydrograph on the bottom of the page shows the variation of flow (MGD) on the vertical axis with time (hrs) on the horizontal axis.

Total pounds of contaminants discharged to receiving water could be calculated by summing up the area under the curve. However, the time significance of pollution impacts to the receiving water are of greater concern. The pollutographs in Figure 9 show the "first-flush" phenomenon. These pollutographs and data from other studies (62) suggest the majority of pollutants (lb) are often discharged into receiving waters during the beginning of the storm while the pollutant load decreases with time. However, when rainfall events occur close together and few dry days are available for pollutant accumulation, the surface may be clean enough that the "first-flush" effect may not be observed (63).

The "first-flush" phenomenon has led to a number of investigations (64-68) in which pollutant concentrations, runoff volume and rainfall intensity were measured as a function of time in the hopes that these studies would demonstrate that at least some of the runoff need not be treated. Figure 10 (64) shows this diagramatically. These studies indicate that runoff elements of any one drainage system can vary significantly from another and that each drainage system should be studied individually to determine which, if any, portions of the runoff may be discarded without treatment.

Studies concerned with the change in stormwater runoff quality with time have been conducted in Toronto, Canada; Ann Arbor, Michigan; Cincinnati, Ohio; Detroit, Michigan; New Orleans, Louisiana; Washington, DC; Racine, Wisconsin; and Lubbock, Texas.

In a 1967 Toronto study (69) four different storm sewers were sampled during four different storms for a period of approximately

To convert lb to kg, multiply by 0.454.
To convert MGD to m3/day, multiply by 3,785.

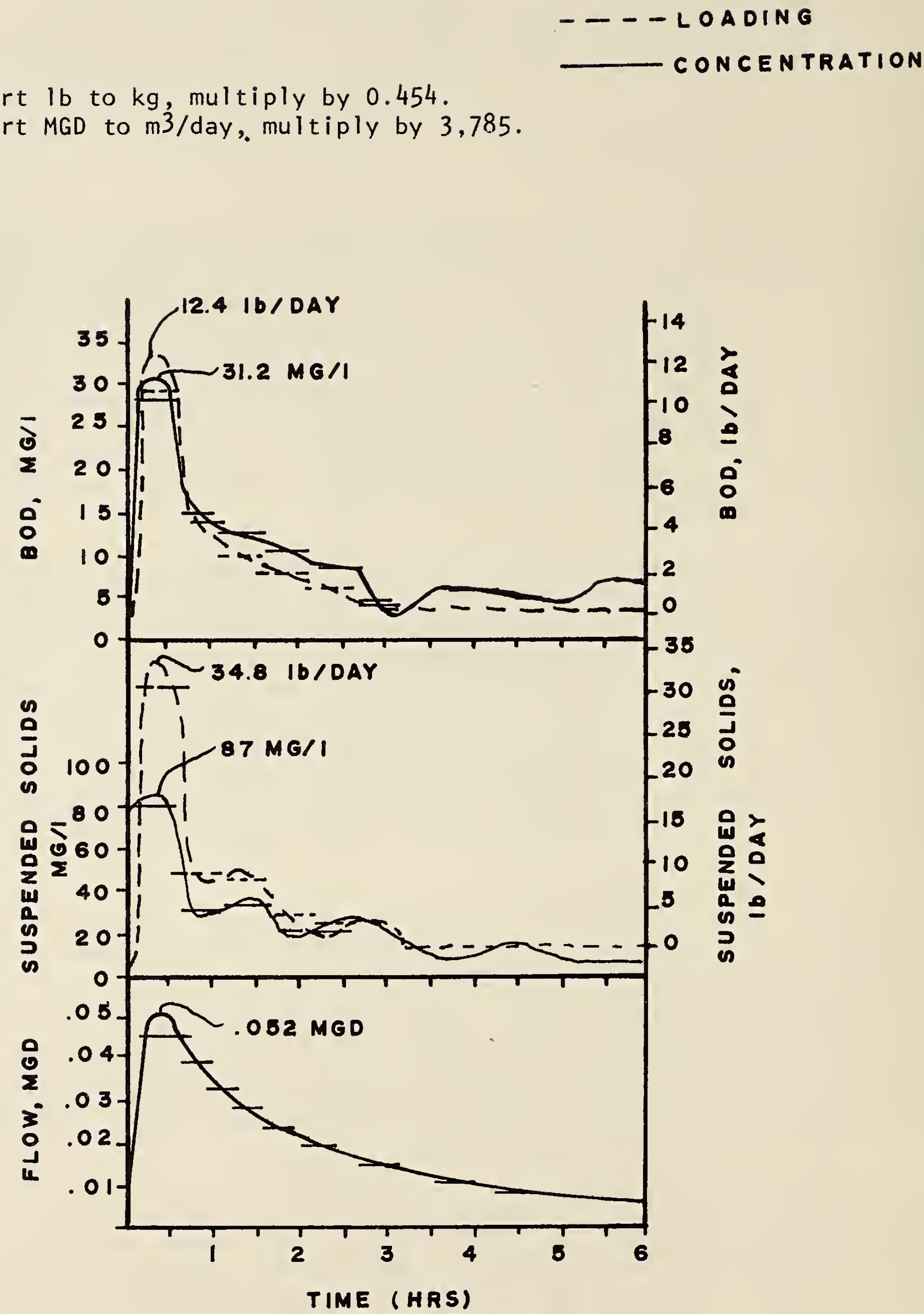

Figure 9. Variation in flow, BOD, and suspended solids during the storm of October 27, 1972 from an urban watershed near West Lafayette, Indiana (61).

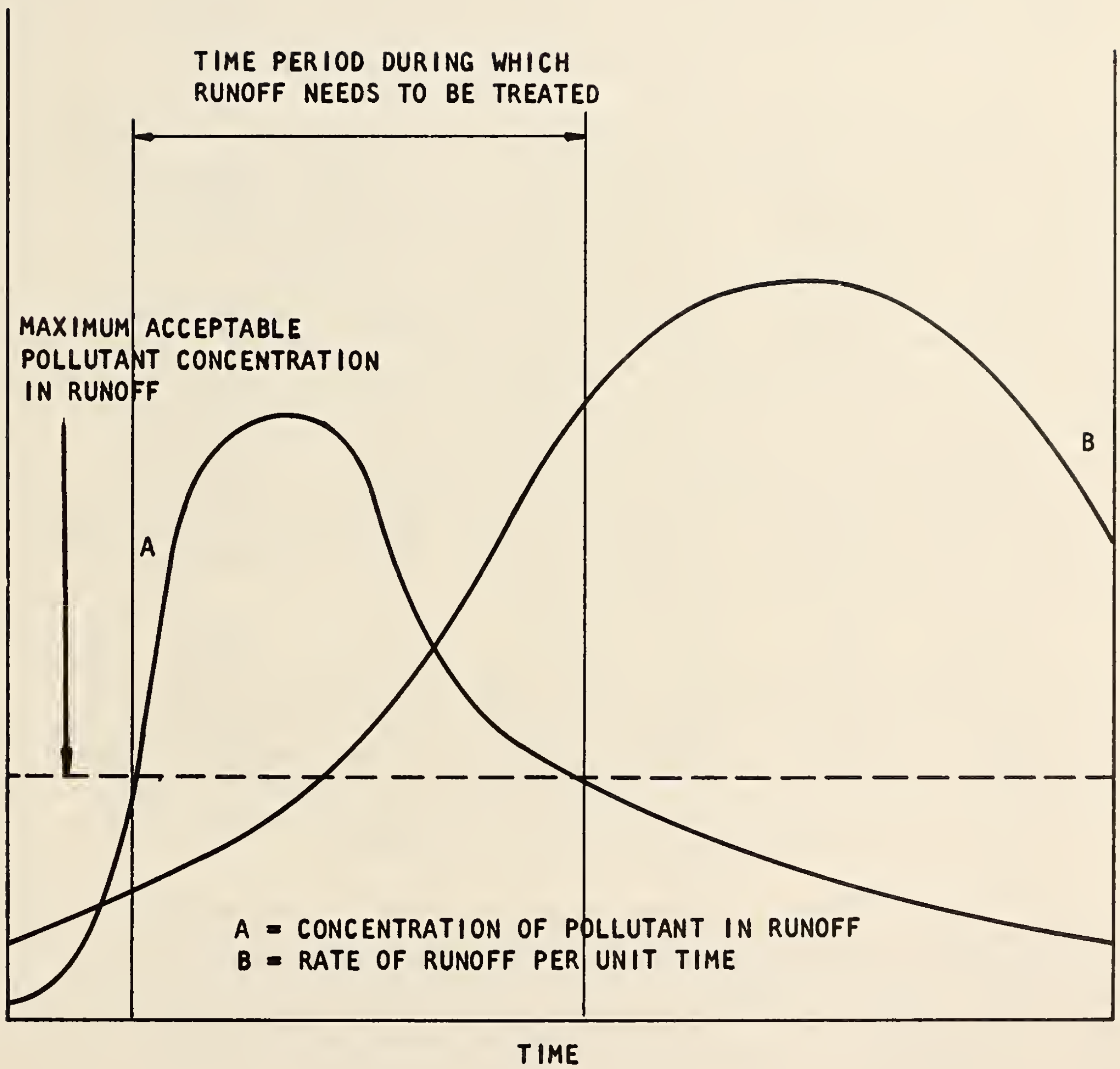

Figure 10. Diagrammatic quality and quantity hydrographs for stormwater runoff (64).

50 minutes after runoff began. Though there were no definite patterns for BOD, it seemed that the heaviest concentrations appeared in the first 10 to 15 minutes. This was followed by a sharp drop and then leveling off in concentration for the remainder of the time. The suspended solids values were very erratic with two of the sewers experiencing a possible first flush, similar to the BOD occurrence, while the other two sewers acted exactly opposite one another with one sewer continuing to increase in suspended solids and the other continuing to decrease. For total coliform, a first flush was evident in three of the sewers. One sewer, however, continued to increase in total coliform, as it did in the case of suspended solids, perhaps due to the fact that the rainfall was intermittent at this site and not continuous as it was at the other sites.

In a 1968 study at Ann Arbor, Michigan the average annual discharge concentrations at various time increments for storms were reported (44). The time increments were from 0-4, 4-9, 9-19, 19-34, and greater than 34 minutes. Reported values are shown in Table 15. The phenol concentration remained fairly constant with a slight decrease at the end, as did the soluble PO_4. Total PO_4 increased and decreased throughout the entire runoff period, finally ending up with almost the same concentration as in the beginning. Both BOD and volatile settleable solids decreased constantly as time went on. Ammonia nitrogen was fairly constant with a slight dip from 9-19 minutes. Nitrate nitrogen increased steadily, while organic nitrogen decreased steadily until after 34 minutes, at which time it increased. Suspended solids had a sharp decrease from 4-9 minutes then increased to a peak from 19-34 minutes before returning to the original values. Volatile suspended solids exhibited the same format as did the settleable solids.

In Cincinnati, the mean concentration of constituents in urban land runoff were also reported (33). The time increments were 0-15, 15-30, 30-60, 60-120 and greater than 120 minutes. Reported values are shown in Table 16. Suspended solids, volatile suspended solids, COD, BOD, total nitrogen, and soluble PO_4 all exhibited the same characteristic of reaching their maximum values from 0-15 minutes, and then steadily decreasing until past 120 minutes.

A single catch basin was studied during a storm in Detroit (28). Although total coliforms showed generally decreasing values as time went on, the maximum value was reported 36 minutes into the storm. Total and volatile solids both varied considerably during the runoff with a general decrease appearing after about an hour. The BOD, as in the previous studies, showed a constant decrease after the original first flush.

Time after discharge start (min),
Detroit, Michigan (28).

Constituent	Units	0-4	4-9	9-19	19-34	>34
Phenols	mg/l	18	20	15	13	16
BOD	mg/l	47	32	25	34	18
NH_3 N	mg/l	0.9	1.0	0.75	1.0	1.1
Organic N	mg/l	1.3	1.1	1.0	0.7	1.1
SS	mg/l	2390	1130	1810	2820	2270
VSS	mg/l	301	207	177	237	178
Sett.S.	mg/l	2000	1040	1420	2210	1280
V.Sett.S.	mg/l	239	156	104	110	8.0
Sol. PO_4	mg/l	0.9	1.0	1.0	0.6	0.7
Total PO_4	mg/l	5.5	4.0	4.2	6.2	5.2
NO_3 N	mg/l	1.2	1.1	1.4	1.7	1.7
Total N	mg/l	3.4	3.2	3.15	3.4	3.9

Time after discharge (min),
Cincinnati, Ohio (34).

Constituent	Units	0-15	15-30	30-60	60-120	>120
SS	mg/l	390	280	190	200	160
VSS	mg/l	98	69	47	58	38
COD	mg/l	170	130	110	97	72
BOD	mg/l	28	26	23	20	12
Total N	mg/l	3.6	3.4	3.1	2.7	2.3
Sol. PO_4	mg/l	0.99	0.86	0.92	0.83	0.63

Because the quality of New Orlean's swimming beach on Lake Pontchartrain was deteriorating due to stormwater runoff, facilities have been constructed to treat this runoff (70). As a result, five years of data on the quality of stormwater runoff and its estimated change with time have been gathered (Table 17).

Fecal coliform rapidly increased for about an hour and a half into the runoff, and then decreased.

The studies conducted in the urban locations of Washington, DC (48), Lubbock, Texas (71), and Racine, Wisconsin (72), all found high concentrations of suspended solids and oxygen demanding materials in the early phase of the runoff. This was then followed by a gradual decrease in contaminant concentration as the runoff continued. In Racine it was found that over 90 percent of the suspended solids and total organic carbon was discharged during the first 30 minutes of runoff.

Quality and Quantity Prediction Models

Despite the lack of uniformity in characteristics of individual urban storm sewer systems, a number of predictive models have been developed (36, 40, 43, 45, 13, 73) which, given the necessary data

Table 17. Estimated storm runoff quality versus time in minutes for New Orleans (70).

Constituent	Units	0	18	36	54	72	90	108	120	144
Total solids	mg/l	208	275	310	300	285	275	265	255	250
Suspended solids	mg/l	50	137	150	135	120	115	110	105	105
Dissolved solids	mg/l	147	162	210	210	210	205	200	200	195
Volatile solids	mg/l	26	29	33	34	33	32	32	31	30
COD	mg/l	340	375	540	670	660	640	630	630	630
BOD	mg/l	29	31	33	29	29	29	29	29	29
Fecal coliform	10^4/100 ml	0.4	5	6	7	8	8.5	8	7	6

inputs, enable computerized predictions of the quantity and quality of urban storm runoff and combined sewer overflow. Generally, these predictive models are only as reliable as the field data used to calibrate them. Some studies have tried to compensate for the lack of published flow rate and total runoff volume data by extrapolating the available data to lb/acre/yr (kg/ha/yr) values. However, most of the predictive modeling work has been done by using average annual precipitation records and estimated coefficients of runoff. The various methods of runoff determination are presently being studied by EPA. The ultimate goal of these studies is the development of an effective method for determining runoff volumes and flow rates for design purposes, and to aid in decision making for the abatement of water pollution. Also, the Federal Highway Administration (FHWA) is developing an urban freeway storm drainage model and manual (74). The model will include methods for estimating flows.

The Stormwater Management Model (SWMM) has been developed for EPA (75-78) for determining runoff and overflow rate volumes and qualities, for both separate and combined sewer areas. In addition, the model has the capacity to determine the effect of installing storage or treatment systems for the discharges, and the effect of these discharges on the quality of the receiving body of water. This model has been tested against actual rainfall and runoff data in the cities of San Francisco, Cincinnati, Washington, DC and Philadelphia (76).

The model uses real data from a given area in its computations. Some of these data are rainfall hyetographs and rainfall history, climatic conditions, land use, population density, income level, overland drainage hydraulic conditions, sewerage system details, street cleaning procedures, infiltration rates, diurnal variation of dry weather flow and quality, quality and quantity of water in catch basins, and their density, and industrial wastewater flow rates and quality. Where real data are not available the model will substitute discrete default values or will allow the user to substitute his own estimated values.

A unique application of the model is its ability to estimate stormwater runoff quality in areas that are presently served by combined sewerage systems. This is done by omitting the subroutine (FILTH) which inputs dry weather flow and quality to the sewerage system. THe resultant flows are only those associated with stormwater runoff. The effectiveness of a proposed storm sewer system may also be tested by entering the hypothetical system into the program for a given area and then tracing the routed hydrographs through the storm sewers for rainfalls of various intensities and duration.

Models for predicting runoff and quality characteristics have also been developed by the Office of Water Resources Research at Texas Tech University (71), and the University of Cincinnati (79). A recent report has evaluated eighteen stormwater runoff models (80).

Table 18 contains a reproduction from that report showing the capabilities of the existing models. These predictive models represent an important initial step toward successful handling of the urban stormwater problem and may have application for predicting the quality and quantity of highway runoff.

Condon (81) in a review of urban runoff studies drew the following conclusions:

1. The factors which most affect the runoff load are land use and degree of imperviousness.

2. On an annual total load basis, the urban runoff pollution as expressed by BOD_5 is approximately equal to the secondary plant effluent, (80% removal) from the same.

3. In urban runoff the largest portion of the pollutants result from:

    a. Wash-out of materials deposited on the impervious areas.

    b. The erosion of developing areas and drainage channels caused by the high volumes of runoff generated on the impervious portions.

4. The amount of pollution produced per unit area increases with population density and/or the number of developed parcels. The SS and BOD concentration of the runoff increase with runoff rates because the time rate of flow increases at a greater rate than the pollutant concentrations decrease. This is most usually the case up to and including the five year storm.

Table 18. Comparison of major model categories (80).

	Catchment Hydrology							Sewer Hydraulics								Wastewater Quality							Miscellaneous						
	Multiple Catchment Inflows	Dry-Weather Flow	Input of Several Hyetographs	Snowmelt	Runoff from Impervious Areas	Runoff from Pervious Areas	Water Balance Between Storms	Flow Routing In Sewers	Upstream & Down-stream Flow Control	Surcharging and Pressure Flow	Diversions	Pumping Stations	Storage	Prints Stage	Prints Velocities	Dry Weather Quality	Stormwater Quality	Quality Routing	Sedimentation and Scour	Quality Reactions	Wastewater Treatment	Quality Balance Between Storms	Receiving Water Flow Simulation	Receiving Water Quality Simulation	Continuous Simulation	Can Choose Time Interval	Design Computations	Real-Time Control	Computer Program Available
Battelle Northwest	x	x	x		x	x		x		x	x		x	x	x	x	x	x			x					x	x	x	x
British Road Research lab	x	x	x		x			x															x			x			x
Chicago Flow Simulation	x	x	x	x	x	x	x	x					x	x									x		x	x			x
Chicago Hydro-graph Method	x	x	x		x	x	x	x															x			x	x		x
Colorado State University	x	x			x			x	x					x	x														x
Corps of Engineers				x	x	x	x				x		x				x			x		x			x				x
Dorsch Consult	x	x	x		x	x		x	x	x	x		x	x	x								x			x			
Environmental Protection Agency	x	x	x		x	x		x	x	x	x	x	x			x	x	x	x	x	x		x	x		x	x		x
Hydrocomp	x	x	x	x	x	x	x	x	x		x		x	x	x	x	x	x		x		x	x	x	x	x		x	
Massachusetts Institute of Technology	x	x	x		x	x		x						x	x								x			x	x		
Minneapolis - St. Paul	x	x	x		x	x		x			x															x		x	x
Seattle	x	x	x		x	x	x	x	x	x	x	x	x	x												x		x	x
Sogreah	x	x			x	x		x	x	x	x	x	x	x	x			x					x	x		x			
University of Cincinnati	x				x	x		x															x			x			x
University of Illinois	x	x		x	x	x		x	x		x	x	x	x	x											x	x		x
University of Massachusetts	x	x			x		x	x	x					x	x										x				x
Water Resources Engineers	x	x	x		x	x		x	x	x	x	x	x	x	x	x	x	x		x			x	x		x			
Wilsey and Ham	x				x	x		x																		x	x		

SECTION V
HIGHWAY RELATED STUDIES

Throughout the literature cited in previous sections, references were made to the contributions of urban roadway and vehicular traffic runoff pollution. The indications that these roadways have a significant effect upon urban runoff since they constitute a high percentage of the total area in cities and the impervious roadway surfaces have high runoff coefficients are not surprising. In 1959 and 1960, runoff samples from street gutters were analyzed in Seattle, Washington to determine the effect of stormwater runoff on the aquatic vegetation of Green Lake (82). Two different locations for sampling were chosen, one on arterial streets and the other on residential streets. For 35 storms analyzed, some of the median values were as follows:

Total organic nitrogen - 0.40 mg/l
Total phosphorus - 0.155 mg/l
Oil - 59 mg/l, and
Fecal coliforms - 1600 MPN/100 ml

The study recommended discontinuing most urban drainage to the lake.

The American Public Works Association (38) conducted one of the first in-depth studies relating to the contributions of runoff from streets and roadways to water pollution. Although several sources of runoff pollution were recognized in this 1969 study (street litter, catch basins, roof discharges, and various chemicals), only street litter was extensively sampled and analyzed for its water pollution potential.

A significant aspect of the study was the calculation of street litter accumulation rates for various land uses. This rate was found to range from 0.5 to 8 lb/day/100 ft (0.8 to 12.0 kg/day/100 m) of curb. Average loadings varied from 2.4 lb/day/100 ft (3.6 kg/day/100 m) of curb in single-family residential areas to 4.7 lb/day/100 ft (7.1 kg/day/100 m) of curb in commercial areas.

Although the amount and composition of street litter was found to vary with the day of the week, the season, land use, population density, and pedestrian and vehicular traffic, the main component, by weight, was nearly always the dust and dirt fraction (less than 1/8 in. (0.32 cm) in size). The total dust and dirt fraction varies from 45 to 83 percent of the total litter. The accumulation rate varied from 0.4 to 5.2 lb/day/100 ft (0.6 to 7.8 kg/day/100 m) of curb. The accumulation rate by land use was as follows:

Single-family residential, 0.7 lb/day/100 ft (1.1 kg/day/100 m) of curb.

Multiple-family residential, 2.3 lb/day/100 ft (3.5 kg/day/100 m) of curb.

Commercial area, 3.3 lb/day/100 ft (5.0 kg/day/100 m) of curb.

The water pollution potential of the street litter was based on an analysis of the soluble portion of the dust and dirt fraction. Approximately 3 percent of the total dust and dirt was soluble. The weighted average amounts of the constituent pollution parameters were as follows:

5 mg/g BOD_5
40 mg/g COD
0.48 mg/g total nitrogen
Less than 0.05 mg/g phosphates
More than 10 million/g total bacteria counts
More than 1 million/g coliforms

The most determinable measure of pollution potential was deemed to be the BOD_5 of the dust and dirt. Thus, based on a BOD_5 of 5 mg/g, or 0.8 lb/day/street mile (0.226 kg/day/street km), the average pollution potential of street litter was estimated at one percent of raw sewage and five percent of secondary treatment effluent BOD_5.

Another in-depth study (1974) of significance was conducted by URS Research Company on the water pollution aspects of street surface contaminants (12). In this study, samples of street litter were collected from eight representative cities across the United States. Sample collection methods included the use of a rain simulator to ensure the collection of very fine, soluble materials that are often not picked up by sweeping techniques. Calculations based on a hypothetical but typical U.S. city* indicated that the pollution load of street surface runoff during the first hour of a moderate-to-heavy storm (with rainfall intensity at least 0.5 in./hr or 1.27 cm/hr) would be many orders of magnitude greater than the same city's untreated sanitary sewage during the same time period. A comparison of the pollution load of runoff with raw sewage and secondary treatment effluent is shown in Table 19.

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*The hypothetical city has the following characteristics:

Population	100,000
Total land area	14,000 acres (5,666 ha)
Land use distribution:	
Residential-	75%
Commercial-	5%
Industrial-	20%
Streets (tributary to receiving waters)	400 curb miles (640 curb km)
Sanitary sewage	12 mgd (0.53 m^3/s)

Table 19. Calculated quantities of pollutants which would enter receiving waters in a hypothetical city (12).

	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)	$4,000 \times 10^{10}$	$460,000 \times 10^{10}$	4.6×10^{10}

Note: Since the above calculations were based only on a 5-day accumulation of street litter, the above discharge of contaminated runoff could conceivably occur many times in a year. The one hour storm represents a moderate to heavy storm with rainfall intensity at least 0.5 in./hr.

To obtain metric units of kg/hr, multiply by 0.454.

The loading rates (lb/curb mile or kg/curb km) of street surface contaminants between cleanings for eight cities in the United States, expressed as weighted average values for all samples, were found to be as follows:

	lb/curb mile	kg/curb km
Total solids	1400	392
Volatile solids	100	28
BOD_5	13.5	3.78
COD	95	26.6
Phosphates	1.1	0.3
Nitrates	0.094	0.026
Kjeldahl nitrogen	2.2	0.61
Total coliform, no./curb mile or km	99×10^9	27.7×10^9
Fecal coliforms, no./curb mile or km	5.6×10^9	0.56×10^9

Substantial quantities of organic pesticides were found in most samples. The total amount for the cities tested was 0.0014 lb/curb mile (0.0004 kg/curb km). However, the amounts varied considerably from site to site. Both chlorinated hydrocarbons and polychlorinated biphenyl compounds (PCB) were found rather consistently. Significant amounts of heavy metals were also detected. Zinc and lead were the most prevalent measuring 0.65 and 0.57 lb/curb mile (0.182 and 0.159 kg/curb km), respectively. Copper loadings were calculated at 0.20 lb/curb mile (0.056 kg/curb km) while nickel, mercury and chromium loadings were 0.05, 0.73 and 0.11 lb/curb mile (0.014, 0.02 and 0.03 kg/curb km), respectively.

The quantity or loading rate of material at a given test site was found to be dependent on a number of factors, including surrounding land use, elapsed time since the last sweeping or rainfall, volume and character of local traffic, condition and type of street surface, season of the year, and public works practices. In general, industrial areas contained substantially heavier than average loadings, while commercial areas were considerably below the average. The total solids loads between cleanings in industrial areas averaged 2800 lb/curb mile (784 kg/curb km); commercial areas averaged 290 lb/curb mile (81.2 kg/curb km). Average loading rates for residential areas were 1200 lb/curb mile (336 kg/curb km), but loadings varied widely from site to site. There was a general tendency for newer, more affluent neighborhoods to be cleaner. The above discussed street surface contaminant loading rates were developed for average time periods of 2 to 10 days between successive street cleanings, either by rain or manual sweeping. Using weighted averages for all samples, the above pollutant loads in terms of lb/curb mile/day (kg/curb km/day) were generally reduced by a factor of 2 to 3. For example, the average rate of pollutant accumulation for the eight cities studied were:

	lb/curb mile/day	kg/curb kg/day
Total solids	730.0	204
BOD_5	4.5	1.26
COD	26.0	7.28
Total nutrients	1.0	0.28
Total heavy metals	1.3	0.36

Asphalt streets were found to have loadings 80 percent heavier than concrete streets. Streets considered in poor to fair pavement condition had loadings about 2.5 times greater than streets in good to excellent condition (12). A pattern in loading rates across a typical street was also revealed. Typically, 78 percent of the material was found within six inches (15.24 cm) of the curb and over 95 percent occurred within the first 40 inches (101.6 cm).

It was also determined that the rate at which rainfall washed loose particulate matter from street surfaces depends on three primary factors:

Rainfall intensity
Street surface characteristics
Particle size

A sizeable percentage of the pollution potential of street debris was found to be contained in the very fine silt-like fraction ($<43\mu$). Although this material accounted for only 5.9 percent, by weight, of the total solids on the street surface, it contained approximately one-fourth of the total oxygen demand and perhaps one-third to one-half of the algal nutrients. This material also accounted for more than half of the heavy metals and nearly three-fourths of the total pesticides. These concentrations of pollutants in the very fine material are of particular importance because conventional street sweeping operations are ineffective in removing this material.

Because of the consistent presence of heavy metals in amounts large enough to interfere with BOD_5 measurements, COD tests were considered to provide a better basis for estimating the oxygen demand potential of street surface contaminants.

In another extensive study (1975) pertaining to the evaluation of the "Contribution of Urban Roadway Usage to Water Pollution", Biospherics Inc. (5) reevaluated the data shown in Table 20, reported by APWA (38) for gutter sweeping studies in Chicago, in 1967. Statistical analyses of these data showed that the amounts of BOD and COD in dust and dirt samples, unaffected by rainfall, are directly proportional to traffic intensity, regardless of zoning, land use, street width and other factors (Table 21 and Figure 11). The dust and dirt was found by these analyses to contain a loading of 0.14 lb (0.063 kg) of BOD and 0.80 lb (0.36 kg) of COD per 1000 ft (304 m) of curb per 10,000 vehicles. As in the URS report (12), the Biopherics Study (5) showed that the bulk of pollutants is associated with very fine particles which are readily removed by light precipitation. The above studies show some unique characteristics of urban runoff different from sanitary sewage. For example, the COD/BOD ratio for urban runoff is generally much higher than for sanitary sewage. It can be indicated that the toxic material content (heavy metals, pesticides, PCB's, roadway de-icing chemicals, etc) may interfere with measured BOD results for urban runoff. Recent Biospherics' data (5) shows COD/BOD ratios in excess of 100 in some highway runoff samples. Also, high coliform counts were reported in highway dust and dirt in this study. Fecal coliform concentration ranged between 0 to 300,000 organisms per gram of dust and dirt, and fecal strep ranged between 0 to 103,500 organisms per gram of dust and dirt. These concentrations were converted to loading rates

Table 20. Variation of dust and dirt loading rates with traffic intensity[a] (38, 5).

Area	Zoning[e]	Traffic (vehicles/day x 10^{-4})	Dust & dirt Avg. BOD, mg/g	Dust & dirt Avg. COD mg/g	Dry weather samples[b] No.	Dry weather samples[b] (lb/day/100 ft)	Wet Weather Samples[c] No.	Wet Weather Samples[c] (lb/day/100 ft)	All samples[d] No.	All samples[d] (lb/day/100 ft)
1	Bus	0.80	5.05	26.7	25	2.73	13	2.11	38	2.53
2	Bus	2.04	4.03	24.8	29	7.00	16	4.72	45	6.19
4	Ind	1.11	2.95	23.0	29	3.60	17	8.76	46	5.37
5	Res.	0	1.72	18.3	5	0.14	12	0.46	17	0.36
6	Res.	0.10	9.10	53.1	7	0.59	11	0.62	18	0.61
7	Res.	0.07	2.18	50.7	5	2.70	11	2.12	16	2.30
8	Res.	0.20	2.81	29.5	0	--	6	0.67	6	0.67
9	Res.	0.59	4.77	61.3	5	0.60	13	1.90	18	1.54
10	Res.	0.59	2.90	32.6	7	0.70	13	1.44	20	1.18
14	Res.	0	6.32	45.6	1	1.98	8	2.62	9	2.55
15	Res.	1.41	2.82	24.6	0	--	7	2.80	7	2.80
17	Res.	0	9.43	72.8	1	0.06	7	0.42	8	0.37
18	Res.	1.73	1.94	32.1	1	0.44	8	2.00	9	1.82
19	Res.	0	2.82	31.8	1	7.16	8	10.53	9	10.16
20	Res.	0.16	3.22	34.6	0	--	9	2.90	9	2.90

a. All reported related data are included with the following exceptions: 1) data from areas 3 and 16 were excluded as no traffic estimates were reported, 2) data from areas 11 and 12 were not given in Reference, 38 , 3) APWA stated that data from area 13 may be regarded as nontypical.

b. No significant amounts of rainfall occurred during accumulation of the "Dry Weather Samples".

c. Precipitation was noted during accumulation of the "Wet Weather Samples".

d. All samples, wet and dry weather, are grouped together.

e. Bus: business; Ind: industrial; Res: residential

To obtain metric units of kg/day/m, multiply lb/day/100 ft by 0.015.

Table 21. Effect of traffic on BOD and COD in roadway dust and dirt[a] (38, 5).

$Y = A + BX$

Y = pounds of BOD or COD which accumulates each day per 1000 feet of curb

A = intercept of the curve on the "Y" axis, lb BOD or COD/1000 ft of curb/day

B = slope of the curve, lb BOD or COD/1000 ft of curb/10,000 vehicles

X = traffic intensity, ten thousands of vehicles per day

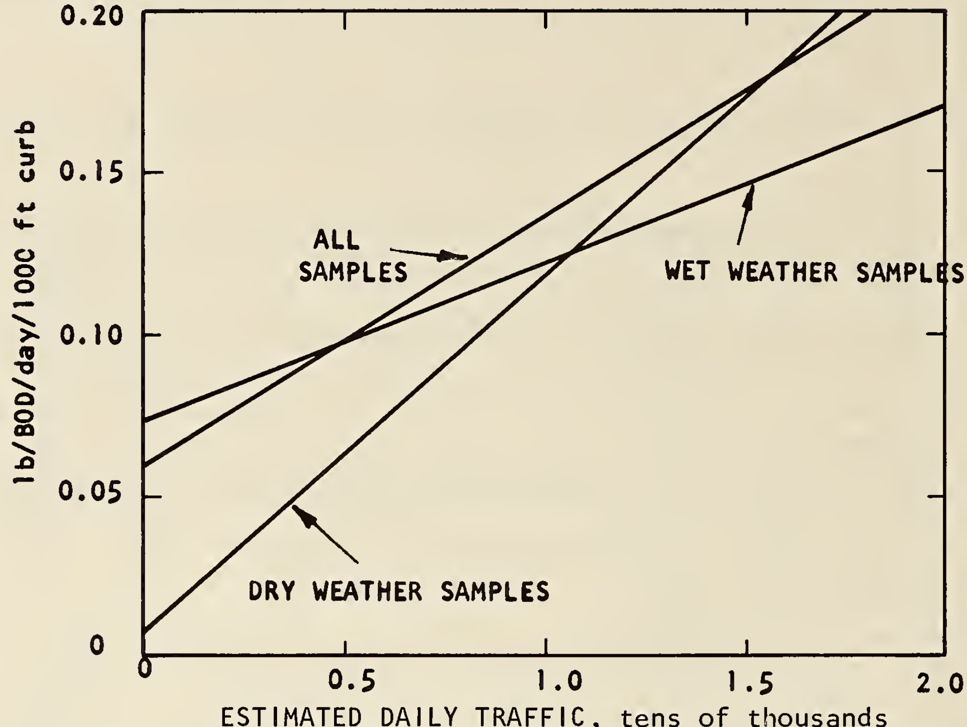
σ = standard deviation

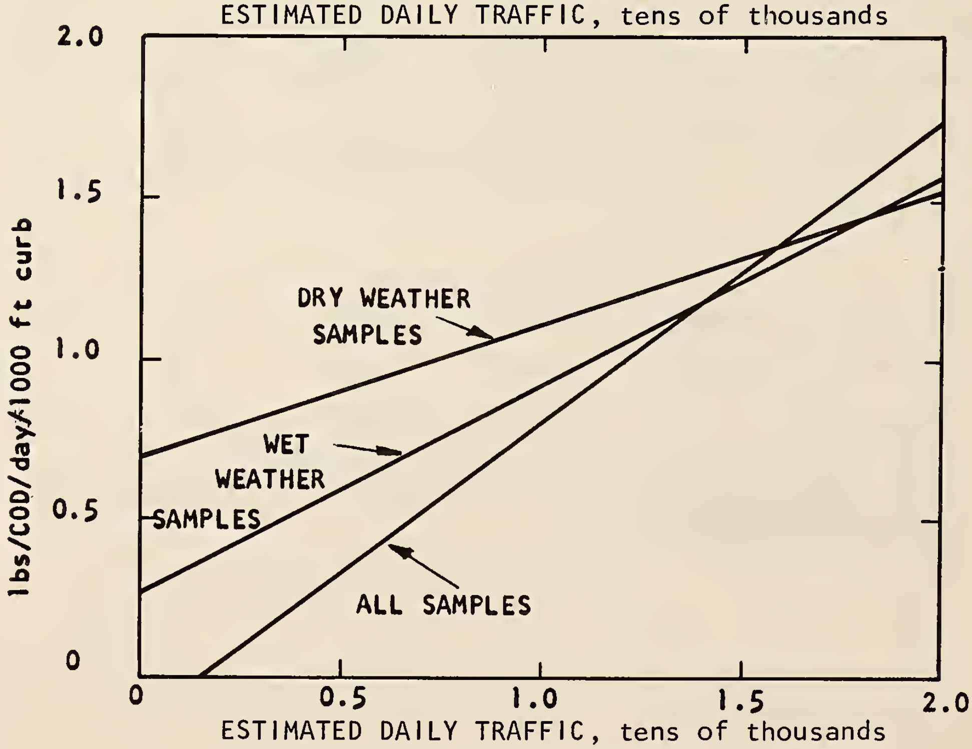
R = correlation coefficient

	A	B	2σ	R
BOD				
1. Dry weather samples	0.0069	0.1235	0.094	0.87
2. Wet weather samples	0.0728	0.0493	0.167	0.39
3. All samples	0.0596	0.0763	0.120	0.68
COD				
1. Dry weather samples	0.272	0.635	0.61	0.81
2. Wet weather samples	0.697	0.404	1.38	0.38
3. All samples	0.139	0.931	1.42	0.71

a. These values were computed by Biospherics Inc., based upon APWA data in Reference 38.

To obtain metric units of kg/day/m, multiply lb/day/100 ft by 0.0015.





(Lines are least square representations computed by Biospherics Inc. based on APWA data in Reference 5).

Figure 11. Effect of traffic on BOD and COD in street dust and dirt (5).

of 3,700 million organisms per mile for fecal coliforms and 6,882 million organisms per mile for fecal strep. Table 22 shows the seasonal variation of fecal and fecal strep coliform. This study (5) concluded that microorganisms in dust and dirt show definite seasonal variations. The highest numbers of fecal coliforms were found in summer followed by fall. The smallest number of fecal coliforms were found in winter and spring. The seasonal variation for fecal strep was not as dramatic, but loadings were highest in the summer.

In a 1973 study (83), emissions from disc pads, brake linings and clutch facings were collected from vehicles driven through test cycles at high and low operating temperatures. It was estimated that the average asbestos produced from passenger cars was 28.51 µg/mi, from light trucks, 87.51 µg/mi, from medium trucks, 290.72 µg/mi and from heavy trucks, 951.12 µg/mi. This study also estimated that 81.9% of asbestos emissions falls onto the road surface, 3.7% becomes airborne and 14.4% is retained within the brake or clutch case of each vehicle type.

Two 1974 studies (84, 85) analyzed rubber loss from tire wear. The average loss of rubber during the lifetime of a tire was found to be 90 mg/km (84). This rate is influenced by vehicle speed, type of vehicle, tire position, amount of turning and road surface. Tire dust is produced in larger quantities at higher speeds, but the mean particle size is smaller. Dispersion of particulates was found to be the main mechanism for tire rubber losses. No volatile hydrocarbon emissions were detected. Particle sizes ranged from 0.1 mm to a few microns. Using a 1970 value of 90 million cars in the United States, an average car use of 14,000 miles (22,400 km) and the above average rate of rubber loss from a tire, a yearly loading of rubber in the United States of 0.7×10^9 kg/year was calculated (84). In another rubber related study, the highway dust in the Liberty Tunnel in Pittsburg, PA was found to contain 2 to 2.5 percent tread rubber (85).

Data from a 1976 Texas study (86), using simulated rainfalls, showed results similar to the URS study (12) when pollutant loadings from asphalt and concrete surfaced highways were compared. Pollutant loadings for COD, TOC, lead and zinc were higher for the asphalt paved highway. However, oil and grease, and total suspended solids did not show this relationship. The authors attributed the higher total suspended solids loading obtained from the concrete surfaced highway to the design characteristics of the two highways. They concluded that the presence of guard walls on the concrete section may have prevented many of the solids from being blown off the pavement surface, and the fact that the concrete surface is more abrasive on tires than is asphalt. The average mass loadings found on the concrete surface were:

Table 22. Seasonal variations in loadings of nontraffic-related pollutants on roadways (5).

Roadway Site	Winter			Spring			Summer			Fall		
	Litter	Fec. Col.	Fec. Strep.	Litter	Fec. Col.	Fec. Strep.	Litter	Fec. Col.	Fec. Strep.	Litter	Fec. Col.	Fec. Strep
	lbs/mi	million org/mi.	million org/mi.	lbs/mi	million org/mi.	million org/mi.	-million lbs/mi.	million org/mi.	million org/mi.	lbs/mi	million org/mi.	million org/mi.
Kenilworth Av. Low Spd. Lane	54.6	0	149.7	48.2	13.2	0.4	111.4	723.9	0.7	35.2	424.4	10.7
Kenilworth Av. High Spd. Lane	49.8	0	16.3	61.8	0	6.1	201.4	163.9	47.6	73.4	0	0.8
I 495	55.6	1.9	15.5	48.8	0.7	8.1	31.2	24.1	20.1	45.4	26.3	605.3
CAMP Station	61.4	0	2.2	48.8	0	96.1	46.4	1785.2	66.9	82.8	32.7	29.1
N. Capitol St. Low Spd. Lane	32.2	139.0	20.9	226.2	8.9	91.4	48.8	1689.9	2519.9	27.0	6.6	25.9

Note:

Data given are average seasonal loadings calculated from samples deposited over a 24-hour period.
To obtain kg/km, multiply lb/mi x 0.282
To obtain million organisms/km, multiply million organisms/mi x 0.62

0.49 lb/1000 sq ft (2.4 kg/1000 sq m) COD
0.016 lb/1000 sq ft (0.078 kg/1000 sq m) oil and grease
0.089 lb/1000 sq ft (0.043 kg/1000 sq m) TOC
0.00097 lb/1000 sq ft (0.0047 kg/1000 sq m) lead
0.00049 lb/1000 sq ft (0.0024 kg/1000 sq m) zinc
0.41 lb/1000 sq ft (2.0 kg/1000 sq m) total suspended solids

The average mass loadings on the asphalt surface were:

0.88 lb/1000 sq ft (4.3 kg/1000 sq m) COD
0.009 lb/1000 sq ft (0.044 kg/1000 sq m) oil and grease
0.213 lb/1000 sq ft (1.04 kg/1000 sq m) TOC
0.00154 lb/1000 sq ft (0.008 kg/1000 sq m) lead
0.0012 lb/1000 sq ft (0.006 kg/1000 sq m) zinc
0.18 lb/1000 sq ft (0.88 kg/1000 sq m) for total suspended solids

During 1977, a highway runoff monitoring program was undertaken to evaluate the runoff characteristics from an all-paved elevated highway site (bridge structure)(87). Rainfall, runoff, runoff quality and dustfall were measured over a three month period during the summer of 1977. Table 23 summarizes the runoff quality data for both pollutant concentrations and pollutant loadings. From the pollutant concentrations data, loadings were calculated by assuming an average runoff/rainfall (Q/R) ratio of 0.90 based on the all-paved area characteristics of the site.

Toxic Materials in Runoff

The presence of toxic materials in urban stormwater has been investigated only in recent studies. A report of a 1971 study of the Potomac estuary cites significant increases in the heavy metal content of sediment samples taken near sewage and stormwater outfalls (88). The authors attributed the origin of such metals to sewage treatment plant effluent, however, they also indicated that urban runoff may be responsible. In a study conducted in Stockholm, Sweden (65), Soderlund et.al. found up to 100 mg/l of lead in snow and attributed this to motor vehicular emissions.

Recently, two comprehensive studies on heavy metal and pesticide distribution in city street debris were conducted by URS Research Company (12, 89). A summary of the heavy metals analyses for seven cities in the USA is shown in Table 24. The concentration of heavy metals in storm runoff was estimated to be 10 to 100 times greater than in sanitary sewage. On a slug load basis (lb/hr or kg/hr), the metal content of runoff was found to be 100 to 1000 times greater than sanitary sewage (89). However, the metal content of storm runoff is usually not sufficient to cause noticeable reductions in biological treatment efficiency in plants handling combined sewage/storm drain systems. The solubilities of heavy metals in a simulated receiving

Table 23. Summary of highway runoff quality data for the Lubbock, Texas monitoring site (87).

	Concentration, mg/l		Pollutant loadings, lb/acre	
	Avg.	Range	Avg.	Range
Fe	2.6	0.9 - 5.9	0.26	0.02 - 1.23
Pb	0.7	0.2 - 1.6	0.06	0.02 - 0.25
Zn	0.3	0.08 - 0.8	0.02	0.01 - 0.10
Cd	0.02	0.003 - 0.04	0.001	0.0002-0.002
TSS	143	26 - 533	29	1 - 50
TVS	64	13 - 280	4	0.5 - 11
TDS	196	27 - 714	12	3 - 38
TS	402	79 - 1527	29	9 - 88
COD	268	73 - 740	19	7 - 69
TOC	51	6 - 128	5	2 - 13
Kjeldahl-N	4.0	1.4 - 10.0	0.6	0.04 - 2.77
NO_3	0.7	0.1 - 2.0	0.07	0.004 - 0.18
pH		6.9 - 7.3		6.9 - 7.3

To obtain kg/ha, multiply lb/acre by 1.12.

Table 24. Heavy metals content of roadway dust and dirt (12).

	Heavy Metals Content (µg/g)						
City	Cd	Ni	Pb	Zn	Cu	Cr	Hg
San Jose, California	3.4	160	2000	1400	550	220	470
	--	14	150	47	3	23	14
Phoenix, Arizona	--	42	140	390	63	32	24
Milwaukee,Wisconsin	1.5	13	840	980	230	20	--
Baltimore, Maryland	2.8	87	630	1300	360	440	--
Atlanta, Georgia	00	49	180	260	150	24	52
Tulsa, Oklahoma	--	35	93	190	97	10	60
Seattle, Washington	--	61	1100	810	160	180	75
Average	--	58	650	670	200	120	

water environment were shown to be low, most being less than 10 percent of the available metal. However, copper, cadmium, lead and zinc were found sufficiently soluble to cause toxic effects to certain aquatic organisms under selected conditions. In most samples, more than half of all the heavy metals occurred as particles smaller than 495 μ. The larger particles (>246μ) were found to be the most soluble (89).

The pollutant loading (lb/curb mile, kg/km) and pollutant concentration (mg/kg) of the above heavy metals were determined for various land-use categories. The three general land-use categories used for comparison were residential, commercial, and industrial. Further breakdowns of each of these categories were also defined and compared (89).

Industrial areas were shown to contain the greatest loadings of heavy metals, while both industrial and commercial areas had the greatest concentrations, depending on the particular metal. Cities with high particulate levels of air pollution recorded high loadings of heavy metals. An analysis of street surface contaminants on rural roads and highways indicated that the city street particulates have a greater pollution potential on a concentration (mg/kg) basis. The BOD_5 concentration of urban samples was found to be an order of magnitude greater than the rural samples. Grease and oil were found to be the major organic constituents of the street particulates, but no definite correlation was established between organic concentrations (mg/kg) and land use (89).

Among pesticides, endrin, methoxychlor, lindane, and methyl parathion were each found in samples from one or more of the eight cities surveyed (12). DDD, p,p'DDT and dieldrin were found in all eight cities at average levels of 72, 72 and 28 mg/g, respectively. Surprisingly, polychlorinated biphenyls (PCB's) were found in each of the cities at an average level of 530 mg/g. In a 1975 study (90) four herbicides: diuron, linuron, fenac and trifluralin were applied to test plots of cotton, and the runoff from natural and simulated storm events were monitored. The maximum loss of herbicide in runoff water was 5.5% of the herbicide applied. Four months after herbicide application, less than 1% of the amount found in runoff 24 hours after application could be detected.

Contaminants are deposited on roadways via mechanisms which are both related and unrelated to traffic. Loadings of the traffic related depositions will be proportional to total traffic and may arise directly (tire rubber, motor oil) or indirectly (abraded materials from roadway surfaces) from the motor vehicle. The bulk of traffic-related materials deposited on roadways do not originate directly from the motor vehicle (5). Much of the street contaminants are representative of local geology and, to a lesser extent, products abraded from the roadway surfaces and are largely inorganic.

Less than 5 percent by weight (5) of the traffic related deposits originate directly from motor vehicles; however, these pollutants are among the most important by virtue of their potential toxicity. Among these pollutants are many heavy metals as described below.

1. Traffic-related lead is deposited principally through the use of leaded fuels, and some results from the wear of tires in which lead oxide is used as a filler material.

2. Zinc is also used as a filler material in tires and at high concentrations in motor oil as a stabilizing additive.

3. Copper, nickel, and chromium are wear metals from metal plating, bearings, bushings, and other moving parts within the engine. Considerable copper is deposited as a result of wear of copper impregnated brake linings.

Newton, et.al., (91) calculated the theoretical average amount of lead that can be contributed by auto exhaust to street runoff and compared this to actual values obtained by analyzing samples of snow, ice and water near several heavily traveled streets and highways. They concluded that the theoretical average lead concentration of 0.23 mg/l was lower than the actually observed average of 5.5 mg/l. However, both these concentrations were sufficiently large to indicate that street runoff can be a significant nonpoint source of lead contamination of surface water.

A 1974 study on "Quality of Urban Freeway Stormwater" in Milwaukee, Wisconsin found lead concentrations in the range of 0.6 to 1.1 mg/l in freeway runoff (92). Farris et.al. (93) evaluated the quality of highway runoff from the I-90 corridor. Lead (0.6-5.0 mg/l) was the major heavy metal followed by zinc (0.01-1.5 mg/l). Other heavy metals, copper, cadmium and chromium were also analyzed, but were found to be in very low concentrations (mean values Cu 0.10 mg/l, Cd < 0.01 mg/l and Cr < 0.02 mg/l). The major portion of the heavy metals was found to be associated with the particulate (undissolved) solids.

In a 1977 review paper, Laxen and Harrison discussed the fate of lead emissions from highway traffic as it is dispersed throughout the environment via highway runoff and airborne deposition (94). The distribution of lead depends on many complex variables including; particle size, traffic density, driving mode and speed, site topography and prevailing meteorological conditions. Some lead is never exhausted but rather is deposited in the engine, manifold and exhaust system, and some is retained in the engine oil. Other lead is temporarily stored in the exhaust system under normal driving conditions, but upon rapid acceleration is resuspended and emitted. Smith, in a 1976 review paper (95) concluded that 70-80% of the lead emitted from gasoline combustion will eventually be released to the atmosphere. Based upon these emission percentages and assuming average driving conditions and car maintenance, an automobile may release up to 130 mg of lead per mile. Laxen and Harrison reported that Sylvester and DeWalle (96) have calculated a deposition rate for lead on a busy highway of 2.35 mg/m^2/day, considerably above the background deposition rate of 0.046-0.186 mg/m^2/day measured at various remote sites in Britain (97) and 0.065 mg/m^2/day for a U.S. watershed (98).

Lead dispersion in the environment is largely a function of particle size. The majority of lead is emitted in one of two distinct particle size ranks, small particles <1μm in diameter and larger particles between 5 and 50 μm (94). Large particles are rapidly deposited within or near the highway system, usually within 30 m to 50 m (95) from the paved surface (Table 25). Smaller particles normally escape the highway system and are deposited at sites remote from the emission source (94). Lead which falls on the road surface is almost exclusively insoluble and associated with particulates. Highway runoff commonly contains lead concentrations which are 1,000 to 10,000 times greater than background concentrations in surface water. Lead which is deposited on the highway right-of-way is effectively immobilized within the top few centimeters of soil, and cause an insignificant contribution to water pollution. Nightingale (111), also studied the buildup of heavy metals in urban storm runoff retention basins in Fresno, California and reported that the majority of lead was concentrated in the top 5 cm of the soil. Lead content for baseline or uncontaminated conditions of the upper soil horizons are generally given as 10-20 μg per gram, dry weight basis (95). Table 25 gives lead content of contaminated roadside surface soils. Comparing baseline conditions with values reported in Table 25, the lead content near the paved surface of a heavily traveled highway may exceed 30 times baseline.

Table 26 is a summary of lead concentrations associated to solids and Table 27 is a summary of lead concentrations in runoff and snow samples. Laxen and Harrison (94) point out that the articles reviewed indicate that lead impurities in de-icing salt may contribute lead to the highway environment in some locations (Table 27), however, this contribution probably does not represent more than 5% of the total highway lead.

Concentrations of heavy metals were monitored in highway runoff with time on the western and eastern outfalls of Highway I-495 in the Washington, DC area during several storm events (5). The roadway areas drained by the two outfalls were approximately 15,000 and 600 sq ft (1393.5 m^2 and 55.7 m^2), respectively. Runoff from these drainage areas contained mostly materials previously deposited on the roadway. Storm events were monitored by measuring total rainfall, runoff flow rate and concentration of pollutants in runoff samples taken at known intervals throughout the storm. Figure 12 shows the data on rainfall, flow rate and lead and zinc concentrations in the

Table 25. Lead contamination of roadside surface soils (95).

Traffic volume[a] (veh/24 hr)	Location	Extracting agent	Sampling depth[b] (cm)	Sampling distance perpendicular to roadway and soil lead content[c]: Closest to roadway, m / lead (µg/g)	Midway (m) / lead (µg/g)	Farthest from roadway, m / lead (µg/g)	Constant soil lead level achieved (m)	Ref. no.
56,000	Maryland	Hydrochloric acid	0-5	7.6 / 122	15 / 75	30 / 63		99
(24,000)	Maryland	Hydrochloric acid	0-5	7.6 / 403	15 / 231	30 / 92		99
54,700	New Jersey	Perchloric acid	0-15	7.6 / 169	38 / 98	67 / 78		100
(12,800)	New Jersey	Perchloric acid	0-15	7.6 / 134	38 / 60	67 / 58		100
64,180	Minneapolis-St. Paul	Nitric, sulfuric perchloric acids	0-6.25	1.5 / 700			15	101
(1,900)	Minneapolis-St. Paul	Nitric, sulfuric perchloric acids	0-6.25	1.5 / 128			15	101
16,000	Brisbane Australia	Perchloric acid	0-5	2 / 145	125 / 30	250 / 25	25	102
(3,700)	Brisbane Austrailia	Perchloric acid	0-5	2 / 130	125 / 20	250 / 20	25	102
7,000	Denver	Nitric acid	0-15	1.5 / 500	30 / 30	91 / 30	15-18	103
>4,000	Illinois	Unidentified	0-10	0 / 450	30 / 20	60 / 20	20	104
(2,000)	Illinois	Unidentified	0-10	0 / 25	30 / 17	60 / 17	10	104
1,200	New Zealand	Nitric, Hydro-fluoric acids	0.5	10 / 160	30 / 90	100 / 55		105
48,000	Maryland	Hydrochloric acid	0-5	8 / 540	16 / 202	32 / 140		106
(20,000)	Maryland	Hydrochloric acid	0-5	8 / 522	16 / 378	32 / 164		106
23,000	Ohio	Hydrochloric acid	0-5	8 / 150	16 / 101	32 / 55		106
7,500	Missouri	Hydrochloric acid	0-5	8 / 242	16 / 140	32 / 61		106
70,000	California	Nitric acid	0-7.5	15 / 118	197 / 85	364 / 81	76[d]	107
(58,000)	California	Nitric acid	0-7.5	15 / 118	198 / 74	362 / 85	77[d]	107
29,000	Michigan	Nitric acid	0-15	6 / 150	73 / 50	158 / 50		108
17,500	England	Nitric/sulfuric acid	0-10	1 / 130		25 / 80	50	109
Lead ore truck route	Missouri	Unidentified	0-8	11 / 137	46 / 24	259 / 850	50	110

[a]In studies with more than one traffic volume examined, the data for the highest and (lowest) volume roads are given.

[b]In studies with more than one sample depth, the depth exhibiting the highest Pb level is given.

[c]In studies with both sides of the roadway sampled, the side exhibiting the highest Pb level is given (dry wt basis).

[d]No samples collected between 15 and 76 m.

Table 26. Selected values of 'solid-associated' lead (94).

Source	Lead concn (mg kg^{-1} of solid)	Reference	Reference no.
Street sweepings - urban	1000	Sartor and Boyd (1972)	12
Street sweepings - urban	20000	Pitt and Amy (1973)	89
Highway sweepings	4900	Pitt and Amy (1973)	89
Highway dust and dirt	4100	Shaheen (1975)	5
Highway dust - urban	1000	Day et.al. (1975)	112
Highway dust - urban	1800	Anon. (1975)	113
Street dust	2230	Singh (1974-1975)	114
Street dust - urban	1000 - 4000	Harrison (1976)	115
Dust - rural	85	Day et.al. (1975)	112
Street dust - rural	440	Harrison (1976)	115
Airborne dust 0 - 48 m from highway	9200	Sylvester and De Walle (1972)	96
Airborne dust over eastern Atlantic	100 - 1500	Chester and Stoner (1973)	116
Residue from snow sample	11700	Van Loon (1972)	117
De-icing salt	9	Hedley and Lockley (1975)	118
Suspended sediment in highway runoff	5800	Sylvester and De Walle (1972)	96
Suspended sediment in highway runoff	3100	Angino (1972)	64
Settleable solids in highway runoff	16000	Sylvester and De Walle (1972)	96

Table 27. Selected values of soluble and total lead in highway runoff and snow samples (94).

Source	Total lead concn Mean ($mg\ l^{-1}$)	Total lead concn Range ($mg\ l^{-1}$)	Reference	Reference no.
Snow from road surface	5.5	3.6 - 8.5	Newton *et.al.* (1974)	51
Snow from highway	102	86 - 113	Oliver *et.al.* (1974)	119
Snow dumps	9.8		Van Loon (1972)	117
Highway runoff		2 - 8	Sylvester and De Walle (1972)	96
Highway runoff		1 - 14	Siccama and Porter (1972)	120
Highway runoff	6.2		Pitt and Amy (1973)	89
Highway runoff	2.1	<0.25 - 12	Hedley and Lockley (1975)	118
Highway runoff		1 - 4	Shaheen (1975)	5
Urban stormwater	0.59	<0.1 - 12.6	Bryan (1974)	121
Urban stormwater		0 - 1.9	Field (1975)	122
	Soluble lead concn Mean ($\mu g\ l^{-1}$)	**Soluble lead concn** Range ($\mu g\ l^{-1}$)		
Highway snow	100	50 - 2000	Van Loon (1972)	117
Highway snow	60		Oliver *et.al.* (1974)	119
Highway runoff	100	10 - 1800	Shaheen (1975)	5
Background waters	3 - 5	0.5 - 100	Wilson (1976)	123

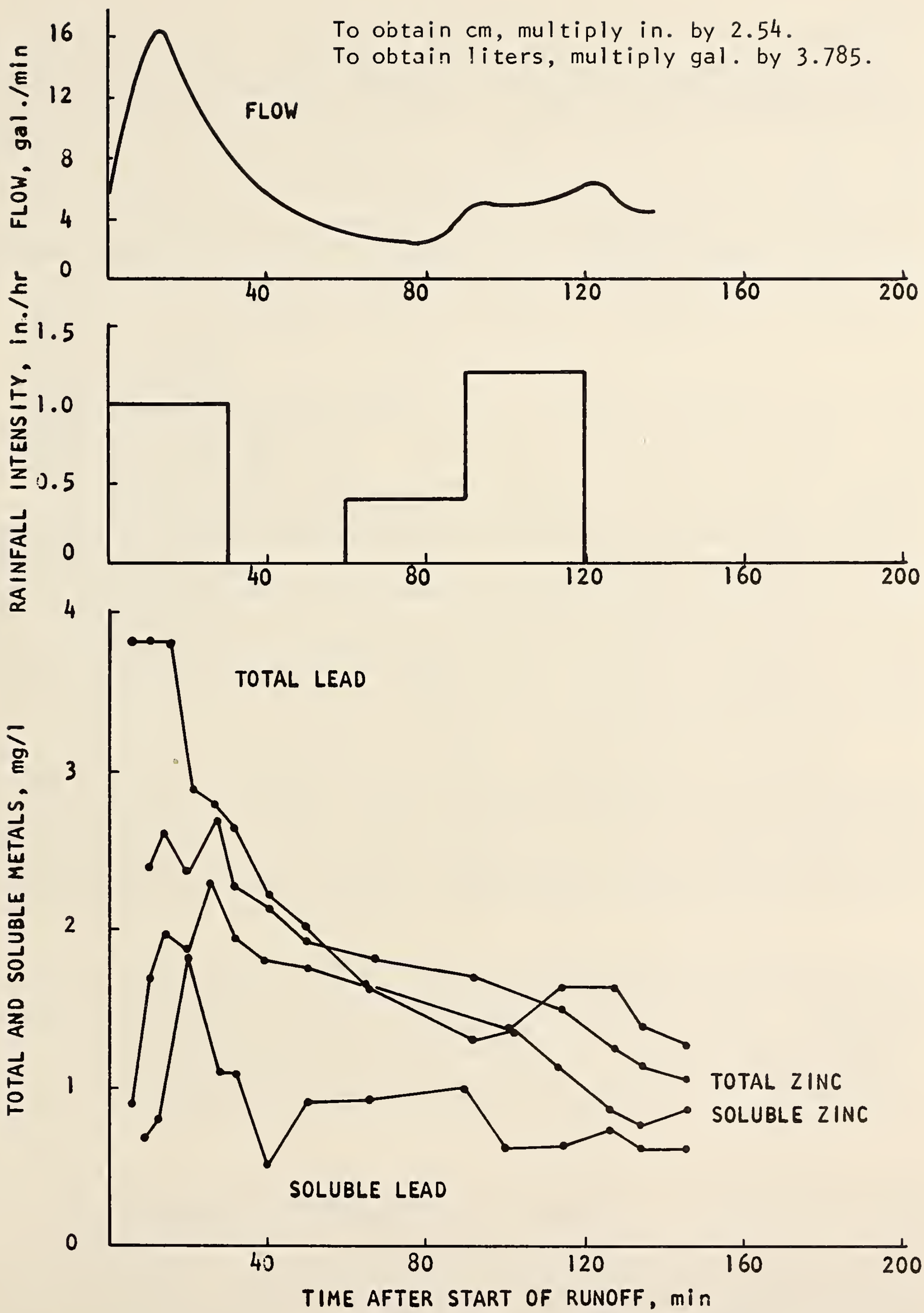


Figure 12. Storm event of September 2, 1973 at the western outfall, I-495 overpass NW branch (5).

runoff for the storm event of September 2, 1973.

Inspection of the data reveals a marked first flush effect in which the concentration of lead and zinc are initially high and then fall off to lower, but still significant levels. The first flush was less noticeable during storms with a low, even rate of runoff. Runoff samples taken after three hours of continuous flow were found to contain significant concentrations of the heavy metals. Concentrations of lead and zinc tended to increase again, after the initial flush of the roadway surface when there was an increase in the runoff flow rate. The second concentration peak could be quite high, depending upon flow kinetics and amounts of pollutants already washed off the roadway.

There are several ways in which stormwater runoff from urban roadways can affect receiving bodies of water. First, dramatic effects may result during stormwater runoff periods in which shock loadings of toxic materials are abruptly introduced. Since such events will occur several times over the course of a year in most areas, permanent changes may be introduced in the biological species existing in the affected downstream length of the receiving stream. Secondly, there may exist on a more or less permanent basis, a dry weather sphere of influence near the roadway/receiving water interface. Particulates introduced into the water during storm events will settle out at various distances downstream, and the pollutants associated with these particulates may then exert a continuing effect upon the stream biology as they provide a source of slowly dissolving toxic materials such as heavy metals, PCB's and grease.

Growing concern about the presence of lead in the environment has led to recent regulations concerning fuels and fuel additives by the U.S. EPA. These regulations call for the general availability of one grade of lead free fuel by July 2, 1974 for use in 1975 and later model cars equipped with pollution control devices (124). The lead content of the unleaded gasoline is required to be limited below 0.05 gms/gal. (0.01 gms/l).

In addition, the proposals call for a scheduled reduction of the lead content of regular gasoline through restrictions during refinery production. These regulations require that the average concentration of leaded gasoline should be below 0.86 gms of lead per 1 gal. (3.785 liters) by January 1, 1978. These regulations should lead to a significant reduction of lead content in auto emissions, as well as highway runoff in the future.

During the Biospheric's study (5), it was also observed that soluble zinc levels were higher than soluble lead in the runoff despite the fact that materials deposited on roadways contained approximately eight times more lead than zinc. This indicates that the deposited zinc compounds are more soluble than the lead compounds. Additionally, the ratio of total lead to zinc in the runoff was much lower than expected, which suggests that zinc is washed from the roadways at a faster rate.

Copper, chromium and nickel concentrations found in the bottom samples of the Anacostia River (5) are shown in Figure 13 as a function of the distance from the runoff flume beneath the center of the roadway. The metal concentrations were at a maximum in the immediate area of the roadway.

A major source of nickel and chromium may be impurities in de-icing salts applied to highway surfaces (94). In a 1973 study (125) samples of highway de-icing salt were analyzed for trace elements and the following ranges (mg/kg) were found:

Manganese (0.04-0.08)
Iron (0.08-0.09)
Lead (0.09-0.30)
Copper (not detectable-0.0004)
Nickel (0.002-0.003)
Chromium (0.003-0.01)

Apart form the above discussed metals, (which are the most commonly discussed in highway related literature) other metals such as cadmium, mercury and iron may be of concern in highway runoff. Cadmium is a relatively rare element being concentrated in zinc bearing sulfide ores and consequently in all zinc containing products. However, no noteworthy concentration of cadmium could be found in highway related studies. The mercury content of roadway dust and dirt was reported from studies in five cities of the USA (38). The mercury concentrations ranged from 14 to 75 µg/g of dirt. The main source of mercury was concluded to be atmospheric fallout. Concern has also been expressed for release of mercury from bottom sediments by highway deicing salts (126). Chloride ions complex strongly with mercury, while sodium and calcium ions can compete with mercury ions for exchange sites on bottom sediments. Feick, et.al. (126) have stated that the addition of NaCl or $CaCl_2$ increases the realtive amount of mercury in the water in equilibrium with the sediemnts by two to five orders of magnitude.

Large magnetic fractions, found in the roadway deposits in Washington, DC (5), indicate that large amounts of ferrous iron may be present in roadway pollutant accumulations. Magnetic, a magnetic oxide containing ferrous iron was identified in the roadway dirt in the Washington, DC study. The magnetic fraction originates from area soils which contain magnetic iron compounds. Additional magnetic materials are deposited as a result of corrosion of motor vehicle bodies, engine and exhaust systems.

Highway De-icing and its Impact on Highway Runoff

De-icing chemicals, principally sodium chloride, have been used in the United States for snow and ice control on pavements since early in this century. Initially, little use was made of the application of straight chemicals except in cities; salt (sodium chloride) was usually added to

To obtain meters, multiply yards by 0.91.

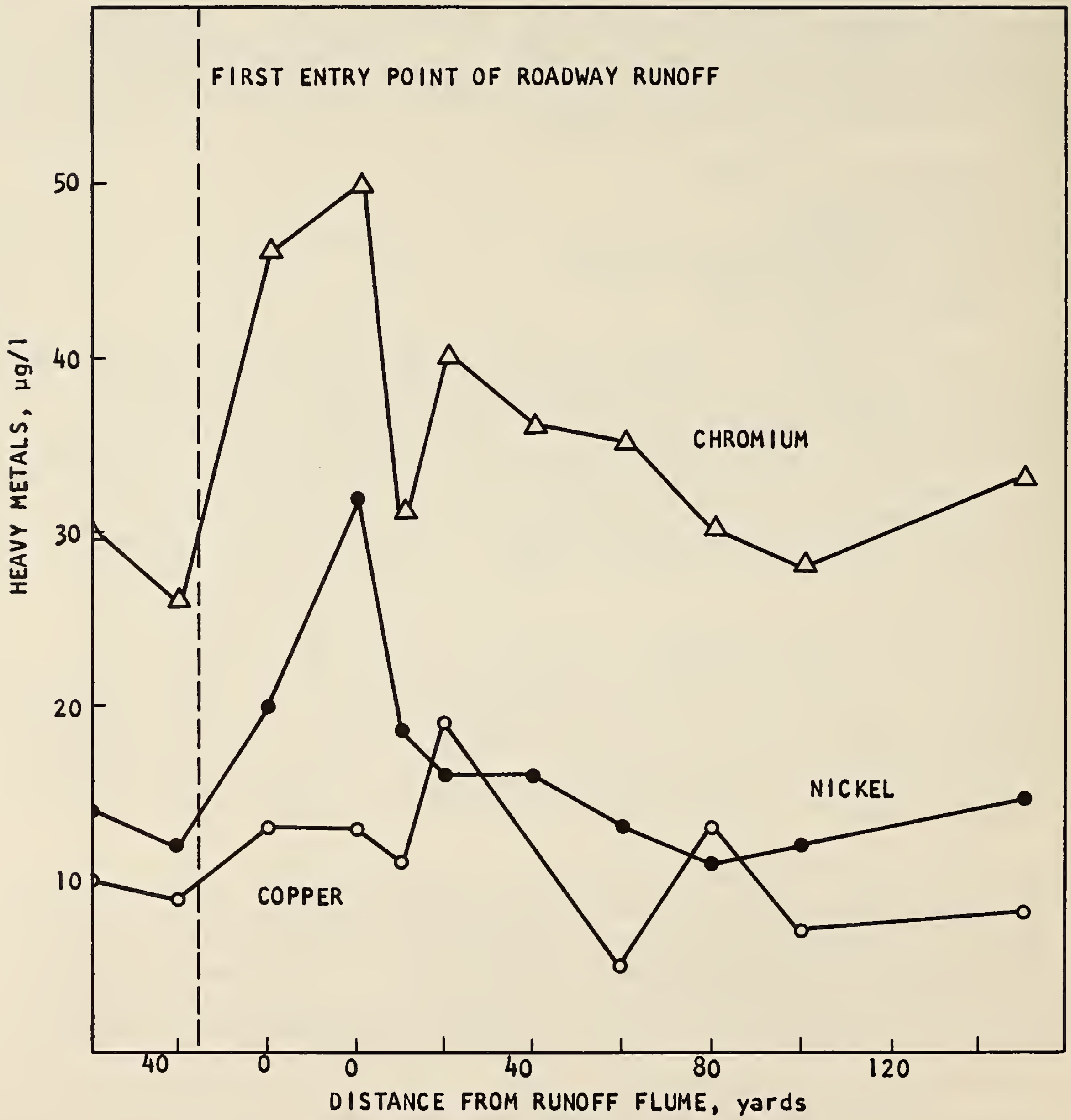


Figure 13. Heavy metals in stream bottom samples - northwest branch of Anacostia River at I-495 (5).

abrasives only to keep them free-flowing (127). In 1941, however, the state of New Hampshire began using straight sodium chloride as a general policy. A total of 3,865 tons (3,505 metric ton) of salt were used during the winter of 1941-42, though this figure includes an unspecified quantity mixed with sand.

The salt consumption in the United States increased gradually between 1940 and 1970 because of new road construction and increased auto use (128). Estimated salt usage quantities recorded by the Salt Institute for the past eight winter seasons are shown in Table 28 (128). This data indicates that the national salt usage in the last eight years leveled off to between 9 and 10 million tons per year (8.2 to 9.1 million metric tons per year). It is believed that the salt usage variations shown in Table 28 are a result of changes in temperature and other weather conditions (128).

Table 28. Salt usage in United States (128).

Winter year	Salt usage, tons/year
1969 - 70	8,855,000
1970 - 71	9,583,984
1971 - 72	8,721,014
1972 - 73	8,420,092
1973 - 74	8,628,829
1974 - 75	9,492,557
1975 - 76	9,937,180
1976 - 77	10,071,514

Note: To convert tons/year to metric tons/year, multiply by 0.907.

Public demand to maintain open travel routes for fast speeds and increased emphasis on traffic safety has made it necessary for winter maintenance operations to apply salt directly to roadways. Practically all highway authorities in the U.S. firmly believe that ice and snow must be removed as quickly as possible from roads and highway, and that "bare pavement" conditions are essential to protect the lives and safety of people. Maintaining bare pavement conditions does, however, require frequent and liberal applications of road de-icers. The de-icers are usually applied during early phases of snow storms to prevent the bonding of snow to the pavements. Procedures vary, but a common sequence is salting, snow plowing, and resalting. Sodium chloride and calcium chloride combinations are used in varying degrees and frequencies depending upon temperature, storm conditions, volume of traffic, time allowed for reactions, distribution of salt over the road surface, and amount of ice on road.

Salt rates usually range from 400 to 1200 lb (181-545 kg) per two-lane mile with applications repeated until the pavement is free of ice and snow (129). Massachusetts has standardized an application rate of 350 lb/lane mile (158.5 kg/lane mile) of straight salt at 25°F and rising temperatures; and a 5 to 1 premix ($NaCl:CaCl_2$) at 25°F and falling temperatures (10). New York City applies salt at the rate of 1/8 lb/sq yd (0.068 kg/m^2) or approximately 1500 lb/mile (420 kg/km) of 20 ft (6 m) wide pavement (130). Over the winter season, many roads and streets may receive more than 20 tons (18.14 metric tons) of salt per lane mile or 100 tons (90.7 metric tons) or more per mile for a typical multiple lane highway. Additional detailed data on the amounts of salts and other de-icing compounds used by state highway departments in past years is readily available in the literature (9, 10, 129-136).

Much of the salt spread on roads eventually enters a receiving watercourse, either as direct runoff or by percolation into the groundwater system. Some of the chloride concentrations found in highway runoff are shown below.

High chloride values in runoff (129).

Location	Source	Date	Chlorides, mg/l
Chippewa Falls, Wisconsin	Highway	1956-1957	10,250
Madison, Wisconsin	Street	1956-1957	3,275
Chicago, Illinois	JFK Expressway	1966-1967	25,100
Des Moines, Iowa	Cummins Pkwy Storm Drain	1958-1969	2,720

In Chippewa Falls, Wisconsin, chloride concentrations as high as 10,250 mg/l were recorded during winters. The street runoff in Madison, Wisconsin showed chloride concentrations in summers of only 16 mg/l compared to winter values of 3275 mg/l. Surface runoff from Interstate Highway 95 in Maine contained 38 to 845 mg/l of chloride with a mean concentration of 570 mg/l (136). In Chicago, Illinois (38) the chloride content of drainage samples varied from 1900 to 4500 mg/l when no salt was being applied to highways and flow was between 0.1 to 0.3 cfs (0.17-0.51 m^3/min). The chloride content increased to 11,000 to 25,000 mg/l during snowfall periods with flows between 0.1 to 1.5 cfs (0.17-2.55 m^3/min). The Chicago study further indicated that nearly all the de-icing salts subsequently left the area in the form of runoff. Assuming 1.5 tons (1.36 metric tons) of salt applied per mile of a two lane highway for each inch (2.54 cm) of snow, a chloride level of 1300 mg/l could be expected in the runoff (132).

Sequential storm drain sampling in Des Moines, Iowa, showed that chloride levels are highest at the beginning of runoff and concentrations decrease rapidly thereafter (133). Individual results ranged from a low of 9 mg/l to a high of 2320 mg/l chlorides. High chloride levels in three Milwaukee rivers (134), and Meadow Brooks, Syracuse, New York (135) have been attributed solely to the de-icing salts entering these streams through highway snowmelt. However, Hutchinson (136) studied some major rivers in Maine and concluded that sodium and chloride ion concentrations in those rivers were not being seriously affected by the salt applied to highways. Similar insignificant effects were noticed by Schraufnagel in the Duck Creek tributary in Wisconsin (137). Such studies are, however, in minority. Most other literature (9, 10, 129-136, 138-141) shows significant increases in chloride levels in receiving waters due to highway salting.

Contamination of groudwaters by highway salts has also caused some concern in recent years (10, 129, 142-144). In a 1974 study in Massachusetts (145), it was found that most of the salt that percolates downward with groundwater recharge enters the ground within 30 feet (10 m) from the paved edge of the highway. Results from this study also indicated that in autumn the amount of chloride, as sodium chloride, retained in this 30 ft (10 m) wide and 15 ft (5m) deep strip of soil adjacent to the highway, ranged from 15 to 55 percent of the amount of salt applied during the previous season. The amount of chloride retained in this soil zone from one salt season to the next depended on depth-to-water table, soil particle size and the amount and seasonal distribution of precipitation. The authors (145) concluded that the increase in the concentration of chloride in the groundwater adjacent to the highway during the summer was attributable to the salt application of the previous winter. In an earlier study (146), the same authors observed that at one of the groundwater monitoring sites along a Massachusetts highway, the concentration of chloride in the groundwater increased from less than 100 mg/l in 1965 to about 400 mg/l in 1971. Hutchinson (147) in a 1969 study, observed that salt entering potable water supplies, via runoff or percolation through soil, can render wells completely useless because of high salt concentrations.

Adams (148) in a 1973 study synthesized the model in Figure 14 from available literature concerning the fate of salt in the environment as related to highway salting. This model shows three main pathways which salts travel after deposition on a highway. First, the dissolved salt is carried away with highway runoff and directly enters surface waters. Secondly, moving traffic may splash salt or salt solution onto right-of-way areas where salt may percolate downward through the soil to the water-table or be assimilated by plants through their root systems. While percolating through the soil strata, the cations Na^+ and Ca^+ will be captured by the anionic properties of clay particles in the soil, except in very sandy soils where these cations can migrate significant distances. The anion Cl^- readily percolates through the soil strata

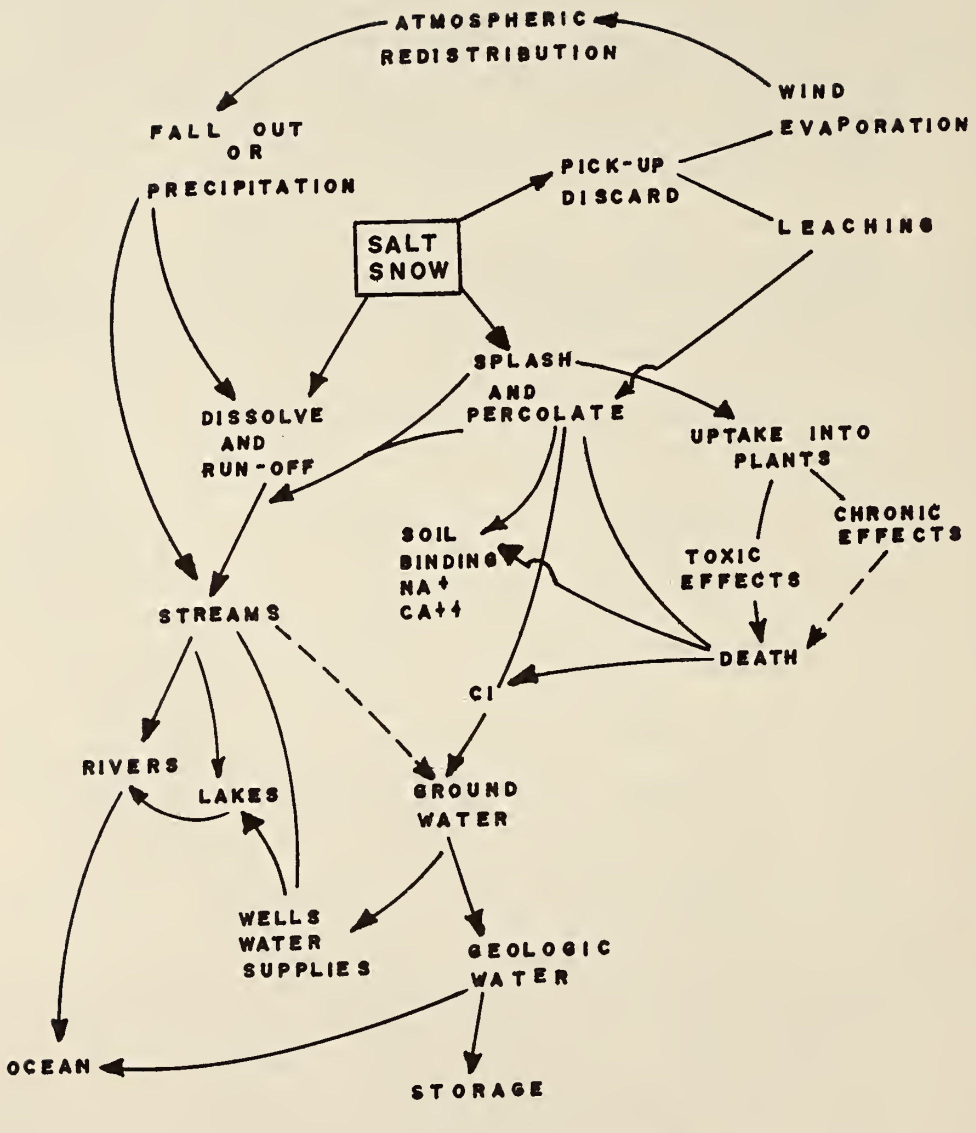


Figure 14. Fate of salt in the environment (148).

because it has the same charge as the clay particles. Thirdly, salt laden ice and snow may be plowed from the highway subsurface and dumped directly into streams and rivers, or it may be transported to a storage area from where environmental contamination may occur if the salt storage piles are left unprotected.

Salt introduced into the environment will eventually find its way to the ocean, via surface or subsurface waters or stored in underground pools of water (148). Throughout its transport to oceans or underground pools (geologic water), salt is free to interact with living and non-living environmental processes, possessing the potential for causing ecological alterations. However, any long term effects of salt on the environment are not known.

Highway salts can cause injury and damage across a wide environmental spectrum and these effects, although not yet evident in certain areas of the country, may appear in the future (10). All living organisms must survive in a precarious balance between too little, just right and too much salt, each in accordance with its genetic limitations and special adaptions (148). It has been indicated that highway salts can seriously disturb a health balance in soils, trees and other vegetation comprising the roadside environment. Figure 14 shows the two effects that salt can have on vegetation. Chronic effects are the burning or browning of foilage while toxic effects are those which affect the physiological processes. Both may cause death to parts of plants or the entire plant, and dead portions, unless removed, are recycled to the roadside environment (148). Total soluble salts, and sodium and chloride ions reduce soil fertility and structure, depress plant water uptake, and are toxic to plants and vegetation above certain limits (10). Salt concentrations greater than 1% (1g/100g of water) endanger health, reproduction, and longevity in all species adapted to fresh water environments including man (148). High salt concentrations in drinking water pose a possible threat to persons with heart disease (9,10). A new development in salt pollution concerns the potential role of sodium serving as a trace element towards stimulating excessive growth of blue-green algae (9,149).

Salt added to ponds or small lakes can affect their physical characteristics (148). The delay or failure of seasonal mixing due to salinity induced stratification has been observed in Irondequast Bay, New York (150) and in First-Sister Lake, Michigan (151). The lower depths in lakes depend on this seasonal mixing for oxygen. Therefore, failure of seasonal mixing by significant additions of salt could contribute to the biological process of aging in lakes called eutrophication (148).

Despite the growing environmental concern about the de-icing salts, it is clear that there is no suitable substitute for road salt at present. Special additives present within much of the highway de-icers sold today, may create worse pollution problems than chloride salts. Schraufnagel (152) described some substitute de-icing compounds. He finds glycols and alcohols, although effective, can exert significant biological oxygen demand and severly deplete dissolved oxygen in receiving waters. However, some agencies are sincerely working toward reducing the amount of salts used in critical areas, such as watersheds used for water supply (11). Prewetting of salt has been used in order to accelerate the action of salt and at the same time utilize less total material (153).

Auto Exhaust Emissions and Particulate Dust Fallout

Previous studies have indicated that emissions from motor vehicles account for approximately 39% of all emitted air pollutants (154). Since these emissions are concentrated near highways, several studies have been conducted to measure the air pollution from highways (155, 156). It is virtually impossible to precisely estimate the amount of pollutants that reach the road surface from source emission calculations alone, because the pathways that the pollutants travel are highly variable and unmeasured. Therefore, it is more meaningful to measure the amount of pollutants that are washed off the road surface during a rainstorm and to measure the vehicle released airborne matter that settles out.

It is generally expected that some of the larger particulate matter (>1-10μ) may settle out and may also deposit some of the substances that are adsorbed to it. In a 1959 study Tufts (157) found a large number of particles in the 1-5μ range in samples taken within 10 ft (3.05 m) of moving automobiles but noted no significant mass of lead in particles larger than 1μ. In a 1964 study, Mueller et.al. (158) also concluded that up to 68 percent of the mass of lead in exhaust aerosol particles was contained in particles less than 0.3μ in diameter. From 62-80 percent of the particulate mass consisted of particles below 2μ. In more recent studies (1971) Lee et.al. (159) reported 95 percent of the measured lead in auto exhaust being associated with particles smaller than 0.5μ. As a result of irradiation by sunlight the percentage of soluble lead in the particulate matter increased from 70 to 85 percent. The exhausted nitrate was associated with even smaller particles.

Also, numerous particulates are discharged through the blow-by which consist almost entirely of unchanged lubricating oil (160). Cukor et.al. (161) measured particulate matter concentrations of 39-206 μg/m^3 near a freeway and found that the benzene extractable fraction, ranging from 2.2-12.1 percent of the particulate matter, closely resembled lubri

Lead has been added to most gasoline since 1923 as an anti-knock agent in the form of tetraethyllead (TEL) or tetramethyllead (TML) (162). Today, the amount of TEL ranges from 2 to 4 g/gal. (0.53 to 1.06 g/l) gasoline. The anti-knock fluid contains lead alkalys and organic scavengers, ethylene dichloride, and dibromide, whose function is to combine with the lead to form inorganic lead salts, chiefly bromo-chloride. These inorganic lead salts are mostly retained in the exhaust system at low speeds and then discharged in increasing quantities as the vehicle speed increases. The discharged lead is deposited along the roadway, the right-of-way, and some fraction is carried away, all being dependent upon the roadway configuration, traffic speed, and meterological conditions.

In a 1957 study, Prince (163) reported the lead content of soils near highways to range between 14 and 96 ppm. Singer and Hanson found mean accumulations of 240 ppm lead at a distance of 1.5 m from highways but it reached a constant value of 75 ppm at a distance greater than 15 m from the roadside. A sample 1.5 m from the roadside with the highest traffic volume (64,000 cars/day) had a concentration of 700 ppm while the highway with the lowest traffic (1900 cars/day) gave a concentration of 128 ppm.

In a 1970 study, Lagerwerff and Specht (106) found concentrations of 0.94 ppm Cd, 7.4 ppm Ni, 540 ppm Pb and 162 ppm Pb and 162 ppm Zn in top soil 8 meters away from the 48,000 car/day Washington-Baltimore Parkway. The metal concentration gradients with increasing distance followed the order Cd > Pb > Zn > Ni. The concentrations of N, P and Cl also decreased as a function of distance from traffic. The authors ascribed the Pb from combustion of leaded gasoline, the Ni from atmospheric abrasion of Ni containing automobile parts. The joint presence of Zn and Cd was traced back to the common lubricating oil additive; anti-oxidant Zn - dithiophosphate, which resulted in a Cd concentration in lubricating oil of 0.20-0.26 ppm. Use of technical Zn - oxide and Zn - diethyl or dimethyl carbonate in rubber vulcanization may also introduce Cd as an impurity. Cadmium concentration in rubber ranges from 20-90 ppm.

Similar findings are being reported by Toukada (164) of the University of Washinton who calculated a Pb accumulation of 150 kg/year in the bottom muds of Hall Lake, a small lake adjacent to Interstate 5. However, when the particles with which the lead is associated stay in suspension the lead may accumulate in the food chain. Pagenkopf (165) reported for example, an increased lead content in trout in the West Gallatin River where is runs adjacent to Interstate 191 in Montanta.

In a 1966 study, Johnson et.al. (166) examined the effects of dustfall on water quality in the Seattle, Washington area. The purpose of the study was to determine if dustfall played a significant role in the water quality of local lakes and reservoirs. Average annual dustfall statistics were obtained from previous studies and are shown in Table 29.

It was concluded that dustfall impairs the water quality by adding foreign chemicals and minerals into the receiving body of water in the following three ways:

1. It can decrease the quality of water for drinking purposes.

2. It can act as a nutrient for use by aquatic plant life such as algae and water weeds.

3. It can act as a corrosive agent on piping.

Another highway runoff study reported data on airborne pollutants in the Seattle area (96). In this study, nine dustfall jars were placed at right angles to the highway under consideration. The results shown in Table 30 indicate that dust particle concentrations were greatest in the middle of the road and decreased with increasing distance from the road surface.

Table 29. Average annual dustfall in various Unites States cities (166).

City	Year	Dustfall tons/mile^2/month	Dustfall metric tons/km^2/month
Seattle	1954-1956	25.47	8.90
Seattle	1963-1964	38.92	13.62
New York	1951-1955	63.80	22.33
Chicago	1954-1956	54.94	19.23
Cincinnati	1950-1956	22.30	7.80
Pittsburgh	1951-1953	51.1	17.88
Tacoma	1954-1956	15.5	5.43
Detroit	1951-1953	68.0	23.80

Heavy metals retained in dustjars were also analyzed in the Washington study (96). These results are shown in Tables 31 through 34. The results in Table 31 indicate that lead composed the greatest concentration followed by zinc, chromium, copper, nickel and cadmium. The heavy metals composed about 1.1% of the total fallout by weight.

Table 32 reveals that zinc is by far the most soluble metal form in the dustfall followed by lead (32% and 4% respectively). Table 33 lists those heavy metals that are adsorbed to the suspended solids in the runoff. Lead was found to be the highest in concentration followed in order by zinc, copper and nickel. The results shown in Table 34 indicate that a larger portion of the heavy metals are in solution or suspension and not adsorbed to the suspended particles. Table 35 lists those heavy metals present in settleable solids from sampling site drains and catch basins.

<u>Dustfall Quantity</u> - Typical dustfall concentrations for various U.S. cities range from 10 to 100 tons/mile^2/month (3.5 - 35 metric ton/km^2/month), although values as high as 2000 tons/mile^2/month (70 metric tons/km^2/month) have been recorded (167). Previously cited Table 20 lists dustfall data for some U.S. cities. Specific data for

Table 30. Pollutants collected in dustjars perpendicular to state highway 520 (96).

Dustjar number	Distance from center, m	Total SS from dust, mg/m^2 day	% NVS dust	Total-P, mg/m^2 day	Total-N, mg/m^2 day
1	23.0	146.0	-	0.420	1.240
2	17.5	190.5	-	0.588	1,273
3	9.5	276.0	72.3	0.139	1.670
4	0	4450.0	94.0	0.134	1.335
5	12.0	1120.0	81.3	0.325	1.380
6	17.5	1870.0	87.5	0.350	1.537
7	19.5	318.0	75.0	0.473	1.805
8	24.5	251.0	-	0.662	2.120
9	48.5	150.0	-	0.490	1.128
Average				0.398	1.413

(2.51 cm rainfall was collected in the dustjars during the 12-day collection period).

Milwaukee County, Wisconsin is available for periods between 1951 through 1971 (168). In all, 68 sites were checked on a monthly basis and averaged over a 12 month period. A summary of the annual deposition rates between 1951 and 1971 for six zoning classifications is shown in Table 36. The data shows that the total dustfall deposit increased from 120.8 tons/mile^2/month (59.57 metric ton/km^2/month) in 1951, to 170.2 tons/mile^2/month (83.93 metric tons/km^2/month in 1967 and then decreased gradually to 104.4 tons/mile^2/month (36.54 metric ton/km^2/month) in 1971 due to increased vigilance and air pollution control efforts.

Other Highway Related Studies

There are only a few other studies reported in the literature related to highway system and their effect on the environment. The majority of this literature deals with noise and air pollution and other socio-economic impact evaluations developed as a part of the environmental impact statements that are now required prior to the construction of a highway system. Such studies have not been included within the scope of this state-of-the-art report. However, mention must be made of a number of pertinent studies that are currently underway and are directly related to and will have a bearing on the contents of this report in ensuing years.

Table 31. Heavy metals adsorbed to particulates found in dustjars[a] (96).

Jar	Lead, Pb		Zinc, Zn		Nickel, Ni		Copper, Cu		Cadmium, Cd		Chromium, Cr	
No.[d]	Conc.[b]	%[c]	Conc.	%	Conc.	%	Conc.	%	Conc.	%	Conc.	%
3	2.44	0.88	0.371	0.134	<0.132	<0.048	0.106	0.038	<0.011	e	<0.026	<0.009
4	28.90	0.65	2.530	0.057	0.142	0.003	0.425	0.010	<0.008	e	1.82	0.041
5	8.68	0.78	1.296	0.116	<0.118	<0.011	0.212	0.019	<0.009	e	0.850	0.076
6	26.10	1.39	1.940	0.104	0.231	0.012	0.315	0.017	0.019	0.001	1.330	0.071
7	2.88	0.91	0.839	0.264	0.163	0.051	0.140	0.044	<0.009	e	<0.023	<0.007
Av.		0.92		0.135		0.025		0.026				0.041

a. Heavy metals extracted from particulates by digestion with H_2O_2 and HNO_3 after filtering out particulates.

b. Concentration in mg/m^2/day of highway surface

c. Heavy metal concentration expressed as per cent of weight of total SS retained in the jar

d. Jars not shown did not have enough particulate fall out to measure.

e. Below detectable limit.

Table 32. Amount of soluble heavy metals collected in dustjars perpendicular to the highway and soluble amount expressed as percentage of total amount (soluble + insoluble + adsorbed) collected in dustjars (96).

Dust Jar No.	Pb		Zn		Ni		Cu		Cd		Cr	
	$mg/m^2 \cdot day$	soluble amount as % of total amount of HM collected in the dust jars	$mg/m^2 \cdot day$	%	$mg/m^2 \cdot day$	%	$mg/m^2 \cdot day$	%	$mg/m^2 \cdot day$	%	$mg/m^2 \cdot day$	%
1	<0.185		0.093		<0.093		<0.019		<0.007		<0.019	
2	"		0.148		"		"		"		"	
3	"	<7.0	0.277	40.5	"		"	<15.2	"		"	
4	0.185	0.6	0.222	8.0	"	<39.5	0.037	> 8.0	"		"	<1.0
5	0.518	5.6	0.352	21.3	0.148	>55.6	<0.019	< 8.2	"		"	<2.2
6	0.185	<0.7	0.830	30.0	<0.039	<28.4	<0.019	< 5.9	0.019	>50.0	"	<1.4
7	"	<5.7	1.314	61.0	"	<36.4	0.019	12.0	<0.007		"	
8	"		0.869		"		0.110		"		"	
9	"		0.185		"		0.093		"		"	
aver.		~3.9		~32.2		~32.0		~9.9		~50.0		~1.5

Table 33. Heavy metals adsorbed to the suspended solids in Highway 520 runoff[a] (96).

Date 1972	Drain No.[b]	Lead, Pb		Zinc, Zn		Nickel, Ni		Copper, Cu		Cadmium, Cd		Chromium, Cr	
		Conc.[c]	%[d]	Conc.	%	Conc.	%	Conc.	%	Conc.	%	Conc.	%
6-5	5-1	4.310	0.861	1.00	0.201	<0.045	<0.009	0.219	0.044	0.010	0.002	<0.005	<0.001
6-6	6-1	3.99	0.800	0.788	0.158	0.094	0.019	0.166	0.033	<0.005	<0.001	<0.010	<0.002
6-8	2-1	3.78	0.450	0.285	0.034	0.025	0.003	0.042	0.005	<0.008	<0.001	<0.008	<0.001
6-8	5-1	4.16	0.208	0.321	0.016	0.104	0.005	0.040	0.002	<0.020	<0.001	<0.060	<0.003
6-10	2-1	0.290	0.120	0.113	0.047	0.010	0.004	0.014	0.006	<0.002	<0.001	<0.002	<0.001
6-22	6-1	0.790	1.040	0.140	0.184	0.005	0.007	0.018	0.023	0.001	<0.001	0.006	0.008
Avg.			0.580		0.076		0.008		0.019		--		--

a. Samples filtered through Whatman #42 filter paper and digested with H_2O_2 and HNO_3.
b. First number is the drain and second number represents the collection sequence for that drain.
c. Concentration is in mg/l.
d. Heavy metal as percent by weight suspended solids.

Table 34. Total heavy metal concentrations (soluble and particulate) in SH 520 runoff on June 6, mg/l (96).

Drain	Pb	Zn	Ni	Cu	Cr	Cd
4-1	8.45	2.16	0.27	0.15	0.01	0.02
4-2	5.60	1.16	0.14	0.14	<0.01	0.01
5-1	5.60	2.24	0.19	0.17	<0.01	0.01
5-2	2.18	0.93	0.13	0.11	<0.01	0.01
5-3	3.41	1.64	0.13	0.13	0.02	0.009
6-1	4.30	1.93	0.19	0.12	<0.01	0.02

Table 35. Heavy metals in settleable solids collected from SH 520 drains and I-5 and SH 518 catchbasins[a] (percent by weight of dry settleable solids in sample) (96).

Metal	SH 520 6-6-72		I-5	SH 518
	Drain 4-1	Drain 7-1	N.B.	W.B.
Lead	1.680	1.603	0.770	0.300
Zinc	0.100	0.147	0.443	0.089
Nickel	0.007	0.026	0.007	0.011
Copper	0.034	0.039	0.048	0.019
Cadmium	0.001	0.004	0.001	0.001
Chromium	0.046	0.017	0.016	0.003
Traffic Intensity	39,000	39,000	73,000	615,000

a. Settleable solids <400 mesh.

Table 36. Summary of annual deposition rates (168) tons/mile^2/month.

Zoning classification:	1951*	1966	1967	1968	1969	1970	1971
Agricultural	14.0	26.0	29.5	24.0	18.3	21.4	13.4
Residential	22.4	23.4	22.8	22.5	19.4	21.7	13.8
Local business	36.5	26.1	29.2	29.6	23.1	23.4	17.1
Commercial and light manufacturing	45.8	36.8	45.6	40.6	35.1	23.3	27.5
Industrial	82.1	41.7	43.1	42.4	40.8	37.5	33.6
Total	120.8	154.0	170.2	159.1	136.7	127.3	104.4

*First year of complete data.
(For metric ton/km^2/month, multiply by 0.35).

For example, a study to determine the physical, chemical and biological nature of constituents of highway surface runoff is presently being conducted by the California Division of Highways and is scheduled to be completed by 1978. The Florida Department of Transportation with the United States Geological Survey is engaged in studying the quantity and quality of stormwater in southeast Florida for three urban sites consisting of a residential area, a highway area and a shopping area. The Commonwealth of Massachusetts, Department of Public Works in cooperation with the U.S. Geological Survey, has an on-going program to study the effects of de-icing chemicals upon surface and groundwaters on seven selected sites. The Wisconsin Department of Transportation is also conducting an investigation of road salt content of soil and water adjacent to highways. A study to develop a method for predicting the increase in sediment loading in a stream resulting from highway construction is the subject of a Pennsylvania Highway Planning and Research Study at Buckwell University. Additional studies on highway construction erosion and acid and iron pollution abatement are underway for the Pennsylvania Department of Transportation.

Also, a significant amount of data has recently been collected in an extensive highway monitoring program conducted under the same project as this state-of-the-art report (U.S. Department of Transportation Contract No. DOT-FH-11-8600) (169). This state-of-the-art report is volume one of six volumes that resulted from this study. Volume two, Procedural Manual for Monitoring of Highway Runoff, describes the methodology for the design and conduct of a highway monitoring program including; equipment selection and maintenance, site selection, data acquistion, sample handling and analysis and data handling procedures. Volume three, Predictive Procedures for Determining Pollutant Characteristics in Highway Runoff utilizes that accumulated data to formulate a highway pollutant accumulation and washoff model.

The model is designed as a means to assist the highway designer in writing Environmental Impact Statements. The model uses site specific characteristics (average daily traffic, percent of area paved (impervious), barrier type, etc) and a rainfall record to predict pollutant accumulation and washoff. Volume four, the Rexnord Report, provides a complete documentation of all work performed under Contract No. DOT-FH-11-8600 including details of site selection, field monitoring, data analysis, conclusions, and significant findings. Volume five, Highway Runoff Data Storage Program developed to organize and analyze the extensive data collected during this research project including; purpose of the study, methodology, findings and recommendations for future research.

Six highway sites were selected across the country for highway runoff monitoring under this study. Site selection was based upon such factors as; geographic location, climatic conditions, traffic characteristics, highway design and drainage characteristics. Three of the selected sites were located in Milwaukee, Wisconsin. Of these three, two sites were used for investigating runoff from a completely paved (impervious) area and an all pervious area at an inlet onto a highway; the third site was on a highway draining an approximately two mile long, 106 acre isolated highway drainage area. The other three sites were located in Harrisburg, Pennsylvania; Nashville, Tennessee; and Denver, Colorado. Only the Harrisburg, Pennsylvania site was located in a rural environment while the other sites are located in urban/suburban environments. Data was obtained for precipitation, dustfall, runoff flow volume and quality, traffic characteristics and maintenance practices.

Table 37 summarizes the pollutant concentrations (flow composite values) and pollutant loadings from all six monitoring sites over the two year sampling program, 1976-77. In addition to the flow composited values, discrete samples of highway runoff were taken over the duration of a storm event. Pollutographs were developed using this discrete data, plotting concentrations and loads over time. Figure 15 and 16 show typical pollutographs for suspended solids and lead. The "first flush" phenomenon is evident when these pollutographs are compared to the hydrograph.

Samples were also obtained for bacteriological studies. At the completely paved site in Milwaukee, Wisconsin high concentrations of total and fecal coliforms were reported. Values ranged from 3,000 to 600,000 counts per 100 ml for total coliform and 10 to greater than 100,000 counts per 100 ml for fecal coliform. These concentrations were generally comparable to the quantities found at several other sites in Milwaukee, Harrisburg, Nashville and Denver. It was felt that the high concentrations observed at the completely paved Milwaukee site, which is an elevated bridge structure, may be due to bird droppings and rodents living in the storm sewers. Fecal to

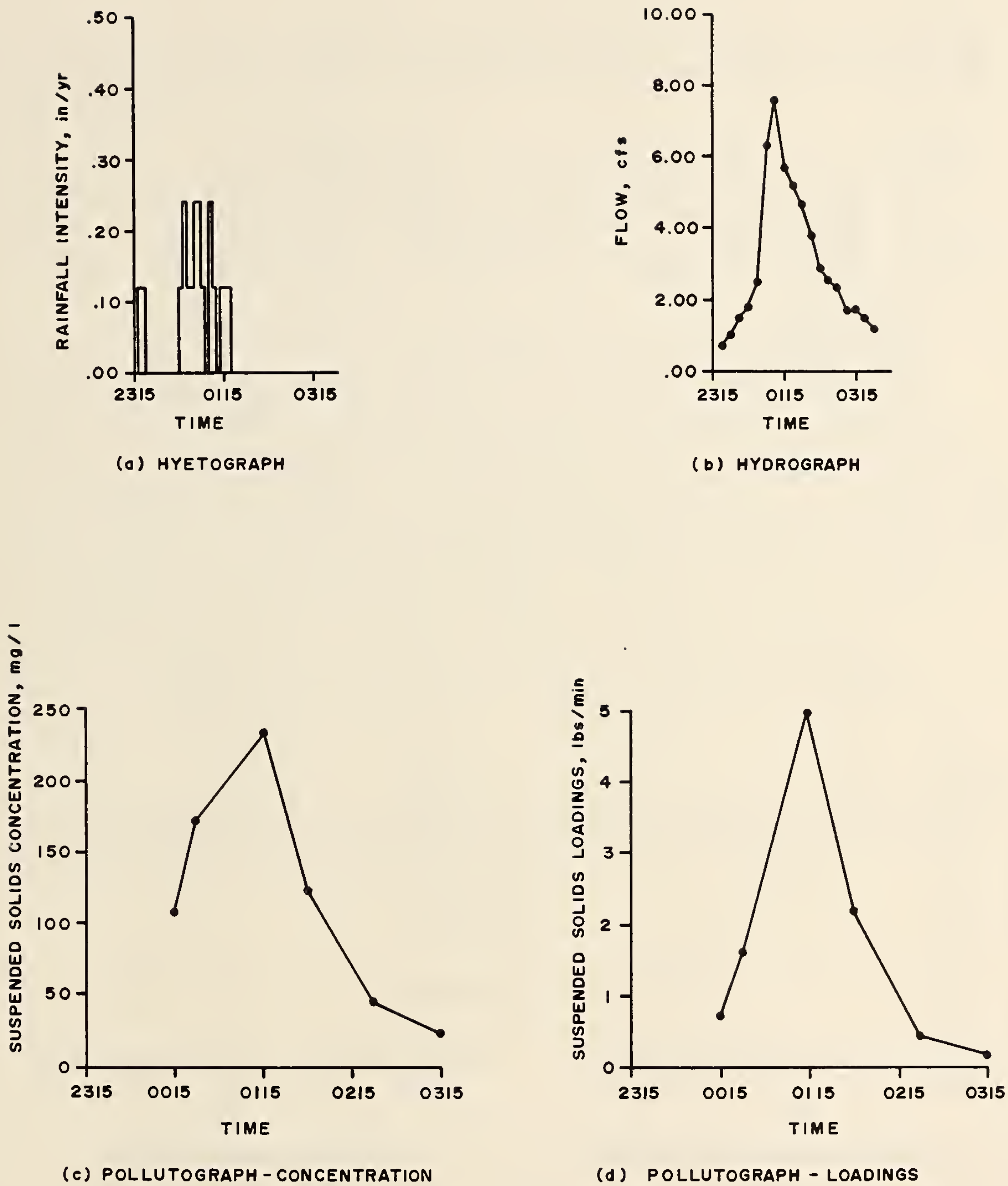
Table 37. Summary of highway runoff quality data for all six monitoring sites - 1976-1977.

	Pollutant concentration, mg/l		Pollutant loading, lbs/acre[a]	
	Average[b]	Range	Average[b]	Range
TS	1147	145-21640	51.8	0.04-535.0
SS	261	4-1656	14.0	0.008-96.0
VSS	77	1-837	3.7	0.004-28.2
BOD_5	24	2-133	0.88	0.000-4.1
TOC	41	5-290	2.1	0.002-11.5
COD	147	5-1058	6.9	0.004-34.3
TKN	2.99	0.1-14	0.15	0.000-1.04
NO_2+NO_3	1.14	0.01-8.4	0.69	0.000-0.42
TPO_4	0.79	0.05-3.55	0.047	0.000-3.6
Cl	386	5-13300	13.0	0.008-329.0
Pb	0.96	0.02-13.1	0.058	0.000-0.48
Zn	0.41	0.01-3.4	0.022	0.000-0.12
Fe	10.3	0.1-45.0	0.50	0.000-3.5
Cu	0.103	0.01-0.88	0.0056	0.000-0.029
Cd	0.040	0.01-0.40	0.0017	0.000-0.14
Cr	0.040	0.01-0.14	0.0028	0.000-0.29
$Hg\times10^{-3}$	3.22	0.13-67.0	0.00059	0.000-0.00214
Ni	9.92	0.1-49.0	0.27	0.007-1.33
TVS	242	26-1522	9.34	0.01-44.0

To obtain kg/ha, multiply lbs/acre by 1.12.

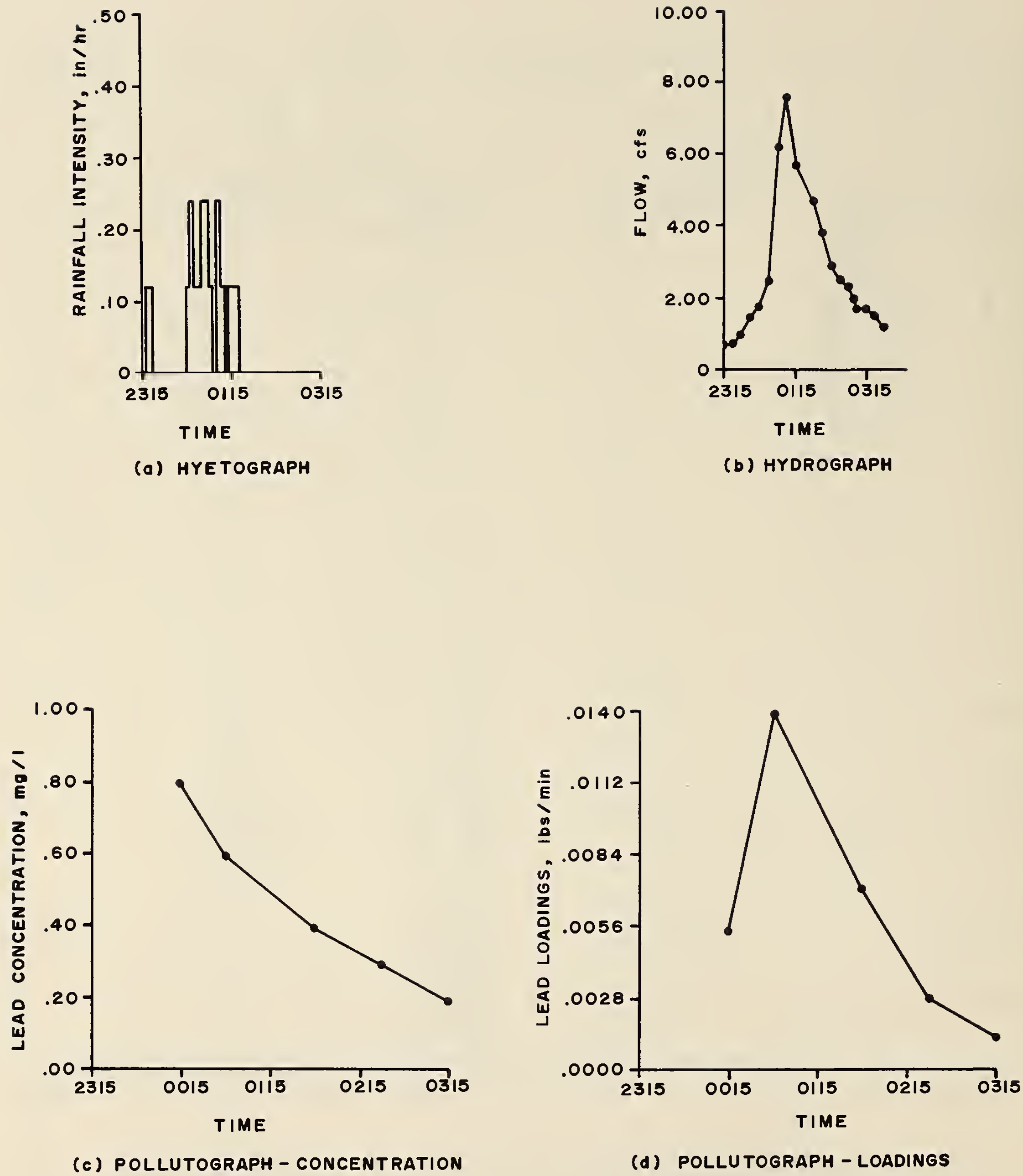
Note: [a]One site was an elevated bridge (paved only), one site was an all grassy right-of-way area (unpaved only) and the averages for the other four sites included both paved and unpaved areas.

[b]Average of 151 storm events. However, not all parameters were monitored for every event.



To obtain cm, multiply in. by 2.54.
To obtain kg, multiply lbs by 0.454.
To obtain m^3/sec, multiply cfs by 0.028.

Figure 15. Rain, flow and suspended solids quality data at Milwaukee, Hwy. 45 site - March 3, 1976.



To obtain cm, multiply in. by 2.54.
To obtain kg, multiply lbs by 0.454.
To obtain m3/sec, multiply cfs by 0.028.

Figure 16. Rain, flow and lead quality data at Milwaukee, Hwy. 45 site - March 3, 1976.

fecal strep ratios observed for runoff samples from this bridge structure averaged 0.63, indicating pollution of animal origin rather than human sources.

Analysis of oil and grease samples showed average concentrations of 20 mg/l at the completely paved site in Milwaukee, 1 mg/l at the completely pervious site in Milwaukee and values ranging from 3 to 16 mg/l at all other sites. Pesticides were not consistently detected and when found, were at low concentrations (below 1 μg/l).

The conclusion was that storm generated runoff from the highways monitored were not a major source of PCB's or herbicides/pesticides. Twenty-one samples were analyzed for asbestiform material. No asbestiform material was detected in 19 of the 21 samples from five sites. Only two samples from the Nashville site showed the presence of some asbestiform fibers. Upon further investigation, no asbestiform material could be detected in special samples collected off the highway surface itself. It is believed that in the past the City of Nashville may have utilized some sewer pipes made of asbestos and this may have been the source of such identification. However, the exact source of asbestiform material in the two Nashville samples could not be determined with surety. Further investigations regarding the presence, sources and migration of various pollutants in highway runoff is presently continued under another FHWA contract (DOT-FH-11-9357).

Data from these and other studies will be continuously used to expand upon the present state-of-the-art of the water pollution effects of the highway system development, operation and maintenance.

SECTION VI
CONCLUSIONS

The following conclusions may be draw from the literature reviewed in the previous sections:

1. The factors which most affect quantity and quality of highway runoff are traffic volume, rainfall intensity and pattern, highway drainage characteristics, operation and maintenance characteristics and degree of imperviousness of the drainage area.

2. Maintenance of adequate drainage is one of the most important aspects of highway design. The selected drainage design significantly influences runoff rates. The Rational method is the most widely used method of runoff rate estimation.

3. In general, highway runoff characteristics are similar to that of urban runoff and may exert significant shock pollutional loads on receiving waters. However, no conclusive data showing significant adverse effects of highway runoff alone on receiving waters are presently available in the literature.

4. The quantity of pollutants on urban street surfaces varies widely. The weighted average of total solids accumulations between succesive cleanings, a period of 2 to 12 days, for eight cities in the USA was found to be 1400 lb/curb mile (329 kg/km). The contaminant loadings were found to be highest in industrial areas and lowest in commercial areas. The pollutional loadings in residential areas were approximately one-half of the loadings in industrial areas.

5. A high percentage of street surface pollutants are associated with the very fine dust and dirt particles. For example: 57% of the BOD_5 load is contained in the 246 micron or less fraction.

6. Substantial quantities of toxic materials (heavy metals, pesticides, etc) are present in street surface contaminants with the amounts varying considerably from site to site. Zinc and lead were found to be the most prevalent heavy metals, measuring 0.65 and 0.57 lb/curb mile (0.182 and 0.159 kg/km) respectively. Copper, nickel and chromium may be found in smaller quantities in highway surface runoff.

7. Because of the consistent presence of heavy metals in amounts large engough to interfere with BOD_5 measurements, the COD test is considered to be a better parameter for measuring the oxygen demand potential of highway runoff.

8. Highway runoff exhibits a marked "first flush" phenomenon similar to urban runoff. However, the "first flush" is less noticeable during storms with a low, even rate of runoff.

9. Highway salting rates usually range from 400 to 1200 lbs per two-lane mile (181 to 544 kg/km) with applications repeated until the pavement is free of ice and snow. Over the winter season, a typical multiple lane highway may use 100 tons (90.7 metric tons) or more of salt per mile (1.6km). Such wide usage of de-icing salts has raised several environmental concerns relating to chloride contamination of ground and surface waters and damage to roadside soil, trees and other vegetation.

10. Significant amounts of vehicle released airborne matter (range from 10-100 tons/mile^2/month or 3.5 - 35 metric ton/km^2/month or more) is settled out and washed off the road surface during rainstorms. The dustfall contains toxic metals such as lead, and other pollutants which then are carried in the highway runoff.

SECTION VII
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SECTION VIII
GLOSSARY OF TERMS

Ammonia Nitrogen (NH4) - A form of nitrogen which is an essential nutrient to plants (can cause algal blooms if all nutrients are present in sufficient quantities). A product of natural decomposition of fecal matter, urea and other animal protein.

At-Grade-Freeway - Ground level freeways; follows as nearly as practical the natural surface of the terrain.

Average Daily Traffic (ADT) - An average value for the daily vehicular traffic on a specific roadway.

Biochemical Oxygen Demand (BOD_5) - The amount of oxygen required by bacteria in a five day period while decomposing organic matter under aerobic conditions.

Cadmium (Cd) - An element of high toxic potential when taken by mouth and possible association with renal arterial hypertension at sublethal levels.

Chemical Oxygen Demand (COD) - A determination of chemically oxidizable organic material. The sample is "completely" oxidized by chemical methods, instead of the incomplete oxidation by bacteria in the BOD_5 test.

Chromium (Cr) - A toxic element when present in the hexavalent chromium ion form.

Chute - Steeply inclined open or closed channels, which convey the collected water to a lower level.

Copper (Cu) - An essential and beneficial element in human metabolism, but quantities above 1 mg/l tend to impart an undesirable taste to drinking water.

Crown - The high point in a pavement cross section.

Cubic Feet Per Second (cfs) - One cubic foot volume of water passing a point per unit second.

Culvert - A conduit for conveying water through an embankment. It is a "grade separation" for water and the traffic above it.

Curb and Gutter - Paved area along the edge of pavement that channels surface runoff from roadways and eliminates the need for side ditches.

DDD - An organochlorine insecticide (l, l-dichloro-2, 2-bis (p-chlorophenyl) ethane)

DDT - An organochlorine insecticide (l, l, l-trichloro-2, 2-bis-(p-chlorophenyl) ethane).

Depressed Freeway - Freeways below ground level either with side slopes or due to right-of-way restrictions retaining walls.

Dieldrin - An organochlorine insecticide of fairly complex molecular structure.

Dissolved Oxygen (DO) - The amount of oxygen dissolved in a liquid. If at equilibrium with the overlaying atmosphere it is then considered saturated. Must be present to support aerobic aquatic life. Is consumed naturally in the "self-purifying" process of waterways.

Drainage Area - The area in acres contributing to the point for which channel capacity is to be determined.

Drainage Channels - Channels such as gutters, chutes, roadway channels, toe-of-slope channels, intercepting channels, median swales, and channel changes.

Drainage Ditch - A channel provided in a cut section to remove the runoff from the roadway and the cut slope.

Downspout - A vertical metal drainage pipe which removes the drainage water from bridge inlets.

Elevated Freeway - Above ground freeway located either on viaducts or on embankments.

Embankment - A structure of soil, soil-aggregate or broken rock between the embankment foundation and the subgrade.

Endrin - An organochlorine insecticide which has the same structural formula as dieldrin and is its isomer.

Erosion - Wear or scouring of soil caused by flow of water, or by wind.

Fecal Coliform (F Coli) - Indicators of recent fecal pollution in water supplies by pathogenic bacteria, expressed as a number of organisms. Most of this group of bacteria predominately inhabit the intestines of man or animals.

Flush Shoulder - That portion of the roadway contiguous with the travel way for accommodations of stopped vehicles.

Highway Drainage - The removing or diverting of surface water from the highway right-of-way.

Hydraulics - The physical science and technology of the static and dynamic behavior of fluids.

Inlet - A structure which permits the admission of surface or stormwater into a storm sewer.

Impervious - Impenetrable - Completely resisting entrance of liquids.

Iron (Fe) - An element that imparts a bitter taste to water and a brownish color to clothing laundered in such water.

Lead (Pb) - A highly toxic heavy metal when ingested for either brief or prolonged periods (cumulative poison).

Lindane - An organochlorine insecticide which is the gamma isomer of benzene hexachloride.

Loading - The average amount of total solids found on street surfaces per unit distance per day (i.e., lbs/curb mi/day).

Loess - Consists of clay and silt particles which are believed to have been transported by wind. Loess deposits tend to occur in periglacial areas, or zones that were immediately adjacent to and in front of maximum glacial advances. Several hundred thousand square miles of the earth's surface are covered with these deposits.

Manhole - A drainage structure which permits the entry of men and equipment for inspection and maintenance. Manholes are used at every change in grade or direction of the storm sewer and also at the junction of two or more large storm sewers.

Manganese (Mn) - An element which produces a brownish color in laundered goods and impairs the taste of beverages, including coffee and tea.

Median - The portion of the roadway which divides the opposing traffic.

Mercury (Hg) - A heavy metal which can cause severe neurological disorders when it is ingested in large quantities. (Particularly dangerous because small quantities can be concentrated by aquatic organisms which are frequently eaten by man).

Methoxychlor - An organochlorine insecticide (1, 1, 1-trichloro-2, 2-bis (p-methoxyphenyl) ethane).

Methyl Parathion - An organophosphate insecticide (0, 0-dimethyl o-p-nitrophenyl phosphorothioate).

Micrograms Per Gram (µg/g) - The micrograms of a specific pollutant found per gram of total solids.

Micron (µ) - A unit of length equal to 1×10^{-6} meters.

Milligrams Per Liter (mg/l) - The milligrams of a substance per liter of water on a dry weight basis.

MPN (Most Probable Number) - A statistical indication of the number of bacteria present in a given volume (usually 100 ml).

Nickel (Ni) - An element which is very toxic to most plants (especially agricultural crops) but less so to animals.

Nitrate (NO_3) - A form of nitrogen which is an essential nutrient to plants (can cause algal blooms if all other nutrients are present in sufficient quantities). Product of bacteria oxidation of other forms of nitrogen, from the atmosphere during electrical storms and from fertilizer manufacturing.

Organic Nitrogens (Org N) - "Original" form of nitrogenous nutrients. Gradually converted to ammonia nitrogen and to nitrites and nitrates, if aerobic conditions prevail. An indication of algal activity potential of a water.

Orthophosphate (PO_4) - A measure of the total inorganic phosphate content. Other inorganic phosphate forms (polyphosphate) convert to this form after several hours to several days. Inorganic phosphate is an important nutrient to plants, and excessive amounts can cause algal blooms if the right conditions prevail.

Outfall - The termination of a storm sewer into a body of water.

Pavement Abrasion - Wear on the paved roadway surfaces.

Paved Surfaces - Roadway including shoulders which support the vehicles.

Phenols - A group of aromatic alcohol compounds.

(Polychlorinated Biphenyls) PCB - Organochlorine compounds of a pesticidal nature which are usually used for industrial purposes (such as plastic manufacture).

Pounds Per Curb Mile (lb/curb mi) - A measure of loading intensity of a pollutant per unit distance.

Right-of-Way - A general term denoting land, property, or interest therein, usually in a strip, acquired for or devoted to a highway.

Roadbed - The graded portion of a highway within top and side slopes prepared as a foundation for the pavement structure and shoulder.

Roadway - The portion of a highway, including shoulders, for vehicular use. A divided highway has two or more roadways.

Runoff - That part of the precipitation which runs off the surface of a drainage area and reaches a stream, other body of water, or sewer.

Shoulder - The portion of the roadway contiguous with the traveled way for accommodation of stopped vehicles for emergency use, and for lateral support of base and surface courses.

Storm Sewer - Carries storm and surface water and street wash exclusive of domestic and industrial wastes.

Superelevate - The raising of one pavement edge in a curvilinear section in order to allow the vehicle to negotiate the curvature at the design speed.

Swale - A shallow depressed area at or near the center of the median used to drain the median area and portions of the roadway.

Toe-of-Slope - The point at which an elevated freeway embankment side slope meets the existing ground.

Topography - The configuration of the physical features of the land.

TOC (Total Organic Carbon) - A test to measure the carbonaceous organic material present in a sample.

Total Coliforms (T Coli) - Bacterial indicators of less recent pollution and/or the existence of defects in water treatment or distribution. (These bacteria are of nonfecal origin usually originating in soil).

Trunk Sewer - A sewer to which one or more branch sewers are tributary.

Underdrain - A metal pipe with perforations for the purpose of intercepting ground water or seepage.

Vertical Curve - That portion of the vertical alinement that affects gradual change between tangent grades.

Viaduct - A bridge carrying a road or railroad over an obstruction.

Water Table - The upper limit of the ground saturated with water.

Water Spread - The number of allowable inlets which determines the width of storm water on the paved surface.

Zinc (Zn) - When present in excess in water supplies, it can impart a milky appearance and metallic taste to the water. Is toxic to many organisms in large quantities.

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FEDERALLY COORDINATED PROGRAM (FCP) OF HIGHWAY RESEARCH AND DEVELOPMENT

The Offices of Research and Development (R&D) of the Federal Highway Administration (FHWA) are responsible for a broad program of staff and contract research and development and a Federal-aid program, conducted by or through the State highway transportation agencies, that includes the Highway Planning and Research (HP&R) program and the National Cooperative Highway Research Program (NCHRP) managed by the Transportation Research Board. The FCP is a carefully selected group of projects that uses research and development resources to obtain timely solutions to urgent national highway engineering problems.*

The diagonal double stripe on the cover of this report represents a highway and is color-coded to identify the FCP category that the report falls under. A red stripe is used for category 1, dark blue for category 2, light blue for category 3, brown for category 4, gray for category 5, green for categories 6 and 7, and an orange stripe identifies category 0.

FCP Category Descriptions

1. Improved Highway Design and Operation for Safety

Safety R&D addresses problems associated with the responsibilities of the FHWA under the Highway Safety Act and includes investigation of appropriate design standards, roadside hardware, signing, and physical and scientific data for the formulation of improved safety regulations.

2. Reduction of Traffic Congestion, and Improved Operational Efficiency

Traffic R&D is concerned with increasing the operational efficiency of existing highways by advancing technology, by improving designs for existing as well as new facilities, and by balancing the demand-capacity relationship through traffic management techniques such as bus and carpool preferential treatment, motorist information, and rerouting of traffic.

3. Environmental Considerations in Highway Design, Location, Construction, and Operation

Environmental R&D is directed toward identifying and evaluating highway elements that affect the quality of the human environment. The goals are reduction of adverse highway and traffic impacts, and protection and enhancement of the environment.

4. Improved Materials Utilization and Durability

Materials R&D is concerned with expanding the knowledge and technology of materials properties, using available natural materials, improving structural foundation materials, recycling highway materials, converting industrial wastes into useful highway products, developing extender or substitute materials for those in short supply, and developing more rapid and reliable testing procedures. The goals are lower highway construction costs and extended maintenance-free operation.

5. Improved Design to Reduce Costs, Extend Life Expectancy, and Insure Structural Safety

Structural R&D is concerned with furthering the latest technological advances in structural and hydraulic designs, fabrication processes, and construction techniques to provide safe, efficient highways at reasonable costs.

6. Improved Technology for Highway Construction

This category is concerned with the research, development, and implementation of highway construction technology to increase productivity, reduce energy consumption, conserve dwindling resources, and reduce costs while improving the quality and methods of construction.

7. Improved Technology for Highway Maintenance

This category addresses problems in preserving the Nation's highways and includes activities in physical maintenance, traffic services, management, and equipment. The goal is to maximize operational efficiency and safety to the traveling public while conserving resources.

0. Other New Studies

This category, not included in the seven-volume official statement of the FCP, is concerned with HP&R and NCHRP studies not specifically related to FCP projects. These studies involve R&D support of other FHWA program office research.

* The complete seven-volume official statement of the FCP is available from the National Technical Information Service, Springfield, Va. 22161. Single copies of the introductory volume are available without charge from Program Analysis (HRD-3), Offices of Research and Development, Federal Highway Administration, Washington, D.C. 20590.