EPA-600/2-77-064c
August 1977

Environmental Protection Technology Series

NATIONWIDE EVALUATION OF COMBINED SEWER OVERFLOWS AND URBAN STORMWATER DISCHARGES

Volume III: Characterization of Discharges

Municipal Environmental Research Laboratory
Office of Research and Development
U.S. Environmental Protection Agency
Cincinnati, Ohio 45268

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COMBINED SEWER OVERFLOWS AND URBAN STORMWATER DISCHARGES

Volume III: Characterization of Discharges

by

Martin J. Manning
Richard H. Sullivan
Timothy M. Kipp
American Public Works Association
Research Foundation
Chicago, Illinois 60637

Contract No. 68-03-0283

Project Officer

Richard Field
Storm and Combined Sewer Section
Wastewater Research Division
Municipal Environmental Research Laboratory(Cincinnati)
Edison, New Jersey 08817

MUNICIPAL ENVIRONMENTAL RESEARCH LABORATORY
OFFICE OF RESEARCH AND DEVELOPMENT
U.S. ENVIRONMENTAL PROTECTION AGENCY
CINCINNATI, OHIO 45268

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FOREWORD

The Environmental Protection Agency was created because of increasing public and government concern about the dangers of pollution to the health and welfare of the American people. Noxious air, foul water, and spoiled land are tragic testimony to the deterioration of our natural environment. The complexity of that environment and the interplay between its components require a concentrated and integrated attach on the problem.

Research and development is that necessary first step in problem solution and it involves defining the problem, measuring its impact, and searching for solutions. The Municipal Environmental Research Laboratory develops new and improved technology and systems for the prevention, treatment, and management of wastewater and solid and hazardous waste pollutant discharges from municipal and community sources, for the preservation and treatment of public drinking water supplies and to minimize the adverse economic, social, health, and aesthetic effects of pollution. This publication is one of the products of that research; a most vital communications link between the researcher and the user community.

The study describes what has been learned from a variety of field investigations which allow the quality of urban stormwater runoff and combined sewer overflows to be characterized in terms of their pollutional strengths.

Francis T. Mayo
Director
Municipal Environmental Research
Laboratory

ABSTRACT

An analysis was made of existing data to characterize the pollutional strength of urban stormwater runoff and combined sewer overflows. Published and unpublished data were evaluated.

Extensive evaluation was made of census track data to develop data concerning land use and population densities in urban areas to assist modelling of urban stormwater discharge.

Utilizing the developed data, an analysis of receiving water impacts was made.

It was found that much of the available data was developed without consideration of the quantity of flow at the time quality was being considered. A wide variety of methods used to sample flows further complicates the use of much reported data.

The estimated runoff pollutional contributions were found to exceed any contributions of treated sanitary flows at the time of a storm event. Thus, runoff pollution can govern the quality of receiving water due to the shock effect and long term buildup of solids.

This report is submitted in partial fulfillment of EPA Contract 68-03-0283 by the American Public Works Association. Work was completed as of November 1976.

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ACKNOWLEDGEMENTS

This volume was written as part of USEPA Contract #68-03-0283, "Nationwide Evaluation of Combined Sewer Overflows and Urban Stormwater Discharges." Insofar as the basis for the conduct of the overall project was existing published and unpublished sources of information, this report represents a compendium of contemporary approaches to the assessment of urban stormflow discharges; some of the data employed to support these approaches; and the apparent deficiencies that remain to be reconciled by further research and investigation.

The development of this volume was under the direction of Richard H. Sullivan, General Manager of the American Public Works Association. Another principal involved in this effort was Martin J. Manning, formerly Director of Research for the American Public Works Association, and now Manager, Wastewater Division, Department of Public Works, City of Houston, Texas. Other contributors to this report were:

American Public Works Association:

Daniel Eberhardt	William Murphy	Russell Doyle
Kelvin Shiu	Timothy Kipp	Linda Kalafut
Shin Ahu	Ken Pai	Susan Groeneveld

University of Florida:

Wayne Huber	Miguel Medina	Sheikh Hasan
James Heaney	Michael Murphy	Tony Arroyo
	Michael Fladmark	

A project steering committee was created as part of the research effort. This committee provided advice, assistance, and direction during the conduct of the work, and included:

Murray McPherson, ASCE
Donald G. Shaheen, Biospherics, Inc.
Kenneth Eff, Formerly of Corps of Engineers
Michael A. Ports, Water Resources Administration, State of Maryland
M.T. Augustine, Water Resources Administration, State of Maryland
Herbert Poertner, Consultant
Francis J. Condon, USEPA
J. Charles Baummer, National Commission on Water Quality

ACKNOWLEDGEMENTS (CONTINUED)

Additional help and assistance in the review of project end products and draft reports was also provided by the project management and steering committee of a similar work performed for the Province of Ontario, Canada, including the following individuals:

Thomas Koplyay, Environmental Protection Service, Canada
Donald Weatherbe, Ministry of the Environment, Ontario, Canada
Charles Howard, Charles Howard & Associates, Ltd., Winnipeg, Manitoba, Canada
Don Waller, Nova Scotia Technical College, Halifax, Nova Scotia, Canada
Harry Torno, USEPA, Washington, D.C.

The USEPA Project Officer for this research activity was Richard Field, Chief, Storm and Combined Sewer Section of the Municipal Environmental Research Laboratory in Edison, New Jersey.

SECTION I

FINDINGS AND RECOMMENDATIONS

The various sections of this report are concerned with the pollution of urban sewered and unsewered stormwater discharges and combined sewer overflows. In addition, the pollutional effects of these varied sources of contamination are discussed under the heading of "Receiving Water Impacts," Section V. A discussion of the characterization of urban development as required for the modelling activities performed in connection with Volume II of this report, whose theme is the national control and cost assessment for urban storm-generated pollution, has been provided.

The information for this report has been derived from published and unpublished sources of data. This volume has been designed to provide a summarization of much that is known of urban runoff pollution. The drawing together of its different sections, however, also helps to pinpoint those parts of the total spectrum of urban runoff pollution that may require broader and better understanding. It seems likely that practical approaches to alleviation of urban runoff problems, where they exist, can only proceed from a clear perception of the problem, and the more cost-effective solutions attendant upon these preceptions.

Findings and recommendations are presented in order to clarify the origins and effects of urban runoff pollution. Relevant data for future urban runoff impact characterizations are also discussed.

URBAN RUNOFF POLLUTION ORIGINS

An evaluation of the origins of urban runoff pollution is needed for an understanding of the mechanisms by which runoff is contaminated. Clearer understanding also serves to suggest viable pollution control alternatives to the traditional sanitary engineering approaches of wastewater collection, transportation, treatment, and disinfection. Given the contributions of pollutants from various sources and pollutant repositories, preventive methods that may alleviate their pollutional potentials may be possible.

Contaminants may be prevented from entering water courses in runoff by a number of innovative techniques. Among others, it is apparent that regulatory activities concerned with the interim stabilization of vacant property in construction sites will reduce the pollutant contributions from erosion. Urban development policies and guidelines that consider on-site runoff detention may eliminate pollutional contributions from developed sites. Design standards for street design employing uncurbed cross sections and sediment traps may be helpful in reducing street surface pollutional contributions. Further, local codes governing the discharge of roof drainage leaders to pervious areas or on-site runoff detention sites may prove effective in reducing roof runoff pollution contributions.

In addition, public works programs, practices, and equipment may also affect the quality of urban runoff. More effective street cleaning programs employing efficient cleaning equipment at a relatively high frequency of cleaning can alleviate the pollutional contributions from street surface contaminant, as can efficient and properly-programmed catch basin cleaning activities and snow and ice control practices among others.

Thus, considerable value may be derived from the careful study and evaluation of potential runoff pollution sources and repositories if prevention and control is to be an effective supplement to customary abatement measures.

A. Finding: Existing data and information on many sources and repositories of potential runoff pollution are very limited. Much of the existing information available is reported in studies that have either investigated street surface pollutant accumulations or pollutional sources and repositories that are non-urban in nature. Most of the latter represents data and technology that originate in a variety of studies from a number of disciplines. The summary of information in the foregoing sub-sections on vegetation resulted from investigations in agriculture, silviculture and forestry; erosion information was a product of research in agriculture; and air pollution contribution data was derived from investigations of air quality. The purposes and intent of these studies were not to address the issues of urban water-borne pollution. Thus, the applicability of these sources of information is limited.

B. Recommendation: Various sources and depositories of potential pollutants should be further measured, evaluated and characterized in terms of their urban runoff pollutional characteristics. These analyses should be of specific sources or repositories and correlated to those physical and other factors instrumental to their becoming sources of runoff pollution. The pollutional sources and repositories that should be considered should include among others:

1. Contamination of receiving waters through discharges in melt water of the contaminants entrapped in snow and ice deposits directly from source contamination or through snow and ice control methods. Much of the interest exhibited to date in this area has been in terms of chloride contributions as they are liberated from snow and ice control materials. More recently, investigations have provided general characterization data not only for these pollutional contributions, but for source contaminants entrapped within snow and ice deposits as well. Melt water contributions and their occurrence, magnitude over time or in relationship with varying precipitation events, and temperatures remain to be more fully investigated.

2. Water quality impairing characteristics of atmospheric particulates. Atmospheric intermedia effects as such are little understood, and the contributions of contaminants to surface runoff pollution from these sources may be significant within urban areas. A clearer understanding of these water quality effects would serve to indicate some of the impacts of air pollution heretofore undefined and further pinpoint the necessity for both air pollution and water pollution control. An evaluation of air pollutional contributions to runoff in terms of sanitary engineering water quality parameters alone would prove to be enlightening.

3. Pollutional contributions from the weathering or wear products of street surface and other impervious surface materials. Indications exist that these materials may represent heretofore undefined sources of runoff contamination. Determination of the magnitude of pollution involved would prove helpful in establishing effective control strategies for these sources.

4. Water quality characteristics of urban sediment, corrosion, and erosion products. The study of erosion and erosion products have generally been related to non-urban conditions. Their water quality characteristics are not clearly defined, but should be if the true water quality impacts are to be established.

5. Pollution contributions attributable to tree and leaf litter evaluated in sanitary engineering water quality terms. Vegetative contributions, as such, may afford a significant source of urban runoff water quality impairment during those periods of the year when leaf fall occurs. A clearer understanding of these contributions would be helpful in the assessment of their relative impacts.

6. Pollutional potentials of accumulations on other non-street impervious surfaces. Little real data exist for the assessment of pollutional potentials from these sources.

7. Economic-aesthetic impact of coarse and floatable solids. Only fragmentary data is available as to the impact upon property and property values from the discharge of coarse and floatable solids.

DISCHARGE POLLUTION

The majority of data on runoff pollution generally takes the form of discharge measurement information. Within a given urban drainage area, discharge pollution measurements represent the integration of the pollutional contributions from all available sources. As such, runoff pollution information is the most complete representation of the pollutional experience that may be anticipated within a defined basin for given rainfall and runoff conditions.

A. Finding: Runoff discharge pollution data are reported on the basis of mean concentration values for the purposes of gross characterization. The time-related effects such as first flush contributions or variations of concentration with flow in time, are not reflected in these average values. Seldom has sufficient discharge information been collected to provide a more complete characterization reflecting these variations.

B. Recommendation: A detailed study of runoff discharges from a completely developed urban drainage basin should be performed. Runoff, as collected by a storm drainage collection system, should be metered and sampled to reflect the time-related responses of the system as to flow and concentration for a variety of rainfall and runoff events. Discreet samples of runoff should be collected and analyzed to provide quality information on these urban runoff flows. The analysis should seek to provide some indications of runoff characterization over time.

SAMPLING METHODS

Variability in sampling methods for both wet and dry samples are reported in the literature. Insofar as these sampling methods vary, the reported results may also vary.

A. Finding: A need exists for consistent and comparable sampling results.

B. Recommendation: Standardization for sample taking and analysis should be developed.

In view of this general finding, the following recommendations for further research are proposed:

1. Standardize data collection and analytical methods for the evaluation of street and non-street impervious surface accumulations and their pollutional potentials for runoff.

2. Investigate and standardize sample handling and processing techniques for a subsequent analytical evaluation of the potential physical, chemical and biological water quality characteristics of dry samples. Current practices in the handling of dry samples are varied and often unrelated to the mechanisms by which these potential contaminants become runoff pollution. Thus, further study in this area is warranted.

3. Develop standard methods and procedures for the metering of runoff flows and for the collection and analysis of urban runoff samples. Significant efforts in developing standard methods for sampling discharges has been performed to compare alternative sampling techniques and find desirable standard methods. (75) Proceeding from this work, further methodological

development applicable to the specifics of urban runoff pollution samples should be established.

4. Establish standard procedures for the collection of verification data to be employed in the evaluation of existing analytical methodologies. These procedures should include methods appropriate for the accumulation of precipitation data, receiving water quantity metering, sample collection, sample processing preparation and sample preservation techniques.

5. A sampling program is needed which measures both effluent quality and surface (street dust and dirt) quality.

WET WEATHER FLOWS

Comparisons of wet and dry weather flow pollutional contributions based on available data and existing analytical methods suggest that significant contributions originate in a number of identifiable sources--street surfaces, non-street impervious areas, pervious areas, catch basins and the collection system itself. Rainfall contributions themselves may also prove to be significant. Evaluative mechanisms exist by which pollutional contributions may be calculated. In sufficient information, however, specific to the sources analyzed is available to provide an estimating basis for many of the pollutants that should be evaluated. As an added consideration, little or no verification data is available with which to compare the results of these estimating methods with real runoff quality data.

A. Finding: Comparisons of estimated runoff pollutional contributions to those of other wastewater flows and treated effluents from various levels of treatment show that runoff solids contributions--total and suspended--far exceed those associated with other wastewater flows at any level of treatment. Runoff BOD estimates exceed those of secondary effluents; runoff COD estimates are greater than primary treatment effluent contributions; and runoff metal contributions--zinc and lead--are estimated to be greater than those of raw domestic wastewater. In view of the significance of runoff pollutional contributions, the following recommendations for additional investigation are of particular importance.

B. Recommendation: A field demonstration effort should be instituted on one or more select small-scale urban drainage sub-basins to achieve a number of significant objectives. Among these would be:

1a. Identification of the pollutional contributions associated with urban sources and repositories of contaminants for various measures of oxygen depletion, nutrients, pesticides, metals, and other contaminants.

1b. Comparison of sampling and analytical results for both identified potential pollutional contributions--street surface, rooftops, erosion products, rainfall, etc.--and for the actual equivalent discharges related to these potential pollutional contributions.

1c. Evaluation of the effectiveness of local control methods applicable to the prevention of runoff contamination.

1d. Comparison of both potential and actual pollutional contributions among existing types of development in various land uses.

1e. Assessment of the impacts of the first flush phenomenon, including the contributions of catch basins and sewer system accumulations.

2. The accumulation and removal mechanisms applicable to the deposition of pollutants on street surfaces and other impervious surfaces. These would include: airborne, waterborne, vehicular-produced, and miscellaneous dispositions, as well as wind erosion, runoff, transportation-related, and intentional removals. These accumulation and removal mechanisms should be evaluated in terms of various street configurations, paving types,curb and other barrier heights, land use and other variables.

3. The removal of street surface contaminants by runoff flows to establish the physical processes involved. Such evaluation should consider the hydraulic modelling of rainfall and runoff on representative street sections if necessary.

4. The evaluation of the effectiveness of street cleaning equipment including new cleaning technologies in reducing the levels of potential pollution on street surfaces. Such studies should relate air and water pollution.

5. The quantitative contributions of urban erosion sediments in relationship with the major variables involved--soil characteristics, cover management practices, rainfall and other hydralogical conditions, physical configurations,and other measurable parameters. Although annual estimating methods exist for agricultural sediment production,either shorter-term single rainfall erosion responses remain to be determined or the applicability of existing estimating methods to urban areas and individual rainfall occurences should be validated.

6. Sources of potential pollution for urban runoff to provide a basis of prediction in connection with existing analytical methodologies or the development of new expanded methodologies. Little real information in this regard is available.

7. Further study and evaluation of calibration techniques employing verification data for the calibration of existing models and their use for the prediction of pollutional contributions due to subsequent runoff events. Recalibration techniques employing discharge information have been shown to be promising approaches for fine tuning models to assure higher levels of accuracy in prediction. These procedures should be further evaluated and more highly developed for existing models where they may apply.

URBAN DATA

Urban development data serve as key parameters in a number of existing runoff pollution estimating methods.

A. Finding: Deficiencies exist within available data as to reputable and comparable land use information for total urbanized areas including central cities,suburbs and the unincorporated urban fringes. Information on imperviousness; length of combined, separate and storm sewers; street length; location and length of swales; and extent of drainage areas are not well defined, and existing sources of this information are limited.

B1. Recommendation: Further research into urban development characteristics should be instituted, and recommended procedures for the collection of this data should be established.

B2. Recommendation: Various urban development parameters should be studied and analyzed as to their applicability as meaningful parameters for the estimation of urban runoff pollution. This analysis should proceed on the basis of real runoff quality discharge information. The relative importance of various urban development parameters with respect to runoff discharge pollutional characteristics should be established.

RECEIVING WATER IMPACTS

The existing analytical methods available for the evaluation of receiving water impacts are generally based on steady-state conditions emphasizing dissolved oxygen and non-conservative pollutants.

A. Finding: Under given wet weather conditions, runoff pollution can govern the quality of receiving waters due to their shock effects and long term build-up of solids. High-level dry weather treatment may not be a guarantee of receiving water quality created by wet-weather conditions. The relative pollutional contributions among urban and non-urban sources indicate that non-urban locales contribute a significant portion of the pollutional load within the receiving water in many instances.

Recommendation:

1. Research to establish on a nationwide basis, the comparison of the pollutional contributions in receiving waters as needed. These may be proposed on generalized per acre annual emission for various types of land use.

Recommendation:

2. Effects of benthal deposits and other sources of pollutional impacts on receiving water should be further studied and evaluated. The impact of these deposits resulting from combined sewer overflows and stormwater runoff on water quality is generally significant and of considerable interest. The fate of heavy metals is of particular concern.

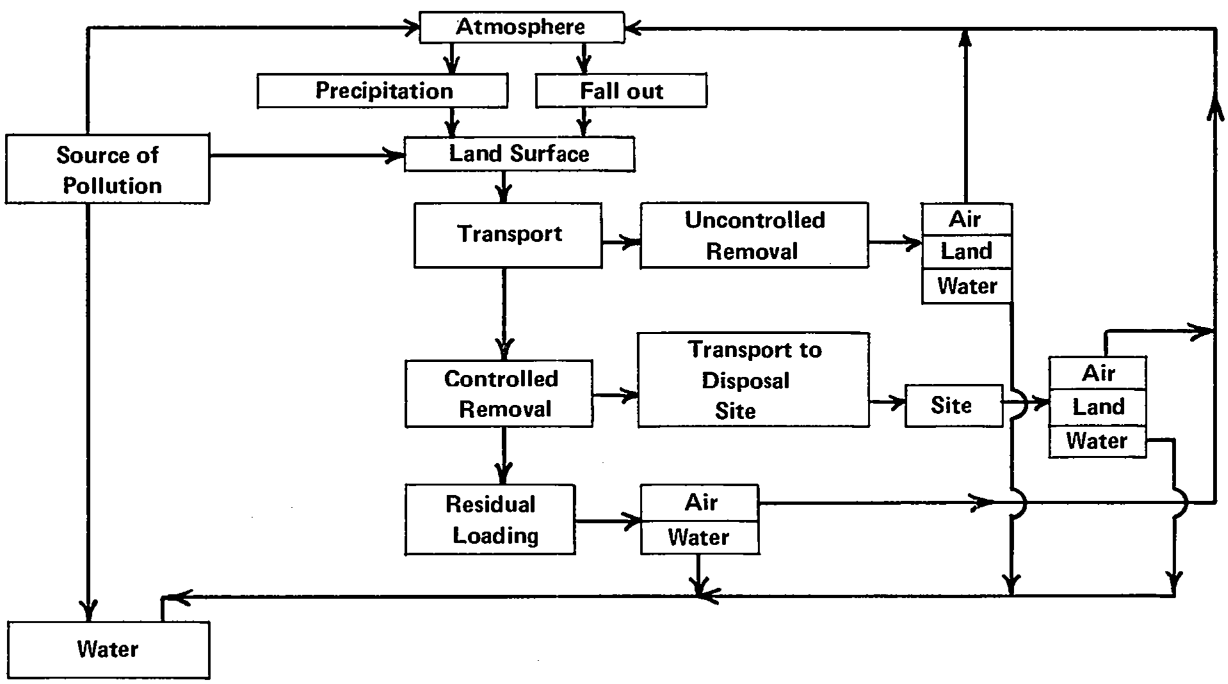
Section III of this volume reviews at length the available information concerning the various sources and points of release to stormwater systems. Table 1 contrasts sources by points of release. Strategies for control must consider the points where source control can be effective, as contrasted to the feasibility and cost of controlling the pollutants at the point of release prior to contaminating stormwater.

TABLE 1. MAJOR POTENTIAL SOURCES OF URBAN STORMWATER POLLUTION BY POINTS OF RELEASE TO STORMWATER SYSTEMS

Potential Major Sources	Point of Release to Stormwater						
	Roadways	Roofs	Other Impervious Areas	Pervious Areas	Catch Basins	Sewer Systems	Rain
1. Transportation Activities	X		X		X		X
2. Applied Chemicals (Direct & Indirect)	X		X	X			X
3. Air Pollutional Dustfall	X	X	X	X			X
4. Vegetation	X		X	X	X		
5. Erosion/Sediment	X	X	X	X	X		X
6. Solid Waste/Litter	X		X	X	X		
7. Connections with Sanitary Sewer System						X	

The distinction between a secondary source and a point of release must be arbitrary. Figure 1 attempts to vividly portray the interrelationships of the sources and control activities. Figure 2 indicates some of the activities and phenomenom which produce the "source". Similar system analyses of each of the major sources identified in Table 1 would indicate a similar blurring and need for careful analysis of the total system.

Figure 1. Relationship between air and water pollution.



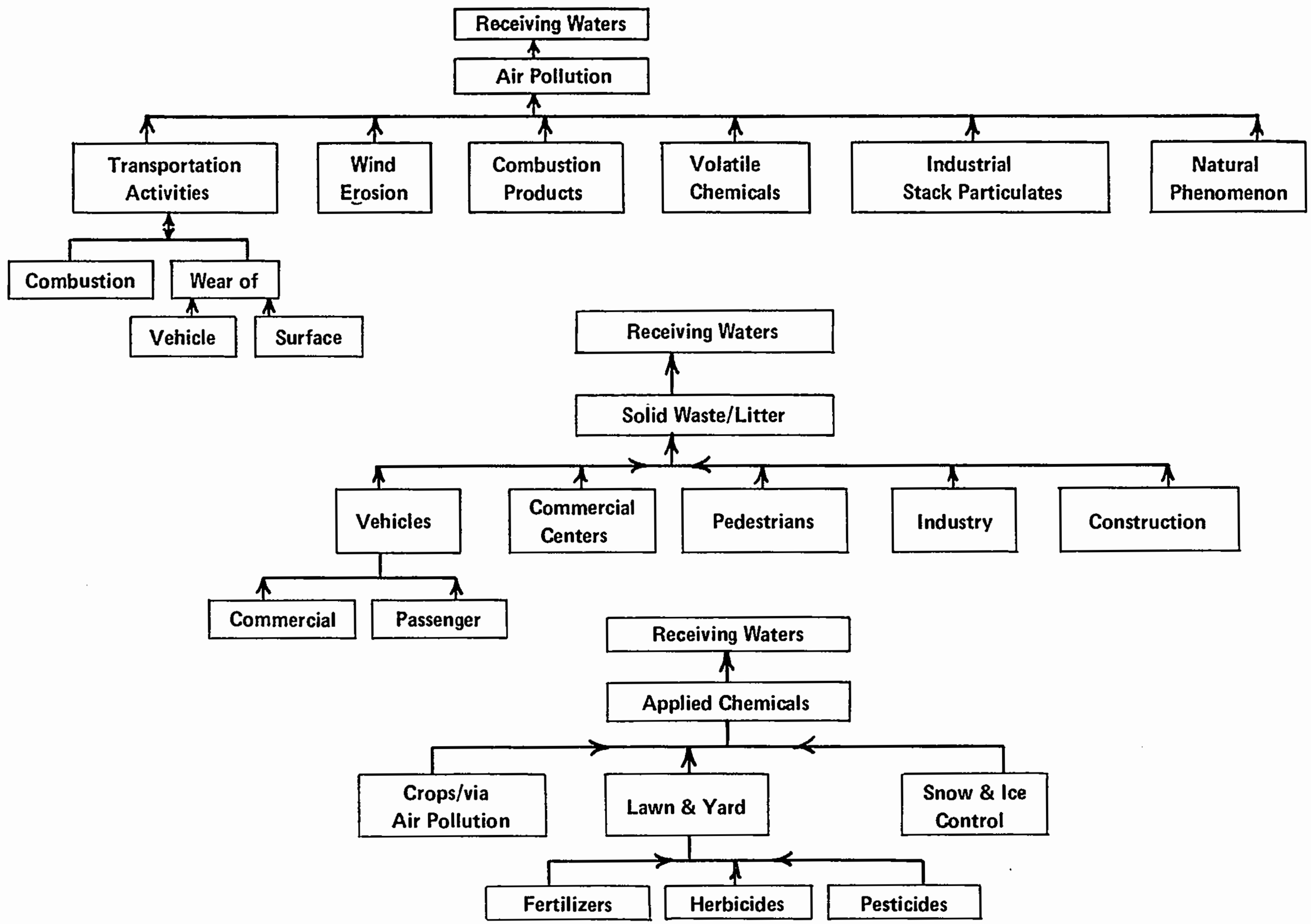


Figure 2. Illustrative components of potential pollution sources.

SECTION II

THE STUDY

The American Public Works Association (APWA) and the University of Florida (UF) jointly, under contract with the United States Environmental Protection Agency (USEPA), have conducted a study to characterize urban sewered and unsewered stormwater discharges and combined sewer overflows, and to determine the cost of control or abatement of receiving water pollution from such sources.

This study, "Nationwide Characterization, Impacts and Critical Evaluation of Stormwater Discharges, Non-Sewered Urban Runoff and Combined Sewer Overflows" encompasses a number of objectives. These include the generalization of the quantity and quality characteristics of urban storm sewered discharges, combined sewer overflows and non-sewered urban runoff; an assessment of the pollutional significance of these storm-generated flows on a national basis as to their impacts, applicable prevention, abatement and control methods, and the related costs of better managing their pollutional contributions; and the critical evaluation of these flows in relation to other known pollutional discharges. An additional objective of this work was to determine gaps and weaknesses in existing information and to make recommendations for improving this store of data where it appears to be sparse.

The origins of this project were defined as existing published and unpublished sources of information and data. Thus, a broad survey of the literature and other data sources was instituted by both APWA and UF.

Among the most useful data sources were USEPA research reports which describe:

- Storm-generated discharge magnitudes for various urban drainage basin characteristics

- Pollutional characteristics of these discharges including solids measures, oxygen consumption measures, nutrients, heavy metals, PCB's, chlorinated hydrocarbons, chlorides, cyanides and ferrocyanides and bacteriological measures

- The pollutional significance of these discharges on receiving streams and treatment systems

- Recommended degrees of prevention, abatement and treatment appropriate to the encountered on a case-by-case study basis

- Abatement cost

Some broad inconsistencies exist within the body of information uncovered as to the handling and reporting of various aspects of the complex physical processes involved, sampling methods and equipment, the pollutants measured and associated characterizing parameters and the results identified. While the diversity and variation encountered is representative of the current state-of-the-art, it also reflects the evolutionary character of this area of study over the past ten years or so. Nevertheless, the information uncovered is representative of the best available for the purposes of this project.

Specifically, this research effort has successfully tapped these reference sources within the data available to:

1. Characterize urban storm sewered discharges, combined sewer overflow and non-sewered urban runoff quantitites (flowrates and volumes) of basin physical characteristics, climatology, and urban development characteristics.

2. Characterize the quality of flow related, storm generated pollutants with respect to select pollutants in terms of generally identified urban basin parameters.

3. Determine the pollutional significance of these storm generated discharges with respect to receiving waters and the means to effect control of these pollution sources.

4. Critically evaluate the pollutional character of these discharges by comparison with various other wastewater flows.

5. Evaluate the use of alternative indicators for defining stormwater induced flow strength.

6. Summarize briefly the use of alternative sampling plans and methods.

7. Determine gaps in current knowledge through an evaluation of the state-of-the-art and to make recommendations for strengthening the existing body of knowledge concerning runoff induced pollutional problems.

Many of the results of the literature investigation form the basis of this report. These encompass such topical areas as the characterization of runoff quantity and quality, the generalization of demographic and physical development characteristics of urbanized areas, and a compilation of receiving water impacts due to the quantity and quality contributions of storm-caused discharges.

Section III reviews runoff quantity and quality, including summarization of what is known of direct runoff pollutional sources, general characterization of dry weather flows including raw sanitary wastewater flows; primary, secondary and advanced treated municipal wastewater effluents; and results of various studies of discharge pollution from combined sewer overflows and recorded runoff discharges. This section of the report also includes a comparison of the various pollutional sources as they might be theoretically studied in a hypothetical case study derived from various actual sources.

Section IV which considers the demograhpic and physical development characteristics of urban areas, covers the assumptions and derivation of these elements for their subsequent use in the computations for Volume II of this report. Although information for individual cities is available for some data, little is known of the complete relationships of central city, suburbs, and urbanizing areas associated with urban areas. Thus, some generalizations were developed to provide a first basis for the estimation of pollutional contributions on a national basis. Eventually less complex estimating procedures were used to prepare the cost estimate.

The review of receiving water impacts, Section V, compiles the results of a number of studies that have addressed this issue. This summary indicates the effects of the pollutional contributions of sanitary wastewater effluents, stormwater discharges and combined sewer overflows. Volume II, Section VII develops data for the Des Moines, Iowa area.

Section VI addresses the apparent gaps within existing available information. The additional data that would be helpful in the delineation of the pollutional effects of storm sewer discharges, combined sewer overflows, and unsewered runoff are discussed. Thus, the information contained in this volume is intended to provide a freestanding but supplementary document to the other volumes of this project. This volume as such, comprises an important adjunct of the overall study effort that not only details many of the sources of information, assumptions, and background employed in the overall research project; but should also provide helpful insights as to future needed research, deficiencies in existing information, and alternative approaches to the fulfillment of data needs, as well to others interested in the significant pollutional contributions of stormwater discharges, combined sewer overflows, and general runoff, and their effective prevention, control, and abatement.

SECTION III

CHARACTERIZATION OF URBAN SEWERED AND UNSEWERED STORM SEWER DISCHARGES AND COMBINED SEWER OVERFLOWS

Little doubt now exists that stormwater runoff represents a significant source of water pollution. It bears importantly upon the quality of the nation's streams, esturaries, lakes and oceans. Too little is known, however, of the mechanisms through which rainfall and runoff are converted from a desirable and beneficial natural phenomenon to one that also creates the hazards of water quality deterioration. An important factor in this conversion from an asset to a liability is man and his activities and their broad influence on nature and natural processes.

Considerable research has been devoted to a better understanding of the problems of runoff contamination in both urban and non-urban environments. Of particular concern to environmentalists has been urban surface runoff and its contributions to the deterioration of receiving water quality. These pollutional effects of runoff may be the end-product of both direct and indirect contributions of contaminants.

Direct pollutional contributions include those discharged in surface runoff from separate storm drainage collection systems or contributed by uncontained surface runoff entering receiving waters at locations other than clearly defined points of discharge.

Indirect pollutional contributions involve point discharge or overflows due to planned or unplanned addition of stormwater to other wastewater flows. These may include the sewer overflows from combined sanitary and stormsewer systems due to hydraulic overloading. They may also involve surcharge spills resulting from uncontrolled runoff inflow into sanitary sewer system and, in some cases, excessive subterranean infiltration.

Traditionally, direct runoff pollutional contributions have been disregarded. Surface runoff was generally characterized as a phenomenon to be quantitatively controlled. Drainage and flood control objectives were paramount in urban practice and runoff pollution was considered non-existent or, at least, a low-priority problem. Although early investigative efforts in Europe (1) and the United States (2) began to suggest the importance of surface runoff pollution, serious consideration of its effects is fairly recent. A recapitualtion of early stormwater quality findings is summarized in Table 2. It was not until a 1964 report by the U.S. Public Health Service (3) that the problem of runoff quality began to assume national importance. In the ensuing period, a number of research efforts have sought to characterize runoff pollution, to evaluate its pollutional impacts, and to explore means for its control and abatement.

TABLE 2. CHARACTERISTICS OF SEPARATE STORMWATER

	City	BOD mg/l	Total Solids mg/l	Suspended Solids mg/l	Coliform mg/l	Total Chlorides mg/l	COD mg/l
1.	East Bay						
	Sanitary District, California						
	Minimum	3	726	16	4	300	
	Maximum	7,700		4,400	70,000	10,260	
	Average	87	1,401	613	11,800	5,100	
2.	Cincinnati, Ohio						
	Average	17		227			111
3.	Los Angeles County						
	Average 1962-63	161	2,909			199	
4.	Washington, D.C.						
	Catch-basin samples during storm						
	Minimum	6		26		11	
	Maximum	625		36,250		160	
	Average	126		2,100		42	
5.	Seattle, Washington	10			16,100		
6.	Oxney, England	100[2]	2,045				
7.	Moscow, U.S.S.R.	186-285	1,000-3,500[2]				
8.	Leningrad, U.S.S.R.	36	14,541				
9.	Stockholm, Sweden	17-80	30-8,000		40-200,000		18-3,100
10.	Pretoria, South Africa						
	Residential	30			240,000		29
	Business	34			230,000		28
11.	Detroit, Michigan	96-234	310-914	102-213[1]	930,000[2]		
12.	Criteria New York State:						
	A. Potable water						
	(to be filtered)				5,000	600[2]	10
	(not to be filtered)				50		10
	B. Body contact water				2,400	NA	

[1]Mean
[2]Max.

Source: American Public Works Association, "Water Pollution Aspects of Urban Runoff," USEPA Report No. 11030DNS01/69 (NTIS No. PB 215 532), January, 1969.

One approach to the runoff problem has been to empirically characterize discharges in various drainage basins across the country. This has often involved the study of drainage flows from urban drainage basins or those subject to urbanization. In some cases, relationships between discharge and receiving water quality data have been co-related to physical basin characteristics and given rainfall events. Inconsistency exists within this body of information, however, due to the variability in research objectives being addressed, the pollutants being evaluated, the sampling techniques employed and the measurements made. Many are the by-products of human activities; their origins may be traced to man-made facilities and activities.

A body of knowledge is now being developed through the study of some of the pollutant source characteristics previously described in Figures 1 and 2. Although this area of study was developed primarily for non-urban environments and non-point discharges, some generalizations are now being applied in urban cases to estimate pollutional effects. The use of the Universal Soil Loss Equation(USLE) (4) for the estimation of sediment contributions is a good example of a non-urban technology used in an urban application.

In urbanized areas, the pollutional potentials of street litter accumulations have been studied in an effort to assess the magnitudes of the pollutants that are available to surface runoff. Considering the developed urban street as a temporary sink for the accumulation of pollutants that are representative waste products of a complex urban environment, methods for estimating the quantity of runoff pollution have been devised under the assumptions that the urban street is a logical extension of the urban drainage system and that the runoff and pollutional contributions from pervious areas will be negligible for most runoff events. This approach to the definition of urban runoff pollution may be construed as a special case of the study of contaminant source characteristics.

All of these methods represent some of the various mechanisms that have been used to assess the direct pollutional contributions of urban runoff. The priorities associated with the evaluation, abatement and control of indirect pollutional contributions have generally been much higher. Indirect contributions are overflow pollutional effects due to the admixture of runoff with other wastewater flows. Interest in uncontrolled discharges of combined sewer overflows has generally taken the form of sampling programs, and pollutional contributions have been determined through discharge measurements on a case-by-case basis. Similarly, the control and abatement of combined sewer overflows has been developed on a specific site basis.

This section will cover what is generally known of these various methods of characterizing the pollutional contributions of urban runoff--either direct or indirect. This will include consideration of some of the apparent sources of runoff pollution; the pollutional potential of urban street surface accumulations; some of the estimating methods employed to assess the pick-up and transport of pollutants by surface runoff for both point and non-point runoff; representative findings for direct and indirect runoff discharge sampling activities; and, finally, a generalized comparison of pollutional contributions from these and other sources.

RUNOFF QUANTITY CHARACTERIZATION

The quantity of stormwater surface runoff varies for different locales across the country. Some of the major causes of this variation are climate, topography, soils and catchment characteristics, vegetative growth types, and land use. A number of surface runoff estimating methods exist that take cognizance of these valuables. Some of these have been employed for this purpose and are reported in Section V, Volume II of this report in some detail.

The following parts of this report are directed to the quality characterization of these flows and the pollutional contributions they present.

SOURCES OF RUNOFF POLLUTION

Some of the apparent sources of storm runoff pollution include animal and vegetable wastes; the residuals from transportation activities; air pollutants; erosion products, including a variety of chemical constituents such as fertilizers and pesticides; various litter components; snow and ice control, chemicals, and antiskid and corrosion inhibiting additives and others.

Transportation Activities As A Source Of Runoff Pollution

Transportation is vital to urban life. The flows of trucks, buses and automobiles on urban roadways contributes benefits to the urban economy at the expense of environmental impairment. These environmental expenses are from transportation's role in contributing to air, land, noise, and water pollution. The direct effects of vehicular operation represent one important aspect of those environmental concerns. Another aspect involves transportation-related activities such as snow and ice control that are performed to assure the safe movement of traffic during periods of snowfall or freezing weather.

Vehicular Contributions--

Traffic-related pollutants are generated during daily vehicular operation and the wearing processes of the vehicle. Daily operational pollutants are fuel leakage, lubricants, hydraulic fluids, battery acids, coolants, particles from clutch and brake lining wear, particulate exhaust emissions, and debris from the private and commercial transport of passengers and materials. Vehicular components, such as glass, plastic, metals, rubber, dirt and rust are pollutant contributors via natural weathering and wear. Vibrations and impacts during operation accelerate the wearing process.

A major contribution from the operation of vehicles is pollution from incomplete hydrocarbon combustion which can deposit almost immediately upon the street surface or be released to the atmosphere for subsequent deposit on land or be scoured by rain.

Fuel, lubricants, and hydraulic fluids add to pollutant generation both directly and through the degradation products of asphaltic pavements. Vehicles produce structural damage to pavements, curbs, and gutters accelerating the degradation of these structures and increasing the quantities of pavement residues generated. Hydrocarbons exert relatively large oxygen demands. Fuel, lubricants, and hydraulic fluids also produce insoluble films in receiving waters that are aesthetically unsightly and hinder natural reaeration; this, in turn, inhibits natural biological processes. Compounds such as lead, nickel, and zinc used in the manufacturing of vehicles may also be harmful to the environment. Nitrogenous emissions increase nutrient loads.

Traffic-related pollution generation is probably influenced by seasonal, geographic and local traffic conditions. The literature provides some data and results of research dealing with the type and quantity of these pollutant elements and compounds present in receiving water due to urban wash-off.

Only two research efforts have attempted to address themselves to the questions of traffic-related runoff pollution. The first of these studies related average daily street surface accumulations with ranges of average daily traffic (ADT) (5) of 500 to over 15,000 vehicles per day. A summary of the data employed in this general analysis is shown in Table 3. The data represented are a compilation of street accumulation and mass discharge measurements. The comparative analysis resulted in the following general findings:

- Lowest copper and zinc concentrations occurred in locations with light ADT volumes (<500).
- Lowest lead concentrations appeared in locations with light to moderate ADT volumes (<5000).
- Lowest BOD_5, COD, orthophosphate, organic nitrogen, and nickel concentrations occurred in locations with moderate ADT volumes (500 - 5000).
- Lowest street accumulations of total and fecal coli counts appeared in locations with heavy ADT volumes (>15000).
- Nitrates, elemental cadmium, iron and strontium concentrations showed no differences in concentration with ADT volumes. (2)

This analysis was based on a compilation of a number of published observations, none of which were specifically for the definition of traffic-generated pollutional contributions. A specific study of pollutants generated by traffic flows took place in Washington, D.C. (6) This work involved the collection of street accumulation samples and data on traffic volumes during the sampling periods. A linear regression analysis of the results of street measurements compared with traffic volumes produced the regression coefficients shown in Table 4. Although the accumulation rates appear relatively low, they achieve considerable significance when applied to high traffic volume. Thus, an indication of the traffic contributions to street surface accumulations may be estimated on the basis of these rates.

TABLE 3. POLLUTANT LOADINGS AND CONCENTRATIONS WITH RESPECT TO AVERAGE DAILY TRAFFIC VOLUME (ADT)

		Loading lb/curb-mi/day	Loading kg/curb-km/day	Concentrations in Micrograms per Gram of Dry Solids																No./gram	
ADT				BOD_5	COD	OPO_4	TPO_4	NO_3	KH_4	OrgN	Cd	Cr	Cu	Fe	Pb	Mn	Ni	Sr	Zn	TColi[b]	FColi[b]
<500	$\bar{x}$	280	78.8	21,600	153,000	1,500	5,440	8,335	–	5,470	2.8	198	89	21,700	1,210	384	26	19	252	1.3E6	6.9E4
	σ	343	96.5	–	–	–	–	–	–	–	2.0	76	37	9,300	1,180	130	23	15	100	2.0E6	1.6E5
light	R	12-	3.4-	6,320-	45,600-	73-	–	670-	–	1,700-	0.0-	132-	33-	13,000	280-	210-	7-	3-	110-	8.4E4-	5.0E2-
		950	266	39,600	252,000	2,700		16,000		12,800	5.4	295	150	43,000	3,900	620	75	33	420	5.6E6	4.5E5
	N	12	3.4	4	4	3	1	2	–	3	8	9	9	9	9	9	8	8	9	8	8
500-5K	$\bar{x}$	140	39.2	9,500	83,000	741	212	419	–	1,515	2.9	196	107	18,900	1,060	415	17	34	418	2.1E6	3.4E5
	σ	155	43.4	8,520	83,200	950	–	269	–	846	1.6	62	31	3,500	925	140	18	32	198	2.5E6	4.6E5
light to moderate	R	20-	5.6-	1,720-	18,300-	20-	–	64 -	–	890	1 1-	138-	67-	14,000-	66	150-	0-	5-	180-	1.0E5-	5.5E2-
		600	168.0	25,300	277,000	2,800		845		2,200	6.1	320	170	23,000	3.500	700	55	110	760	9.6E6	1.3E6
	N	24	6.7	16	16	15	1	11	–	7	12	12	12	12	15	12	11	12	12	17	16
5K-15K	$\bar{x}$	146	40.9	27,400	163,000	1,340	2,980	836	2,640	2,900	3.8	215	107	22,500	2,010	442	38	18	375	3.1E6	1.7E5
	σ	211	59.1	26,000	165,000	1,250	1,070	979	1,820	2,430	2.5	80	62	10,000	1,480	172	35	10	167	7.1E6	2.8E5
moderate to heavy	R	5-	1.4-	2,900-	18,000-	30-	2,130-	37-	595-	490-	0.0-	9-	9-	2,600-	47-	160-	0-	4-	57-	2.5E4-	6.7E1-
		946	264.9	10,400	526,000	5,050	4,850	3,600	3,390	9,250	9.3	430	300	59,000	5,700	1,100	140	63	780	3.4E7	9.1E5
	N	61	17.1	38	42	43	5	37	9	30	54	54	56	56	54	55	58	51	54	57	53
>15K	$\bar{x}$	82	23.0	5,720	26,980	514	–	501	–	1,600	3.1	203	102	22,900	2,230	357	28	18	389	3.8E5	1.4E5
	σ	104	29.1	–	–	–	–	–	–	–	2.1	93	69	13,400	1,530	105	23	11	160	5.4E5	2.1E5
heavy	R	3-	0.8-	1,940-	21,000-	27-	–	323-	–	0	0.0-	24-	25-	1,400-	470-	100-	0-	5-	150-	1.8E4-	1.2E2-
		326	91.3	8,600	321,000	1,000		600			6.8	345	250	53,000	5,100	500	83	38	720	2.0E6	5.2E5
	N	17	4.8	4	4	4	–	4	–	2	16	16	16	16	15	15	15	15	16	12	11

a = Blanks indicate that no data were available.
b = Coliform counts are expressed in computer notation, i.e., $E6=10^6$.

Source: Amy, G., "Water Quality Management Planning for Urban Runoff," USEPA Report No. EPA-440/9-75-004 (NTIS No. Pb 241 689), December, 1974.

TABLE 4. ACCUMULATION RATES OF TRAFFIC INFLUENCED ROADWAYS MATERIALS
(Washington, D.C. Metropolitan Area)

Parameter	Rate lb/axle-mi	Rate gm/axle-m
Dry Weight	2.38×10^{-3}	6.71×10^{-4}
Volatile Solids	1.21×10^{-4}	3.41×10^{-5}
BOD	5.43×10^{-6}	1.53×10^{-6}
COD	1.28×10^{-4}	3.61×10^{-5}
Grease	1.52×10^{-5}	4.28×10^{-6}
Total Phosphate-P	1.44×10^{-6}	4.06×10^{-7}
Orthophosphate-P	4.31×10^{-8}	1.21×10^{-8}
Nitrate-N	1.89×10^{-7}	5.33×10^{-8}
Nitrite-N	2.26×10^{-8}	6.37×10^{-9}
Kjeldahl-N	3.72×10^{-7}	1.05×10^{-7}
Chloride	2.20×10^{-6}	6.2×10^{-7}
Petroleum	8.52×10^{-6}	2.4×10^{-6}
n Paraffins	5.99×10^{-6}	1.69×10^{-6}
Asbestos	3.86×10^{5} [a]	2.39×10^{5} [a]
Rubber	1.24×10^{-5}	3.49×10^{-6}
Lead	2.79×10^{-5}	7.86×10^{-6}
Chromium	1.85×10^{-7}	5.21×10^{-8}
Copper	2.84×10^{-7}	8.00×10^{-8}
Nickel	4.40×10^{-7}	1.24×10^{-7}
Zinc	3.50×10^{-6}	9.86×10^{-7}
Cadmium	3.11×10^{-8}	8.76×10^{-9}
Magnetic Fraction	1.26×10^{-4}	3.55×10^{-5}
Polychlorinated Biphenyls	1×10^{-4}	2.82×10^{-10}
Litter dry weight	1.69×10^{-4}	4.76×10^{-5}
Litter BOD	3.49×10^{-7}	9.84×10^{-8}

a. In fibers/axle-km

Note: An axle-mile is the length traversed for each axle of a vehicle. Hence in traveling one mile, a two-axle vehicle will contribute two axle-miles.

Source: Shaheen, D.G., "Contributions of Urban Roadway Usage to Water Pollution," USEPA Report No. EPA-600/2-75-004 (NTIS No. PB 245 854), April, 1975.

Snow and Ice Control Contributions--

Snowfall and ice represent significant hazards to pedestrian and vehicular traffic in urban areas. Risks of economic loss due to traffic delays, higher accident levels, and the need for safe assured travel by emergency and other vehicles require that snow and ice be rapidly and effectively removed or controlled.

Large parts of the United States are subject to an annual snowfall sufficient to require some control operations. An indication of the area involved is shown in Figure 3.

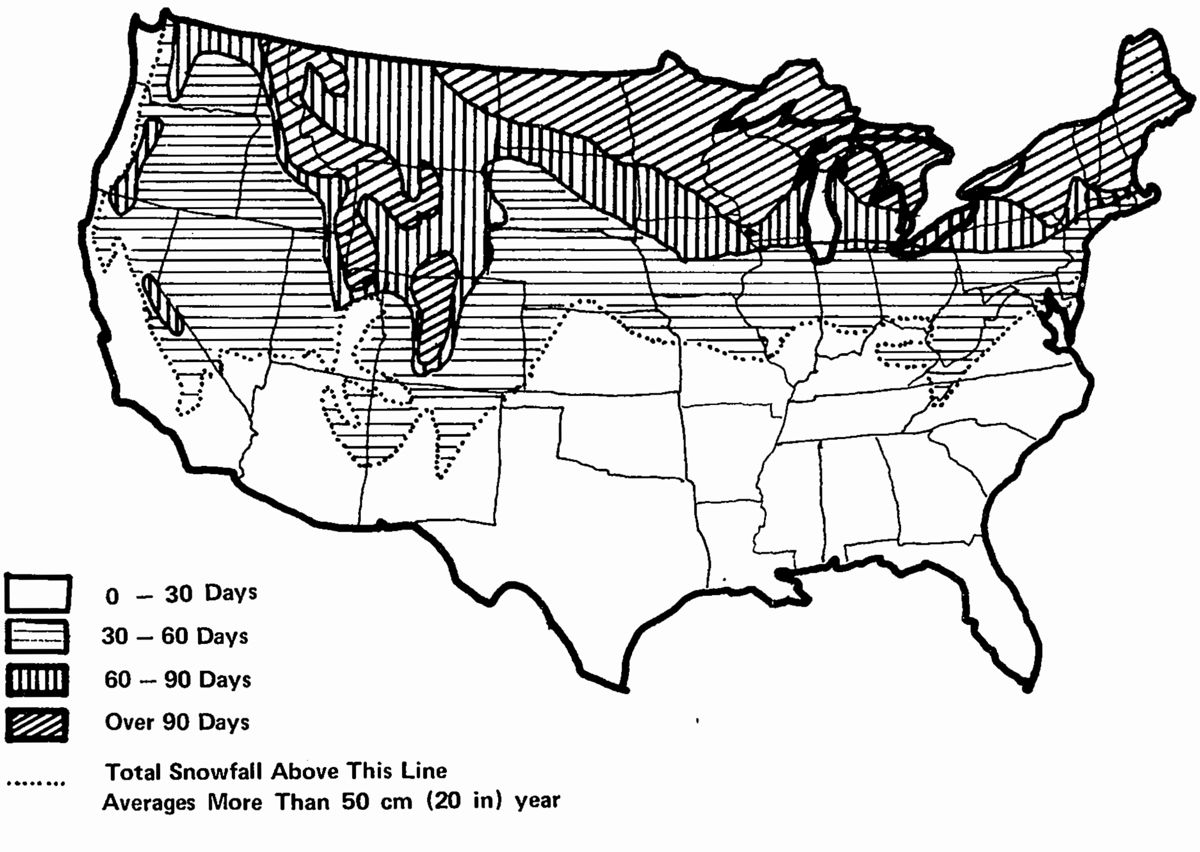


Figure 3. Average annual number of days with snow ground cover.

Source: American Public Works Association, "Managing Snow Removal and Ice Control Programs," APWA Special Report No. 42, 1974.

Another less dramatic, but obviously important aspect of the problem concerns the effects of snow and ice as a prospective source of pollution. These pollutional effects are two-fold. On one hand, snow and ice deposits are a repository of pollutants produced by human activities in urban areas. These pollutants may be generated by vehicular traffic and wear, particulate fallout from air pollution, the erosion of street surfacing materials, construction and demolition waste materials, spilled domestic, commercial and industrial solid wastes, wastes from wild and domestic animals, among others. They are deposited and entrapped in the snow and ice and inevitably reach natural water bodies either through snow removal operations and direct dumping into water bodies or in drainage areas adjacent to such water, or through the natural drainage of melt waters.

In contrast, the immediate demands for snow and ice control may also create a source of potential runoff pollution. In general, snow and ice control practice employs the materials and methods shown in Table 5. The most widely used methods taken the form of plowing, sanding, and salting, although other technological procedures--better removal equipment, alternative chemicals, hydrophobic surfacing or surface treatments, and heated pavements--are being studied or used. (7) The application of sodium and calcium chloride salts with associated anti-caking; and in some areas anti-corrosion additives, abrasive materials, and other chemicals, pose significant problems around potential runoff pollution.

TABLE 5. MATERIALS AND METHODS USED FOR SNOW AND ICE CONTROL

Methods Employed	Materials
Abrasive Application	Cinder
	Sand
Chemical Salt Application	Sodium Chloride
	Calcium Chloride
	Aluminum Chloride
	Ammonia Nitrate
	Ammonium Nitrate
	Potassium Pyrophosphate
	Brine and Marine Salt
	Urea
	Prussian Blue
	Yellow Prussiate of soda
	Sodium Hexametaphosphate
Radiant Heating	---
Melting Machines	---

In the area of direct snowmelt runoff pollution, field measurement data are relatively limited. Some of the pollutants found in urban snow samples collected in Toronto, Ontario, included suspended solids, organics, phosphates, chlorides, lead, oil, trash, soot, and soil. (8) In Madison, Wisconsin winter runoff BOD concentrations ranged from 20 to 30 mg/l; suspended solids were found to be as high as 3,850 mg/l; and chloride concentrations ranged up to 3,275 mg/l. (9) A further indication of the contaminants that may accumulate in snow is shown in Table 6. The data shown reflects the results of snow samples taken from roads in the Ontario municipalities indicated.

TABLE 6. CONSTITUENT CONCENTRATIONS MEASURED IN DIFFERENT CITIES OF ONTARIO

Municipality	BOD_5 mg/l	Suspended Solids mg/l	Chloride mg/l	Diss. Lead mg/l	Total Phosphate mg/l	Phenol mg/l
Thunder Bay	54	21,433	3,051			36
Timmins	15	28,767	505		0.97	25
Sault Ste. Marie	14	34,967	730			30
Toronto	21	—	11,318	0.34	14	115
London	31	12,100	1,490			29
Barrie	—	11,700	—			—

Source: James F. MacLaren Ltd., "Municipal Snow Quality Study, 1973-74," Ontario Ministry of Environment (unpublished report), Ontario.

The concentrations of various pollutants found in urban snow sampled in the Ottawa-Carelton area of Ontario are summarized in Table 7. Comparisons of snow sample concentrations and runoff concentrations indicate that chlorides and BOD_5 are readily transported in runoff while suspended solids, lead, and some of the other metals are more inclined to deposit than to runoff. Pollutants other than chlorides and BOD_5 were generally concentrated in black crust, indicating that pollutant accumulations occur subsequent to snowfall as a product of adjacent urban activity. (8) This is shown more clearly in

TABLE 7. POLLUTANTS AND POLLUTANT LEVELS FOUND IN SNOW DEPOSITS

Pollutant Concentrations, mg/l (or mg/kg snow)

Pollutant	Location	Undisturbed Snow	Windows Adjacent to Street	Snow Disposal Sites	Disposal Site Runoff	Storm Sewer Flow
Suspended Solids	–	–	–	–	96 mg/l	–
	Arterial street	–	3,570 mg/kg	–	–	–
	Collectors	–	1,920-4,020 mg/kg	–	–	–
	Local	–	1,215-2,530 mg/kg	–	–	–
	Parking lot	–	1,620 mg/kg	–	–	–
BOD_5	–	–	–	108 mg/l (mean)	–	–
	Arterial street	–	16.6 mg/kg	–	–	–
	Collectors	–	13.2 mg/kg	–	–	–
	Local	–	5.5 mg/kg	–	–	–
	Parking lot	–	5.5 mg/kg	–	–	–
Chlorides	–	5 mg/kg	0-4,500 mg/kg	175-2,250 mg/kg	–	971 mg/l
Oils	All sites	–	28.6 mg/kg (mean)	28.6 mg/kg (mean)	–	–
Greases	All sites	–	19.6 mg/kg (mean)	19.6 mg/kg (mean)	–	–
Phosphates	–	–	–	1.5 mg/kg (mean)	–	–
	Arterial streets	–	0.032 mg/kg (mean)	–	–	–
	Collectors	–	0.087 mg/kg (mean)	–	–	–
	Local	–	0.065 mg/kg mean)	–	–	–
Lead		0.002-0.25 mg/kg		0.9-9.5 mg/kg	0.048-0.173 mg/l	0.143 mg/l (mean)
	Residential	–	2 mg/kg (mean)	–	–	–
	Industrial	–	4.7 mg/kg (mean)	–	–	–
	Commercial	–	3.7 mg/kg (mean)	–	–	–
	Highway	–	102.0 mg/kg	–	–	–
Cadmium	–	–	–	<0.05 mg/kg	–	–
Barium	–	–	–	<0.50 mg/kg	–	–
Zinc	–	–	–	0.6 mg/kg	–	–
Copper	–	–	–	0.19 mg/kg	–	–
Iron	–	–	–	30.0 mg/kg	–	–
Chromium	–	–	–	<0.02 mg/kg	–	–
Arsenic	–	–	–	<0.02 mg/kg	–	–

Source: J. L. Richards and Associates, Ltd., and Labrecqua, Vezina and Associates, "Snow Disposal Study for the National Capitol Area: Technical Discussion," for the Committee on Snow Disposal, Ottawa, Ontario, June, 1973.

Table 8. The table shows the surface accumulation and the reduction in lead concentration with depth in the snow deposits sampled.

TABLE 8. TOTAL LEAD CONCENTRATIONS AT VARIOUS DEPTHS SAMPLED SNOW DEPOSITS

Depth (in)	Depth (cm)	Total Lead Concentration (mg/kg)
0- 2	(0- 5.1)	237
2- 4	(5.1-10.2)	163
4- 6	(10.2-15.3)	142
6- 8	(15.3-20.4)	126
8-10	(20.4-25.4)	126
10-12	(25.4-30.5)	51
12-14	(30.5-35.6)	72
14-16	(35.6-40.6)	56
16-18	(40.6-45.7)	36
18-20	(45.7-50.8)	22
20-22	(50.8-55.9)	85
22-24	(55.9-61.0)	41

Source: J.L. Richards and Associates, Ltd., and Labrecque, Vezina and Associates, "Snow Disposal Study for the National Capital Area: Technical Discussion," for the Committee on Snow Disposal, Ottawa, Ontario, June 1973.

These findings suggest that many of the same considerations that influence the quality of urban stormwater runoff are also significant in terms of the quality of snow melt water. Thus, although runoff rates may be somewhat attenuated by the physical processes of snow melting, the quality of snow melt runoff is still a source of concern even though non-chemical methods are employed for snow and ice control.

Until recent years highway maintenance officials relied heavily on the use of abrasive materials such as cinders and sand to meet the needs of snow and ice control. But public demand for roads that are usable and safe in all seasons has led to the adoption of a "bare pavement" policy by many highway departments located in the snow belt. (10) To obtain bare pavements in the midst of winter storms, sodium chloride and calcium chloride have come into increasing use. Unlike abrasives, which essentially are skid preventives and traction aids, salts prevent the formation of ice or melt ice or hard packed snow.

The most commonly used deicing agent is common salt, applied by itself or in combination with abrasive materials or other chemical additives. Of the various control methods, deicing chemicals, particularly salts, have proven more effective in melting snow and ice. These materials are not readily blown off of a roadway by wind or by traffic, and are simple to apply and clean up from the roadway. (11)

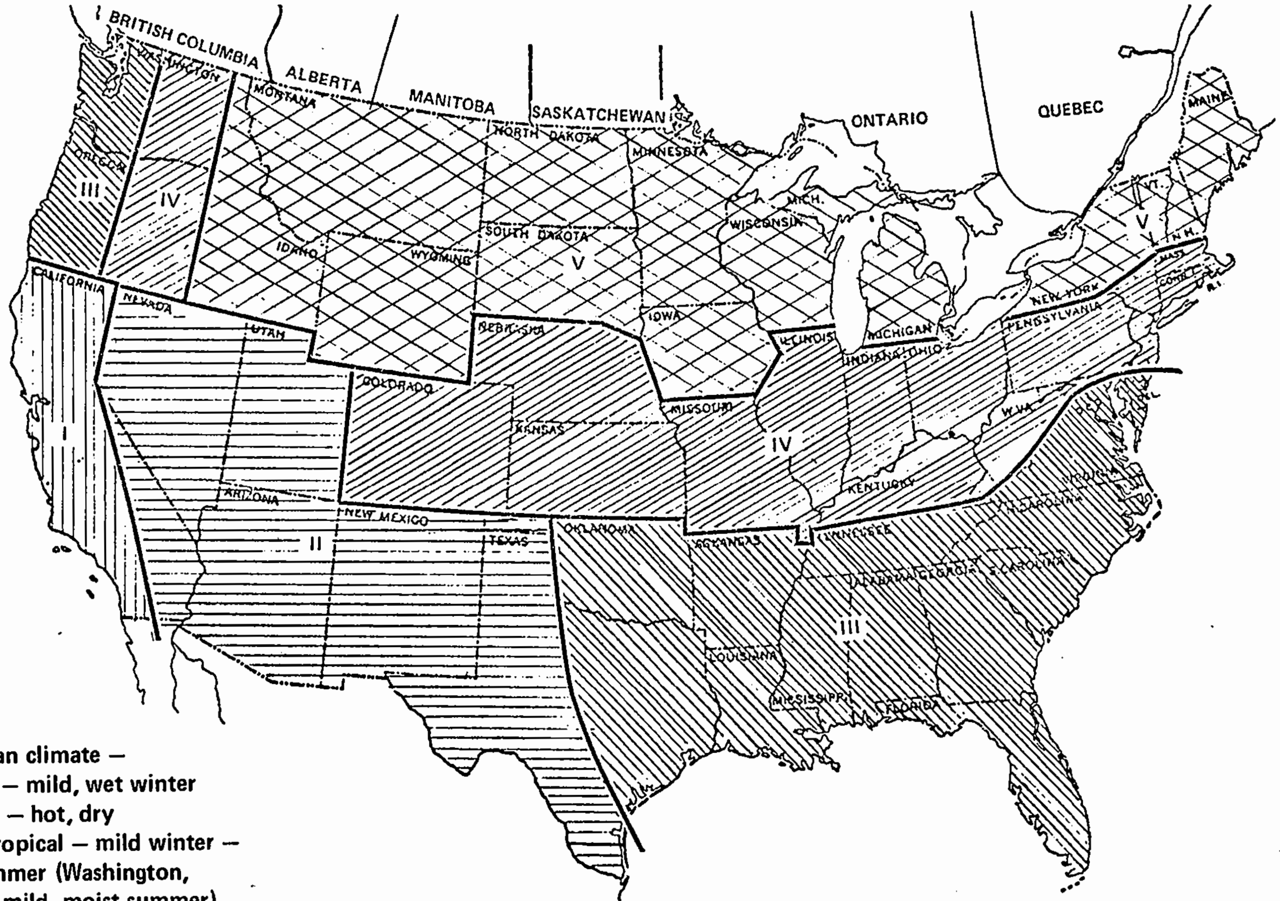
A 1973 APWA survey indicated that almost 85 percent of 289 responding jurisdictions used common salt for snow and ice control. Some of the results of this survey are shown in Table 9. This tabulation shows the usage of various chemicals and abrasive materials in terms of the climatic zones identified in Figure 4. As the table shows, more than one type of chemical or abrasive material may be used in any one jurisdiction.

TABLE 9. CHEMICAL AND ABRASIVE SPREADING
Number and % Using

Material Spread		Climatic Zones[a]					Total		
		I	II	III	IV	V	U.S.	Canada	Total
Rock Salt	No.	1	7	34	114	65	221	24	245
	%	50	70	65.4	94.2	91.5	86.3	72.7	84.8
Evaporated or Solar Salt	No.	0	1	6	10	1	18	3	21
	%	0	10	11.5	8.3	1.4	7.0	9.1	7.3
Sand	No.	1	6	29	56	46	138	24	162
	%	50	60	55.8	46.3	64.8	53.9	72.7	56.1
Cinders	No.	0	0	4	15	5	24	0	24
	%	0	0	7.7	12.4	7.0	9.4	0	8.3
Brine	No.	0	1	0	0	2	3	0	0
	%	0	10	0	0	2.8	1.1	0	1.0
Calcium Chloride	No.	0	0	9	44	28	81	5	86
	%	0	0	17.3	36.4	39.4	31.6	15.2	29.8
Other	No.	0	1	4	4	3	12	4	16
	%	0	10	7.7	3.3	4.2	4.7	12.1	5.5
Total Respondents		2	10	52	121	71	256	33	289

Source: American Public Works Association, "Managing Snow Removal and Ice Control Programs," Special Report No. 42, 1974.

[a]See Figure 4



Climatic Areas

- I Mediterranean climate — dry summer — mild, wet winter
- II Arid climate — hot, dry
- III Humid subtropical — mild winter — hot, wet summer (Washington, Oregon area mild, moist summer)
- IV Humid continental — short winter, hot summer
- V Humid continental — long winter, warm summer

Figure 4. Climatic regions.

Source: American Public Works Association, "Managing Snow Removal and Ice Control Programs," APWA Special Report No. 42, 1974.

Salt application rates of from 85 to 141 kg/lane-km (300 to 500 lb/lane-mi) have been recommended for ice at -7°C (20°F) where an adequate traffic load exists. (12) Application rates have been reported as high as 197 kg/lane-km (700 lb/lane-mi) in metropolitan Toronto, Ontario. These represent annual salt loadings of more than 90 MT/km (160 tons/mi). (8) The different salt application rates compared to population density for various communities in Ontario is shown in Table 10.

TABLE 10. SALTING RATES USED IN ONTARIO

Population Density (No/mi²)	No/ha	Rates of Salt Application (lb/application/lane-mi)	(kg/application/lane-km)
<1,000	<0.6	75 – 800	21 – 218
From 1,000 to 5,000	0.6 – 3.1	350 – 1,800	96 – 491
>5,000	>3.1	400 – 1,200	109 – 327

Source: James F. MacLaren Ltd, "Municipal Snow Quality Study, 1973-74," Ontario Ministry of Environment (unpublished report), Ontario.

It has been theoretically proposed that approximately 1,820 kg (4,000 lb) of salt would be necessary to clear 1.6 km (1 lane-mi) pavement of 0.3 cm (0.125 in) of ice at -7°C (20°F) if enough vehicular traffic exists. (10) In practice, 273 kg (600 lb) of salt will clean 0.5 cm (0.2 in) of ice on a 6.1 m (20 ft) road at -4°C (25°F).

A guide for the use of calcium chloride salts is shown in Table 11. This material is generally employed with common salt, as indicated in this table of deicing chemcial composition recommended by the Pennsylvania State Department of Transportation. A definition of the appropriate temperature range for each mix, as well as the relative chloride yield, is given.

TABLE 11. ASSUMED DE-ICING CHEMICAL MAKEUP

Temperature Ranges °F	°C	De-icing Chemical Makeup	Part Chloride/ Part De-icing Agent
0 – 5	-17.7 – -15	1 NaCl: 1 $CaCl_2$	0.54
5 – 15	-15 – -9.4	2 NaCl: 1 $CaCl_2$	0.56
15 – 25	- 9.4 – -3.9	3 NaCl: 1 $CaCl_2$	0.58
25	−3.9	NaCl	0.6

Source: American Public Works Association, "Managing Snow Removal and Ice Control Programs," APWA Special Report No. 42, 1974.

The chemical makeup of deicing salts is shown in Table 12. The ranges of some of the trace elements found in highway salt are shown in Table 13.

TABLE 12. COMPOSITION OF COMMON DE-ICING SALT

Constituents	Percent by Weight
Sodium Chloride (NaCl)	98.8
Calcium Sulphate ($CaSO_4$)	0.4
Calcium Chloride ($CaCl_2$)	0.1
Magnesium Chloride ($MgCl_2$)	0.05
Water Insolubles	0.65

Source: J.L. Richard and Associates, Ltd., and Labrecque, Vezina and Associates, "Snow Disposal for the National Capital Area: Technical Discussion," June 1973.

TABLE 13. TRACE ELEMENTS FOUND IN COMMON DE-ICING SALT

Trace Element	Range mg/kg
Manganese (M)	0.04-0.08
Iron (Fe)	0.08-0.09
Lead (Pb)	0.09-0.30
Copper (Cu)	Not Detectable — 0.0004
Nickel (Ni)	0.003-0.003
Chromium (Cr)	0.003-0.01
Silicon (Si)	0.3-0.7

Source: J.L. Richards and Associates, Ltd., and Labreque, Vezina andAssociates, "Snow Disposal Study for the National Capital Area: Technical Discussion," June 1973.

The chlorides liberated in common salt amount to approximately 60 percent by weight.

A general expression for estimating the deicing salt loading function has been proposed by the Midwest Research Institute. (14) This loading takes the general form:

$$Y = \frac{A \cdot K \cdot DI}{M \cdot W} \qquad (1)$$

where Y = Loading, kg/lane-km/day (lb/lane-mi/day)

A = dimensionless attenuation factor

K = conversion factor--equal to 2,000 for conversion of tons to pounds or 1,000 for the conversion of metric tons to Kilograms

DI = amount of deicing material applied during the season in metric tons (tons)

M = single-lane mileage of streets and highways to which deicing materials are applied, km (mi)

W = number of days in the winter season, day

Values for A, the attenuation factor, are suggested as 1.0 for urban streets, and 0.7 for non-urban highways. Values for this and the remaining variables can be determined from local records and data sources. The general loading function may also be used to estimate constituent loadings--chlorides or trace elements--as suggested in some of the tabulations previously described. A modified loading function for constituents would take the form of:

$$Y\ con = CY \qquad (2)$$

where $Y\ con$ = constituent loading, kg/lane-km/day (lb/lane-mi/day)

C = constituent concentration, in part per part, and

Y = loading of deicing material, as defined above

The Massachusetts Department of Public Health has pointed out that the chlorides in drainage water can usually be traced to one or two sources or a combination of the two. (12) The first source is the area where the salt is stored. This is very often the same area used for the blending of sand and salt mixtures. This mixing process is often carried out directly on the ground which means that relatively large areas of ground are exposed to the chlorides. The second source, in accordance with the opinions of highway maintenance engineers, is the terminal point of a drainage system where runoff pollutants may be expcected to be concentrated. (15) In a few areas of the country, groundwater wells have become unfit due to increased salinity attributed to deicer use. Some of the salt, thus, finds its way into subsurface aquifers. Most of ther remainder is transmitted directly to surface streams, while some has an appreciable residence time in roadside soils.

Measurements performed on the John F Kennedy Expressway in Chicago, demonstrated the magnitude of chloride conentrations contributed by deicing operations. (15) Following the winter salting operations, the chloride concentration ranged from 1,00 - 4,500 mg/l, with an average of about 2,000 mg/l. Flows in the storm sewer draining the roadway during this period were as high as 0.51 m^3/min (0.3 cfs). During prior periods of snowfall, chloride concentrations of 11,000 - 25,000 mg/l were found with an average of about 14,000 mg/l. Flow in the storm sewer varied from 0.17 - 2.55 m^3/min (0.1 - 1.5 cfs). Figure 5, indicates that virtually all of the deicing salts applied were removed from the site either as a brine runoff during the period following application or as general runoff during subsequent warmer weather. Higher immediate releases on this interstate roadway are to be expected as compared to an urban arterial street due to road configuration.

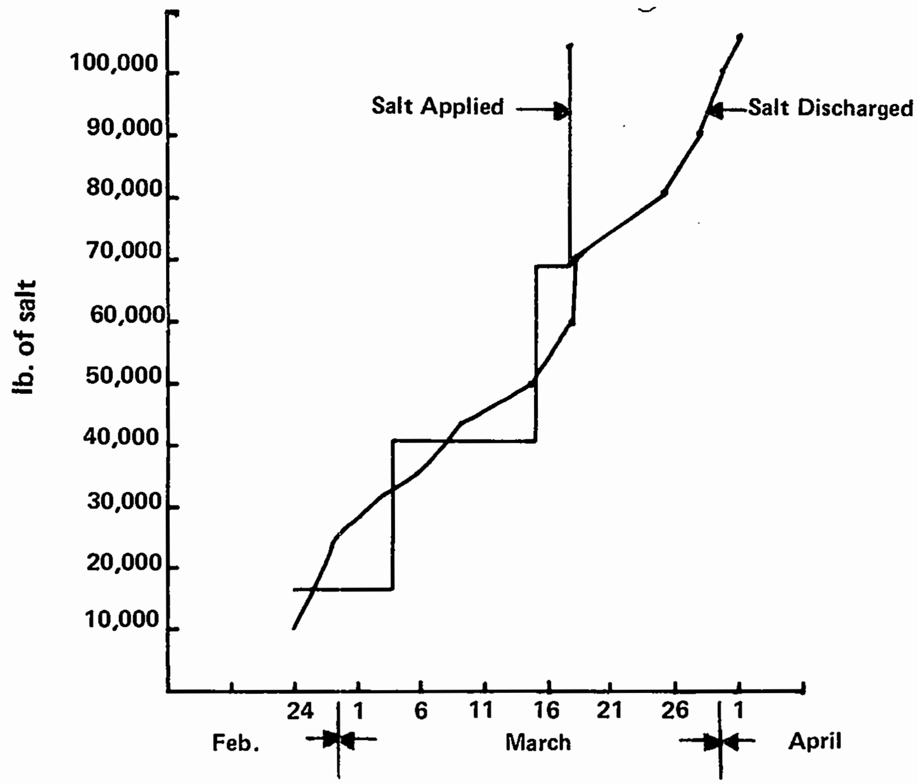


Figure 5. Salt applied as compared to salt discharged, Kennedy Expressway, February 24—April 1, 1967.

Source: American Public Works Association, "Water Pollution Aspects of Urban Runoff," USEPA Report No. 11030DNS01/69 (NTIS No. PB 215 532), January, 1969.

A study in the National Capital Area of Canada concluded that approximately 84 percent of the deicing salts used in the Ottawa-Carelton area were disposed of as brine after application, and that from 6 to 10 percent of the salt was carried to the receiving water in runoff resulting from the melting of background snowfall. (16) Runoff chloride concentrations are thus largely determined by temperature, which dictates that the source of this runoff will be brine or background snow melt, or a mix of the two.

In assessing the effects of salt use as a deicing agent of Lake Ontario, it was estimated in 1971 that 1.5 x 10^6 MT (1.67 x 10^6 tons) chlorides introduced into the lake annually, 20 percent came from roads during snow and ice control operations in the Province of Ontario and New York State. This figure would have exceeded 40 percent if all industrial sources of chloride were completely controlled. (17) Other serious effects attributable to the use of deicing salts can be illustrated by past experience in Springfield, Mass. Increases in the chloride content of the municipal well water supply were ascribed to snow and ice control activities on the adjacent Massachusetts Turnpike. (12) Lake Wingra, one of the lakes in the Madison, Wisconsin area, was found to have quadrupled its chloride levels from 9-11 mg/l to 41-43 mg/l from 1959 to 1965, respectively.

At Cumberland, Wis., a 1959 research study on Beaver Dam Lake showed chloride concentrations increasing with depth, ranging from 8 mg/l near the top to 33 mg/l near the bottom. More severe cases of this density stratification have prevented vertical mixing in some bodies of water, thereby causing a lack of dissolved oxygen at lower levels, with consequent detrimental effects on plants and fish.

A study was performed on salt runoff in the 7.6 m (25 ft) First Sister Lake in a suburban section of Ann Arbor, Mich., in 1965-68. Density stratification, 150 mg/l chloride at 7 m (23 ft), and 60-85 mg/l near the top, occurred due to road salting that prevented complete spring mixing of the waters. Complete fall mixing might also have been prevented, except that some of the salts were taken into the lake bottom during the summer. This lack of mixing prevented oxygen from reaching the lower levels of the lake, and caused some damage to plant and animal life. It was reported that the deeper zones of the lake were most likely without oxygen for about ten months, and the entire lake below the 3 m (10 ft) depth was virtually devoid of dissolved oxygen for about eight months. (18)

A study of Irondequoit Bay in Rochester, New York, was made in 1969-70; winter road salt is the "single major source" of salt in the waters. The bay showed a density stratification of its water sufficient to prevent vertical mixing in the spring, an unusual occurrence for a body so large, 6 km (3.7 mi) long, 1.6 km (1 mi) wide, and a shallow average depth of 7.3 m (24 ft), with a maximum depth of 23 m (75 ft). This stratification also delayed mixing of the salty strata for one month. Dissolved oxygen, from January-November, 1970 a period of severe stratification, was at the maximum, 1 mg/l. Average surface water chlorides were 160 mg/l; average bottom water chlorides were 220-400 mg/l. (19)

Of other chemicals in use for snow and ice control, most appear to be a variant of aluminum chloride, with a much higher effective snow and ice melting rate than common salt. However, limitation of mechanical spreading devices, relatively high costs of these chemicals, and hazards to health and safety restrict the wide use of these materials. (15) Ferric ferrocyanide (Prussian Blue) is sometimes added to salt to prevent caking. Prussian Blue is insoluble in water and, thus, is not considered as contributing to pollutional problems. Some jurisdictions have also used sodium ferrocyanide (Yellow Prussiate of Soda) to prevent caking. This compound is soluble in water, and releases cyanide in the presence of sunlight. (12) A sodium hexametaphosphate material has also been used by some jurisdictions. Its phosphate content acts as a nutrient in receiving waters and thus, contributes to pollutional problems by triggering eutrophication.

Salt is not used on airports because of its corrosive potential for airplanes. Therefore, other chemicals have been used to melt snow and ice on runways. The primary ingredients in many of these compounds are urea and ammonium nitrate. Both of these chemicals act as nutrients, and are oxygen demanding in receiving bodies of water contributing to eutrophication and oxygen depletion.

Ammonium nitrate and potassium pyrophosphate compounds, although not as widely used as calcium chloride, have been applied on sidewalks by individual homeowners. When these are used it can be expected that receiving waters will be affected by them during periods of snow melt. (12)

The spraying of brine is another more expensive method for snow and ice control. This method increases loads on sewage treatment facilities, and may result in the spraying of polluted waters on streets. The use of marine salt is not too much different than the use of mined salt from the viewpoint of its pollutional potential. Other methods used for ice and snow control include radiant heat and melting machines. Because of their limited usefulness for large-scale practical operations, they have little pollutional potential to the environment, and minimal public health implications.

AIRBORNE CONTRIBUTIONS TO URBAN RUNOFF POLLUTION

Airborne materials represent another contributing source of contaminants carried in stormwater runoff. These contaminants originate naturally and through man's activities. Naturally occurring sources may be dust storms and the bulk precipitation of nutrients and wind erosion. Man-made air contributions may result from the combustion of fuel in heating, industry, transportation activities and energy production; through the incineration of wastes and other materials; by various manufacturing processes; wind erosion on construction sites, agricultural activities, and automotive traffic.

Airborne materials may take the form of either particulate matter, aerosols, or gases. Particulate materials may be deposited in a given drainage basin through the processes of sedimentation. The results of this process depend upon particle size, specific gravity, and weather conditions. Larger particles under appropriate climatic conditions may be deposited at locations adjacent to their source, while smaller particles will remain suspended in the air. Airborne materials may also be deposited in rainfall itself. Falling snow and rainfall wash out or scavenge airborne materials and gases and carry them to the ground. The contaminant levels found in rainfall sampled and tested in Cincinnati, Ohio, are shown in Table 14.

TABLE 14. CONCENTRATION OF CONTAMINANTS FOUND IN RAINFALL

Contaminant	Range During Storm (mg/l)	Average Storm Concentration (mg/l)
Suspended Solids	0.5 – 58	13.0
Volatile Suspended Solids	0.5 – 12	3.8
Inorganic N	0.12 – 2.3	0.69
Ortho PO_4	0 – 0.9	0.24

Source: Werbel, S.R., et al., "Urban Land Runoff as a Factor in Stream Pollution," Journal of The Water Pollution Control Federation, Vol. 36, No. 7, July, 1964.

Particulates are perhaps the most prevalent of all the intermedia pollutants between air and water. Deposited particulates add to the total solids loadings available and accessible to surface runoff. Metallic slats and oxides may be significant when collected from the atmosphere and released into receiving waters. On pervious erodible surfaces, these particulates may be removed with soil materials through scouring processes. Particulate depositons on impervious surfaces are more available to runoff and can be readily washed into a surface runoff flow.

Indication of the annual amounts of atmospheric particulates originating from point emmission sources is shown in Table 15. Of the data shown, the majority of the point source particulates are considered to be controllable. It should be noted that non-point aerial sources of particulates are not included in the tabulation.

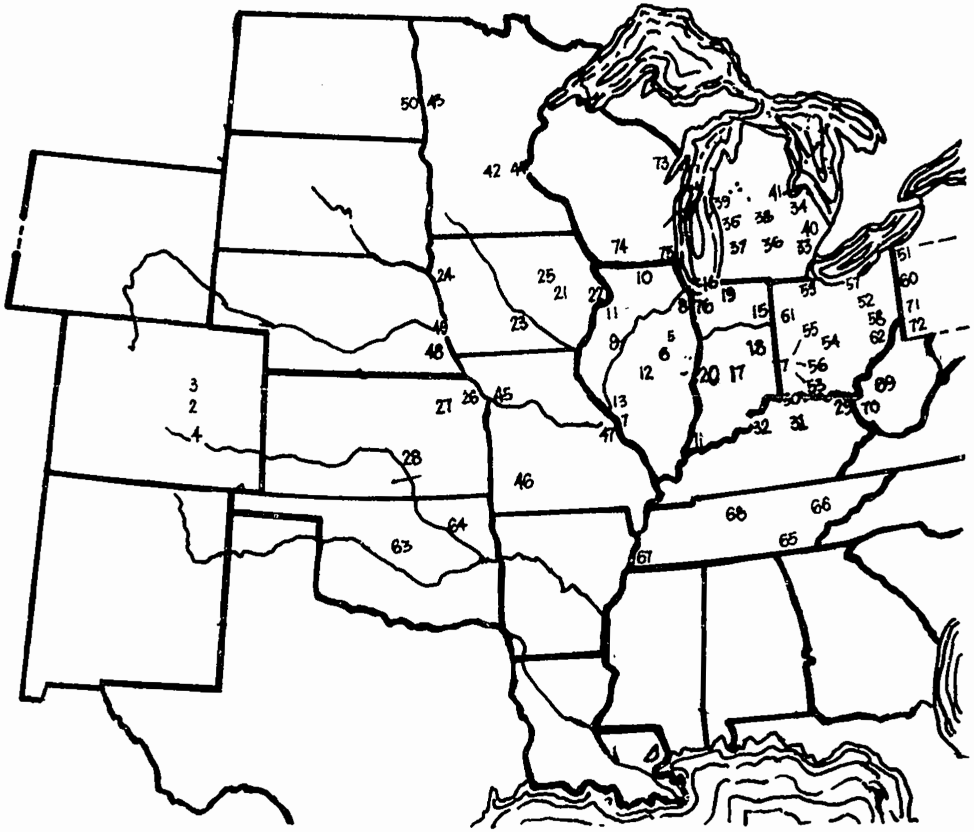
TABLE 15. NATIONWIDE ESTIMATES OF PARTICULATE EMISSIONS, 1940-1970 (10^6 tons/yr)

Source category	1940	1950	1960	1968	1969	1970
Fuel combustion in stationary sources	9.6	9.0	7.6	6.5	6.4	6.8
Transportation	0.4	0.4	0.5	0.8	0.7	0.7
Solid waste disposal	0.4	0.6	1.0	1.4	1.4	1.4
Industrial process losses	8.8	10.8	11.9	13.8	14.3	13.3
Agricultural burning	1.6	1.8	2.1	2.4	2.4	2.4
Miscellaneous	6.4	3.3	2.1	1.7	2.1	1.0
Total	27.1	25.9	25.3	26.6	27.3	25.6
Total controllable[a]	20.7	22.6	23.2	24.9	25.2	24.6

[a]Miscellaneous sources not included.

Source: "National Air Pollutant Emission Trends: 1940-1970," USEPA Report No. AP-115 (NTIS PB 227 739), January, 1973.

A sense of the magnitude of deposited particulates or dustfall can be obtained from data collected in 77 midwestern cities. (20) The cities and the locations are shown in Figure 6. The results of the analysis of measurements collected in the cities are shown in Figure 7. The converted mean dustfalls found in residential areas was 8.12 MT/km^2/mo (23.5 ton/mi^2/mo), while commercial and industrial areas were 14 MT/km^2/mo (40.5 ton/mi^2/mo) and 18.16 MT/km^2/mo (62.5 ton/mi^2/mo), respectively. Dustfall values measured in Chicago in 1966 ranged from 18.5 to 55.3 MT/km^2/mo (64 to 191 ton/mi^2/mo) as determined from data collected at 20 sampling stations.



List of Cities and Code Numbers

City Code No.	City	City Code No.	City
1	Little Rock, Ark.	40	Pontiac, Mich.
2	Colorado Springs, Colo.	41	Saginaw, Mich.
3	Denver, Colo.	42	Minneapolis, Minn.
4	Pueblo, Colo.	43	Morehead, Minn.
5	Champaign-Urbana, Ill.	44	St. Paul, Minn.
6	Decatur, Ill.	45	Kansas City, Mo.
7	East St. Louis, Ill.	46	Springfield, Mo.
8	Joliet, Ill.	47	St. Louis, Mo.
9	Peoria, Ill.	48	Lincoln, Neb.
10	Rockford, Ill.	49	Omaha, Neb.
11	Rock Island-Moline, Ill.	50	Fargo, N. Dakota
12	Springfield, Ill.	51	Akron, Ohio
13	Granite City, Ill.	52	Canton, Ohio
14	Evansville, Ind.	53	Cincinnati, Ohio
15	Ft. Wayne, Ind.	54	Columbus, Ohio
16	Gary, Ind.	55	Dayton, Ohio
17	Indianapolis, Ind.	56	Hamilton, Ohio
18	Muncie, Ind.	57	Lorain, Ohio
19	South Bend, Ind.	58	Steubenville, Ohio
20	Terre Haute, Ind.	59	Toledo, Ohio
21	Cedar Rapids, Iowa	60	Youngstown, Ohio
22	Davenport, Iowa	61	Lima, Ohio
23	Des Moines, Iowa	62	Martin's Ferry, Ohio
24	Sioux City, Iowa	63	Oklahoma City, Okla.
25	Waterloo, Iowa	64	Tulsa, Okla.
26	Kansas City, Kan.	65	Chattanooga, Tenn.
27	Topeka, Kan.	66	Knoxville, Tenn.
28	Wichita, Kan.	67	Memphis, Tenn.
29	Ashland, Ky.	68	Nashville, Tenn.
30	Covington, Ky.	69	Charlestown, West Va.
31	Lexington, Ky.	70	Huntington, West Va.
32	Louisville, Ky.	71	Weirton, West Va.
33	Ann Arbor, Mich.	72	Wheeling, West Va.
34	Flint, Mich.	73	Green Bay, Wisc.
35	Grand Rapids, Mich.	74	Madison, Wisc.
36	Jackson, Mich.	75	Racine, Wisc.
37	Kalamazoo, Mich.	76	Hammond, Ind.
38	Lansing, Mich.	77	Middletown, Ohio
39	Muskegon, Mich.		

Figure 6. Location of the 77 Midwestern Cities.

Source: Hunt, W.F., et al., "A Study of Trace Element Pollution of Air in 77 Midwestern Cities," Paper presented at the Fourth Annual Conference on Trace Substances in Environmental Health, University of Missouri, June 1970.

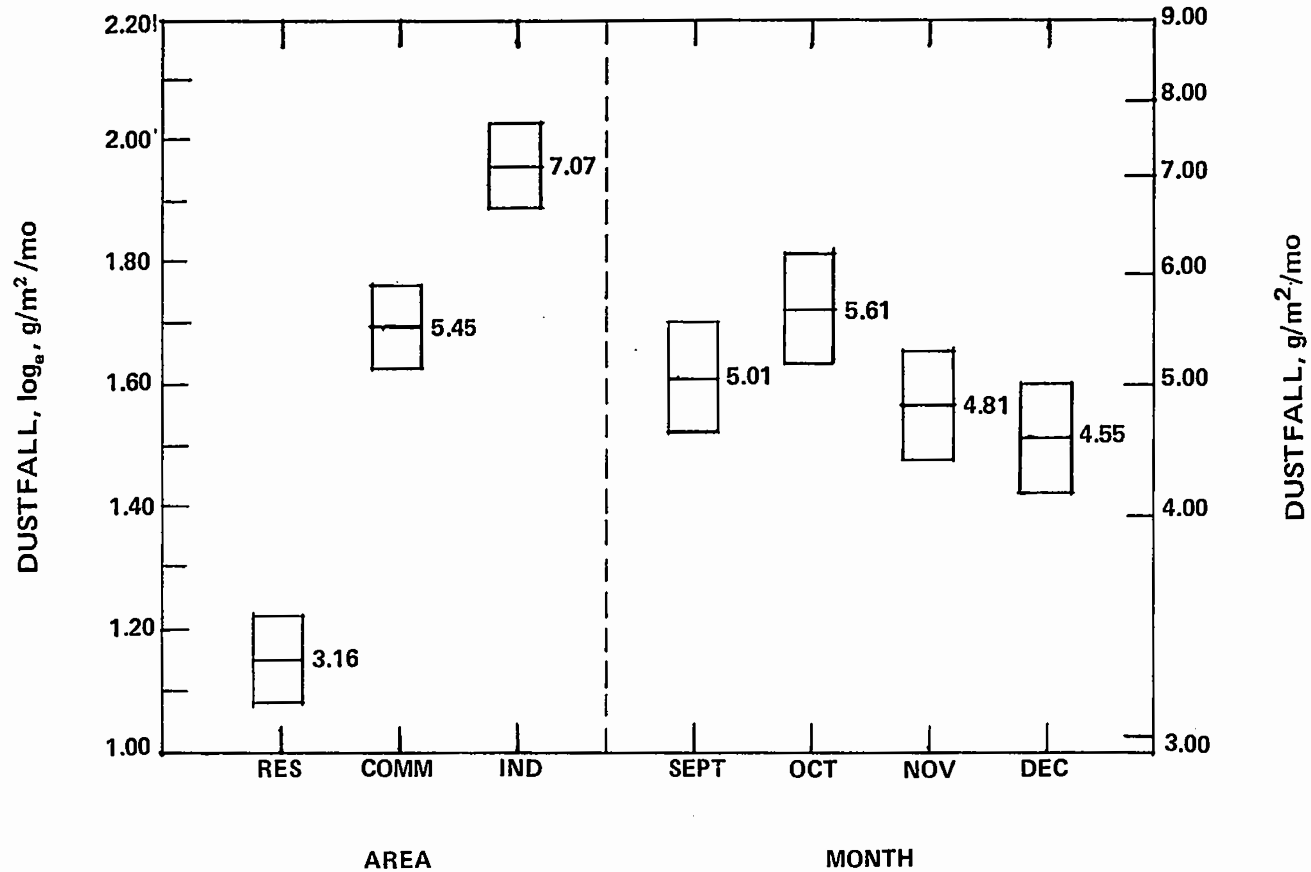


Figure 7. Geometric means and 95 percent confidence intervals for dustfall measurements by land use and month.

Source: Hunt, W.F., et al., "A study of Trace Element Pollution of Air in 77 Midwestern Cities," Paper presented at the Fourth Annual Conference on Trace Substances in Environmental Health, University of Missouri, June 1970.

Some average annual dustfall values for various water resources regions in the continental United States are shown in Table 16.

TABLE 16. AVERAGE ANNUAL DUSTFALL VALUES FOR VARIOUS WATER RESOURCES REGIONS

	Geometric Mean		Range	
Area	**ton /mi^2/mo**	**MT/km^2/mo**	**ton /mi^2/mo**	**MT/km^2/mo**
New England	8.2	2.87	0.5-152	.18-53.2
Mid Atlantic	5.5	1.92	0.3-241	.1 -84.4
Upper Colorado	143.3	50.2	69 -281	24 -98.4
Pacific Northwest	7.2	2.52	0.3-317	.1 -111
Lower Mississippi	62.0	21.7	18 -270	6.3 -95
Missouri Basin	34.7	12.2	6 -103	2.1 -36
Lower Colorado	33.9	12	16 -69	5.6 -24
South Atlantic Guld	5.0	1.75	1.2-296	.42-104
Tennessee	4.2	1.47	1.1-17.2	.38-6.0
Ohio	2.8	.98	1.7-5.9	.6 -2.1
Upper Mississippi	12.5	4.37	0.3-315.3	.1 -110.4
Great Lakes	32.0	11.2	2 -206	.7 -72
Sonris-Red Rainy	23.4	8.2	3.0-73	1.1 -26
Rio Grande Region	29.5	10.33	12 -269	4.2 -94
Texas Gulf Region	32.4	11.34	8 -116	2.8 -41
Arkansas-White-Red	—	—	—	—
California	16.9	5.9	1 -38	.35-13.3
Great Basin	14.7	5.15	5 -56.5	1.8 -20

Source: USEPA National Aerometric Data Bank, Environmental Monitoring and Support Lab, EPA Research Triangle Park, North Carolina.

A comparison of suspended solids concentrations calculated from mean monthly dustfall in the City of Halifax, Nova Scotia, and measured runoff concentrations is shown in Table 17.

TABLE 17. COMPARISON OF SUSPENDED SOLIDS CONCENTRATIONS COMPUTED FROM DUSTFALL AND MEASURED VALUES

(Dustfalls are mean values from two stations adjacent to study area.)

	MONTH						
	MAY	JUNE	JULY	AUG.	SEPT.	OCT.	NOV.
Mean Dustfall							
(ton/mi^2/mo)	7.1	4.9	4.0	6.7	4.5	6.4	6.8
(g/m^2/mo)	2.5	1.72	1.40	2.35	1.58	2.24	2.38
Monthly Rainfall							
(in)	4.3	3.8	3.6	7.2	5.2	4.6	4.6
(cm)	10.9	9.6	9.1	18.3	13.2	11.7	11.7
Calculated Mean Solids Concentration (mg/l)							
- 100% runoff	23	14	15	13	12	20	21
- 35% runoff	65	41	43	37	34	56	59
Measured Mean Surface Runoff Suspended Solids (mg/l)							
- Quinpool Rd. (Table 20)	147			131		104	
- Cambridge St. (Table 21)	191			54		66	

Source: Waller, D.H., "Pollution Attributable to Surface Runoff and Overflows from Combined Sewerage Systems," Central Mortgage and Housing Corporation, Ottawa, Ontario, April, 1971.

This tabulation shows that total monthly dustfalls would contribute from 20 to 90 percent of the measured suspended solids if they were picked up in runoff amounting to 35 percent of the monthly precipitation. It seems likely that deposited particulates assume some significance in urban areas where imperviousness is greater and the likelihood of their transport is higher.

The characteristics of airborne particulates vary from inert materials that contribute only to total solids concentrations, to organics, metals, nutrients, and pesticides. A listing of some of these pollutants appears in Table 18, accumulated from 1957-61 by the National Air Sampling Network.

TABLE 18. CONCENTRATIONS OF SELECTED AIRBORNE PARTICULATE CONTAMINANTS 1957 TO 1961

($\mu g/m^3$)

	Urban		Nonurban	
	Mean	Maximum	Mean	Maximum
Suspended particulates	104	1,706	27	461
Benzene-soluble organics	7.6	123.9	1.5	23.55
Nitrates	1.7	24.8	--	--
Sulfates	9.6	94.0	--	--
Antimony	(a)	0.230	--	--
Bismuth	(a)	0.032	--	--
Cadmium	(a)	0.170	--	--
Chromium	0.020	0.998	--	--
Cobalt	(a)	0.003	--	--
Copper	0.04	2.50	--	--
Iron	1.5	45.0	--	--
Lead	0.6	6.3	--	--
Manganese	0.04	2.60	--	--
Molybdenum	(a)	0.34	--	--
Nickel	0.028	0.830	--	--
Tin	0.03	1.00	--	--
Titanium	0.03	1.14	--	--
Vanadium	(a)	1.200	--	--
Zinc	0.01	8.40	--	--
Radioactivity	4.6[b]	5.435.0[b]	--	--

a. Less than minimum detectable quantity.

b. Picocuries per cubic meter.

Source: American Public Works Association, "Water Pollution Aspects of Urban Runoff," USEPA No. 11030DNS01/69 (NTIS No. PB 215 532), January, 1969.

More specific data for cadmium, lead, and zinc are shown in Table 19.

TABLE 19. GEOMETRIC MEANS FOR CADMIUM AND ZINC FOR 77 MIDWESTERN CITIES kg/km²/mo (ton/mi²/mo)

	LAND USE		
Contaminant	Residential	Commercial	Industrial
Cadmium	0.038 (0.00011)	0.063 (0.00018)	0.073 (0.00021)
Lead	5.212 (0.015)	12.509 (0.036)	9.730 (0.028)
Zinc	5.560 (0.016)	9.382 (0.027)	12.510 (0.036)

Source: Hunt, W.F., et al., "A Study of Trace Element Pollution of Air in 77 Midwestern Cities," Paper Presented at the Fourth Annual Conference on Trace Substances in Environmental Health, University of Missouri, June 1970.

A further indication of the pollutant content of airborne particulates may be suggested by automotive emission factors attributable to vehicular traffic. Some of these are shown in Table 20.

TABLE 20. PARTICULATE AND SULPHUR OXIDE EMISSION FACTORS FOR LIGHT-DUTY GASOLINE POWERED VEHICLES

Pollutant	Emissions g/mi	g/km
Particulate		
Exhaust	0.34	0.21
Tire Wear	0.20	0.12
Sulphur Oxides (SO_x as SO_2)	0.13	0.08

Source: "Compilation of Air Pollutant Emission Factors," USEPA Report No. AP-42 (NTIS No. PB 223 996/0), April, 1973.

Similarly, emission factors for heavy duty vehicles are shown in Table 21.

TABLE 21. EMISSION FACTORS FOR HEAVY-DUTY DIESEL-POWERED VEHICLES

Pollutant	lb/1,000 gal fuel	kg/1,000 l fuel	g/mi	g/km
Particulate	13	1.6	1.2	0.75
Sulfur Oxides (SO_x as SO_2)	27	3.2	2.4	1.5
Carbon Monoxide	225	27.0	20.4	12.7
Hydrocarbons	37	4.4	3.4	2.1
Nitrogen Oxides (NO_x as NO_2)	370	44.0	34	21
Aldehydes (as HCHO)	3	0.4	0.3	0.2
Organic Acids	3	0.4	0.3	0.2

Source: "Compilation of Air Pollutant Emission Factors," USEPA Report No. AP-42 (NTIS No. PB 223 996/0), April, 1973.

In a study carried out in the South Coastal Basin of Southern California, various major components of man-made air and water pollution were examined for their intermedia relationships. (21) A number of conclusions were drawn relative to these relationships. The transfer of suspended solids from one media to another occurs with great ease. The only difference between atmospheric particulates and suspended solids in water is the degree of transfer between the media. The intermedia transfer of sulfur compounds between water and air may occur directly. The transfer from air to water is more easily accomplished than the transfer from water to air.

Sulfuric acid (H_2SO_4) is more toxic than SO_2 or its hydrate. SO_3 and H_2SO_4 can be washed out of the air by rainfall to form sulfite salts which are later converted to sulfates. These sulfate compounds are very hard to breakdown; hence, they will tend to leach into surface and subsurface water supplies. (22)

Man's inability to effectively change the transfer of nitrogen compounds from the air to water has made them a difficult substance to handle. The potential health hazard from nitrogen oxides as air pollutants is great. It is estimated that the total emissions, for 1970, of nitrogen oxides (NO_x) was roughly 20.4×10^6 MT (22.7×10^6 ton) which nearly all is identified as emanating from mobile and stationary fuel combustion sources.

Heavy metals (lead, mercury, cadmium, and nickel) are another category in which air pollution can affect water quality. Occurring naturally in the earth's crust, these metals, when processed, may become hazardous. They deposit in or settle on land and water areas through natural fallout and rainfall. Furthermore, the metals that have settled on the ground can further contaminate surface waters through runoff.

Of the heavy metals, mercury is very toxic. Mercury enters the atmosphere in both gaseous and particulate forms. It has been estimated that mercury precipitates from the atmosphere at a rate between approximately 2.5×10^7 kg/yr (5.50×10^7 lb/yr) and 4.4×10^8 kg/yr (9.68×10^8 lb/yr). (23) More heavily industrialized areas receive much greater fallout than these limits.

Lead is another heavy metal that becomes quickly diluted in the air after emission from cars or other vehicles. Studies have shown the presence of lead in the air 396 m (1,300 ft) downwind from a freeway. (24) These emissions find their way into surface waters via fallout on the land and subsequent storm wash-off and discharge from storm drainage systems. The urban fallout of lead alkyls also finds its way to storm sewers. In England about 7,920 MT/yr (8,800 ton/yr) find their way into storm drainage. The majority of this lead was thought to originate from car exhaust.

Cadmium is released into the air and water mainly through various mining processes and metal smelters. The cadmium which is released into the air is ultimately deposited on the soil and water. Concentrations of cadmium have been found in sewage treatment plant sludges. Furthermore, if these sludges are used as fertilizers or disposed on land, soil contamination is possible.

Carbon monoxide is a lesser intermedial pollutant. Because of its low water solubility and low moisture retention, carbon monoxide does not readily transfer to water or land by natural means, e.g., rainfall. Carbon monoxide, hence, can be looked at essentially as an air-pollutant, it causes little water pollution.

Pesticides and chlorinated hydrocarbons are a unique source of pollution; they are intentionally introduced into the natural environment. A representation of the pesticide cycle is shown in Figure 8. Pesticides are generally directly applied to the land, but at times air application is necessary, thus creating an uncontrolled aerosol condition. Climatic factors such as wind, rain, and fog will determine where the air-applied pesticides will come to rest. A study showed that pesticides were in the air of Antarctica, notably DDT, transported from other continents. (25) In the air DDT can be transported as vapor, tiny crystals or even a mixture with dust particles. The pesticides that are applied to land can be transported to adjacent waters by additional rainfalls and other climatic phenomena. A large portion of the pesticides and chlorinated hydrocarbons in the air that have come from industrial emissions and other operations, will eventually return to the land or waterways through natural fallout and precipitation.

The final category of airborne contributions to be considered are those from non-point sources. Foremost among these would be the products of wind erosion processes. A general procedure known as the Wind Erosion Equation (26) is employed to estimate topsoil losses from agricultural fields over long time intervals. (27) This complex estimating procedure equates soil erodibility, surface roughness, climate, unsheltered field width along the prevailing wind direction, and vegetative cover. Unfortunately, it does not estimate short-term emission rates (27) nor does it, at present, take into consideration wind erosion within an urban development.

Expressions for short-term wind erosion emission factors for various sites have been developed on the basis of field sampling activities. (27) Some of these are shown in Table 22. Values for various construction activities--townhouse and shopping center construction--averaged 442 kg/ha/mo (0.2 ton/ac/mo).

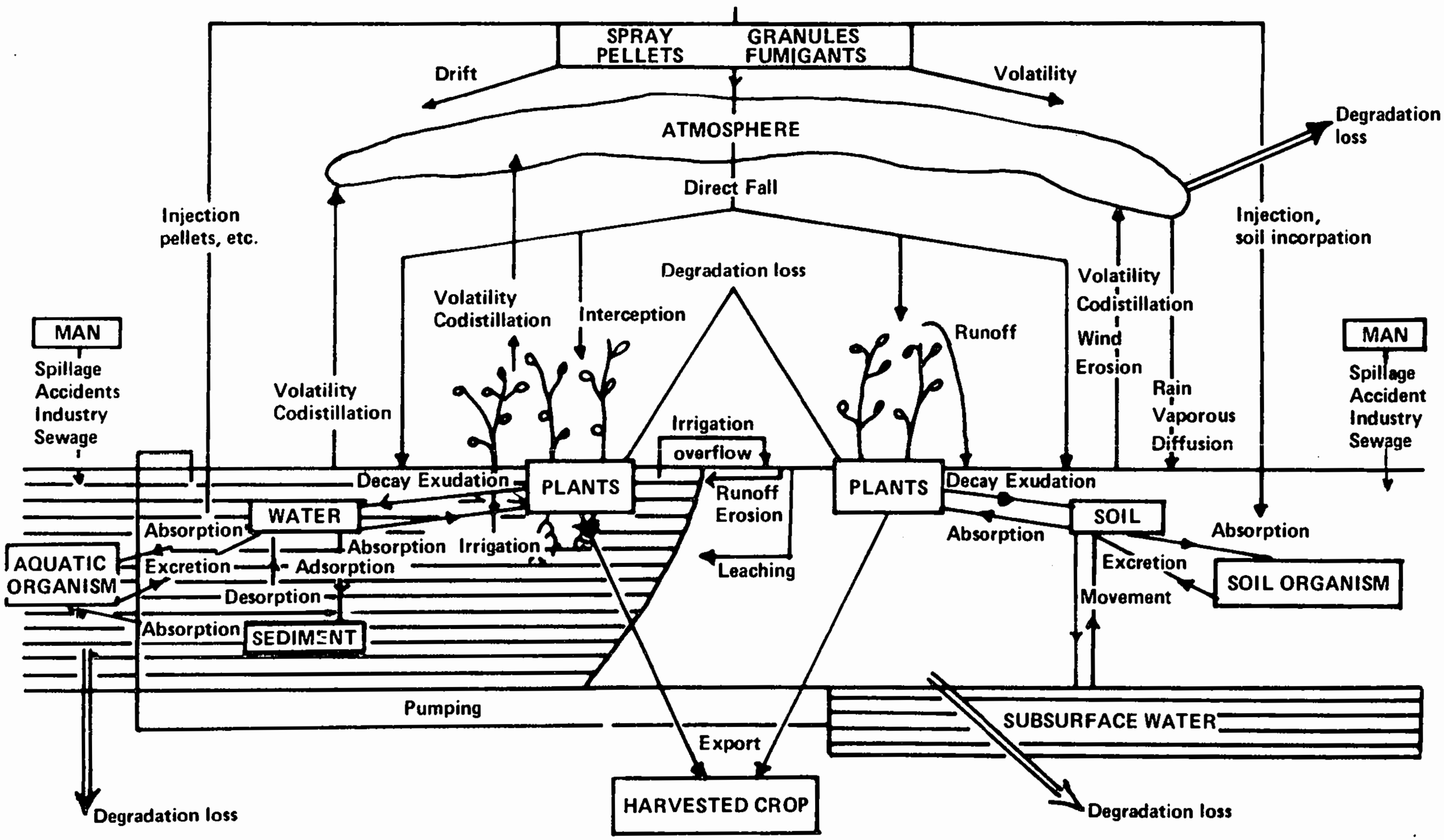


Figure 8. Pesticide cycle in the environment.

Source: Crawford, N.H., and A.S. Donegam, "Pesticide Transport and Runoff Model for Agricultural Lands," USEPA Report No. EPA-660/2-74-013 (NTIS No. PB 235 723), December, 1973.

TABLE 22. WIND EROSION EMISSION FACTORS FOR VARIOUS ACTIVITIES AND SITES

Emission Source	Expression	Applicable Particle Size	Particle Size Characteristics: Diameter	Particle Size Characteristics: Percent By Weight
Unpaved Roads	$e_1 = 0.81 s_1 \left(\frac{s_1}{30}\right)$	<100μm	<2μm	25
			2-30μm	35
			30-100μm	40
Agricultural Tilling	$e_2 = \frac{1.4 s_2 \left(\frac{s_2}{5.5}\right)}{\left(\frac{PE}{50}\right)^2}$	< 75μm	<2μm	35
			2-30μm	45
			>30μm	20
Aggregate Storage Piles	$e_3 = \frac{0.33}{\left(\frac{PE}{100}\right)^2}$	<30μm		

e_1 = emission factor (lb/vehcile-mi),
e_2 = emission factor (lb/ac),
e_3 = emission factor (lb/ton in storage),
s_1 = silt content of road surface material, percent of loose surface dust passing a 200 mesh screen,
s_2 = soil silt content, percentage of surface soil between 2 and 50μm, and
PE = Thornthwaite's precipitation-evaporation index.

Source: Cowherd, C., et al., "Development of Emission Factors for Fugitive Dust Sources," USEPA Report No. EPA-450/3-74-037 (NTIS No. PB 238 262/LK), June, 1974.

The level of construction activity could change emissions by a factor of two or more. Values for the Thornthwait's Precipitation-Evaporation Index (PE) are shown in Figure 9.

The wind drift potentials of the particles emitted from the emission sources identified are shown in Figures 10 and 11. The drift potential is indicated for various wind speeds and is based on materials of various particle diameters and a specific gravity of 2.5.

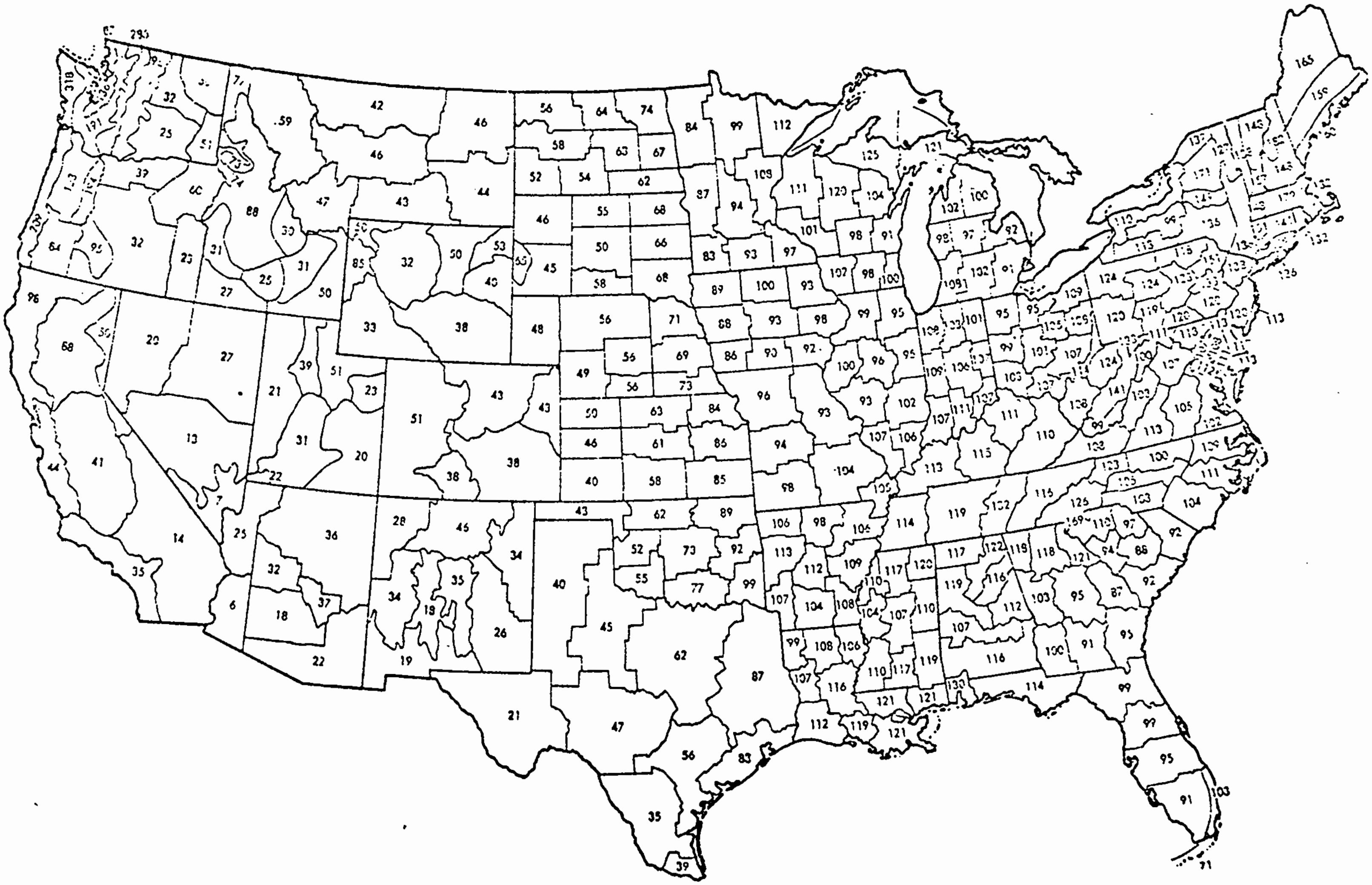


Figure 9. Map of PE values for state climatic divisions.
Thornthwaite's Precipitation – Evaporation Index

Source: Cowherd, C. et al., "Development of Emission Factors for Fugitive Dust Sources," USEPA Report No. EPA-450/3-74-037 (NTIS No. PB 238 262/LK), June, 1974.

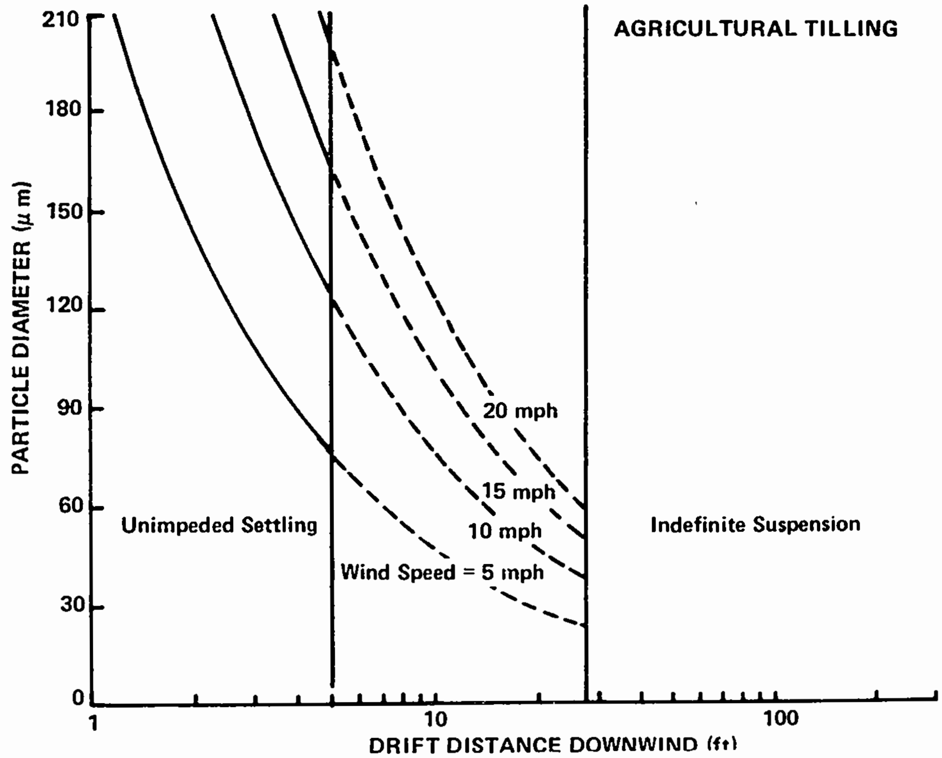


Figure 10. Drift potential of tillage emissions.

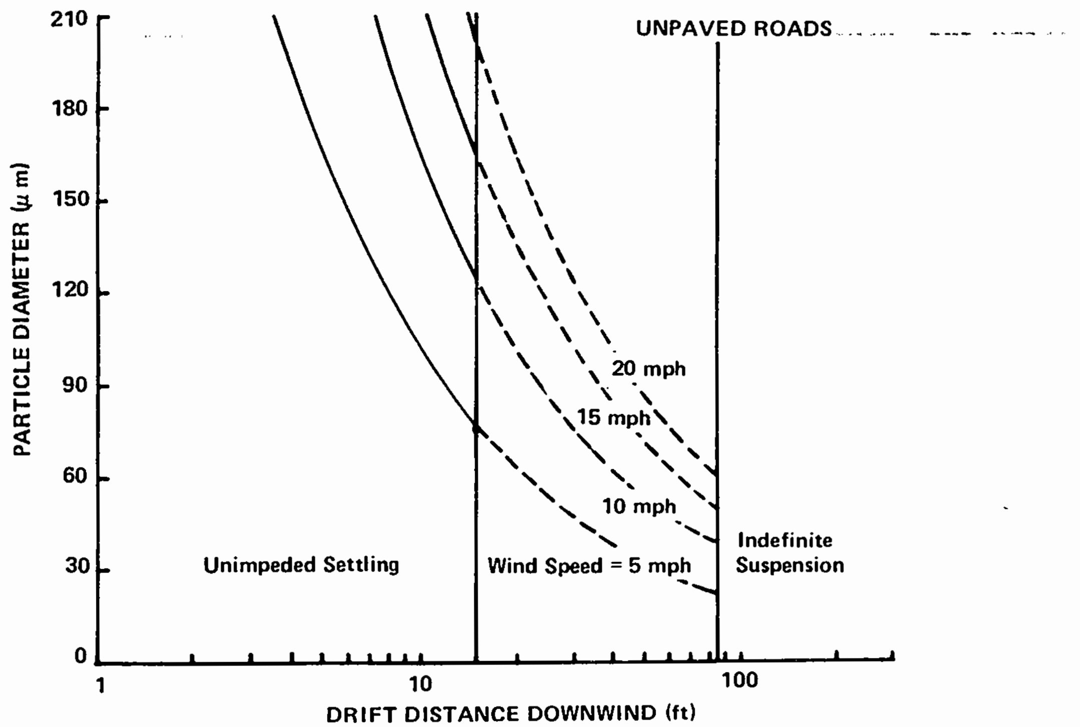


Figure 11. Drift potential of road emissions.

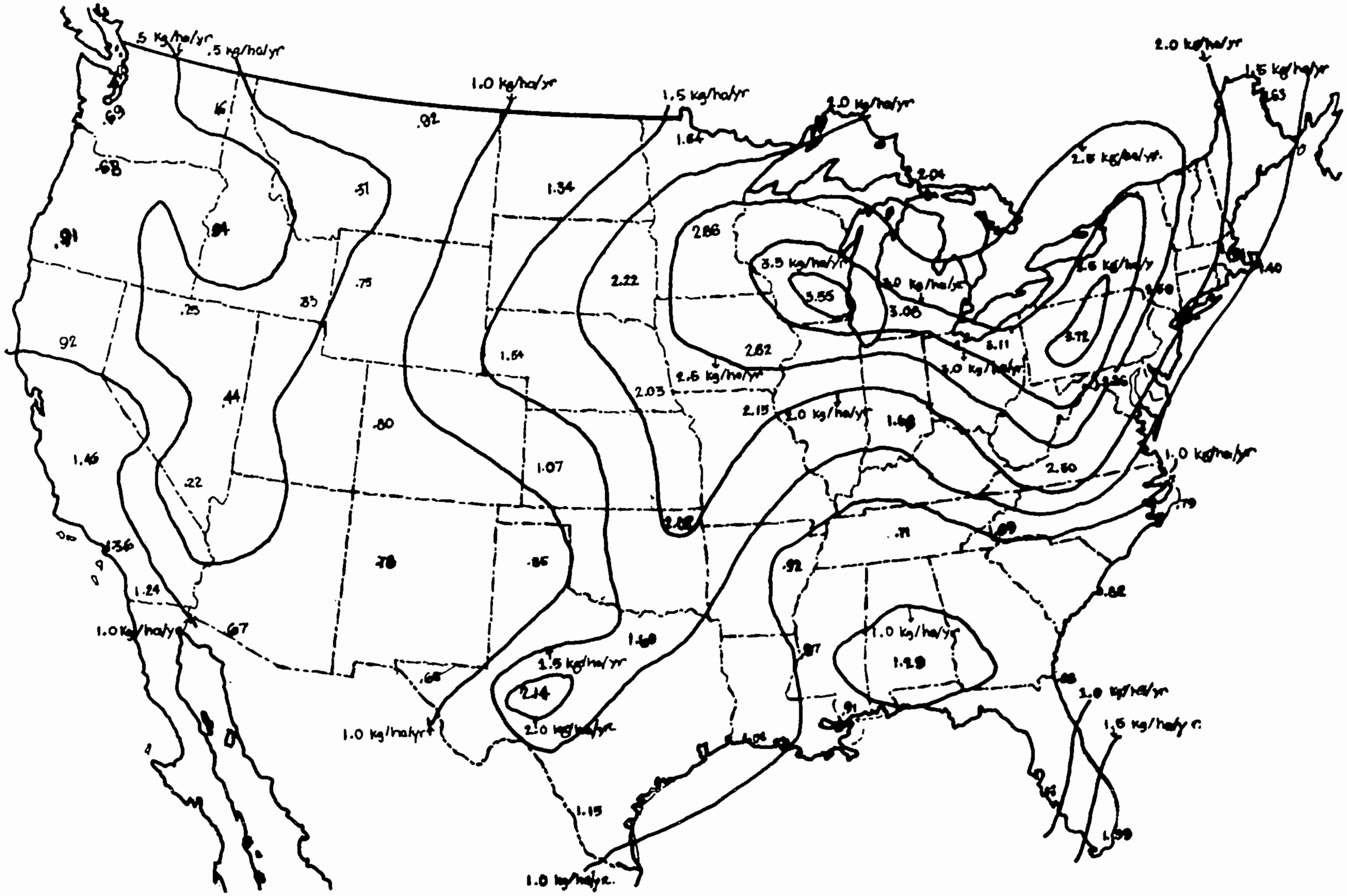
Source: Cowherd, C. et al., "Development of Emission Factors for Fugitive Dust Sources," USEPA Report No. EPA-450/3-74-037 (NTIS No. PB 238 262/LK), June, 1974.

Nutrient contributions may also be attributed to airborne sources. Nitrogen compounds exist in the atmosphere and are returned to earth in the form of precipitation. (28) Similarly, phosphorus precipitation, although typically small, can be enough to cause concern where receiving waters may be subject to eutrophication. (29) Precipitation concentrations for phosphorus range from 0.015 to 0.06 $g/m^2/yr$ (4.9×10^{-5} to 2×10^{-4} $oz/ft^2/yr$). (30)

Man induced changes in the natural balance of these and other airborne materials can have a material impact on the amounts deposited in bulk precipitation (dustfall plus precipitation). It has been estimated that about 1.134 million kg (2.5 million lb) of phosphorus are consumed annually in gasoline fuels for motor vehicles alone. (30) These contributions in and around urban areas can produce significant nutrient inputs through the processes of bulk precipitation.

An indication of general nitrogen contributions in rainfall for the Continental United States is shown in Figure 12. It is apparent that significant local variations from the levels depicted are likely. The dry fallout of nutrients is of critical importance. It has been estimated that between four to ten times the nutrient content of rain falls as bulk precipitation. (31) Other studies have estimated that from 40 to 70 percent of the atmospheric nitrogen contribution comes from dry fallout. (32)

Bulk precipitation of phosphorus is relatively low. Work in Wisconsin estimated that this source ranged from 0.5 to 1.2 percent of the total. (33, 34) Urbanization and industrialization have been noted as major contributors through the phenomena of soil erosion, and industrial emissions. (20)



Note: 1 kg/ha/yr = 0.89 lb/ac/yr

Figure 12. Nitrogen contributions (NO_3-N & NH_4-N) from rainfall.

Source: Uttormark, P.D., et al., "Estimating Nutrient Loadings of Lakes from Non-Point Sources," USEPA Report No. EPA-660/3-74-020 (NTIS No. PB 238 355), August, 1974.

VEGETATION AS A SOURCE OF RUNOFF POLLUTION

Vegetative wastes include leaves, buds, pollen, bark, twigs, seeds, fruit, grasses, and other plant materials common to an urban setting, as well as humic or decomposed plant wastes and leaf leachates. Studies performed in Chicago by the American Public Works Association estimated that vegetative materials as one component of street litter were as high as 21 percent of the annual total litter loading accumulated in a ten-acre residential area. (15) As a source of organic solids, vegetative matter can be a meaningful cause of water quality impairment.

Vegetative waste generation depends upon soils, location, climate, season, land use, landscaping activities, and local public works practices. (15) Although these wastes are generally distributed across pervious urban areas they can enter the runoff stream through a variety of mechanisms. These may be as by-products of sheet erosion, by wind, by direct fall onto impervious areas, or they may be dumped or raked onto street surfaces for subsequent scour by street runoff.

A sense of vegetative pollution contributions to urban runoff can be established from a better understanding of tree litter debris as determined from silviculture studies and from what is known concerning grass litter debris. A review of such data follows.

Tree Litter

Tree litter is one of the major sources of vegetative debris. The prevalent tree types are angiosperms or deiduous trees, and gymnosperms or conifers. An indication of the annual tree litter production from each of these types is shown in Table 23. This information represents tree litter production in a fully forested area with a completely closed canopy. Under these conditions, evergreen tree types produce litter at a higher annual rate than do deciduous tree types.

TABLE 23. COMPARISON OF LITTER PRODUCTION BY EVERGREEN AND DECIDUOUS TREES IN THE NORTHERN HEMISPHERE

	No. of Regions Averaged	Evergreen or Gymnosperms lb/ac/yr	Evergreen or Gymnosperms kg/ha/yr	Deciduous or Angiosperms lb/ac/yr	Deciduous or Angiosperms kg/ha/yr
Total Litter	8	3,300	3,702	2,854	3,202
Leaf Litter	9	2,319	2,601	2,141	2,402

Sources: E. Graham and J.R. Bray, "Litter Production in Forests of the World," *Advances in Ecological Research*, Vol. 2, 1964.

Heaney, J.P., and W.C. Huber, "Urban Stormwater Management and Decision-Making," USEPA Report No. EPA-670/2-75-022 (NTIS No. PB 242 290), May, 1975.

The components of tree litter are shown in Table 24. By far the greatest amount of litter takes the form of leaf fall. Thus, this component would appear to be the most significant in influencing surface runoff quality when allowed to be introduced into these flows.

TABLE 24. SOURCES OF FOREST LITTER

Source	% of Total Litter
Leaves	60-70
Branches	12-15
Bark	1-14
Fruit	1-17

Source: J.P. Heaney and W.C. Huber, "Urban Stormwater Management and Decision-Making," USEPA Report No. EPA-670/2-75-022 (NTIS No. PB 242 290), May, 1975.

The production of tree litter under fully forested conditions depends not only on the tree type, but also on the local climate. An indication of the variation in annual forest litter production appears in Figure 13.

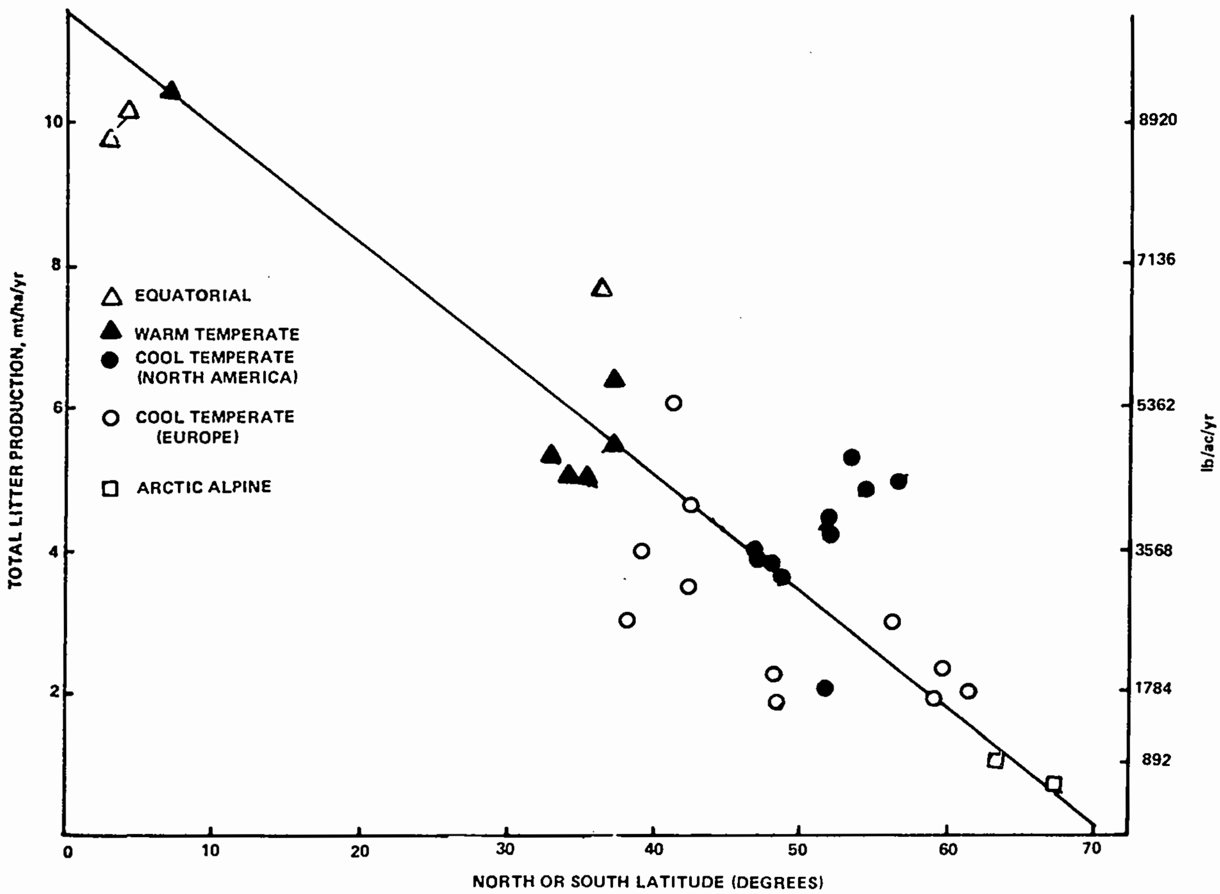


Figure 13. Annual production of total tree litter in relation to latitude.

Source: Gorham, E., and J.R. Bray, "Litter Production in Forest of the World," *Advances in Ecological Research*, Vol. 2, 1964.

These data are presented in terms of four major climatic zones: Equatorial, Warm Temperate, Cool Temperate, and Arctic-Alpine. The majority of the land area of the United States falls into the warm temperate and cool temperate zones. The former lies approximately between 30° and 40° north latitude, and the latter lies between 40° and 50° north latitude. This figure shows that the total tree litter production diminishes with the distance from the Equator. The tabulation of tree litter production by major component is shown in Table 25. This indicates leaf litter and other tree litter components for fully forested, complete tree canopy coverage.

TABLE 25. ANNUAL FOREST LITTER PRODUCTION IN FOUR MAJOR CLIMACTIC ZONES

	Leaves			Other			Total		
	Number of Regions Averaged	lb/ac	kg/ha	Number of Regions Averaged	lb/ac	kg/ha	Number of Regions Averaged	lb/ac	kg/ha
Arctic-Alpine	1	624	700	1	357	400	3	892	1,000
Cool Temperate	15	2,230	2,500	10	803	900	22	3,122	3,500
Warm Temperate	8	3,211	3,600	5	1,695	1,900	7	4,906	5,500
Equatorial	2	6,066	6,800	1	3,122	3,500	4	9,723	10,900

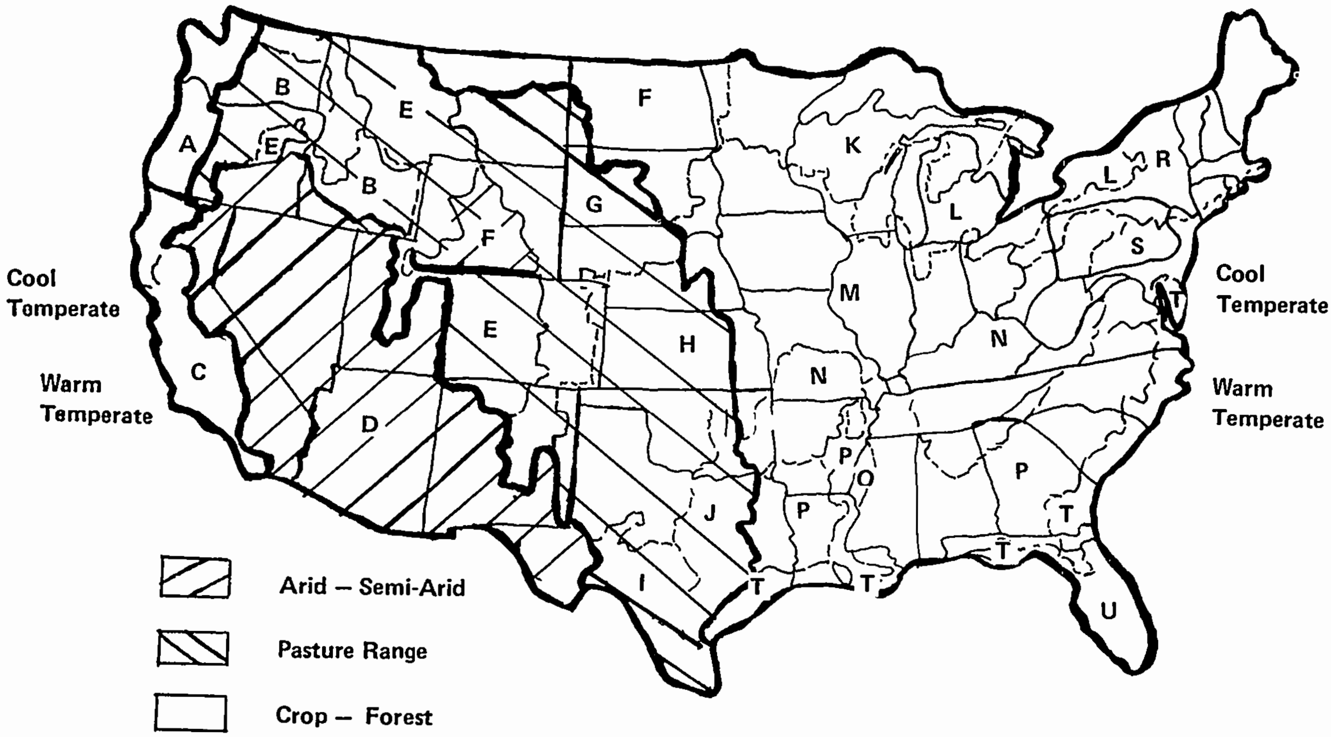
Sources: Gorham, E., and J.R. Bray, "Litter Production in the Forests of the World," *Advances in Ecological Research*, Vol. 2, 1964.

Heaney, J.P., and W.C. Huber, "Urban Stormwater Management and Decision-Making," USEPA Report No. EPA-670/2-75-022 (NTIS No. PB 242-290), May, 1975.

The data reported heretofore on tree litter represent fully forested, complete leafed canopy conditions. This is generally not a circumstance existing in most urban developments. The areal coverage of the leafed portions of urban trees most often is less than 100 percent. Interestingly, variations in tree densities under full canopy conditions do not produce significant changes on the magnitude of tree litter production. The results of tree density thinning produces a decrease in tree litter production roughly proportional to the degree of canopy reduction. (36)

In an urban setting a number of conditions may prevail in determining the amount of tree litter that can influence surface runoff quality. Climate and tree species, maturity, and specific growing conditions obviously influence the amount of tree litter produced. Barring a more complete understanding of these factors in an urban environment, it seems reasonable that gross annual estimates of urban tree litter production may be made on the basis of geographical location, and the relative degree of tree canopy development.

A further indication of the geographical distribution of desirable natural tree growing conditions is shown in Figure 14. The figure shows the major climatic zones indicated previously by latitude and also classifies the land area of the continental United States by its relative aridity and predominant non-urban land uses. The unshaded areas are those likely to provide the least favorable natural conditions for tree growth and crop production. Additional supporting data appear in Table 26. The ranking of land resource regions represents relative vegetative growth productivity. Available data on tree



A.	Northwest coast region	K.	Northern lake region
B.	Columbian region	L.	Southern lake region
C.	California coast region	M.	North-central region
D.	Mountain and basin region	N.	Appalachian-Ozark region
E.	Rocky Mountain region	O.	Mississippi delta region
F.	Northern plains region	P.	South Atlantic slope region
G.	Western plains region	R.	Northeastern region
H.	Central plains region	S.	North Atlantic slope region
I.	South Texas region	T.	Atlantic coast region
J.	Southern prairie region	U.	Florida subtropical region

Figure 14. Climatic zones and prevalent land uses. Continental United States.

Source: "Two-Thirds of Our Land: A National Inventory," Program Aid No. 984, Soil Conservation Service, U.S. Department of Agriculture, 1971.

TABLE 26. RANKING OF LAND RESOURCE REGIONS IN TERMS OF CROP AND FOREST USES WITH ASSOCIATED LITTER PRODUCTION REPORTED

Land Resource Regions in Ranked Order		Percent of Region in Crops and Forest	Leaf Litter lb/ac	Other Litter lb/ac	Total lb/ac
Most Acceptable Regions for Crop and Tree Growth					
O.	Mississippi Delta	90%	—	—	—
A.	Northwest Coast	85%	—	—	—
L.	Southern Lakes	85%	1,700-4,600	1,500	6,100
P.	South Atlantic Slope	85%	3,800	1,600	5,400
K.	Northern Lakes	84%	2,000	—	—
R.	Northeastern	84%	2,100-4,000	—	—
S.	North Atlantic Slope	82%	—	—	—
M.	North Central	79%	—	—	3,800
N.	Appalachian-Ozark	78%	3,800	700	4,500
T.	Atlantic Coast	74%	2,700-3,400	—	—
U.	Florida Subtropical	60%	—	—	—
C.	California Coast	59%	2,100	—	—
F.	Northern Plains	59%	—	—	—
Least Acceptable Regions for Natural Crop and Tree Growth					
B.	Columbian Region	52%	—	—	—
H.	Central Plains	47%	—	—	—
E.	Rocky Mountain	41%	—	—	—
J.	Southern Prairie	27%	—	—	—
D.	Mountain/Basin	19%	—	—	—
G.	Western Plains	18%	—	—	—
I.	South Texas	10%	—	—	—

Sources: Gorham, E., and J.R. Bray, "Littter Production in the Forests of the Worls," *Advances in Ecological Research*, Vol. 2, 1964.

Daubenmere, R., "Nutrient Content of Leaf Litter of Trees in the Northern Rocky Mountains," *Ecology*, Vol. 34, 1953.

Heyward, F., and R.M. Barnette, "Field Characteristics and Partial Chemical Analysis of the Humus Layer of Longleaf Pine Forest Soils," *Bulletin of Florida, Agricultural Experiment Station*, Vol. 302, 1936.

"Two-Thirds of Our Land: A National Inventory," Program Aid No. 934, Soil Conservation Service, U.S. Department of Agriculture, 1971.

litter production are also shown for those regions where such information has been determined. This generalized scheme for classifying natural growth productivity may serve as a guideline to locales where vegetative growth is probable, but it is a weak substitute for measurement of actual local conditions. As a case in point, the desert and semi-desert regions of the Southwest are designated as areas least acceptable for natural tree and crop growth. In urban areas of the Southwest, trees, lawns, and other plantings are grown by use of irrigation and vegetative litter is produced. Tree densities and tree canopy development are probably less than in more humid areas, and their associate litter production is also probably less.

Grass Litter

Grass clippings and other low-lying refuse are another prospective source of organic materials that may enter urban runoff as a pollutant. As may be expected, grass clipping production is also related to the amount of grassed areas. Production figures for various types of grasses appear in Table 27. This information was developed through work performed in the State of Florida. The figures may, as such, represent higher yields than may be experienced in other areas of the country with shorter growing periods.

TABLE 27. ANNUAL YIELD OF VARIOUS GRASS TYPES

Grass	Annual Yield	
Grass Type	lb dry matter/ac	kg dry matter/ha
Rye grass	3676 – 5612	4124 – 6300
White clover	3805 – 5108	4270 – 5730
Pensacola Bahia grass	8126	9120
Coastal Bermuda grass	2542 – 9135	2850 – 10250

Sources: "Florida Field Crop Variety Report, 1971," E.B. Whitty (ed) Agronomy Report AG 72-51, Institute of Food and Agricultural Sciences, University of Florida, Gainesville, Florida, 1972.

Ruelke, O.C., and G.M. Prime, "Preliminary Evaluation of Yield and Protein Content of Six Hybrid Bermuda Grasses, Pensacola Bahia Grass and Pengola Grass Under Three Fertilization Regimes in North Central Florida," *Soil and Crop Science Society of Florida*, Vol. 28, 1968.

Pollutional Effects

Vegetative waste materials can constitute one source of surface runoff quality impairment through the addition of organic matter, nutrients and mineral constituents. Past studies have indicated that water quality effects can result from the decomposition of leaf litter in the presence of water.(36, 37) Coniferous trees and plants contain about half of the mineral content of deciduous types (2 to 5 percent ash content as compared to 4 to 14 percent). (14) Table 28 shows the results of past studies of leaf litter constituents. Some indications of the relative amounts of nutrients produced by various tree types is shown in Table 29. The nutrients available in this vegetative matter can contribute to eutrophication processes when transported to a natural receiving lake or pond. Vegetative organic matter produces oxygen depletion effects, as might be predicted, and also contributes to the solids loadings in surface runoff flow. Maple leaves have been shown to consume 75 percent of their initial dry weight in oxygen over a period of 13 months. (39) Lawn litter and other vegetative matter pose a similar problem from a pollutional standpoint. The total nitrogen content of grasses common to Florida was found to be somewhat higher than that encountered in tree leaf litter. This amounted to 1.7 to 2 percent of their dry weight. (40) Values for the nitrogen content of harvested commercial crops were found to be about 128 kg/ha (114 lb/ac) for hay, 48 kg/ha (43.2 lb/ac) for mixed grains, and 361 kg/ha (322 lb/ac) for alfalfa and pasturage. Phosphorus content was found to be about 13 kg/ha (12 lb/ac) for hay and 9 kg/ha (8.4 lb/ac) for mixed grains. Thus, grasses

TABLE 28. THE CONCENTRATION OF NUTRIENTS IN NEWLY FALLEN GYMNOSPERM AND ANGIOSPERM TREE LEAF LITTER

(% Dry Weight)

	N	P	K	Ca	Mg	Ash
Evergreen	0.58-1.25	0.04-0.10	0.12-0.39	0.55-2.16	0.14-0.23	3.01 4.33
Deciduous	0.51-1.01	0.09-0.28	0.40-1.18	0.99-3.84	0.22-0.77	5.71-15.16
Deciduous/Evergreen	0.3-0.7	-	-	-	-	-
Deciduous	0.5-1.25	-	-	-	-	-

Sources: Daubenmire, R., "Nutrient Content of Leaf Litter of Trees in the Northern Rocky Mountains," *Ecology*, Vol. 34, 1953.
Lutz, H.J. and R.F. Chandler, "Forest Soils," John Wiley and Sons, Inc., New York, 1946.
Carlisle, A., A.H.F. Brown and E.J. White, "Litter Fall Leaf Production and the Effects of Defoliation by Tortrix Viridamal in a Sissile Oak (Quercus Petrala) Woodland," *Journal of Ecology*, Vol. 54, 1966.
Corle, T.S., "Composition of the Leaf Litter of Forest Trees," *J. Elisha Mitchell Science Society*, Vol. 52, 1936.
Graham, E., and J.R. Bray, "Litter Production in Forests of the Worls," *Advances in Ecological Research*, Vol. 2, 1964.
Heaney, J.P., and W.C. Huber, "Urban Stormwater Management and Decision-Making," USEPA Report No. EPA-670/2-75-022 (NTIS No. PB 242-290), May, 1975.

TABLE 29. AVERAGE QUANTITIES OF NUTRIENTS FALLING IN THE LITTER OF DIFFERENT TREES

lb/ac/yr (kg/ha/yr)

TREES Leaves Only	N	P	K	Ca	Mg
Deciduous	13.2	2.5	10.7	52.2	7.3
Evergreen	18.8	1.4	5.2	21.1	3.6
Deciduous	18.9	1.11	—	—	—
Evergreen/Deciduous	13.6-64.7	0.6-4.5	3.2-14.6	19.9-64.8	2.4-12.3

Sources: "Forest Soils," H. J. Lutz and R. F. Chandler, John Wiley and Sons, Inc., New York, 1946
"Litter Fall Leaf Production and the Effects of Defoliation by Tortrix Viridamal In a Sissile Oak (Quercus Petrala) Woodland," A. Carlisle, A.H.F. Brown, E.J. White, *Journal of Ecology*, Vol. 54, 1966
"The Return of Nutrients With Litter in the Forest Ecosystems," Teruhiko Kawahara, *Journal of Japanese Forest Society*, Vol. 53, 1972
"Litter Production in Forests of the World," E. Graham and J.R. Bray, *Advances in Ecological Research*, Vol 2, 1964
Heaney, J.P., and W.C. Huber, "Urban Stormwater Management and Decision-Making," USEPA Report No. EPA-670/2-75-022 (NTIS No. PB 242-290), May, 1975.

from lawns also provide a source of organic material that can, without proper management and disposal, present a significant source of pollution in both urban and non-urban runoff.

Unfortunately, existing reported information on the pollutional characteristics of tree and grass litter does not reflect all of the pollutant parameters of special interest in the study of unoff quality. Measures of oxygen demand, solids contributions, pesticides, and metals are all of interest, but were not uncovered in the review of existing published sources. Thus, additional research and study of vegetative pollutional contributions in both urban and non-urban environments appears to be warranted.

Urban Vegetative Pollutional Contributions

The production of vegetative wastes in urban areas does not occur uniformly during the year. Little waste should be expected during the winter months through most of the country. During the growing season, however, lawn clippings are produced at a more or less uniform rate. Tree litter generally peaks during the autumn with the annual leaf fall. Interestingly, coniferous trees, as well as the deciduous trees, generally shed the greatest amount of their needles during the autumn and winter months, (42) although some leaf fall occurs during the growing season as well.

Tree canopy development in urban areas are considerably less than under fully forested conditions. It is apparent that trees and other vegetation can only be planted in pervious areas, although they may be found to overhang impervious areas. Thus, tree and plant density is a function of available planting space. The extent of vegetative cover is also influenced by the maturity of the trees and bushes located within the urban area. The relative maturity of vegetative cover can be estimated from the general age of the development within the area. As previously noted, the best estimation of vegetative cover and leaf litter production within any given urban drainage area should be determined from local conditions. The utilization of aerial photography for this purpose holds out the greatest promise for developing this type of information and other pertinent data. Investigations by the American Public Works Association in connection with street sweeping estimated that in Chicago, three-quarters of the annual leaf loadings occurred in the fall, while one-quarter of the annual loading apparently occurred during the growing season.(15) Estimation of vegetative contributions to the pollution of storm runoff within a given drainage basin requires a careful evaluation of the factors that dictate vegetative litter production; its seasonal variation through the year and local public works practices related to the collection and disposal of these wastes.

A number of variations in local public works programs exist in response to the handling of vegetative debris, other forms of litter, and other waste materials. The range of programs vary from complete collection and disposal of these wastes to nominal activities that leave the greater part of this responsibility to the individual citizen. It is apparent that the degree of effort exercised by the local jurisdiction can influence the amount of waste which can affect surface runoff. The methods by which these wastes are handled, stored, collected, and disposed of also affect the amount of wastes which can affect runoff quality.

Recent surveys by the APWA help to shed some light on local practice. Data from the 1973 APWA "Survey of Refuse Collection Practice" is presented in Tables 30 and 31. They show the number of jurisdictions in the United States and Canada that make provision for the collection of yard litter as part of solid waste pickup and disposal activities in terms of population ranges. In each case, the majority of the respondent jurisdictions provide this service whether collection is accomplished by the municipality's own forces, by contract, or through private arrangements by individual householders.

TABLE 30. COLLECTION OF YARD LITTER AS PART OF SOLID WASTE COLLECTION ACTIVITIES

Population Range (Thousands)	Municipal Agency No.	Municipal Agency %	Contract or Private No.	Contract or Private %	Both No.	Both %	Jurisdictions Providing Services No.	Jurisdictions Providing Services %	% Not Providing Service	Total No.
0-5	1	10.0	4	40.0	0	0.0	5	50.0	50.0	10
5-10	1	3.4	10	34.5	7	24.1	18	62.0	38.0	29
10-25	7	6.7	54	51.4	16	15.2	77	73.3	26.7	105
25-50	26	12.7	94	45.8	40	19.5	160	78.0	22.0	205
50-100	16	9.6	86	51.8	26	15.7	128	77.1	22.9	166
100-250	12	16.0	51	68.0	12	16.0	75	100.0	0.0	76
250-500	5	13.9	23	63.9	7	19.4	35	97.2	2.8	36
500-1,000	3	12.0	15	60.0	5	20.0	23	92.0	8.0	25
1,000+	1	9.0	5	45.5	2	18.2	8	72.7	27.3	11
Total	72	10.8	342	52.0	115	17.4	529	80.2	19.8	662

Source: 1973 APWA Survey of Refuse Collection Practice.

TABLE 31. COLLECTION OF TREE DEBRIS AS PART OF SOLID WASTE COLLECTION ACTIVITIES

Population Range (Thousands)	Municipal Agency No.	Municipal Agency %	Contract of Private No.	Contract of Private %	Both No.	Both %	Jurisdictions Providing Service No.	Jurisdictions Providing Service %	% Not Providing Service	Total No.
0-5	1	10.0	3	30.0	0	0.0	4	40.0	60.0	10
5-10	2	6.9	3	10.3	4	13.8	9	31.0	69.0	29
10-25	5	9.0	35	77.8	5	9.0	45	42.8	57.2	105
25-50	15	7.3	54	26.4	21	10.2	90	43.9	56.1	205
50-100	9	5.4	48	28.9	12	7.3	69	41.6	58.4	166
100-250	7	9.3	26	34.7	5	6.7	38	50.7	49.3	75
250-500	0	0.0	10	27.8	3	8.3	13	36.1	63.9	36
500-1,000	1	4.0	9	36.0	2	8.0	12	48.0	52.0	25
1,000+	1	9.0	3	27.4	1	9.0	5	45.4	54.6	11
Total	41	6.2	191	28.8	53	8.0	285	43.0	57.0	662

Source: 1973 APWA Survey of Refuse Collection Practice

The data represented in both of these tabulations reflect solid waste pick-up activities on both routine and special collection schedules. Interestingly, the collection of yard litter and tree debris is relatively consistent regardless of population served.

The 1973 APWA "Survey Of Practice As To Street Cleaning, Catch Basin Cleaning, and Snow and Ice Control" also provides some information on local practices in handling leaves and other vegetative matter. In general, the responsibility for direct leaf collection falls on the same agency that performs street cleaning operations. A total of 99.1 percent of 340 responding jurisdictions placed this responsibility within this agency. A summary of practice as to the locations where leaf collections are made is shown in Table 32. Interestingly, the majority of reporting jurisdictions collect leaves from storage containers or from piles in the street. The frequency of leaf collection is shown in Table 33.

TABLE 32. SITES WHERE PUBLIC AGENCY LEAF REMOVAL ACTIVITIES OCCUR

Removal Site	Number of Jurisdictions Reporting Removal From this Location		Number of Jurisdictions Responding	
	No.	%	No.	%
Streets	264	85.2	310	100
Planting Strips between Street and Sidewalk	86	28.5	302	100
Sidewalks	39	13.0	301	100

Source: 1973 APWA "Survey of Practice as to Street Cleaning, Catch Basin Cleaning and Snow and Ice Control."

TABLE 33. FREQUENCY OF LEAF COLLECTION AND LENGTH OF THE SPECIAL COLLECTION SEASON

Frequency of Collection (days)		⩽5	6-10	11-15	16-20	21-25	Total
Collection Frequency times per season	No.	193	26	10	1	1	231
	%	83.6	11.3	4.3	0.4	0.4	100
Special leaf collection season weeks per year	No.	91	109	39	12	2	253
	%	36.0	43.1	15.4	4.7	0.8	100

Source: 1973 APWA "Survey of Practice as to Street Cleaning, Catch Basin Cleaning and Snow and Ice Control."

Table 33 shows that leaf removal operations occur most often in a special collection season of up to 15 weeks at a most prevalent frequency of five collections per season.

The foregoing has attempted to identify some of what is known of the vegetative sources of runoff pollution. Some approximate estimating methods for urban conditions may be hypothesized on the basis of available, limited, non-urban experience. On the assumption that all leaf litter is deposited during the autumnal leaf fall, the following general expression may be used to estimate average daily street loadings of leaves.

$$L_A = \frac{r \cdot V_T \cdot I_s}{100n \cdot G_1} \qquad (3)$$

where L_A is average daily accumulation of tree litter in kg/curb-km/day (lb/curb-mi/day) or pollutant loadings as appropriate

r is the ratio of tree canopy covered area to total area

V_T is average annual tree loadings in kg/ac (lb/ac) or pollutant loadings as appropriate

I_s is the percent of street surface imperviousness

n is the number of days during the leaf fall season

G_1 is curb density, m/ac (ft/ac)

Values for street surface imperviousness and curb length may be determined from careful study of the area under investigation. General estimating expressions for both in terms of population density are given below: (42)

$$I_s = 17.06 - 14.56\ (0.839)^{PD} \qquad (4)$$

$$G_1 = 413.1 - (352.7)\ (0.839)^{PD} \qquad (5)$$

where

I_s and G_1 are as previously defined

PD is gross population density in persons/ac

Although the foregoing provides an estimating method for determining the average daily accumulation of tree litter along the curb, it is likely that the amount of litter or litter borne pollutants that will affect the quality of runoff will be less than that accumulated. Thus, the pollutional contribution might take the form of the expression:

$$P_L = L_A \cdot D \quad (6)$$

where:

P_L is the pollutional accumulation in kg/curb-km/day (lb/curb-mi/day)

L_A is as previously defined

D is an applicable delivery ratio, estimating to range from 0.1 to 0.5

The best approaches to the determination of the pollutant contributions from vegetative sources should be on the basis of locally determined data and the experience of local public works operating practices.

Soil Erosion As A Water Pollution Source

Sediment is perhaps the largest single source of water pollution. Current estimates suggest that 1.8 x 10^9 MT (2 x 10^9 ton) of sediment are desposited in the nation's rivers annually. (44) Sediments are soils or other surficial materials that are products of erosion and may be transported or deposited by the action of wind, water, snow, ice or gravity. (44)

Erosion and sedimentation are naturally and continually occuring geological processes. Normally, soils are protected by vegetation and vegetative residue. In areas where moisture is too limited or fertility too low to sustain close-growing vegetation, the land is subject to periodic erosion from intense rains. Man's actions, including construction and mining activities often remove all of the vegetation in localized areas thus tending to increase the rate of erosion. Removal of the protective cover allows the forces of wind and water to act more directly and forcefully on the exposed soil environment.

Non-point pollutants are organic and inorganic materials entering surface and ground water from non-specific or unidentified sources. In a rural environment, they include sediment, plant nutrients, pesticides, and animal wastes from cropland, rangeland, feeding areas, pastures, and farm woodlots. Sediment is the major pollutant in terms of volume, and may be a carrier of some organics, pesticides, and plant nutrients. (45) In an urban environment, similar pollutants may be experienced from pervious areas as well as those materials that are unique to urban activities - transportation related pollutant sources, air pollution, and other conditions.

As might be anticipated, sediment production has been found to vary according to land use and physical site characteristics. Some examples of annual erosion rates found in connection with a variety of overall land uses are shown in Table 34. A comparison of the relative stability of land under natural cover, with the greater instability of land employed in agricultural uses or disturbed

TABLE 34. EROSION RATES REPORTED FOR VARIOUS SEDIMENT SOURCES

Sediment Source	Erosion Rate ton/mi²/yr	MT/km²/yr	Geographic Location	Comment
Natural	15-20	5.25-7.00	Potomac River Basin	Native Cover
	32-192	11.2-67.2		Native Cover
	200	70	Pennsylvania and Virginia	Natural drainage basin
	320	112.1	Mississippi River Basin	Throughout geologic history
	13-83	4.55-29.1	Northern Mississippi	Forested watershed
	25-100	8.75-35	Northwest New Jersey	Forest & under-developed land
	115	40.3		Soils eroding at the rate they form
Agricultural	12,800	4482.5	Missouri Valley	Loess-region
	13,900	4867.7	Northern Mississippi	Cultivated land
	1,030	360.7	Northern Mississippi	Pasture land
	10,000-70,000	3501.9-24,514		Continuous row crop without conservation practices
	200-500	70-175.1	Eastern U.S. Piedmont	Farmland
	320-3,840	112.1-1,345		Established as tolerable erosion
Urban	50,000	17,510	Kensington, Maryland	Undergoing extensive construction
	1,000-100,000	350.2-35,019		Small urban construction area
	1,000	350.2	Washington, D.C. area	750 mi² area average
	500	175.1	Philadelphia area	
	146	51	Washington, D.C. area watersheds	As urbanization increases
	280	98		
	690	242		
	2,300	805		
Highway Construction	36,000	12,607	Fairfax County, Virginia	Construction on 179 ac
	50,000-150,000	17,510-52,529	Georgia	Cut slopes

Sources: Brandt, G.H., et al., "An Economic Analysis of Erosion and Sediment Control Methods for Watersheds Undergoing Urbanization," Final Report OWRR Contract 14-31-001-3392, Midland, Michigan, 1972.

Heaney, J.P., and W.C. Huber, "Urban Stormwater Management and Decision-Making," USEPA Report No. EPA-670/2-75-022 (NTIS No. PB 242 290), May, 1975.

by the processes of construction activity, demonstrates the influence of human activity. Only in long-term and highly stabilized urban uses is some resemblance of relative stability regained. In these areas, however, the diminished contributions of soil erosion are replaced by solids generated as a product of other human activity--airborne particulates, traffic related depositions, vegetative materials, litter and other solid wastes, salts and abrasives used in snow and ice control, animal wastes, and even the erosion products of street surfacing materials. Only 0.25 mm (0.01 in) of concrete pavement surface erosion annually would produce a potential sediment yield of 4.4 MT/ha/yr (2 ton/ac/yr) or more of pavement surface.

Further information on annual sediment yields is presented in Figure 15. This figure summarizes findings for areas of differing sizes and land uses in the Central Atlantic States. It also demonstrates the extremely high sediment yields found in connection with exposed or uncovered sites, and helps to pinpoint the magnitude of sediment problems associated with construction and other denuded and uncontrolled sites.

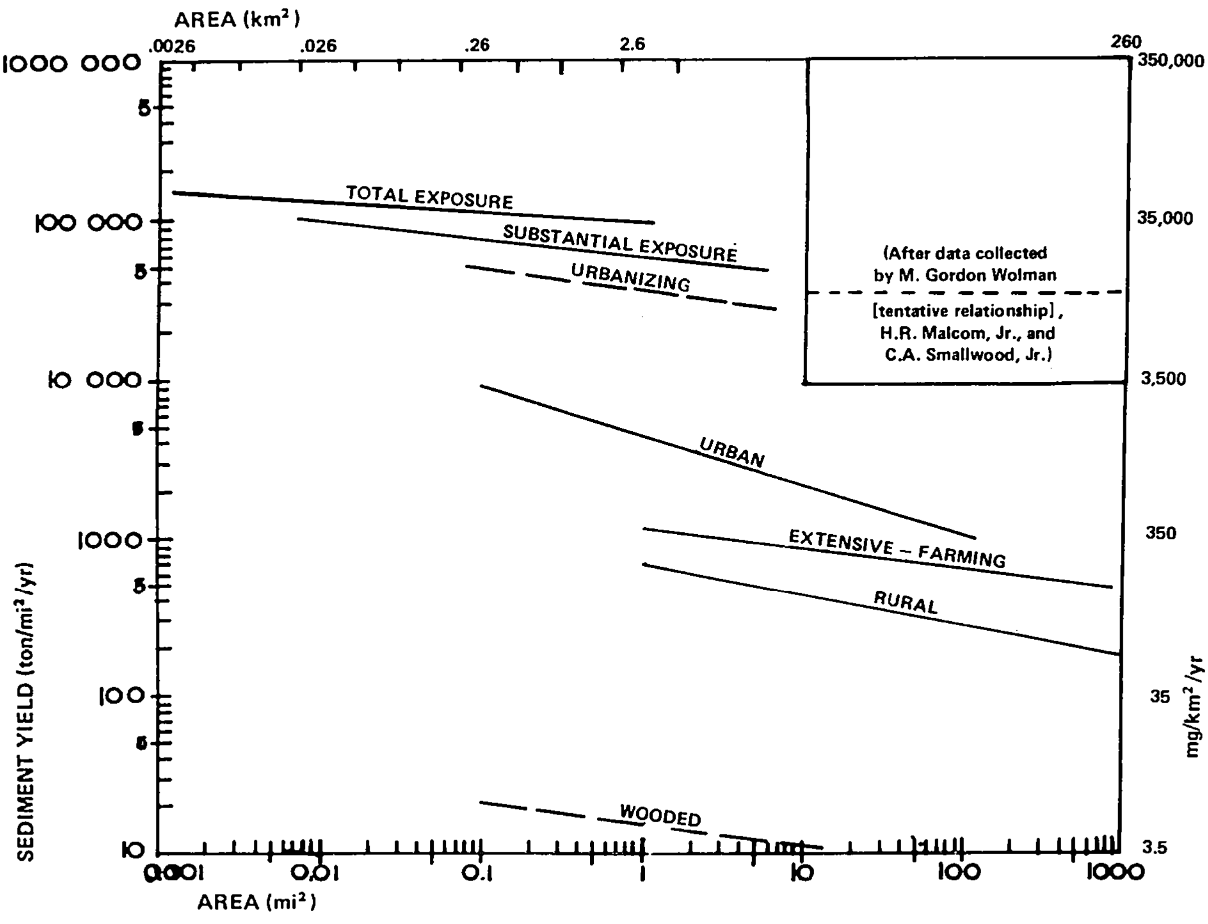


Figure 15. Sediment yield vs. contributory basin area.

Source: Malcom, H.R., and C.A. Smallwood, "Urban Erosion as a Source of Pollution," Paper prepared for the Twentieth Southern Water Resources and Pollution Control Conference, Chapel Hill, North Carolina, April, 1971.

Erosion Effects --

Erosion depends upon wind, gravity, and water. The most meaningful of these from a pollutant generation point of view is water-produced erosion. Wind erosion produces water pollution when materials eroded by wind are blown into drainage ditches, streams, lakes, and reservoirs, or are dropped back to the earth's surface where they become more susceptible to water erosion. Although there are no estimates of the proportion of wind-blown materials going into inland waters, it is believed to be small when averaged over the nation. (45) Wind deposition of soil on land areas has been measured in quantities ranging from more than 15.7 MT/ha/yr (7 ton/ac/yr) near sites of severe erosion to less than 112 kg/ha/yr (100 lb/ac/yr) in other areas. (45) Similar amounts would be directly deposited in bodies of water. In additon to soil particles, associated materials may include organics, nutrients, animal wastes, residues from burning, and pesticides.

Wind erosion is a problem in any area of low, variable precipitation, where drought is frequent, and temperatures, evaporation, and wind speeds are high. It is the dominant problem on about 28 x 10^6 ha (70 x 10^6 ac) or approximately three percent of the land in the United States---an area that includes 22.3 x 10^6 ha (55 x 10^6 ac) of cropland, 3.6 x 10^6 ha (9 x 10^6 ac) of rangeland, and 2.4 x 10^6 ha (6 x 10^6 ac) of "other" land. (46)

The movement of soil by wind action takes place through the mechanisms of saltation, surface creep and atmospheric suspension. Saltation denotes the bouncing movement of particles within the air layer close to the ground surface. Surface creep is induced by the impact of particles descending from saltation. Atmospheric suspension is the process by which fine soil is carried from the surface into the air.

Further discussion of air pollution, air erosion, and available non-point estimating methods was included as part of the preceding section on air pollution.

Similarly, gravity erosion, landslides, and massive soil movements produce an important impact on receiving water quality only when soil is directly introduced into a drainage feature or waterway or when soils are exposed to greater hazards of water erosion.

Water erosion is generally thought to consist of the detachment of soil particles, and the movement of the particles to the channel in which they are transported to their ultimate destination. The erosion process may be broadly classified into the three mechanisms of sheet erosion, gully erosion, and channel erosion. Sheet erosion refers to the relatively uniform loss of topsoil across the soil surface as a result of rainsplash and runoff on a sloped surface. The impact of falling raindrops detaches soil particles, or fines, from the soil aggregate. These fines are then available to be picked up and transported by overland flow.

Initially occurring as sheet flow, overland flow soon begins to concentrate in small rivulets due to surface topography. Gully erosion becomes operative when flow turbulence creates local forces sufficient to dislodge particles from the sides and head of the gully. As the gully grows deeper and wider, flow momentum and inertia becomes significant factors in shaping the stream bed and water course. Channel erosion influences the direction of the stream and this results in changes in the stream cross-section and the meandering of the stream bed.

Channel erosion contributions in some regions can be significant with respect to other sediment sources. Estimates of the relative percentage of sediment production are shown in Table 35 for two watersheds.

TABLE 35. ESTIMATED RELATIVE CONTRIBUTIONS OF SEDIMENT PRODUCTION

Northern California Watershed		Willamette Basin Western Oregon	
Sediment Source	Percentage Of Total	Sediment Source	Percentage Of Total Sediment
Land Surface	20	Forestlands	24
Landslides	25	Agricultural Land	22
Streambank erosion	55	Main Stream Channels	54
Total	100		100

Source: "Anderson, H.W., "Relative Contribution of Sediment from Source Areas and Transport Processes," in *Proceedings of A Symposium on Forest Land Uses and Stream Environment*, Oregon State University, August, 1972, pp. 55-63.

In reality, erosion processes are gradual and continuous; there is no definitive dividing line between the mechanisms of sheet, gully, and channel erosion.

Sediment Prediction Methods --

Erosion production is largely dependent upon rainfall characteristics, climate, vegetative, and other forms of protective cover, soil properties--texture, situation and moisture content--and the drained surface slope and length. A number of methods have been developed to predict soil loss due to sheet erosion. One such method in use is the "Universal Soil Loss Equation" (USLE), (47,48), an estimating technique generally applied to determine annual sediment losses from large areas.

The USLE generally takes the following form:

$$A = R \cdot K \cdot LS \cdot C \cdot P \qquad (7)$$

where:

A = average soil loss for the desired time interval, ton/ac/unit time

R = Rainfall Factor or number of erosion index units (EI) for the desired time interval

K = Soil Erodibility Factor, ton/unit of EI

LS = Slope Length-Gradient Factor

C = Cropping Management Factor

P = Erosion Control Practice Factor

Values for R, the Rainfall Factor, can be computed from the equation:

$$R = EI = \sum (9.16 + 3.31 \log X_i) D_i I \qquad (8)$$

where:

R = Rainfall Factor, or the summantion of erosion index units (EI) for all storms during the desired time interval

E = Rainfall Energy, hundreds of ft-ton/ac

i = Rainfall Hyetograph time increment, i

X_i = Rainfall Intensity during the hyetograph time increment in/hr

D_i = Inches of rainfall during time increment

I = Maximum average 30 minute intensity of rainfall, in

Rainfall factor R, values for annual rainfall and erosion, are shown in Figure 16 for areas east of the Rocky Mountains.

The Soil Erodibility Factor, K, may be determined through the use of the nomographs shown in Figure 17. The K factor depends on five soil characteristics: the percentage of silt and very fine sand, the percentage of organic material, soil structure and soil permeability. Some assistance in the percentage distribution of soil components can be obtained from the use of the soil composition triangle shown in Figure 18.

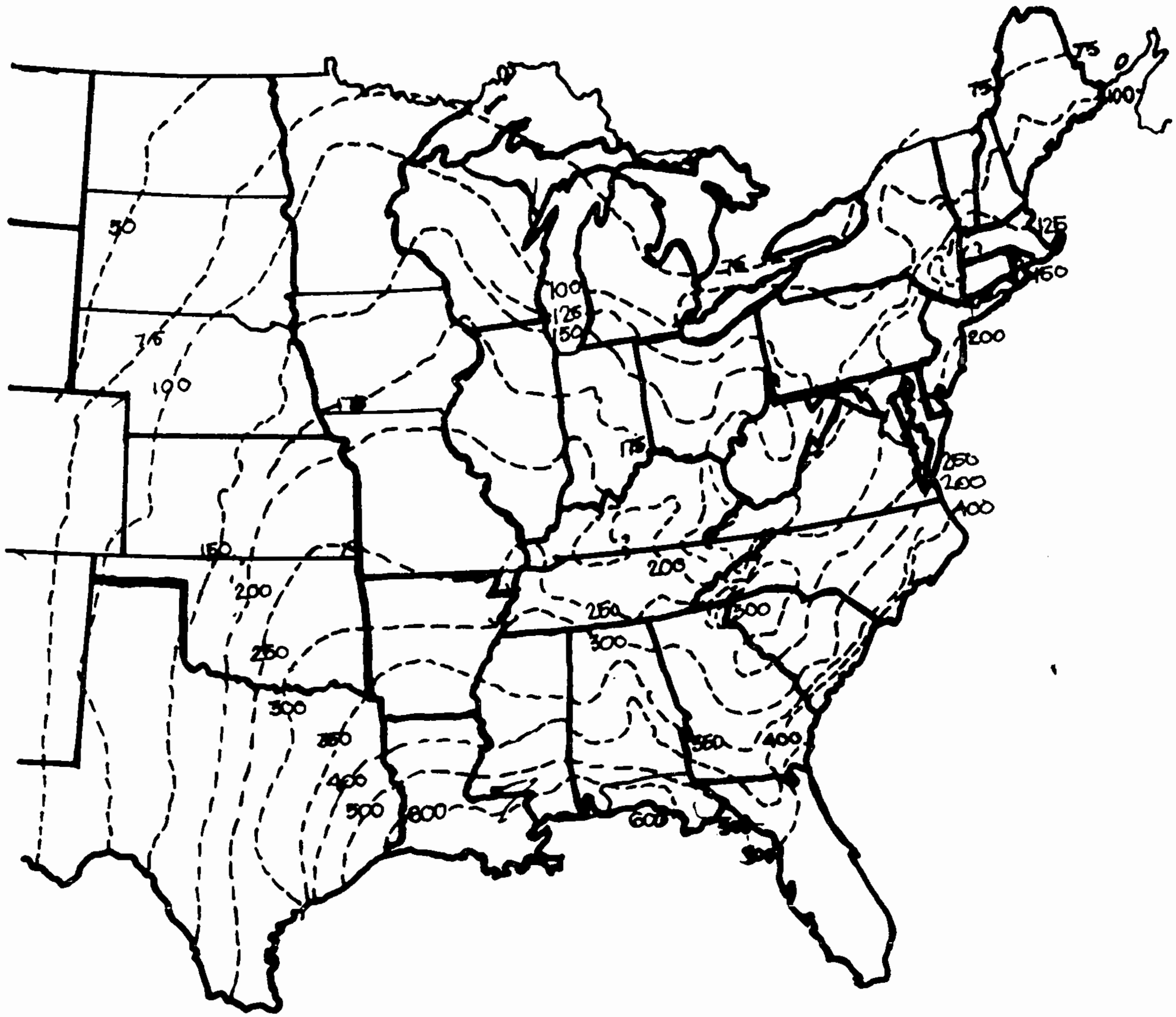


Figure 16. Iso-erodent map (R values for the erosion equation).

Source: Wlsclimerer, W.H., and Smith, D.D., "Predicting Rainfall-Erosion Loses from Cropland East of the Rocky Mountains," *Agriculture Handbook No. 282,* ARS, U.S. Department of Agriculture, May, 1965.

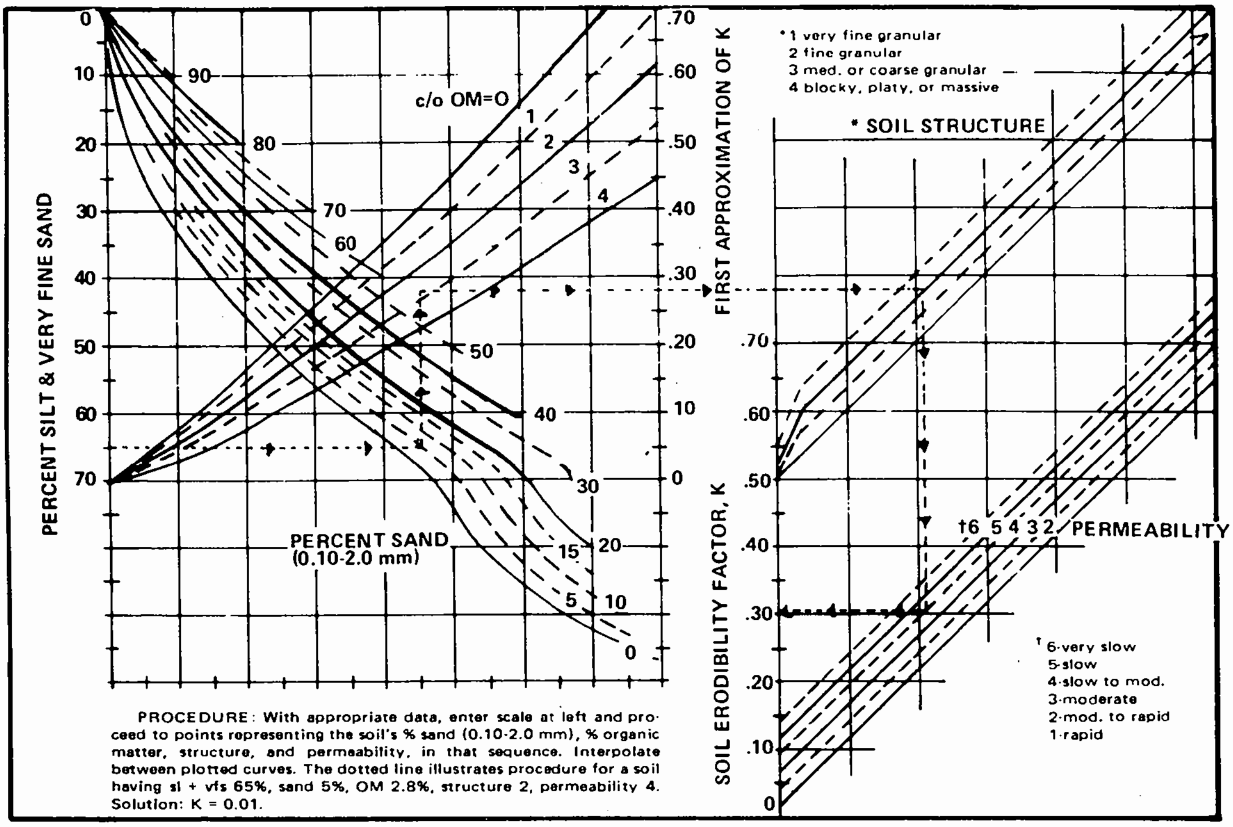
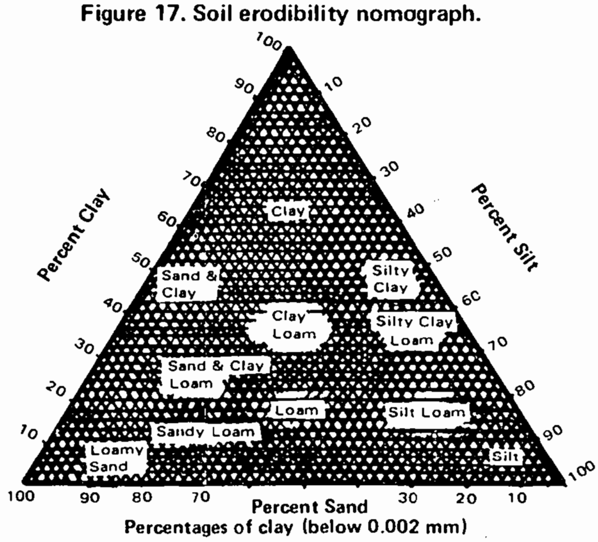


Figure 17. Soil erodibility nomograph.



Percentages of clay (below 0.002 mm)
Silt (0.002 to 0.05 mm), and sand (0.05 to 2.0 mm)
in the basic soil textural classes

Figure 18. Composition triangle of the basic soil textural classes (U.S. Soil Conservation Service).

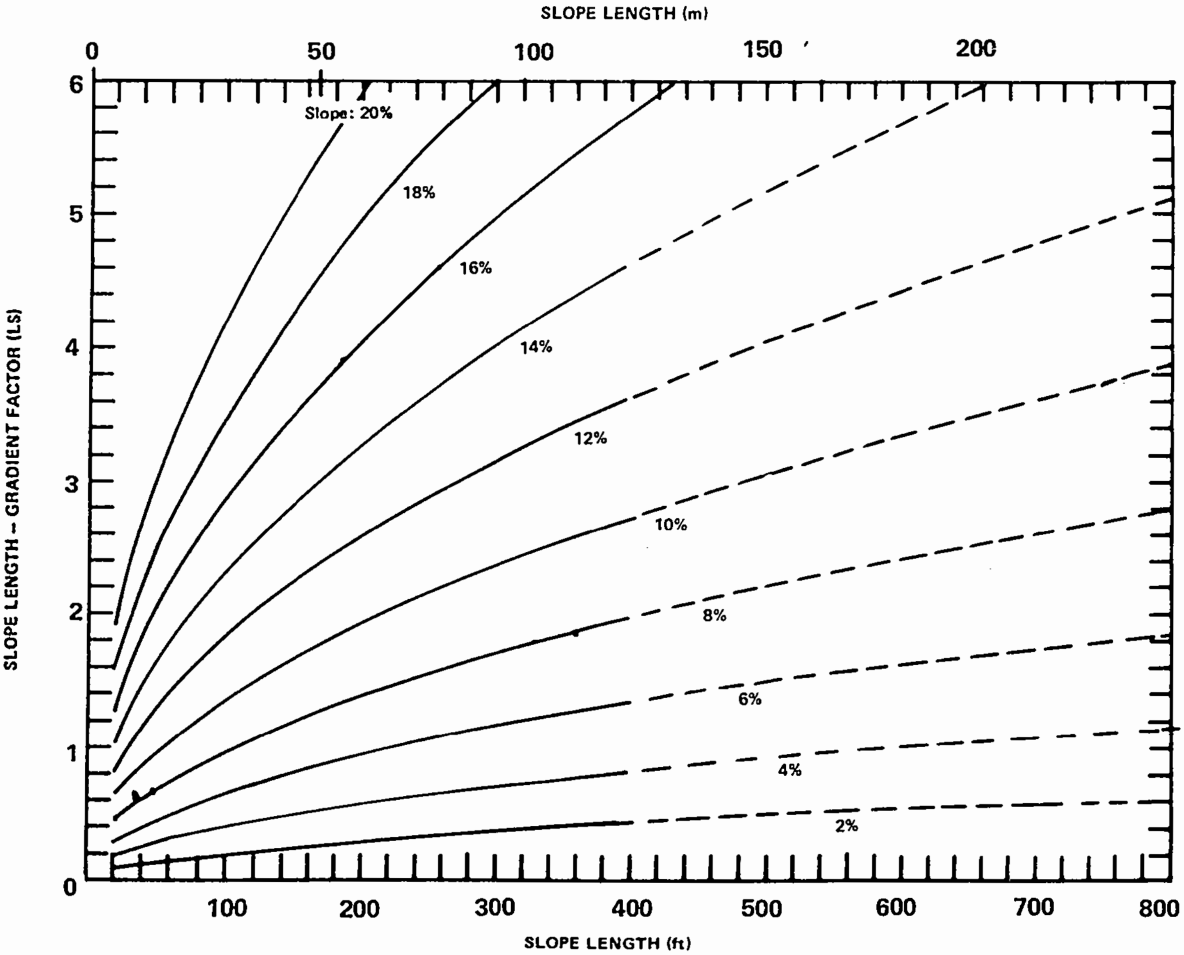


Figure 19. Factor LS by slope length and percent slope.

Source: United States Environmental Protection Agency – Office of Water Programs, "Methods for Identifying and Evaluating the Nature and Extent of Non-Point Sources of Pollution," USEPA Report No. EPA-430/9-73-014, October, 1973.

The Slope Length-Gradient Factor, LS, can be evaluated through the equation:

$$LS = L^{1/2}(0.0076 + 0.0053S + 0.0076S^2) \quad (9)$$

where:

L = Length from the point of overland flow to the discharge channel or to the point where sediment deposition occurs, ft; and

S = Average slope over the runoff length, L, as a percent.

A plot of the Slope Length-Gradient Factor is depicted in Figure 19, where values for LS may be determined for known values of L and S.

The Cropping Managment Factor, C, depends on crop types or ground cover. Some representative values for various ground cover conditions are shown in Table 36.

TABLE 36. CROPPING MANAGEMENT FACTOR C

Type of Cover		Factor C
1. None (fallow ground)		1.0
2. Temporary seedings (90% stand)		
ryegrass (perennial)		0.5
ryegrass (annual)		0.10
small grain		0.05
millet or sudan grass		0.05
field bromegrass		0.03
3. Permanent seedings (90% stand)		0.01
4. Sod (laid immediately)		0.01
5. Mulch		
Hay rate of application in ton/ac		
	1/2	0.25
	1	0.15
	1-1/2	0.10
	2	0.05
small grain straw	2	0.05
wood chips	6	0.06
wood cellulose	1-3/4	0.10
fiberglass	1/2	0.05
6. Asphalt emulsion 11,692 l/ha (1,250 gal/ac)		0.03

Source: Ports, M.A., "Use of the Universal Soil Loss Equation as a Design Standard," ASCE Water Resources Engineering Meeting, Washington, D.C., 1973.

The Erosion Control Practice Factor, P, represents management measures employed to control erosion on the site. Estimated values for P are shown in Table 37 for stripped or disturbed areas.

TABLE 37. EROSION CONTROL PRACTICE FACTORS FOR CONSTRUCTION SITES

Surface Condition With No Cover	Factor P
Compact, smooth, scraped with bulldozer or scraper up and down hill	1.30
Same as above, except raked with bulldozer root raked up and down hill	1.20
Compact, smooth, scraped with bulldozer or scraper across the slope	1.20
Same as above, except raked with bulldozer root raked across slope	0.90
Loose as a disced plow layer	1.00
Rough irregular surface, equipment tracks in all directions	0.90
Loose with rough surface greater than 12½ depth	0.80
Loose with smooth surface greater than 12½ depth	0.90
Structures	
Small sediment basins:	
0.04 basin/ac	0.50
0.06 basin/ac	0.30
Downstream sediment basins:	
with chemical flocculants	0.10
without chemical flocculants	0.20
Erosion control structures:	
normal rate usage	0.50
high rate usage	0.40
Strip building	0.75

Source: Ports, M.A., "Use of the Universal Soil Loss Equation As a Design Standard," ASCE Water Resources Engineering Meeting, Washington, D.C., 1973.

Values of P for urban development have been taken as 1.0.

The Sediment Delivery Ratio, or the percentage of the gross eroded sediment conducted down slope from its origin to a point of delivery, has been estimated as: (48)

$$D = 0.627S^{0.403} \tag{10}$$

where:

$$D = \frac{\text{Sediment yield (ton)}}{\text{Total eroded sediment (ton)}} \times 100; \text{ and}$$

S = Slope of the main channel in percent

It should be noted that no general sediment delivery relationships exist that are applicable to all watersheds due to soil texture, type of erosion, and areas of deposition within the drainage area. (45) Comparisons of several graphical relationships showed that the area of the drainage basin may be a better indication of the sediment delivery ratio. (48) The results of this analysis produced the equation:

$$\log D = 1.534 - 0.142 \log A \qquad (11)$$

where:

D is defined above

A = drainage area in ac

Sediment yield can, therefore, be determined on the basis of an estimate of the gross erosion, as may be computed by the Universal Soil Loss Equation, and some estimate of the Sediment Delivery Ratio, as defined by:

$$\text{Yield} = E \cdot D \qquad (12)$$

where:

E = Gross erosion loss, tons

D = Sediment Delivery Ratio

Care should be taken in the use of the USLE insofar as it is generally employed as an estimating method for annual sediment yield values. Its use to determine sediment contributions resulting from individual short-term events is thus suspect, and should be employed with discretion.

Pollutional Potentials of Sediment--

The major pollutant potential due to soil erosion is due to its contribution to the total solids loadings conveyed through the sediment production and transport processes. Total solids have a physical, chemical, and biological effect on receiving water quality. These include disruptions to aquatic life systems due to the presence of suspended solids and sedimentation, increased turbidity that can result in thermal effects due to increased heat absorption, reduced storage capacity, changed stream flow characteristics, decreased photosynthesis, increased water treatment costs, and other direct and indirect effects.

Erosion products also contribute to oxygen depletion effects due to the introduction of organic matter. This organic material may be green vegetative and humic matter, various naturally occurring organisms and animal wastes, and other similar materials. The organic content of soils in various locations is shown in Table 38.

TABLE 38. ORGANIC CONTENTS OF SURFACE SOILS FROM VARIOUS AREAS OF THE UNITED STATES

Location	Percent Organic Matter	
	Mean	Range
West Virginia	2.88	0.74-15.1
Pennsylvania	3.60	1.70- 9.9
Kansas	3.38	0.11- 3.62
Nebraska	3.83	2.43- 5.29
Minnesota Prairie	5.15	3.45- 7.41
Southern Great Plains	1.55	1.16- 2.16
Utah	2.69	1.54- 4.93

Source: Buckman, H.O., and Brady, N.C., *The Nature and Properties of Soil*, MacMillan Company, New York, 1969 (seventh edution).

The major nutrients--nitrogen and phosphorus--also contribute to pollutant potentials of sediment. Generalizations as to the nitrogen and phosphorus content of surface soils are provided for non-urban land uses in Figures 20 and 21. Estimating functions for nitrogen and phosphorus losses by erosion processes have been proposed.

$$N = a \cdot E \cdot D \cdot Nt \cdot r \qquad (13)$$

where:

N = Nutrient loss by erosion, kg/ha/yr (lb/ac/yr)

a = dimensionless constant
Nitrogen: 10 for S.I. (metric) units or 20 for U.S. Customary units
Phosphorus: 1.72 for S.I. units (metric) or 3.44 for U.S. Customary units

E = Gross erosion loss, MT (tons)

D = Sediment Delivery Ratio

Nt = Total nutrient concentration in the soil, percent by weight

r = Enrichment ratio or $\frac{\text{nutrient content in eroded soil}}{\text{nutrient content in uneroded soil}}$

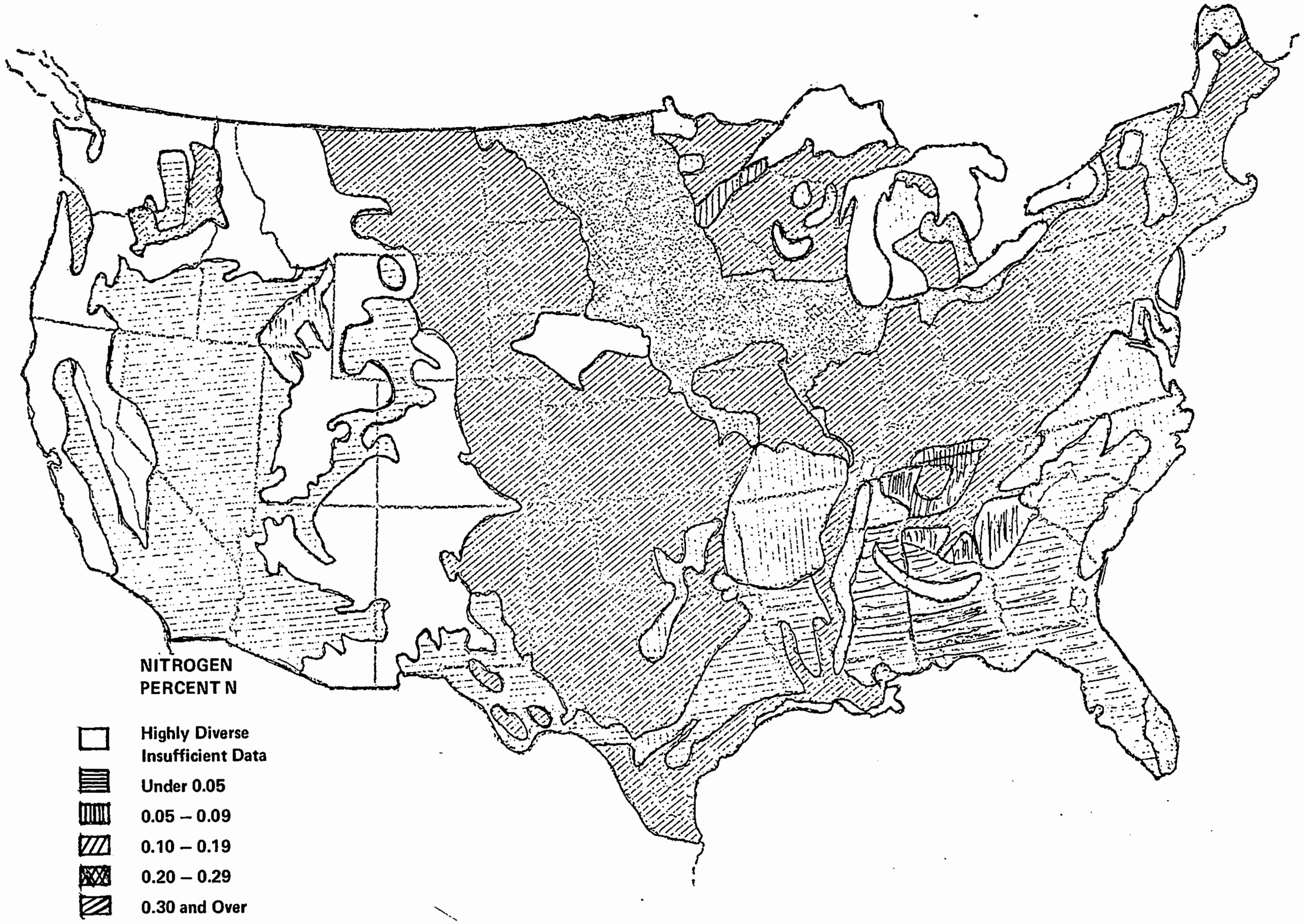


Figure 20. Percent nitrogen (N) in surface soils.

Source: Parker, C.A., et al., "Fertilizers and Lime in the United States," U.S. Department of Agriculture Miscellaneous Publication, No. 586, 1946.

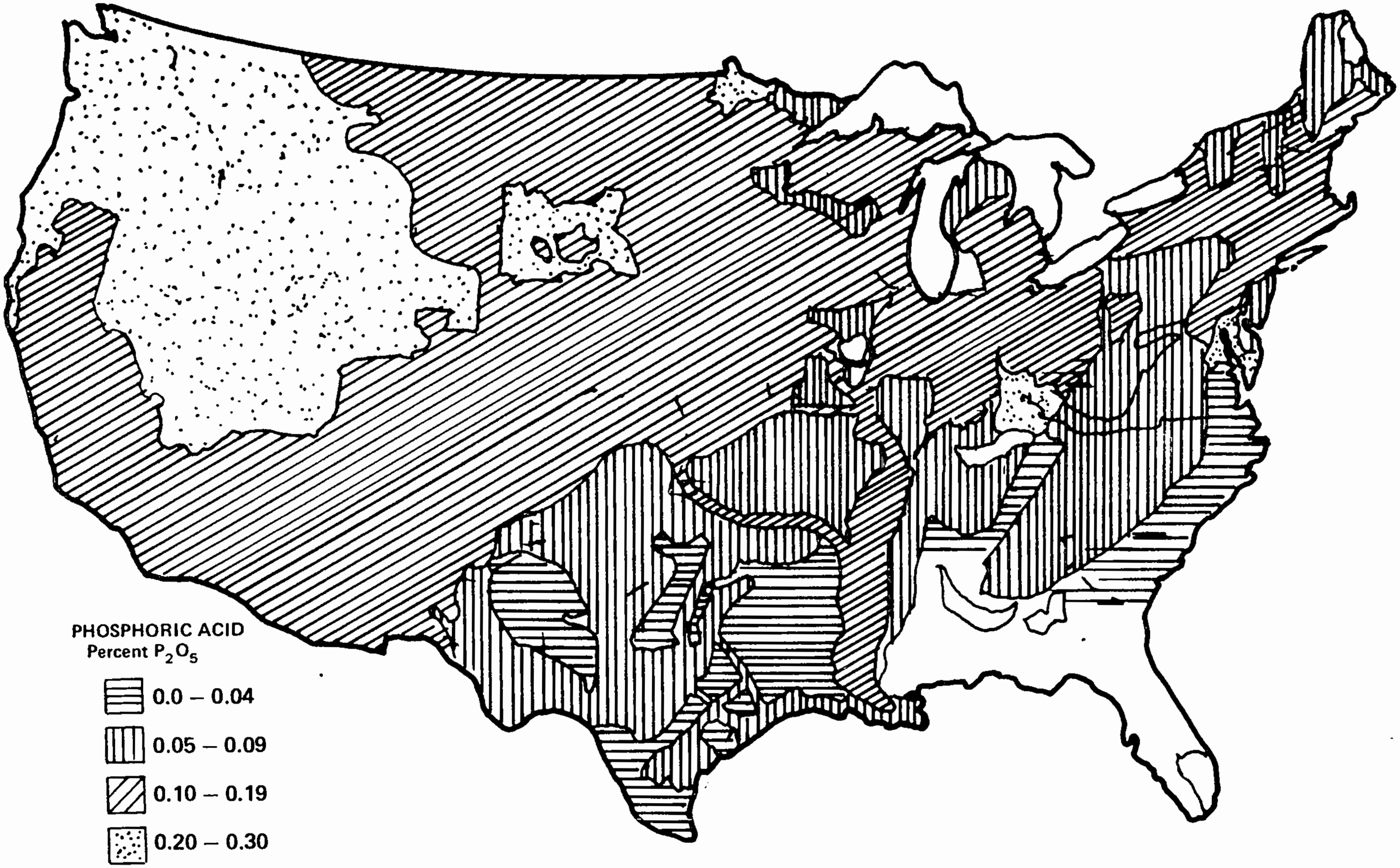


Figure 21. Percent phosphorus in surface soil

Source: Parker, C.A., et al., "Fertilizers and Lime in the United States," U.S. Department of Agriculture Miscellaneous Publication, No. 586, 1946.

Values for gross erosion and the Sediment Delivery Ratio have been discussed previously. Data for nutrient concentrations may be determined for local sampling efforts. Enrichment Ratio values have been found to be from 3.4 to 4.3 for nitrogen, and 1.5 to 1.6 for phosphorus. (49) Other soil constituents may also be transmitted to receiving waters in the process of erosion and transport. These components may include soil salts and some trace metals. Calcium, phosphorus, nitrogen, magnesium compounds, and trace metals such as iron and manganese fall into this category. Other trace metals such as copper, cobalt, and chromium may also be transported in a fixed form within the crystalline structure of sediment. (49)

Depositions of chemicals and materials that are products of human activity may also be transported to receiving waters with sediment. These include fertilizers, insecticides, herbicides, rodenticides, and fungicides. An indication of pesticide usage for urbanized areas is described in Table 39.

TABLE 39. TYPES AND QUANTITIES OF PESTICIDES USED IN URBAN HOMES

Pesticide Category	% of Homes (of 100 surveyed)	Quantity ounces	l
Aerosols	81	2,117.5	62.6
Garden sprays	10	132.5	3.9
Garden dusts	26	559.0	16.5
Herbicides-solids crystalline materials	18	9,312.0	275.4
Herbicides-liquid	18	261.0	7.7

Sources: Apgar, W. and Bertollette, R.B., "Pesticides Usage Profile Study," Research and Demonstration Services, Department of Environmental Resources, Commonwealth of Pennsylvania, Harrisburg, Pennsylvania, 1971.

"A Study of the National Scope of Urban Pesticide Runoff," CONSAD Research Corporation, A draft report prepared under USEPA Contract No. 68-01-2225, November, 1974.

Table 40 gives a further indication of the magnitude and complexity of possible sources.

TABLE 40. ESTIMATED QUANTITIES OF HOME AND GARDEN PESTICIDES USED IN THREE STUDY AREAS

	STUDY AREAS						TOTALS	
	Philadelphia		Dallas		Lansing			
Population	3,866,000		1,327,000		272,000		5,465,000	
No. of Single-Family Dwelling Units	979,413		307,775		56,658		1,243,845	
Herbicides, wt of active ingredients								
	lb x 10^3	kg x 10^3	lb x 10^3	kg x 10^3	lb x 10^3	kg x 10^3	lb x 10^3	kg x 10^3
Phenoxy	79	35.9	11	5.0	13	5.9	103	46.8
Decamba	––		4	1.8	––		4	1.8
Altrazine	––		4	1.8	––		4	1.8
Other Herbicides	14	6.4	5	2.3	––		19	8.6
All Herbicides	93	42.3	24	10.9	13	5.9	130	59.1
Insecticides, wt of active ingredients								
Chlordane	54	24.5	39	17.7	4	1.8	97	44.1
Dieldrin	––		14	6.4	––		14	6.4
Dicofol	11	5.0	––		––		11	5.0
Methoxychlor	2	0.9	––		3	1.4	5	2.3
Dimethoate	15	6.8	––		––		15	6.8
Carbaryl	––		19	8.6	3	1.4	22	10.0
Malallion	104	47.3	66	30.0	4	1.8	174	79.1
Deazinon	––		31	14.1	––		31	14.1
Other Insecticides	48	21.8	82	37.3	10	4.5	140	63.6
All Insecticides	234	106.4	251	114.1	24	10.9	509	231.4
Fungicides, wt of active ingredients								
All Fungicides	90	40.9	26	11.8	4	1.8	120	54.5
All Pesticides	417	189.5	301	136.8	41	18.6	759	345.0

Source: Rumker, R.U, et al., "The Use of Pesticides in Suburban Homes and Gardens and Their Impact on the Aquatic Environment," USEPA (NTIS No. PB 213 960/7), 1972.

Pesticides are considered to be introduced into receiving waters through surface runoff, either in a dissolved form or carried by eroded soil sediment. The levels of pesticides within runoff are dependent upon their local usage, the rate and formulation of the application, their decay rate, topography, climatic conditions, and the time intervals between the applications and the rainfall event. Pesticide concentrations are generally higher in sediment than in a dissolved state. (51) Pesticides are subject to degradation through microbiological activity, by photochemical conversion or through chemical reaction. (51) The relative persistence of pesticides is shown in Table 41.

TABLE 41. REPRESENTATIVE HALF LIVES OF VARIOUS PESTICIDES AND POTENTIAL FOR MIGRATION ON SEDIMENT

Pesticides	Half Life of the Pesticide, Days	Migration Potential
Chlorinated Hydrocarbons		
Aldrin	215 ± 152 (to dieldrin)	High
	2,248 ± 2,040 (including dieldrin loss)	
Dieldrin	360	—
Lindane	568 ± 442	—
Phosphate		
Diazinon	0.9	Possible
Malathron	0.56 ± 0.41	Not likely
Urea, Uracil and Triazine		
Atrazine	130 ± 40	High
Bromacil	205	Possible
Duiron	212 ± 87	Possible
Monuron	166	—
Benzoic Acid		
Diacamba	32 ± 39	—
Phenoxy and Tolidine		
2,4-D	17 ± 8	Low

Source: "A Study of the National Scope of Pesticide Runoff," CONSAD Research Scorp., A Draft Report Prepared Under USEPA Contract No. 68-01-2225, November 1974.

In view of the foregoing, it is apparent that some estimation of pesticides may be possible from a knowledge of pesticide formulation, application, degradation, and the relative distribution between the sediment and fluid fractions of runoff. Data on urban pesticides are limited, however, and estimations as such are subject to these limitations.

Other activities may also contribute to the pollutional impact of sediment. Construction site wastes include petroleum product wastes, demolition and construction materials, soil additives--lime, fly ash, salt, asphalt, calcium chloride, and others--and other special construction chemicals. To this growing list should be added the more obvious contributions due to litter, air pollution, and other waste products of human activity.

Although some estimating methods have been outlined in the foregoing discussions, few, if any, actual field measurements of runoff contained identifiable sediment and sediment related pollutants have been made and reported. Thus, few of the pollutant measures of direct interest from a water quality standpoint can be reported. This is a serious deficiency if a clear understanding of urban and non-urban runoff is to be achieved. It is apparent on this basis, that further study and investigation is required to obtain reputable estimations of sediment and its related pollutional contributions.

Miscellaneous Sources of Urban Runoff Pollution, Intermittent Pollutant Depositories

A number of effects on the pollutional makeup of urban runoff pollution remain to be considered. These include the miscellaneous sources, rooftop drainage, and intermittent pollutant depositories such as catch basins and sewers during low flow which contribute to first flush contributions. These are all included within this section insofar as limited data exist to adequately describe or estimate the relative contributions of each.

Catch Basin Pollutional Characteristics --

Stormwater runoff in urban areas normally flows for a short period of time in the street gutter and is diverted into an inlet structure leading to an underground conduit or open channel for transport to a treatment facility or receiving water body. The underground conduit, either a storm or combined sewer, is often protected by a catch basin built in conjunction with the inlet structures.

Catch basins are normally constructed under the inlet gratings or openings in the street. The typical catch basin is made of concrete, brick, or precast concrete with a total depth of about 2.4 m (8 ft) and with a holding capacity below the outlet sewer invert of about 0.76 m^3 (27 ft^3). (15) A water seal is sometimes included in a catch basin to prevent the escape of sewer odors. Recently, many local authorities have amended these design standards, and provided stormwater inlets without sump storage.

Historically, the purpose of catch basins was to prevent sewer clogging from sand and gravel, and to prevent odor emanation from the sewers. In areas where streets were partially or wholly unpaved, significant quantities of stone, sand, and other materials were washed into the sewer system during periods of rainfall. During the earlier years of sewer construction few attempts were made to maintain self-cleaning velocities in sewers of at least 0.6 m/sec (2 ft/sec). (15) Catch basins are widely used in many jurisdictions in all parts of the country as reported in a 1973 Survey by the American Public Works Association. (52)

There is little information as to the composition of the materials retained in catch basins. The major source of pollutants that will produce accumulations in a catch basin come from street surfaces and other contributing sources of runoff. These pollutants generally can be divided into four categories: floatable, dissolved, suspended, and settleable solids. Each category can be further sub-divided into organic and inorganic components. (53) On this basis, an indication of the pollutional contributions associated with various particle size distributions is provided in Table 42.

TABLE 42. FRACTION OF POLLUTANT ASSOCIATED WITH EACH PARTICLE SIZE RANGE, FROM TEN TEST CITIES,* PERCENTAGE BY WEIGHT

	Particle size, microns					
	>2,000	840 - 2,000	246 - 840	104-246	43 - 104	<43
Total solids	24.4	7.6	24.6	27.8	9.7	5.9
Volatile solids	11.0	17.4	12.0	16.1	17.9	25.6
BOD_5	7.4	20.1	15.7	15.2	17.3	24.3
COD	2.4	4.5	13.0	12.4	45.0	22.7
Kjeldahl nitrogen	9.9	11.6	20.0	20.2	19.6	18.7
Nitries	8.6	6.5	7.9	16.7	28.4	31.9
Phosphates	0	0.9	6.9	6.4	29.6	56.2
Total heavy metals	16.3	17.5	14.9	23.5	27.8	
Total pesticides	0	16.0	26.5	25.8	31.7	

*San Jose-I, San Jose-II, Phoenix-I, Phoenix-II, Milwaukee, Baltimore, Seattle, Atlanta, Tulsa, Bucyrus

Source: Sartor, J.D., and G.B. Boyd, "Water Pollution Aspects of Street Surface Contaminants," USEPA Report No. EPA-R2-72-081 (NTIS No. PB 214 408), November, 1972.

As can be seen, the very fine silt-like material (< 43 microns) accounts for only 5.9 percent of the total solids, but it accounts for about 25 percent of the oxygen demand and from 30 percent to 50 percent of the algal nutrients. Although this concentration of pollutants in the very fine material is of importance, catch basins do not efficiently trap particles in this size range and thus allow a large percentage of these pollutants to pass through. (53) Soil particle size distribution is, of course, a function of the geographic characteristics of a particular site and varies widely.

In the area of specific catch basin sampling, the City of Winnipeg, Manitoba (15) in 1953, conducted a test of the solids in two catch basins, and found the distribution of materials shown in Table 43.

TABLE 43. ANALYSIS OF CATCH BASIN MATERIALS
(Winnipeg, Manitoba)

Material	Catch Basin Contents: Catch Basin 1 (percent)	Catch Basin 2 (percent)
Water	39.4	43.3
Total Solids	60.6	56.7
Organic	3.6	4.4
Cinders and Sand	8.0	18.4
Mud	49.0	33.9

Attempts were also made during a study in Chicago to obtain undisturbed samples of catch basin solids using a tube-within-a-tube sampling device. (15) Unfortunately, core samples could be obtained by this method from only one catch basin, a basin that was completely full of solids. In all others, the moisture content of the mixture was so high that a core of solids could not be lifted out of the basin in an undisturbed condition for examination.

Cores taken from the one catch basin revealed that much of the solids had been washed in from under the adjoining gutter. Those solids obtained from the center of the basin were composed of black, organic material, while the solids near the sides of the chamber appeared to be washed sand. From the tests of the laboratory, the core material provided the following information:

> The solids retention time in a catch basin depends on the rainfall pattern, and may vary from a few minutes during a rainstorm to several months during prolonged periods of insignificant runoff. Results of some field tests which were conducted to determine the change of sludge level in a catch basin indicates that with a flow of 4,012 1 (1,060 gal) in 30 minutes, the depth of sludge above the invert level was eroded 1.75 cm (0.69 in). The COD of the top layer of the solids in the catch basin was measured before and after the washing of solids. The initial COD was 38,300 mg/kg of solids and the BOD was 1,750 mg/kg of solids. After the test the COD was 24,900 mg/kg of solids which amounted to a reduction of 35 percent in the strength of the top layer materials. (15)

Another study in Halifax, Nova Scotia, in 1970, attempted to identify the contribution that sewers and catch basins make to combined sewage composition.(55) Samples were obtained of liquids in catch basins during storm periods. The results, together with related information, are presented in Table 44.

The samples reported were taken at the liquid surface, and may not have represented actual concentrations throughout the full depth of the basin. All of the basins sampled were in residential sections of the study areas. The volatile suspended solids to suspended solids ratio for surface runoff was found to be characteristically around 30 percent. Catch basin samples evidenced a similar or higher ratio for the most part.

TABLE 44. SUMMARY OF CATCH BASIN SAMPLING, 1970
(Halifax, Nova Scotia)

Date	Location Of Basin	Time From Start Of Storm	Storm Rain-fall Prior To Sample	Rainfall Inten-sity At Sample Time	SS	VSS/SS	Coli.	Fecal Coli.	Fecal Strep.
		hr min	in	in/hr	mg/l		No/ 100 ml	No/ 100 ml	No/ 100 ml
Aug. 12	York S.	3 07	0.9	0.84	179	0.21			
	Elm	3 12	0.9	0.72	151	0.18			
Aug. 21	Elm	0 41	0.04	0.04	276	0.54			
	York N.	2 16	0.07	0.06	42	0.52			
	York S.	0 46	0.04	0.06	160	0.51			
	York S.	2 11	0.07	0.06	305	0.40			
	Cambridge	0 56	0.04	0.04	223	0.32			
	Cambridge	2 06	0.07	0.06	153	0.29			
	Cambridge	4 56	0.07	0.22	--	--			
	Gutter				10	--			
	Pit				35	0.23			
	Manhole				139	0.30			
Aug. 24	York S.	9 08	0.9	0.3					
	Gutter				10	--			
	Pit				26	0.62			
	Manhole				56	0.38			
	Cambridge	8 53	0.9	0.36					
	Gutter				82	0.38	120	2	<2
	Pit				185	0.31	65	<2	<2
	Manhole				158	0.32	540	12	<2

Source: Waller, D.H., "Pollution Attributable to Surface Runoff and Overflow from Combined Sewerage Systems," Atlantic Industrial Research Institute, Halifax, Nova Scotia, April 1971.

On three occasions, samples were obtained simultaneously from the gutter, the catch basin, and at the point where the pipe from the catch basin entered the sewer manhole. In each case concentrations at the latter point exceeded those measured in the gutter, indicating that some solids were being picked up in the catch basin. As indicated in Figure 22, a general downward trend in suspended solids from the beginning of a runoff event was suggested.

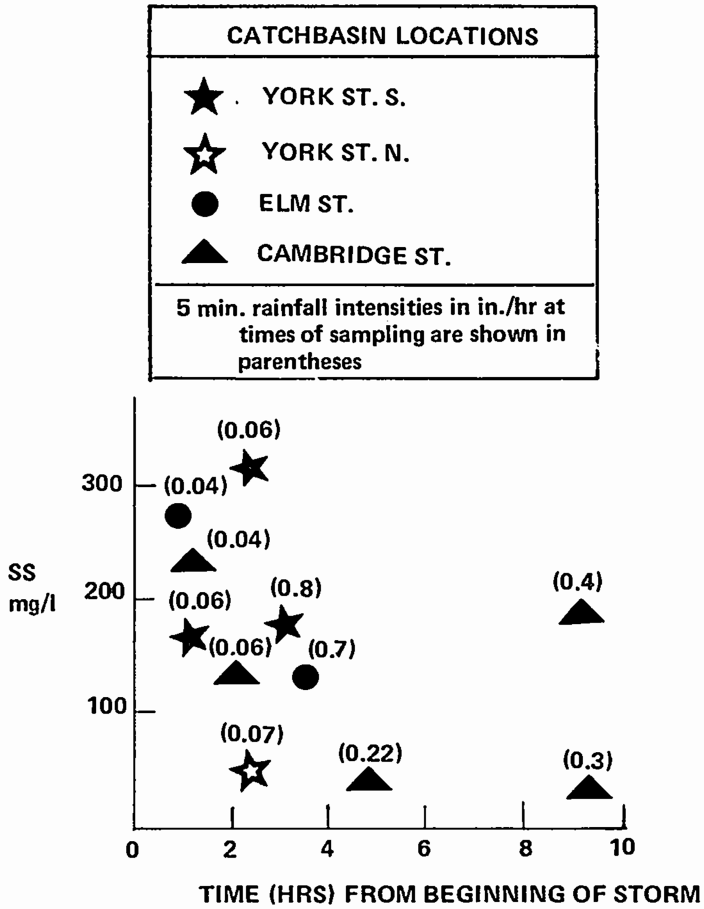


Figure 22. Summary of catch basin sampling results—Halifax, Nova Scotia.

Source: Waller, D.H., "Pollution Attributable to Surface Runoff and Overflows from Combined Sewerage Systems," Atlantic Industrial Research Institute, Halifax, Nova Scotia, April, 1971.

Table 44, suggests, from very limited data, variations in rainfall intensity do not appear to affect catch basin solids concentrations. APWA measured BOD concentrations in Chicago catch basin liquids of from 50 to 250 mg/l. In calculating the pollutional load that could be flushed from all of the basins in the area, it was determined that the liquid content of a catch basin would be flushed out during the first 1 cm (0.4 in) of rainfall in a storm. (15)

Further information on catch basin content sampling is shown in Tables 45 and 46.

The data, as shown, reflect conditions during winter and spring months. Catch basin operation can be considered essentially uniform during all seasons of the year. In terms of operational mode, catch basins act as a short-term sedimentation basin and their efficiency is generally constant, as measured in terms of solids removal and retention times if maintained in a clean condition.

TABLE 45
SUMMARY OF DATA ON CATCH BASIN CONTENT ANALYSIS (SAN FRANCISCO)

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

Source: Sartor, J.D., and G.B. Boyd, "Water Pollution Aspects of Street Surface Contaminants," USEPA Report No. EPA-R-2-72-081 (NTIS No. PB 214 408), November, 1972.

TABLE 46. ANALYSIS OF CATCH BASIN CONTENTS
(Chicago, Illinois)

A.

Tests	Percent Organic Material	Percent Washed Sand
Total solids	58.6	75.2
Fixed solids	45.2	62.8
Volatile solids	13.3	12.4
Sieve analysis		
Retained on No. 10 (200mm)	33.5	6.6
Retained on No. 16 (1190mm)	7.8	1.0
Retained on No. 20 (840mm)	5.0	0.8
Retained on No. 30 (590mm)	6.1	1.4
Retained on No. 325 (44mm)	47.6	90.2
Specific gravities of screen fractions		
No. 10	3.250	2.692
No. 16	3.190	3.111
No. 20	3.178	3.081
No. 30	3.220	3.130
No. 325	3.237	3.515

Source: American Public Works Association, "Water Pollution Aspects of Urban Runoff," USEPA Report No. 11030DNS01/69 (NTIS No. PB 215 532), January, 1969.

B.

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

NOTE: Both sampling series were conducted in April/May, 1971.

Source: Sartor, J.D., and G.B. Boyd, "Water Pollution Aspects of Street Surface Contaminants," USEPA Report No. EPA-R-2-72-081 (NTIS No. PB 214 408), November, 1972.

Pollutant loads (in terms of specific constituents) do vary seasonally, and as would be expected during the summer months the pollutant load on catch basins and the resultant effluents from them will be higher in nitrates and phosphates due to the increased use of fertilizers. It should be stressed that this change in pollutant character and quantity is not a function of catch basin efficiency, but rather, a function of increased pollutant load in the environment. (43)

It appears from the above that catch basins contribute little to the efficiency of sewerage systems. They behave as a reservoir for solids when not cleaned, and of liquids when cleaned. If cleaned regularly, they may reduce the load of heavier solids that may be deposited in sewers or carried through the system. The successful operation of a catch basin, as a settling basin device, is a function of its solids retention capacity. Basins which are frequently cleaned have the capacity for operating at design efficiency in retaining solids. In a relative sense, the retained solids may represent a relatively high proportion of the potential pollution involved, as was previously indicated in Table 42. A comparison of this with Table 43 shows that of the few catch basin depositons measured, all were 44 microns or larger in size. In a dry state, this particle size or greater would represent about 80 percent of all pollutants with the exception of phosphates.

It is apparent that the dissolved pollutant portion of urban runoff will pass into storm or combined sewers regardless of the type of intermediate device employed, whether a catch basin or inlet. The foregoing shows, however, that those pollutants more directly tied to solid particles may be captured within some catch basin configurations. The net impact of this capture of surface runoff quality would then appear to be a direct function of the basin's capture efficiency, retention capacity, and the frequency of cleaning. Dirty catch basins may be expected to exert a significant influence on the pollutional load on receiving waters or wastewater treatment units because of their contributions to a first-flush or pollutants.

In conclusion, it appears that catch basins can be reasonably effective in protecting sewers from loadings of the heavier suspended solids, but that they have a definite potential for contributing to water pollution problems. (43) However, catch basins under most circumstances may be an unnecessary component in combined or stormsewer systems as far as their primary purpose of preventing sewer clogging is concerned. This obsolescence with respect to their historical function is because of two factors: 1) greatly reduced quantities of solids entering the sewer system via the street inlets; and 2) technological advances in sewer design and cleaning, as well as in street cleaning. (53)

The effectiveness of catch basins in influencing the quality of surface runoff, as previously stated, is directly affected by the basin's capture efficiency, retention capacity, and the frequency of cleaning. Uncleaned catch basins containing significant quantities of organic matter act as biological treatment units. Indeed, the catch basin configuration is closely akin to that of a single-cell septic tank. Light storms, thus, might be expected to cause significant disturbances to catch basin accumulations that would contribute materially to a first-flush effect and produce, in combination with depositions within the sewer system, more severe shock loading to the receiving water or treatment facility than would otherwise be the case.

Roof Drainage Contributions --

The three major sources of particulates on roof surfaces are from air pollution dustfall, tree leaves and seed, and bird and animal droppings. In urban areas, roofs represent a large part of the impervious surface that increase runoff. Thus, the relative pollutional contributions of roof runoff to urban surface runoff must be considered in the context of runoff quality.

Of the solids sources outlined above, air pollution contributions have been explored in a previous section of this chapter. Likewise, general information on vegetative contributions have also been presented. No clear definition of the magnitude, distribution or the impact of wild bird and animal wastes can be readily identified from the literature. Some indications of overall roof drainage contributions may be identified through a few past sampling efforts.

During the summer of 1969, a series of investigations of roof drainage were performed in the City of Halifax, Nova Scotia. (55) Roof runoff samples were taken at three sites, with the results shown in Table 47. All of the sampling sites were within 91 m (300 ft) of the shore of Halifax Harbor, and were exposed to seagull wastes as well as other local sources of airborne particulates that might not be reflected at official dustfall sampling sites.

The table shows the results of roof samples for suspended solids, BOD, and bacteriological concentrations. Although the majority of the samples reported were single samples taken during individual runoff events, in those few instances where more than one sample was taken, a general reduction in concentrations appeared to occur. Generally, it was also found that the volatile suspended solids to suspended solids ratio was about 30 percent, which is approximately the same as that found for surface runoff. (55) Values for BOD were found to be relatively low--in most cases less than 10 mg/l.

TABLE 47
SUMMARY - ROOF RUNOFF SAMPLING

Sample Sample Site	Date	Time From Start Of Storm (hr	min)	Rain In Storm Prior To Sample (in)	(cm)	Suspended Solids (mg/l)	Volatile Suspended Solids (mg/l)	BOD (mg/l)	Coliform (per 100 ml)	Fecal Coliform (per 100 ml)	Fecal Strep. (per 100 ml)
	May 15, 1969	*							300	200	1,300
	29	*							0	0	0
	June 4	*							13	6	0
1	17	*							5	5	75
	25	8	05	0.05	0.13				200,000	68	>20,000
	May 1, 1970	15	40	1.37	3.48	<10	–	24.0			
	June 8	0	24	0.29	0.74	187	20				
	May 29, 1969	*							130	70	230
	June 4	*							8	2	2,100
	June 17	*							110,000	30	1.4×10^6
	25	7	50	0.05	0.13				100	<2	<100
	July 13	28	36	1.93	4.90				10	<10	20
	13	30	11	2.29	5.82				10	<10	10
	15	15	37	0.88	2.24	1,314	289	7.0	10	<10	–
	27	15	40	0.20	0.51	44	11	3.5	10	<10	10
	29	1	12	0.07	0.18	499	152	3.9	2	0	10
2	30	0	35	0.04	0.10	158	87	8.1	3	3	7
	Aug. 5	10	07	0.26	0.66	1,401	393	21.8	10	<2	20
	5	13	25	0.45	1.14	421	100	6.5	1,700	0	20
	6	1	05	0.12	0.30	691	108	6.0	280	3	<10
	6	1	40	0.17	0.43	350	45	4.6	2,600	5	<10
	7	16	15	0.73	1.85	1,070	541	5.7	1,400	560	<10
	10	4	06	0.12	0.30	352	55	3.4	20	<10	4
	12	4	50	0.07	0.18	628	117	1.5	540	2	< 2
	25	0	26	0.06	0.15	1,289	309	21.9	2	<2	<10
	25	16	41	0.33	0.84	582	215	–	1,000	<2	<10
	May 27, 1970	15	25	1.37	3.48	<10	–	23.0			
	May 15, 1969	*							860	860	1,000
	June 4	*							40	30	8,400
	17	*							2,800	5	14,000
	25	8	45	0.05	0.13				<10	<2	2,500
	July 13	29	41	2.10	5.33				3,200	2,600	25,000
	13	31	06	2.41	6.12				420	420	900
	15	15	47	0.88	2.24	40	1	2.3	5	2	37,000
	27	15	25	0.19	0.48	682	120	–	<10	<10	50
	29	1	22	0.07	0.18	93	32	6.4	2	1	550
3	30	0	45	0.04	0.10	430	91	13.8	12	12	530
	Aug. 5	10	0	0.26	0.66	154	66	6.6	20	20	5,000
	5	13	20	0.45	1.14	91	37	3.3	570	17	40
	6	1	15	0.15	0.38	140	35	2.8	1,300	270	10
	6	2	35	0.21	0.53	40	–	2.7	1,200	21	290
	7	16	05	0.73	1.85	65	21	3.2	280	200	400
	10	4	14	0.12	0.30	147	33	4.6	< 2	<10	10
	12	4	40	0.07	0.18	38	14	3.0	< 2	<2	14
	25	1	31	0.14	0.36	87	17	7.1	< 2	<2	<10
	26	16	31	0.33	0.84	157	71	3.1	< 2	<2	670
1	Median					–	–	–	13	6	75
2	Values					582	117	6	10	3	10
3						93	34	3	20	12	550

* Time of start of storm not recorded.

Source: Waller, D.H., "Pollution Attributable to Surface Runoff and Overflows from Combined Sewer Systems," Atlantic Industrial Research Institute, Halifax, Nova Scotia, April 1971.

Comparisons of measured nutrient concentrations from various sources are shown in Table 48. The nutrient concentrations reported for roof runoff appear lower than for the other sources sampled, with the exception of nitrates.

TABLE 48
MEDIAN NUTRIENT CONCENTRATIONS
(mg/l)
(number of samples shown in parentheses)

Source of Sample	Year*	Total Inorganic PO_4	NH_3	NO_3
Surface Runoff -	1969	0.6 (7)	2.2 (6)	—
	1970	0.5 (101)	1.6 (104)	<0.2 (104)
Roof Runoff -	1969	—	0.7 (11)	—
	1970	<0.1 (4)	0.7 (4)	0.6 (4)
Combined Sewage-	1970	1.0 (16)	1.4 (16)	0.2 (16)
Retention Tank				
Effluent -	1970	1.2 (12)	1.8 (14)	0.1 (13)

*1969 analysis are on pooled samples from several sampling points. 1970 analysis are on composite samples at individual sites.

Source: Waller, D.H., "Pollution Attributable to Surface Runoff and Overflows From Combined Sewer Systems," Atlantic Industrial Research Institute, Halifax, Nova Scotia, April 1971.

Thus, roof drainage provides a source of solids and other pollutants which may quickly enter stormwater runoff.

Comparisons of solids concentrations reported in Table 47 and then again in Table 49, indicate that a major source of roof contaminants originates from atmospheric dustfall.

TABLE 49
MEAN SOLIDS CONCENTRATIONS BASED ON DUSTFALL AND RAINFALL AMOUNTS IN VICINITY OF ROOF RUNOFF SAMPLING SITES

Site	Ton/mi²/mo August, 1970 Insoluble Dustfall ton /mi²	MT/km²	Average Concentrations based on Insoluble Dustfall and August 1969 Rainfall of 1.48 in (3.76 cm) (mg/l)
1	4.3	1.5	40
2	6.6	2.3	62
3	2.9	1.0	27

Source: Waller, D.H., "Pollution Attributable to Surface Runoff and Overflows from Combined Sewer Systems," Atlantic Industrial Research Institute, Halifax, Nova Scotia, April 1971.

The largest part of the deposited particulates on a flat roof could be expected to be washed into the runoff flow, while contributions from gabled roofs with their direct exposure to prevailing winds would be relatively small. (15) It seems that overall roof runoff contributions may be reduced by local public policies requiring the disconnection of roof leaders from sanitary and combined sewer systems, and even storm sewers. If properly handled in residential and other areas with available permeable surfaces, a relatively high degree of entrapment of roof runoff pollutant contributions may be possible on sodded or densely planted areas.

First Flush Effects --

First-flush can be defined as the phenomenon in which the most contaminated storm and combined sewer discharges occur at the beginning of a significant runoff event. A first-flush may originate from a number of sources including drainage area pollutant accumulations, catch basin depositions, roof top accumulations, and sewer solid dispositions. All of these sources can determine how contaminated these first-flush flows will be.

Surface accumulations can originate from debris dropped or scattered by individuals; sidewalk sweepings; debris and pollutants deposited on or washed into streets from yards and other adjacent areas; wastes and dirt from building construction and demolition; animal wastes; remnants of household and commercial refuse dropped during collection or scattered by wind or animals; oil, tire and exhaust residues contributed by motor vehicles; fallout of airborne particulates; etc.

Data on the rate at which pollutants accumulate on an urban watershed are rare. Pollutant accumulation has been discussed in various other sections of this report. One source of information on the buildup of contaminants on streets are shown in Table 50. The rate of buildup of pollutants varies with land use. Industrial and commercial areas were evidently dirtier than residential areas. Average daily accumulations were approximately one and one-half to five times as great in commercial and industrial areas as they were in residential areas.

More detailed information concerning pollutant loadings from street surfaces is given in a later discussion of Street Surface Pollution Potentials.

The incorporation of pollutants into urban runoff would likely proceed in the following way. The first raindrops that fall on an urban watershed simply wet the land surface. Additional rainfall collects on the impervious surfaces and fills any depression storage. This early rain begins to dissolve the pollutants in the gutters, streets and on other impervious surfaces and, as this runoff water actually begins to flow off the watershed, it carries dissolved material with it.

TABLE 50. AVERAGE DAILY POLLUTANT BUILDUP ON URBAN STREETS (CHICAGO)

Amount of Dust and Direct and Strength of BOD by Land Use

Land Use	Amt. of D/D by land use lb/curb-mi/day	kg/curb-km/day	Soluble BOD of D/D mg/g
Commercial	174.2	49.2	7.7
Industrial	242.9	68.5	3
Multiple family	121.4	34.3	3.6
Single family residence	37.0	10.4	5
Assumed weighted average	79.2	22.4	5

Amount of Pollutant by Type of Land Use

Item	Single Family	Multiple Family	Comercial
Water Soluble (mg/g)	6.0	5.6	12.4
Volatile water soluble (mg/g)	3.8	3.4	6.9
BOD (mg/g) soluble only	5.0	3.6	7.7
COD (mg/g) soluble only	40	40	39
PO_4 (mg/g) soluble only	0.05	0.05	0.07
N (mg/g) soluble only	0.48	0.61	0.41
Total plate counts/g (x 1,000)	10,900	18,000	11,700
Confirmed coliform/g (x 1,000)	1,300	2,700	1,700
Fecal enterococci/g	645	518	329

Source: American Public Works Association, "Water Pollution Aspects of Urban Runoff," USEPA Report No. 11030DNS01/69 (NTIS No. PB 215 532), January 1969

As the rainfall continues overland, flow velocities become sufficient to pick up solids. The suspended solids discharged in the first-flush do not appear to represent a large amount of solids unless a high flow which results in surface scouring happens to occur. Lighter suspended solids which are, of course, transported at lesser velocities than heavier settleable solids may be suspended in the overland flow. At low flow velocities, particles may simply be rolled along the gutter bottom surface toward the stormwater inlet.

The rain that initially falls on pervious surfaces percolates into the ground. If the rainfall is sufficiently intense or prolonged, soil infiltration capacity may be exceeded and excess rainfall will begin to fill depression storage on pervious surfaces. Finally, if the rainfall is of sufficient intensity and duration, runoff will begin to flow off the pervious areas, onto adjacent impervious areas and hence, into stormwater inlets. Present experience, however, indicates that the amount of runoff and resultant pollutant loads contributed from pervious surfaces in urban areas may be small compared to those coming from impervious areas, except for rainfalls of high intensity and long enough duration to create runoff. For most low intensity rainfall events the contributions from pervious urban areas may be neglected in determining the quality of surface runoff. This is especially true of pervious surfaces covered with vegetation such as lawns and planting areas. Formulas for determining runoff for areas of various pervious and impervious character have been developed for storm sewer design purposes.

The first-flush phenomenon is not always observed, and there is little data available to indicate how often or under whay exact conditions it will occur. In addition, few sources can be found that describe the visual phenomenon of the first-flush in clear detail. A USEPA funded project reported a sampling investigation of the influent to a wastewater treatment facility after a rainstorm of 8 mm (0.25 in.) following a dry period of eight days. The description indicates the existence at that time in the system of a first-flush phenomenon.

> The initial sample obtained was grey, appeared to be normal late night flow, but after only two minutes the rate began to increase rapidly and the sewage became black and gave off a very strong odor, indicating septicity. This odor did not disappear until the flow again returned to nearly normal. The results of sample No. 2 indicate the flushing of grit and putrescible material undergoing anaerobic digestion from the bottom of the sewers. (56)

A two-year study in Halifax, Nova Scotia provided information on the composition of combined sewage, surface runoff, roof runoff, and effluent from a combined sewage tank. (55) This study showed that the characteristics of combined sewage can be expected to vary with the rate of flow, with time during the storm, and with time since the previous runoff event. This is depicted in Figure 23. This figure shows the variation in flow and composition of combined sewage in terms of time.

Both of the storm events represented demonstrate a first-flush effect with high concentrations of solids after the beginning of significant rainfall, and the subsequent general diminishment of these concentrations with time and continuing flow.

A detailed engineering investigation and comprehensive technical study to evaluate the pollutional effects from combined sewer overflows was conducted on the Sandusky River at Bucyrus, Ohio. The results of the findings are presented in Figures 24 thru 29 covering concentrations of BOD, suspended solids, total solids, nitrate nitrogen, ammonia and organic nitrogen, and total phosphates, respectively. (57) All these figures clearly present the first-flush effects of the storm flow on the water quality of the overflows.

Combined sewer overflow investigations in Des Moines, Iowa (58) produced results as depicted in Figure 30. All of the storm events studied demonstrated a first-flush effect with high concentrations of solids after the beginning of significant rainfall, and the subsequent general diminishment of these concentrations with time and continuing flow.

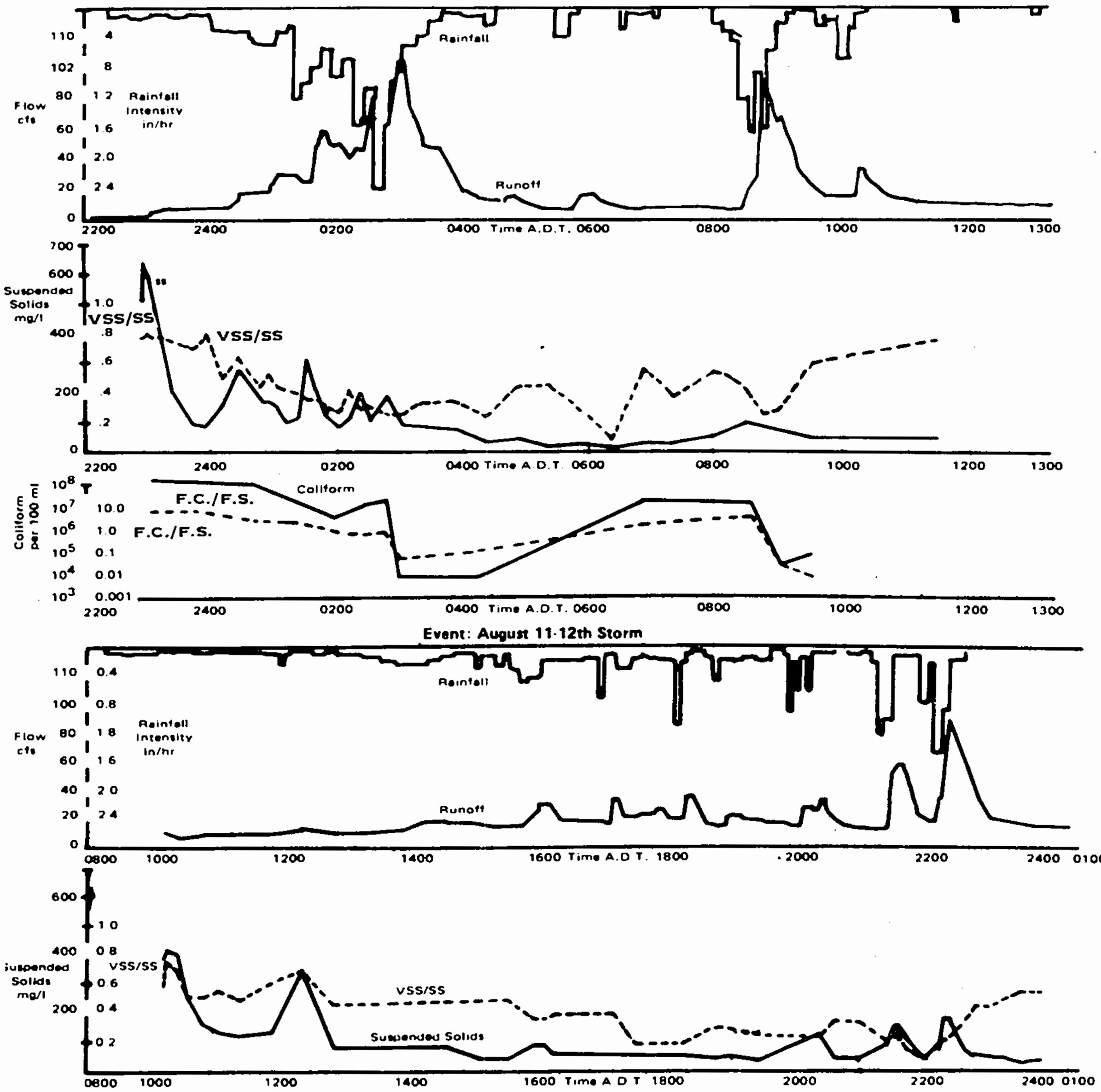


Figure 23. Variations in flow and composition of combined sewage for two runoff events.

Source: Waller, D.H., "Pollution Attributable to Surface Runoff and Overflows from Combined Sewer Systems," Atlantic Industrial Research Institute, Halifax, Nova Scotia, April, 1971.

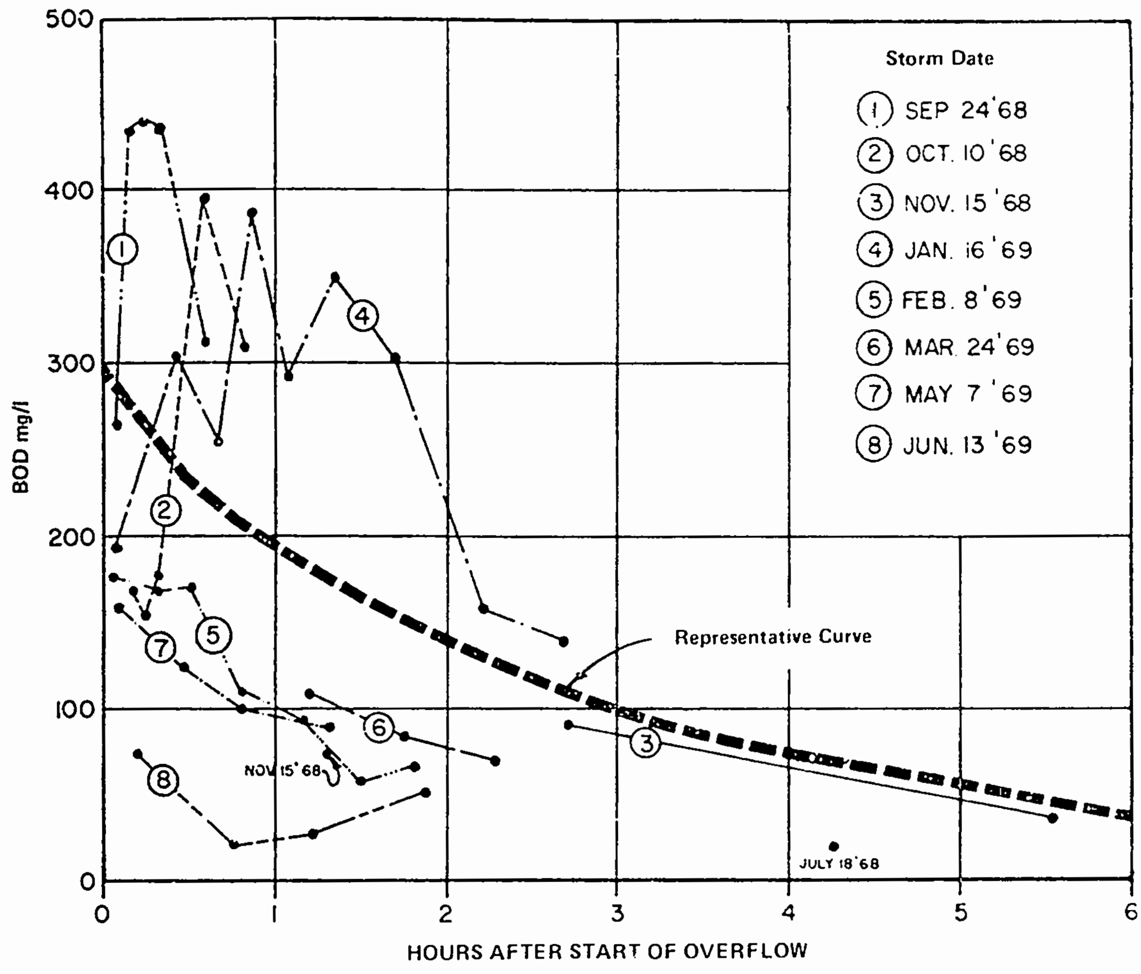


Figure 24. BOD concentration vs. time.
(Bucyrus, Ohio)

Source: Burgess and Niple, Ltd., "Stream Pollution and Abatement from Combined Sewer Overflows, Bucyrus, Ohio," USEPA Report No. 11024FKN11/69 (NTIS No. PB 195 162), November, 1969.

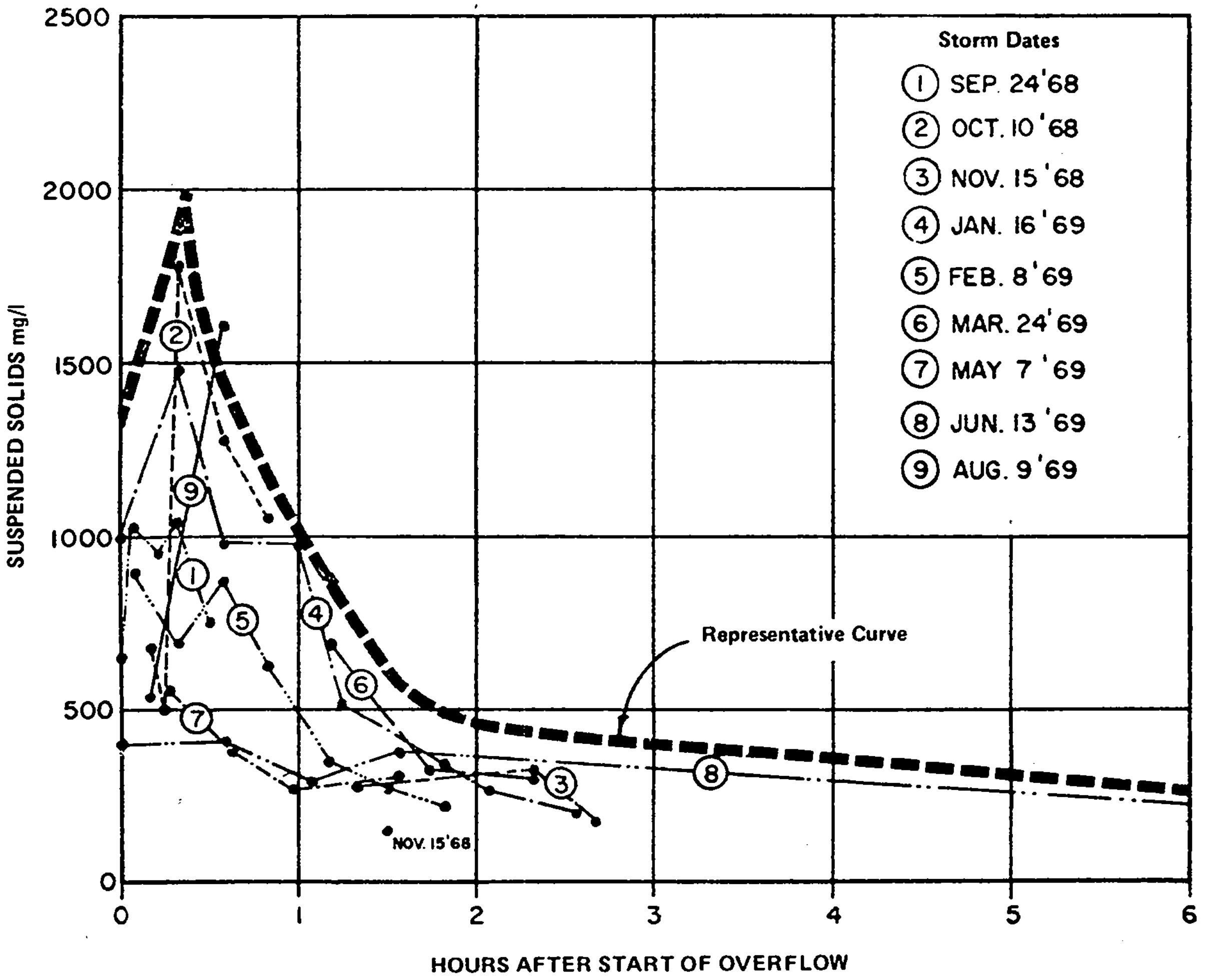


Figure 25. Suspended solids concentration vs. time. (Bucyrus, Ohio)

Source: Burgess and Niple, Ltd., "Stream Pollution and Abatement from Combined Sewer Overflows, Bucyrus, Ohio," USEPA Report No. 11024FKN11/69 (NTIS No. PB 195 162), November, 1969.

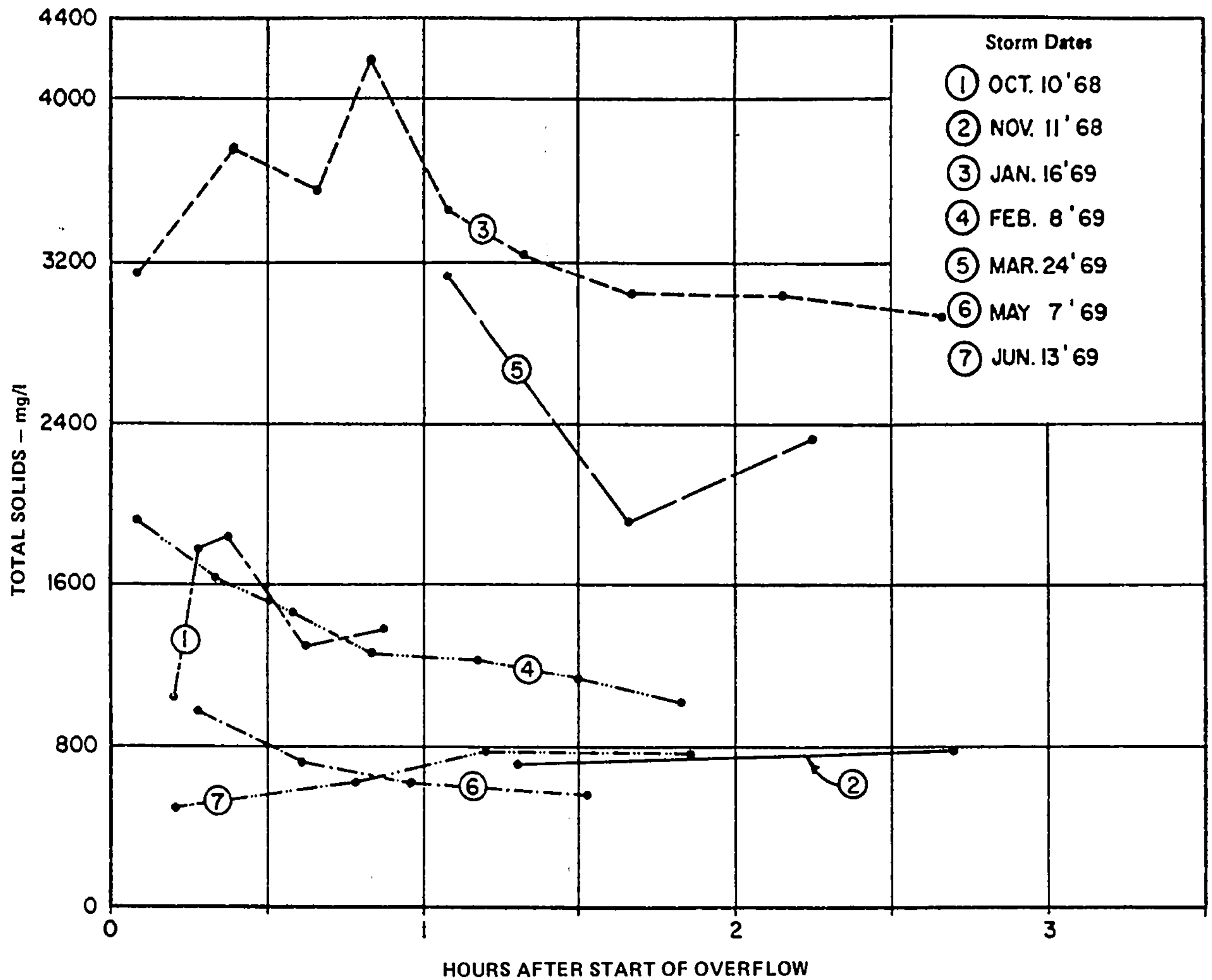


Figure 26. Total Solids (Bucyrus, Ohio)

Source: Burgess and Niple, Ltd., "Stream Pollution and Abatement from Combined Sewer Overflows, Bucyrus, Ohio," USEPA Report No. 11024FKN11/69 (NTIS No. PB 195 162), November, 1969.

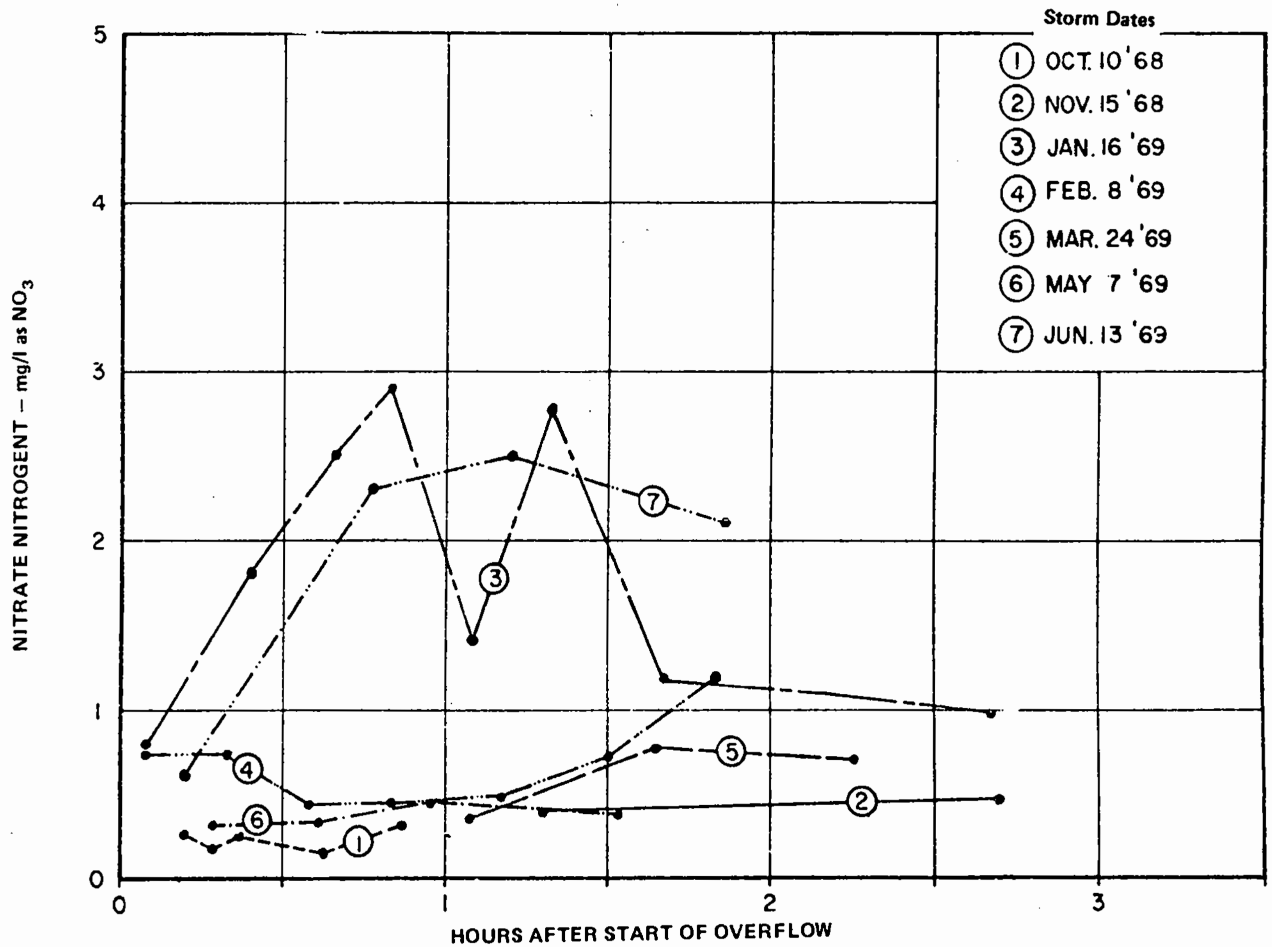


Figure 27. Nitrate nitrogen.
(Bucyrus, Ohio)

Source: Burgess and Niple, Ltd., "Stream Pollution and Abatement from Combined Sewer Overflows, Bucyrus, Ohio," USEPA Report No. 11024FKN11/69 (NTIS No. PB 195 162), November, 1969.

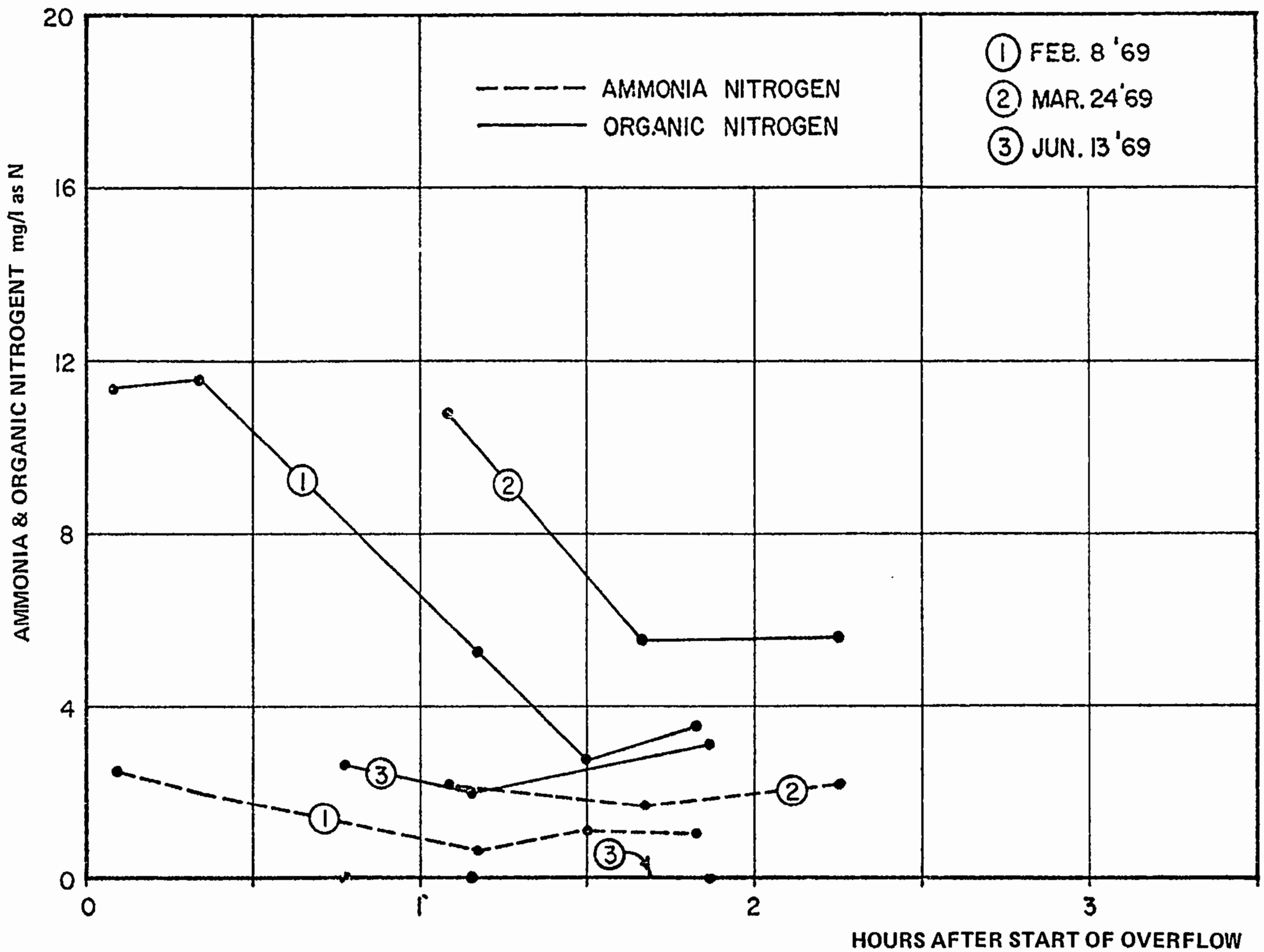


Figure 28. Ammonia & organic nitrogen.
(Bucyrus, Ohio)

Source: Burgess and Niple, Ltd., "Stream Pollution and Abatement from Combined Sewer Overflows, Bucyrus, Ohio," USEPA Report No. 11024FKN11/69 (NTIS No. PB 195 162), November, 1969.

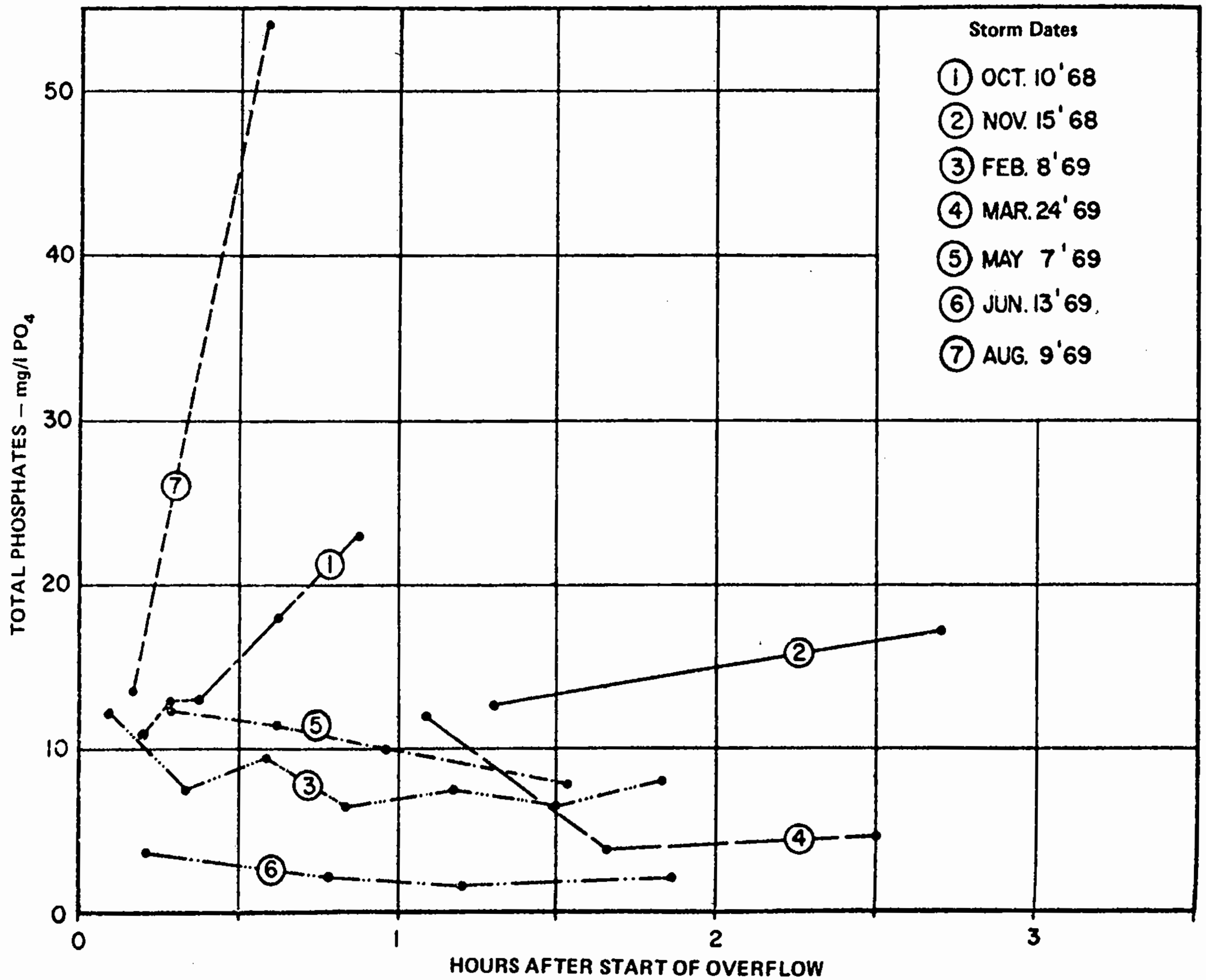
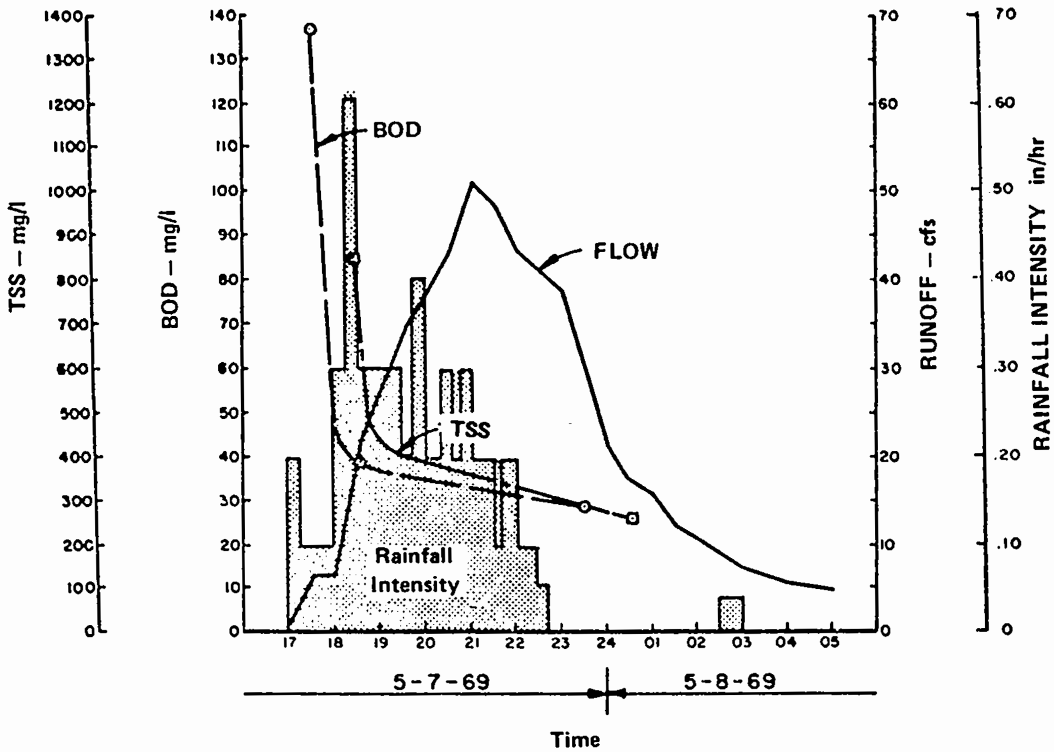


Figure 29. Total phosphates.
(Bucyrus, Ohio)

Source: Burgess and Niple, Ltd., "Stream Pollution and Abatement from Combined Sewer Overflows, Bucyrus, Ohio," USEPA Report No. 11024FKN11/69 (NTIS No. PB 195 162), November, 1969.



PERTINENT DATA

RUNOFF PERIOD: 1700 HRS 5-7-69
TO 1600 HRS 5-8-69

TOTAL RUNOFF: 23.2 AC FT
0.238 IN

RAINFALL PERIOD: 1650 HRS 5-7-69
(AT R.G. No.5) TO 2240 HRS 5-7-69

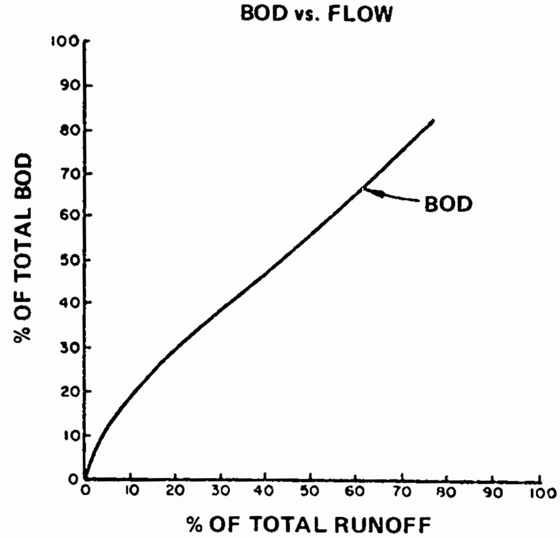
TOTAL RAINFALL = 1.14 IN

VOLUMETRIC COEFFICIENT OF
RUNOFF = 0.208

ANALYZED RUNOFF: 22.9 AC FT
(99% OF TOTAL)

COMPOSITE PERIODS (2)
(1) 1730 HRS 5-7-69 TO
0030 HRS 5-8-69
COMPOSITE BOD = 31 mg/l
TSS = 381 mg/l
(2) 0130 HRS TO 0830 HRS 5-8-69
COMPOSITE BOD = 22 mg/l
TSS = 97 mg/l

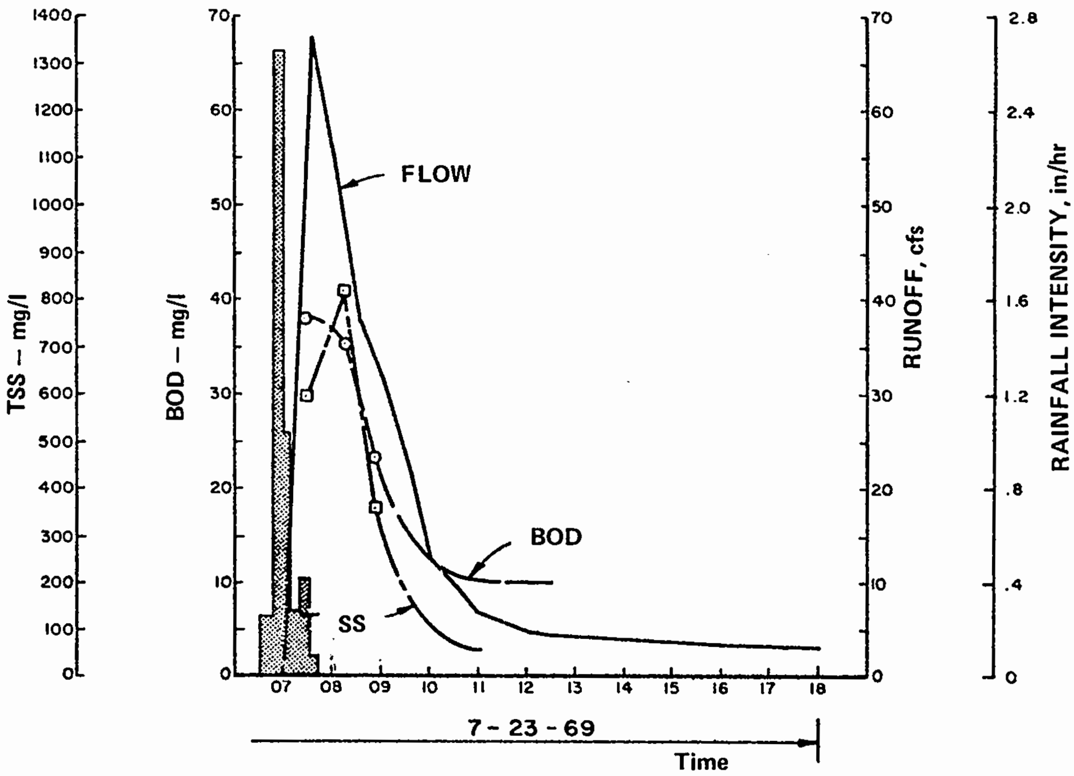
VOLUMETRIC RELATIONSHIP
BOD vs. FLOW



RUNOFF CHARACTERISTICS
STATION 0 – 11
20th Street Storm Sewer

Figure 30. Runoff characteristics.

Source: Davis, Peter L., and F. Borchardt, "Combined Sewer Overflow Abatement Plan, Des Moines, Iowa," USEPA Report No. EPA-R2-73-170 (NTIS No. PB 234 183), April, 1974.



PERTINENT DATA

RUNOFF PERIOD: 0700 HRS
TO 1800 HRS 7-23-69

TOTAL RUNOFF: 9.30 AC FT
0.097 IN

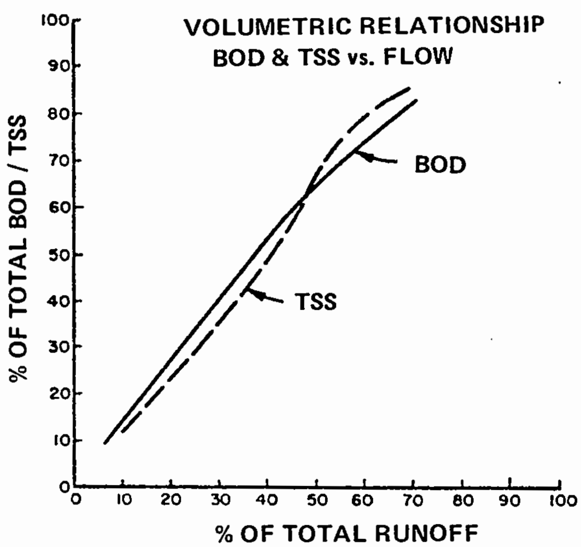
RAINFALL PERIOD: 0630 HRS
(AT R.G. No.5) TO 0745 HRS

TOTAL RAINFALL = 0.69 in

VOLUMETRIC COEFFICIENT OF
RUNOFF = 0.141

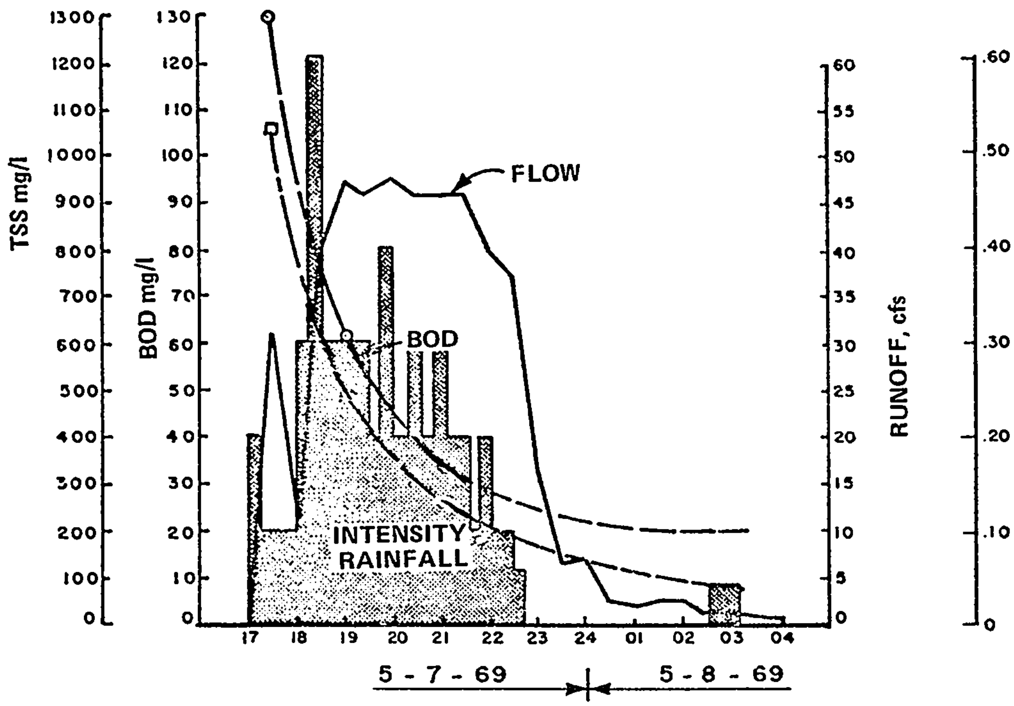
ANALYZED RUNOFF: 5.90 AC FT
(64% OF TOTAL)

RUNOFF SAMPLES: 3 GRABS
(1) 0725 HRS: BOD = 37.5 mg/l
TSS = 588 mg/l
(2) 0815 HRS: BOD = 36.0 mg/l
TSS = 808 mg/l
(3) 0850 HRS: BOD = 23.1 mg/l
TSS = 356 mg/l

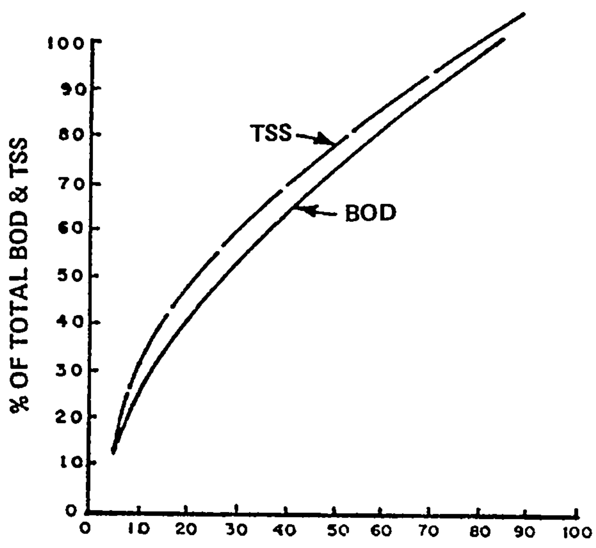


RUNOFF CHARACTERISTICS
STATION 0 – 11
20th Street Storm Sewer

Figure 30 Runoff characteristics.



VOLUMETRIC RELATIONSHIP
BOD & TSS vs. FLOW



PERTINENT DATA

RUNOFF PERIOD: 1700 HRS. 5-7-69
TO 0400 HRS. 5-8-69

TOTAL RUNOFF: 19.29 AC FT
0.171 IN

RAINFALL PERIOD: 1650 HRS 5-7-69
(AT R.G. No.5) TO 2240 HRS 5-7-69

TOTAL RAINFALL = 1.14 IN

VOLUMETRIC COEFFICIENT OF
RUNOFF - 0.150

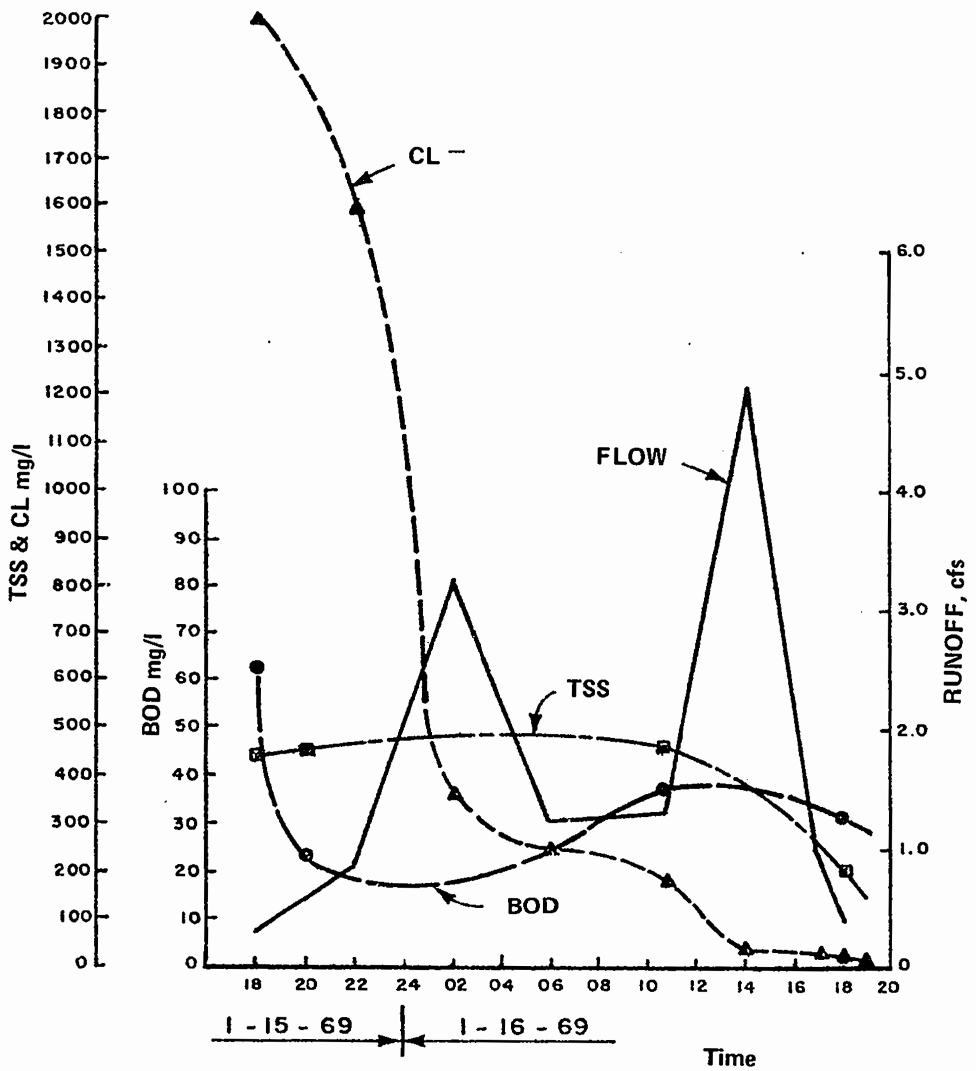
ANALYZED RUNOFF: 18.75 AC FT
(97.4 OF TOTAL)

COMPOSITE PERIOD: 1700 HRS - 2300 HRS 5-7-69

COMPOSITE BOD = 44.8 mg/l
TSS = 343 mg/l

RUNOFF CHARACTERISTICS
STATION 0 – 8
Ingersoll Run Overflow at Outlet

Figure 30. Runoff characteristics. (Continued)



PERTINENT DATA

RUNOFF PERIOD : 1800 HRS 1-15-69
TO 1800 HRS 1-16-69

PRECIPITATION : NONE - SNOWMELT

COMPOSITE PERIOD : SAME AS ABOVE

COMPOSITE BOD = 31 mg/l
TSS = 302 mg/l
CL − = 100 mg/l

RUNOFF CHARACTERISTICS
STATION S– 3
Cummins Parkway Storm Sewer

Figure 30. Runoff characteristics.

Studies in Seattle, Washington in 1971 also generated information on combined sewer overflow pollutant concentrations versus time. (59) A plot of these data with flow and rainfall intensity is shown in Figures 31 and 32. These show that solids concentrations increase to a peak subsequent to the flow peak

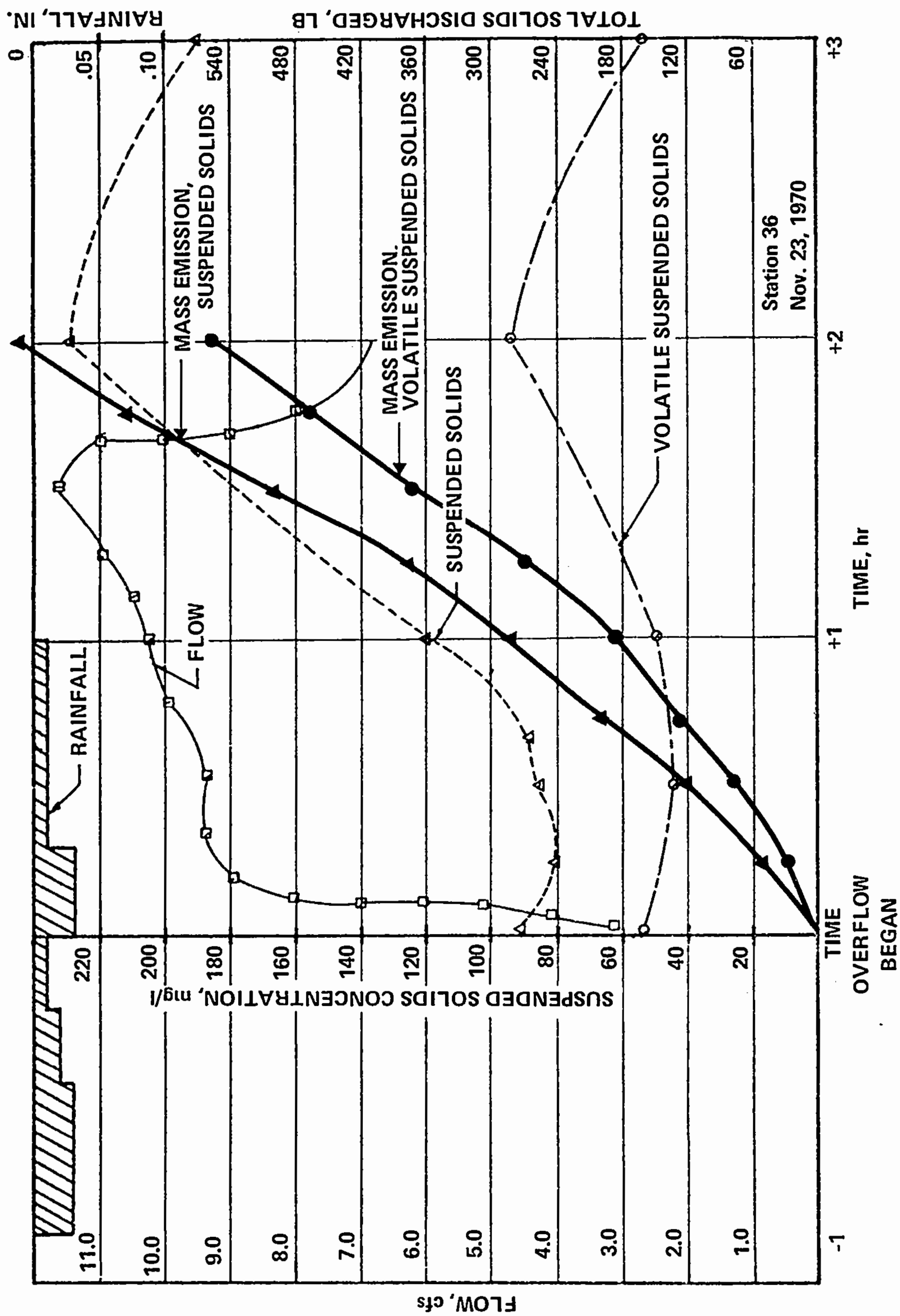


Figure 31. Flow and solids vs time.

Source: Municipality of Metropolitan Seattle, "Maximizing Storage in Combined Sewer Systems," USEPA Report No. 11022ELK12/71 (NTIS No. PB 209 861), December, 1971.

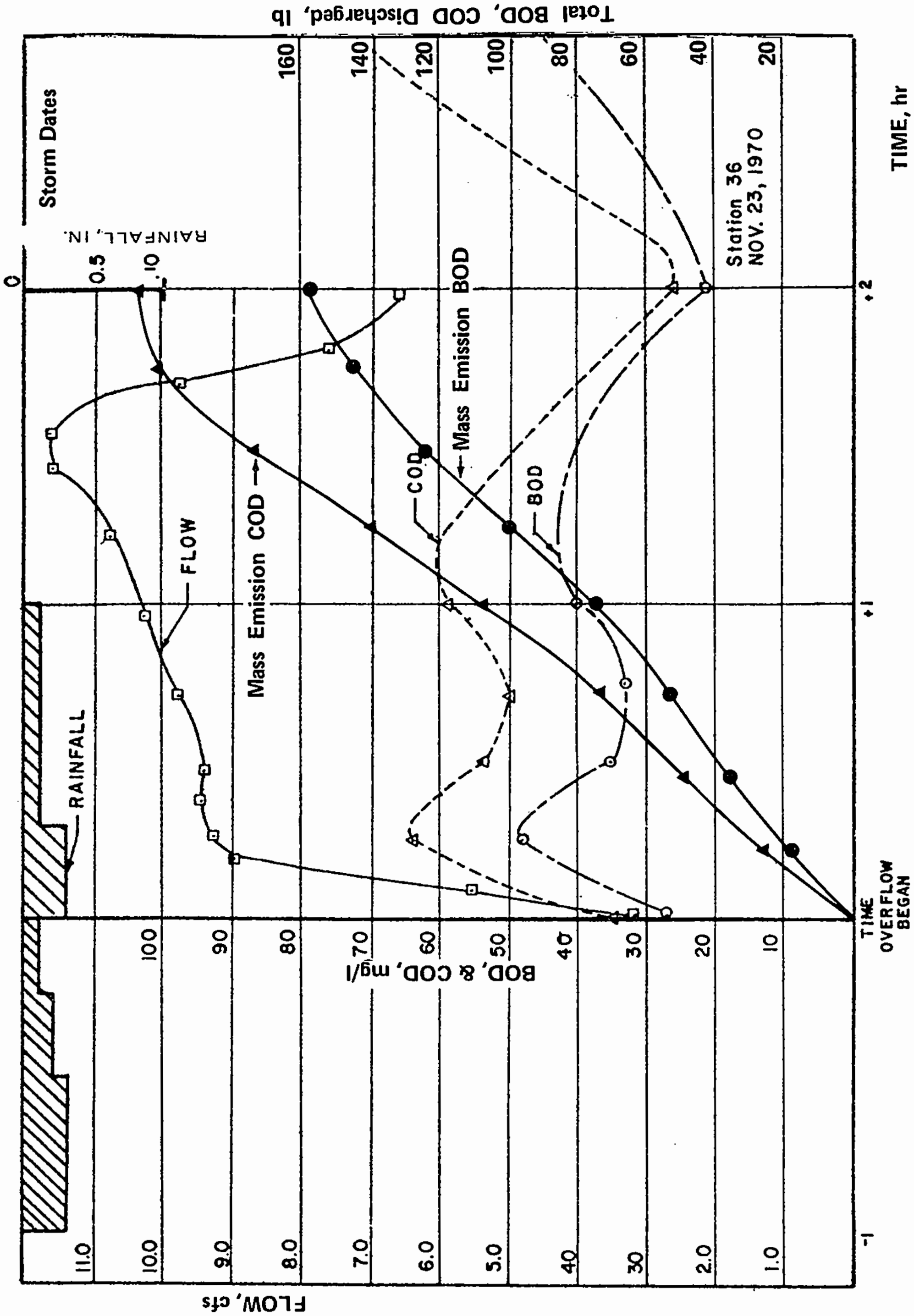


Figure 32. Flow, BOD, and COD vs. time.

Source: Municipality of Metropolitan Seattle, "Maximizing Storage in Combined Sewer Systems," USEPA Report No. 11022ELK12/71 (NTIS No. PB 209 861), December, 1971.

experienced while COD and BOD peak very early and diminish with increasing flow--a condition consistent with the first-flush phenomenon. It should be recognized that these data, however, are for an overflow and do not as such, indicate flows and pollutant strengths during the first hour of rainfall where first-flush characteristics may be better defined.

Detailed tabulation of the characteristics of the first flush phenomenon are also found in the literature on combined sewer overflow investigations. Results of a monitoring program for the District of Columbia are plotted in Figure 33 and shown in Table 51. (60) As shown in the table, the sampling occurred at relatively small time steps, the data clearly demonstrated the gradual changes in concentrations of each of the contaminants.

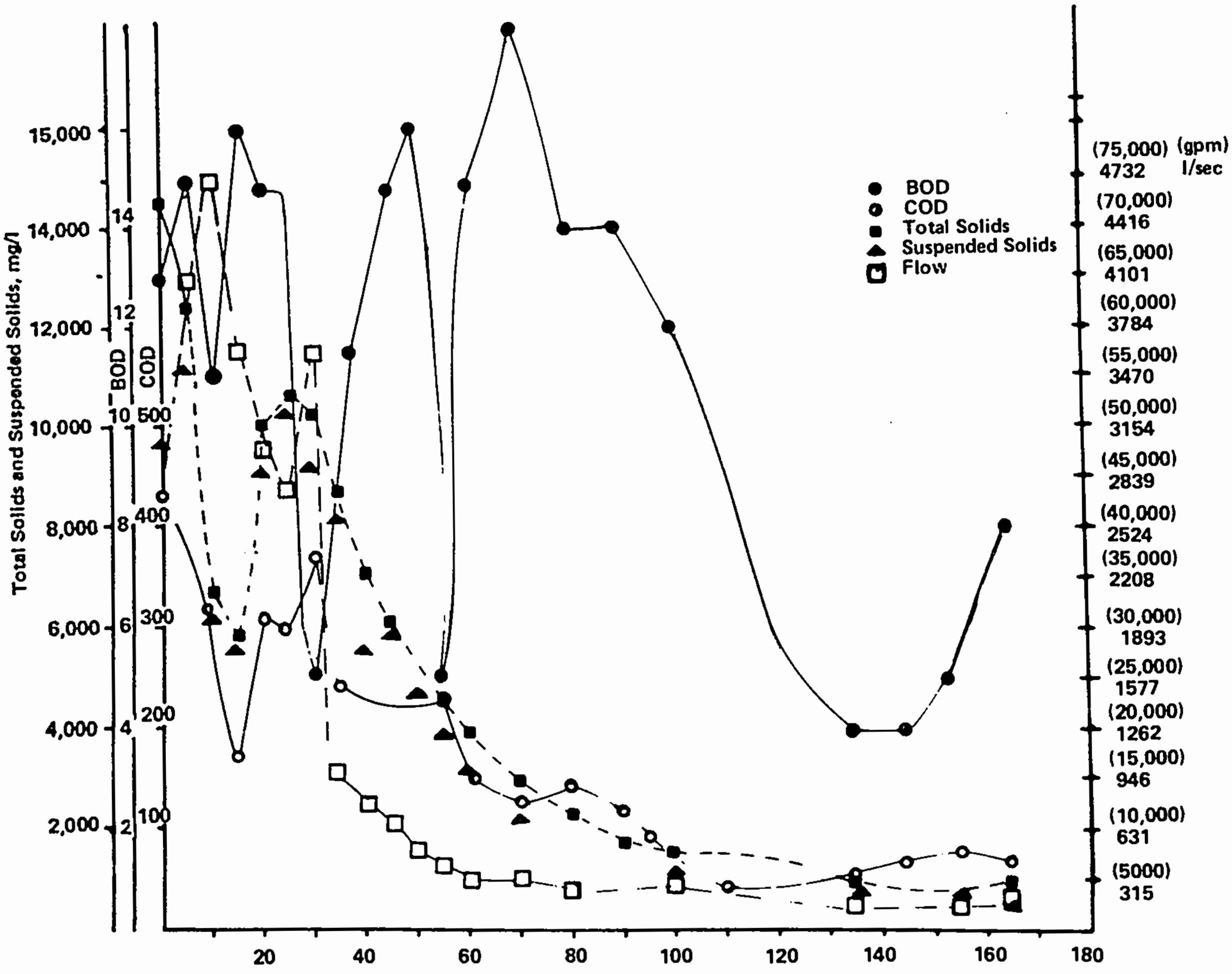


Figure 33 Flow, BOD, COD, Total Solids, Suspended Solids

Source: Roy F. Watson, Inc., "Combined Sewer Overflow Abatement Alternatives, Washington, D.C.," USEPA Report No. 1024EXF08/70 (NTIS No. PB 203 680), August, 1970.

An analysis of the mass emission (not shown) indicates that after 30 minutes the rate of discharge of the key pollutants is minimal.

TABLE 51. CHARACTERISTICS OF COMBINED SEWER OVERFLOWS IN SEWER DISTRICT GOOD HOPE RUN, DISTRICT OF COLUMBIA

Location of Sampling Site – 17 Minn. and 16 S.E.

Storm		Total Rainfall		Sampling Interval	Elapsed Time	Flow		pH	COD	BOD	Total Solids	Total Volatile Solids	Suspended Solids	Volatile Suspended Solids	Settleable Solids	Total P	Total N
Date	Time	in	cm	min	min	gpm	l/sec		mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l
July 28	1:20–2:00 p.m.	1.6	4.1	5	0	21,000	1,325	6.2	430	13	14,600	912	9,600	880	6,756	4.5	4.0
				5	5	65,600	4,140	6.2	400	15	12,560	996	11,200	860	7,640	2.8	2.8
				5	10	75,000	7,730	6.1	280	11	6,638	278	6,050	60	3,330	1.5	2.5
				5	15	67,900	3,655	6.0	170	16	5,830	268	5,520	40	2,660	1.8	2.5
				5	20	47,700	3,010	6.1	310	15	10,002	600	9,020	430	6,528	2.4	4.0
				5	25	43,300	2,730	6.0	300	15	10,682	484	10,010	370	6,906	2.0	2.5
				5	30	57,900	3,655	6.0	370	5	10,242	512	9,170	380	5,702	2.6	3.0
				5	35	15,400	970	6.2	240	8	8,676	488	8,150	410	6,662	1.6	2.5
				5	40	12,500	790	6.2	230	13	7,198	460	5,560	460	2,912	1.8	2.0
				5	45	10,200	645	6.3	210	15	6,092	390	5,900	210	2,332	2.2	3.2
				5	50	7,900	500	6.2	210	16	4,898	288	4,620	180	2,530	2.0	3.0
				5	55	6,090	385	6.3	230	4	4,598	378	3,920	280	3,616	1.6	2.0
				10	60	4,570	290	6.4	150	15	3,908	284	3,140	300	2,792	1.6	2.2
				10	70	5,000	315	6.3	120	17	2,898	228	2,160	180	1,016	1.5	1.8
				10	80	3,740	235	6.6	140	14	2,310	200	1,920	200	1,036	1.4	2.0
				10	90	3,620	230	6.8	120	14	1,670	110	1,020	50	360	2.1	2.0
				35	100	4,770	300	6.9	53	12	1,454	136	1,160	100	524	1.0	1.6
				10	135	2,020	130	7.0	48	4	1,140	136	640	120	–	1.0	1.4
				10	145	2,625	165	6.3	67	4	770	138	480	100	–	0.5	1.5
				10	155	2,190	140	7.0	77	5	944	136	720	120	396	1.0	2.4
				30	165	3,180	200	7.0	67	8	776	76	480	–	280	1.0	1.2
					195	1,140	70	7.1	29	3	778	142	520	100	200	0.4	1.6
July 28	5:00–5:30 p.m.	0.20	0.5	10	0	2,020	130	7.0	58	4	578	90	380	100	248	0.3	2.0
				10	10	2,500	160		96	6	488	90	320	100	144	0.4	1.6
				10	20	4,010	255	6.9	77	7	446	151	300	120	192	0.4	1.4
				10	30	2,640	165	7.0	77	5	539	96	340	100	157	1.8	3.4
				10	40	3,600	230	7.1	48	5	1,070	120	920	120	472	1.0	1.2
				10	50	4,200	265	7.1	106	5	1,842	136	1,500	180	812	0.8	1.2
				10	60	3,090	195	7.1	86	5	1,580	84	1,300	160	708	0.4	1.2
				10	70	1,640	105	7.2	77	4	1,984	12	1,740	180	984	0.2	1.2
					80	2,020	130	7.1	38	3	1,240	106	980	140	496	0.2	1.0
August 2	8:17–9:30 p.m.	2.9	7.4	10	0	34,400	2,170	6.3	400	16	10,346	538	9,568	524	5,353	2.0	4.0
				10	10	16,800	1,060	6.3	259	12	6,626	368	6,560	210	4,700	1.8	4.0
				10	20	10,100	640	6.2	210	36	4,290	250	4,210	250	2,370	1.5	2.5
				10	30	5,660	360	6.2	140	16	3,318	226	2,610	50	1,290	1.0	2.0
				10	40	4,400	280	6.5	184	36	2,478	188	1,200	70	710	1.0	2.0
				10	50	3,520	220	6.6	119	17	1,838	180	1,550	80	1,060	1.0	1.5
				10	60	2,470	155	6.8	108	12	1,090	40	1,278	232	480	1.0	2.0
				10	70	1,960	125	6.9	140	31	1,290	184	910	60	662	1.0	1.6
				10	80	1,995	125	7.0	129	13	1,342	178	840	20	700	1.4	1.0
				10	90	1,601	100	7.0	65	40	680	164	200	0	40	0.4	1.0
				10	100	1,410	90	7.0	86	14	1,130	200	548	40	400	0.2	1.0
					110	1,340	85	7.1	54	17	910	72	416	12	268	0.4	0.6

Source: Roy F. Watson, Inc., "Combined Sewer Overflow Abatement Alternatives, Washington, D.C.," USEPA Report No. 1024EXF08/70 (NTIS No. PB 203 680), August, 1970.

A summary of data from a study of urban freeway drainage is presented in Table 52. (59) This shows that a first flush effect occurs at the beginning of storm runoff. Relatively high concentrations of contaminants, particularly suspended solids, COD, and settleable solids can be observed early in the runoff, then diminishes rapidly after 15 to 30 minutes.

TABLE 52. URBAN FREEWAY DRAINAGE WATER QUALITY (Seattle)

Date	Time Since Last Rain	Time After Start of Runoff	Suspended Solids mg/l	Settleable Solids mg/l	COD mg/l	BOD mg/l	$NO_2 + NO_3$ Nitrogen mg N/l	Total PO_4 Soluble mg P/l	Free NH_3 mg N/l	Oil mg/l
3-2-70	12 days	0-15 min.	1494	31.0	1617	198	2.52	.37	.01	55.0
		15-30 min.	25	<0.1	909	181	2.50	.18	.01	16.0
		30-40 min.	11	<0.1	893	162	2.45	.16	.01	18.0
3-6-70	3 days	0-20 min.	504	1.1	222	22	0.58	.33	.18	55.0
		4 hrs.	177	0.2	185	21	1.00	.28	.20	47.0
		8 hrs.	228	0.7	150	9	0.38	.20	.09	27.0
		12 hrs.	141	0.2	103	12	0.51	.16	.11	30.0

Source: Municipality of Metropolitan Seattle "Maximizing Storage in Combined Sewer Systems," USEPA Report 11022ELK12/71 (NTIS No. PB209861), December, 1971.

Comparisons of the quality characteristics from a first-flush and an extended overflow period, are also reported on in a study of the existing combined sewer system in the City of Milwaukee, Wisconsin. The findings are shown in Table 53.

TABLE 53. COMPARISON OF QUALITY CHARACTERISTICS FROM FIRST-FLUSH AND EXTENDED, COMBINED-OVERFLOW DATA

Analysis	Concentration During First Flush[1]	Concentration of Extended Overflow[2]
COD	581 ± 92	161 ± 19
BOD	186 ± 40	49 ± 10
Total Solids	861 ± 117	378 ± 46
Total Volatile Solids	489 ± 83	185 ± 23
Suspended Solids	522 ± 150	166 ± 26
Volatile Suspended Solids	308 ± 83	90 ± 14
Total Nitrogen	17.6 ± 3.1	5.5 ± 0.8
Ortho-Phosphate	2.7 ± 1.0	—
PH	7.0 ± 0.1	7.2 ± 0.1
Coliform Density per ml ($\times 10^3$/ml)	$142 \pm 108 \times 10^3$	$62.5 \pm 27 \times 10^3$

1 Data represent 12 overflows at 95 percent confidence level range.

2 Data represent 44 overflows at 95 percent confidence level range.

Source: Rex Chainbelt, Inc., "Screening/Flotation Treatment of Combined Sewer Overflows," USEPA Report No. 11020FDC01/72 (NTIS No. PB215 695), January, 1972

As may be expected, the quality of the combined sewer overflow changed rapidly after the end of the first flush period. According to the findings, the period persisted for about 20 to 70 minutes after the storm runoff began. (61)

The first-flush effect can also be disclosed by the efficiency of pollutant removal in a wastewater treatment unit process. Tables 54 and 55 present the results of the operation of a demonstration unit in the treatment system. Removal of BOD, COD, suspended solids, and volatile suspended solids

TABLE 54. COMBINED SEWER OVERFLOW POLLUTANT REMOVAL BY SCREENING SCREEN MESH 50 (297μ)

Pollutant	Removal During First Flushing %[1]	Removal During Extended Overflows %[2]
COD	39 ± 15	26 ± 5
BOD_5	33 ± 17	27 ± 5
Suspended Solids	36 ± 16	27 ± 5
Volatile Suspended Solids	37 ± 18	34 ± 5

[1] Represents 8 overflows
[2] Represents 46 overflows
Data at 95 percent confidence level

Source: Rex Chainbelt, Inc., "Screening/Flotation Treatment of Combined Sewer Overflows," USEPA Report No. 11020FDC01/72 (NTIS No. PB 215 695), January, 1972.

TABLE 55. COMBINED SEWER OVERFLOW POLLUTANT REMOVALS BY SCREENING/FLOTATION

		Removal During Extended Overflows – %[2]		
Pollutant	During First Flushes %[1]	Without Chemical Flocculants (1969-1970 Data)	With Chemical Flocculants (1969 Data)[3]	With Chemical Flocculants (1970 Data)[4]
COD	64 ± 6	41 ± 8	40 ± 14	57 ± 11
BOD_5	55 ± 8	35 ± 8	46 ± 17	60 ± 11
Suspended Solids	72 ± 6	43 ± 7	59 ± 11	71 ± 9
Volatile Suspended Solids	75 ± 6	48 ± 11	58 ± 10	71 ± 9
Total Nitrogen	46 ± 7	29 ± 14	19 ± 11	24 ± 9

All data at 95 percent confidence level
Overflow Rate ~190 $l/m^2/min$ (2.5 gpm/ft^2)

[1] Represents 12 overflows
[2] Represents 38 overflows
[3] 2.5 – 3.5 mg/l C31 Dow Polyelectrolyte, 6 mg/l Clay
[4] 3–6 mg/l C31, 20–25 mg/l $FeCl_3$

Source: Rex Chainbelt, Inc., "Screening/Flotation Treatment of Combined Sewer Overflows," USEPA Report No. 11020FDC01/72 (NTIS No. PB 215 697), January, 1972.

in the screening operation during the first-flush were in the range of 30 to 40 percent. During the extended overflows period, removal efficiencies dropped to the 20 to 30 percent level. In the operation of the screening flotation system, the percentage removal of contaminants during the first-flush period was generally higher than during extended overflows, except during use of chemical flocculants in 1970 (61) due to the operating characteristics of the treatment method.

First-flush occurences appear to be related to the length of time between overflows. The study conducted in the City of Milwaukee demonstrates the effects of the length of time between overflows on the concentrations of contaminants in combined sewer overflows. The results of the study are shown in Tables 56 and 57.

TABLE 56. FIRST-FLUSH EVALUATIONS

Days Since	COD (mg/l)			BOD (mg/l)			SS (mg/l)			VSS (mg/l)		
Last Overflow	Mean	σ	N	Mean	σ	N	Mean	σ	N	Mean	σ	N
0	178.1	39.9	8	50.1	21.3	7	192.5	99.6	8	100.6	44.9	8
1	122.5	57.2	10	26.8	15.3	8	119.4	43.3	9	68.4		10
2	139.0	43.4	6	45.3	20.3	4	127.7	23.1	6	63.8	17.8	6
3	164.9	62.1	7	51.0	29.5	3	150.7	86.8	7	95.6	46.2	7
4	78.0	—	1	12.0	—	1	208.0	—	1	66.0	—	1
5	221.5	198.7	2	101.0	—	1	364.0	186.7	2	196.0	80.6	2
6	316.0	224.7	3	60.0	41.5	3	295.3	232.4	3	178.7	130.1	3
8	716.0	288.5	2	170.0	14.1	2	805.5	529.6	2	462.5	304.8	2
11	301.3	301.2	3	135.3	168.6	3	470.4	431.0	5	131.0	140.1	3
17	267.0	26.9	2	113	—	1	214.5	70.0	2	140.5	33.2	2
19	353.0	26.9	2	134.5	14.8	2	297.5	166.2	2	205.5	95.5	2

σ = standard deviation
N = number of samples

Source: Rex Chainbelt, Inc., "Screen/Flotation Treatment of Combined Sewer Overflows," USEPA Report No. 11020FDC01/72 (NTIS No. PB 215 695), January, 1972.

TABLE 57. COMPARISON OF RAW COMBINED SEWER OVERFLOW QUALITY

	Interval shorter than four days				Interval longer than four days			
	COD (mg/l)	BOD (mg/l)	SS (mg/l)	VSS (mg/l)	COD (mg/l)	BOD (mg/l)	SS (mg/l)	VSS (mg/l)
Mean	149.6	39.6	149.8	81.5	404.0	132.1	388.9	227.7
σ	54.6	22.1	73.4	38.8	230.5	77.8	246.7	140.1
N	31	23	31	32	22	19	21	21

σ = standard deviation
N = number of samples

Source: Rex Chainbelt, Inc., "Screen/Flotation Treatment of Combined Sewer Overflows," USEPA Report No. 11020FDC01/72 (NTIS No. PB 215 695), January, 1972.

As shown in Table 56, there is an obvious jump in potential strength between the time intervals of four and five days for all the listed combined sewer overflow characteristics. Table 57 compares data between time and intervals of less than and over four days. According to these investigations, four-day antecedent dry periods will produce a significant first-flush. (61)

Variables that influence the occurrence of the first-flush phenomenon may include: the length of time between overflows, dry-weather flow variations, the intensity of rainfall and runoff, area of the catchment, population density, sewer network configuration, land use, and the sewer system interceptor capacity. (61)

In the Halifax, Nova Scotia study, the characteristics of the combined wastewater flow were found to depend upon the relative proportions of sewage, surface runoff, roof runoff, catch basin contents, and sewer solids included in the flow. If surface runoff and roof runoff were the only significant contributions to wet weather combined sewage flow, it could be expected that as the rate of flow due to contribution of runoff increased, combined sewage quality would approach the pollutant concentrations of surface runoff. As storms continued, lower concentrations in surface runoff would result in lower combined sewer concentrations. (55)

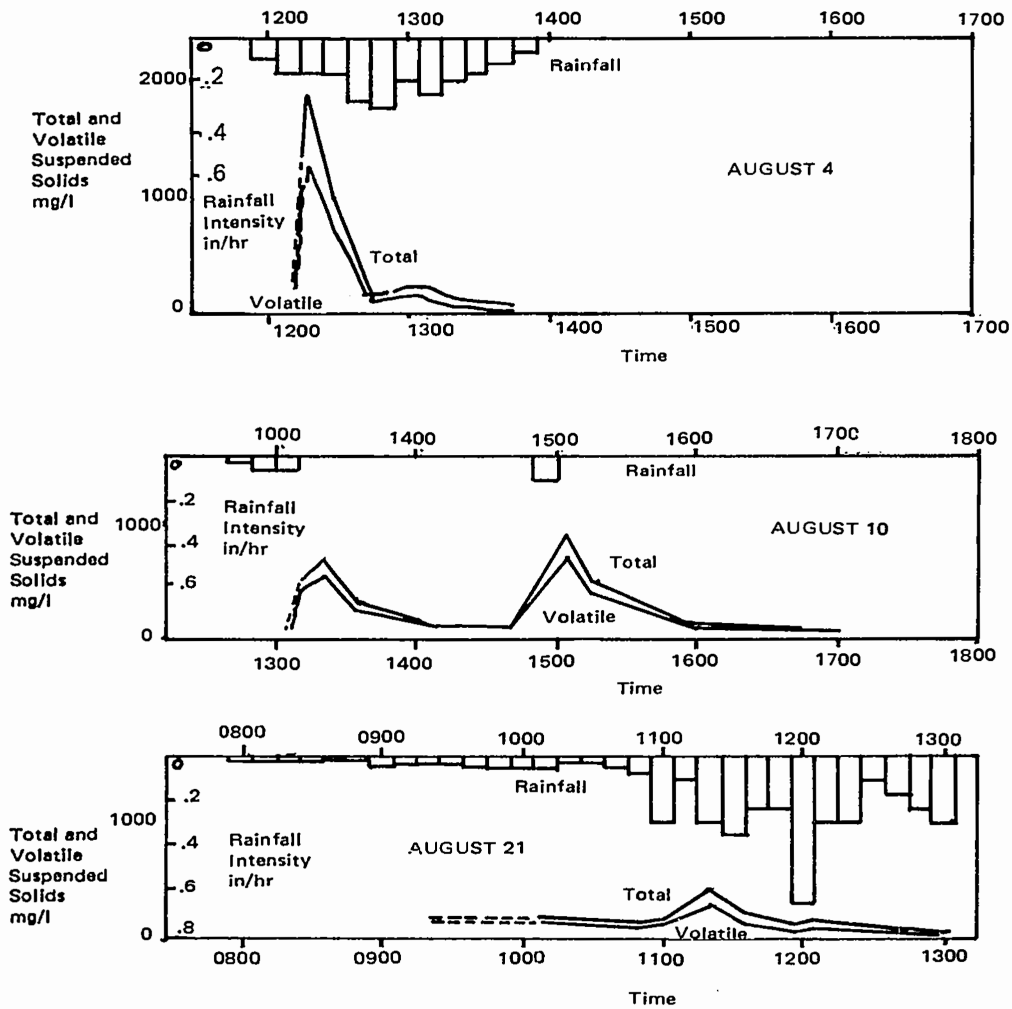
If the contributions from street and building sewers and catch basins are significant, a first-flush of organic solids should result from a small flow increase at the beginning of a runoff event. Thus, a higher concentration would be experienced at the first occurrence of a given flow than would be experienced with subsequent occurrences of a similar flow during the same event. (55)

Each of these effects is depicted to some degree, as shown in Figure 34.

Subsequent solids peaks are associated with the contributions of surface runoff, and are due to high relative runoff rates and their consequent removal of pollutants within the drainage area.

A further analysis based on the ratio of volatile suspended solids to total suspended solids showed that values of 0.75 were experienced during flushing periods. This value was compared to a value of 0.8 for dry weather flow, 0.3 for surface runoff and catch basin flows, and values of 0.75 to 0.8 for solids flushed from sewers at velocities from 0.46 to 1.5 m/sec (1.5 to 5 ft/sec). These comparisons suggest that in Halifax, the first-flush originates primarily from organic solids depositions within the sewer system, and that other effects may often be masked by these contributions.

Other studies have noted the existence of a first-flush. A study of surface runoff from an estate with separate sewers in Oxney, England, showed BOD's up to 100 mg/l and suspended solid concentrations up to 204 mg/l. It was found that BOD's tended to increase with the length of dry weather prior to a runoff event. After about 10 days, little change occurred. (62)



The dashed line joins the time at which runoff started at the surface runoff samplers to the time of collection of the first combined sewage sample.

Figure 34. First flush effects in combined sewage flows. (Halifax, Nova Scotia)

Source: Waller, H. D., "Pollution Attributable to Surface Runoff and Overflows from Combined Sewer Systems," Atlantic Industrial Research Institute, Halifax, Nova Scotia, April, 1971.

Stormwater samples from Seattle street gutters contained BOD's of about 10 mg/l; coliforms of up to 16,000 MPN's/100 ml; organic nitrogen of up to 9.0 mg/l; nitrate nitrogen up to 2.8 mg/l; and phosphorus up to 784 mg/l soluble and to 1,400 mg/l total, as phosphorus. The highest concentrations usually were found when the rainfall was low and there was little detention time in the system before sampling.

A study performed in Durham, North Carolina, on the characterization of urban land runoff in separate sewer systems, generally corroborated the Nova Scotia combined sewer experience. (64) Figure 35, portrays higher concentrations of total suspended and volatile solids during the rising limb of the hydrograph, with subsequent diminution of these concentrations until the next peak on the hydrograph is approached. This tends to indicate the existence of a first-flush effect and the later effects of higher subsequent rates of runoff. One of the major findings of the study, however, indicated that the significant independent variables found as a result of a regression analysis of pollutant concentrations determined from 36 storm events were the discharge rate and the time from the start of the storm event. The elapsed time from the last storm was not found to be an important consideration in this analysis, nor was the elapsed time from the last storm peak discharge of major significance. These items must be considered in relation to the physical features of Durham which differ from Halifax in such major items as percent pervious area and type of sewer system.

These results tend to suggest little or no early influence on solids due to solids accumulation within the basin itself. It seems likely therefore that the major part of first-flushing effects are due to depositions and erosion within the natural channel drainage collection system itself. In the Halifax study, the few values for suspended solids concentrations in surface runoff greater than 400 mg/l that did occur coincided with higher discharges later in the storm events studied. This showed that surfaces accumulations and surface runoff solids may not account for much of the first-flush effect experienced in many drainage areas. (55)

It is likely, therefore, that a first-flush effect exists in combined and even in separate storm systems, to some degree. The major source of this first flush is the solids depositions within the collection system, as opposed to the pollutants accumulated on the drainage basin itself. Contributions for the latter source appear to be more important during subsequent discharge peaks. In combined sewer collection systems, this is reflected by the relative diminution in volatile suspended solids concentration with time. It is also likely that first-flush effects may be less apparent in large drainage areas than in small ones. In large basins, first-flush contributions from individual upstream sewer areas may be diluted by flows from downstream areas where first-flushes have already been discharged. Thus, the apparent net effect of total system first-flush contributions may be moderated due to their relative distribution over time. (55).

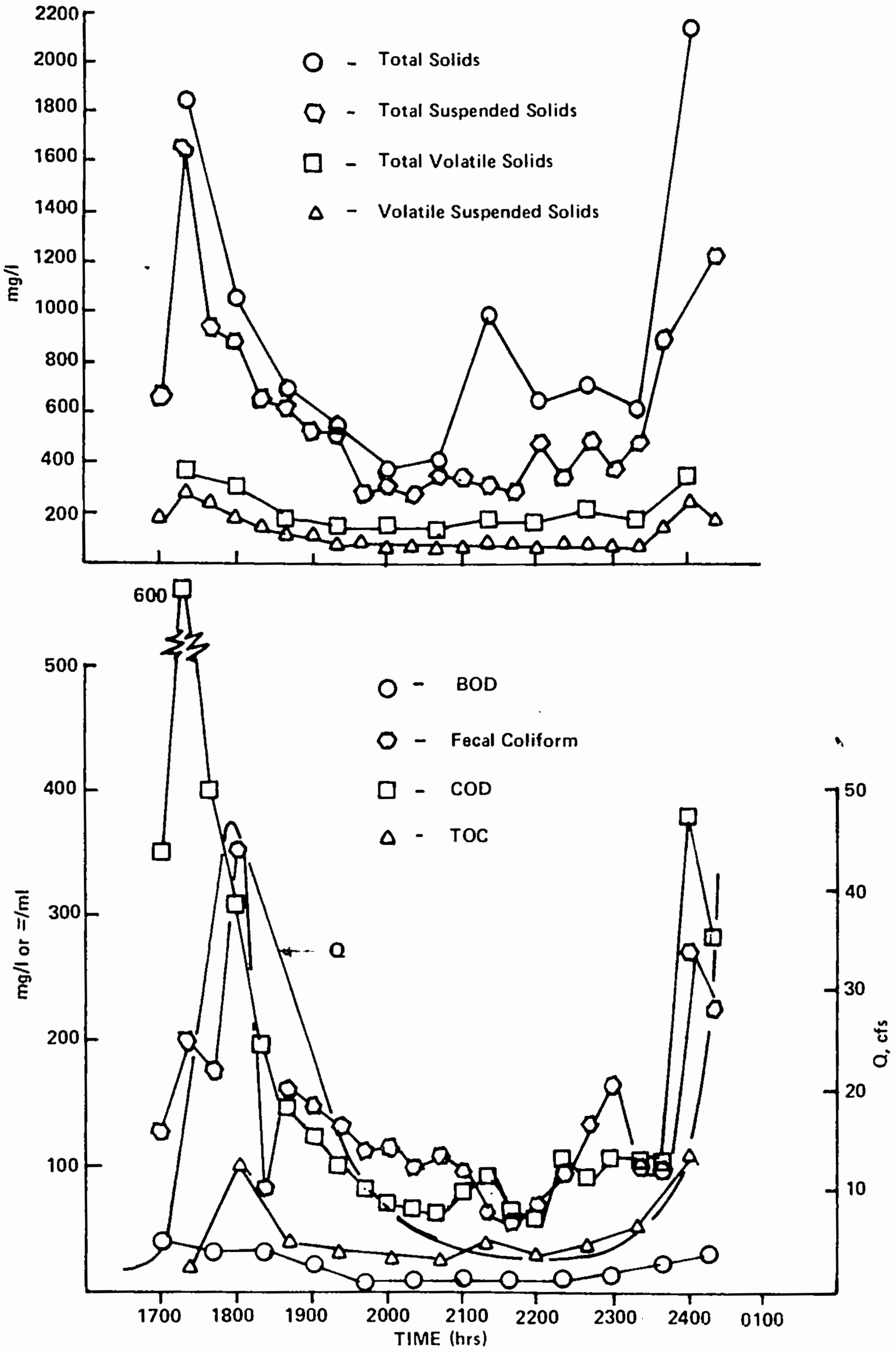


Figure 35. Pollutant variation with flow and time for storm event no. 13.

Source: Colston, N.V., "Characteristics and Treatment of Urban Land Runoff," USEPA Report No. EPA-670/2-74-096 (NTIS No. PB 202 865), December, 1974.

STREET SURFACE POLLUTION POTENTIALS

Much of the pollutional load borne in urban stormwater has been assumed to be largely due to the washing away of pollutants deposited on urban streets. The street network of an urban area serves as a depository for the materials that result from activities on and around city streets. Where urban streets function as an extension of the runoff collection system, the assumption of significant street pollutional contributions would appear to hold--particularly for rainfall events that minimize the relative contributions from other pollutant sources. Street surface accumulations, therefore, and the pollutant potentials of their constituent fractions may represent an important aspect of urban runoff discharge pollution.

Street Surface Accumulation Sources

Street surface accumulation sources are as diverse as the urban environments that produce them. Some of these may be characterized as: street surfacing materials; grass clippings, street trees, and yard refuse; air pollution emission sources; local soils; truck spillage; illicit dumping; construction site wastes; adjacent vacant lots; the products of transportation activities, including both vehicle-produced and vehicle-transported materials; roof surfaces; parking lots and other impervious surfaces; and materials applied for specific purposes, such as chemicals and abrasives for snow and ice control purposes, or fertilizers, persticides and herbicides. A more detailed evaluation of some of these varied sources appears in previous portions of this section.

Major Street Surface Accumulation Components

The components of urban street surface accumulation have been roughly classified on the basis of materials type as: rock, metal, paper, vegetation, wood, glass, and dust and dirt. The distribution of street surface accumulations into these categories are shown in Figure 36. At most of the sites included in this figure, the largest and most stable component identified was the dirt and dust fraction.

Another approach to the classification of street accumulation components used in recent studies of street surface pollution categorized these materials on the basis of particle size. Major components have been defined as the litter, dust and dirt, and flush fractions. Litter is the largest fraction and has been generally defined as the portion retained on a U.S. No. 6 sieve, 3.35 mm (0.013 in) mesh. (15) Dust and dirt is the fraction passing the same size screens. Dust and dirt has been called that part of urban street litter "having the greatest pollution causing effect." (15) The flush fraction represents that part of the pavement surface contaminants that can only be removed by a flush of water after complete sweeping and vacuuming.

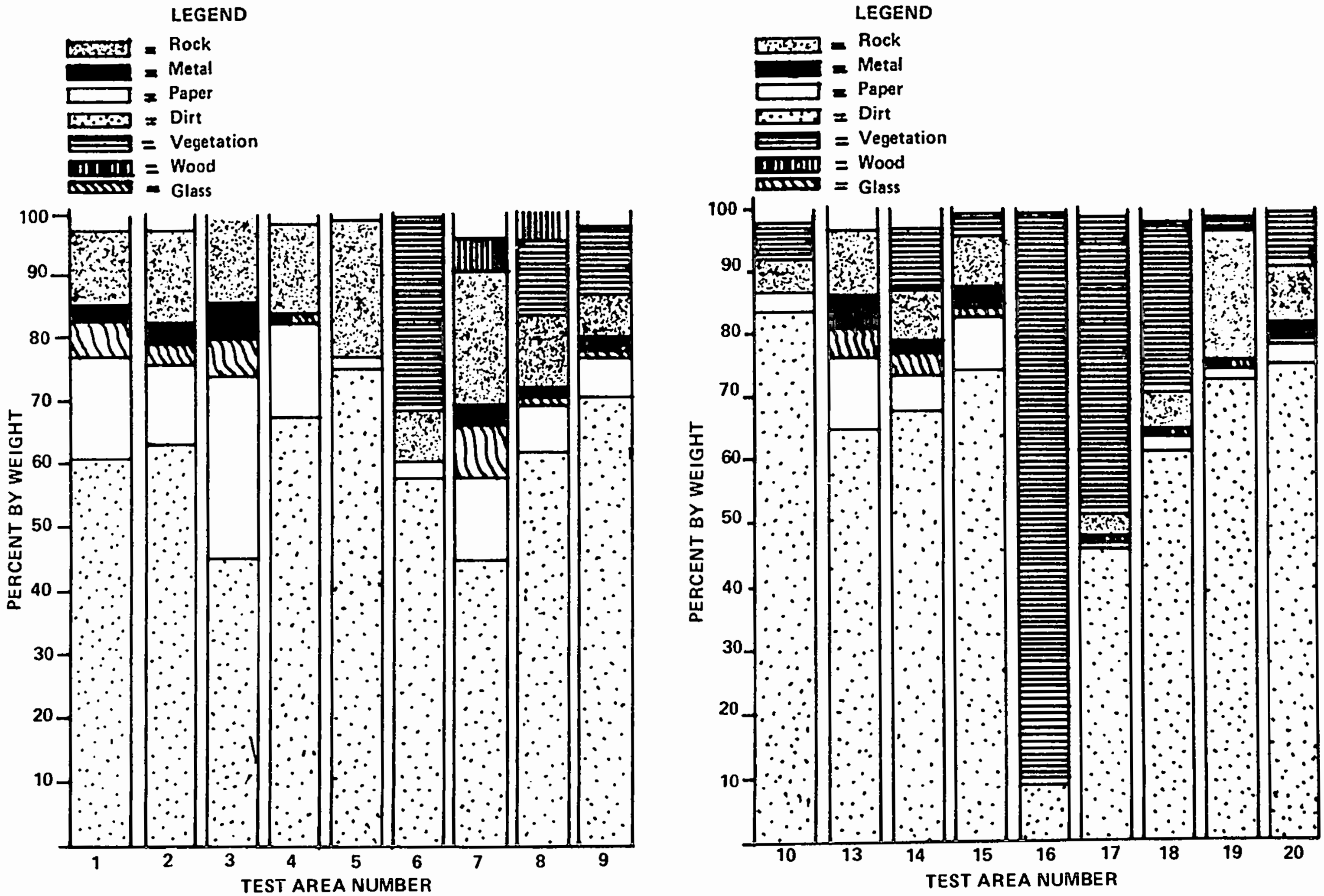


Figure 36. Average components of street litter, Chicago.

Source: American Public Works Association. "Water Pollution Aspects of Urban Runoff," USEPA Report No. 11030DNS01/69 (NTIS No. PB 215 532), January, 1969.

Street Accumulation Sampling Efforts

A number of studies have been performed to determine the pollutional potentials of street surface accumulations. One of these studies was conducted by the APWA on street accumulation samples collected in Chicago. (15) Another study, performed by the URS Research Company, sampled various sites in a number of cities across the country. (43) The latest study, by Shaheen, collected samples in Washington, D.C. to evaluate the pollutional contributions of transportation activities. (6) Still another survey was conducted in Omaha, Nebraska during the summer of 1974 by the U.S. Army Corps of Engineers District. (65) The detailed results of this latter study unfortunately, were not available at the time of this writing. The data accumulated under this investigation will be used for local sturm planning studies.

The sampling methods employed in each of these studies proved to be somewhat varied. This variation involved the size of the area sampled, sampling technicques, the types of samples collected, the handling of samples for testing purposes, and the laboratory tests performed. A summary of sampling techniques are shown in Table 58. The variability of methods applied, is the reason in part, for the degree of variation experienced in the comparison of test results reported in a later portion of this section.

Sampling methods were tested in the case of the Shaheen study, (6) using a simulated material made up of particles passing the U.S. No. 6 sieve (3.35 mm (0.013 in)). Vacuum sweeping was found to satisfactorily recover virtually all of the simulant on various types of surfaces with reputable results.

Laboratory Analysis of Street Accumulation Samples

A number of laboratory analyses were performed on collected samples in each of the major studies. A summary of the types of analyses performed are shown in Table 59. As might be expected, one of the greatest problems encountered in performing laboratory analyses on collected dry solid samples concerns their handling and processing to assure analytical results comparable with the pollutional parameters and test procedures routinely employed for water analyses.

The general practices employed for some of these solids analyses used aqueous suspensions of mixed or homogenized dry samples. Homogenization in itself may be assumed to change the physical characteristics of the street surface materials in a way that may not occur through normal street activities or runoff transport. It would appear to impose inaccuracies as a general method except where it may be required by specific analytical testing procedures. The aqueous suspensions in themselves may not represent the dissolved and colloidal pollutant fractions experienced in an actual runoff. In addition, they may not represent actual runoff particulate concentrations that can exert an influence on some of the analytical tests exercised--BOC_5, COD, and other constituents. It seems likely, therefore, that the measured values for some street surface pollutants may be estimates of soluble and colloidal constituents adulerated by the contributions of particulates resulting from physical sample alterations due to processing procedures.

TABLE 58. SAMPLING METHODS FOR MEASURING STREET SURFACE ACCUMULATIONS

Sampling Programs	APWA[a]	URS[b] Research Co.	Biospherics[c] Inc.	Omaha[d] District U.S. Corps of Engineers
Sample Area	Length: Full block frontage from building line parallel to curb Width: Gutter	Length: 12-15 m (40-50 ft) parallel to curb Width: 7.6 m (25 ft) ⊥ to curb 74-93 m^2 (800-1,000 ft^2)	Length: 18-31 m (60-100 ft) or more parallel to curb Width: Gutter, 1.2 m (4 ft) ⊥ to curb	Length: 1.5 m (5 ft) parallel to curb Width: Gutter, 1.2 m (4 ft) ⊥ to curb
Land Uses	Residential Commercial Industrial	Residential Commercial Industrial	Isolated from land use to the degree possible to reflect roadway contribution Some commercial	Primarily Residential
Sampling Techniques	A. Hand Sweeping B. Vacuum Sweeping	A. HandSweeping B. Vacuum Sweeping C. Flushing of hand swept areas D. Simulated rainfall on unswept street E. Simulated rainfall on swept street	A. Hand Sweeping B. Vacuum Sweeping C. Flushing	A. Hand Sweeping
Sampling Techniques Most Often Employed	A	A on each site C on occasion	A,B,C on each site	A on each each site
Samples Taken	Dry Samples	Dry Samples Liquid Samples	Dry Samples Liquid Samples	Dry Samples
Samples Tested	Dry Samples passing the 0.3 cm (0.18 in) mesh pulverized with subsequent screening by U.S. No. 40 sieve [0.00375 cm (0.0015 in)]	Homogenized dry samples and liquid samples composited on the basis of land use	Dry litter samples retained on U.S. No. 6 sieve [0.03 cm (0.012 in)] Liquid samples (flush fraction)	Dry samples passing the U.S. No. 10 sieve [0.02 cm (0.008 in)]

Sources: [a]American Public Works Association, "Water Pollution Aspects of Urban Runoff," USEPA Report No. 11030DNS01/69 (NTIS No. PB 215 532), January, 1969.

[b]Sartor, J.D. and G.B. Boyd, "Water Pollution Aspects of Street Surface Contaminants," USEPA Report No. EPA-R2-72-081 (NTIS No. PB 214 408), November, 1962.

[c]Shaheen, D.B., "Contributions of Urban Roadway Usage to Water Pollution," USEPA Report No. EPA-600/2-75-004 (NTIS No. PB 245 854), April, 1975.

[d]Information on U.S. Corps of Engineers survey program was determined by telephone conversation with Mr. Jack Rose, the project engineer for the Omaha District in March, 1975.

TABLE 59. LABORATORY ANALYSES OF STREET ACCUMULATION SAMPLES

Sampling Program	APWA[a]	URS[b] Research Company	Biospherics[c] Inc.	Omaha District[d] U. S. Army Corps of Engineers
Samples	Dry	Liquid-Dry Composite	Litter (dry) Dust-Dirt (dry) Flush (liquid)	Dry
Pollutant Analyses	Volume	--	Dry Volume	--
	Dry Weight	Dry Weight (total solids dry & liquid)	Dry Weights (total solids liquid)	Dry Weight
	Water Sol. Fraction	--	--	--
	Vol. Water Sol. Fraction	--	Vol. Solids	--
	BOD_5	BOD_5	BOD_5	BOD_5
	COD	COD	COD	COD
	NO_3	NO_3	NO_3	--
	--	--	NO_2	--
	Kjeldahl N	Kjeldahl N	Kjeldahl N	Kjeldahl N
	So PO_4	--		--
	--	Total PO_4	Total PO_4	--
	--	--	Ortho-PO_4	--
	--	--	Chlorides	--
	--	--	Asbestos	--
	--	--	Rubber	--
	--	--	Petroleum	--
	--	--	n-paraffins	--
	--	Cadium	Cadium	--
	--	Nickel	Nickel	Nickel
	--	Lead	Lead	Lead
	--	Zinc	Zinc	Zinc
	--	Copper	Copper	--
	--	Chromium	Chromium	Chromium
	--	Mercury	--	Mercury
	--	Chlorinated Hydro-carbons	Chlorinated Hydro-carbons	
	--	PCB's	PCB's	
	--	Organic Phosphates	--	
	--	--	Cyanides	
	--	--	Hexavalent Chromium	
	Total Coliform	Total Coliform	Total Coliform	Total Coliform
		Fecal Coliform	Fecal Coliform	
	Fecal Enterococcus	--	Fecal Streptococcus	

• Note: Information on the Corps of Engineers analyses is incomplete as of this writing

Sources: [a]American Public Works Association, "Water Pollution Aspects of Urban Runoff," USEPA Report No. 11030DNS01/69 (NTIS No. PB 215 532), January, 1969.

[b]Sartor, J.D. and G.B. Boyd, "Water Pollution Aspects of Street Surface Contaminants," USEPA Report No. EPA-R2-72-081 (NTIS No. PB 214 408), November, 1972.

[c]Shaheen, D.B., "Contributions of Urban Roadway Usage to Water Pollution," USEPA Report No. EPA-600/2-75-004 (NTIS No. PB 245 854), April, 1975.

[d]Information on U.S. Corps of Engineers survey program was determined by telephone conversation with Mr. Jack Rose, the project engineer for the Omaha District in March, 1975.

Insofar as the effects of runoff transport mechanisms are not reflected in these values, street surface pollutant measures provide one valid estimate of urban pollution potentials, although the relationship of these potentials to the actual pollution experienced in any runoff event may remain somewhat unclear.

Street Surface Material Accumulation

The interaction of diverse urban environmental processes are generally assumed to account for the accumulation of street surface materials. Patterns of urban development, physical drainage area characteristics, local climatology, construction practices, public works operations and maintenance, transportation patterns, and human, social, economic and behavioral characteristics represent some of these variables. Collectively, they prove too complex to analyze readily. Thus, more generalized parameters have been used to characterize street surface pollutants.

The most consistently used of these is gross land use. Street surface materials are generally characterized by their accumulation and pollutional composition in residential, commercial, and industrial areas. Other independent variables that have been used for characterization purposes are: Climate, landscaping, or land treatment adjacent to the paved streets, and street surfacing materials. (43) Traffic volumes have also been used to characterize the pollutional contributions associated with street traffic. (6)

The physical mechanisms by which street surface materials accumulate is not wholly understood. Some theoretical generalizations have been suggested by Sartor, *et al.* (43) and Shaheen *et al.* (6) These may be readily understood from the standpoint of the following simplified conceptual mass balance:

$$A_1-A_0 = D_a+D_w+D_t+D_m-(R_a+R_w+R_t+R_p) \quad (14)$$

where:

A_1-A_0 reflects the net change in the storage of material accumulations on the street surface where A_0 is a base line accumulation entrapped within the street surface and A_1 is the existing accumulation susceptible to ready removal.

D_a are airborne depositions including air pollutants, vegetative products, litter, trash, and other wind-blown wastes.

D_w are water-borne depositions of sediment from other pervious and impervious surfaces, and ground water constituents where sump pumps may be used.

D_t are vehicle-produced materials such as exhaust emissions, the products of vehicular wear, the products of street surface abrasion and wear; and also include vehicle-transported materials such as undercarriage deposits and spillage of transported materials.

D_m are depositions from miscellaneous sources such as snow and ice control chemicals and materials, litter, trash, dead animals, animal wastes, and yard wastes.

R_a are material removals by the wind erosion processes.

R_w are removals due to runoff in all forms--rainfall, snow melt, irrigation surpluses, and other water sources.

R_t are transportation-related material removals due to traffic generated blowoffs or through the pickup and transport of materials on individual vehicles.

R_p are intentional removals effected by public works operations and programs such as street cleaning and flushing, solid waste collection and disposal; and street maintenance activities.

The foregoing suggests the major mechanisms involved in the accumulation of street surface materials. It has been hypothesized that the accumulation of street materials would take the form of the curve represented in Figure 37.

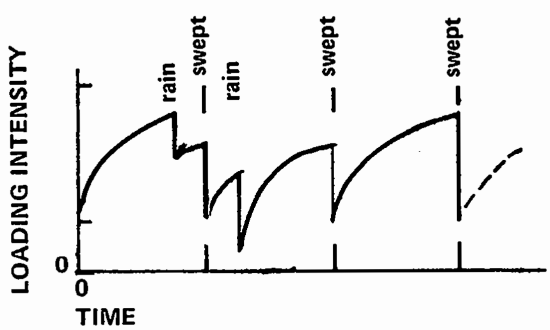


Figure 37. Accumulation of contaminants — typical case (natural build-up with periodic sweeping and intermittent rainfall)

Source: Sartor, J.D., and G.B. Boyd, "Water Pollution Aspects of Street Surface Contaminants," USEPA Report No. EPA-R2-72-081 (NTIS No. PB 214 408), November, 1972.

This approach considers the sum of the contributions of all deposition processes at a constant rate. The net effects of the various removal processes, with the exception of runoff and street cleaning, result in an accumulation function that was essentially linear in its early time steps and subsequently asymptotic to a maximum accumulation value as the time interval became long, and constant rate depositions were balanced by removal processes.

A general expression for this theoretical approach, (6) assuming a clear street at the outset is:

$$L_t = \frac{C}{K}(1 - e^{-Kt}), \quad \text{where:} \qquad (15)$$

L_t is the street accumulation at time t, lb/curb-mi

C is a constant average deposition rate, lb/curb-mi/d

K is an overall average removal constant

t is time step, in days.

Another similar approach to the same problem provides a general recursive expression in the form: (6)

$$L_t = (L_{t-1} + C)(1-\lambda) \quad (16)$$

where L, C and t are as defined above and λ is the removal constant.

This expression simply says that the street loading at time t is given by the loading at time t-1, plus what is deposited, minus what is removed during the interval [t-1, t]. It can be shown inductively that this recursive expression is a polynomial of degree t in λ, i.e., -

$$L_t = C \sum_{i=1}^{t} (1-\lambda)^i \quad (16a)$$

A graphical comparison of both expressions for various overall removal constants, K and λ, is shown in Figure 38. Attempts to verify this theoretical approach with data collection on street surface accumulations and antecedent times, based on actual street cleaning and rainfall intervals, have proved inconclusive to date.

Support for the concept of maximum levels of street surface accumulations and non-linear overall accumulation rates, however, was developed in the Biospherics study in Washington, D.C. (6) Amounts of street surface materials were found to level off after three to four days of accumulation. Average ratios of single to multiple-day measurements indicated that overall accumulation rates were non-linear.

In the Washington study (6) two processes were suggested as influencing removal rates--the mechanical break-up of deposited particles to smaller sizes, and the removal of particles by vehicular traffic through blow-off or physical pick-up and transport.

The simplified mass balance previously described suggests some of the difficulties involved in defining the complex processes of street surface material accumulations. An insufficiency of real field data limits a more complete analysis of these processes.

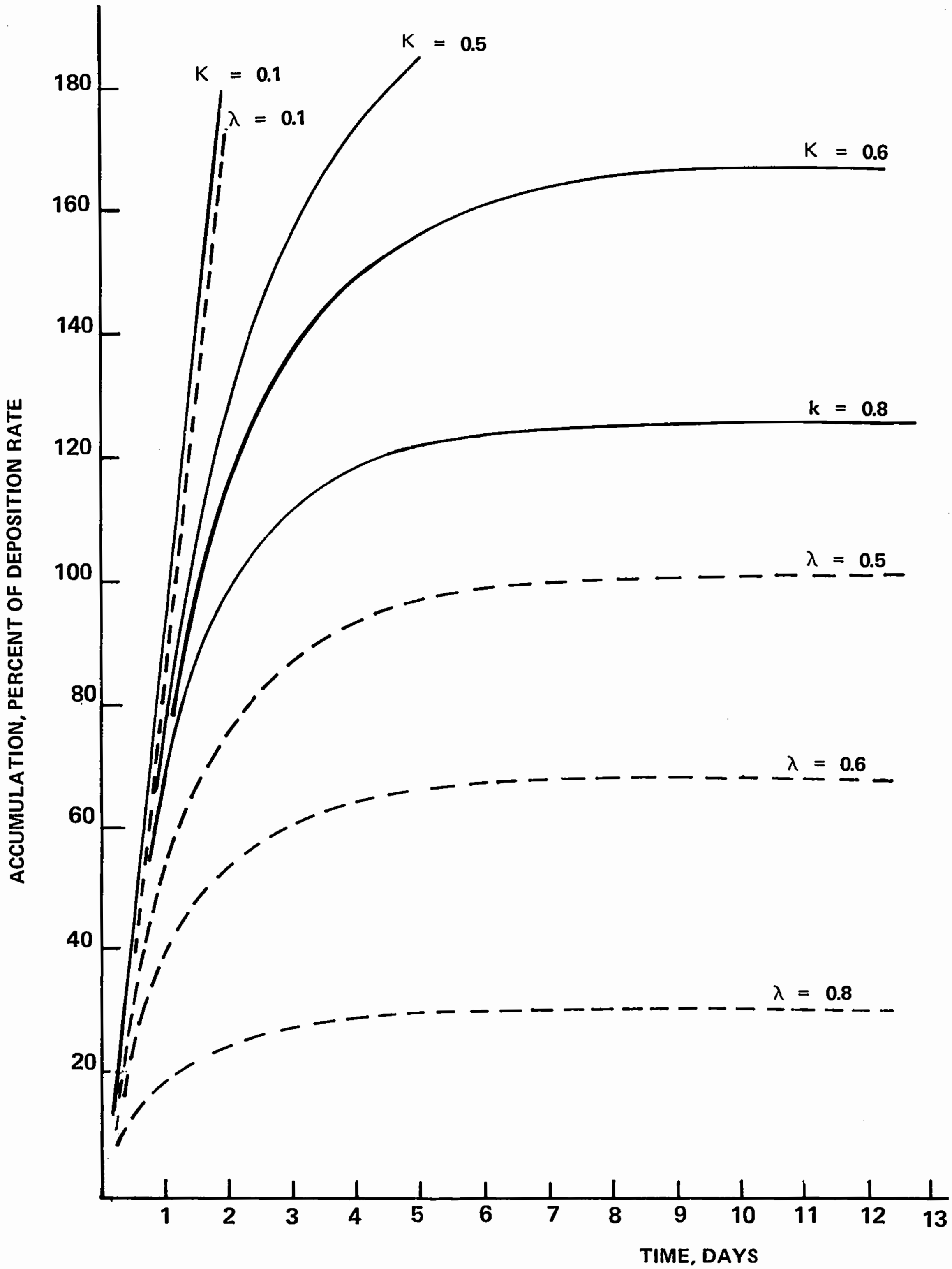


Figure 38. Theoretical street accumulations at various time intervals and overall removal constants, k & λ.

Street Surface Accumulation Measurements

The majority of street surface accumulation measurements are reported as average daily accumulations, as opposed to rate-defined accumulations as previously discussed. These data are based on actual street measurements and the units most often reported are kg/curb-km/day (lb/curb-mi/day).

Mean values from the Chicago study (15) for both total street refuse and dust and dirt are reported in Table 60.

TABLE 60. AMOUNT OF TOTAL REFUSE AND DUST AND DIRT BY LAND USE

	Amount of Total Litter By Land Use		Amount of Dust and Dirt[1] By Land Use	
Land Use	kg/curb-km/day	lb/curb-mi/day	kg/curb-km/day	lb/curb-mi/day
Single Family Residential	30	105.6	10	37.0
Multiple Family Residential	52	184.8	34	121.4
Commercial	80	285.1	49	174.2
Industrial	113	401.3	68	242.9

[1]. Where total litter was all material swept up and Dust and Dirt was fraction passing 0.31 cm (0.125 in) screen.

Source: American Public Works Association, "Water Pollution Aspects of Urban Runoff," USEPA Report No. 11030DNS01/69 (NTIS No. PB 215 532), January, 1969.

Similar information is reported in the results of a later multi-city sampling project by the URS Research Company. (43) A summary of these results appears in Table 61.

TABLE 61. MEAN VALUES OF STREET SOLIDS ACCUMULATION BY LAND USE

	Accumulations of Street Solids	
Land Use	kg/curb-km/day	lb/curb-mi/day
Residential	166	590
Commercial	51	180
Industrial	395	1,400

Source: Sartor, J.D., and G.B. Boyd, "Water Pollution Aspects of Street Surface Contaminants," USEPA Report No. EPA-R2-72-081 (NTIS No. PB 214 408), November, 1972.

The street accumulation measurements enforced in Washington, D.C. (6) generally do not provide data on measurement relationships to land use. These observations were made to evaluate traffic-related pollutional contributions. Sampling sites were selected to minimize influence of all but traffic on street surface contaminants. Two commercial sites were sampled, however, where land-use influences were considered likely. A tabluation of mean accumulation values for these sites is given in Table 62. These values have been reported in a three-component format, indicating the mean amounts of street litter, dust and dirt, and flush fractions as defined in the study. (67)

TABLE 62. MEAN STREET SURFACE ACCUMULATIONS FOR COMMERCIAL LOCATIONS (WASHINGTON, D.C.)

	Litter Fraction[1]		Dust and Dirt[2]		Flush Fraction[3]	
Site	lb/curb-mi/day	kg/curb-km/day	lb/curb-mi/day	kg/curb-km/day	lb/curb-mi/day	kg/curb-km/day
CAMP Station Street Samples						
Mean	53	15	174.7	49	9.3	3
Range	19.5-99.2	5-28	55.2-365.3	16-103	4-18.8	1-5
Shopping Center Parking Lot Samples						
Mean	7.4	2	60.2	17	——	–
Range	2.1-13.9	1-4	35.3-108.8	10-31	——	–
Overal						
Mean	27.6	11	134.7	38	9.3	3
Range	2.1-99.2	1-28	35.3-365.3	10-103	4-18.8	1-5

[1]Litter Fraction: that portion of the particulates retained by a U.S.A. No. 6 sieve, greater than 3.35 mm in diameter.

[2]Dust and Dirt: particulates smaller than 3.35 mm in diameter (U.S.A. No 6 sieve).

[3]Flush Fraction: components of the dust and dirt fraction which were not picked up at high efficiencies by the sweeping and vacuuming techniques.

Source: Shaheen, D.B.,"Contributions of Urban Roadway Usage to Water Pollution," USEPA Report No. EPA-600/2-75-004 (NTIS No. PB 245 854), April, 1975.

Samples collected by the U.S. Corps of Engineers in Omaha, Nebraska, (65) by hand-sweeping methods resulted in composite street solids accumulation values for older residential areas of 29 kg/curb-km/day (103 lb/curb-mi/day). Of this amount, the dust and dirt fraction was 21 kg kg/curb-km/day (75 lb/curb-mi/day). In newer residential areas, the total debris was 6 kg/curb-km/day (14 lb/curb-mi-day). The major focus of this sampling effort was directed to residential land uses since most of the commercial and industrial streets in the area were uncurbed.

Street surface measurement information supplemented by mass discharge data developed from runoff discharge information uncovered by the existing literature, was compiled and statistically analyzed by the URS Research Company. (5) The result of this analysis provided the street solids accumulation values indicated in Table 63.

TABLE 63. STREET SOLIDS ACCUMULATION LOADING RESULTING FROM THE ANALYSIS OF EXISTING DATA

Land Use	Street Surface Loadings lb/curb-mi/day	kg/curb-km/day
Residential	149	42
Commericial	74	21
Light Industry	389	110
Heavy Industry	203	57
Open Space	12	3
All Uses	156	44

Source: Amy G., "Water Quality Management Planning for Urban Runoff, USEPA Report No. EPA-440/9-75-004 (NTIS No. PB 241 689), December, 1974.

A comparative summary of reported values for dust and dirt or its closest equivalent is shown in Table 64. The values indicated in this table are averages of field measurements performed using somewhat different methods and subject to varying definitions of similar characteristics. Some of these variations were previously mentioned. Ready comparisons of these data should

TABLE 64. COMPARATIVE SUMMARY OF REPORTED VALUES FOR STREET SURFACE SOLID ACCUMULATION LOADINGS BY LAND USE (Dust and Dirt Fractions)

Land Use	APWA[1]	URS[2] Research Company 1972	Biospherics[3] Inc.	Omaha[4] District U.S. Corps of Engineers	URS[5] Research Company 1974
	Reported Values in kg/curb-km/day (Values in lb/curb-mi/day)				
Residential	——	166 (590)	——	4-21 (13-75)	42 (149)
Single Family	10 (37)	——	——	——	——
Multi-Family	34 (121)	——	——	——	——
Commercial	49 (174)	51 (180)	49 (175)	——	21 (74)
Industrial	68 (243)	395 (1,400)	——	——	——
Light	——	——	——	——	110 (389)
Heavy	——	——	——	——	57 (203)
Open Space	——	——	——	——	3 (12)
All Uses	——	——	49 (175)	——	44 (156)

Source: [1]American Public Works Association, "Water Pollution Aspects of Urban Runoff," USEPA Report No. 11030DNS01/69 (NTIS No. PB 215 532), January, 1969.

[2]Sartor, J.D., and G.B. Boyd, "Water Pollution Aspects of Street Surface Contaminants," USEPA Report No. EPA-R2-72-081 (NTIS No. PB 214 408), November, 1972.

[3]Shaheen, D.G., "Contributions of Urban Roadway Usage to Water Pollution," USEPA Report No. EPA-600/2-75-004 (NTIS No. PB 245 854), April, 1975.

[4]Telephone conversation; Omaha District Corps of Engineers, 1975.

[5]Amy, G., "Water Quality Management Planning for Urban Runoff," USEPA Report No. EPA-440/9-75-004 (NTIS No. PB 241 689), December, 1974.

be somewhat suspect on this basis. However, all the street measurement data show a relative compatibility as to magnitude, with the possible exception of the URS Research Company data. (5) This is two or more times other reported values, with the exception of the commerical land use, and is consistently higher in all cases due to variations in measurement practices.

Street Surface Material Deposition Characteristics

The distribution of surface materials on paved streets varies due to street geometry, traffic patterns, vehicular parking practices, and type of pavement. The results of a sampling program conducted in a number of cities are presented in Table 65.

TABLE 65. AVERAGE PERCENT TOTAL SOLIDS LOAD ACROSS STREET WIDTH

Distance From Curb Face	Cumulative Percentage of Total Loading
0.5 ft (0.15 m)	78
1.0 ft (0.3 m)	88
3.5 ft (1.1 m)	97
8.0 ft (2.4 m)	98
to street centerline	100

Source: Sartor, J.D., and G.B. Boyd, "Water Pollution Aspects of Street Surface Contaminants," USEPA Report No. EPA-R2-72-081 (NTIS No. PB 214 408), November, 1972.

The table shows that the majority of street surface solids will accumulate within 15 cm (6 in) of the curb face and virtually all accumulations may be accounted for within 1.1 m (3.2 ft). Little accumulation occurs within the traveled lanes, although greases and other automotive fluids that may bond to the street surface, may be found along the centerlines of traffic and parking lanes. Vehicular movement tends to blow particulates out of the traffic lanes, the cross-sectional slope of the street downward to the curb enhances particulate movement to the curb by gravity, and the curb face usually provides trapped area for some of the moving solids. Parked vehicles also add to the accumulation through the entrapment of moving material, and because they interfere with the planned removal of street accumulation by street cleaning.

It has also been found that street surface materials are not uniformly accumulated longitudinally along streets. This is due to variations in street geometry. Intersections, bus stops, driveways, deceleration lanes, turning lanes, etc. were all found to produce major variations in the distribution of street surface accumulations. Intersections were found to be one-third as heavy in accumulations than the other street portion and driveways were found to be 30 percent less than curbed street sections. (5) Assuming that these estimates are valid, a theoretical block distribution of 0.5 blocks/ha (128 blocks/mi^2) each block being 200 m by 100 m (660 ft by 330 ft) from right-of-way centerline, would result in only seven to thirteen percent overall reduction in accumulations (assuming fully curbed sections in a single-family residential area with off street parking) due to variations in geometry alone. For commercial areas the reduction would be somewhat less.

The relative effects of curb height on measured accumulations of street surface materials were studied in Washington, D.C. The results are shown in Figure 39.

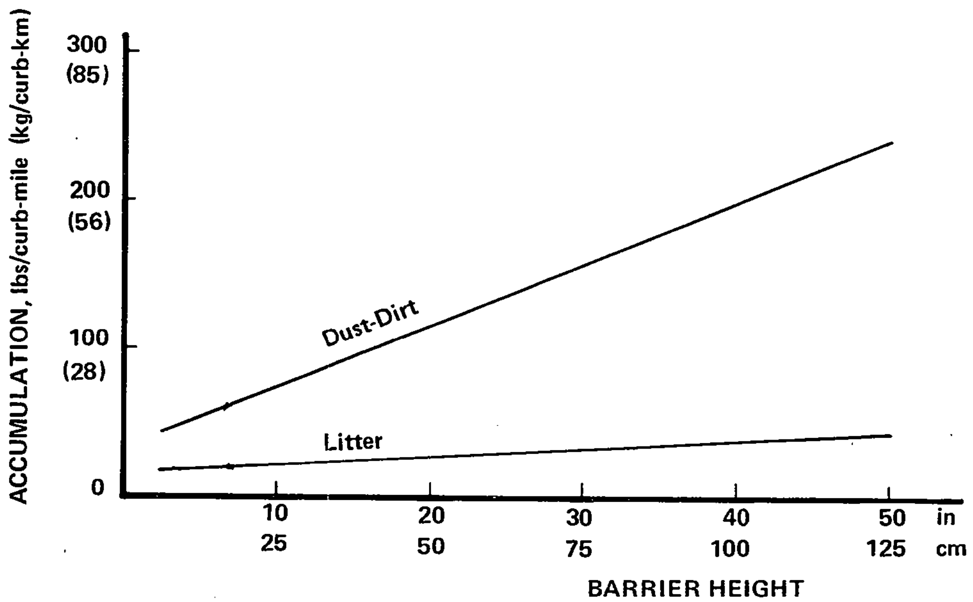


Figure 39. Accumulation of litter and dust and dirt with barrier height.

Source: Shaheen, D.G., "Contributions of Urban Roadway Usage to Water Pollution," USEPA Report No. EPA-600/2-75-004 (NTIS No. PB 245 854), April, 1975.

The variation in average total accumulation values for six sampling locations compared to the height of the curb or barrier are shown along with a regression line for the reported data. Both litter and dust and dirt fractions generally increase with increasing curb height. Thus, shifting patterns due to traffic-generated or natural winds would be inhibited by curb height with greater amounts of materials captured on streets as a function of increasing curb height. The implications of this particle capture phenomenon on street development policies is immediately apparent. A strategy directed to the removal or entrapment of street surface particulates might require a revision of street standards. This would be the case whether removal and entrapment was by street cleaning and materials disposal or through the elimination of curbing and the use of strategically located plantings or vegetation.

An analysis of available sampling data collected in Washington (6) indicated the effects of pavement surface type and changes in the relative distribution of street accumulation components over time. The data was grouped on the basis of sampling time intervals and pavement surface type. It was assumed that initial or first samples taken at the beginning of the sampling periods, represent valid estimates of street surface accumulation characteristics. The composition of collected street surface accumulation samples at various collection frequencies is shown in Table 66. This information shows that a disparity among sample components exists for each pavement surface type for one and three-day frequency samples.

TABLE 66. PERCENTAGE OF TOTAL STREET SOLIDS ACCUMULATION FOR DEFINED SAMPLE COMPONENTS FOR ALL SITES AT VARIOUS COLLECTION FREQUENCIES

Sample Collection Frequency, days	Sample Components (% of Total Accumulation): Litter Fraction, Concrete Pavement	Litter Fraction, Asphalt Pavement	Dust-Dirt Fraction, Concrete Pavement	Dust-Dirt Fraction, Asphalt Pavement	Flush Fraction, Concrete Pavement	Flush Fraction, Asphalt Pavement
1	5.1	32.0	92.2	67.6	1.8	0.4
3	7.5	--	91.4	--	1.1	--
3.6	--	31.4	--	60.9	--	7.7
Many days	43.0	45.0	55.3	52.1	1.7	2.9

Source: Shaheen D.G., "Contributions of Urban Roadway Usage to Water Pollution," USEPA Report No. EPA-600/2-75-004 (NTIS No. PB 245 854), April, 1975.

Similarity exists in the distribution of components among the many day (or initial) samples. The time-related changes in the composition of accumulations are similar for each type of pavement. In each case, the relative proportion of dust and dirt diminishes with time due to the weathering of accumulated materials and their removal by runoff and other climatic effects. Precipitation data were unavailable to make any estimates of specific wash-off event characteristics.

Comparisons of litter and dust and dirt components on concrete and asphalt surfaces also showed some notable variation. Although the sum of percentages of litter and dust and dirt fractions were similar for each pavement, litter material was found to be a greater proportion of the total accumulation for asphalt surfaces while dust and dirt was greater for concrete pavement. Pavement surface type and the definition of the litter and dust and dirt fractions are probably responsible for much of this difference. Paving surface materials, depending on their type, age, wear and weathering characteristics, could contribute to either litter or dust and dirt when classification is based on the U.S. No. 6 sieve, 3.35 mm (0.012 in). In view of the general characteristics of these paving materials, asphaltic concrete wear or weathering products would probably contribute more to the litter fraction, while Portland cement concrete would produce more dust and dirt sized materials. An annual pavement thickness reduction of 0.32 cm (0.125 in) on a 10.9 m (36 ft) wide roadway could produce from 56 to 110 kg/curb-km/day (200 to 400 lb/curb-mi/day) if everything was captured on the roadway, depending on the surfacing material. On the assumption that all surficial materials on concrete pavements will be added to the dust and dirt sized fraction (< U.S. No. 6 sieve), litter sized accumulations on concrete may be considered to be fairly representative of other litter contributions for the sampling sites reported. On this basis, 20 to 26 percent of the total accumulation on asphalt surfaces may be associated with surficial materials. This would also amount to approximately 33 to 39 percent of the measured dust and dirt fraction on an asphalt surface.

It has been noted that debris accumulations on asphaltic surfaces have been found to be about 80 percent heavier than on all concrete streets, while mixed concrete and asphalt surfaces are about 65 percent heavier. (43) This general observiation was verified by other sampling programs. (64)

Thus, the distribution and magnitude of deposited street surface materials are subject to a number of considerations. Street geometry, curb height, and pavement type are merely a few. Climatic effects, topography, and prevalent soil types among other factors, also contribute to street accumulation deposition characteristics, and they may explain some of the variance experienced in field sampling these materials.

Physical Characteristics of Street Surface Contaminants

The particle size distribution of street surface accumulations is one of their most important characteristics. The association of relative pollutant concentrations with particle size bears not only on the movement of pollutants to receiving waters but also on some of the methods that may be employed to control these pollutants. Physical wastewater treatment processes are also dependent upon particle size distributions as are street cleaning operations.

Particle size distributions have been studied in each of the major street sampling activities to date. The Chicago study analyzed large particle sizes (15), the results of which are shown in Table 67.

TABLE 67. SIEVE ANALYSES OF SELECTED STREET SOLIDS SAMPLES AVERAGE AND RANGE (CHICAGO, ILLINOIS)

Particle Size (microns)	Commercial Site	Industrial Site
>2,000	5.8%	3.4%
	2.5-12.4%	--
1,190-2,000	7.8%	7.0%
	5.2-12.4%	--
840-1,190	5.2%	6.4%
	4.1- 6.9%	--
590-840	6.6%	12.8%
	5.0- 8.4%	--
< 590	74.6%	70.4%
	58.8-82.5%	--

Source: American Public Works Association, "Water Pollution Aspects of Urban Runoff," USEPA Report No. 11030DNS01/69 (NTIS No. PB 215 532), January, 1969.

The greatest percentage by weight of the materials are below 590 microns (0.023 in). Insofar as coarse sand may be described as from 420 to 2000 microns (0.0165 to 0.0786 in) in size, the majority of the street materials samples appear comparable in size to find sand 74 to 2000 microns (0.0029 to 0.0786 in), silt 5 to 74 microns (0.002 to 0.0029 in) and clay soils, less than 5 microns (0.002 in) in size.

A more detailed analysis of street surface material samples was performed in connection with a later study. The results of the analysis are shown in Table 68.

TABLE 68. PARTICLE SIZE DISTRIBUTION OF STREET SOLIDS SELECTED CITY COMPOSITES – PERCENT

Size Ranges Microns	Milwaukee	Bucyrus	Baltimore	Atlanta	Tulsa
>4,800	12.0	--	17.4	--	--
2,000-4,800	12.1	10.1	4.6	14.8	37.1
840-2,000	40.8	7.3	6.0	6.6	9.4
246-840	20.4	20.9	22.3	30.9	16.7
104-246	5.5	15.5	20.3	29.5	17.1
43-104	1.3	20.3	11.5	10.1	12.0
30-43	4.2	13.3	10.1	5.1	3.7
14-30	2.0	7.9	4.4	1.8	3.0
4-14	1.2	4.7	2.6	0.9	0.9
<4	0.5	--	0.9	0.3	0.1

Source: Sartor, J.D., and G.B. Boyd, "Water Pollution Aspects of Street Surface Contaminants," USEPA Report No. EPA-R2-72-081 (NTIS No. PB 214 408), November, 1972.

Similar analyses performed on the samples collected in Washington, D.C., are shown in Table 69.

TABLE 69. PARTICLE SIZE ANALYSIS IN PERCENT FOR STREET SOLID SAMPLES COLLECTED FROM SPECIFIC SITES (WASHINGTON, D.C.)

	Particle Size Ranges, microns							
Site	3,350-1,700	1,700-850	850-420	420-250	250-150	150-75	75-45	≤45
Interstate Highway	5.4	8.0	16.2	22.2	19.4	17.8	7.4	3.6
	4.1-10.6	5.2-14.0	11-21.5	16.9-26.6	16.2-20.9	11.2-23.0	2-15.2	0.9-6.0
Unused Interstate	4.6	6.2	6.6	11.8	16.1	24.5	15.7	14.5
Highway	--	--	--	--	--	--	--	--
Arterial Roadway	11.8	13.2	22.4	23.8	14.8	9.5	3.0	1.6
	5.9-31.5	8.5-17.9	16.2-29.1	15.1-29.6	9-17.5	6.4-13.6	1.2-8.7	0.2-3.6
Arterial Roadway	3.2	7.1	19.4	25.2	19.1	17.6	7.6	0.6
	1.7-4.6	3.6-11.8	16.1-22.4	20.2-31.5	15.4-23.6	10.1-22.8	2.6-10	0.3-1.5
Urban Highway	8.7	9.6	14.4	14.3	12.3	17.2	13.4	10.0
	5.3-11.2	7.7-10.8	13.4-15.7	13.2-16	10.4-14.1	13.5-19.2	11.2-15.6	8.3-12.8
Shopping Center	1.8	6.3	19.7	25.4	15.4	16.4	10.8	4.3
	0.3-2.8	4.0-9.0	6.6-25.6	20.4-31.5	11.8-18.9	10.3-20.1	6.3-18.2	0.6-6.8
Commercial Street	5.5	8.0	18.6	23.0	16.3	17.0	10.6	1.0
	4.1-9.0	5.7-9.8	17.6-20.4	19.9-27.6	14.8-17.7	12.4-19.9	2.8-16.3	0.3-1.7

Source: Shaheen, D.G., "Contributions of Urban Roadway Usage to Water Pollution," USEPA Report No. EPA-600/2-75-004 (NTIS No. PB 245 854), April, 1975.

On the assumption that there is compatibility between the analytical methods employed, a comparison of findings from all three studies is presented in Table 70.

TABLE 70. COMPARISON OF STREET SOLID PARTICLE SIZE DISTRIBUTION ANALYSIS RESULTS

Location	Comparable Ranges of Particle Sizes, microns			
	2,000-850	850-250	250-45	≤45
Chicago [a]				
Commercial	13.0%	--	--	--
Industrial	13.4%	--	–	--
Milwaukee[b]	40.8 *	20.4	6.8	7.9
Bucyrus[b]	7.3 *	20.9	35.8	25.9
Baltimore[b]	6.0 *	22.3	31.8	18.0
Atlanta[b]	6.6 *	30.9	39.6	8.1
Tulsa[b]	9.4 *	16.7	29.1	7.7
Washington[c]				
Interstate Highway	--	38.4	44.6	3.6
Unused Interstate Highway	--	18.4	56.3	14.5
Arterial Roadway	--	46.1	27.3	1.6
Arterial Roadway	--	44.6	44.3	0.6
Urban Highway	--	28.7	42.9	10.0
Shopping Center	--	45.1	42.6	4.3
Commercial Street	--	41.6	43.9	1.0

*Actual particle size ranges reported are 840-2,000μ, 840-246μ, 246-43μ and less than or equal to 43μ

Sources: (a) American Public Works Association, "Water Pollution Aspects of Urban Runoff," USEPA Report No. 11030DNS01/69 (NTIS No. PB 215 532), January, 1969.

(b) Sartor, J.D., and G.B. Boyd, "Water Pollution Aspects of Street Surface Contaminants," USEPA Report No. EPA-R2-72-081 (NTIS No. PB 214 408), November, 1972.

(c) Shaheen, D.G., "Contributions of Urban Roadway Usage to Water Pollution," USEPA Report No. EPA-600/2-75-004 (NTIS No. PB 245 854), April, 1975.

The overall comparisons indicate that some similarities exist among the sample sites analyzed. In most cases, the major fraction of street surface accumulations is from 850 to 45 microns (0.033 to 0.0018 in). This would be equivalent to a material range of coarse sand to medium silt. In individual cases, the coarser or finer fractions may be relatively greater. This is most likely due, however, to the make-up of local soils. (43) A prevalence of local soils composed of silts or clays could result in greater small-particle fractions while local gravels or coarse sands could make large-particle fractions more significant.

An analysis of the specific gravity of selected samples was performed in connection with the Chicago study. The resulting ranges of specific gravity for the fractions of individual samples tested are shown in Table 71.

TABLE 71. SPECIFIC GRAVITY ANALYSIS OF VARIOUS FRACTIONS OF SELECTED STREET DUST AND DIRT SAMPLES (CHICAGO, ILLINOIS)

Land Use	Specific Gravity Range of Test Findings
Commercial	2.588-3.027
Commercial	2.295-2.578
Commercial	2.197-2.484
Industrial	2.488-2.652

Source: American Public Works Association, "Water Pollution Aspects of Urban Runoff," USEPA Report No. 11030DNS01/69 (NTIS No. PB 215 532), January, 1969.

Most local soils in the Chicago area may be characterized as having a specific gravity of from 2.6 to 2.7. Thus, most of the values shown indicate the presence of non-mineral constituents including organics. The highest specific gravity noted was probably due to the metallic contributions added from an overhead rapid transit railway at the sampling site.

Pollutional Potentials of Street Surface Contaminants

The pollutional potentials of street surface accumulations have been found dependent on the particle size distribution of these materials. The distribution of solids has been previously considered. A summary of the findings associated with field observations made in a number of cities is given in Table 72.

TABLE 72. FRACTION OF POLLUTANT ASSOCIATED WITH EACH PARTICLE SIZE RANGE (% By Weight)

	Particle Size (micron)					
	>2,000	840-2,000	246-840	104-246	43-104	<43
Total Solids	24.4	7.6	24.6	27.8	9.7	5.9
Volatile Solids	11.0	17.4	12.0	16.1	17.9	25.6
BOD_5	7.4	20.1	15.7	15.2	17.3	24.3
COD	2.4	4.5	13.0	12.4	45.0	22.7
Kjeldahl Nitrogen	9.9	11.6	20.0	20.2	19.6	18.7
Nitrates	8.6	6.5	7.9	16.7	28.4	31.9
Phosphates	0	0.9	6.9	6.4	29.6	56.2

Source: Sartor, J.D.; and G.B. Boyd, "Water Pollution Aspects of Street Surface Contaminants," USEPA Report No. EPA-R2-72-081 (NTIS No. PB 214 408), November, 1972.

The table provides a summary tabulation of solids content, oxygen demand, and some of the nutrients that may exist in runoff flow. Interestingly, the fraction of the total solids of 246 microns (0.0097 in) or less, while less than 50 percent of the total accumulation by weight, accounts for the majority of all pollutants reported. More than a quarter of the volatile solids, nitrates, and phosphates are associated with the fraction of 43 microns (9.0017 in) or less. Thus, the management of small particles may assume a relatively high degree of importance in street runoff quality control.

A more detailed analysis of the organic constituents contained in composited samples was performed to identify tannins and lignins having their source in vegetation; carbohydrates from food wastes, methylene blue active substances from anionic detergents, organic acids, and grease and oil. The results of this analysis are shown in Table 73.

TABLE 73. ORGANIC ANALYSIS OF SELECTED STREET SOLID SAMPLES

Constituent	Assumed Loading		% of Total Assumed Loading Associated With Particle Size	
	lb/curb-mi	kg/curb-km	>246 microns	<246 microns
Tannins and Lignins	0.17	0.05	44.3	55.7
Carbohydrates	1.06	0.30	61.5	38.5
Organic Acids	––	––	––	––
MBAS	0.07	0.02	64.9	35.1
Grease and Oil	18.0	5.07	52.6	47.4

Source: Pitt, R., and G. Amy, "Toxic Materials Analysis of Street Surface Contaminants," USEPA Report No. EPA-R2-73-283 (NTIS No. PB 224 677/AS), August, 1973.

The major amounts of carbohydrates, methylene blue active substances, and grease and oil are associated with the small particle fraction below 246 microns (0.0097 in). Vegetative debris, as represented by the analysis of tannins and lignins are apparently associated with the fraction above 246 microns.

An analysis of the pollutants associated with various particle size ranges was conducted on samples collected in Washington, D.C. The results are shown in Table 74. The values reported are based on the dust and dirt fraction rather than on a total solids fraction made up of a composite of litter, dust and dirt, and flush materials. The findings generally corroborate those reported in the previous table (based on composite solids). Those pollutant percentages associated with the 250 micron (0.0098 in) or less size account for a significant amount of the total pollutant load. Visual comparison of the data suggests that the pollutant percentages are similar for all size ranges, with the exception of the largest and smallest fractions.

TABLE 74. PERCENTAGE OF POLLUTANT POTENTIAL ASSOCIATED WITH VARIOUS RANGES OF STREET SOLIDS PARTICLE SIZE (WASHINGTON, D.C.)

Pollutant	Ranges of Particle Size, microns				
Dust and Dirt	3,350-850	850-420	420-250	250-75	≤75
Commercial Street	18.8	20.4	27.6	30.1	3.1
Shopping Center	8.7	22.8	23.0	28.7	16.8
Isolated Roadways	13.2	16.2	21.1	35.2	14.3
Volatile Solids					
Commercial Street	25.1	17.0	17.1	34.0	6.8
Shopping Center	9.4	17.3	10.4	29.9	33.0
Isolated Roadways	16.4	10.2	11.7	36.0	25.7
BOD					
Commercial Street	20.8	19.0	24.5	28.6	7.1
Shopping Center	11.3	16.7	21.0	26.0	25.0
Isolated Roadways	11.9	14.5	15.0	33.7	24.9
COD					
Commercial Street	21.2	16.0	18.2	37.0	7.6
Shopping Center	6.4	13.7	13.1	33.8	33.0
Isolated Roadways	10.7	10.6	12.7	39.6	26.4
Total PO_4-P					
Commercial Street	11.9	14.5	18.3	47.5	7.8
Shopping Center	4.2	12.5	22.4	28.7	32.2
Isolated Roadways	12.2	14.0	17.2	37.6	19.0
NO_3-N					
Commercial Street	17.1	14.1	18.7	40.9	9.2
Shopping Center	14.4	13.5	12.2	32.0	27.9
Isolated Roadways	9.3	12.2	16.1	35.4	27.0
NO_2-N					
Commercial Street	52.8	11.2	0.0	16.9	19.1
Shopping Center	5.3	13.9	17.6	17.3	45.9
Isolated Roadways	15.3	15.8	11.7	31.2	26.0
Total Kjeldahl N					
Commercial Street	31.5	28.8	18.5	18.9	2.4
Shopping Center	8.6	29.6	17.6	25.8	18.4
Isolated Roadways	20.2	19.5	16.5	26.9	16.9

Source: Shaheen, D.G., "Contributions of Urban Roadway Usage to Water Pollution," USEPA Report No. EPA-600/2-75-004 (NTIS No. PB 245 854), April, 1975.

A similar analysis of other pollutants by size range was also conducted on the Washington, D.C. samples. These appear in Table 75.

TABLE 75. PERCENTAGES OF POLLUTANT POTENTIALS ASSOCIATED WITH VARIOUS PARTICLE SIZES OF STREET SOLIDS (WASHINGTON, D.C.)

	(microns)				
Pollutant	3,380-850	850-420	420-250	250-75	≤75
Grease	11.6	10.3	12.5	40.1	25.5
Petroleum	10.8	9.1	12.5	39.9	27.7
n-Paraffin	10.2	9.0	11.6	40.7	28.5
Asbestos	13.0	15.5	20.5	39.6	11.4
Rubber	3.0	5.4	11.3	37.8	42.5
Chlorides	13.5	17.0	16.6	33.6	21.6
Fecal Streptococcus	5.4	1.2	2.6	63.6	27.2

Source: Shaheen, D.G., "Contributions of Urban Roadway Usage to Water Pollution," USEPA Report No. EPA-600/2-75-004 (NTIS No. PB 245 854), April, 1975.

The majority of all of these pollutants is associated with the smaller particle size ranges. These findings generally agree with those previously indicated for grease and oil.

A summary of the precentages of elemental heavy metals in various particle size ranges is presented in Tables 76 and 77. The distribution of pollutants to particle size ranges in both tables shows fair agreement for the same metals. The table indicates that cadmium is most frequently associated with the fraction of 246 microns (0.0097 in) or less, while iron, manganese, and nickel are more related to the fraction above 246 microns (0.0097 in).

TABLE 76. PERCENT OF HEAVY METALS IN VARIOUS STREET SOLIDS PARTICLE SIZE RANGES

	(microns)			
Average Of Four Cities: Tulsa, Baltimore, San Jose II, Seattle	<104	104 to 246	246 to 495	>495
Zinc	20	26	21	33
Copper	26	33	15	26
Lead	14	28	35	23
Iron	11	21	21	47
Cadmium	36	52	12	0
Chromium	20	24	17	39
Manganese	16	20	20	44
Nickel	23	17	31	29
Strontium	34	12	15	39

Source: Pitt, R., and G. Amy, "Toxic Materials Analysis of Street Surface Contaminants," USEPA Report No. EPA-R2-73-283 (NTIS No. PB 224 677/AS), August, 1973.

TABLE 77. PERCENTAGES OF ELEMENTAL HEAVY METAL POLLUTANTS ASSOCIATED WITH VARIOUS STREET SOLIDS PARTICLE SIZE RANGES (WASHINGTON, D.C.)

	Ranges of Particle Size, microns				
Pollutant	3,380-850	850-420	420-250	250-75	⩽75
Lead	6.5	18.3	15.5	42.8	16.9
Chromium	16.8	13.2	16.6	36.8	16.6
Nickel	25.9	11.8	16.2	29.4	16.7
Zinc	7.2	13.9	24.9	40.4	13.6
Copper	8.1	11.7	13.8	44.2	22.2

Source: Shaheen, D.G., "Contributions of Urban Roadway Usage to Water Pollution," USEPA Report No. EPA-600/2-75-004 (NTIS No. Pb 245 854), April, 1975.

A similar distribution for pesticides is given in Table 78. The majority of pesticides appear to be associated with smaller particle size ranges with the exception of the polychlorinated byphenyls (PCB's) which demonstrate a higher association with size ranges above 246 microns (0.0097 in).

TABLE 78. PERCENTAGES OF PESTICIDES ASSOCIATED WITH VARIOUS STREET SOLIDS PARTICLE SIZE RANGES

	Ranges of Particle Size, microns			
Pesticides	⩽104	104-246	246-840	840-2,000
Dieldrin	42	36	21	1
DDD	30	30	30	10
Polychlorinated Biphenyls (PCB's)	18	14	33	35
p,p-DDT	42	35	22	1

Source: Sartor, J.D., and G.B. Boyd, "Water Pollution Aspects of Street Surface Contaminants," USEPA Report No. EPA-R2-72-081 (NTIS No. PB 214 408), November, 1972.

The foregoing summaries of measured pollutant associations with various particle size distributions demonstrates the relative importance of these fractions of street surface accumulations. Cost-effective methods of control for a given pollutant should be attuned to this consideration, regardless of the control measures under consideration. A large number of the pollutants reported are associated with smaller particle sizes. Thus, the management of small particles plays an important role in control and abatement methods.

The distribution of pollutants among samples collected at various collection frequencies and different pavement types are shown in Table 79. The table shows the comparison of the percentages of the total street surface accumulation attributable to the litter fraction, and the dust and dirt plus the flush fraction; and the percentage

TABLE 79. THE PERCENTAGE OF TOTAL POLLUTANT LOADS ASSOCIATED WITH THE MAJOR FRACTIONS OF STREET ACCUMULATIONS AND PAVEMENT TYPES

Sample Collection Frequency Days	Sample Fraction	Total Accumulation		BOD_5		COD		Volatile Solids	
		Asphalt	Concrete	Asphalt	Concrete	Asphalt	Concrete	Asphalt	Concrete
1	Litter	32	5.1	61.3	27.7	59.1	12.9	88	33.2
	Dust/Dirt-Flush	68	94.9	38.7	72.3	40.9	87.1	12	66.8
3	Litter	--	7.5	--	29.7	--	27.8	--	9.4
	Dust/Dirt-Flush	--	92.5	--	70.3	--	72.2	--	90.6
3.6	Litter	31.4	--	63.5	--	89.9	--	75.5	--
	Dust/Dirt-Flush	68.6	--	36.5	--	10.1	--	24.5	--
Many Days	Litter	45.0	43	70.7	79.9	88.3	85.7	87.3	58.5
	Dust/Dirt-Flush	55.0	57	29.3	20.1	11.7	14.3	12.7	41.5

Source: Shaheen, D.G., "Contributions of Urban Roadway Usage to Water Pollution," USEPA Report No. EPA-600/2-75-004 (NTIS No. PB 245 854), April, 1975.

of the contaminant loading related to each. The pattern of each is somewhat different for each pavement type. The asphalt litter or approximately 32 percent of the total accumulation, accounts for 61.3 percent of the total BOD_5 while only the concrete litter, or 5.1 percent of the total accumulation produces 27.7 percent of the total BOD_5. A fair degree of consistency in the proportions of pollutants attributable to each litter fraction over time for unweathered samples occurs for total accumulations, and BOD_5 and volatile solids on asphaltic surfaces and for total accumulations, and BOD_5 on Portland cement surfaces. Among weathered samples, the distribution of fractions and pollutants appear relatively the same for most pavement type comparisons.

A reasonable degree of linear association appears to exist for the percentage of the total BOD_5 and COD, compared to street accumulation fraction percentages, when data from both street surfacing types are commingled. Although the data are limited and, therefore, suspect, this tends to suggest that some consistency may be assumed in the distribution of pollutants compared to mass accumulations for some pollutants.

The foregoing indicates that the effect of rainfall and the removal of the dust and dirt and flush sized accumulations by runoff can be identified through net changes in their composition over time. This is evidenced by the greater relative influence due to the litter fraction with weathering of the accumulation regardless of pavement surfacing. A higher relative proportion of the dust and dirt and flush particles and pollutants will probably be removed from concrete than asphalt surfaces. This would be due to the large relative proportion of street materials in these size ranges on concrete surfaces.

A tabulation of average dust and dirt accumulations and related pollutant concentrations is shown in Table 80. The table shows mean values of

TABLE 80. AVERAGE DAILY DUST AND DIRT ACCUMULATION AND RELATED POLLUTANT CONCENTRATIONS FOR SELECT FIELD OBSERVATIONS

Pollutant		Land Use Categories				
		Single Family Residential	Multiple Family Residential	Commercial	Industrial	All Data
Dust and Dirt Accumulation lb/curb-mi/day kg/curb-km/day						
Chicago[1]	Mean	35(10)	109(31)	181(51)	325(92)	158(44)
	Range	19-96(5-27)	62-153(17-43)	71-326(80-151)	284-536(80-151)	19-536(5-15)
	No. of Obs	60	93	126	55	334
Washington[2]	Mean	--	--	134(38)	--	134(38)
	Range	--	--	35-365(10-103)	--	35-365(10-103)
	No. of Obs	--	--	22	--	22
Multi-City[3]	Mean	182(51)	157(44)	45(13)	288(81)	175(49)
	Range	3-950(1-268)	8-770(2-217)	3-260(1-73)	4-1,500(1-423)	3-1,500(1-423)
	No. of Obs	14	8	10	12	44
All Data	Mean	62(17)	113(32)	116(47)	319(90)	159(45)
	Range	3-950(1-268)	8-770(2-217)	3-365(1-103)	4-1,500(1-423)	3-1,500(1-423)
	No. of Obs	74	101	158	67	400
BOD mg/kg	Mean	5,260	3,370	7,190	2,920	5,030
	Range	1,720-9,430	2,030-6320	1,280-14,540	2,820-2,950	1,288-14,540
	No. of Obs	59	93	102	56	292
COD mg/kg	Mean	39,250	41,970	61,730	25,080	46,120
	Range	18,300-72,800	24,600-61,300	24,800-49 8,410	23,000-31,800	18,300-498,410
	No. of Obs	59	93	102	38	292
Total N-N (mg/kg)	Mean	460	550	420	430	480
	Range	325-525	356-961	323-480	410-431	323-480
	No. of Obs	59	93	80	38	270
Kjeldahl N (mg/kg)	Mean	--	--	640	--	640
	Range	--	-	230-1,790	--	230-1,790
	No. of Obs	--	--	22	--	22
NO_3 (mg/kg)	Mean	--	--	24	--	24
	Range	--	--	10-35	--	10-35
	No. of Obs	--	--	21	--	21
NO_2-N (mg/kg)	Mean	--	--	0	--	15
	Range	--	--	0	--	0
	No. of Obs.	--	--	15	--	15
Total PO_4 (mg/kg)	Mean	--	--	170	--	170
	Range	--	--	90-340	--	90-340
	No. of Obs	--	--	21	--	21

TABLE 80 (cont'd)

Pollutant		Land Use Categories				
		Single Family Residential	Multiple Family Residential	Commercial	Industrial	All Data
PO_4-P (mg/kg)	Mean	49	58	60	26	53
	Range	20-109	20-73	0-142	14-30	0-142
	No. of Obs	59	93	101	38	291
Chlorides (mg/kg)	Mean	--	--	220	--	220
	Range	--	--	100-370	--	100-370
	No. of Obs	--	--	22	--	22
Asbestos fibers/lb (fibers/kg)	Mean	--	--	57.2×10^6 (126×10^6)	--	57.2×10^6 (126×10^6)
	Range	--	--	$0\text{-}172.5 \times 10^6$ ($0\text{-}380 \times 10^6$)	--	$0\text{-}172.5 \times 10^6$ ($0\text{-}380 \times 10^6$)
	No. of Obs	--	--	16	--	16
Ag (mg/kg)	Mean	--	--	200	--	200
	Range	--	--	0-600	--	0-600
	No. of Obs	--	--	3	--	3
As (mg/kg)	Mean	--	--	0	--	0
	Range	--	--	0	--	0
	No. of Obs	--	--	3	--	3
Ba (mg/kg)	Mean	--	--	38	--	38
	Range	--	--	0-80	--	0-80
	No. of Obs	--	--	8	--	8
CD (mg/kg)	Mean	3.3	2.7	2.9	3.6	3.1
	Range	0-8.8	0.3-6.0	0-9.3	0.3-11.0	0-11.0
	No. of Obs	14	8	22	13	57
Cr (mg/kg)	Mean	200	180	140	240	180
	Range	111-325	75-325	10-430	159-335	10-430
	No. of Obs	14	8	30	13	65
Cu (mg/kg)	Mean	91	73	95	87	90
	Range	33-150	34-170	25-810	32-170	25-810
	No. of Obs	14	8	30	13	65
Fe (mg/kg)	Mean	21,280	18,500	21,580	22,540	21,220
	Range	11,000-48,000	11,000-25,000	5,000-44,000	14,000-43,000	5,000-48,000
	No. of Obs	14	8	10	13	45
Hg (mg/kg)	Mean	--	--	0.02	--	0.02
	Range	--	--	0-0.1	--	0-0.1
	No. of Obs	--	--	6	--	6
Mn (mg/kg)	Mean	450	340	380	430	410
	Range	250-700	230-450	160-540	240-620	160-700
	No. of Obs	14	8	10	13	45
Ni (mg/kg)	Mean	38	18	94	44	62
	Range	0-120	0-80	6-170	1-120	1-170
	No. of Obs	14	8	30	13	65

TABLE 80 (cont'd)

Pollutant		Land Use Categories				
		Single Family Residential	Multiple Family Residential	Commercial	Industrial	All Data
Pb (mg/kg)	Mean	1,570	1,980	2,330	1,590	1,970
	Range	220-5,700	470-3,700	0-7,600	260-3,500	0-7,600
	No. of Obs	14	8	29	13	64
Sb (mg/kg)	Mean	--	--	54	--	54
	Range	--	--	50-60	--	50-60
	No. of Obs	--	--	3	--	3
Se (mg/kg)	Mean	--	--	0	--	0
	Range	--	--	0	--	0
	No. of Obs	--	--	3	--	3
Sn (mg/kg)	Mean	--	--	17	--	17
	Range	--	--	0-50	--	0-50
	No. of Obs	--	--	3	·	3
Sr (mg/kg)	Mean	32	18	17	13	21
	Range	5-110	12-24	7-38	0-24	0-110
	No. of Obs	14	8	10	13	45
Zn (mg/kg)	Mean	310	280	690	280	470
	Range	110-810	210-490	90-3,040	140-450	90-3,040
	No. of Obs	14	8	30	13	65
Fecal Strep No./gram	Geo. Mean	--	--	370	--	370
	Range	--	--	44-2,420	--	44-2,420
	No. of Obs	--	--	17	--	17
Fecal Coli No./gram	Geo. Mean	82,500	38,800	36,900	30,700	94,700
	Range	26-130,000	1,500-1,000,000	140-970,000	67-530,000	26-1,000,000
	No. of Obs	65	96	84	42	287
Total Coli No./gram	Geo. Mean	891,000	1,900,000	1,000,000	419,000	1,070,000
	Range	25,000-3,000,000	80,000-5,600,000	18,000-3,500,000	27,000-2,600,000	18,000-5,600,000
	No. of Obs	65	97	85	43	290

Source: [1]American Public Works Association, "Water Pollution Aspects of Urban Runoff," USEPA Report No. 11030DNS01/69 (NTIS No. PB 215 532), January, 1969.

[2]Shaheen, D.G., "Contributions of Urban Roadway Usage to Water Pollution," USEPA Report No. EPA-600/2-75-004 (NTIS No. PB 245 854), April, 1975.

[3]Sartor, J.D., and G. B. Boyd, "Water Pollution of Street Surface Contaminants," USEPA Report No. EPA-R2-081 (NTIS No. PB 214 408), November, 1972.

[4]Amy, G., "Water Quality Management Planning for Urban Runoff," USEPA Report No. EPA-440/9-75-004, (NTIS No. PB 241 689), December, 1974.

Note: Data for this table has had the flush fraction and some URS Data edited out – this data represents sweeping values only. Tables 60 and 64 reflect the flush fraction and thus differ from Table 80.

daily values of all reported samples collected by mechanical and pneumatic methods, but not flushing. All the data included in these values were defined in terms of a specific sampling location. Although the preponderance of the reported data included in this tabulation was taken on asphaltic pavements (in many cases with a concrete gutter), a few samples were collected on concrete pavement. In these few cases, dust and dirt accumulations were uniformly lower in magnitude than those measured on asphalt. A more detailed description of street measurements is given in Appendix B, Data Management for Street Surface Solids Accumulation Samples.

Although the table does not reflect accumulations measured by flush sampling methods, some detailed investigations were conducted in the Washington study (6) of the significance of flush samples. As it is normally used, flushing with limited amounts of water is accomplished subsequent to mechanical and pneumatic sampling. Flush sample data, therefore, indicate some of the particulate and soluble accumulations that are not readily removed from a pavement surface by high efficiency mechanical and pneumatic cleaning. Rainfall simulation studies have shown that approximately a 90 percent capture of settleable materials took about one-half hour of simulated rainfall at a rate of 2 cm/hr (0.8 in/hr) on new asphalt and concrete. Dissolved, colloidal and suspended materials required about an hour at the same simulated rainfall rate. (43) Thus, it is not clear that flushing with limited water quantities, even though under pressure, is wholly representative of residual materials to be found on street pavements. Flushing is important, however, as an indication of some pollutants that do occur in high percentages in this fraction. A relative distribution of the percentages of pollutants associated with the flush component of dust and dirt plus flush samples, is shown in Table 81.

TABLE 81. PERCENTAGE OF POLLUTANTS FOUND IN DUST AND DIRT AND FLUSH SAMPLES ATTRIBUTABLE TO THE FLUSH FRACTION

Pollutant	Number Of Observations	Average Percentage In Flush Fraction	Range Of Flush Fraction Percentages *
Accumulation (dry weight)	82	7	5.2-8.8
Volatile Solids	82	20	17.1-22.9
BOD	82	36	31.1-40.9
COD	82	16	13.3-18.7
Total PO_4-P	82	15	11.7-18.3
PO_4-P	82	43	33.7-52.3
NO_3-N	82	69	63.7-74.3
NO_2-N	82	97	95.4-98.6
Kjeldahl N	82	33	27.9-38.1
Chlorides	82	43	35.7-50.3
Asbestos	68	13	5.4-20.6
Lead	10	4	2.5-5.5
Chromium	10	17	5.7-28.3
Copper	10	5	2.0-8.0
Nickel	10	5	3.5-6.5
Zinc	10	2	1.2-2.8
F. Strep	82	44	35.3-52.7
F. Coli	82	76	67.1-84.9

* Ranges inferred at 95% confidence interval

Source: Shaheen, D.G., "Contributions of Urban Roadway Usage to Water Pollution," USEPA Report No. EPA600/2-75-004 (NTIS No. PB 245 854), April, 1975.

The table clearly shows that, although the flush sample contributes relatively little to the street accumulation by weight, it does influence BOD_5, phosphate and nitrate, Kjeldahl nitrogen, chlorides, and bacteriological indicators. In addition, it accounts for virtually all of the nitrates measured. This suggests that significant amounts of these pollutants are associated with street accumulations that are incapable of capture with present mechanicial and pneumatic street cleaning methods.

Application of Street Surface Contaminant Data

The previous discussions have related the results of field measurements of street surface contaminants from a number of urban sites across the country. The values related provide an indication of the magnitude of potential pollutants to be expected from a variety of urban land uses. They also form the basis for analytical techniques and models employed to estimate urban runoff pollutional contributions; evaluate alternative control and abatement methods; project the influence of land use changes on runoff quality; and perform other analytical functions.

As noted in Appendix B, available data on street surface contaminants are relatively limited, and subject to some variation due to sampling and analytical procedures. Thus, this body of data does not provide universal answers to pollutional loadings from street surface contaminants. Verification of the results obtained from using this data in applicable models is therefore desirable. Verification involves the collection of runoff discharge data from representative urban drainage basins. These data preferably should include precipitation information, runoff quantities over time, and an array of related discrete samples taken in a manner representative of average conditions of flow quality. Verification in this case takes the form of comparisons of measured and estimated results for the same runoff event within the defined drainage basin.

Another approach to the application of measurements of runoff discharge was employed by the University of Florida in the STORM and SWMM modelling as reported in Volume II, Section V.

Measured and Calibrated Results

This calibration effort was limited to street accumulation values only. Non-point runoff estimating methods such as the Universal Soil Loss Equation or estimations of contributions from other sources such as roof runoff, catch basins and first flush effects, were not employed for calibration purposes. In spite of this fact, the potentials of model calibration as a means to more effectively reflect local variations in input due to climate, region, local development, soils, and other factors are clearly of value. Adjustments to the given street surface accumulation values cited within this section with locally obtained data on pollutant concentrations or mass emissions can result in more accurate analytical tools for the evaluation of urban runoff as well as new insights into the problems of prevention, abatement, and control.

STREET SURFACE ACCUMULATION REMOVAL MECHANISMS

Street surface accumulations are removed from streets by a number of methods--both planned and unplanned. Planned removal mechanisms involve the various street cleaning methods that may be used in any urban area. Unplanned removals include those accomplished by wind erosion processes; surface runoff including rainfall, snow melt and irrigation surpluses; and, transportation-related removals due to traffic-generated blow-off, or by the pick-up and transport of materials on or attached to individual vehicles. The most significant of these removal processes are those attributable to street cleaning and surface runoff.

Street Cleaning Practice

Some of the pollutants that are accumulated on urban streets are removed by street cleaning operations. The amount of material removed by street cleaning will vary according to local practice in terms of the frequency of cleaning, cleaning methods, and the effectiveness of these methods. Thus, street cleaning activities affect the amounts of materials removed and, more importantly, the effect street cleaning has on the accumulation of pollutants on streets.

Street cleaning operations usually employ abrasive (mechanical) or abrasive and pneumatic machinery and, in some cases, water flushing equipment. Abrasive street cleaning equipment employs brooms to impart sufficient energy to street accumulation particles for their collection. Two types of brooms are generally used--the gutter broom to remove material from the gutter area and make it accessible to the main or pick-up broom and the pick-up broom which moves the material to a conveyor and collection bin. Brooms may be made up of a number of materials--natural fiber, steel filaments, and synthetic fibers.

In tests performed in Pomona, California using a simulant material [No. 16 Sand, 0.12 cm (0.049 in)], on a 0.9 m by 91 m (3 ft by 300 ft) strip, a four-wheel abrasive sweeper operated with pick-up efficiencies of from 80 to 98 percent at broom pattern widths of 17.8 and 22.9 cm (7 and 9 in). A three-wheeled abrasive sweeper produced similar results. Vacuum sweepers resulted in pick-up efficiencies in the range of 97 to 99.5 percent. (15) This range of efficiency is higher than that experienced in actual practice because the conditions of the tests were ideal for equipment performance.

A study of sweeper performance in connection with radiological decontamination described abrasive sweeper effectiveness by the following genral exression: (69)

$$M = M^* + (M_o - M^*)e^{-KE} \qquad (17)$$

where:

M = the mass remaining after sweeping (g/ft^2)

M_o = the initial mass before sweeping (g/ft^2)

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

e = 2.718

K = a dimensionless empirical constant dependent upon the sweeper characteristics

E = the amount of sweeping effort involved (equipment min/ 1000 ft^2 swept)

A comparison of removal effectiveness between abrasive and vacuum sweeping was made as part of the same study. (69) The results are shown in Table 82.

TABLE 82. COMPARISON OF REMOVAL EFFECITVENESS FOR ABRASIVE AND VACUUM SWEEPING

Machine Type	Relative Effort (E) min/1,000 ft^2	20 g/ft^2 177-300μ (%)	100 g/ft^2 71-177μ (%)	600 g/ft^2 74-177μ (%)
Abrasive	2.17	92.5	58.0	46.0
Vacuum	2.88	95.0	94.5	89.5
Abrasive	4.32	94.5	––	62.6
Vacuum	5.83	98.5	––	91.4

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

g/ft^2 = Initial mass level
μ = Particle size range of simulant
% = Removal effectiveness = (Mo-M*)/Mo x 100
s.g. = 2.65

Source: Sartor, J.D. and G.B. Boyd, "Water Pollution Aspects of Street Surface Contaminants," USEPA Report No. EPA-R2-72-081 (NTIS No. PB 214 408), November, 1972.

This shows pick-up effectiveness for various particle size ranges determined as a result of strip tests. Thus, removal effectiveness would be somewhat higher than might be experienced under actual cleaning conditions. In any case, vacuum cleaning apparently operates at a higher removal effectiveness than abrasive cleaning for smaller particle size ranges.

The results of street tests to determine the effectiveness of street cleaning in a number of cities in terms of percent removal are shown in Table 83.

TABLE 83. SUMMARY OF STREET CLEANING EFFECTIVENESS TESTS[1]

A.

	City	Test No.	Street Type	Street Condition	Equipment Type	Equipment Condition	Pick-Up Broom Speed (rpm)	Strike cm	Strike in.	Vehicle Speed Gear	Vehicle Speed km/hr	Vehicle Speed mph
1	Milwaukee	Mi-3	Concrete	Good	Wayne 945	Fair	2,000	20.3	8	3rd	8.8	5.5
2	Baltimore	Ba-7	Asphaltic	Fair	Wayne 945	New	2,000	14.0	5½	2nd	6.4	4.0
3	Scottsdale	SC-1	Asphaltic	Good	Wayne 985	Worn (50%)	---	12.7	5	2nd	8.8	5.5
4	Atlanta	At-9	Asphaltic	Good	Elgin Pelican	Fair	n.a.	15.2	6	2nd	5.5	3.4
5	Tulsa	Tu-6	Concrete	Good	Elgin Pelican	Worn (50%)	n.a.	10.2	4	2nd	6.6	4.1
6	Phoenix	PII-2	Asphaltic	Poor	Mobile TE-3	Fair	1,700	12.7	5	2nd	8.8	5.5

B.

	Test No.	Initial Loading g/m^2	Initial Loading $lb/1,000\ ft^2$	Residual Loading g/m^2	Residual Loading $lb/1,000\ ft^2$	Removal Effectiveness
1	Mi-3	18.2	3.72	9.6	1.96	47
2	Ba-7	53.1	10.86	47.0	9.62	11
3	SC-1	36.2	7.40	16.0	3.28	56
4	At-9	27.8	5.68	18.8	3.85	32
5	Tu-6	64.5	13.24	41.9	8.57	35
6	PII-2	108.0	22.09	40.7	8.32	62

1. All units, abrasive type

n.a. = not available

Source: Sartor, J.D., and G.B. Boyd, "Water Pollution Aspects of Street Surface Contaminants," USEPA Report No. EPA-R2-72-081 (NTIS No. PB 214 408), November, 1972.

These results show a range of overall removal effectiveness for abrasive cleaning equipment of from 11 to 62 percent. Overall average removal effectiveness was found to be 50 percent. The effectiveness of removal varies with particle size. The concentration of pollutants in street solids also varies with particle size. The effectiveness of abrasive street sweeping equipment decreases with a decrease in particle size, as shown in Table 84, the concentration of pollutants in street solids increases with a decrease in particle size. It is noted, for example, that the particles of less than 43 microns represent only 5.9 percent of the total solids while they are 24.3 percent of the total BOD.

TABLE 84. ABRASIVE SWEEPER EFFICIENCY WITH RESPECT TO PARTICLE SIZE

Particle Size (Microns)	Sweeper Efficiency (%)
>2,000	79
840 - 2,000	66
246 - 840	60
104 - 246	48
43 - 104	20
< 43	15
Overall	50

Source: Sartor, J.D., and G.B. Boyd, "Water Pollution Aspects of Street Surface Contaminants," USEPA Report No. EPA-R2-72-081 (NTIS No. PB 214 408), November, 1972.

From the foregoing it is apparent that removal effectiveness should be determined in terms of equipment type and its related efficiency in removing particles of various sizes. As is apparent, the relative interval between street cleaning may have a strong bearing on the amount of potential pollution available to runoff on urban streets. An indication of current practice as to street cleaning intervals is shown in Table 85. As might be predicted, the shortest cleaning intervals are used in central business areas. The data shown do not reflect the methods of cleaning employed.

TABLE 85. STREET CLEANING INTERVALS (DAYS) FOR VARIOUS POPULATION RANGES AND LAND USES

		Days Between Sweeping Events					
		Residential			Commercial		Industrial
Population Range		Low Density	Medium Density	High Density	Central Business	Local Business	
10,000	Mean	64.8	51.0	36.0	5.5	11.6	32.0
to	σ	15.2	12.2	11.6	1.3	3.8	12.6
50,000	n	47	49	37	50	48	29
50,000	Mean	60.7	49.8	37.6	9.7	15.2	36.5
to	σ	9.4	7.5	5.4	17.6	17.2	19.5
100,000	n	32	32	31	33	30	25
100,000	Mean	55.3	50.0	47.5	5.8	9.4	19.5
to	σ	12.1	9.9	11.0	1.6	3.3	3.9
250,000	n	25	23	23	26	22	18
250,000	Mean	41.5	44.1	39.0	7.4	10.3	23.0
to	σ	13.5	13.5	6.4	2.7	4.1	15.5
1,000,000	n	19	18	18	16	18	18
All	Mean	58.9	48.1	38.1	6.8	11.5	29.3
Data	σ	13.7	11.4	9.0	8.9	9.3	16.0
	n	127	126	113	128	121	93

Note: σ is defined as the correlation coefficient
N is defined as number of responses

Source: 1973.APWA Survey of Street Cleaning, Catch Basin Cleaning and Snow and Ice Removal Practice.

An alternative or supplementary approach to street cleaning involves the use of flushing with water. In some jurisdictions flushing is employed to supplimentother street cleaning activities. An investigation of street flushing performed in connection with radiological decontamination using a synthetic test material--industrially processed clay loam, produced some results of interest. Simulant materials applied at levels of approximately 0.1, 0.4 and 1.1 kg/m^2 (22, 72.7 and 220 lb/1,000 ft^2)(70), were removed by manual hose flushing and mechanized flushing. Manual flushing operations were performed with a hose at a nozzle pressure of from 5.27 to 5.62 kg/cm^2 (75 to 80 psi) with a 1.5 cm (0.6 in) nozzle orifice on a standard 3.7 cm (1.5 in) fire hose. Mechanized flushing was accomplished with two different equipment units. One was a conventional 11,340 l (3,000 gal) flushing unit with three nozzles, operating at a nozzle pressure of 3.87 kg/cm^2 (55 psi), a nozzle orifice of 0.16 cm (0.06 in) and a spray direction of 60° to the line of travel. The other unit employed a 2.6 m (8.5 ft) long spreader of a 5 cm (2 in) diameter of 5.98 kg/cm^2 (85 psi) an angle of application with the pavement of 30° and a spray direction of 60° to the line of travel.

The findings of various field measurements were characterized in the form:

$$M = M^* + (M_o - M^*)\ e^{-3K_oE^{1/3}} \qquad (18)$$

In which $M^* = M^*_o(1 + e^{-\alpha M_o})$

where $$M = M^*_o(1 + e^{-\alpha M_o}) + \left[M_o - M^*_o\ (1 + e^{-\alpha M_o})\right] e^{-3K_oE^{1/3}}$$

M = Residual street loading after flushing, g/ft^2

M^* = Residual street loading remaining after an infinite flushing effort, g/ft^2

M_o = Initial street loading, g/ft^2

M^*_o = A constant limiting upper value for M^* for each pavement and cleaning method, g/ft^2

α = Loading spreading coefficient dependent on pavement surface, cleaning method, loading particle size and density

K_o = Efficiency constant

E = Flushing effort, equip. $min/10^3ft^2$

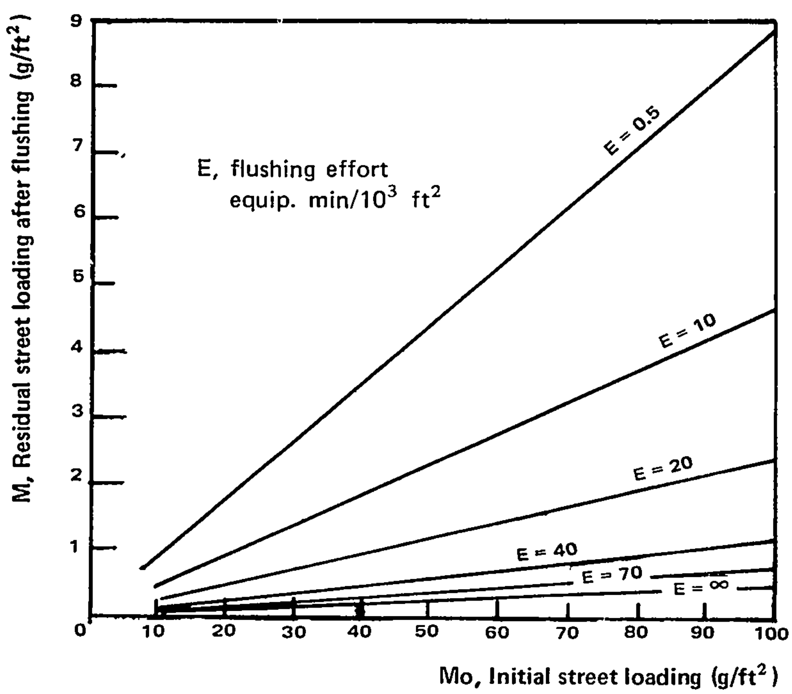
Values for some of the factors defined in the previous equation are shown in Table 86.

TABLE 86. REPRESENTATIVE VALUES FOR VARIOUS FACTORS IN DETERMINING EFFICIENCY OF STREET FLUSHING

Flushing Method	Asphalt Pavement d	K_o	M_o^*	Concrete Pavement d	K_o	M_o^*
3-nozzle flusher	0.0081	1.05	2.0	0.0064	1.05	1.0
14 flat jet nozzles	0.0081	1.05	2.0	0.0064	1.05	1.0
firehose	0.0081	0.42	2.0	0.0064	0.42	1.0

Source: Owen, W.L., et al., "Stoneman II Test of Reclamation Performance: Volume II, Performance Characteristics of Wet Decontamination Procedures," USNRDL-TR-325, U.S. Naval Radiological Defense Laboratory, San Francisco, California, July, 1960.

Some of the results of this study are shown in Figures 40, 41 and 42.



Source: Owen, W.L., et al., "Stoneman II Test of Reclamation Performance: Volume II, Performance Characterisitcs of Wet Decontamination Procedures," USNRDL-TR-325 (NTIS No. AP 248 069/LK), U.S. Naval Radiological Defense Laboratory, San Francisco, California, July, 1960.

Figure 40. Residual mass as a function of initial mass loading for various levels of flushing effort on concrete surfaces, mechanized flushing.

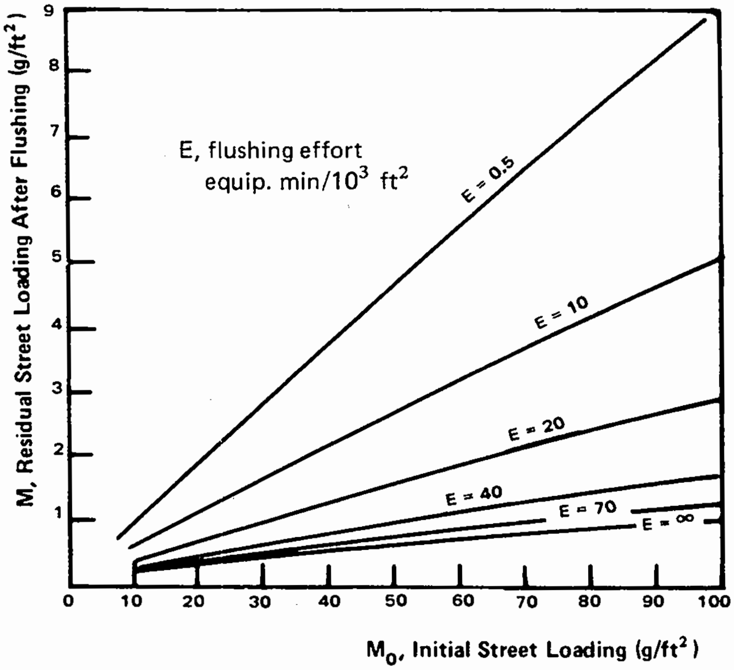


Figure 41. Residual mass as a function of initial mass loading for various levels of flushing effort on asphalt surfaces, mechanized flushing.

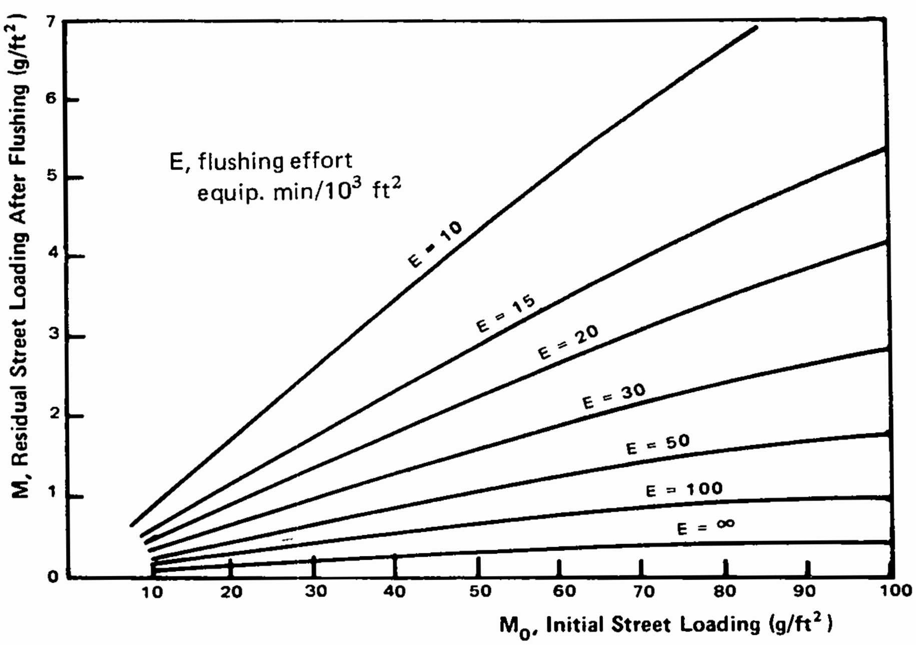
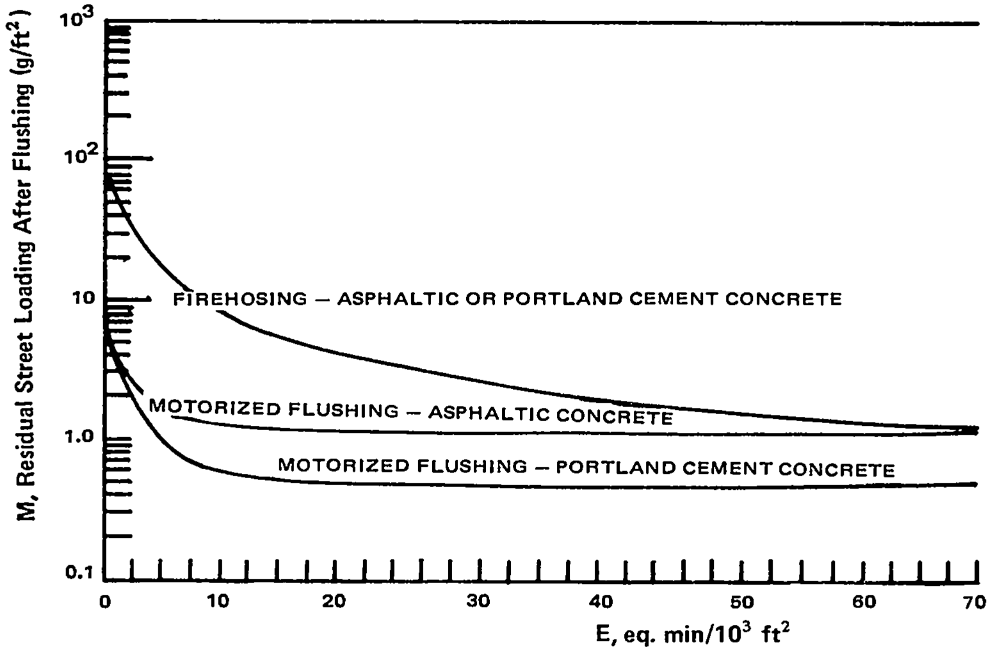


Figure 42. Residual mass as a function of initial mass loading for various levels of flushing effort on asphalt and concrete surfaces, firehose flushing.

Source: Owen, W.L., et al., "Stoneman II Test of Reclamation Performance: Volume II, Performance Characteristics of Wet Decontamination Procedures," USNRDL-TR-325 (NTIS No. AP 248 069/LK), U.S. Naval Radiological Defense Laboratory, San Francisco, California, July, 1960.

The relative effectiveness of the three flushing methods is shown in Figure 43. This comparison was based on an initial street loading of 1.08 kg/m^2 (0.22 lb/ft^2).



Source: Owen, W.L., et al., "Stoneman II Test of Reclamation Performance: Volume II, Performance Characteristics of Wet Decontamination Procedures," USNRDL-TR-325 (NTIS No. AP 248 069/LK), U.S. Naval Radiological Defense Laboratory, San Francisco, California, July, 1960.

Figure 43. Comparative effectiveness of motorized flushing and firehosing on pavement.

Uncontrolled Removal

Uncontrolled removals are accomplished through wind erosion processes, transportation-related removals due to traffic generated blow-off or the pick-up and transport of accumulations on and by means of vehicles and through removals due to runoff in all forms. Of these, surface runoff constitutes the most significant removal process in terms of receiving water pollution.

An indication of general wind erosion processes for lands adjacent to roadways was discussed in the previous section on airborne contributions to urban runoff pollution. In addition, vehicular emissions for unpaved roads was also discussed. Studies in Washington State (72) produced traffic dust emission estimates shown in Table 87. This information indicates particulate emission factors in lb per vehicle-mi for a number of road types at specific vehicular speeds.

TABLE 87. TRAFFIC DUST EMISSION FACTORS

Speed km/hr	Speed mph	Type of Road And Test Site	Weight/Vehicle Distance: Total Particulates kg/veh-km	Total Particulates lb/veh-mi	Below 10 Microns kg/veh-km	Below 10 Microns lb/veh-mi	Below 2 Microns kg/veh-km	Below 2 Microns lb/veh-mi	Percent Below 10 Microns	Number of Tests
16.7	10	Gravel Road, Duwamish Valley 10th Ave. S. from S. 92nd to S. 96th	0.95	3.5	0.16	0.58	0.028	0.10	16.7	1
33.3	20	Same	1.91	7.0	0.54	1.9	0.067	0.24	27.4	17
50.0	30	Same	6.05	22.2	2.53	9.0	0.22	0.77	40.4	1
33.3	20	Dusty Pave Road – No Curbs S. Kenyon-7th Ave. S. – S. Chicago 8th Ave. S. Duwamish Valley	0.23	0.83	0.047	0.17	0.006	0.022	20.3	3
33.3	20	Paved Road With Curbs – Flushed Weekly Swept Biweekly* – 6th Ave. S. Between S. Alaska and S. Lander	0.04	0.14	0.0015	0.0055			3.82	1
33.3	20	Gravel Road East of Redmond N.E. 40th Between 260th Ave. N.E. and 272nd Ave. N.E.	1.99	7.3	0.56	2.0			27.1	1

* The standard deviation of the average grains per actual cubic foot (g/acf) of 17 samples at mph on 10th Ave. S. is 0.010. In 95% of the cases the true average would lie between 0.133 g/acf±0.010 x 1.96 which would give a 6.0 lb/veh-mi to 8.1 lb/veh-mi emission factor.

Source: Roberts, John Warren, "The Measurements, Cost and Control of Air Pollution From Unpaved Roads and Parking Lots in Seattle's Duwamish Valley," A thesis submitted in partial fulfillment of the requirements for the degree of Master of Science in Engineering, University of Washington, 1973.

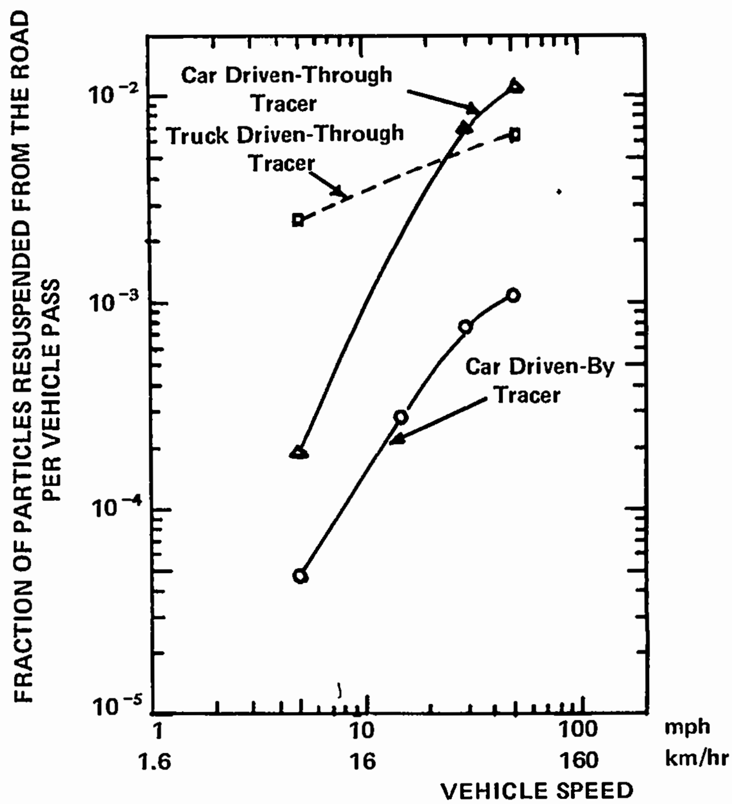
* Every 14 days (per phone call 4/25/75 John Roberts)

Another study resulted in estimates of the surface deposition fraction that is resuspended with each passing vehicle. (71) This study employed a phosphorescent tracer (specific gravity = 4.1) with a mass median diameter of approximately 5 mm (0.2 in). From this study the following can be said:

$$\text{Resuspension factor} = \frac{\text{airborne concentration/m}^3}{\text{surface concentration/m}^3}$$

Resuspension factors of the trace material were found to increase with the square of vehicle speed and ranged from 10^{-5} to 10^{-2}. The resuspension due vehicles travelling in an adjacent lane to the trace material was approximately one order of magnitude less.

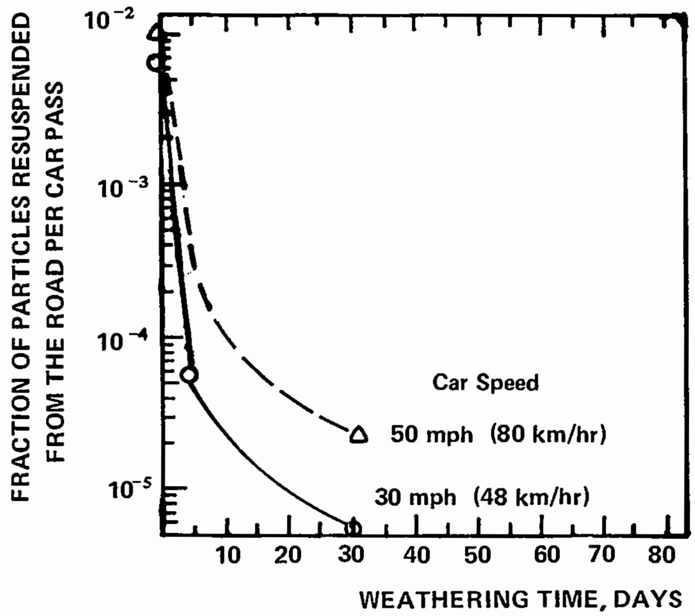
The variation in resuspended particulates with vehicular speed is shown in Figure 44.



Source: Sehmel, G.A., "Particle Resuspension from an Asphalt Road Caused by Car and Truck Traffic, *Atmospheric Environment*, Pergamon Press, Vol. 7 (291-309), Great Britain, 1973.

Figure 44. Particle resuspension rates from an asphalt road caused by vehicle passage.

The effects of particle weathering were found to decrease resuspension rapidly with time. Weathering effects are demonstrated in Figure 45.



Source: Sehmel, G.A., "Particle Resuspension from an Asphalt Road Caused by Car and Truck Traffic," *Atmospheric Environment*, Pergamon Press, Vol. 7 (291-309), Great Britain, 1973.

Figure 45. Particle resuspension rates from an asphalt road as a function of weathering (car driven through tracer).

Estimates of traffic related accumulation removal rates, as defined by the general equation first discussed in an earlier section, were developed in the Washington, D.C. study. (6)

$$L = \frac{C}{K} (1 - e^{-KT}) \qquad (19)$$

where:

L = roadway pollutant loading, lb/mi

C = per axle deposition rate, lb/axle/mi

e = 2.718

K = fractional traffic related removal rate /axle

T = total traffic in axles

The resulting estimated values for K were from 1 x 10^{-5} to 3 x 10^{-5} per axle. These values, however, were computed on the basis of dust and dirt loading that was attributable to traffic contributions only.

As to the problem of vehicular pick-up and transport of street accumulations, the study in Washington State (72) reported that material deposits on a passenger car were found to be as much as 36.4 kg (80 lb) after the vehicle was driven on country roads. This was supported by another direct measurement of materials collected on a passenger car driven through the farmlands of Illinois, that showed approximately 27.3 kg (60 lb) of transported materials. (6)

The most significant uncontrolled street surface accumulation removal mechanism is surface runoff. The wash-off of street surface accumulations has been characterized as:

$$P_o - P = P_o(1 - e^{Krt}) \qquad (20)$$

where: P_o is the initial street accumulation loading in lb

P is the street accumulation remaining at time interval t, after removal at runoff rate, r

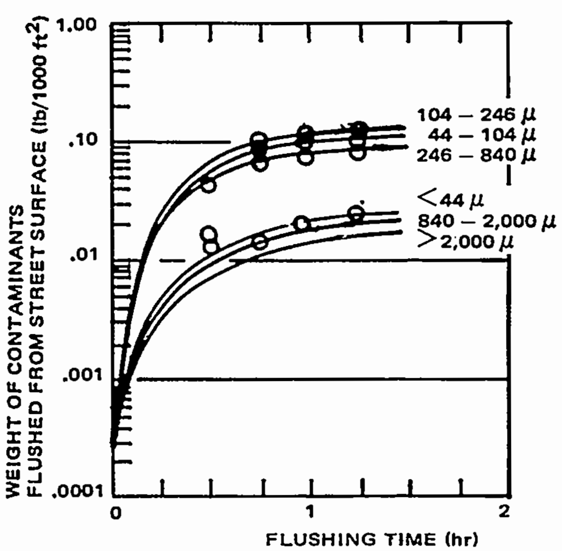
r is the average runoff in in./hr

K is a constant dependent on street surface characteristics

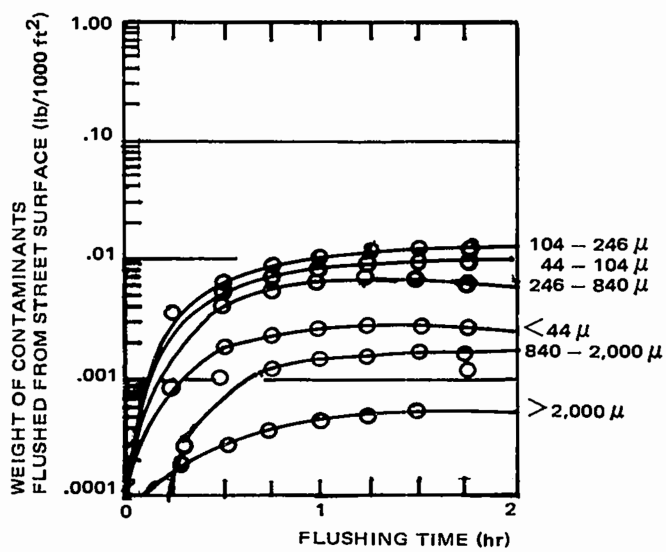
t is the time interval

$e = 2.718$

Studies of the wash-off of contaminants on streets, using a rainfall simulator device, showed that the above mathematical expression accurately describes this phenomenon. (43) Some of the results of these studies are presented in Figure 46. Values of the constant K were found to be dependent on street surface characteristics. Unfortunately, representative values for K for various street surface types were not reported. Although values for K are critical, general practice to date has been to assume a 90 percent removal of the initial street accumulation with a uniform runoff of 1.2 cm/hr (0.5 in/hr).

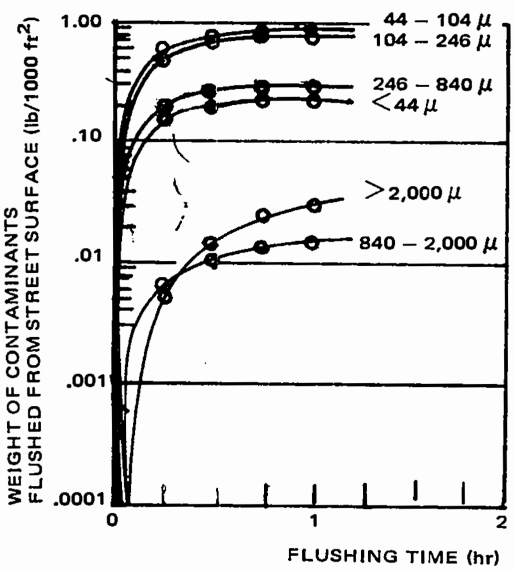


a. Concrete, Rainfall 0.8 in./hr

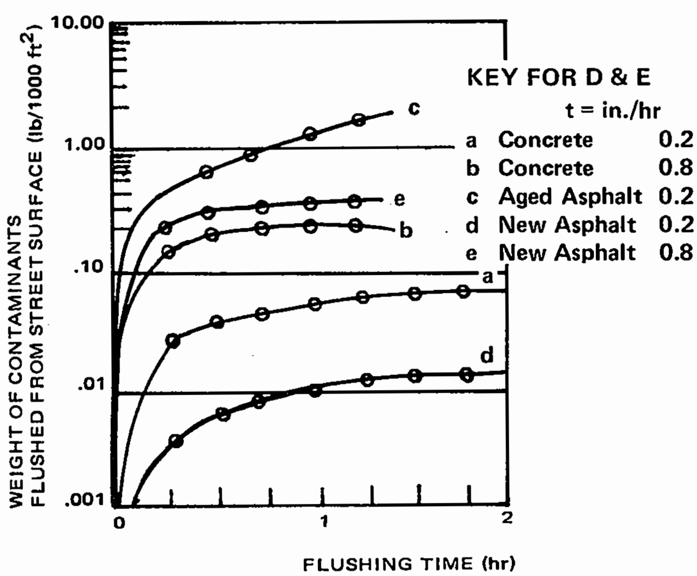


b. New Asphalt, Rainfall 0.2 in./hr

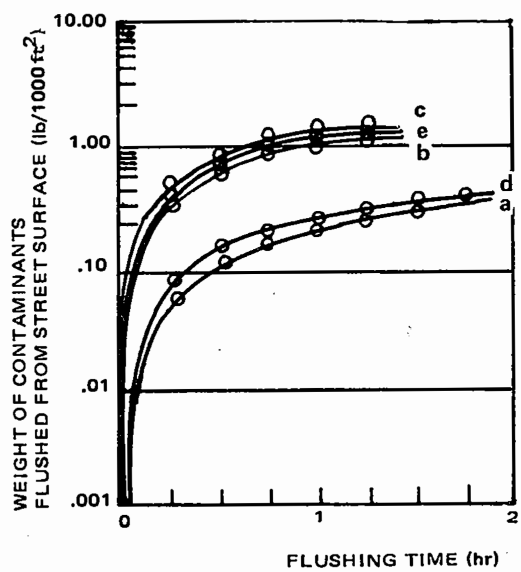
Figure 46. Particle transport across street surfaces by type of pavement and rainfall intensity.



c. New Asphalt, Rainfall 0.8 in./hr



d. Transport of Total Settleable Matter



e. Transport of Dissolved and Colloidal Suspended Matter

Figure 46. Particle transport across street surfaces by type of pavement and rainfall intensity.

Source: Sartor, J.D., and G.B. Boyd, "Water Pollution Aspects of Street Surface Contaminants," USEPA Report No. EPA-R2-72-081 (NTIS No. PB 214 408), November, 1972.

The foregoing discussion has described both controlled and uncontrolled street accumulation removal processes. The major focus of these procedures has been in the area of discharge sources of receiving water quality impairment. Other non-point sources of runoff pollution have been discussed at length earlier in this section.

INDIRECT RUNOFF POLLUTION SOURCES - SANITARY WASTEWATER FLOWS

The foregoing portions of this section have been devoted to identifying the major apparent sources of pollution accessible to surface runoff. These sources contribute to runoff pollution that enters receiving waters as point discharges from separate storm sewer systems and as general surface runoff. They also contribute to the pollutional loads associated with discharges or overflows due to the planned or unplanned addition of surface runoff to other wastewater flows. While these may result from uncontrolled runoff inflow into sanitary systems, the more general case is the overflow of combined sanitary and storm sewage due to hydraulic overloading. From the standpoint of relative pollutional contributions, sanitary wastewater assumes an overall significance because of its relative pollutional strength, and may be an additional source of pollution in storm overflows.

Some reported values for the concentrations of various constituents within raw domestic sewage are shown in Table 88. The values shown are average values. The ranges shown reflect daily averages and not diurnal variations.

TABLE 88. REPORTED POLLUTANT CONCENTRATIONS FOR RAW DOMESTIC SANITARY WASTEWATER FLOWS (mg/l)

Pollutant	Average Concentration	Range
Total Solids	860	700-1,014
Total Volatile Solids	300	—
Total Suspended Solids	160	100- 220
Total Dissolved Solids	680	500- 854
BOD_5	150	100- 235
COD	320	200- 523
Total Nitrogen-N	30	24- 40
NO_3-N	—	—
NH_4-N	21	17- 25
Total Phosphorus-P	8	6- 10
Chlorides	50	—
Lead	34	—
Zinc	7	—
Coliforms (MPN/100 ml)	10^6	—

Sources: Pound, C.E., and R.W. Crites, "Wastewater Treatment and Reuse by Land Application: Volume I," USEPA Report No. EPA-660/2-73-0060 (NTIS No. PB 225 940), May, 1973.

Cornell, Howland, Hayes and Merryfield, Clair A. Hill and Associates, "Wastewater Treatment Study, Montgomery County, Maryland," Reston, Virginia, November, 1972.

Thomas, R.E., et al., "Feasibility of Overland Flow for Treatment of Raw Domestic Wastewater," USEPA Report No. EPA-660/2-74-087 (NTIS No. PB 238 926/AS), December, 1974.

In the same vein, some reported values for various levels of treatment of domestic sanitary wastewater flows are shown in Tables 89, 90, and 91. These values are presented to indicate the quality characteristics of raw and treated wastewater flows. As such, they should be considered as informative but suspect, insofar as they may not compare favorably with locally acquired data.

TABLE 89. REPORTED POLLUTANT CONCENTRATIONS FOR PRIMARY TREATED DOMESTIC SANITARY WASTEWATER FLOW (mg/l)

Pollutant	Average Concentration	Range
Total Solids		
Total Volatile Solids		
Total Suspended Solids	66	23 172
Total Dissolved Solids		
BOD_5	48	23 102
COD	115	71 158
Total Nitrogen-N	9	5 18
NO_3-N		
NH_3-N	4.4	1.4 12.9
Total Phosphorus-P	3.4	2.3 5.9
Chlorides		

Source Thomas R.E., et al., "Feasibility of Overland Flow for Treatment of Raw Domestic Wastewater," USEPA Report No. EPA 660/2 74 087 (NTIS No. PB 238 926/AS), December, 1974.

TABLE 90. REPORTED POLLUTANT CONCENTRATIONS FOR SECONDARY TREATED DOMESTIC SANITARY WASTEWATER FLOWS (mg/l)

Pollutant	Average Concentration	Range
Total Solids	425	
Total Volatile Solids		
Total Suspended Solids	25	
Total Dissolved Solids	400	
BOD	25	
Cod	70	
Total Nitrogen-N	20	
NO_3-N	8.2	-
NH_4-N	9.8	
Total Phosphorus-P	10	
Chlorides	72	45 -100
Sulfate	125	
Boron	0.8	0.7- 1.0
Sodium	50	-
Potassium	14	
Calcium	24	
Magnesium	0.2	
iron	0.1	-
Lead	0.1	
Mercury	5 mg/l	
Nickel	0.2	-
Zinc	0.2	

Sources Pound, C.E., and R.W. Crites, "Wastewater Treatment and Reuse by Land Application: Volume I," USEPA Report No. EPA 660/2 73 0060 (NTIS No. PB 225 940), May, 1973.
Reed, S.C., et al., "Wastewater Management by Disposal on the Land," Report 171, Corps of Engineers, Hanover, New Hampshire, May, 1972.

TABLE 91. REPORTED POLLUTANT CONCENTRATIONS FOR RAW WASTEWATERS AND ADVANCED TREATED DOMESTIC SANITARY WASTEWATER FLOWS EMPLOYING CHEMICAL COAGULATION, FILTRATION, AND ACTIVATED CARBON ABSORPTION

	Raw Wastewater		Tertiary	
Pollutant	Average Concentration	(Range)	Average Concentration	(Range)
Total Suspended Solids	160	(100 - 220)	6	(0 – 13)
BOD	68	(100 – 235)	10	(1 - 24)
COD	362	(200 - 523)	27	(2 – 50)
Total Phosphorus	8	(5.4 - 10)	0.4	(0.1 – 1.0)

Source Cornell, Howland, Hayes and Merryfield, Clair A Hill and Associates, "Wastewater Treatment Study, Montgomery County, Maryland," Reston, Virginia, November, 1972.

Wet-weather combined sewer flows are often characterized in terms of the admixing of dry-weather flow and surface runoff. However, a number of opinions have been expressed concerning combined sewage. One viewpoint describes the mixing of sanitary wastewater and storm runoff in terms of an initial period in which dry-weather flows are pushed ahead of storm runoff; a subsequent period in which the scouring of sewer depositions occur; and a third period in which flows are an admixture of sanitary sewage and surface runoff. (73)

Overflows occur when the hydraulic capacity of the collection system, interceptor line or the dry-weather treatment facility is exceeded. Values for interceptor sewer capacity have been reported as peak to average dry-weather flow ratios in the range of 1.0 to 8.0, with a median of 4.0. In terms of dry-weather treatment capacity, these values have been reported as 0.80 on an annual basis, with a range of from 0.5 to 1.50. (74) However, the values that are reported above for dry-weather treatment capacity, are not very representative of short-term runoff. There are studies that have produced evidence of a strong correlation between the strength of sewage or surface runoff and rate of discharge.

DIRECT AND INDIRECT RUNOFF DISCHARGE POLLUTION

One source of information on direct and indirect urban runoff pollution is available through past studies of runoff discharges and combined sewer overflows from drainage basins in various parts of the country. A number of published references were reviewed to determine the extent and adequacy of existing data sources. The following discussion relates the results of this investigation for both direct and indirect runoff. The emphasis, to the degree an emphasis exists, will be on direct runoff. However, quality of combined sewer overflows may be more accurately reflected by local conditions such as the collection and interception system, and treatment plant hydraulic capacity.

Sampling Activities

The most realistic indications of direct and indirect runoff quality contributions from a given drainage basin are those determined by direct measurement. The selection of the sampling methods employed is an important determinant in the quality of the collected data. In the review of published sources, sampling activities were found to vary considerably. Composite samples have generally been taken most often. These were usually obtained by automatic devices or by manual grab sampling. Related flow measurements were made in only a few instances. Similarly, flow-related discrete samples were collected rarely, although discrete manual grab samples were often used in conjunction with automatically collected composite samples.

Sampling site location also plays an important role in defining sampling results. As an example, it is likely that combined sewer sampling generally occurs within or at the discharge of a piped collection system in order to reflect the quality of the flow to receiving waters. Separate system sampling may occur at locations within the collection system or at the receiving water. Very often, the separate system may take the form of earthen channels in whole of in part. Sampling downstream of earthen channel sections add solid components and other pollutants during a meaningful runoff event due to gully and channel erosion and other direct contributions. This condition would not be experienced to the same degree in a combined sewer system. Thus, sampling from non-piped or lined channels should be viewed with caution when considering solids content.

The sampling of urban runoff, and combined sewer overflows with all their fluctuations and different characteristics, requires a high degree of monitoring. Wide variations in the quality and quantity of direct and indirect runoff, and the unpredictability of rainfall complicate monitoring activities. Thus, it is difficult to obtain good information on the quality and quantity of these flows.

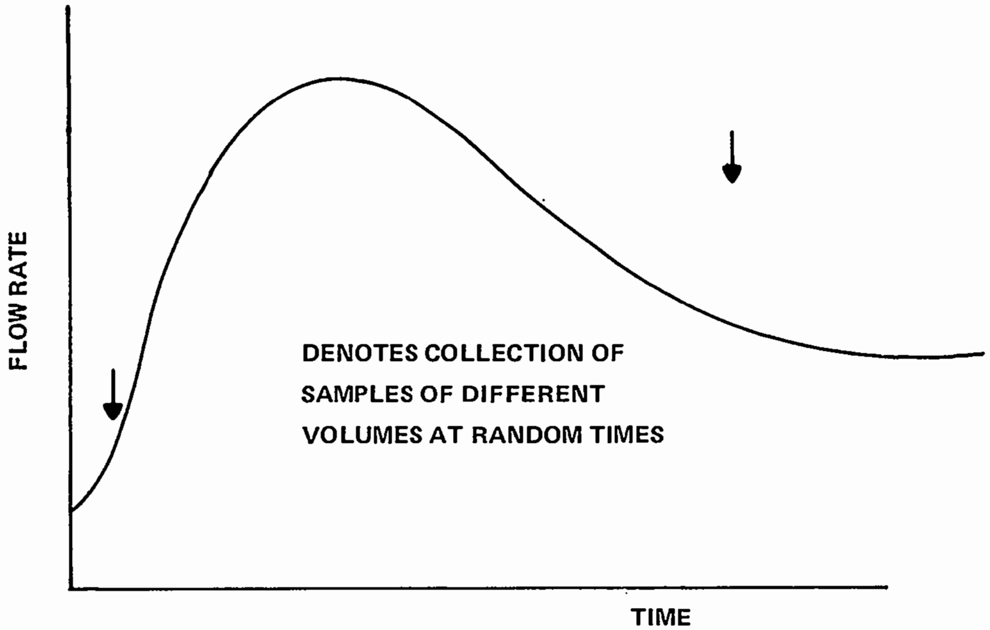
Direct and indirect runoff sampling requires the measurement of both flow and quality parameters throughout a storm event. This may be especially true when first-flush quality and flow characteristics may be important. Automatic sampling equipment is a desirable tool in runoff measurement. Unfortunately, few automatic monitoring stations measure both flow and collect samples for quality determinations. Although many samplers are actuated by floats, static head transducers, and pressure switches; standard flow measuring devices such as weirs and flumes are generally problematical in both sewered and channelized collection systems due to the cost involved and difficulties in calibration.

Samples, collected either manually or with automatic equipment, may be classified as discrete or composite samples. Discrete samples are collected at selected intervals where each sample is retained for separate analysis. As such, they represent water quality at a particular instant in time.

Discrete sampling and flow measurements taken at a sufficient frequency during a flow event provides one of the most effective representations of runoff quality variations with time and flow. Data collected on this basis can provide useful information in the form of mass emission rates, and the characterization of local first-flush effects.

Of discrete sampling, random grab samples are the easiest and most economical, but they are also least reliable in terms of representing quality flow time characteristics unlessthese latter element are measured as well. An indication of some of the problems associated with random grab samples is shown in Figure 47.

Storm discharges vary in flow with respect to time and also in constituent strength. Grab samples taken at the points of the hydrograph shown are relatively unique. Mean values of pollutant concentrations taken on this basis may not be very descriptive of the runoff or combined sewer overflow being sampled. A more effective use of grab samples would be to verify samples collected with an automatic sampling device.



Source: Wullschleger, Richard E., ET AL., "Recommended Methodology for the Study of Urban Storm Generated Pollution and Control," USEPA Report No. EPA-600/2-76-145, Envirex, Inc., August 1976.

Figure 47. The problem of timing discrete grab samples with respect to a runoff event.

Simple composite samples, are made up of a series of smaller samples of constant volume that are collected and combined in a single container. Composite sampling is an attempt to synthesize a sample which will represent the average discharge characteristics over a period of time. Composite samplers may draw a series of discrete portions into individual containers which are then added together manually. As an alternative they may be drawn as a series of discrete samples that are mixed automatically in a single container to make up the composite sample.

Proportional flow composite samples are those collected in relation to flow volumes to represent average constituents strength during the sampling period. One approach to proportional flow composites is to collect equally sized samples at a frequency that is inversely proportional to the volume of flow. As the flow volume increases, the time interval between samples is reduced. The samples are, thus, representative of constant flow volume increments. This theoretical rainfall event is shown in Figure 48.

Another approach to the collection of flow proportioned composite samples can be accomplished by increasing sample volumes in proportion to the flow, but keeping the sampling frequency constant. Figure 49, shows such a sampling scheme with respect to a theoretical runoff hydrography.

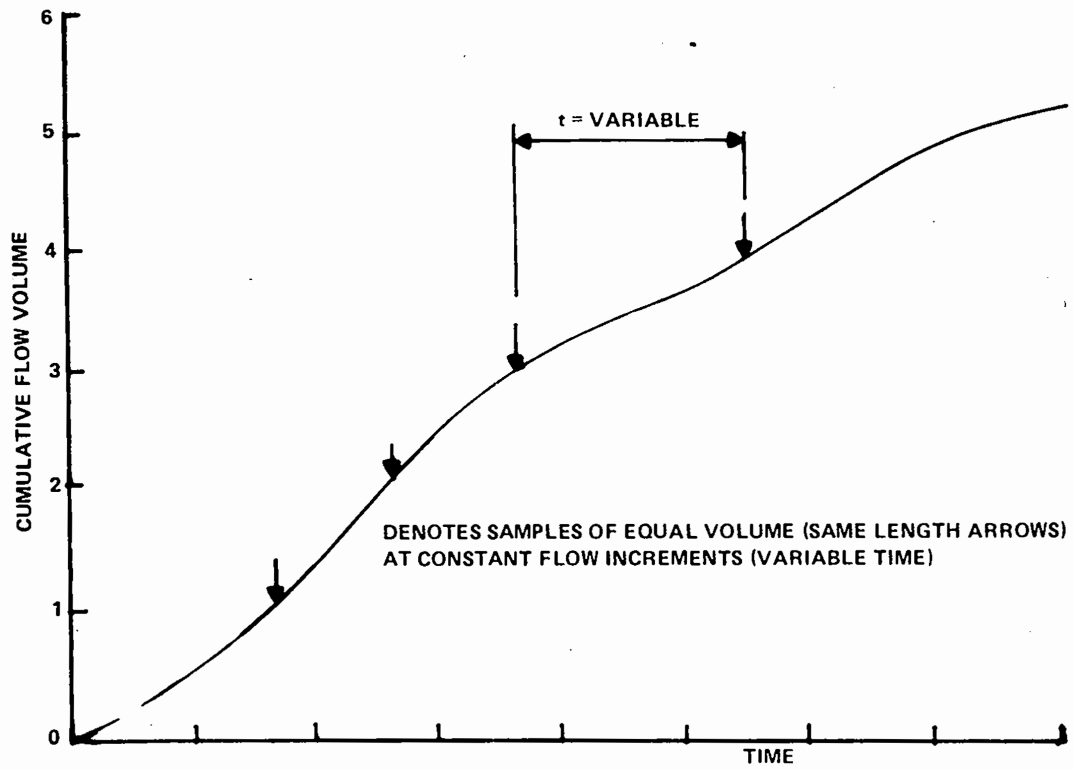


Figure 48. Method of compositing equal volume samples at equal flow increments.

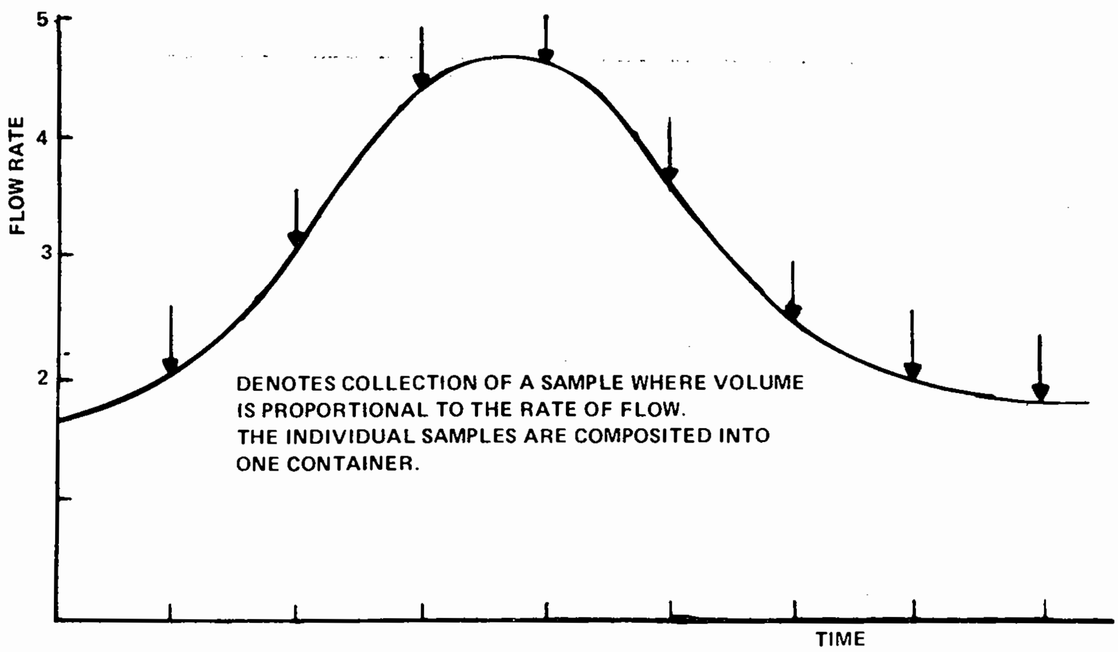


Figure 49. Method of compositing variable volume samples at fixed intervals.

Source: Wullschleger, Richard E., ET AL., "Recommended Methodology for the Study of Urban Storm Generated Pollution and Control," USEPA Report No. EPA-600/2-76-145, Envirex, Inc., August 1976.

The differences between constant flow volume and constant time composite sampling techniques are relatively small and in most cases, both procedures approach true average values. Interestingly, smaller time or volume increments between samples, will represent greater accuracy as to true runoff or overflow conditions. The logical extreme of reducing these increments is equivalent to an array of discrete grab samples at known values of flow and time.

Sequential composite sampling is accomplished by taking composite samples representative of a short period, with each being held in a separate container. An example of sequential sampling may be taken as 24 one-hour composites that may be used to represent daily quality characteristics. As previously noted the accuracy of this sampling approach depends upon the length of the time intervals selected with shorter intervals producing results closer to actual conditions. It should be noted that sequential composites should also be related to some average flow level to provide the most meaningful results; but unfortunately this is not always the case in actual practice.

A recent study on sampling methods and equipment identified some of the most desirable characteristics for a general sampling device. (75) These were:

1. Ability to take a sequentially timed series of discrete samples. It should be possible to use an external signal to allow sample volumes to be taken proportional to flow rate or increments of flow. Five minutes should be the minimum sampling interval.

2. Four different sample containers should be filled at each sampling: (a) for solids and BOD testing to hold no preservatives; (b) for metals and TOD analysis acid added to preserve sample; (c) for nitrogen and phosphorus, $HgCl_2$ added; and (d) sterilized containers used for bacterial analysis. The fourth set of containers could also be used for grease and oil, pesticides, or other tests.

3. Capability of using 1 to 3 liter sample containers so that individual discrete sample analyses can be made.

4. Capability of programming the time interval at which samples are taken, so the sampling interval can be short during the early stages of the storm with longer intervals automatically used as the storm continues.

5. Facilities hold 96 sample containers - this would allow sampling every 10 minutes for four hours.

6. Refrigeration capabilities to hold samples at $4^{o}C$ ($39^{o}F$)

7. Capability of lifting samples 7.6 m (25ft) or more without affecting sample size.

8. Availability of a self-contained power source.

9. Capable of being automatically activated to indicate sampling at beginning of storm.

10. Inlet line to be sufficiently large to eliminate problems of plugging.

11. Inlet sampling velocity to be sufficiently high to keep heavy particles in suspension throughout their flow to the sample container.

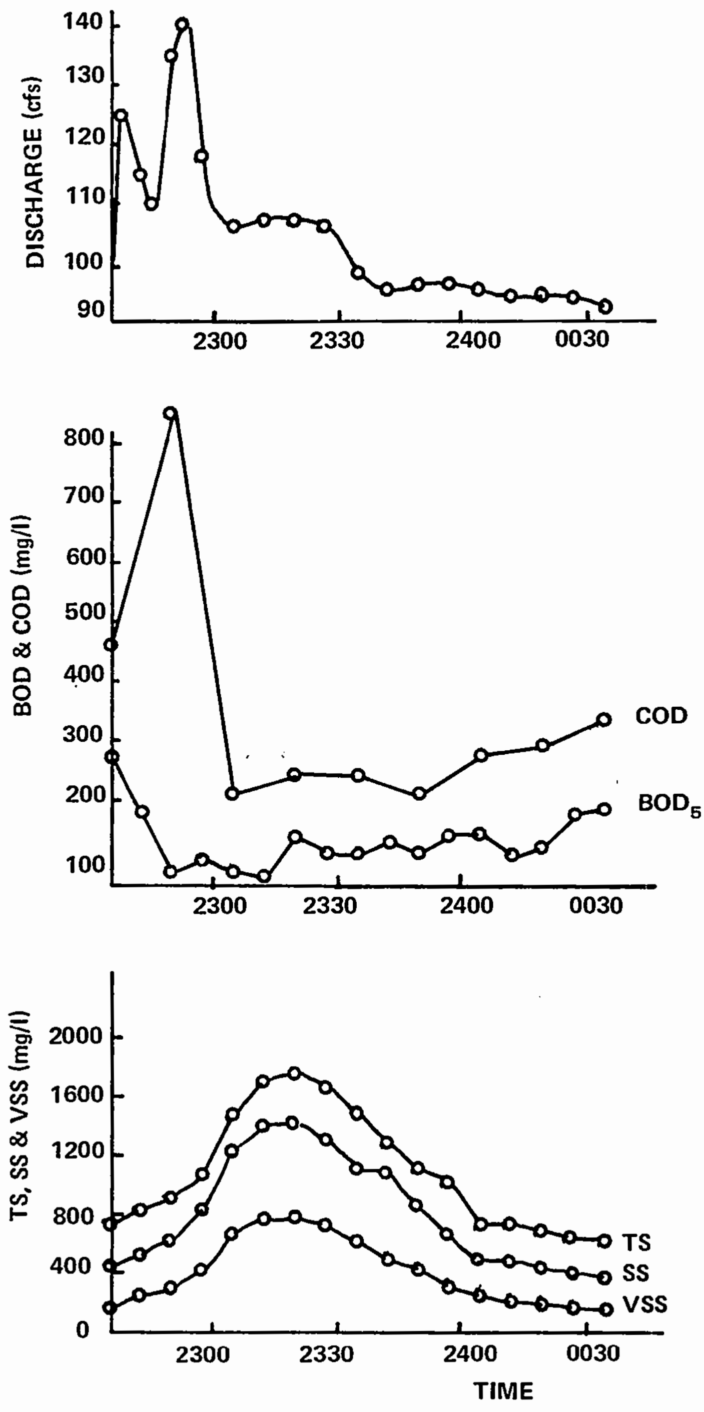
12. Inlet device of such a configuration to allow obtaining a representative sample throughout the depth of the stream flow. Light floating material and heavy bottom sludge should be included in each sample.

13. Inlet device should not plug easily and should be self-cleaning. Sample lines should be purged so that the next sample is not contaminated by any of the previously taken samples.

The ideal sampling mechanism does not now exist, however, improved samplers are being developed. In recognition of the problems in sampling and the use of automatic samplers, the USEPA has developed a number of sampler design goals similar in intent to the previously described characteristics. (76)

The success of a sampling program depends on the selection of the sample site and the point at which samples are collected. Recent work in Durham, North Carolina, showed that variations in results may be expected at differing depths within a runoff flow. (64) The selection of sampling methods should be determined on the basis of the objectives to be served. If average values for constituent concentrations over a number of events will suffice, then composite sampling may produce sufficiently accurate results If more definitive determinations of specific occurences related to flow during an event are important, composite sampling may suffice if the flow or time increment which activate sampling frequency are sufficiently short. As the needs for accuracy increase, discrete sampling with related flow and time measurements at a sufficiently high collection frequency may be required.

During a runoff event the composition and rate of flow may change continuously. No single grab sample can adequately represent the flow and pollutant concentration variations that may be experienced. An example of this variation is shown in Figure 50. A large number of samples is required to characterize the results of a given storm event. Thus, careful selection of the sampling objectives to be served and the methods and procedures to be used, is necessary. used, is necessary.



Source: University of Cincinnati, "Urban Runoff Characteristics," USEPA Report No. 11024DQU10/70 (NTIS No. PB 202 865), October, 1970.

Figure 50. Indirect runoff quantity and quality data. Bloody Run Sewer Watershed.

Direct (Storm) and Indirect (Combined) Runoff Discharge Characteristics

Some overall indications of the quality of direct and indirect runoff discharges can be determined from the published reports of studies performed in various locales. These locales have often been urban or urbanizing. On occasion, discharge quality and quantity have been related to basin characteristics and given rainfall events. Inconsistencies exist within this body of information, however, due to variability in the research objectives being addressed, the pollutants evaluated, the sampling technique employed, and the measurements performed. The majority of existing direct and indirect runoff discharge quality information appears in the form of mean pollutant concentrations or averages of sample results from one or more runoff events. These average results are at times taken without regard to rainfall-runoff relationships and other variations in time.

Some overall indications of the quality of direct surface runoff discharges are given in Table 92. Similarly, mean concentrations of various pollutants found in measured combined sewer overflows are depicted in Table 93. This form of data provides an estimate of average quality characteristics. Time-related effects such as the "first-flush" are not reflected in these values.

A simple evaluation of these flows indicates that direct runoff generally has solids concentrations equal to or greater than untreated sanitary sewage. BOD_5 concentrations are approximately those of secondary effluents. Bacterial contamination of separate storm wastewater is about two to four orders of magnitude less than untreated sewage. Combined sewer overflows and sanitary bypasses generally average less than half the strength of untreated sewage, but are important because of their volumetric magnitude. A rainfall intensity of 2.5 cm/hr (1 in/hr) may produce flows up to 100 times normal dry-weather flows.(77)

Discharge quality, time and runoff flow data have been published in only a few locales. Foremost among these is a published study from Durham, North Carolina (64) that studied a separate storm runoff collection system in terms of the quality of surface runoff with respect or runoff quantity during a number of rainfall events.

The Durham study represents perhaps the most advanced approach to the characterization of runoff quality to date, insofar as it proceeds from real discrete data taken with careful attention to runoff and basin characteristics. A summary of further findings from this study is shown in Table 94. It should be remembered that these findings are basin specific and as such, reflect the characteristics of the catchment studied. Therefore, the transferability of these findings to other basins may well be limited.

As to the quality characterization of runoff discharges, it is apparent from the foregoing that the available discharge information leaves much to be desired. The original objective for the majority of this information was obviously to produce order-of-magnitude estimates of the pollution represented by runoff discharges. In fulfilling this end, the reported average data is successful. Realistic discharge quality data, however, requires considerably more. Thus, further research in this area of investigation is indicated.

TABLE 92. MEAN DISCHARGE QUALITY DATA FOR SEPARATE STORM SYSTEMS

Location	No. Runoff Events	No. of Samples	Total Solids mg/l	Susp. Solids mg/l	BOD_5 mg/l	COD mg/l	Total Organic Carbon mg/l	NO_3 mg/l	Organic Kjeldahl Nitrogen mg/l	N as NH_3 mg/l	Total N mg/l	PO_4 mg/l	Soluble On the PO_4 mg/l	Total P mg/l	Chloride mg/l
1 Tulsa, Okla.(1)	14	36	2,242	2,052	13	110	43	--	1.11	--	--	--	3.49	--	11
2 Tulsa, Okla.	16	23	275	169	8	45	22	--	0.95	--	--	--	0.35	--	10
3 Tulsa, Okla.	16	48	680	280	8	65	22	--	1.48	--	--	--	1.92	--	13
4 Tulsa, Okla.	15	46	616	340	14	103	42	--	0.97	--	--	--	1.05	--	19
5 Tulsa, Okla.	13	50	271	136	18	138	48	--	0.72	--	--	--	0.87	--	3
6 Tulsa, Okla.	10	15	346	195	12	90	34	--	0.65	--	--	--	0.86	--	9
7 Tulsa, Okla.	18	60	413	84	8	48	15	--	0.80	--	--	--	0.67	--	49
8 Tulsa, Okla	8	13	382	240	15	115	37	--	0.60	--	--	--	1.15	--	10
9 Tulsa, Okla.	11	16	417	260	10	117	35	--	0.67	--	--	--	1.02	--	5
10 Tulsa, Okla.	11	34	431	300	11	107	28	--	0.88	--	--	--	0.70	--	10
11 Tulsa, Okla.	11	26	575	401	14	116	33	--	0.66	--	--	--	1.11	--	6
12 Tulsa, Okla.	11	27	199	89	8	45	26	--	0.39	--	--	--	0.54	--	4
13 Tulsa, Okla.	10	30	469	332	15	88	35	--	1.46	--	--	--	1.13	--	15
14 Tulsa, Okla.	5	18	592	445	11	58	29	--	0.06	--	--	--	0.39	--	13
15 Tulsa, Okla.	8	22	273	183	10	41	34	--	0.36	--	--	--	0.31	--	2
16 Washington, DC(2)	--	64	2.166	--	19	321	--	--	--	--	2.1	1.3	--	--	--
17 Madison, Wis.(3)	--	--	280	--	--	--	--	--	3.5	--	--	0.98	--	--	--
18 Atlanta, Ga.(4)	--	--	--	--	7	28	--	--	--	--	--	0.4	--	--	--
19 Atlanta, Ga.	--	--	--	--	20	84	--	--	--	--	--	0.3	--	--	--
20 Atlanta, Ga.	--	--	--	--	26	67	--	--	--	--	--	1.6	--	--	--
21 Seattle, Wash.(5)	--	--	--	168	27	266	--	0.58	--	1.87	--	--	2.38	--	--
22 Seattle, Wash.	--	--	--	34	42	96	--	0.33	--	0.38	--	--	0.55	--	--
23 Seattle, Wash.	--	--	--	305	6	76	--	0.66	--	0.18	--	--	0.35	--	--
24 Seattle, Wash.	--	--	--	54	10	57	--	0.51	--	0.18	--	--	0.20	--	--
25 Roanoke, Va. (6)	--	--	460	--	18	--	--	--	--	--	--	--	--	--	--
26 Roanoke, Va.	--	--	514	--	20	--	--	--	--	--	--	--	--	--	--
27 Roanoke, Va.	--	--	937	--	26	--	--	--	--	--	--	--	--	--	--
28 Minneapolis, Minn.(7)	4	84	--	--	26	164	--	--	--	--	--	--	--	0.62	--
29 Cincinnati, Ohio(8)	--	--	--	227	17	111	--	--	--	--	3.1	1.1	--	--	--

TABLE 93. MEAN DISCHARGE QUALITY DATA FOR COMBINED SEWER OVERFLOWS

Location	No. Runoff Events	No. of Samples	Total Solids mg/l	Susp. Solids mg/l	BOD_5 mg/l	COD mg/l	NO_3 mg/l	N as NH_3 mg/l	Total N mg/l	PO_4 mg/l	Total P mg/l	Chlorides mg/l
1 Washington, DC[9]	25	94	883	--	71	381	--	1.5	3.5	3.0	--	--
2 Washington, DC	4	--	--	475	131	--	--	--	--	--	--	--
3 Washington, DC	2	--	--	574	137	--	--	--	3.5	1.0	--	--
4 Washington, DC	--	--	--	319	77	--	--	--	--	--	--	--
5 Portland, Ore.[10]	--	103	--	106	--	242	--	--	--	--	--	--
6 Philadelphia, Penn.[11]	44	--	--	178	49	--	--	--	--	--	--	--
7 Milwaukee, Wis.[12]	26	150	378	166	49	161	--	--	5.5	--	--	--
8 Chippewa Falls, Wis.[13]	--	360	--	287	170	--	--	--	--	--	--	--
9 Atlanta, Ga.[14]	--	--	--	--	210	442	--	--	--	6.5	--	--
10 Atlanta, Ga.	--	--	--	--	84	164	--	--	--	1.7	--	--
11 Atlanta, Ga.	--	--	--	--	133	286	--	--	--	2.3	--	--
12 Seattle, Wash.[15]	--	--	--	340	27	266	0.27	0.23	--	--	--	--
13 Seattle, Wash.	--	--	--	212	62	196	0.34	1.98	--	--	--	--
14 Seattle, Wash.	--	--	--	1,464	68	353	0.51	5.08	--	--	--	--
15 Seattle, Wash.	--	--	--	53	34	371	0.54	0.78	--	--	--	--
16 Seattle, Wash.	--	--	--	64	51	288	0.54	1.36	--	--	--	--
17 Seattle, Wash.	--	--	--	280	148	736	1.52	1.34	--	--	--	--
18 Seattle, Wash.	--	--	--	96	27	100	0.84	0.36	--	--	--	--
19 Seattle, Wash.	--	--	--	207	49	210	0.44	2.18	--	--	--	--
20 Seattle, Wash.	--	--	--	200	15	160	0.21	0.91	--	--	--	--
21 Seattle, Wash.	--	--	--	194	33	250	0.22	2.75	--	--	--	--
22 Seattle, Wash.	--	--	--	777	235	817	0.33	3.0	--	--	--	--
23 Seattle, Wash.	--	--	--	317	66	211	0.82	2.5	--	--	--	--
24 Seattle, Wash.	--	--	--	192	19	200	--	1.38	--	--	--	--
25 Seattle, Wash.	--	--	--	245	66	272	0.42	6.25	--	--	--	--
26 Seattle, Wash.	--	--	--	93	39	124	0.87	2.05	--	--	--	--
27 Seattle, Wash.	--	--	--	286	42	165	1.11	1.26	--	--	--	--
28 San Francisco, Cal.[16]	50	--	209	68	49	155	--	--	--	--	--	--
29 Detroit, Mich.[17]	--	60±	--	634	72	--	--	--	4.5	--	1.45	--
30 Cleveland, Ohio[18]	--	177	590	234	92	308	--	--	--	--	--	--
31 Cincinnati, Ohio[19]	4	33	1,073	--	210	438	--	--	--	--	--	--
32 Bucyrus, Ohio[20]	--	--	1,647	--	170	372	4.54	3.13	--	--	--	203
33 Bucyrus	--	--	863	--	107	476	3.79	1.08	--	--	--	120
34 Bucyrus	--	--	916	--	168	391	3.89	2.7	--	--	--	147
35 Sacramento, Cal.[21]	6	18	161	--	207	261	--	--	--	--	--	--
36 Columbus[22]	38	--	544	134	102	--	--	--	--	--	--	--

SOURCES FOR TABLES 92 AND 93

[1] American Public Works Association, "Water Pollution Aspects of Urban Runoff," USEPA Report No. 11030DNS01/69 (NTIS No. PB 215 532), January, 1969.

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[3] Lager, J.A.,and W.G. Smith, "Urban Stormwater Management and Technology an Assessment," USEPA Report No. EPA-670/2-74-040 (NTIS No. PB 240 687/LK) May, 1974.

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[9] Municipality of Metropolitan Seattle, Op. Cit.

[10] Ibid.

[11] Rex Chainbelt, Inc., "Screening/Flotation Treatment of Combined Sewer Overflows," USEPA Report No. 11020FDC01/72 (NTIS No. PB 215 695), January, 1972.

[12] .Lager, J.A., and W.C. Smith, Op. Cit.

[13] Rex Chainbelt, Inc., Op. Cit.

[14] Ibid.

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[17] Ibid.

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[19] Sylvester, R.O., "An Engineering and Ecological Study for the Rehabilitation of Green Lake," University of Washington, Seattle, Washington, 1960.

[20] Colston, N.V., "Characteristics and Treatment of Urban Land Runoff," USEPA Report No. EPA-670/2-74-096 (NTIS No. PB 202 865), December, 1974.

[21] Waller, D.H., Op. Cit.

[22] Ibid.

TABLE 94. REGRESSION EQUATIONS PREDICTING POLLUTANT CONCENTRATION (mg/l) IN URBAN LAND RUNOFF IN A NATURAL CHANNEL CORRECTED TO FLOW AT MID-DEPTH

Pollutant	mg/l
COD	$113.\ CFS^{0.11}\ TFSS^{-0.28}$
TOC	$32.\ CFS^{0.0}\ TFSS^{-.28}$
TS	$420.\ CFS^{0.14}\ TFSS^{-.18}$
TVS	$130.\ CFS^{0.09}\ TFSS^{-.11}$
TSS	$222.\ CFS^{0.23}\ TFSS^{-.16}$
VSS	$44.\ CFS^{0.18}\ TFSS^{-.17}$
Kjel. N.	$0.85\ CFS^{0.87}\ TFSS^{-.29}$
Total P.	$0.80\ CFS^{0.03}\ TFSS^{-.29}$
Al**	$10.\ CFS^{0.05}\ TFSS^{-.15}$
Ca	$12.5\ CFS^{-.4}\ TFSS^{-.09}$
Co**	$0.07\ CFS^{0.18}\ TFSS^{+.13}$
Cr	$0.18\ CFS^{-.04}\ TFSS^{+.06}$
Cu**	$0.08\ CFS^{0.10}\ TFSS^{+.08}$
Fe	$4.6\ CFS^{0.24}\ TFSS^{-.18}$
Pb	$0.27\ CFS^{0.125}\ TFSS^{-.29}$
Mg	$10.\ CFS^{-.02}\ TFSS^{-.16}$
Mn	$0.45\ CFS^{0.11}\ TFSS^{-.27}$
Ni**	$0.12\ CFS^{0.03}\ TFSS^{-.01}$
Zn	$0.22\ CFS^{0.10}\ TFSS^{-.22}$

*CFS = Cubic Feet Per Second
* TFSS = Time from Storm Start (Hours)
**Mid-Depth Correction Assumed as 0.9

Source: Colston, N.V., "Characterization and Treatment of Urban Land Runoff," USEPA Report No. 670/2-74-096 (NTIS No. PB 202 865), December, 1974.

COMPARISON OF WET AND DRY WEATHER FLOWS

A number of the characteristics of runoff pollution have been discussed at some length in this section. These have included consideration of a number of the sources of direct runoff pollution--transportation activities, vegetative debris, air pollution depositions, erosion products, catch basin depositions, roof drainage, animal wastes, and first flush contributions. In addition, street surface potentials were also considered as a direct runoff pollutional source.

While not wholly definitive, this review of the sources of pollution, provies a number of insights into the current state of the art of source assessment. In addition, it provides a concept of the multiplicity of contributing sources and suggests areas for further research.

Another area of review concerned the characterization of direct runoff pollution from the viewpoint of runoff dicharge measurements. For the most part, existing data collection in this area have been for the purposes of gross runoff characterization. These reported results have been presented most often as average values for various measures of pollution. A more detailed characterization of discharge pollution, however, is also available but in a limited form. This considers the magnitude and nature of various pollutional concentrations in terms of flow and time, as determined from the detailed analysis of a single basin in Durham, North Carolina. (64)

In view of the variety of potential contributions to runoff pollution, a number of questions must arise as to their relative effects and relationships. The following discussion evaluates these issues from the standpoint of a hypothetical case study, in terms of existing assessment methods. It is anticipated that this case study evaluation will provide approximate estimates of the magnitudes of pollution to be contributed from these various sources, based on available data and existing analytical methods. In addition, some estimates of other pollutional contributions from other wastewater flows will be developed for the purposes of comparison.

Since information on sources of pollution are derived from a variety of published reports, a hypothetical approach will serve as a practical illustrative mechanism to demonstrate estimates of source contributions. It will also show those contributing elements for which little or no data now exists. Finally, it will point out the relative magnitudes of contributions from various wastewater flows for similar time periods.

Hypothetical Case Comparisons

The hypothetical case considered in the following analysis is based on an urban area of approximately 260 km^2 (100 mi^2) and an overall population density of 21.25 persons/ha (8.6 persons/ac). The distribution of land use within this area was assumed to be as shown in Table 95.

TABLE 95. HYPOTHETICAL LAND-USE DISTRIBUTION

Land Use	Percent of Area
Residential	65
Commercial	6
Industrial	12
Park/Undeveloped	17
	100

Source: Land-use distribution as derived from data for the City of Denver, Colorado.

The general configuration of the hypothetical urban area is assumed to be approximately square, and it is tributary to a receiving stream with a main channel length of 16.1 km (10 mi) and a gradient of 0.25 percent.

Precipitation data from two individual storm events produced hydrographs for descriptive purposes as shown in Figure 51. The hydrographs show estimates of total flows for the rainfall distribution indicated. The two rainfall events selected were used to demonstrate conditions where runoff from pervious areas would or would not be contributed to the overall runoff from the area. Pervious contributions were estimated for the second rainfall event only.

A generalized rainfall distribution was assumed to fall over the entire basin; this condition is unlikely to occur in reality, but it proves helpful in the analysis. The hydrographs are broken into their components for flows attributable to street imperviousness, non-street imperviousness, and pervious areas where they occur. Flows from non-street impervious areas are assumed to contribute wholly to total flows although, in reality, roof drainage may be discharged to pervious areas on occasion.

Estimates of total and street imperviousness were determined from the generalized expressions which were developed and are described in Section 4, Data Development for Application of the STORM Model in 50 Urbanized Areas.

$$\text{Percent Total Imperviousness} = 104.95 - 81.27(0.974)^{PD}$$
$$\text{Percent Street Imperviousness} = 17.06 - 14.56(0.839)^{PD}$$

where: PD = population density, persons/ha (persons/ac)

Application of these empirical expressions resulted in an estimated overall total imperviousness of 39.9 percent. Imperviousness attributable to street paving was estimated to be 13.8 percent, and non-street imperviousness was thus assumed to be 26.0 percent, more or less.

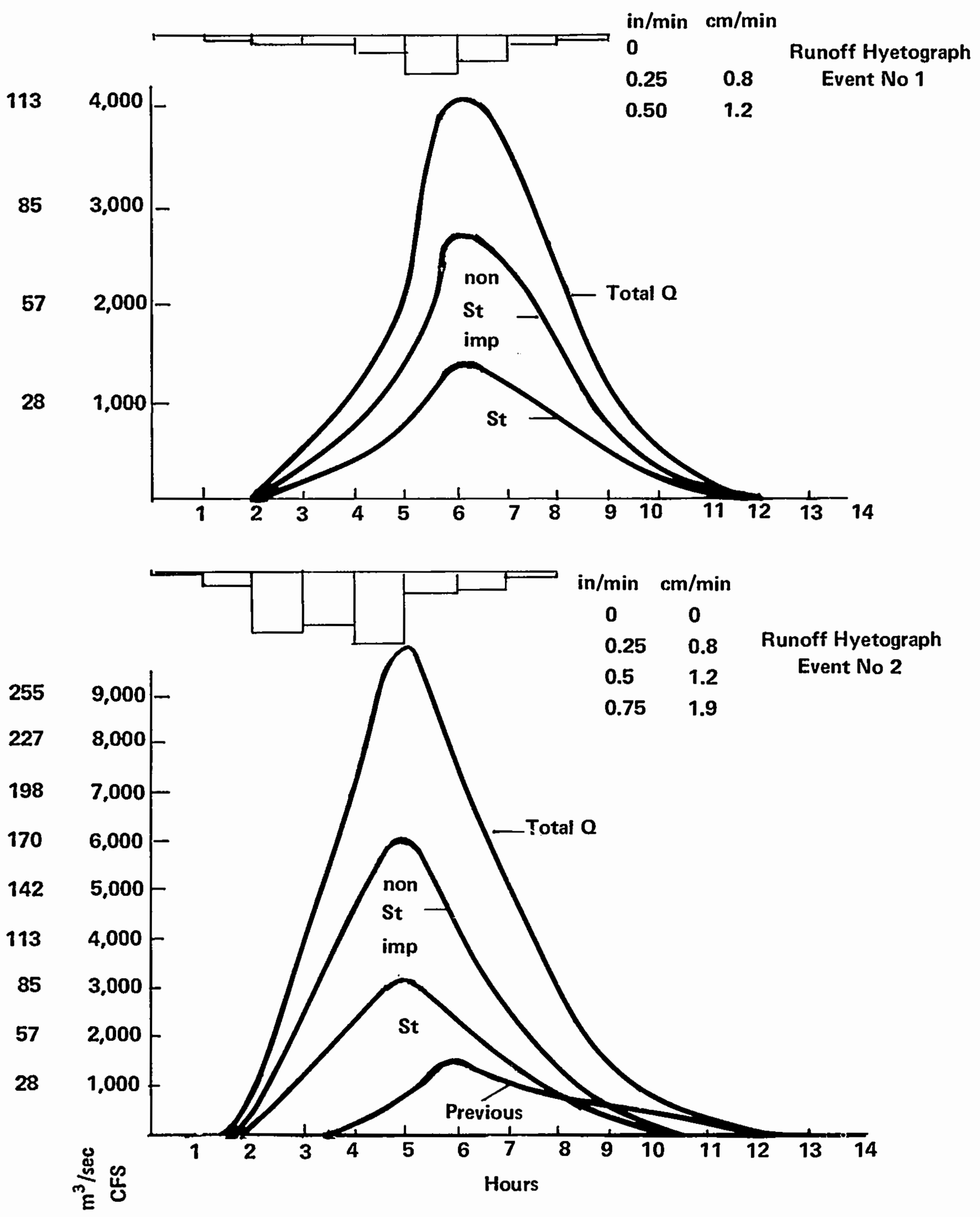


Figure 51. Hypothetical Runoff Hydrographs

Direct Runoff Pollution

Direct runoff pollution contributions were estimated in terms of those parts of the urban environment that contribute to the overall runoff and the pollutants that these different parts are likely to contribute. The major limitation associated with this approach was the availability of data on the pollutional characteristics of these runoff sources.

The major sources of contribution considered were those associated with rainfall, street surface areas, impervious rooftops, parking lots, sidewalks and other areas, and pervious areas such as lawns and undeveloped sites. The pollutional contributions associated with rainfall itself were based upon contaminant levels measured in Cincinnati, Ohio. (78) On the basis of the runoff estimated from street and non-street impervious areas, rainfall pollutional contributions could be those presented in Table 96.

TABLE 96. POTENTIAL POLLUTIONAL CONTRIBUTIONS ADDED BY RAINFALL

	Event No. 1		Event No. 2		Mass Emission Rate	
Pollutant	lb.	kg.	lb.	kg.	lb/ac-in	kg/ha-cm
Suspended Solids	45,860	20,820	104,550	47,466	74,000	33,067
Volatile Solids	13,410	5,088	30,560	13,874	21,600	9,652
Inorganic Nitrogen	2,440	1,108	5,550	2,520	3,930	1,756
Hydrolyzable Phosphates	850	386	1,930	876	1,370	612
BOD_5	Unknown		Unknown		Unknown	

Source: Derived from data reported in "Urban Land Runoff as a Factor in Stream Pollution," Weibel, S.R., Anderson, R.J., and Woodward, R.L., *Journal Water Pollution Control Federation*, Vol. 36, No. 7, July, 1964.

The pollutional contributions for street surface areas were derived from the general tabulation of street surface contaminants discussed previously. A composite value for the dust and dirt accumulation based on the percent of each land use and the relative road density attributable to each was computed to be 33.7 kg/curb-km/day (119.6 lb/curb-mi/day). The dust and dirt values and related potential pollutant concentrations employed are shown in Table 97.

TABLE 97. DUST AND DIRT AND POTENTIAL POLLUTANT CONCENTRATIONS USED WITH EVENTS 1 AND 2

Pollutant	Concentration
Dust and Dirt	32.6 kg/curb-km/day (119.6 lb/curb-mi/day)
BOD_5	5,030 mg/kg
COD	46,120 mg/kg
Kjeldahl Nitrogen	640 mg/kg
Total PO_4	170 mg/kg
Ortho PO_4	53 mg/kg
Cadmium	3.1 mg/kg
Lead	1,970 mg/kg
Zinc	470 mg/kg

Average street cleaning frequencies were also composited to produce a value for 43 days between cleanings for all land uses. (52)

The accumulation period of street surface contaminants was determined through comparison of composite street cleaning frequencies and the analysis of average probable rainfall frequencies based on Chicago rainfall data. (15) This analysis was selected since the Chicago data in total simulated the annual national average precipitation. The findings of this analysis defined the average probable rainfall occurrence period as approximately four days for events of 0.1 cm (0.04 in) or more, and 20.5 days for precipitation events of 1.2 cm (0.5 in) or more. On this basis, it was assumed that the average range of accumulation period would vary from 4 to 20.5 days. In this hypothetical case, street surface accumulations were considered to start with clean street conditions.

The total solids accumulated over this accumulation period and removed by the runoff from the described precipitation events, is shown in Table 98.

The related contributions for select conservative and non-conservative pollutants are also shown in this tabulation for both of the rainfall events. In addition to solids measures, these include amounts of oxygen demand, nutrients, and some metals. The BOD values shown were derived from standard analyses techniques and as such, are only theoretical estimates. They represent possible minimum values. BOD values, so determined, have been proposed to be questionable due to the toxic constituents in runoff and other inherent factors, and their inhibitive effect on biological activity. (64)

TABLE 98. ESTIMATED TOTAL SOLIDS AND POLLUTANT CONTRIBUTIONS COMPUTED FOR EVENTS 1 AND 2

Pollutant	Event No. 1 lb	Event No. 1 kg	Event No. 2 lb	Event No. 2 kg
Total Solids	1,797,000–9,209,500	815,838–4,181,113	1,897,000–9,722,100	861,238–4,413,833
BOD_5	9,040–46,320	4,104–21,029	9,540–48,900	4,331–22,200
COD	82,880–424,740	37,628–192,832	87,490–448,380	39,720–203,564
Kjeldahl Nitrogen	1,150–1,570	522–2,674	1,210–6,220	549–2,824
Total PO_4	210–1,570	95–713	320–1,650	145–749
Ortho PO_4	100–490	45–222	100–520	45–236
Cadmium	6–29	3–13	6–30	3–14
Lead	3,540–18,140	1,607–8,235	3,740–19,150	1,698–8,694
Zinc	840–4,330	381–1,966	890–4,570	404–2,075

The pollutional contributions associated with non-street impervious areas were also computed for the two defined runoff events. Unfortunately, the data available for estimation purposes were limited to suspended solids and metals such as cadmium, lead, and zinc. For the purposes of computation the same accumulation period as employed for street surface accumulations was used in connection with the basic dustfall information, and are shown in Table 99.

TABLE 99. DUSTFALL AND POLLUTANT POTENTIALS USED WITH EVENTS 1 AND 2

Land Use	Dustfall kg/ha/day (lb/ac/day)	Cadmium kg/ha/day (lb/ac/day)	Lead kg/ha/day (lb/ac/day)	Zinc kg/ha/day (lb/ac/day)
Residential	120	1.27×10^{-5}	1.73×10^{-3}	1.84×10^{-3}
	(107)	(1.13×10^{-5})	(1.54×10^{-3})	(1.64×10^{-3})
Commercial	208	2.07×10^{-5}	4.15×10^{-3}	3.1×10^{-3}
	(185)	(1.85×10^{-5})	(3.70×10^{-3})	(2.77×10^{-3})
Industrial	269	2.42×10^{-5}	3.23×10^{-3}	4.15×10^{-3}
	(240)	(2.16×10^{-5})	(2.88×10^{-3})	(3.70×10^{-3})

Source: Hunt, W.F., et al., "A Study of Trace Element Pollution of Air in 77 Midwestern Cities," Paper presented at the Fourth Annual Conference on Trace Substances in Environmental Health, University of Missouri, June, 1970.

The computed data obtained from this estimating process are shown in Table 100.

TABLE 100. ESTIMATED SUSPENDED SOLIDS AND POLLUTANT CONTRIBUTIONS FROM DUSTFALL FOR EVENTS 1 AND 2

	Event No. 1		Event No. 2	
Pollutant	Maximum kg (lb)	Minimum kg (lb)	Maximum kg (lb)	Minimum kg (lb)
Suspended Solids	16,802,742	3,278,593	17,737,909	3,461,073
	(37,043,900)	(7,228,100)	(39,105,600)	(7,630,400
Volatile Suspended Solids*	5,040,822	983,578	5,321,372	1,038,322
	(11,113,170)	(2,168,430)	(11,731,680)	(2,289,120)
BOD_5*	4,672	4,672	10,696	10,696
	(10,300)	(10,300)	(23,580)	(23,580)
Cadmium	1.8	0.4	1.9	0.4
	(4.1)	(0.8)	(4.3)	(0.8)
Lead	263	52	276	54
	(580)	(114)	(610)	(120)
Zinc	281	54	300	59
	(620)	(120)	(660)	(130)

*Volatile Suspended Solids estimated at 30 percent of suspended solids and an average median BOD_5 value of 4.6 mg/l from Waller, D.H., "Pollution Attirutable to Surface Runoff and Overflows from Combined Sewer Systems," Atlantic Industiral Research Institute, Halifax, Nova Scotia, April, 1971.

As previously noted, the foregoing summary does not reflect all of the pollutants involved in non-street impervious runoff. However, it provides an estimate of contributions for which some data are available. The dustfall data used to estimate non-street impervious runoff applies most appropriately to roof runoff as opposed to parking lot or sidewalk runoff.

The pollutional contributions due to pervious area runoff were estimated for the second event only. Under the assumptions made in this analysis, pervious area runoff was estimated for this event and not for the initial event. The pollutional contributions in this analysis were limited to sediment (total solids) as estimated by the Universal Soil Loss Equation, and nitrogen and phosphorus, computed as a function of sediment. (14) It should be noted that the Universal Soil Loss Equation and other estimating methods are used for annual estimates. In the analysis proposed in this section, these are assumed to apply as well for the short-term events studied.

The results of this analysis are shown in Table 101. The results shown are limited to only 3 pollutants due to the limited availability of data.

TABLE 101. ESTIMATED SOLIDS AND POLLUTANTS CONTRIBUTIONS FROM PERVIOUS AREAS FOR EVENT 2

	Event No. 2	
Pollutant	lb	kg
Total Solids	12,371,100	5,616,479
Total Nitrogent	1,410,300	640,276
Phosphorus (P_2O_5)	427,000	19,386

A summary of the findings of the foregoing analysis are compiled in Table 102. The data shown within this tabulation are low estimates for all pollutants, with the exception of total solids and suspended solids. Similarly, a summary of results for the second rainfall event is shown in Table 103.

TABLE 102. SUMMARY OF ESTIMATED DIRECT POLLUTIONAL CONTRIBUTIONS FROM VARIOUS SOURCES FOR EVENT 1

Source		Total Solids kg (lb)	Suspended Solids kg (lb)	BOD_5 kg (lb)	COD kg (lb)	PO_4 kg (lb)	Cadmium kg (lb)	Lead kg (lb)	Zinc kg (lb)
Rainfall		20,820	20,900	Unk.	Unk.	386	Unk.	Unk.	Unk.
		(45,900)	(45,900)			(850)			
Streets	Min.	815,101	630,853	4,082	37,603	141	3	1,588	363
		(1,797,000)	(1,390,800)[a]	(9,000)	(82,900)	(310)	(6)	(3,500)	(800)
	Max.	4,177,337	'3,285,352	21,001	7,192,640	712	14	78,210	1,950
		(9,209,500)	(7,243,000)	(46,300)	(424,700)	(1,570)	(30)	(18,100)	(4,300)
Non-Street	Min.	3,862,818	3,270,594				0.5	45	45
Imperviousness		(8,516,100)[a]	(7,228,100)	4,672	Unk.	Unk.	(1)	(100)	(100)
	Max.	19,130,204	16,802,743	(10,300)			1.8	272	272
		(42,175,100)	(37,043,900)				(4)	(600)	(600)
Pervious		0	0	0	0	0	0	0	0
Totals	Min.	4,698,739	3,930,267	8,754	37,600	526	3	1,633	7,408
(Range)		(10,359,000)	(8,664,800)	(19,300)[b]	(82,900)[b]	(1,160)[b]	(7)[b]	(3,600)[b]	(900)[b]
	Max.	23,328,361	20,108,915	25,673	192,640	1,098	15	78,482	2,223
		(51,430,500)	(44,332,800)	(56,600)	(424,700)	(2,420)	(34)	(18,700)	(4,900)

NOTES:

[a]Estimated from an estimating function in the form suspended solids = 0.79 (Total Solids) – 22, in mg/l derived from mean discharge data.

[b]Low estimates due to incomplete available data.

TABLE 103. SUMMARY OF ESTIMATED DIRECT POLLUTION CONTRIBUTIONS FROM VARIOUS SOURCES FOR EVENT 2

Source		Total Solids kg (lb)	Suspended Solids kg (lb)	BOD_5 kg (lb)	COD kg (lb)	PO_4 kg (lb)	Cadmium kg (lb)	Lead kg (lb)	Zinc kg (lb)
Rainfall		47,446	47,446	Unk.	Unk.	7,875	Unk.	Unk.	Unk.
		(104,600)	(104,600)			(1,930)			
Streets	Min.	860,460	650,902	4,309	39,689	145	3	1,678	408
		(1,897,000)	(1,435,000)[1]	(9,500)	(87,500)	(320)	(6)	(3,700)	(900)
	Max.	4,432,527	3,453,997	722,226	203,390	748	14	78,709	2,087
		(9,722,100)	(7,614,800)	(49,000)	(448,400)	(1,650)	(30)	(19,200)	(4,600)
Non-Street	Min.	4,277,671	3,461,073				0.5	54	59
Imperviousness		(9,430,700)	(7,630,400)	10,705	Unk.	Unk.	(1)	(120)	(130)
	Max.	20,394,903	17,737,909	(23,600)			2	277	299
		(44,963,300	(39,105,600)				(4)	(610)	(660)
Pervious		5,611,407	4,418,012	Unk.	Unk.	Unk.	Unk.	Unk.	Unk.
		(12,371,100)	(9,740,100)[1]						
	Min.	10,796,984	8,577,432	15,014	39,689	1,021	3	1,733	467
		(23,803,400)	(18,910,100)	(33,100)[2]	(87,500)[2]	(2,250)[2]	(7)[2]	(3,820)[2]	(1,030)[2]
	Max.	30,463,603	25,657,364	32,931	203,390	1,624	15	8,986	2,386
		(67,161,100)	(56,565,100)	(72,600)	(448,400)	(3,580)	(34)	(19,810)[2]	(2,386)

NOTES:

1 Estimated value from an estimating function in the form suspended solids (mg/l) = 0.79 (Total Solids, mg/l) – 22 derived from available mean discharge data.

2 Low estimates due to incomplete data.

This event reflects sediment contributions from pervious areas in addition to the other sources previously described. For this event, sediment estimates represented from 18 to 52 percent of the solids contributed.

An alternative approach to the estimation of direct pollutional contributions was employed for the first event, using the discharge characterization equations developed in Durham, North Carolina. (64) The results of this computation appear in Table 104. This characterization was performed on an urbanizing basin and represent the response of that basin to experienced rainfall events. As such, the magnitude of the solids estimated by this method are considerably less than those previously identified in Table 102. The other pollutants identified, however, generally fall within the range of previously estimated values, with the exception of lead which is somewhat less.

TABLE 104. ESTIMATED DIRECT POLLUTION CONTRIBUTIONS FOR EVENT 1 COMPUTED FROM THE DURHAM, NORTH CAROLINA, CHARACTERIZATION DATA

	Event No. 1	
Pollutant	**lb**	**kg**
Suspended Solids	3,445,200	1,564,121
COD	555,000	251,970
Lead	1,450	638
Zinc	1,200	545

Other Wastewater Flows

Other wastewater flows for the hypothetical community might include raw domestic sanitary sewage, primary treatment domestic wastes effluents, secondary treatment domestic wastes effluents, and those domestic wastes effluents that result from advanced treatment processes. An average daily per capita flow of 515 l (136 gal) and the general characterization of these flows designated as resulting from indirect runoff pollution sources as previously discussed, were applied to hypothetical case conditions to prepare the estimated contributions shown in Table 105. These estimates apply to the period of flow encompassed by the runoff period.

TABLE 105. ESTIMATED POLLUTIONAL CONTRIBUTIONS FROM OTHER WASTEWATER FLOWS DURING EVENT 1 AND 2

	Raw		Primary		Secondary		Advanced	
Pollutant	kg	lb	kg	lb	kg	lb	kg	lb
Total Solids	137,108	302,000	––	––	67,737	149,200	––	––
Suspended Solids	24,515	56,200	10,533	23,200	3,995	8,800	953	2,100
BOD	23,926	52,700	7,673	16,900	3,995	8,800	1,589	3,500
COD	51,030	112,400	18,342	40,400	11,168	24,600	4,313	9,500
Lead Zinc	5,403	11,900	––	––	16	35	––	––
	1,135	2,500	––	––	32	32	––	––

Comparison of Waste Contributions

On the basis of the foregoing estimates, some simple comparisons of relative contributions may be made for the period covered by the selected short-term runoff events. The comparison for both events is shown in Table 106.

TABLE 106. COMPARISON OF WASTE CONTRIBUTIONS FOR EVENTS 1 AND 2

Source	Total Solids kg (lb)	Suspended Solids kg (lb)	BOD kg (lb)	COD kg (lb)	Lead kg (lb)	Zinc kg (lb)
Direct Runoff	4,698,739	3,930,267	8,754	37,603	1,633	408
Event 1	(10,359,000)	(8,664,800)	(19,300)	(82,900)	(3,600)	(900)
Event 2	10,796,984	8,577,432	15,014	39,689	1,724	454
	(23,803,400)	(18,910,100)	(33,100)	(87,500)	(3,800)	(1,000)
Raw Domestic	136,984	24,492	23,904	50,984	5,398	1,134
Sanitary	(302,000)	(56,200)	(52,700)	(112,400)	(11,900)	(2,500)
Primary Treated						
Domestic Sanitary	––	10,523	7,666	18,325	––	––
Effluent	––	(23,200)	(16,900)	(40,400)	––	––
Secondary Treated						
Domestic Sanitary	67,676	3,992	3,992	11,158	16	32
Effluent	(149,200)	(8,800)	(8,800)	(24,600)	(35)	(70)
Advanced Treatment						
Domestic Sanitary	––	953	1,588	4,309	––	––
Effluent	––	(2,100)	(3,500)	(9,500)	––	––

On the basis of these estimates, direct runoff contributions of solids materially exceed those associated with domestic sanitary wastewater flows at any level of treatment. Domestic sanitary flows represent two percent or less of the total estimated solids loadings. Estimated BOD contributions from direct runoff are greater than those from secondary and advanced treatment domestic wastewater effluents. However, these contributions are less than for raw wastewater, and about the same as primary treatment effluents, for the events evaluated. Similar comparisons also exist for COD contributions, except for primary treated domestic sanitary effluents. In this instance, direct runoff contributions exceed those of primary treatment effluents.

Direct runoff contributions represent at least 44 percent of the total pollutional load on an annual basis. In the category of metal contributions, direct runoff produced higher levels of lead and zinc for treated effluents, but not for raw domestic wastes. These contributions may be on the order of at least 24 and 28 percent per annum, respectively, of the total lead and zinc contributions.

The foregoing comparison indicates that the relative contributions of pollutants associated with direct runoff can be significant during a runoff event. The estimations shown do not encompass all pollutants from all direct runoff sources. As such, they represent relatively conservative estimates; and the comparisons suggested tend to minimize the contributions of direct runoff.

The relative contributions of direct runoff will be found to diminish as the time intervals investigated become longer. The investigation of longer term comparative contributions will be considered in Section V of this report for a number of individual urbanized areas across the country, and finally for all urbanized areas. These evaluations will provide some comparative results that will be helpful in better identifying these time-increment effects.

SECTION IV

URBAN DATA DEVELOPMENT TO ASSIST MODELLING ACTIVITIES

One of the key elements of this study has been the analysis of 50 urban areas through the use of models and other analytical devices. The results of this analytical activity were to provide base-line estimates from which the nationwide characterization of pollutional loads and impacts, and the costs of alternative control strategies could be developed. This section addresses the basic assumptions and methods employed to prepare some of the data desirable for use of models and other analytical tools in this application.

Runoff quality and quantity analysis require data concerning features such as lengths of steets and roads, population density, and types of land use. The absence of such data has hindered the use of a modelling as only general approximations could be used or considerable site specific data gathered.

The data developed by the APWA presented in this section is based upon a detailed analysis of 50 urban areas. Such a broad base of information should be particularly helpful in adjusting models where site specific data is not available and should encourage the development of models which more accurately relate to land use and population density considerations.

The estimation of runoff quality by existing models depend upon the assumption that pollutants accumulate over time on street surfaces. Models do not accommodate accumulation of pollutants on non-street impervious areas as outlined in Section III. Nor do models provide for pollutant contributions from pervious urban areas for runoff events when these contributions from pervious urban areas for runoff events when these contributions may be expected to occur. The basic assumption of street surface accumulation would seem to best apply in well developed urban environments where drainage patterns are consistent with street networks and impervious surfaces may be expected to entrap many of the pollutional products of the area. In an urban setting, basic modelling philosophies hypothesize that the quality of urban runoff may be estimated from runoff quantity computations based on given hydrologic and physical basic characteristics; the computed transport of the potential pollutants contained in accumulated street litter by the runoff; and the calculation of the related pollutional loading based on its relationship to the transported solids. The foregoing assumes, of course, that the mechanisms of runoff solids transport and the pollutant-to-solid estimation processes within the model are accurate representations of the real physical processes involved.

As the modelling effort for this study was directed to an evaluation of 50 urban areas, certain assumptions were made to accommodate its operation on this relative scale. Some of these assumptions are as follows:

- Urban areas may be assumed to be the Urbanized Areas as defined by the Bureau of Census.

- Average daily street solids accumulations are assumed to be a representative indication of the accumulation of many pollutants within an urban area. It is further assumed that the STORM model will adequately estimate the total solids transported in a runoff flow for a given event. As pollutant concentrations are estimated directly with the solids so estimated, it is also assumed that only those pollutants that bear some reasonable level of linear correlation with solids can be estimated through the modelling process. Those that do not, should not be estimated in the modelling effort.

- The distribution of urban land use may be characterized in terms of population density, on the basis of central city land-use characteristics taken with respect to the entire Urbanized Area. This assumption originates in the fact that little comparable land-use data could be found for full urbanized areas.

- Estimates of imperviousness and specific curb length, in terms of unit of curb length per unit area, may be made through their relationship with population density.

It is apparent that the assumptions made must be carefully considered with respect to the accuracy assigned to the results of this evaluation effort. The mechanism proposed, however, is one that may be improved upon as better data becomes available. On this basis, it represents a prototype assessment methodology that may afford even better results as knowledge of runoff phenomenon improves.

URBAN AREAS

Urban areas in this study have been taken as the Urbanized Areas defined by the Bureau of the Census of the U.S. Department of Commerce in the 1970 census. (81) A total of 252 urbanized areas were defined in 1970; they are generally characterized as having:

- A central city or urban core of 50,000 or more inhabitants.

- Closely inhabited surroundings, consisting of incorporated places of 100 housing units or more; and small unincorporated parcels with population densities of 1,000 inhabitants per 2.59 km^2 (1 mi^2) or more.

- Other small unincorporated areas that may eliminate enclaves, square up the geometry of the urbanized area or provide a linkage to other enumeration districts fulfilling the overall criteria within 2.5 km (1.5 mi) of the main body of the urbanized area. (82)

The distribution of urbanized areas across the United States is shown in Figure 52.

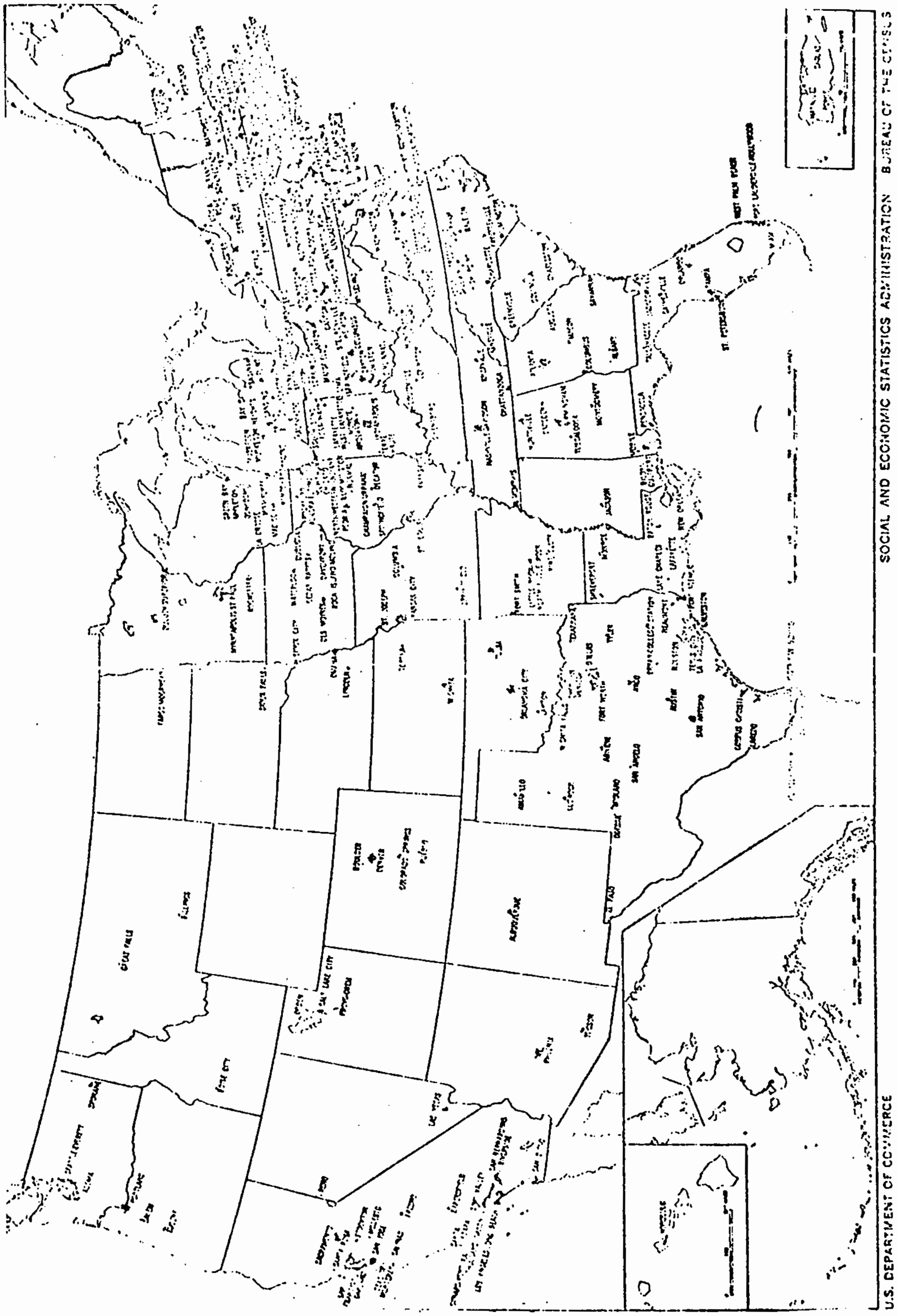


Figure 52. Urbanized areas, 1970.

The choice of a sample of 50 urbanized areas was based upon a representative distribution reflecting variations in climate and geography. This sample of 20 percent of all urbanized areas appears in Figure 53.

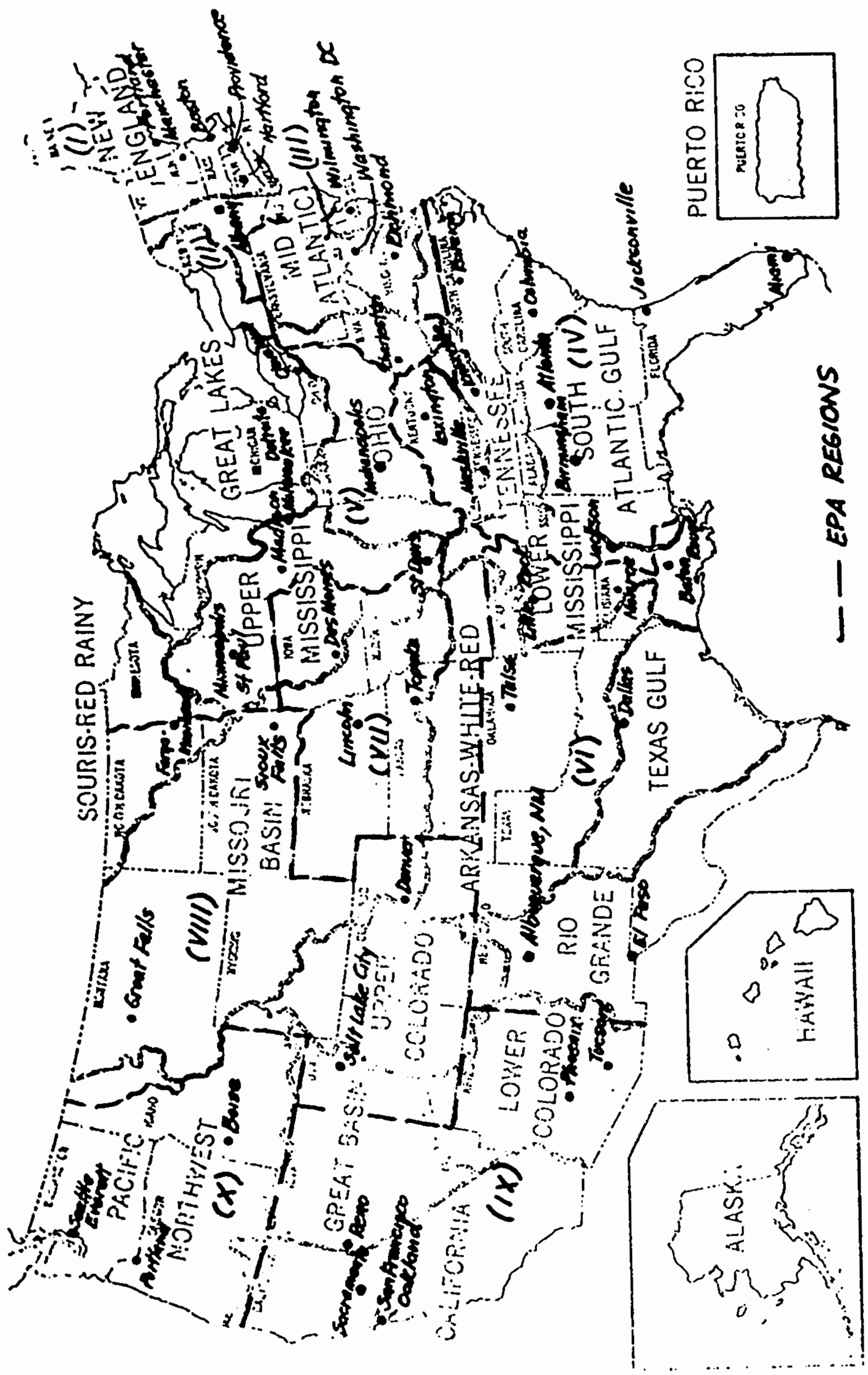


Figure 53. Distribution of urbanized areas sample with respect to water resource and USEPA regions.

Source: U.S. Water Resources Council, "Coordination Director for Planning Studies and Reports," August 1971,(as amended).

Figure 53 (cont'd)

KEY TO USEPA REGIONS, SAMPLE URBANIZED AREAS

USEPA	Core City	State
Region I	Hartford	Connecticut
	Portland	Maryland
	Boston	Massachusetts
	Providence	Rhode Island
Region II	Albany	New York
Region III	Wilmington	Delaware
	Richmond	Virginia
	Charleston	West Virginia
	District of Columbia	
Region IV	Birmingham	Alabama
	Jacksonville	Florida
	Miami	Florida
	Atlanta	Georgia
	Lexington	Kentucky
	Jackson	Mississippi
	Raleigh	North Carolina
	Columbia	South Carolina
	Knoxville	Tennessee
	Nashville	Tennessee
Region V	Indianapolis	Indiana
	Detroit	Michigan
	Minneapolis	Minnesota
	St. Paul	Minnesota
	Cleveland	Ohio
	Madison	Wisconsin
	Milwaukee	Wisconsin

	Core City	State
Region VI	Little Rock	Arkansas
	Topeka	Kansas
	St. Louis	Missouri
	Lincoln	Nebraska
Region VIII	Denver	Colorado
	Great Falls	Montana
	Fargo-Moorhead	North Dakota
	Sioux Falls	South Dakota
	Salt Lake City	Utah
Region IX	Phoenix	Arizona
	Tuscon	Arizona
	Oakland	California
	Sacramento	California
	San Francisco	California
	Reno	Nevada
Region X	Boise	Idaho
	Portland	Oregon
	Seattle-Everett	Washington

The Water Resources Region represents the major basins within the United States as defined by the U.S. Water Resources Council. (83) The populations reflected in the sample of urbanized areas appears in Table 107.

TABLE 107.
POPULATION DISTRIBUTION OF THE SAMPLE OF URBANIZED AREAS

Population Range	Number of Urbanized Areas
50,000 < Pop. ≤ 100,000	7
100,000 < Pop. ≤ 250,000	12
250,000 < Pop. ≤ 500,000	11
500,000 < Pop. ≤ 1,000,000	7
1,000,000 < Pop.	13

MAJOR URBAN RUNOFF CATCHMENTS

The major urban runoff drainage areas were determined for each of the urbanized areas selected for detailed study. These drainage areas were defined in terms of the major catchments or receiving waters draining each urbanized area, as shown in Table 108. This table shows the major catchments identified, and the percent of the urbanized area contributing to each. These catchment areas have been used to provide a basis for determining many of the urban area parameters necessary for the broader evaluation effort.

TABLE 108. URBANIZED AREA RUNOFF CATCHMENTS

	Urbanized Area	Total Area ac	ha	Percent of Urbanized Area	Major Catchment
1.	Albany-Schenectady Troy, N.Y.	96,640	39,110	100	Hudson River
2.	Albuquerque, N.M.	72,960	29,530	100	Rio Grande River
3a.	Atlanta, Ga.	25,430	10,290	9	Flint River
b.		63,250	25,590	23	South River
c.		189,720	76,780	68	Chattahoochee River
4.	Baton Rouge, La.	54,400	22,020	100	Mississippi River
5a.	Birmingham, Al.	32,350	13,090	22	Village Creek
b.		39,790	16,100	28	Valley Creek
c.		71,860	29,080	50	Cahaba River
6.	Boise, Id.	18,560	7,510	100	Boise River
7.	Boston, Ma.	424,960	171,980	100	Massachusetts Bay
8.	Charleston, W. Va.	39,680	16,060	100	Kanawha River
9.	Cleveland, Oh.	413,440	167,310	100	Lake Erie
10.	Columbia, S.C.	65,920	26,680	100	Congaree River
11.	Dallas, Tx.	431,360	174,570	100	Trinity River
12.	Denver, Co.	187,520	75,890	100	South Platte River
13.	Des Moines, Ia.	69,760	28,230	100	Des Moines River
14a.	Detroit, Mi.	75,170	30,420	13	Lake St. Clair
b.		9,030	3,650	2	Lake Erie
c.		146,130	59,140	26	Clinton River
d.		327,750	132,640	59	Detroit River
15.	El Paso, Tx.	76,160	30,820	100	Rio Grande River
16.	Fargo—Moorehead, N.D.	15,360	6,220	100	Red River
17.	Great Falls, Mt.	14,080	5,700	100	Missouri River
18.	Hartford, Ct.	83,840	33,930	100	Connecticut River
19.	Indianapolis, In.	243,840	98,680	100	White River
20.	Jackson, Ms.	46,080	18,650	100	Pearl River
21.	Jacksonville, Fl.	224,640	90,910	100	St. Johns River
22.	Knoxville, Tn.	55,040	22,270	100	Tennessee River
23a.	Lexington, Ky.	17,050	6,910	67	Elkhorn Creek System
b.		8,550	3,450	33	Hickman Creek System
24.	Lincoln, Ne.	33,280	13,470	100	Salt Creek
25.	Little Rock—North Little Rock, Ar.	60,800	24,600	100	Arkansas River
26a.	Madison, Wi.	10,620	4,300	24	Lake Waubesa
b.		15,250	6,170	34	Lake Monona
c.		18,290	7,400	42	Lake Mendota
27.	Manchester, N.H.	24,960	10,100	100	Merrimac River
28.	Miami, Fl.	165,760	67,080	100	Biscayne Bay/Atlantic Ocean
29.	Milwaukee, Wi.	292,480	118,360	100	Lake Michigan
30.	Minneapolis—St. Paul, Mn.	461,440	186,740	100	Mississippi River
31.	Monroe, La.	25,600	10,360	100	Ouachita River
32.	Nashville—Davidson, Tn.	220,160	89,100	100	Cumberland River
33.	Phoenix, Az.	248,320	100,490	100	Salt River
34.	Portland, Me.	35,840	14,500	100	Fore River/Portland Harbor
35.	Portland, Or.	170,880	69,150	100	Williamette/Columbia Rivers
36.	Providence—Pawtucket—Warwick, R.I.	156,160	63,200	100	Providence River/ Narragansett Bay
37.	Raleigh, N.C.	45,440	18,390	100	Walnut Creek
38.	Reno, Nv.	24,320	9,840	100	Truckee River
39a.	Richmond, Va.	24,580	9,950	26	Chickahominy River
b.		68,220	27,610	74	James River

TABLE 108 (cont'd)

	Urbanized Area	Total Area ac	ha	Percent of Urbanized Area	Major Catchment
40.	Sacramento, Ca.	156,160	63,200	100	Sacramento River
41.	Salt Lake City, Ut.	117,760	47,660	100	Great Salt Lake
42.	San Francisco—Oakland, Ca.	435,840	176,380	100	San Francisco Bay/Pacific Ocean
43a.	Seattle—Everett, Wa.	17,870	7,230	7	Sammamish Lake
b.		93,390	37,800	35	Lake Washington
c.		153,050	61,940	58	Puget Sound
44.	Sioux Falls, S.D.	17,280	6,990	100	Big Sioux River
45.	St. Louis, Mo.	295,040	119,400	100	Mississippi River
46.	Topeka, Ks.	33,920	13,730	100	Kansas River
47.	Tucson, Az.	67,200	27,200	100	Santa Cruz River
48a.	Tulsa, Ok.	63,480	25,690		Verdigres River
b.		51,704	20,930		Arkansas River
49.	Washington, D.C.	316,800	128,200	100	Potomac River
50.	Wilmington, De.	70,400	28,490	100	Delaware River

URBAN PHYSICAL DEVELOPMENT AND DEMOGRAPHIC CHARACTERISTICS

There are few sources of standardized data covering the physical development characteristics of urbanized areas. The evaluation of urban runoff impacts requires definition of some of these characteristics. Urban land use patterns, the level of surface imperviousness, street density and improvement standards, and other development-related parameters are all basic building blocks within the evaluation process. While data on physical development characteristics are generally available locally in individual jurisdictions, the scope of this overall evaluation effort did not envision an on-site survey of prospective urbanized area modelling sites. Thus, other methods for estimating these parameters were necessary.

The most important source of urban demographic data in the U.S. Bureau of the Census. The 1970 Census provides a wealth of standardized information accumulated in a land-area classification system that is compatible with the purposes of this evaluation effort. The choice of the "urbanized area" as a basic unit for the definition of urban runoff contributions has already been discussed. One additional unit of areal definition was also adopted for the purposes of the overall evaluation effort--the census tract. These units of area and demographic data accumulation were selected as the smallest manageable units of area to be used. By definition, census tracts are relatively uniform, stable area units in terms of population characteristics, economic status and living conditions; they generally average about 4,000 residents. (86)

The estimation of urban physical development characteristics for the 50 study areas has been preapred from census tract area measurements and demographic data. The key demographic parameter employed for this purpose is gross population density. (85) This parameter was used to characterize land use, imperviousness, street density, street cleaning frequencies, and other model input requirements.

The data source used to characterize urbanized areas in terms of their respective population densities was made available through the National Planning Data Corporation. This data source provided census tract population, area and related population densities. Additional data on land use were also provided for some land-use types. Land use will be discussed in more detail in the following portions of this section.

Urbanized areas and drainage catchments were characterized through development of population density profiles. These profiles were developed by identifying and ranking census tracts in ascending order by gross population density. The ranked census tracts so determined were grouped into five categories, designated on the basis of area. These categories were arbitrarily chosen as one, approximately one-third sized part, and for, approximately one-sixth parts of the total catchment area. The one-third sized area category represents the most sparsely populated census tracts within the catchment.

The results of the population density profiling process are shown in Figures 54a thru 54g, for various population groups by section of the country. These figures demonstrate the cumulative gross population densities reported over each urbanized area, as fitted to a geometric regression line. As these lines show, the overall gross population densities indicated at the 100 percent level vary from those shown at other percentage levels for each urbanized area. Variations may also be noted among the gross population density profiles reported for individual urbanized areas. The gross population density profiles, thus, suggest the level of variation that exists in the demographic and physical development characteristics of the urbanized areas selected for detailed study. This data in a modified form was used in the cost assessment reported in Volume II.

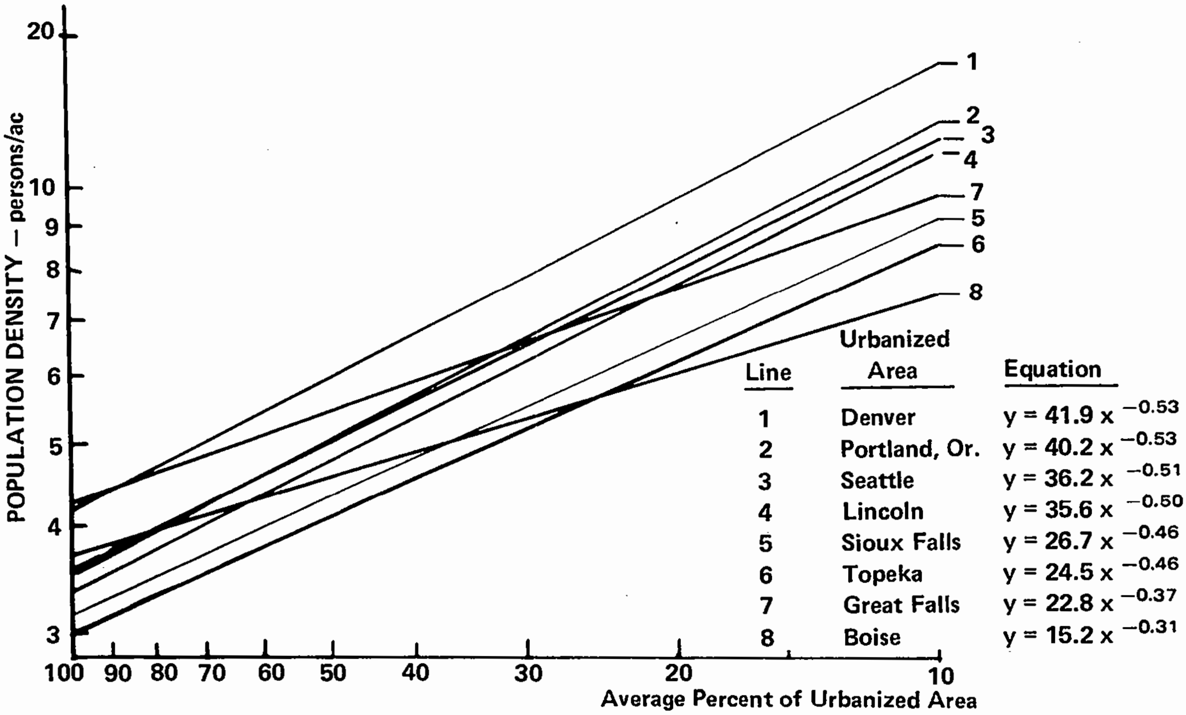


Figure 54a. Population density profiles for urbanized areas—Pacific Northwest—Missouri.

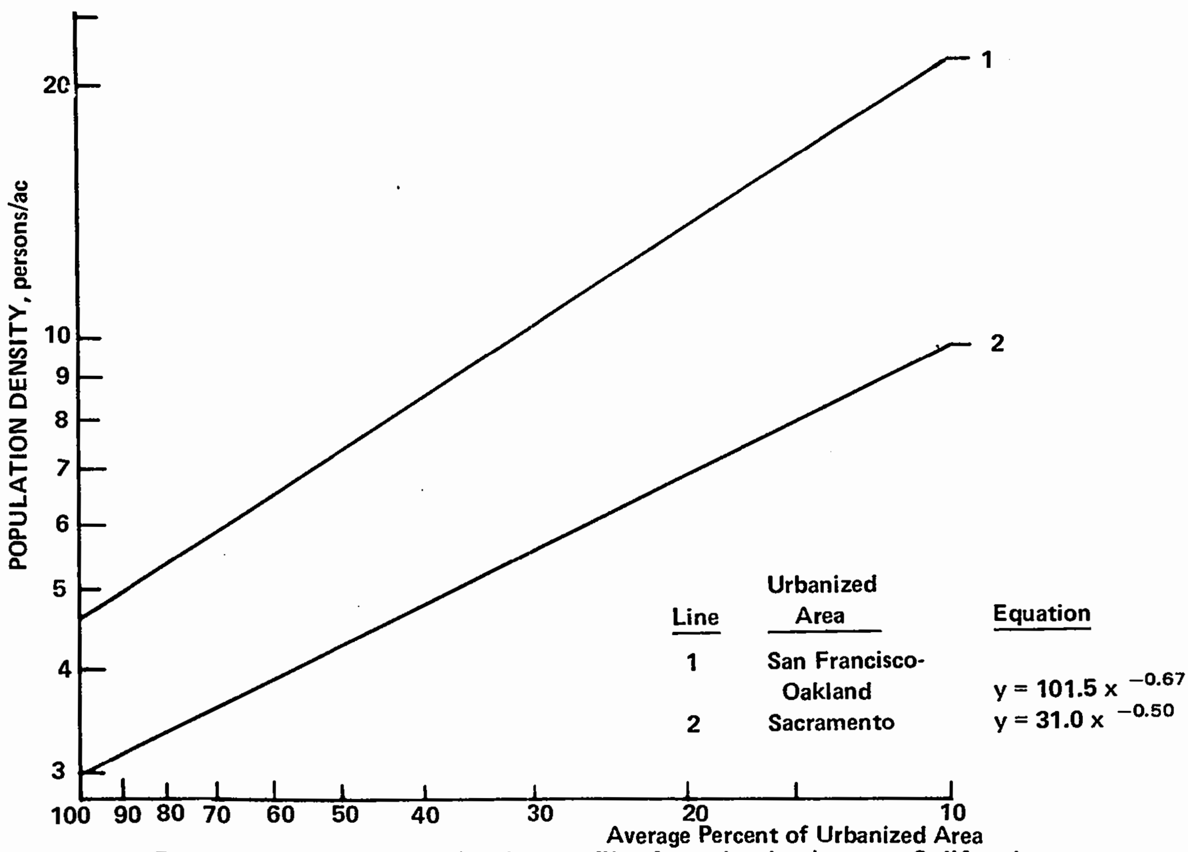
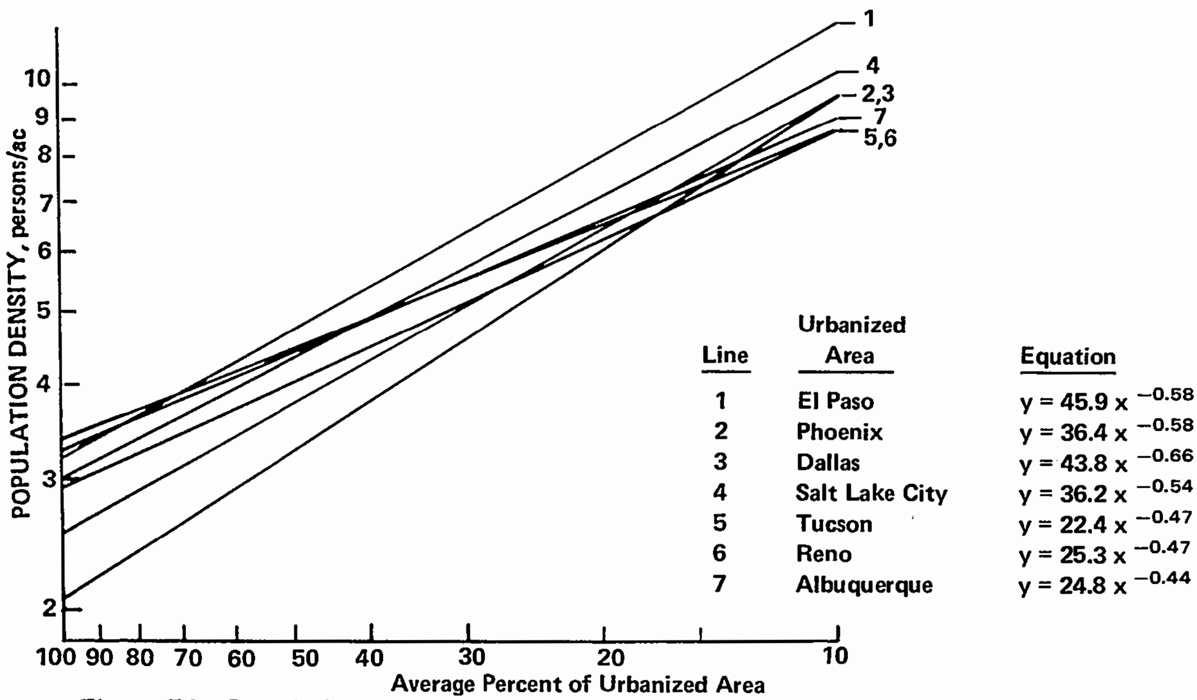
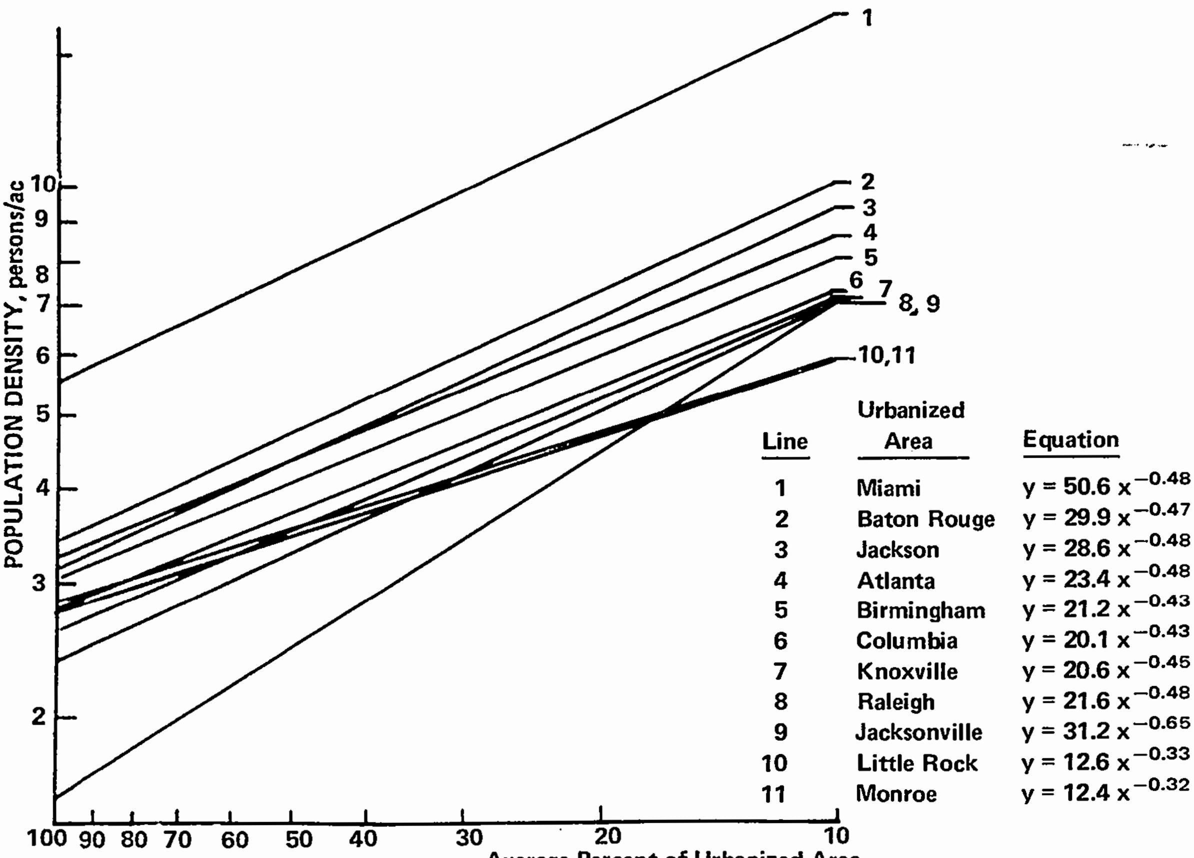


Figure 54b. Population density profiles for urbanized areas—California.



Line	Urbanized Area	Equation
1	El Paso	$y = 45.9\ x^{-0.58}$
2	Phoenix	$y = 36.4\ x^{-0.58}$
3	Dallas	$y = 43.8\ x^{-0.66}$
4	Salt Lake City	$y = 36.2\ x^{-0.54}$
5	Tucson	$y = 22.4\ x^{-0.47}$
6	Reno	$y = 25.3\ x^{-0.47}$
7	Albuquerque	$y = 24.8\ x^{-0.44}$

Figure 54c. Population density profile for urbanized areas—Arkansas—Lower Colorado Upper Colorado—Great Basin—Rio Grande—Texas Gulf.



Line	Urbanized Area	Equation
1	Miami	$y = 50.6\ x^{-0.48}$
2	Baton Rouge	$y = 29.9\ x^{-0.47}$
3	Jackson	$y = 28.6\ x^{-0.48}$
4	Atlanta	$y = 23.4\ x^{-0.48}$
5	Birmingham	$y = 21.2\ x^{-0.43}$
6	Columbia	$y = 20.1\ x^{-0.43}$
7	Knoxville	$y = 20.6\ x^{-0.45}$
8	Raleigh	$y = 21.6\ x^{-0.48}$
9	Jacksonville	$y = 31.2\ x^{-0.65}$
10	Little Rock	$y = 12.6\ x^{-0.33}$
11	Monroe	$y = 12.4\ x^{-0.32}$

Figure 54d. Population density profiles for urbanized areas—South Atlantic Gulf-Upper Mississippi.

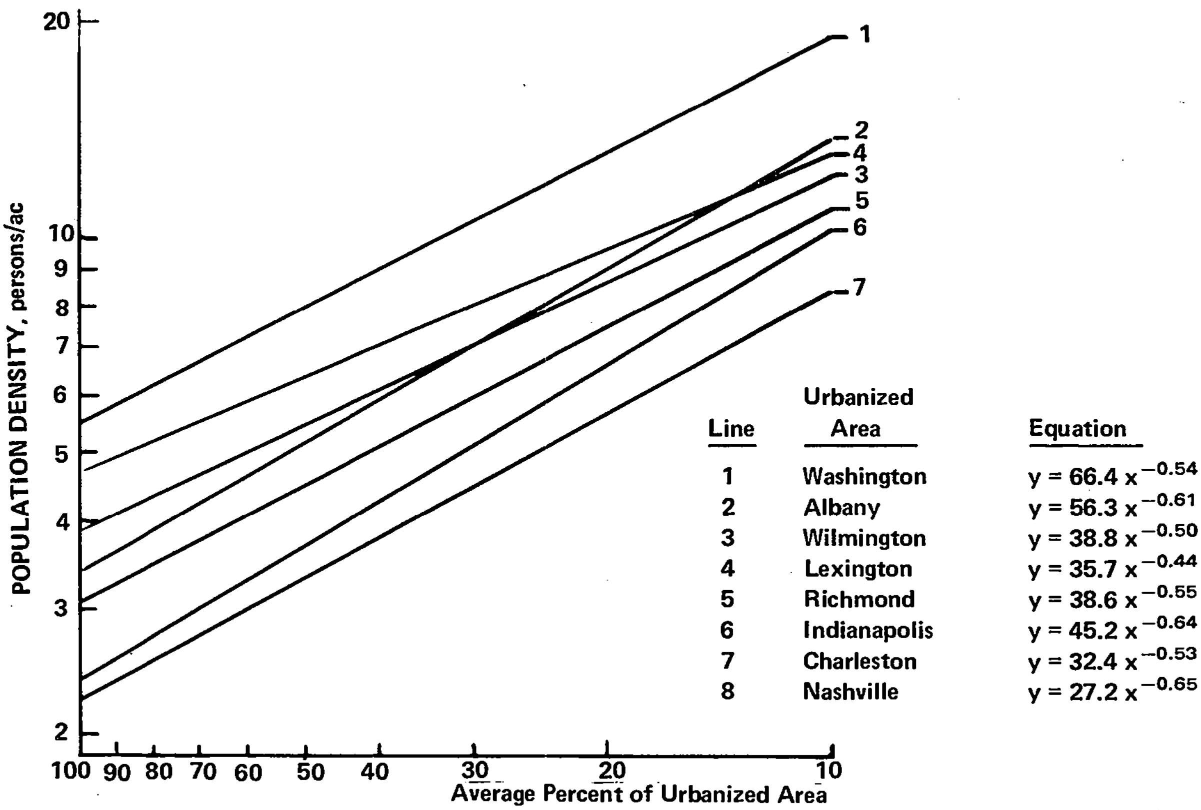


Figure 54e. Population density profiles for urbanized areas—Mid Atlantic—Ohio.

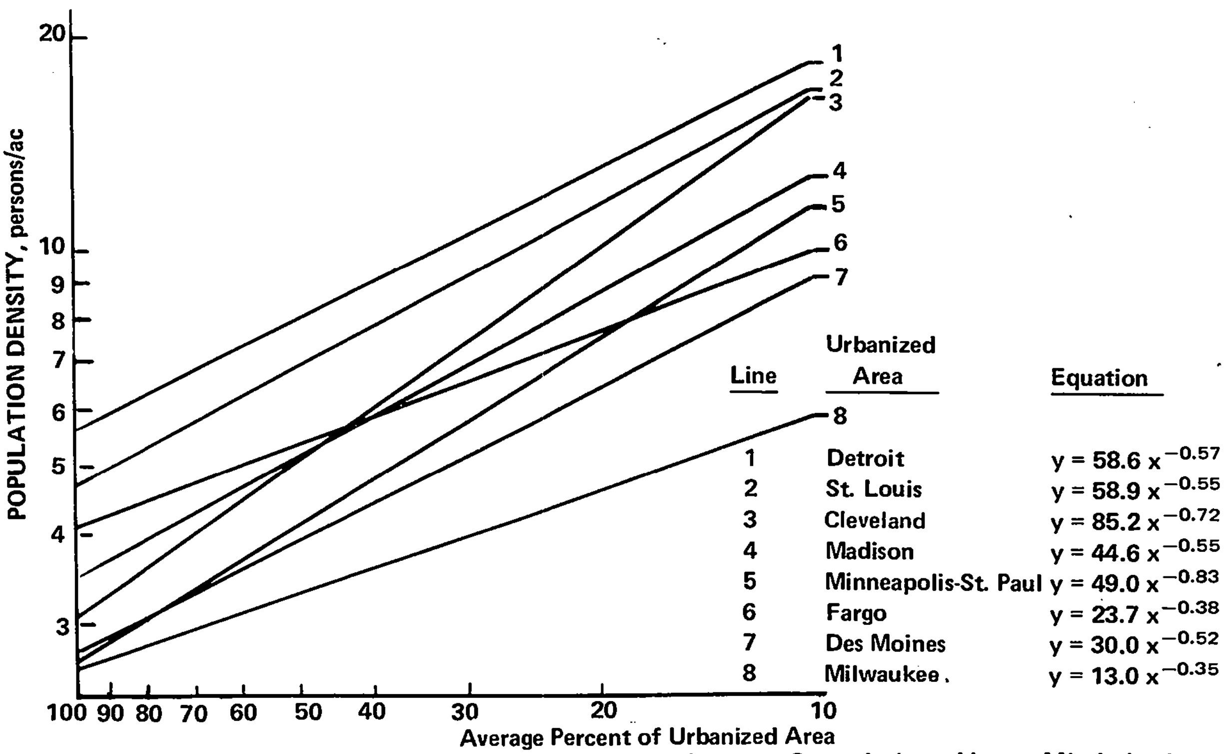


Figure 54f. Population density profiles for urbanized areas—Great Lakes—Upper Mississippi.

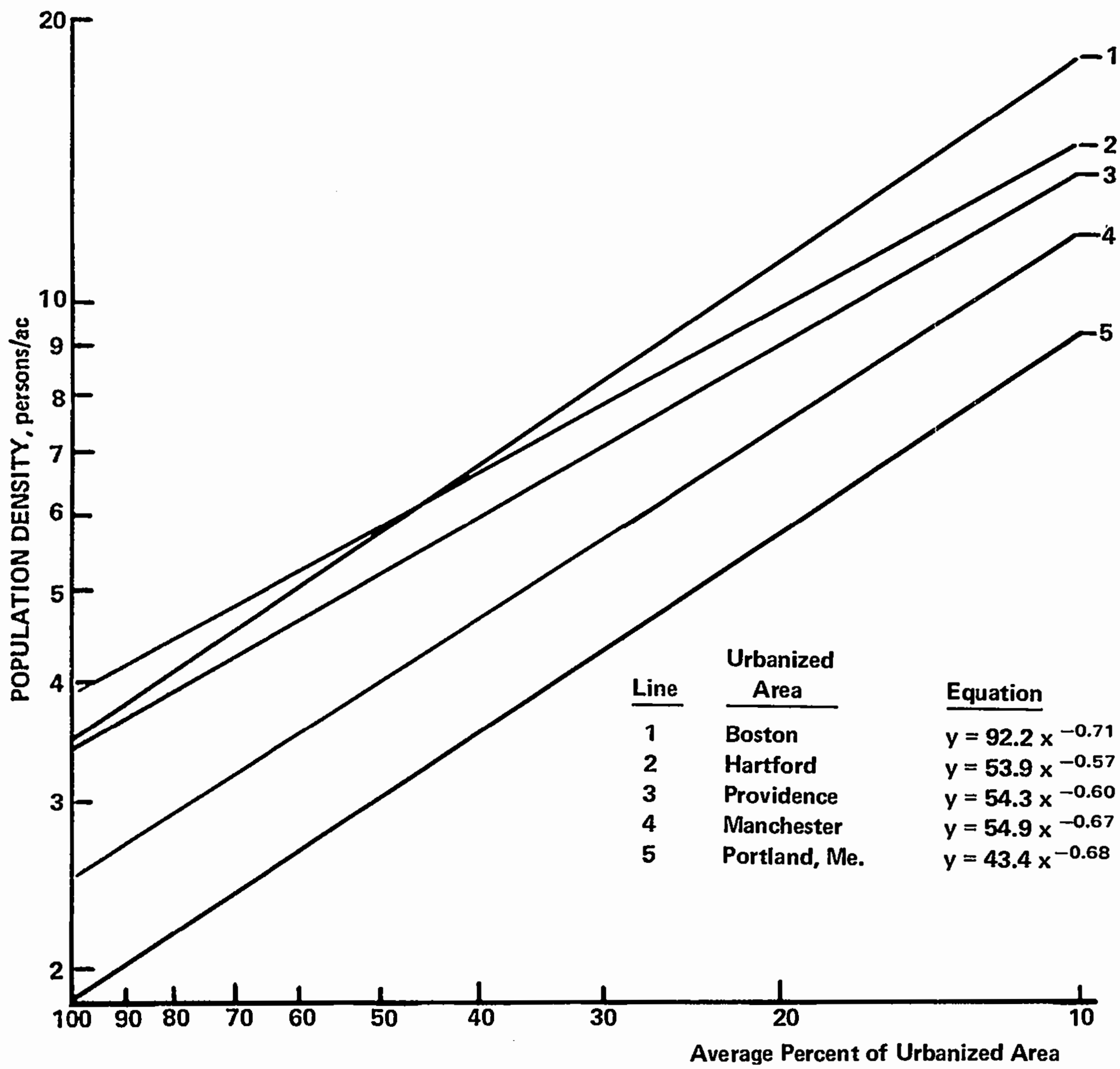


Figure 54g. Population density profiles for urbanized areas—New England

LAND USE CHARACTERIZATION

A key ingredient of the evaluation effort is urban land use. Pollution potentials, physical development characteristics, and public works operations practices have been characterized in terms of urban land use. Land use, however, is seldom defined for entire urbanized areas--particularly where portions of an urbanized area may fall into different political jurisdictions.

As stated, one of the sources of land-use data employed in this project was the population density files created by the National Planning Data Corporation. These files were developed from 1970 census data and the mapping available through the Metropolitan Map Series available from the U.S. Department of Commerce. These maps were electronically planimetered and the and the areas determined were grouped into four major categories: Total census tract areas; water surface areas; apparent non-residential land-use areas; and areas containing special institutional population concentrations. (86)

Data from 48 of the 106 cities reported representing central cities as opposed to suburban communities and were complete enough to use in the development of a land-use estimating method. A regression analysis compared gross land utilization rates determined from mid-1960's land-use area data with overall population density determined from the reported cities. The results are represented in Figure 55.

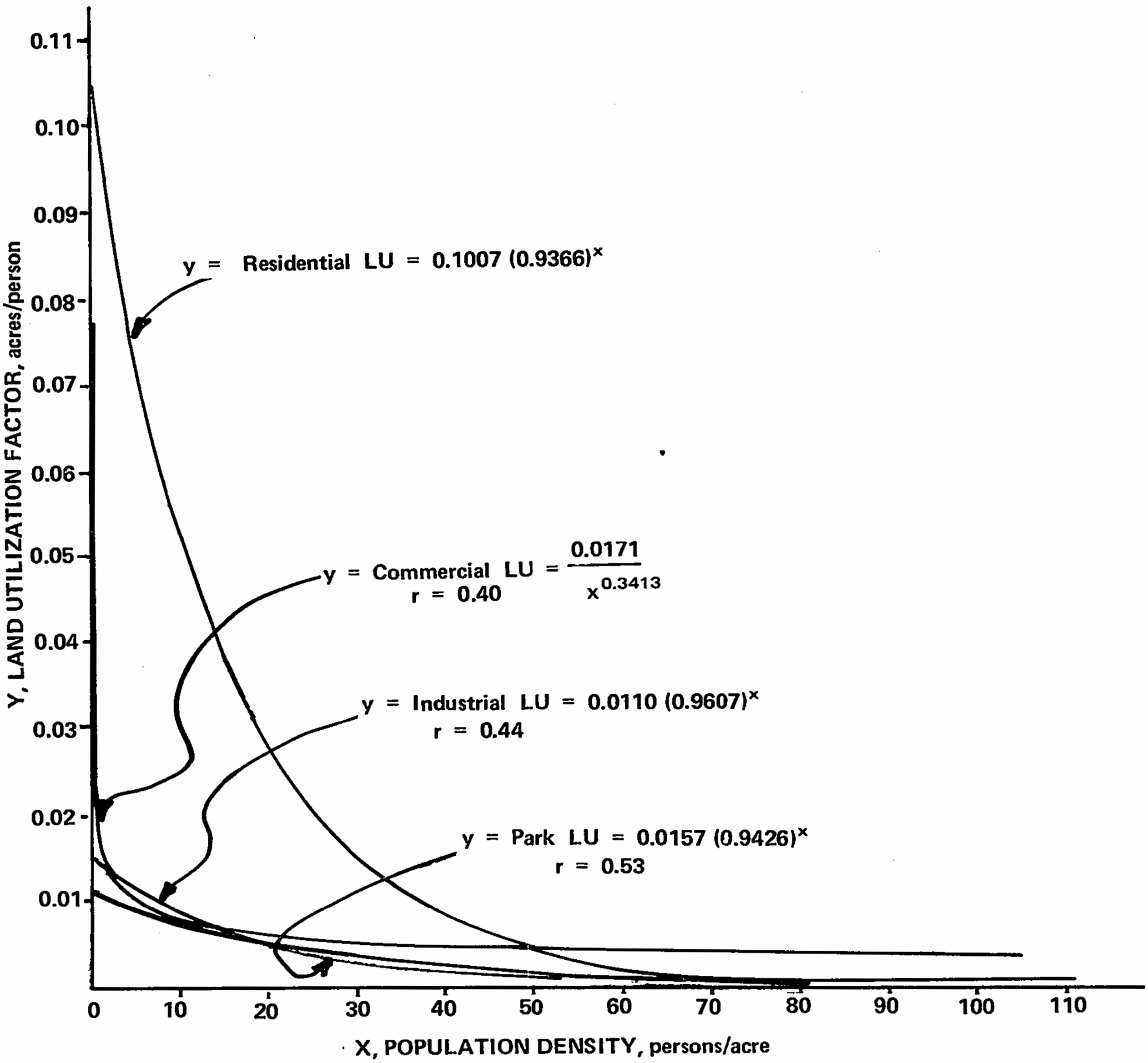


Figure 55. Land utilitzation rates for various cumulative population densities — nationwide.

The figure shows residential, industrial, commercial and park land utilization rates from the data uncovered on a nationwide basis. Relatively low correlations were indicated for commerical, park and industrial land uses. Regional analysis of land-use data was performed on the available central city information for the water resource regions shown in Figure 56. On this basis, a theoretical construct of land use for each of the Water Resources Regions or aggregates of regions where data proved limited was created for land use estimating purposes. The results of this analysis is plotted in Figures 57 thru 60. Thus, two alternatives are posed for land use estimating within urbanized areas -- nationally and more specifically for water resource regions where possible.

Generally, this information shows that better correlations can be expected for data sets representing a broad span of population density. On a regional basis, better comparisons would have been possible with larger data sets for each region that represented a broad range of population density. Insofar as better or more inclusive data was not uncovered, the functions developed on the basis of the regional analysis of 48 cities were used as estimators of land use in the nationwide analysis.

The total census tract areas and water surface areas are considered the most accurate values available. The commerical and industrial land use areas contained within the files are viewed as low values because map measurements for these areas were performed on 1:24,000 scale maps and, as such, were limited to obvious or large-size parcels in these use categories. The residential land-use areas from the data files also appeared less accurate. Residential land-use areas are residual areas not otherwise classified in other use categories. As such, they are generally considered as high values since they also contain the land areas that may be suitable for future residential development. (86)

The National Data Planning Corporation data files were used to define land use in those parts of urban catchments where population densities were high. It was assumed that high population densities indicate relatively complete development and that with complete development, the data files would provide relatively accurate information.

The basic land-use estimating methods employed in the study were derived from data developed in past work by Bartholomew (87) and Manvel. (88) The land used data identified from these sources did not prove as up-to-date as might be desired. Of the two, the latter source provided more current data on land use as of the middle 1960's. A total of 106 cities was surveyed and all were of 100,000 population or more. All of the cities reported were central cities or cities representing some part of an urbanized area.

A more detailed analysis of how the above methods were used is presented in Volume II, Section 3, Description of the Urbanized Areas.

FIGURE 56. LAND-USE REGIONS

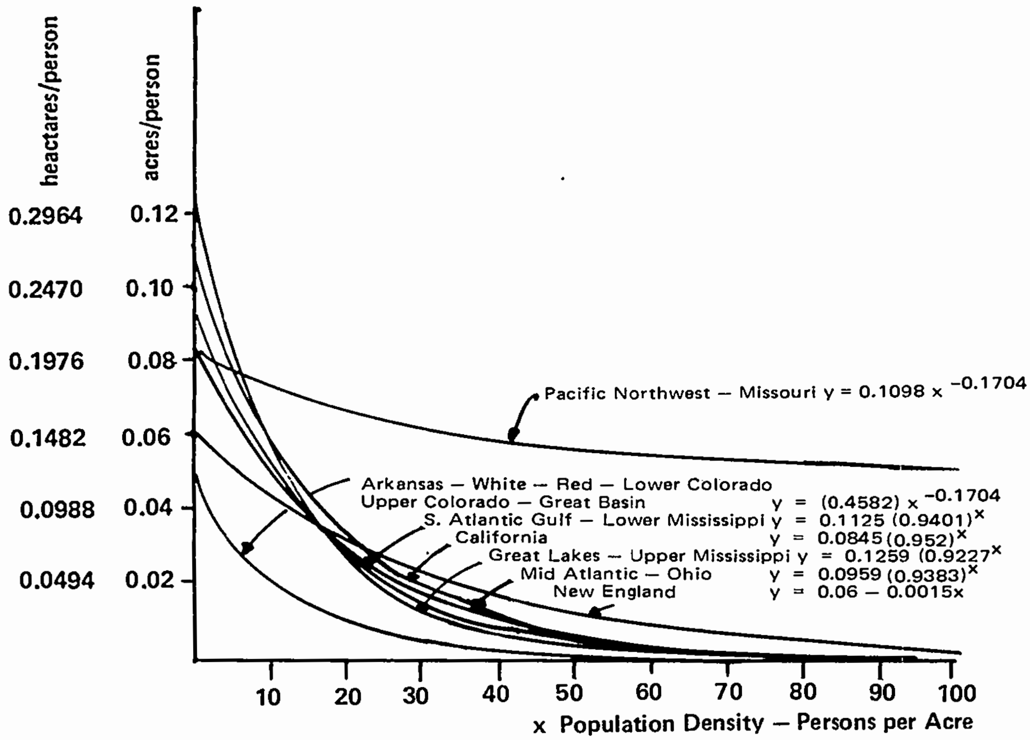


Figure 58. Commercial land utilization rates for various water resources regions.

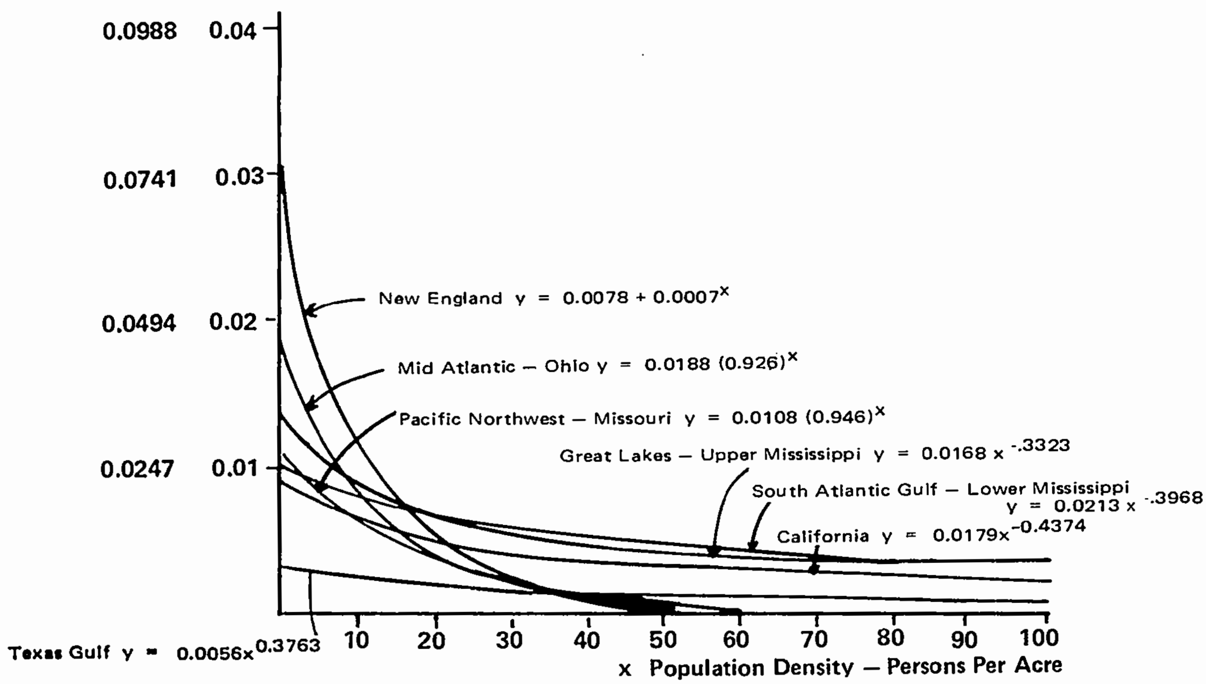


Figure 57. Residential land utilization rates for various water resources regions.

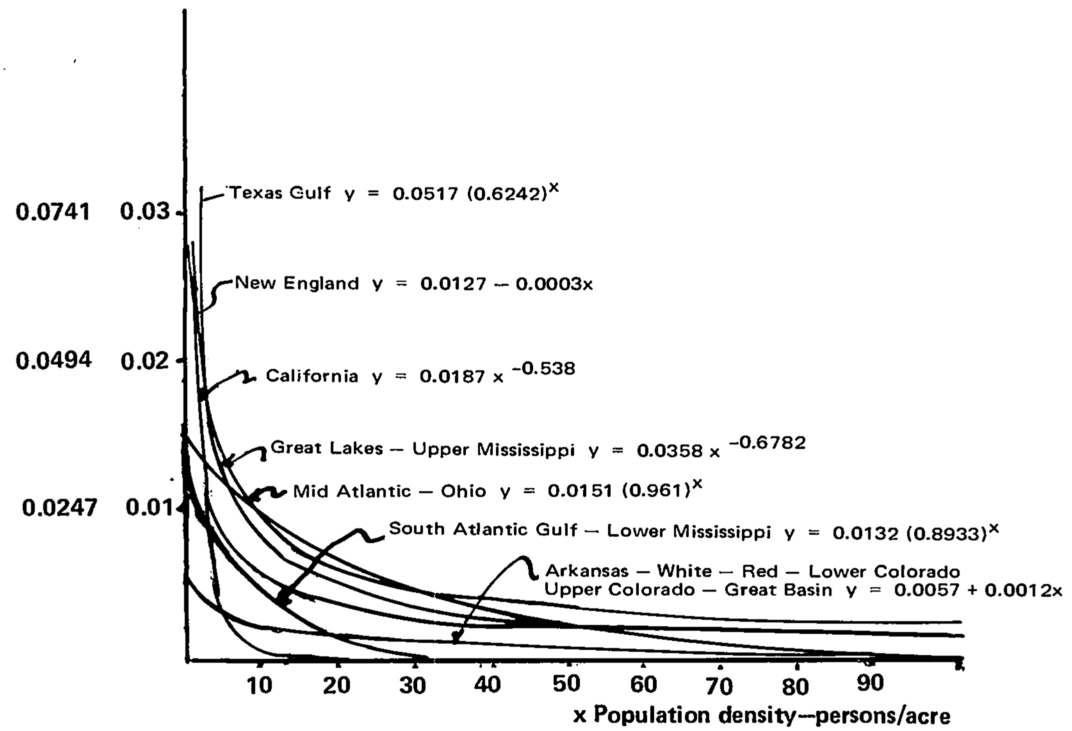


Figure 59. Industrial land utilization rates for various water resources regions.

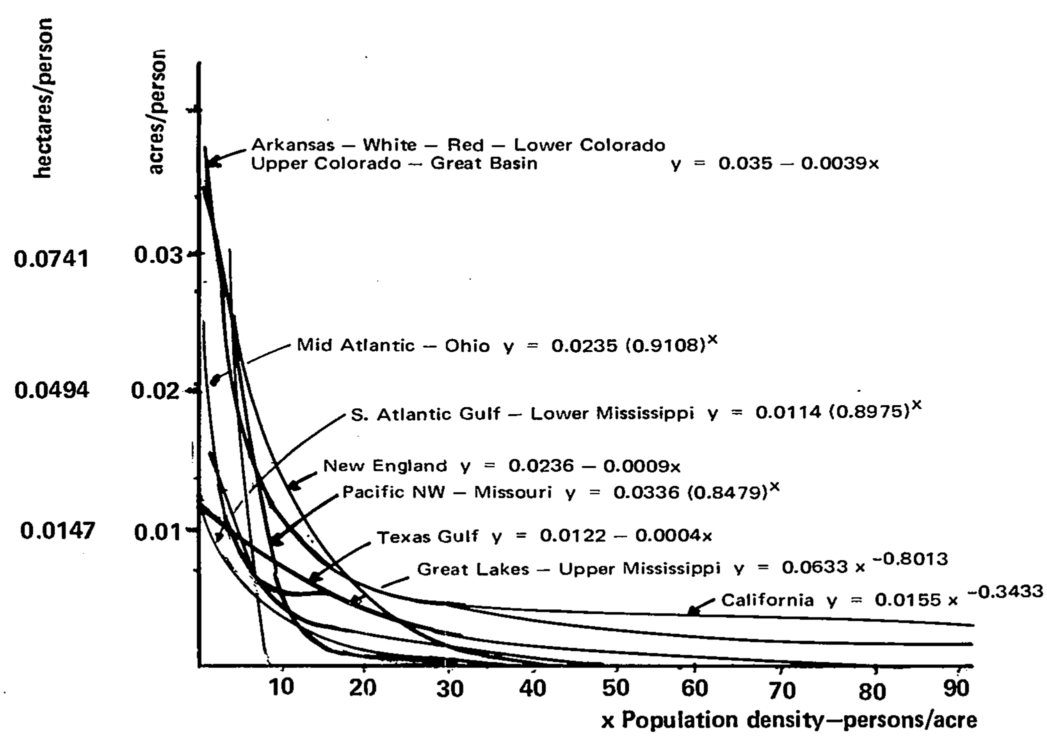


Figure 60. Park land utilization rates for various water resources regions.

RUNOFF QUALITY CHARACTERIZATION

The estimation of runoff quality by the use of the STORM model depends upon the accumulation of pollutants within a drainage basin over time. The urban street cross-section is considered a logical repository for pollutants carried by wind and water from their places of origin, and a depository for the pollutant products of street and related activities. Based on this assumption, the model estimates runoff quality in terms of the amounts of pollutants that will accumulate in urban streets and be washed off during a rainfall event.

On this basis, the model deals with runoff pollutants in terms of their relationship to urban street litter. Proceeding from the average daily accumulations of litter, the model estimates the quantity of soluble pollutants picked up by a give street runoff. (80) For the purposes of this evaluation, it was assumed that STORM will adequately estimate the quantity of solids removed by a particular rainfall event. The materials so transported were assumed to constitute the total solids load contributed by the street litter. Pollutant loads were estimated on the basis of their relationship to the amounts of total solids so removed.

Three studies funded by the USEPA represent the source of the majority of the existing information on daily street litter accumulation and street litter pollutional potentials. The first of these was performed by the American Public Works Association in the City of Chicago. (15) The URS Research Company performed another study that sampled street litter in a number of cities across the country. (43) The remaining study was completed by Biospherics, Incorporated based on street litter samples collected in Washington, D.C. (6)

Some of the findings of the sampling programs conducted for these studies are summarized in Table 109. The data shown reflects mean values for all reported data, regardless of the method of sampling or other differences in samples. These values are, therefore, somewhat different from those reported in other sections of this report; but were used as beginning values for modelling computations. Statistical comparisons of the means among land use types and overall estimates indicated that average values for residential, industrial and park land uses were significant enough to differentiate these values from the overall mean, while the value for commercial land use was not. Thus, the mean value for commercial data was taken as the estimated population mean. Similarly, comparisons of daily street solids were prepared on a regional basis. The results of these comparisons are shown in Table 110. These data are inconsistent with those cited in Section III in so far as they are early estimates of these values.

TABLE 109. AVERAGE DAILY ACCUMULATIONS OF STREET SOLIDS

Land Use	APWA[a] lb/curb-mi/day (kg/curb-km/day)	URS Research Co.[b] lb/curb-mi/day (kg/curb-km/day)	Biospherics, Inc.[c] lb/curb-mi/day (kg/curb-km/day)	Overall lb/curb-mi/day (kg/curb-km/day)
Residential				
Mean	80 (23)	229 (64)	71 (20)	103 (29)
Range	19-153 (5-43)	3-2,700 (0.8-761)	7-378 (2-107)	3-2,700 (0.8-761)
n	153	42	58	253
Commercial				
Mean	181 (51)	46 (13)	126 (36)	160 (45)
Range	71-326 (20-92)	3-260 (0.8-73)	17-712 (4-201)	3-712 (0.8-201)
n	126	17	22	165
Industrial				
Mean	325 (92)	292 (82)	––	316 (89)
Range	283-536 (80-151)	4-1,850 (1-521)	––	4-1,850 (1-521)
n	55	20	––	75
All Uses				
Mean	158 (45)	206 (58)	86 (24)	154 (43)
Range	19-536 (5-151)	3-2,700 (0.8-761)	7-712 (2-201)	3-2,700 (0.8-761)
n	334	79	80	493

Sources: [a]American Public Works Association, "Water Pollution Aspects of Urban Runoff," USEPA Report No. 11030DNS01/69 (NTIS No. PB 215 532), January, 1969.

[b]Sartor, J.D., and G.B. Boyd, "Water Pollution Aspects of Street Surface Contaminants," USEPA Report No. EPA-R2-72-031 (NTIS No. PB 214 408), November, 1972.

[c]Shaheen, D.G., "Contributions of Urban Roadway Usage to Water Pollution," USEPA Report No. EPA-600/2-75-004 (NTIS No. PB 245 854), April, 1975.

TABLE 110. REGIONAL DAILY STREET SOLIDS ACCUMULATION VALUES

Water Resource Region	Residential lb/curb-mi/day (kg/curb-km/day)	Commercial lb/curb-mi/day (kg/curb-km/day)	Industrial lb/curb-mi/day (kg/curb-km/day)	Open Space lb/curb-mi/day (kg/curb-km/day)
Arkansas-White-Red				
Lower Colorado	(1)	(1)	(1)	0
Mean	51 (14)	21 (6)	58 (16)	
Range	6-238 (2-67)	3-53 (0.8-15)	4-130 (1-37)	
σ		20.4 (6)	54 (15)	
n	12			
Great Lakes			0	0
Mean	84 (24)	181 (51)		
Range	19-770 (5-217)	6-326 (2-92)		
σ				
n	157	128		
Mid Atlantic—Ohio	0	(2)	0	0
Mean		57 (16)		
Range		4-168 (1-47)		
σ		77 (22)		
n		4	4	
California	0	(1)		0
Mean		18 (5)	104 (29)	
Range		3-26 (0.8-7)	19-204 (5-57)	
σ				
n		4		
S. Atlantic—Gulf	(2)	0	0	0
Mean	178 (50)			
Range	31-295 (9-83)			
σ				
n	4			
Pacific Northwest	(1)	0	0	0
Mean	30 (8)			
Range	12-45 (3-13)			
σ				
n	4			
Texas Gulf	0	0	0	0
Mean				
Range				
σ				
n				
New England	0	0	0	0
Mean				
Range				
σ				
n				
Nationwide				
Mean	103 (29)	154 (43)	316 (89)	
Range	3-2,700 (0.8-761	4-1,850 (1-521)		
σ	205 (58)	207.3 (58)	272.6 (77)	
n	253	493	75	

σ = standard deviation
n = number of observations

(1) denotes a difference from the nationwide estimate of the population mean at a level of significance of 0.1.

(2) denotes a difference from the nationwide estimate of the population mean at a level of significance of from 0.1 to 0.2

Source: American Public Works Association, "Water Pollution Aspects of Urban Runoff," USEPA Report No. 11030DNS01/69 (NTIS No. PB 215 532), January, 1969.

Sartor, J.D., and G.B. Boyd, "Water Pollution Aspects of Street Surface Contaminants," USEPA Report No. 72-031 (NTIS No. PB 214 408), November, 1972.

Shaheen, D.G. "Contributions of Urban Roadway Usage to Water Pollution," USEPA Report No. EPA-600/2-75-004 (NTIS No. PB 245 854), April, 1975.

On the basis of these street solids accumulation values, population density values and land utilization rates previously defined, composite accumulation values were determined for various population densities. The composite values were computed from the general equation:

$$S = \frac{P(\Sigma S_L \cdot LU_L \cdot R_L) + So\ Ro}{P(\Sigma LU_L \cdot R_L) + Ro} \qquad (21)$$

where:

S = Composite daily solids accumulation

P = Population density

S_L = Daily solids accumulation for each given land use

LU_L = Land utilization rate for each given land use

R_L = Relative road density expected within each given land use

So = Daily solids accumulation for undeveloped land

Ro = Relative road density expected within undeveloped areas

All of the elements contained within the compositing expression may be defined from the foregoing with the exception of the relative road density expected within each given land use. Some values for relative road density are shown in Table 111.

TABLE 111. RELATIVE ROAD DENSITY VALUES

	Average Specific Curb Length		Range of Specific Curb Length	
Land Use	mi/ac	km/ha	mi/ac	km/ha
Residential	0.076	0.302	0.051 – 0.115	0.203 – 0.457
Commercial	0.082	0.326	0.054 – 0.127	0.215 – 0.505
Industrial	0.041	0.163	0.033 – 0.064	0.131 – 0.245
Park	0.042	0.167	–––	–––
Undeveloped	0.016	0.064	–––	–––
All land uses	0.069	0.274	0.053 – 0.127	0.131 – 0.505

Source: AVCO Economic Systems Corporation, "Storm Water Pollution From Urban Land Activity," USEPA Report No. 11034FKL/07-70 (NTIS No. PB 195 281), July, 1970.

The resulting composite street solids accumulation values related to population density and land use for all but park and undeveloped area contributions are shown in Figure 61. These values are dependent upon the assumptions that national land utilization factors are applicable as estimates of land use. Related estimations of suspended solids and BOD_5 are also shown for those street surface contributions for the indicated land uses. Values for park and undeveloped areas were found to be unavailable from existing data sources. Assumed values for these land values were taken as 13.6 kg/curb-km/day (16 lb/curb-mi/day) for the purposes of the modelling analysis.

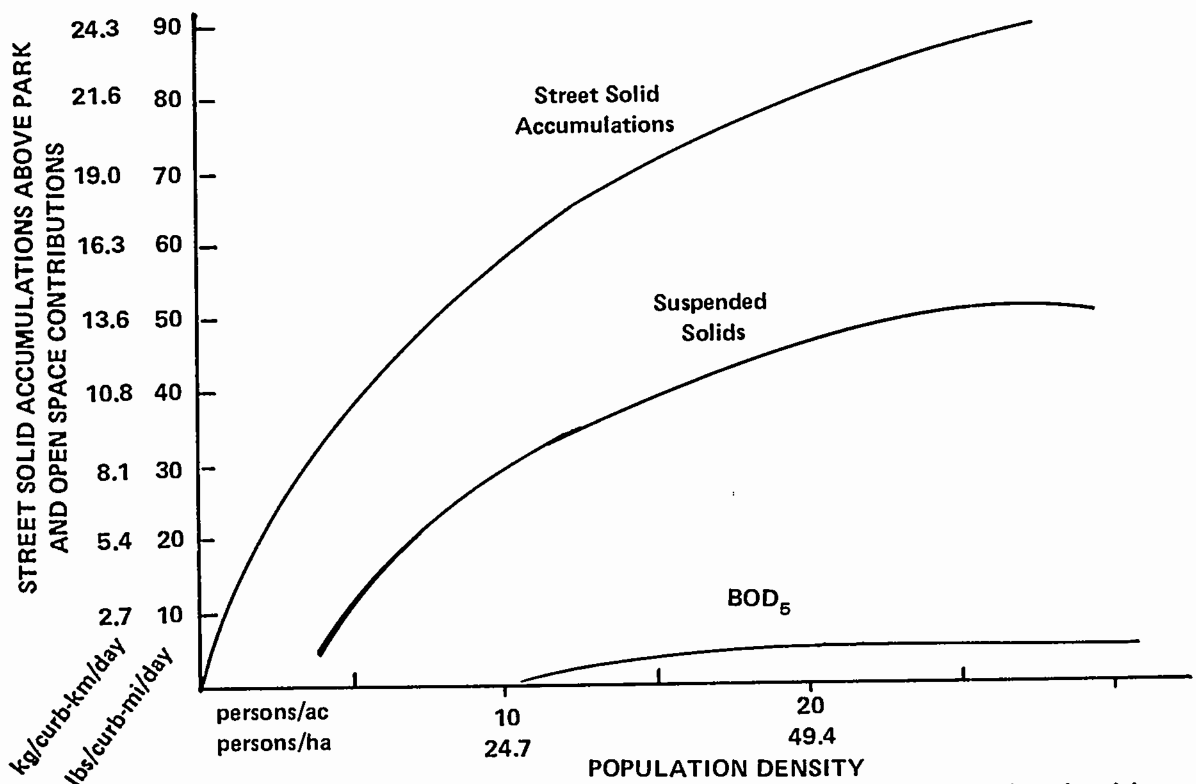


Figure 61. Average daily street solid accumulations for various population densities for all but park and undeveloped area contributions — nationwide.

Pollutant loadings are estimated on the basis of their relationship to the total solids removed and transportated during a runoff event. Pollutant data are available from the studies performed to date for the purpose of investigating street litter pollutant potentials. (6, 15, 43) Another source of data is available through past studies of runoff discharges from drainage basins in various parts of the country. These studies have often involved urban and urbanizing basins and they have, on occasion, related discharges and effluent quality data to various basin characteristics. Little consistency exists within this body of information, due to variations in the types of quality parameters measured and the techniques used in collecting data. The majority of discharge quality data appears in the form of mean concentrations or simple averages of sample results from one or more runoff events.

Statistical comparisons of the pollutant concentrations for individual land uses with overall concentrations for the pollutant data sets selected in the array of concentrations is shown in Table 112. This table shows overall concentrations of the various pollutants, as well as those concentrations specific to given land uses. These specific concentrations are shown where a difference of means at a level of significance of at least 0.2 is indicated.

The values for BOD_5 are given in both mg/kg and mg/l formats due to their low correlation with solids. Organic nitrogen is also reported as mg/l since its correlation to total solids (discharge) proved to be negligible. The values reported for asbestos, cadmium, chromium, copper, iron, lead, manganese, nickel, strontium and zinc are all derived from street surface accumulation data in view of the fact that virtually no information was available from the discharge data for comparative purposes. As such, these values may prove somewhat low if the relative comparisons for the other pollutants are also applicable to metals.

TABLE 112. RELATIVE POLLUTANT LOADS

Pollutant	Residential mg/kg	Commercial mg/kg	Industrial mg/kg	Open Space mg/kg	Overall mg/kg
Suspended Solids	0	0	0	0	
Mean					576,000
Range					154,800-915,200
σ					192,100
n					42
Volatile Solids	0	0	0	0	
Mean					332,300
Range					108,400-652,000
σ					142,110
n					22
BOD_5	(1)	(1)	0	0	
Mean	29,840	83,600			53,180
Range	7,890-66,400	25,500-175,000			5,800-250,000
σ	15,330	51,970			52,610
n	18	10			52
BOD_5	0	0	0	0	
Mean					24 mg/l
Range					3-126 mg/l
σ					24.5
n					43
COD	(2)	(2)	0	0	
Mean	207,600	393,200			288,700
Range	57,000-509,000	101,000-690,900			49,100-880,600
σ	125,000	200,200			190,700
n	14	11			41

TABLE 112 (cont'd)

Pollutant	Residential mg/kg	Commercial mg/kg	Industrial mg/kg	Open Space mg/kg	Overall mg/kg
TOC	0	0	0	0	
Mean					32 mg/l
Range					15-48 mg/l
σ					9.5 mg/l
n					17
NO_3	0	0	0	0	
Mean					0.8 mg/l
Range					0.1-0.5 mg/l
σ					0.5 mg/l
n					9
Organic N	0	0	0	0	
Mean					1.32 mg/l
Range					0.39-3.5 mg/l
σ					0.96
n					23
Sol. Ortho-Phosphate	0	(1)	0	0	
Mean		3,150			1,860
Range		170-6,670			170-7,100
σ		2,270			1,833
n		10			40
Total PO_4	0	0	0	0	
Mean					1.3 mg/l
Range					0.3-0.5 mg/l
σ					1.19 mg/l
n					14
Chlorides	0	0	0	0	
Mean					18.8 mg/l
Range					2-74 mg/l
σ					20.7 mg/l
n					19
Asbestos	0	0	0	0	
Mean					12.3×10^6 fibers/kg
Range					$2.4 \times 10^6 - 13.9 \times 10^6$ fibers/kg
σ					7.1×10^6 fibers/kg
n					6
Cadmium	(1)	0	0	0	
Mean	3				3
Range	0-8.8				0-25
σ	2.4				3.5
n	44				78

TABLE 112 (cont'd)

Pollutant	Residential mg/kg	Commercial mg/kg	Industrial mg/kg	Open Space mg/kg	Overall mg/kg
Chromium	(1)	0	(1)	0	
Mean	183		284		213
Range	49-390		74-760		49-760
σ	77		168		113
n	48		17		82
Copper	0		0	0	
Mean		162			117
Range		25-810			33-810
σ		195			95
n		15			78
Iron	0	0	(2)	0	
Mean			26,200		22,860
Range			8,100-72,000		5,000-72,000
σ			14,490		11,300
n			21		81
Lead	(2)	(1)	0	0	
Mean	1,580	3,000			2,080
Range	220-5,700	0-10,000			0-10,000
σ	1,230	2,460			1,930
n	43	17			81
Maganese	0	0	(1)	0	
Mean			540		400
Range			180-1,600		100-1,600
σ			880		206
n			20		80
Nickel	0	(2)	0	0	
Mean		52			36
Range		6-170			0-170
σ		50			37
n		17			82
Strontium	0	0	0	0	
Mean					21
Range					0-110
σ					20
n					80
Zinc	0		0	0	
Mean		515			390
Range		190-1,100			110-1,100
σ		241			200
n		17			82
T. Coli	0	0	0	0	
Mean					20.7×10^6 /kg
F. Coli	0	0	0	0	
Mean					2.9×10^6 /kg

Notes: (1) denotes a difference from the overall estimate of population mean at a level of significance of 0.1 or less.
(2) denotes a difference from the overall estimate of population mean at a level of significance of from 0.2 to 0.1.
All units are in mg/kg unless otherwise noted.

CHARACTERIZATION OF STREET CLEANING OPERATIONS AND OTHER PHYSICAL DEVELOPMENT FACTORS

The characterization of street cleaning operations, imperviousness and curb length per unit area also were important inputs to the modelling effort. Street cleaning operations involve street cleaning frequency or the period between cleanings in days, and street cleaning efficiency or the percent of street litter picked up by cleaning operations.

The basic source of street cleaning data was from the 1973 APWA Survey of Street Cleaning, Catch Basin Cleaning and Snow and Ice Removal Practice the results of which were given in Table 85.

Street cleaning effectiveness has been found to vary with the particle size distribution of street surface accumulations; accumulation loadings and the loading distribution on the street surface; the street surface type and condition; the type of cleaning equipment used and its characteristics; number of passes of the cleaning equipment; and the equipment operator's ability. Overall sweeping effectiveness for conventional street sweepers has been found to be about 50 percent. (43) Improved removal effectiveness has been found for vacuumized sweepers, but data for this equipment is not generally available. A review of some of the data from the 1973 APWA Survey of Street Cleaning, Catch Basin Cleaning and Snow and Ice Removal Practice, however, indicates that of 363 respondent municipal jurisdictions, only 27 had purchased any vacuumized equipment and then in only limited quantities. As of that time, the relative impact of vacuum equipment on cleaning effectiveness had not been felt to any great degree. It is, therefore, assumed that the main effort in street cleaning operations is still being performed by conventional street sweepers, although a trend to vacuumized equipment may be underway.

Physical development relationships, such as imperviousness and specific curb length, have been estimated from the functions indicated in Figures 62 and 63. These estimating curves were developed on the basis of the original Washington, D.C. data on imperviousness, curb length and population density, first developed by Graham, Costello and Mallon. (89) This information was extended by the addition of reported values from other cities in the nation and regression lines were developed. The distribution of the cities from which data were evolved for this analysis were: Durham, N.C.; Roanoke, Va.; District of Columbia; Bucyrus, Ohio; Milwaukee, Wis.; Tulsa, Ok.; and San Francisco, Calif.

Other Data Requirements

The foregoing discussions have identified estimates and estimating methods for a number of the data requirements necessary for the analysis of the 50 urbanized areas selected. In general, these have covered urban development and runoff quality data needs. Other data needs, such as pollution control and abatement data, are developed in other sections of the report. Rainfall data have been obtained from the U.S. Weather Service. Control and abatement information is developed in Volume II of this report.

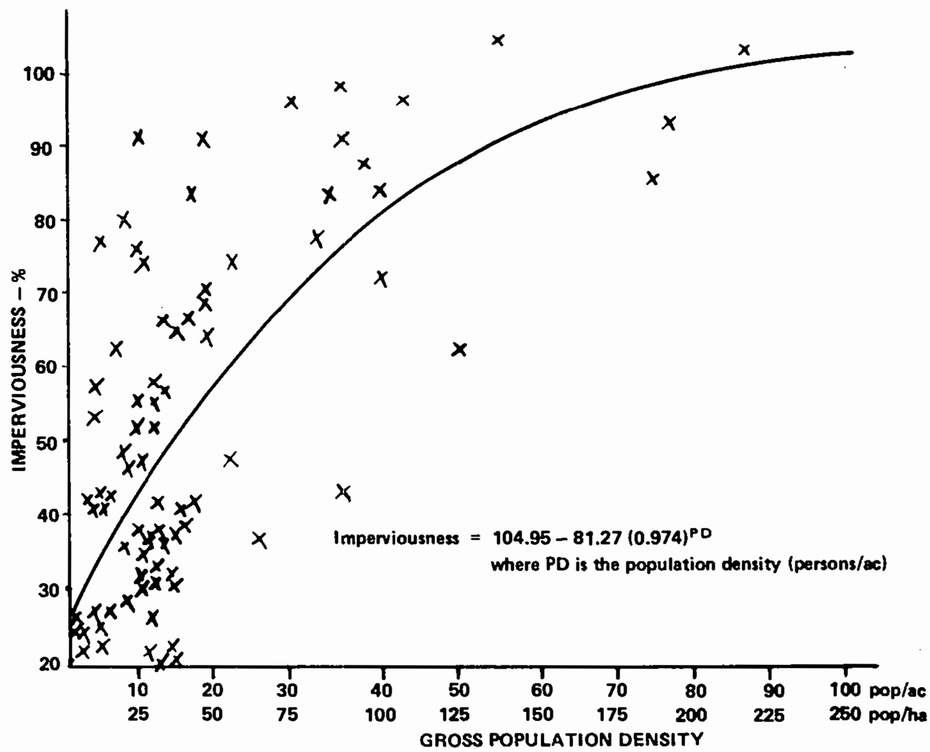


Figure 62. Imperviousness vs. population/density — nationwide, 1974.

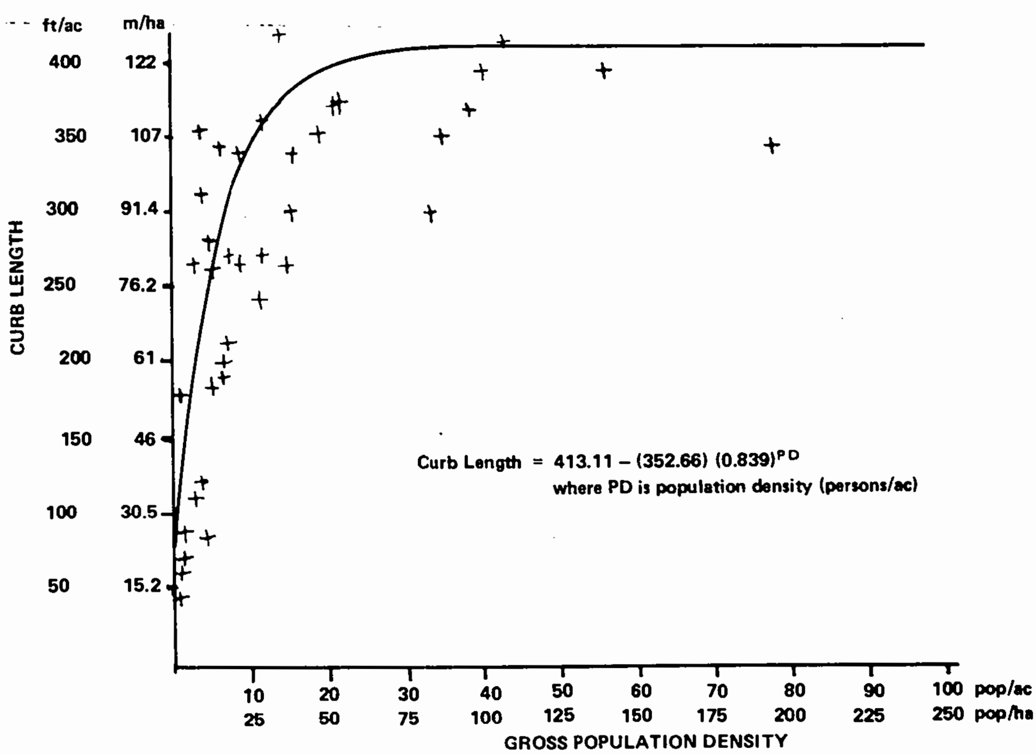


Figure 63. Specific curb length vs. population density nationwide, 1974.

SECTION V

RECEIVING WATER IMPACTS OF URBAN RUNOFF

Receiving waters are those water bodies--lakes, streams, estuaries, bays, and oceans--that are the recipients of wastewater flows. The value of these water resources is beyond realistic assessment. The degradation of their quality influences their use as water supplies for home, farm, or factory and for aesthetic and recreational enjoyment. Quality impairment may also upset and even destroy the diverse and complex biological systems inhabiting and dependent upon these water bodies.

Water quality impairment is most often the product of pollutional contaminants in wastewater flows. Municipal and industrial wastewaters, and the introduction of contaminants through the direct and indirect contributions of runoff, all add to the problems of maintaining water quality. Initiatives undertaken to alleviate the pollution associated with municipal and industrial wastewater effluents have lightened the burden of insuring receiving water quality.

The pollutional problems associated with runoff, however, remain to be resolved. It has been estimated that from 40 to 80 percent of the annual total of oxygen-demanding contaminants are contributed from sewer overflows, stormsewers, uncontrolled runoff and bypasses in urban areas where municipal and industrial wastewater effluents have received secondary treatment. (90)

Some of the toxic contaminants yielded in runoff are also significant. A modestly sized city may discharge from 45.5 to 114 MT/yr (50 to 125 t/yr) of lead and from 2.7 to 13.6 MT/yr (3 to 15 t/yr) of mercury annually in its runoff. Similarly, from 70 to 90 percent of the annual suspended solids loading may be attributed to urban runoff. (90) Most significantly, these contaminants may occur as shock loadings on the receiving water as a result of individual rainfall events.

The net effects of these and other wastewater contaminants on the sensitive balance of a receiving water may be disastrous. The introduction of solids, oxygen consuming contaminants, nutrients and toxic materials that exceed a water body's natural assimilation capacity, can provide major changes in its character. Combined sewer overflow discharges from Bucyrus, Ohio to the Sandusky River resulted in distinct symptoms of gross pollution. Sections of the river were devoid of dissolved oxygen; sludge deposits and extensive algal growth were apparent; and in some of its reaches, the river was completely devoid of life. (57) Similarly, frequent fish kills in Sugar Creek in Illinois were traced to combined sewer overflows from Springfield following rainstorms. (91)

Other, more subtle effects on receiving water quality may also be discerned. Certain organic chemicals used as insecticides and herbicides, when introduced into a receiving body, may accumulate in various fish and snail species in concentrations higher than those found in the water itself. (92) Similarly, the methylation of mercury and its accumulation in fish is detrimental to natural stream fauna and the predators that may rely upon this source of food. (93)

Thus, the relative impacts of wastewater flows may bear significantly on receiving water quality, with a resulting impairment of its value. Although all of the processes involved are not clearly understood, some insights are possible through a summary of some of the past efforts undertaken to study the phenomena involved.

RECEIVING WATER ASSIMILATION CAPACITY (94)

The impacts resulting from the addition of wastewater contaminants to a receiving water are largely determined by the assimilative capacities of the water body. Assimilation refers to the transformation and incorporation of these materials by the aquatic system. Assimilative capacity is determined by the interaction of complex physical, chemical, and biological aquatic subsystems. A number of factors, such as the velocity and volume of flow, water body bottom contours, rate of water exchange, currents, depth of flow, light penetration, temperature, pH, hardness, alkalinity and nutrients, all contribute to relative assimilation capacity. The introduction of contaminants to a receiving water in amounts that exceed the ability of the water body to recover, or the addition of toxic materials or those that may accumulate to undesirable levels, will result in the impairment of receiving water quality.

The addition of a given pollutant will tend, over time, to reach a steady state condition within a water body that is determined by its rate of addition, the rate of its removal or dilution by circulation, and the rate of its decomposition or removal by biological, chemical, or physical processes. A straightforward conceptual model of the processes involved is shown in Figure 64 .

It is apparent that receiving water capacity is determined largely by the nature and characteristics of the water body. Dilution in a stream may be determined from the rate of contaminant addition and the stream's volume of flow. This does not hold for lakes and estuaries where long average retention times may allow the accumulation of conventional contaminants. Some representative estimates for average retention times are shown in Table 113 . The dilution and circulation characteristics of receiving waters are most important for conventional pollutants--solids, heavy metals, etc. Other non-persistent contaminants, such as decomposable organic, are also subject to the rate of their decomposition as part of the definition of their relative impact. Some of the products of this decomposition are persistent contaminants that may also accumulate to produce long-term water quality impacts.

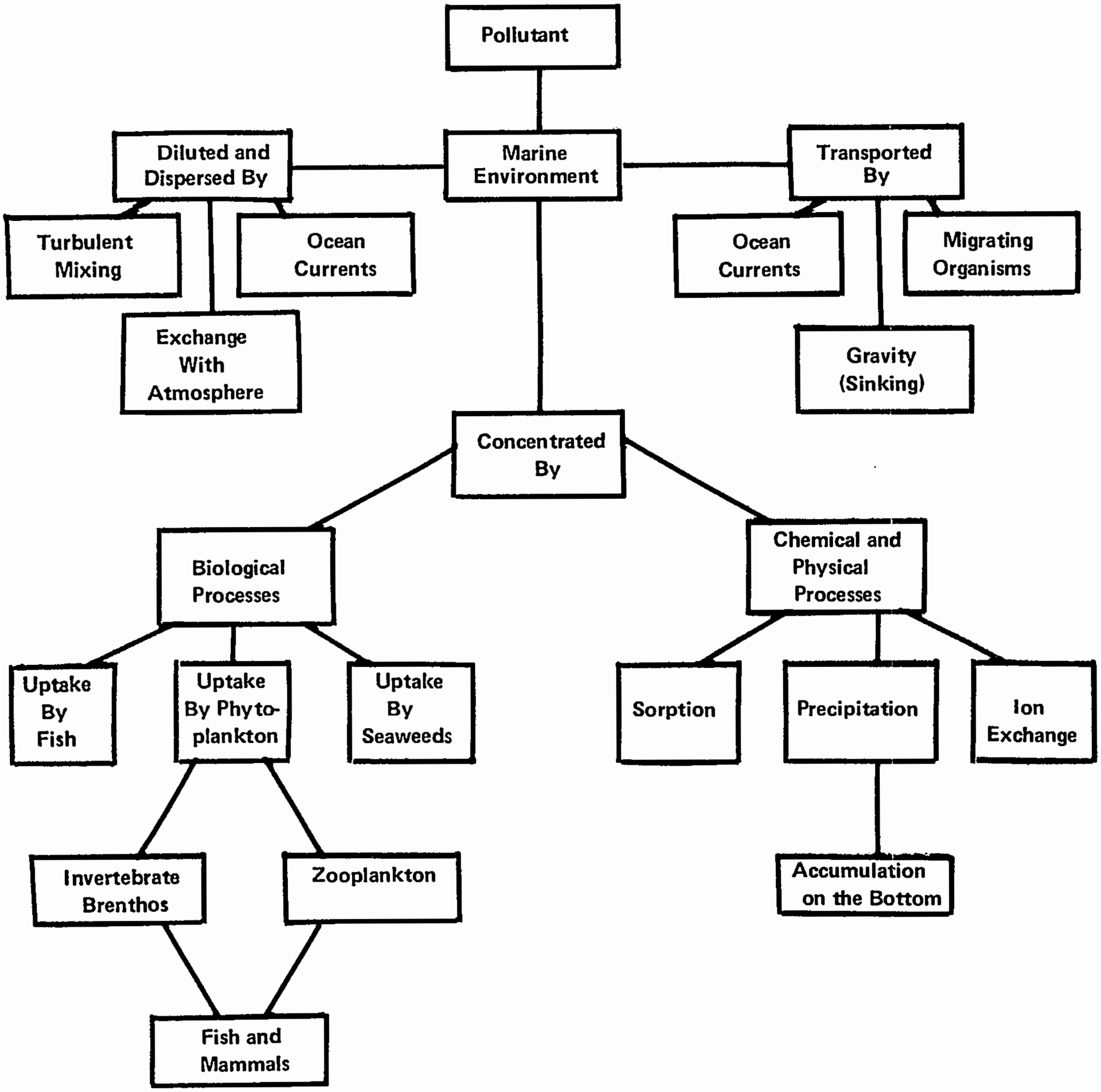


Figure 64. Processes that determine the fate and distribution of a pollutant added to the marine environment.

Source: Ketcham, B.H., "Man's Resources in the Marine Ecology," *Pollution and Marine Ecology*, Interscience Publishers, New York, 1967.

TABLE 113. AVERAGE DETENTION TIMES AND HALF-LIVES FOR RIVER WATER IN THE GREAT LAKES AND IN VARIOUS ESTUARIES AND COASTAL REGIONS

	Surface Area mi^2	Surface Area km^2	Theoretical Mean Retention Time	Half Life
Lake Superior	31,820	82,870	183 years	128 years
Lake Michigan	22,420	58,390	100 years	69 years
Lake Huron	23,010	59,920	30 years	21 years
Lake Erie	9,930	25,860	2.8 years	1.9 years
Lake Ontario	7,520	19,580	8 years	5.6 years
Capes Cod to Hatteras to 1,000 ft contour	29,000	75,520	1.6 – 2.0 years	1.1 – 1.4 years
New York Bight	483 – 662	1,260 – 1,720	6 – 7.4 days	4.1 – 5.05 days
Bay of Fundy	3,300	8,590	76 days	52 days
Delaware Bay high flow	––	––	48 – 126 days	33 – 87 days
Raritan Bay high flow	45	120	15 – 30 days	10 – 21 days
Long Island Sound	930	2,420	36 days	25 days

Sources: Beeton, A.M., "Changes in the Environment and Biota of the Great Lakes," *Entrophication: Causes, Consequences, Correctives,* National Academy of Sciences, Washington, D.C., 1969.

Ketchum, B.H., and D. J. Keen, "The Exchanges of Fresh and Salt Waters in the Bay of Fundy and in Passamaquoddy Bay," *Journal of Fisheries Research Board of Canada,* 10 (3): 97–124.

Ketchum, B.H., and D.J. Keen, "The Accumulation of River Water Over the Continental Shelf Between Cape Code and Chesapeak Bay," *Marine Biology and Oceanography,* London, pp. 346-357.

Ketchum, B.H., "The Flushing of Tidal Estuaries," *Sewage and Industrial Wastes,* 23 (2): 198-208.

Riley, G.A., "Hydrography of the Long Island and Block Island Sounds," *Bulletin Bingham Oceanographic Collection,* Yale University, 8: 5-39.

Thus, the impacts of wastewater contaminants on a receiving water may be characterized in terms of the following factors:

- The makeup of the contaminants
- The degree of discharge quality enhancement achieved through treatment
- The amounts of pollutants entering a receiving water
- The response of the ecosystem

These factors suggest that impact assessment and reasonable receiving water quality requirements should be the product of the detailed analysis of each receiving water body performed in the light of real data and realistic objectives. Historically, however, water quality criteria have taken a number of forms. The major form of criteria has been an array of allowable limits organized on the basis of specific public health and other needs, associated with subsequent beneficial water uses. Select general water quality criteria developed on this basis are shown in Table 114. These types of criteria are extremely useful, insofar as they may be related to the deleterious effects of using poor quality receiving waters for specified purposes. They are also limiting, however, because they are overall criteria and may not reflect the impact of contamination on receiving waters of varying characteristics and sensitivities. These impacts may be determined only through the type of analysis previously suggested.

Other approaches to the definition of water quality criteria have dealt with one or more of the impact factors outlined above. These include effluent criteria, implied standards of treatment, and, in some cases, effluent limitations imposed as a result of existing or potentially undesirable conditions with a receiving water.

TABLE 114. WATER QUALITY CRITERIA FOR VARIOUS SUBSEQUENT BENEFICIAL USES

Intended Use	Drinking Water	Livestock	Irrigation	Water Contact	Boating & Aesthetics
Quality Limit	Maximum Permissible Concentrations	Recommended Maximum Concentration	Limiting or Recommended Maximum Concentration	Limiting Threshold	Limiting Threshold
ABS (detergent) mg/l	0.5	––	––	2.0	5.0
Aluminum, mg/l	––	5	5	––	––
Ammonia–N, mg/l	0.5	––	––	––	––
Arsenic, mg/l	0.5	0.2	0.1	––	––
Barium, mg/l	1.0	––	––	––	––
Berylium, mg/l	––	––	0.1	––	––
Boron, mg/l		5.0	0.75	––	––
Cadmium, mg/l	0.01	50 mg/l	0.01	––	––
Carbon Absorbable Organics					
Carbon Chloroform extract mg/l	0.2	––	––	––	––
Carbon alcohol extract mg/l	1.5	––	––	––	––
Chlorides, mg/l	250	––	350	––	––
Chromium, mg/l	0.05	1.0	0.1	––	––
Coliform					
Fecal/100 ml	2,000	––	1,000	––	––
Total/100 ml	20,000	––	––	––	––
Color, Standard Cobalt Scale Units	75	––	––	100	100
Coblat, mg/l	––	1.0	.05	––	––
Copper, mg/l	1.0	0.5	0.2	––	––
Cyanide, mg/l	0.02	––	––	––	––
Electrical Conductivity μ m hos/cm	––	––	2,250	––	––
Emulsified Oil and Grease mg/l	0	––	––	20	50
Floatable Oil and Grease mg/l	0	––	––	5	10
Fluorides, mg/l					
50-54°F (10-12°C)	2.4				
55-58°F (13-14°C)	2.2				
59-64°F (15-18°C)	2.0	2.0	1.0	––	––
65-71°F (19-22°C)	1.8				
72-79°F (23-26°C)	1.6				
80-91°F (27-33°C)	1.4				
Iron, mg/l	0.3	––	5.0	––	––
Lead, mg/l	0.05	0.1	5.0	––	––
Lithuim, mg/l	––	––	2.5	––	––
Maganese, mg/l	0.05	10 mg/l	0.2	––	––
Mercury, mg/l	0.002	––	0.2	––	––
Molybdenum, mg/l	––	––	0.01	––	––

Note:
The foregoing values are a mix of most stringent limits as cited in the sources defined. It should be recognized that the values shown are from existing standards and do not reflect the "national interim primary regulations" or "secondary regulations" to be published by the USEPA under the Safe Drinking Water Act of 1974.

TABLE 114 (continued)

	Drinking Water	Livestock	Irrigation	Water Contact	Boating & Aesthetics
	Maximum Permissible Concentrations	Recommended Maximum Concentration	Limiting or Recommended Maximum Concentration	Limiting Threshold	Limiting Threshold
Nitrate—N, mg/l	10	--	--	--	--
Nitrate—N, mg/l	1	--	--	--	--
Nickel, mg/l	--	--	0.2	--	--
Phenols	1 mg/l	--	--	--	--
Pesticides					
Chlorinated Hydrocarbon Insecticides mg/l					
Aldin	0.001	0.001	--	--	--
Chlordane	0.003	0.003	--	--	--
DDT	0.05	0.05	--	--	--
Dieldrin	0.001	0.001	--	--	--
Endrin	0.0005	0.0005	--	--	--
Heptachlor	0.0001	0.0001	--	--	--
Heptachlor Epoxide	0.0001	0.0001	--	--	--
Lindane	0.005	0.005	--	--	--
Methoxychlor	1.0	1.0	--	--	--
Toxaphene	0.005	0.005	--	--	--
Carbonate and Organophosphorus Pesticides, mg/l	0.1	0.1	--	--	--
Chlorophenoxy Herbicides, mg/l					
2,4-D	0.02	0.02	--	--	--
2,4,5-TP(Silvex)	0.03	0.03	--	--	--
2.4.5-T	0.002	0.002	--	--	--
Range of pH	5.9-9.0	--	4.5-9.0	6.5-8.3	6.0-10.0
Selenium, mg/l	0.01	0.05	0.02	--	--
Silver	0.05	--	--	--	--
Sodium Absorption Ratio, SAR			15.0		
Sulfate, mg/l	250	--	1,000	--	--
Suspended Solids, mg/l	--	--	--	100	100
Soluble Salts, mg/l	--	3,000	--		
Threshold Odor Number	--	--	--	256	256
Total Dissolved Solids	500	--	500-5,000	--	--
Transparency, Secche Disk, ft	--	--	--	--	20
Turdidity, silica scale units	--	--	--	50	--
Vanadium, mg/l	--	0.1	0.1	--	--
Visible Sewage Solids	None			None	None
Zinc, mg/l	5	25	2.0	--	--
Residual Sodium Carbonate (meq)	--	--	2.5	--	--

Sources: Chen, C.W., "Management of Urban Strom Runoff," American Society of Civil Engineers, Urban Water Resources Research Program, Technical Memorandum No. 24, New York, 1974.

National Academy of Science—National Academy of Engineering Committee on Water Quality Criteria, *Water Quality Criteria, 1972*, USEPA Report No. EPA-R3-73-033 (NTIS No. PB 236 199/AS), March, 1973.

POLLUTIONAL SOURCES

Impacts on receiving waters are generated by the contribution of pollutants from both urban and non-urban sources. Treated and untreated municipal and industrial wastewater effluents are important contributions. The direct and indirect additions of pollution due to stormwater runoff are also important. Direct contributions may take the form of runoff discharges and unsewered runoff. Indirect runoff contributions may involve combined sewer overflows or sanitary sewer bypasses that result from excessive inflow or infiltration, or other sources of excessive flows.

Non-urban sources include agricultural, silvicultural, and mining land uses. In addition, the non-point contributions due to erosion from construction activity may be included as both an urban and non-urban source of pollution.

A major pollutant in non-sewered runoff contributions for both urban and non-urban land uses is sediment. It has been estimated that 3.6 billion MT (4 billion tons) of sediment are produced annually through the processes of erosion. (43) An indication of the relative magnitudes of sediment generation from non-urban land uses is shown in Table 115.

TABLE 115. REPRESENTATIVE RATES OF EROSION FROM VARIOUS LAND USES AND PERCENT OF NON-URBAN PRODUCTION ATTRIBUTABLE TO EACH

Non-Urban Land Use	$Ton/mi^2/yr$	Metric $Ton/km^2/yr$	% of Total Sediment Production Nationwide
Forest	24	8	0.5
Grassland	240	84	6.0
Abandoned Surface Mines	2,400	840	84.0
Cropland	4,800	1,670	6.0
Harvested Forest	12,000	4,180	1.0
Active Surface Mines	48,000	16,720	1.0
Construction	48,000	16,720	3.0

Source: United States Environmental Protection Agency — Office of Water Programs, "Methods for Identifying and Evaluating the Nature and Extent of Non-Point Sources of Pollution," USEPA Report No. EPA-430/9-73-014, October, 1973.

Although the greatest rates of sediment production are associated with construction and active surface mining, they represent a relatively low percentage of national production on a mass basis. The greatest percentage is that associated with crop lands. An indication of the pollutional contributions attributable to some non-urban land uses is shown in Table 116.

TABLE 116. ANNUAL MASS DISCHARGES FROM SOME RURAL AREAS

	Annual Average Load, lb/ac/yr (kg/ha/yr)				
	Suspended Solids	BOD_5	COD	N	PO_4
Corn	13,200 (14,790)	120 (134)	1,300 (1,460)	237 (266)	27.7 (31)
Wheat	1,730 (1,940)	15.5 (17.4)	170 (190)	31 (35)	3.6 (4.0)
Apple Orchard	185 (207)	3.7 (4.1)	27.8 (31.2)	0.8 (0.9)	3.9 (4.4)

Source: Weidner, R.B., et al., "Rural Runoff as a Factor in Stream Pollution," *Journal of the Water Pollution Control Federation*, 41(3): 377, 1969.

An appropriate measure of the relative strength of direct urban runoff discharges was shown in Table 92. A similar array of data for combined sewer overflows is shown in Table 93.

A more meaningful relative comparison of various contaminant contributions from sources in Des Moines, Iowa appears in Table 117. This estimates the relative distribution of BOD_5, nitrates, and ortho-phosphates from the apparent sources of these contaminants--treatment plant effluent, bypasses, combined sewer overflows and urban runoff. Interestingly, approximately 64 percent of the BOD_5, 43 percent of the nitrates, and 44 percent of the ortho-phosphates, on an annual basis, are attributable to controlled and uncontrolled wet-weather sources. Of these, combined sewer overflows direct runoff represents around 25 percent of the BOD_5, 8 percent of the nitrates, and 2 percent of the ortho-phosphates.

A similar analysis of data collected in Durham, North Carolina, produced the estimates shown in Table 118. The data are based on a separate system and attributes about 99 percent of the annual yield of suspended solids, 88 percent of the ultimate BOD, and 91 percent of the COD to urban runoff alone, with secondary treatment of sanitary wastewaters. The relative impact of secondary treatment on the overall annual suspended solids, ultimate BOD and COD delivered to the receiving water, amounts to only 4 percent, 46 percent, and 48 percent, respectively. During approximately 20 percent of the year, downstream water quality is controlled by runoff. (58)

TABLE 117
SUMMARY OF PRESENT ANNUAL METRO AREA DISCHARGES

Condition	Days	BOD lb	BOD kg	NO_3 lb	NO_3 kg	$O.PO_4$ lb	$O.PO_4$ kg
WWTP Effluent							
Dry Weather	257	4,060,600	1,845,700	400,900	182,200	1,737,300	789,700
'Wet' Weather	108	2,246,400	1,021,100	237,600	108,000	1,036,800	471,300
Subtotal	365	6,307,000	2,866,800	638,500	290,200	2,774,100	1,261,000
'Wet' Dry Weather Overflow	108	2,235,600	1,016,200	9,700	4,400	263,500	119,800
'Wet' Weather Combined Sewer Overflows							
2.72 in. Rain (6.9 cm)	1	40,500	18,400	240	110	6,350	2,890
1.50 in. Rain (3.8 cm)	5	101,500	46,100	680	310	12,200	5,540
0.75 in. Rain (1.9 cm)	12	32,500	14,800	220	100	3,250	1,490
0.375 in. Rain (1.0 cm)	18	0	0	0	0	0	0
0.175 in. Rain (0.4 cm)	20	0	0	0	0	0	0
Subtotal	56	174,500	79,300	1,140	520	21,800	9,910
Urban Storm Water							
2.72 in. Rain (6.9 cm)	1	292,000	132,700	6,800	3,100	3,900	1,770
1.50 in. Rain (3.8 cm)	5	765,000	347,700	15,300	6,950	9,200	4,180
0.75 in. Rain (1.9 cm)	12	966,000	439,100	19,300	8,770	12,000	5,450
0.375 in. Rain (1.0 cm)	18	495,200	225,100	9,900	4,500	6,200	2,820
0.175 in. Rain (0.4 cm)	20	149,800	68,100	3,000	1,360	1,900	860
Subtotal	56	2,668,000	1,212,700	54,300	24,680	33,200	15,090
Total Annual Discharge	365	11,385,100	5,175,000	703,640	319,800	3,092,600	1,405,800

Source: Davis, P.L., and F. Borchardt, "Combined Sewer Overflow Abatement Plan, Des Moines, Iowa," EPA-R2-73-170, NTIS PB 234 183, April 1974.

TABLE 118
TOTAL ANNUAL YIELD OF POLLUTANTS FROM MUNICIPAL AND URBAN RUNOFF WASTES DURING 1972

	Municipal Raw Sanitary		Percent	Effluent		Urban Runoff		Total Yield		Percent Overall Removal
	lbs/ac/yr	kg/ha/yr	Removal*	lbs/ac/yr	kg/ha/yr	lbs/ac/yr	kg/ha/yr	lbs/ac/yr	kg/ha/yr	Efficiency
Suspended Solids	335	375	85	50	56	6,690	7,497	6,740	7,553	4
Ultimate BOD	685	768	91	61	68	470	527	531	595	46
COD	1,027	1,151	91	92	103	938	1,051	1,030	1,155	48

*Assumed

Source: Colston, N.V., "Characterization and Treatment of Urban Land Runoff," USEPA Report EPA-670/2-74-096, December, 1974.

Perhaps a better indication of wet weather effects is shown in Table 119.

TABLE 119
TOTAL YIELD OF POLLUTANTS DURING STORM PERIODS FROM URBAN RUNOFF AND MUNICIPAL WASTES

	Municipal Raw Sanitary		Percent	Effluent		Urban Runoff		Total Yield		Percent Overall Removal
	lbs/ac/yr	kg/ha/yr	Removal*	lbs/ac/yr	kg/ha/yr	lbs/ac/yr	kg/ha/yr	lbs/ac/yr	kg/ha/yr	Efficiency
Suspended Solids	64	72	85	10	11	6,617	7,415	6,627	7,426	1
Ultimate BOD	130	146	91	12	13	447	501	459	514	20
COD	195	218	91	18	20	895	1,003	913	1,023	16

Source: Colston, N.V., "Characterization and Treatment of Urban Land Runoff," USEPA Report EPA-670/2-74-096, December, 1974.

During the "wet" weather periods of the year the direct contributions from runoff are significantly greater than those of wastewater effluents and even raw sanitary wastes. In addition, the relative overall removal efficiency can be estimated to control only one percent of the suspended solids, 20 percent of the ultimate BOD, and 16 percent of the COD production in the basin. This represents around one-quarter, somewhat less than one-half, and one-third respectively, of the overall efficiencies computed for these pollutants on an annual basis. It is apparent that the relative overall effect of sanitary wastewater treatment would be even less for individual high intensity rainfall events.

Since non-urban land uses occupy 97 percent of the land area of the United States, it seems apparent that the largest quantitites of uncontrolled pollutants originate from these areas, as opposed to urban sources, on an annual discharge basis. Indeed, the impact of rural contributions on receiving water quality can be significant. Results from a study in Des Moines, Iowa are shown in Table 120. This table shows that the majority of organic loadings found in the Des Moines River originated in upstream rural areas. Only urban orthophosphate contributions were found to approach those from rural areas. The control and abatement of the contributions of the Des Moines community were considered insignificant compared to the receiving water demands imposed by upstream pollutant sources. (58) Although the annual pollutional discharges from rural areas are significantly greater than those of urban areas, this does not dismiss the relative impact or importance of urban pollution sources.

TABLE 120
ESTIMATES OF ANNUAL POLLUTANT CONTRIBUTIONS FROM URBAN AND NON-URBAN SOURCES, DES MOINES

Parameter	Low Water Year		High Water Year		Average Water Year	
	lb	kg	lb	kg	lb	kg
BOD_5						
Incoming	15,549,000	7,067,700	100,070,000	45,486,400	65,225,000	29,647,700
Metro Area	11,385,100	5,175,000	11,385,100	5,175,000	11,385,100	5,175,000
NO_3						
Incoming	2,431,000	1,105,000	60,032,000	27,287,300	22,222,000	10,100,900
Metro Area	703,640	319,800	703,640	319,800	703,640	319,800
$O.PO_4$						
Incoming	593,000	269,500	7,292,000	3,314,500	2,940,000	1,336,400
Metro Area	3,092,600	1,405,700	3,092,600	1,405,700	3,092,600	1,405,700

Source: Davis, P.L., and F. Borchardt, "Combined Sewer Overflow Abatement Plan, Des Moines, Iowa," USEPA Report EPA-R2-73-170, NTIS PB 234 183, April, 1974.

In urbanized areas, the regrading of land surfaces, the construction of structures and facilities that result in greater basin imperviousness, and the installation of drainage structures, all add to higher runoff rates and shorter times of runoff concentration. This factor, and the array of pollutants, including heavy metals, from urban areas, all contribute meaningfully to receiving water impacts. The significance of land use is shown in Figure 65. In this

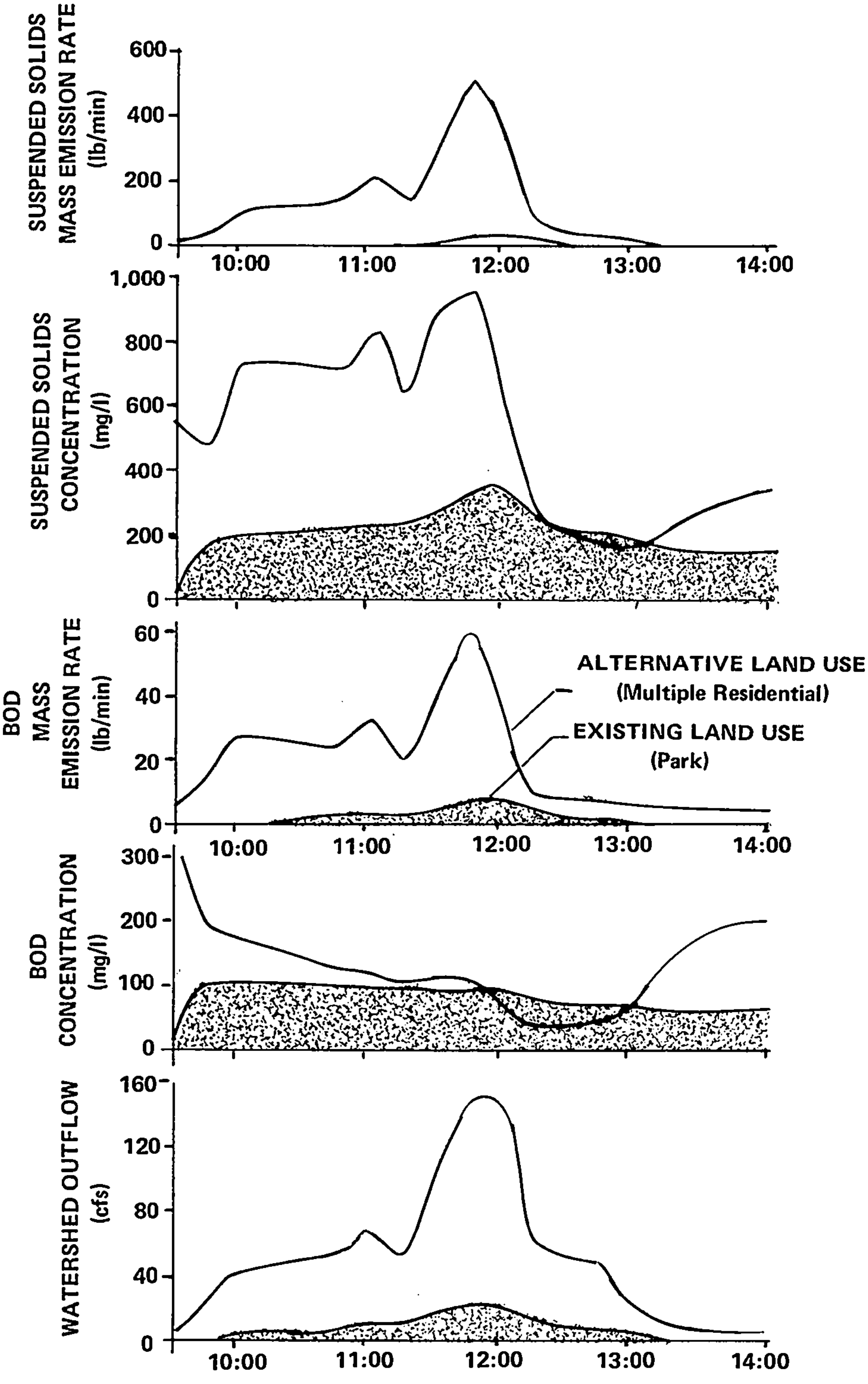


Figure 65. Effect of changed land use on characteristics of subcatchment runoff from Shelby Street Watershed, San Francisco

Source: Roesner, L.A., et al., "A Model for Evaluating Runoff Quality in Metropolitan Master Planning," ASCE Urban Water Resources Research Program Technical Memorandum No. 23, New York, N.Y., April, 1974.

figure, the modelling effects of changing land use, from a park use to a multiple residential use, resulted in higher runoff discharges and generally higher pollutional load from that area by more than 10 times. (80) Thus, although urban areas represent only three percent of the nation's land area, the relative pollutional contributions and receiving water impacts associated with urban areas are disproportionate to their size and must be dealt with in order to insure receiving water quality.

RECEIVING WATER IMPACT

Receiving water impacts are generally the time-related effects of pollution on the water body. Thus, in a flowing stream, river or estuary, some of the impact of pollutant contributions may be realized at locations far downstream from the point of discharge. In addition, certain pollutant additions may produce depositions that exert long term effects on the aquatic system. In lakes and other water bodies with long term flow retention capabilities, the most widely noted impact is eutrophication or the changes due to excessive nutrient enrichment.

Receiving water impacts have been evaluated in a number of ways. These generally involve the assessment of individual water quality parameters through the estimation of the mass balance of pollutant loadings in successive segments of the water body. Of particular interest is the analysis of biological oxygen demand to assess the effects of biodegradable organic contaminants on dissolved oxygen levels in a receiving stream. With the advent of the computer, more complex evaluations of impact have become possible. These may include the modelling of receiving water hydrodynamics, chemical, and biological pollutant transformations and their ecological effects on various biota. (97) They may also involve the impact of specific pollutants on specific biological groupings. (98)

Dissolved Oxygen

Dissolved oxygen concentrations are often considered the most important indicator of surface water quality. Low concentrations result in poor environmental conditions for fish and other aquatic life. Complete or major oxygen depletion creates or threatens to provide septic conditions. Aquatic dissolved oxygen is primarily from atmospheric sources and is also produced by aquatic plant life. The decomposition of organic pollution by oxygen consuming microorganisms may cause large decreases in surface water dissolved oxygen concentrations. Biological oxygen demand, BOD, is a measure of the potential oxygen depletion associated with the biological decomposition of organic material over a given time interval and temperature. Decreases in dissolved oxygen depend upon the amount of BOD in the receiving water, the exertion rate of the BOD, and also the dissolved oxygen content and the reaeration characteristics of the water body. (99)

Various hypothetical case studies have been developed to indicate the relative impacts of direct urban runoff and combined sewer overflow contributions on dissolved oxygen levels in receiving waters. One such analysis involved the estimation of the effects of direct urban runoff on a receiving stream. (100) The hypothetical city was of 100,000 population and a drainage area of 50 km^2 (19.3 mi^2). In addition, the city has 1,368 km (850 mi) of streets, a street surface contaminant loading of 42 kg/curb-km/day (150 lb/curb-mi/day), and a sanitary wastewater flow of 0.52 m^3/sec (12 mgd). Further, an uncontaminated receiving water of 2.8 m^3/sec (100 cfs) and a critical rainfall event of 6.4 mm (0.25 in) were also assumed. The results of this analysis produced the discharges shown in Table 121.

TABLE 121
COMPARISON OF STORMWATER AND SANITARY WASTEWATER DISCHARGES FOR CASE STUDY

	Metric Ton/Yr*						
Discharge	Total Solids	COD	BOD_L	Total Phosphates	Kjeldahl Nitrogen	Lead	Zinc
Raw Storm Water	17,000	2400	1200	50	50	31	6
Raw Sewage	5,200	4800	4400	200	800	---	---
Treated Sewage (secondary)	520	480	440	10	80	---	---
Storm Water as Percent of Storm-water and Raw Sewage	77	33	21	20	6	---	---
Storm Water as Percent of Storm-water and Treated Sewage	97	83	73	83	39	---	---

*Metric Ton = 1,000 kg = 1.1 tons

Source: Pitt, R.E., and Field R., "Water Quality Effects from Urban Runoff," a paper presented at the 1974 American Water Works Association Conference, Boston, Massachusetts.

As this table indicates, the major contributions of pollutants would be attributable to direct runoff when secondary treatment of sanitary sewage was provided for all contaminants but Kjeldahl Nitrogen. Figure 66 depicts the projected stream impacts of these contributions on dissolved oxygen levels for steady state conditions. The analytical approach employed is based on the assumption that pollutants accumulate in urban drainage basins. The degree of accumulation is projected in this case to reflect varying effects on the receiving water.

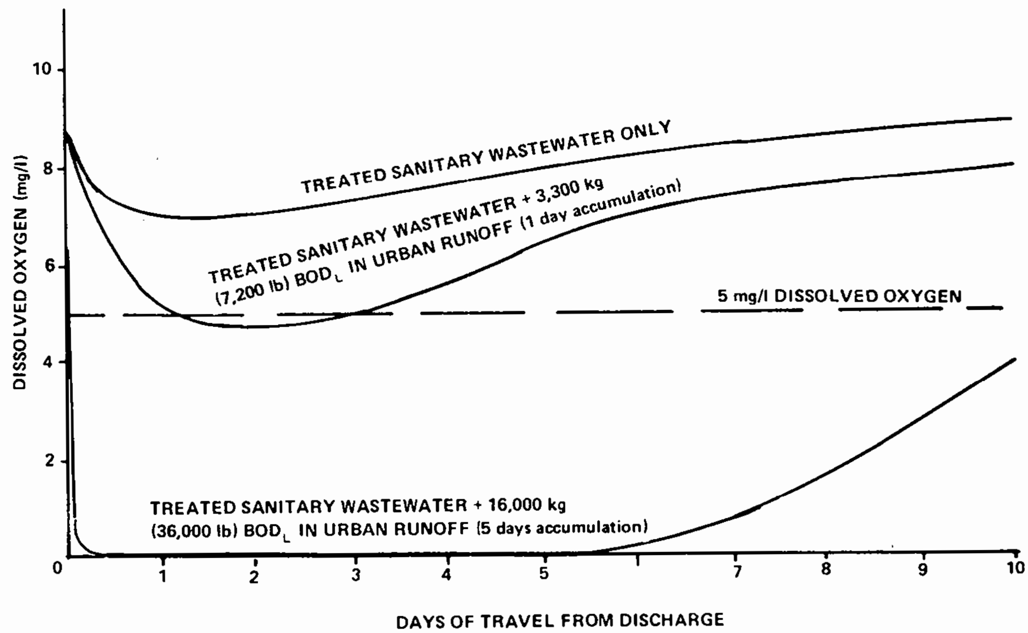


Figure 66. Oxygen sag curves for case study.

Source: Pitt, R.E., and Field R., "Water Quality Effects from Urban Runoff," Paper presented at the 1974 American Water Works Association Conference, Boston, Massachusetts.

Assuming a desirable dissolved oxygen level of 5 mg/1, the level attributable to the effect of treated sanitary effluents is well above this criterion. The contributions of runoff reflecting the contaminant removals from every one day's accumulation will force the dissolved oxygen level below the 5 mg/1 limit, and septic conditions will be realized in the receiving water from the runoff contributions estimated from five day's pollutant accumulation.

Another steady state analysis was performed on a similar hypothetical city to suggest the impacts attributable to combined sewer overflows, but not direct runoff or sources other than sanitary sewage. (101) Although the case study involved the same population, in this case the drainage area was taken as 81 km^2 (31 mi^2), a dry-weather flow of 0.55 m^3/sec (12.5 mgd) was assumed and the receiving stream was taken to have a discharge of 56 m^3/sec (2,000 cfs). Data from Bucyrus, Ohio, (57) on overflow quality and a rainfall event with a recurrence interval of one year produced the results in Table 122 . This table indicates sag-point dissolved oxygen concentrations and the number of days during which dissolved oxygen is below a 4.0 mg/1 level for various degrees of treatment of sanitary sewage and combined sewer overflows. In each case, dry weather flows alone produced conditions above the 4.0 mg/1 criterion for all levels of treatment. The net effects of degree of treatment on sanitary effluents and combined sewer overflows are indicated in both minimum dissolved oxygen levels and the number of days below standard. The greatest relative beneficial effects of stream impacts are associated with primary treatment of overflows.

TABLE 122
SAG-POINT DISSOLVED OXYGEN LEVELS AND THE RELATED NUMBER OF DAYS BELOW CRITERIA

Plant Overflows	Minimum Dissolved Oxygen, mg/l	Days Below Standard	Minimum Dissolved Oxygen, mg/l	Days Below Standard	Minimum Dissolved Oxygen, mg/l	Days Below Standard
Untreated	1.0	5	1.8	4	2.5	4
Primary Treatment	2.8	3	3.5	3	3.9	1

Source: Untitled paper prepared by Robert Crim, USEPA, Washington, D.C.

The foregoing hypothetical examples, while illustrative, do not reflect the myriads of other influences that also contribute to receiving water impacts. Although desirable, few receiving streams can be assumed to be uncontaminated. Few receiving waters can be considered free of the effects of other sources of pollution or the residual effects of past rainfall events. The analytical methods for determining BOD exertion rates for runoff (64) and the methods of assessing receiving water reaeration (102) may be suspect. Even the method by which discharges are introduced into the receiving water (103) and the resulting dispersion of discharges in the aquatic environment (104) have an important bearing on resulting impacts.

A real world theoretical analysis of organic pollutant of storm and receiving stream was developed in connection with a study of storm and combined sewer pollution in Atlanta, Georgia, and its effects on the South River. (95) The results of the analysis are shown in Figure 67. The average annual dissolved oxygen deficits for dry-weather flows are shown, as well as the projected impacts of a two-week storm confined to the headwaters of the drainage areas. Average dissolved oxygen concentrations for dry weather flow amounted to 3.9 mg/l, although minima of 1.9 mg/l were experienced. Annual average BOD loads from separate storm areas were found to be approximately 55 percent of the loads from combined sewer areas.

The impact of direct and indirect runoff contributions are also demonstrated in the figure for various exertion constants and treatment conditions. As indicated, the relative influence of storm runoff and combined sewer overflows are significant for the assumed conditions. It was suggested that the impacts of combined sewer overflows were due not only to the increased volume of biodegradable organic materials contributed, but also to higher deoxygenation rates due to the percentage of sanitary sewage.

Another steady state analysis of receiving water dissolved oxygen concentrations on the urbanized Third Fork Creek Basin in Durham, North Carolina, produced the results shown in Table 123. In this table, the impacts of treated sanitary effluents and direct runoff contributions were analyzed. Deoxygenation rates in this analysis were determined by the laboratory analysis of representative runoff samples by COD analysis over time, which were taken to provide an estimate of ultimate BOD exertion rates. The impact of small rainfall events was found to be negligible for the assumed conditions. In addition, treated sanitary effluents exerted no effect on dissolved oxygen levels. For larger storm events the impact of the various parts of the runoff hydrograph--the "first flush," hydrograph peak, the falling limb tail--were evaluated. For each of the larger storms the "first flush" and hydrograph peak contributions exert a greater effect on dissolved oxygen than the remainder of the runoff. This indicates the relative effects of the earlier components of the runoff event and the significance of the "first flush." In comparison to a tentative criterion of 5 mg/l dissolved oxygen, the runoff pollutional contributions associated with a one to two-year return period storm or greater, could produce subcritical dissolved oxygen levels in the receiving water. The enhancement of dissolved oxygen by various levels of treatment is also shown.

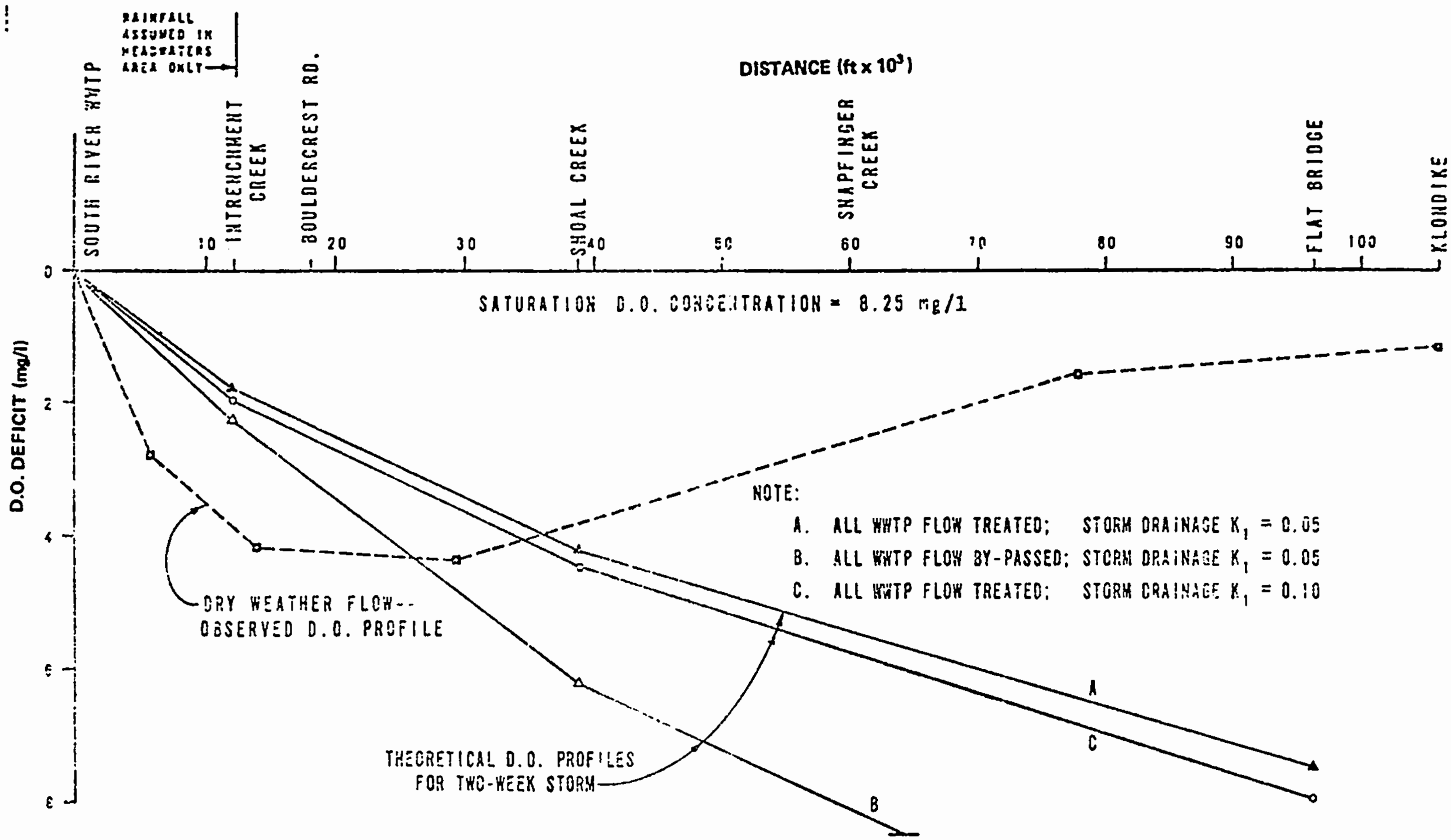


Figure 67. Theoretical annual average dissolved oxygen profiles in South River for two-week storm.

Source: Black, Crow and Eidsness, Inc., "Storm and Combined Sewer Pollution Sources and Abatement," USEPA Report No. 11024ELB01/71 (NTIS No. PB 201 725), January, 1971.

TABLE 123. RESULTS OF OXYGEN–SAG COMPUTATIONS FOR STUDY WATERSHED

Storm Type	Rain-fall in (cm)	Dura-tion (hr)	Return Period (yr)	Storm Component	Storm Flow (cfs)	Regeneration Coefficient (day^{-1})	Ultimate BOD (mg/l)	Deoxygena-tion Coefficient (day^{-1})	Flow Time to Sag Point (day)	D.O. Deficit at Sag Point (mg/l)	D.O. at Sag Point (mg/l)	D.O. (mg/l) at Sag Point With Stated BOD Removal from Stormwater 20%	40%	60%
Small Storm	0.1 (0.25)	1	–	Total Storm	40	4.00	40	0.12	0	0	10.0	–	–	–
Small Storm	0.1 (0.25)	3	–	Total Storm	20	5.70	31	0.12	0	0	10.0	–	–	–
1-2 year Storm	1.0 (2.54)	5	1 to 2	First Flush	200	1.25	75	0.12	2.0	5.6	4.5	5.6	6.7	7.8
				Peak	315	0.86	62	0.12	2.6	6.3	3.8	5.0	6.3	7.5
				Falling Limb	200	1.25	47	0.12	1.9	3.5	6.5	7.2	7.9	8.6
				Tail	75	2.75	37	0.12	0.8	1.4	8.7	8.9	9.1	10.0
5-year Storm	3.3 (8.4)	5	5	First Flush	500	0.58	85	0.12	3.4	11.7	0*	0.7	3.0	5.3
				Peak	1,100	0.32	70	0.12	4.8	14.7	0*	0*	1.2	4.1
				Falling Limb	800	0.40	54	0.12	4.2	9.7	0.3	2.3	4.2	6.1
				Tail	300	0.90	42	0.12	2.4	4.1	5.9	6.8	7.6	8.4
7-day, 10-year Low Flow	–	–	–	–	0.3	0.13	15	0.12	6.0	11.9	0*	0*	0*	0*

*Anaerobic

Notes:

1. Treatment Plant Paramteters for all Cases: Flow = 5.1 cfs; BOD = 27 mg/l; D.O. = 3.3 mg/l
2. Water temperature assumed to be 60 °F.
3. Initial stormwater D.O. estimated at 9.5 mg/l based on watershed observations.

Source: Colston, N.V., "Characteristics and Treatment of Urban Land Runoff," USEPA Report No. EPA-670/2-74-096 (NTIS No. PB 202 865), December, 1974.

An evaluation of the Milwaukee River Watershed (99) in Wisconsin led to the findings indicated in Table 124. This table shows estimates of dissolved

TABLE 124. POTENTIAL EFFECT OF COMBINED SEWER OVERFLOWS ON THE WATER QUALITY OF THE MILWAUKEE RIVER ABOVE THE NORTH AVENUE DAM[a]

				RIVER CONDITION IN AUGUST WITH AVERAGE FLOW (170 cfs)[c]						
				WITHOUT OVERFLOW			WITH COMBINED SEWER OVERFLOW			
Rainfall Runoff Depth in. (cm)	Annual Number of Runoff Events	Volume of Combined Sewer Overflows[b] ac-ft (ha-m) Per Event	BOD Per Event[f] lb (kg)	Volume/Day ac-ft (ha-m)	BOD/Day lb (kg)	DO lb/gal (mg/l)	Volume/Day ac-ft (ha-m)	BOD[f] lb (kg)	BOD[f] lb/gal (mg/l)	DO[d] 24 Hour After Overflow lb/gal (mg/l)
0-0.05 (0-0.13)	16	4.4 (0.54)	1,800 (816.5)	340 (42)	4,600 (2,087)	42 (5.0)	344 (42)	6,400 (2,903)	58 (7)	33 (3.93)
0.05-0.10 (0.13-0.25)	8	13.2 (1.6)	5,400 (2449.4)	340 (42)	4,600 (2.087)	42 (5.0)	353 (44)	10,000 (4,536)	83 (10)	26 (3.07)
0.10-0.30 (0.25-0.76)	15	35 (4.3)	14,000 (6350.3)	340 (42)	4,600 (2,087)	42 (5.0)	375 (46)	18,600 (8,437)	150 (18)	3.0 (0.35)
0.30-0.60 (0.76-1.5)	9	78 (9.6)	32,000 (14515.0)	340 (42)	4,600 (2,087)	42 (5.0)	418 (52)	36,600 (16,601)	267 (32)	0
0.60-1.00 (1.5 -2.5)	3.25	140 (17.2)	58,000 (26308.0)	340 (42)	4,600 (2,087)	42 (5.0)	480 (59)	62,600 (28,395)	401 (48)	0
1.00-2.00 (2.5 -5.1)	1.32	260 (32.0)	108,000 (48987.7)	340 (42)	4,600 (2,087)	42 (5.0)	600 (74)	112,600 (51,074)	576 (69)	0
4.00-5.00 (10.2 -12.7)	0.12	700 (86.3)	287,000 (130180.3)	340 (42)	4,600 (2,087)	42 (5.0)	1,040 (128)	291,000 (132,267)	860 (103)	0

[a]For purposes of this computation, each overflow event is assumed to mix with the volume of river flow for one day.
[b]Interceptor sewer capacity assumed to be 1.0 DWF, contributing area equals 2,100 ac (850 ha).
[c]Average August river flow based on 16 years of record (1949-1964) for Estabrook Park gauge. Average 5-day 20°C BOD of river and combined sewer overflow.
[d]Dissolved oxygen concentration at summer water temperature of 77°F (25°C).
[e]Frequency analysis based on 16 years of record (1949-1964) in the Chicago metropolitan area.
[f]Average 5-day BOD at 20°C of 150 mg/l, as reported by R.J. Burm, et. al., in 1968, for overflows from combined sewers of Detroit.

Source: "A Comprehensive Plan for the Milwaukee River Watershed: Inventory, Findings and Forecasts," Southeastern Wisconsin Regional Planning Commission, Waukesha, Wisconsin, December, 1970.

oxygen concentrations in the river for both dry and wet-weather conditions. All wet-wether contributions have been assumed to take the form of combined sewer overflows, with a BOD concentration of 150 mg/1. The comparison of dissolved oxygen concentrations for dry and wet-weather conditions suggests the relative impact of combined sewer overflows estimated to annually contribute about 10 percent of the average BOD arriving at the North Avenue impoundment during an average year. In an average year the remaining 90 percent of annual BOD originates in upstream flows and is due to industrial discharges, non-sewered runoff, stormsewer discharges, and sanitary sewer system bypasses. It should be noted, in addition, that the dissolved oxygen concentrations cited do not reflect sag point conditions, but rather conditions 24 hours after the overflow.

An analysis of the impacts of organic loadings on the Upper Potomac Estuary in Washington was performed to evaluate their effects on dissolved oxygen levels in various reaches of the receiving water. (106) A plan of the Potomac Estuary and the major receiving water quality problems identified in this water body are depicted in Figure 68. As an estuary, the receiving water is subject to tidal influences. The new outflow velocities experienced in the estuary due to these influences are shown in Table 125. As part of the overall analysis, data from two separate years were evaluated. One year, 1966, represented a low annual flow within the estuary while the second year, 1971, was one with an average annual flow.

A BOD_5 profile of the estuary appears in Figure 69. This figure indicates both acutal data and modelled estimates of BOD_5 concentrations. Definite BOD_5 peaks can be discerned from this profile. These were due to pollutional contributions from the discharges of Rock Creek, the Anacostia River and the treated effluents of the Blue Plains Wastewater Treatment Plant. The peaks at Rock Creek and the Anacostia River were not as discernible in the dry-weather BOD_5 profiles for the average flow year, 1971. A related low flow dissolved oxygen concentration profile is shown in Figure 70. This indicates the modelled and actual dissolved oxygen responses to the organic loadings represented for low-flow conditions. Both modelled and actual profiles depict substandard levels in various parts of the estuary. One of the major contributions to low dissolved oxygen levels is the treated effluents discharged from the Blue Plains Treatment Plant.

The effects of a storm event on the estuary are shown in Figure 71. Pre-storm conditions show a small peak due to Rock Creek contributions and significant additions due to the effluent from the Blue Plains Treatment Plant. Under storm conditions the contributions from direct and indirect runoff are apparent. The additions from Rock Creek are significant for the assumed storm conditions. Over time, the peak can be seen to proceed downstream.

An indication of the effects of dry-weather flow treatment is indicated in Figure 72. These data demonstrate the depression of dissolved oxygen levels associated with storm runoff and combined sewer overflows, over time, even though higher quality effluents are being discharged from the treatment facility. Thus, storm runoff and combined sewer overflows may exert a significant impact on receiving water bodies, and this must be considered in the analysis of receiving water quality.

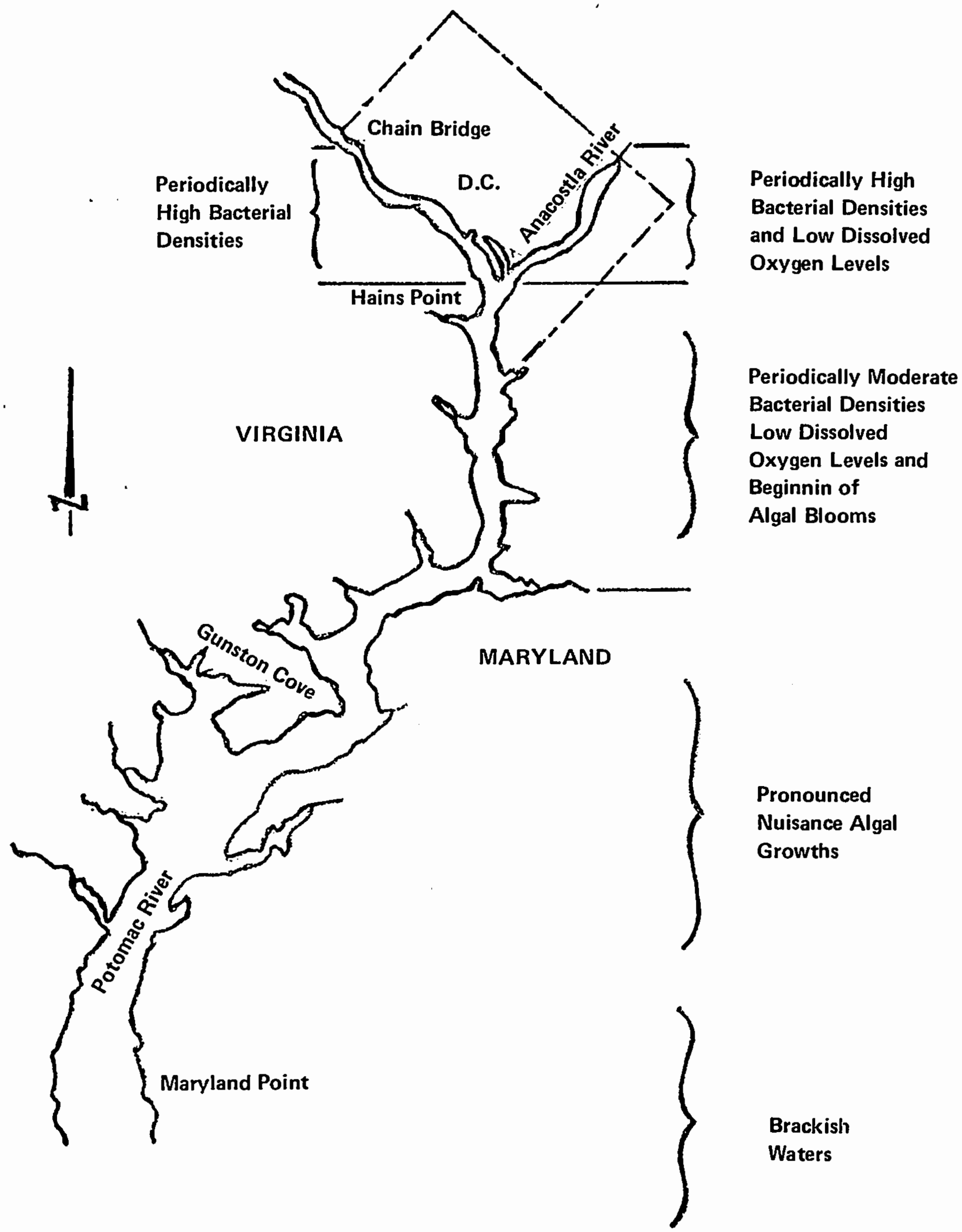


Figure 68. The Potomac estuary and its major pollution problems.

Source: Metcalf and Eddy Engineers and Water Resources Engineers, Inc., "Reconnaissance Study of Combined Sewer Overflows and Storm Sewer Discharges," a report prepared for the Department of Environmental Services, District of Columbia, Washington, D.C., March, 1973.

TABLE 125. TIDAL AND NET RIVER VELOCITIES

	24-HOUR VELOCITY, mi/day (km/day)					
	Downstream		Upstream		Net	
Location	1966	1971	1966	1971	1966	1971
Potomac River						
1. Roosevelt Island	1.21 (2.02)	3.27 (5.45)	0.46 (0.76)	0 (0)	0.75 (1.25)	3.27 (5.45)
2. Just below Blue Plains Plant	5.16 (8.60)	5.91 (9.85)	4.43 (7.38)	3.36 (5.60)	0.73 (1.22)	2.55 (4.25)
3. Hallowing Point	5.86 (9.77)	5.80 (9.67)	5.54 (9.23)	4.90 (8.17)	0.32 (0.53)	0.90 (1.50)
Anacostia River						
1. Main River at Upper End of Kingman Lake	1.22 (2.03)	1.47 (2.45)	1.11 (1.85)	0.81 (1.35)	0.11 (0.18)	0.66 (1.10)
2. Between Douglas & 11th Street Bridges	0.90 (1.50)	0.90 (1.50)	0.89 (1.48)	0.80 (1.48)	0.1 (0.16)	0.02 (0.03)

Source: Metcalf and Eddy Engineers and Water Resources Engineers, Inc., "Reconnaisance Study of Combined Sewer Overflows and Storm Sewer Discharges," a report prepared for the Department of Environmental Services, District of Columbia, Washington, D.C., March, 1973.

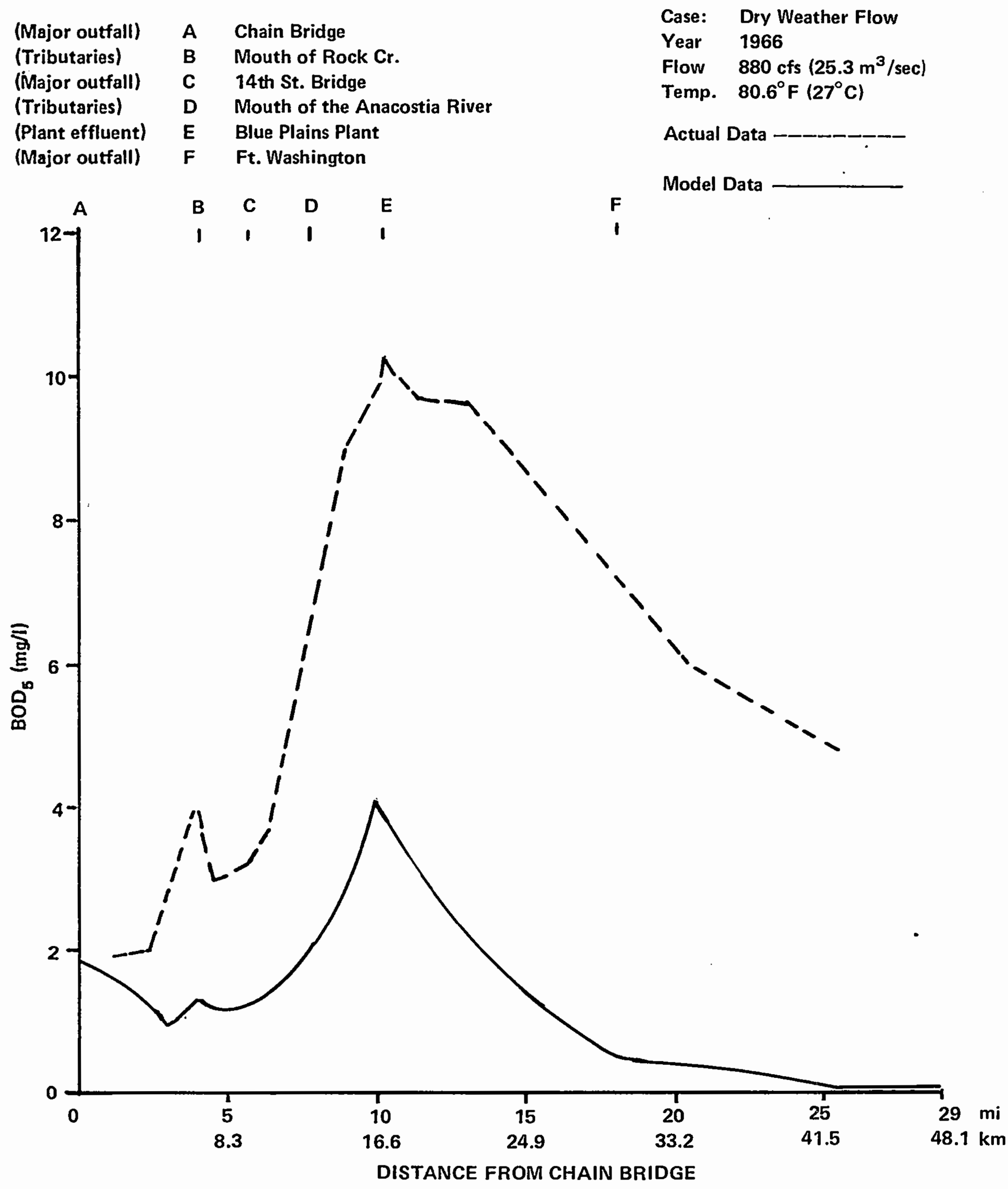


Figure 69. BOD_5 in the Potomac estuary. 1966 dry weather.

Source: Metcalf and Eddy Engineers and Water Resources Engineers, Inc., "Reconnaissance Study of Combined Sewer Overflows and Storm Sewer Discharges," a report prepared for the Department of Environmental Services, District of Columbia, Washington, D.C., March, 1973.

MAIN RIVER

(Major outfall)	A	Chain Bridge
(Tributaries)	B	Mouth of Rock Cr.
(Major outfall)	C	14th St. Bridge
(Tributaries)	D	Mouth of the Anacostia River
(Plant effluent)	E	Blue Plains Plant
(Major outfall)	F	Ft. Washington

Case: Dry Weather Flow
Year 1966
Flow 880 cfs (25.3 m^3/sec)
Temp. 80.6°F (27°C)

Standard ▮▮▮▮▮▮▮▮▮▮▮▮▮▮
Actual Data ---------
Model Data ————

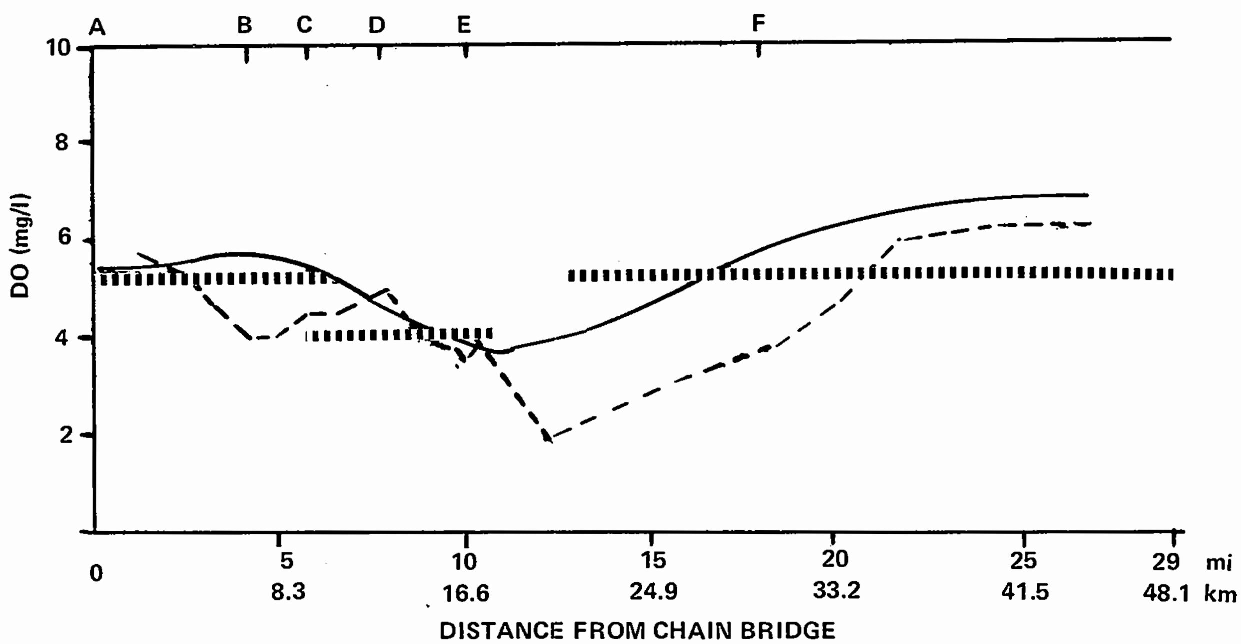


Figure 70. Dissolved oxygen in the Potomac estuary.
1966 dry weather.

Source: Metcalf and Eddy Engineers and Water Resources Engineers, Inc., "Reconnaissance Study of Combined Sewer Overflows and Storm Sewer Discharges," a report prepared for the Department of Environmental Services, District of Columbia, Washington, D.C., March, 1973.

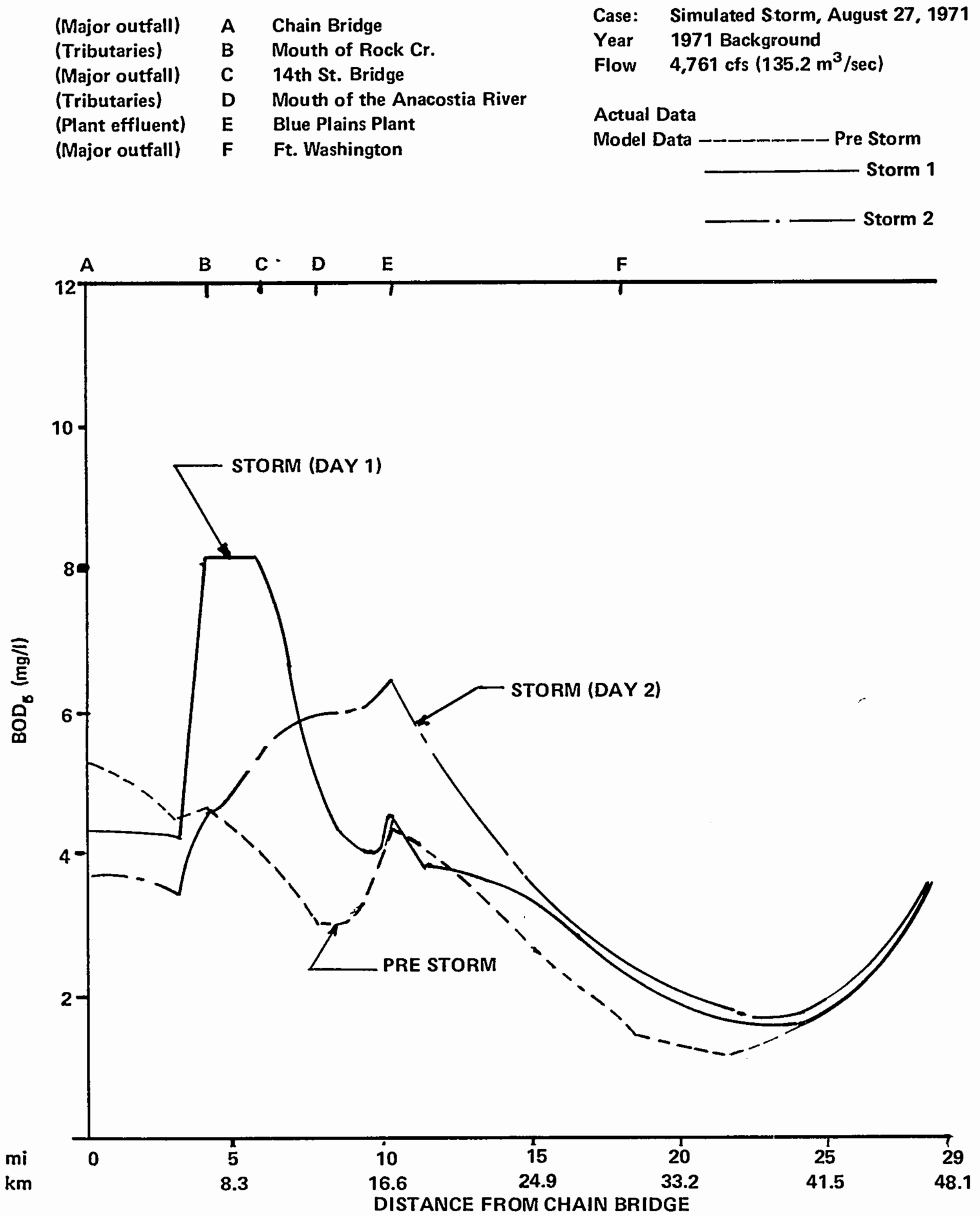


Figure 71. BOD_5 in the Potomac estuary. 1971 storm condition.

Source: Metcalf and Eddy Engineers and Water Resources Engineers, Inc., "Reconnaissance Study of Combined Sewer Overflows and Storm Sewer Discharges," a report prepared for the Department of Environmental Services, District of Columbia, Washington, D.C., March, 1973.

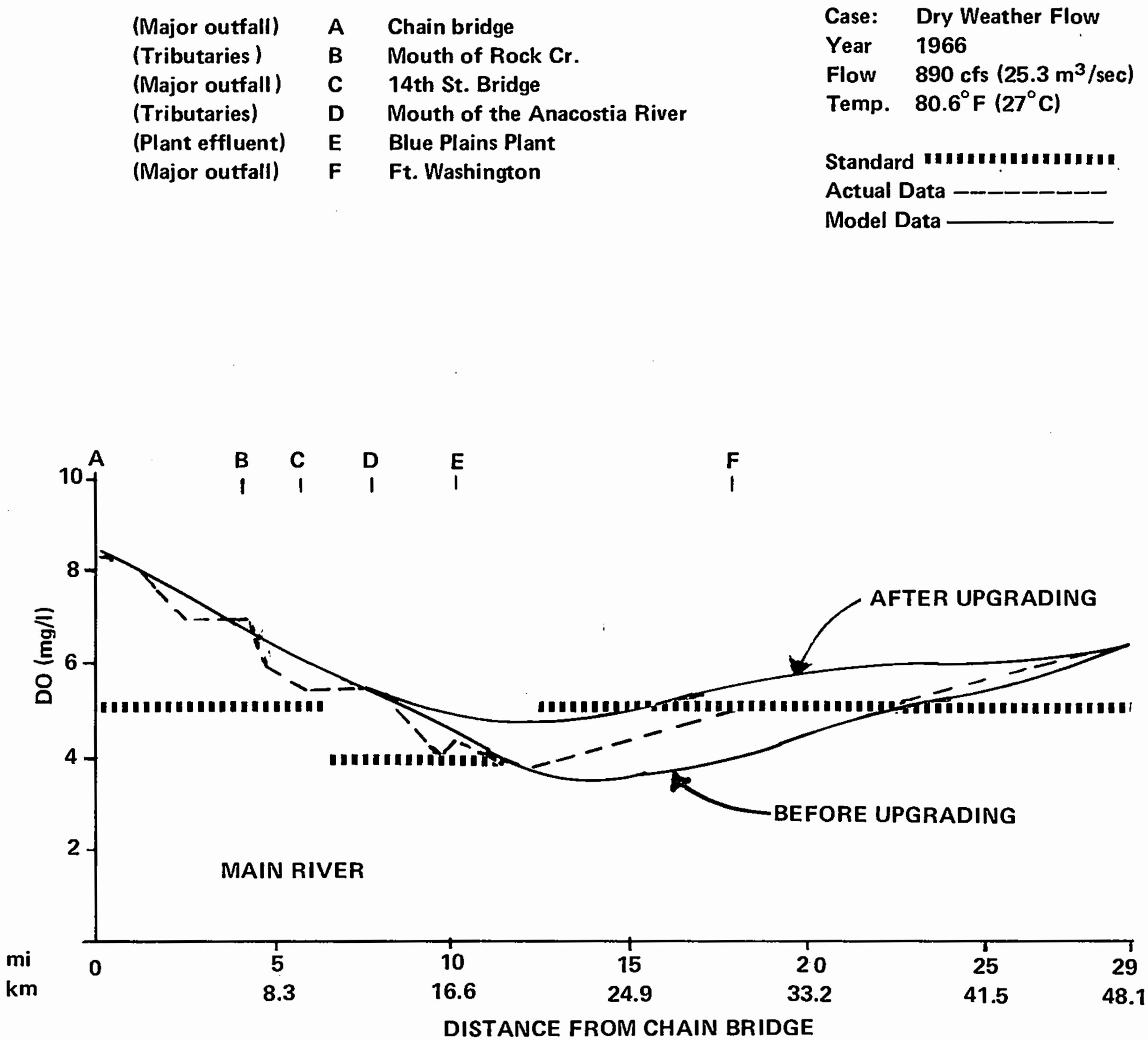


Figure 72. Dissolved oxygen in the Potomac estuary due to dry-weather flow treatment enchancement.

Source: Lager, John A., P.E., Vice President, Metcal and Eddy, Inc., "Application of Simplified Math Models for Combined System Impact Analysis," Palo Alto, California.

An assessment of a lake response to the contribution of oxygen-consuming contaminants was performed as part of the study of Onondaga Lake in New York. (105) In this analysis, the total oxygen demand was estimated to reflect the contributed effects of both carbonaceous and nitrogenous oxygen demand. Sufficient nitrifying bacteria were found in the lake waters, on the basis of 20-day oxygen demand tests, to indicate a significant impact.

An evaluation of lake hydrodynamics based on the structure of the lake and water currents produced the "stabilization zone" depicted in Figure 73. The "stabilization zone" is defined as that volume of the lake that will effectively stabilize the major sources of total oxygen demand under critical conditions of minimal lake water currents. Estimates of total oxygen demand for a number of sources were used in the analysis. These included waste discharges, air pollutants, benthic demand and the total oxygen demand produced within the lake itself.

Air pollution contributions were defined from a country-wide air pollution study, benthic demands were estimated from core samples and waste discharge contributions were determined from a detailed waste discharge survey of tributary streams. The lake stabilization depicted is a response to the average daily additions of total oxygen demand from each of these sources. Assumed variations in total oxygen demands to the receiving waters resulted in the curve shown in Figure 74. This curve relates the percentage of dissolved oxygen saturation at 17.4°C (63.3°F) for various levels of total oxygen demand contributions to the lake. A comparison of estimated existing loadings and projected loadings due to new sewage treatment facilities are shown in Table 126.

The indicated values are average daily loadings, based on a grab sampling program, with the exception of combined sewer overflows. Overflow quality estimates were taken as a percentage of the BOD tributary to the Metro Treatment Plant. These estimated loading values in Figure 74, indicate that septic conditions would be experienced with existing daily loadings and that approximately 50 percent of the saturated dissolved oxygen level (4.7 mg/l) could be realized by improvements to treated wastewater effluents. In this analysis, combined sewer overflows were considered relatively insignificant. The values assigned, however, were based on average conditions and as such, may not reflect the immediate impacts of direct runoff contributions throughout the tributary area other than overflows on select tributaries. These might be expected to produce greater short-term effects than shown.

The previous analyses have centered primarily on the impact of the apparent direct pollutional contributions of storm runoff and combined sewer overflows. The effects of shock loadings of biodegradable organic materials due to individual rainfall events, may appear to represent relatively transient conditions which, while undesirable, will dissipate over relatively short periods of time. Longer-term impacts may also result from these and other pollutional contributions to the receiving water body.

A study of receiving water impacts on the Menomonee and Milwaukee Rivers in Milwaukee, Wisconsin, disclosed some of these longer-term impacts. (99) This study was conducted to evaluate a combined sewer overflow detention tank and its effects

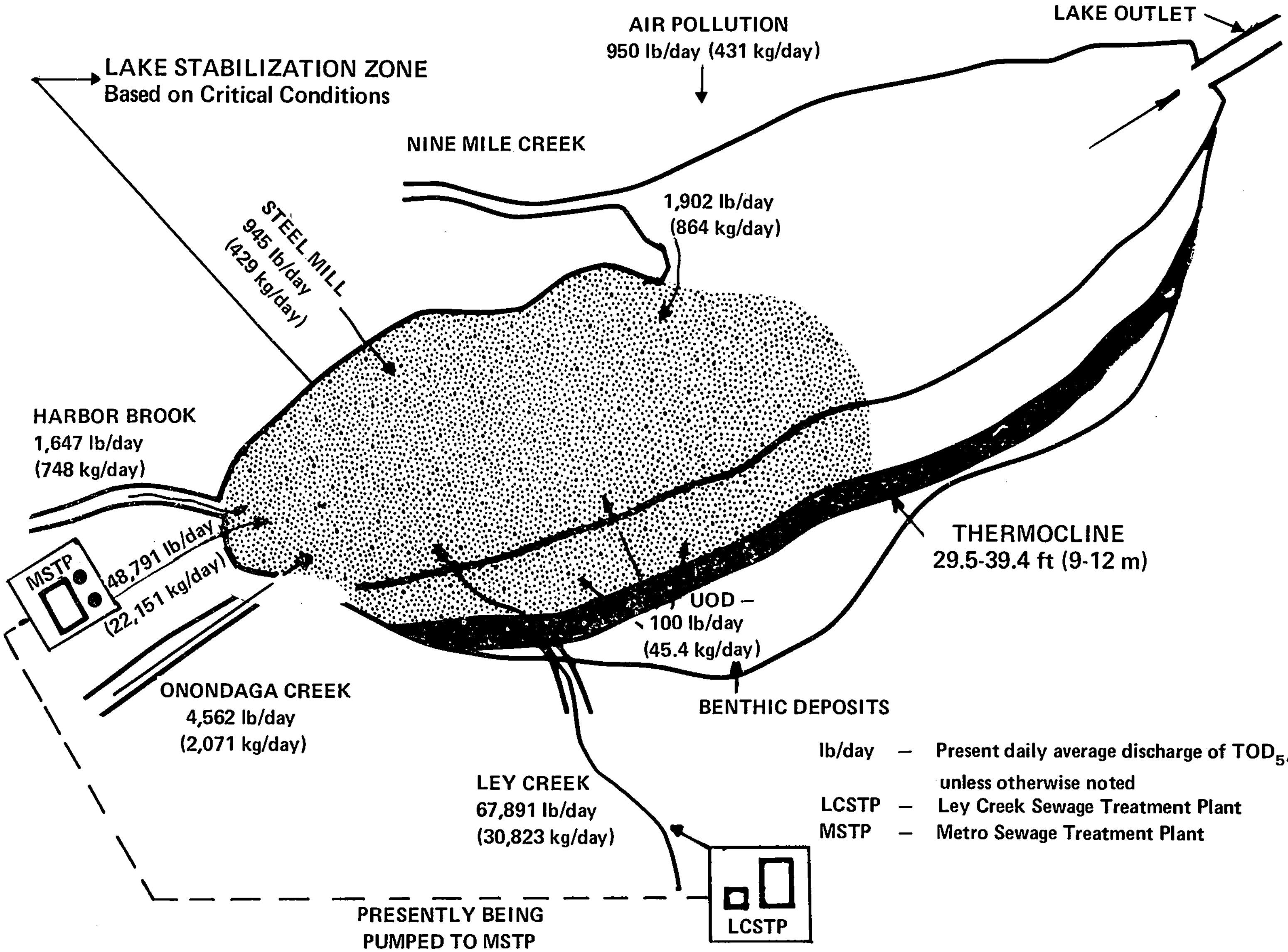


Figure 73. Onondaga Lake stabilization zone.

Source: O'Brien and Gere Consulting Engineers, "Onondaga Lake Study," USEPA Report No. 11060FAE4/71 (NTIS No. PB 206 472), April, 1971.

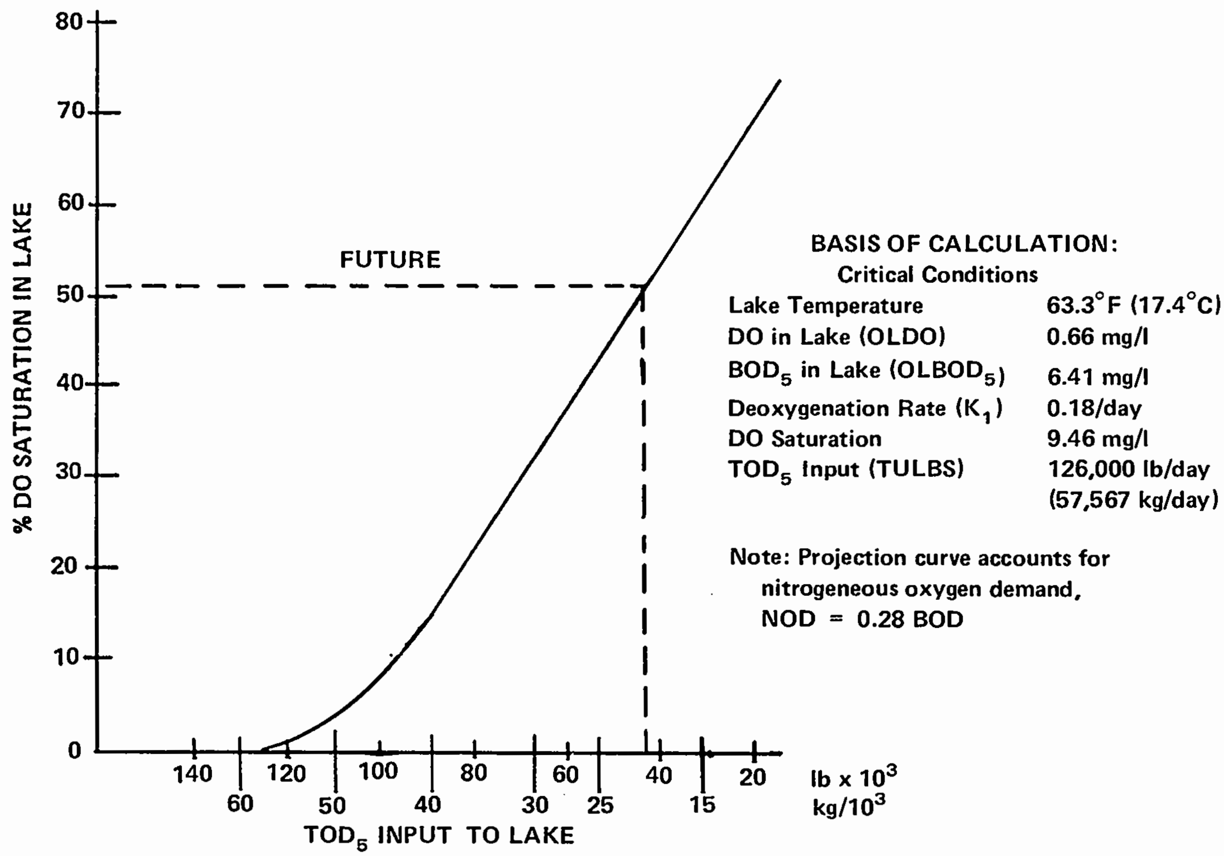


Figure 74. Lake dissolved oxygen versus BOD input.

Source: O'Brien and Gere Consulting Engineers, "Onondaga Lake Study," USEPA Report No. 11060FAE4/71 (NTIS No. PB 206 472), April, 1971.

TABLE 126. EXISTING AND PREDICTED LOADINGS TO ONONDAGA LAKE

	Existing Loadings		Existing Future Loadings	
	TOD_5			
	lb/day	kg/day	lb/day	kg/day
Metro Plant Effluent	48,791	22,200	8,100	3,690
Ley Creek Plant Effluent	67,891	30,860		
Lay Creek			13,381	6,080
Onondaga Creek	4,562	2,070	4,562	2,070
Harbor Brook	1,647	750	1,647	750
Combined Sewer Overflows	10,750	4,890	10,750	4,890
Nine Mile Creek	1,902	860	1,902	860
Steel Mill	945	430	945	430
Air Pollution	950	430	950	430
Benthic Demand	100	45	100	45
Total	137,538	62,500	43,337	19,700

Source: O'Brien and Gere Consulting Engineers, "Onondaga Lake Study," USEPA Report No. 11060FAE4/71 (NTIS No. PB 205 472), April, 1971.

on receiving water quality. Benthal deposits in the Milwaukee River were found to demonstrate a marked capacity to degrade water quality as measured by dissolved oxygen. An indication of this effect at two monitoring stations is shown in Figure 75. This figure shows that from 0.8 to 2.0 mg/l of dissolved

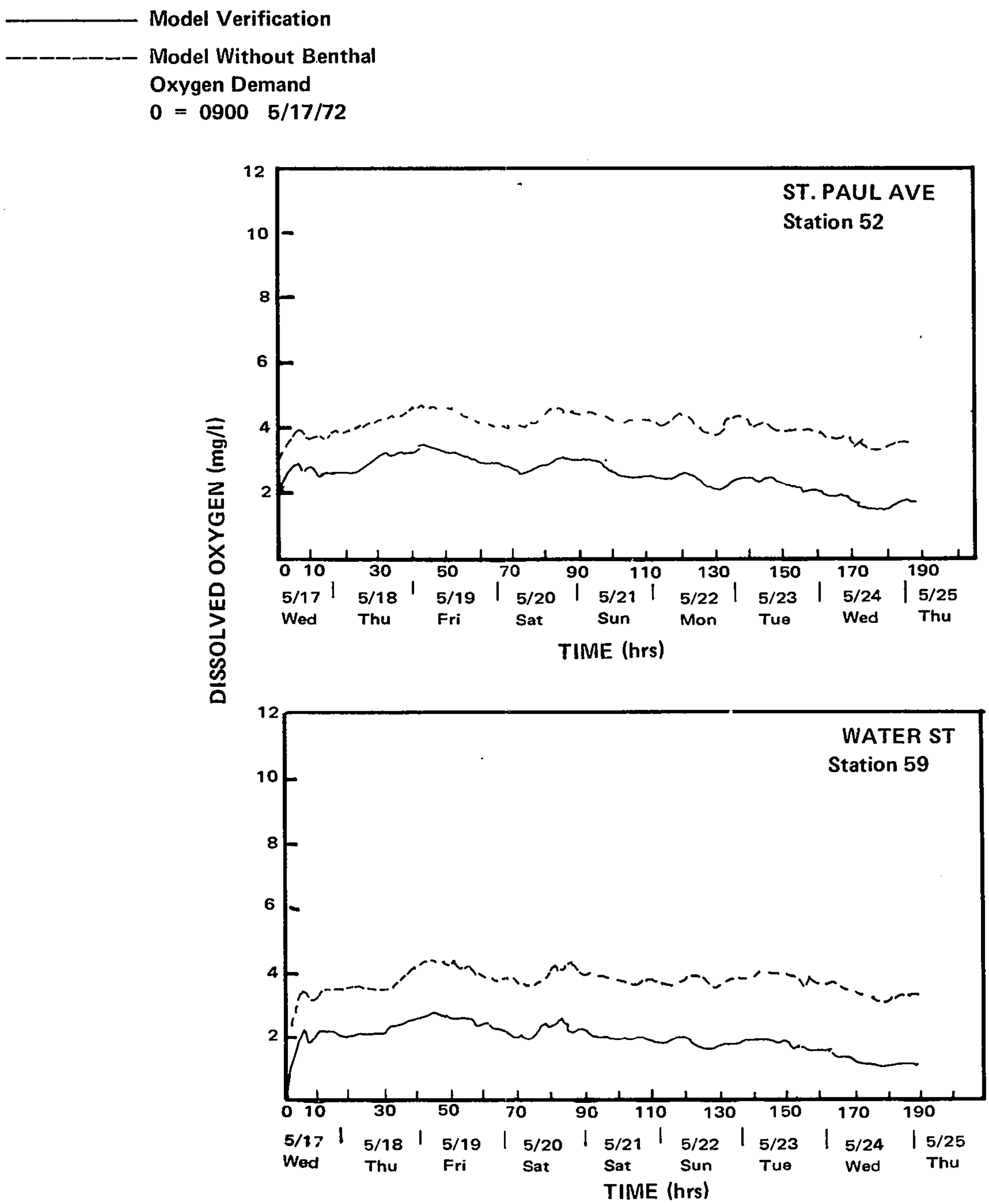


Figure 75. Oxygen demand effects of benthal deposits on dissolved oxygen levels.

Source: Consoer, Townsend and Associates, "Detention Tank for Combined Sewer Overflow, Milwaukee, Wisconsin," Demonstration Project prepared for the Milwaukee Department of Public Works, Wisconsin Bureau of Engineers, USEPA No. EPA-600/2-75-071 (NTS No. PB 250 427), December, 1975.

oxygen variation was due to these deposits. The variation in these benthal effects, with respect to increasing flows in the Milwaukee River, appear in Figure 76. This figure shows a reduction in dissolved oxygen deficits due to benthal deposits with increasing flow, as would be appropriate for a finite pollutant source. Thus, in mature streams and in other water bodies where sedimentation processes may occur, the deposition of contaminants may be expected to contribute to longer-term quality impairment. The resuspension of these contaminants caused by the flushing effects of large quantities of runoff can also magnify the impact of these events on water quality.

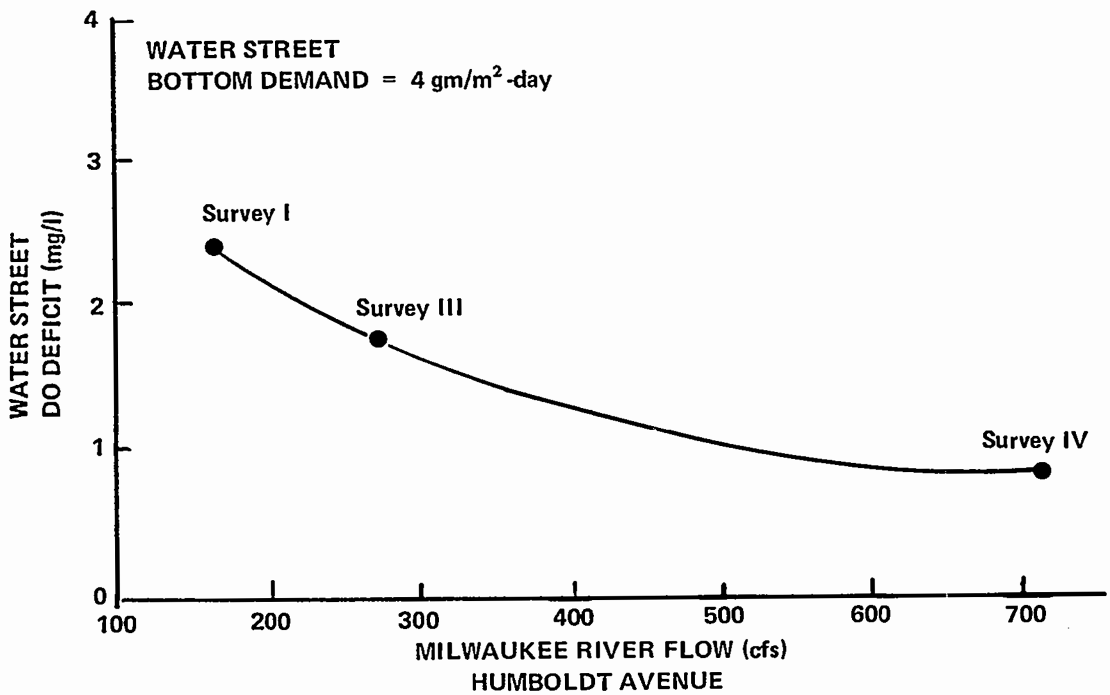


Figure 76. Dissolved oxygen deficit due to benthal oxygen demand.

Source: Consoer, Townsend and Associates, "Detention Tank for Combined Sewer Overflow, Milwaukee, Wisconsin," Demonstration Project prepared for the Milwaukee Department of Public Works, Wisconsin Bureau of Engineers, USEPA No. EPA-600/2-75-071 (NTS No. PB 250 427), December, 1975.

Nutrients

Abundant contributions of nutrients to a receiving water can produce nuisance conditions due to the growth of algae and aquatic plants, the production of highly organic sediments, and radical variations in dissolved oxygen concentrations due to the photosynthetic activity of these algae and plants. In lakes, nutrient enrichment can be a critical consideration in the beneficial uses of the water bodies. The effects of nutrient enrichment have been defined as:

- A steady decrease in the dissolved oxygen content of the hypolimnion when measured prior to the fall overturn.
- An increase in anaerobic areas in the lower portions of the hypolimnion
- An increase in dissolved materials, especially nutrients such as nitrogen, phosphorus, and simple carbohydrates
- An increase in suspended solids, especially organic materials
- A shift in aquatic organism community structure, involving changes in species types and the abundance of species and biomass
- A steady decrease in light penetration
- An increase in organic materials and nutrients, particularly phosphorus, in bottom deposits
- Increases in total phosphorus in the spring of the year. (94)

Few simple generalizations can be expressed covering nutrient loadings, concentrations, and the production of aquatic biota due to a number of physical influences such as receiving water depth, shore line extent, flow-through and detention time. (75) An indication of specific loading level guidelines are shown in Table 127.

TABLE 127. PERMISSIBLE LOADING LEVELS FOR TOTAL NITROGEN AND PHOSPHORUS
$lb/yd^2/yr$ ($gr/m^2/yr$)

Mean Depth Up To:		Permissible Loading, Up To:				Dangerous Loading in Excess Of:			
ft	m	N		P		N		P	
16.4	5	1.0	(0.54)	0.07	(0.04)	2.0	(1.1)	0.13	(0.07)
32.8	10	1.5	(0.8)	0.10	(0.05)	3.0	(1.6)	0.20	(0.11)
164.0	50	4.0	(2.2)	0.25	(0.14)	8.0	(4.3)	0.50	(0.27)
328.1	100	6.0	(3.3)	0.40	(0.22)	12.0	(6.5)	0.80	(0.43)
492.1	150	7.5	(4.1)	0.50	(0.27)	15.0	(8.1)	1.00	(0.54)
656.2	200	9.0	(5.0)	0.60	(0.33)	18.0	(9.7)	1.20	(0.65)

Source: Bartsch, A.F., "Role of Phosphorus in Eutrophication," USEPA Report No. EPA-R-3-72-001 (NTIS No. PB 228 292), August, 1972.

The addition of nutrients to receiving waters is an extremely complex process that must take into account transport mechanisms involving groundwater, point source discharges, overland flow, precipitation, atmospheric and dustfall contributions, and other source contributions such as nutrient enrichment due to resident flora and fauna. (35) It is generally considered that the effects of nutrient enrichment can be best controlled in the light of available treatment technologies by limiting the amount of phosphorus contributed to receiving waters. (29)

An estimated nutrient balance for the Milwaukee River Watershed is shown in Table 128. In this tabulation, the major contributions of phosphorus are due to rural and agricultural runoff. Urban runoff, although significant on a per-unit basis, is relatively unimportant from the standpoint of the percentage of the basin attributable to urban land uses. Some of the effects of this nutrient and aquatic plant-rich river environment on diurnal dissolved oxygen levels are shown in Figure 77. The data demonstrates the variations in dissolved oxygen concentrations that may occur as a result of the photosynthetic activities of aquatic life. These variations range from 1.5 to 10 mg/l in a single day.

As might be expected, radical diurnal changes in dissolved oxygen levels within a receiving water can cause a severe upset to the aquatic system and endanger various species of resident biota. Although the Milwaukee River watershed is primarily non-urban in character, the loading rates suggested indicate the potentials of the nutrient enrichment from urban receiving waters. A study of 52 lakes in the Minneapolis-St. Paul, Minnesota, area (96) showed that the quality of storm runoff was generally inferior to lake quality. Total coliform levels were 35 times greater, total phosphorus was six times greater, total Kjeldahl nitrogen was four times greater, and chloride levels were three times greater, on the average, than the assumed threshold concentration of 100 ppb that may produce eutrophication and poor aesthetic quality. Of the 52 lakes surveyed, 25 percent had phosphorus concentrations larger than this threshold value. This was generally attributable, in part, to storm runoff since all other identified wastewater effluents are discharged to the river system in the area.

Nutrient enrichment is an important consideration in evaluation of receiving water impacts. Enrichment can produce nuisance aquatic plant life that, in turn, can create environmental conditions deleterious to other receiving water biota, as well as an impairment to receiving water aesthetics. Urban runoff is a rich source of nutrients that can upset the balance of urban receiving waters. Interestingly, it has been found that although low concentrations of phosphate will slow algal growth rates, total algae production is dependent on the degree of phosphate replenishment from available sources. (107) Thus, even though advanced wastewater treatment may provide effective phosphorus control for domestic and industrial sanitary waste flows, untreated urban runoff may provide a consistent source of phosphate replenishment.

TABLE 128. MAJOR SOURCES OF PHOSPHORUS IN THE MILWAUKEE RIVER WATERSHED UNDER 1967 CONDITIONS (lb/yr x 0.45 = kg/yr)

Source[a]	Unit Amount of Phosphorus (As P)	Above West Bend		At North Branch		At Milwaukee County Line		At North Avenue Bay		Milwaukee River North Branch		Cedar Creek	
		lb	Percent	lb	Percent	lb	Percent	lb	Percent	lb	Percent	lb	Percent
Urban Runoff	460 lb/m^2/yr	800	5	2,600	5	7,200	7	29,400	5	1,000	8	1,300	6
Rural and Agricultural Runoff	60 lb/m^2/yr	12,500	61	16,000	32	37,000	33	37,000	11	9,000	69	8,000	34
Sewage Treatment Plant Effluent	1.9 lb/capita/yr	6,000	30	29,000	59	60,000	54	60,000	18	2,000	15	13,000	56
Private Sewage Disposal Systems	0.2 lb/capita/yr	1,000	5	2,000	4	7,000	6	7,000	2	1,000	8	1,000	4
Sanitary Sewer Overflows	--[b]	--[b]	--	--[b]	--	--[b]	--	168,000	51	--[b]	--	--[b]	--
Combined Sewer Overflows	--[c]	--[c]	--	--[c]	--	--[c]	--	30,000	9	--[c]	--	--[c]	--
Total		20,300	100	49,600	100	111,200	100	331,400	100	13,000	100	23,300	100

[a]Contributions from precipitation onto water surfaces and from industries were considered neglibible.

[b]Contributions considered negligible in upstream areas. The volume of overflow that takes place annually in Milwaukee County upstream from the North Avenue Dam was estimated to be 2,730 million gallons with phosphorus concentration as P equal to 2/3 of 10.7 mg/l (strength of bypassed influent Jones Island Sewage Treatment Plant).

[c]There are no combined sewer service areas in the Milwaukee River watershed upstream from Milwaukee County. The volume of overflow that takes place annually upstream from the North Avenue Dam was estimated to be 745 mg with phosphorus concentrations as P equal to 45 percent of 10.7 mg/l.

Source: Southeastern Wisconsin Regional Planning Commission, "A Comprehensive Plan for the Milwaukee River Watershed: Inventory, Findings and Forecasts, Regional Planning Commission, Waukesha, Wisconsin, December, 1970.

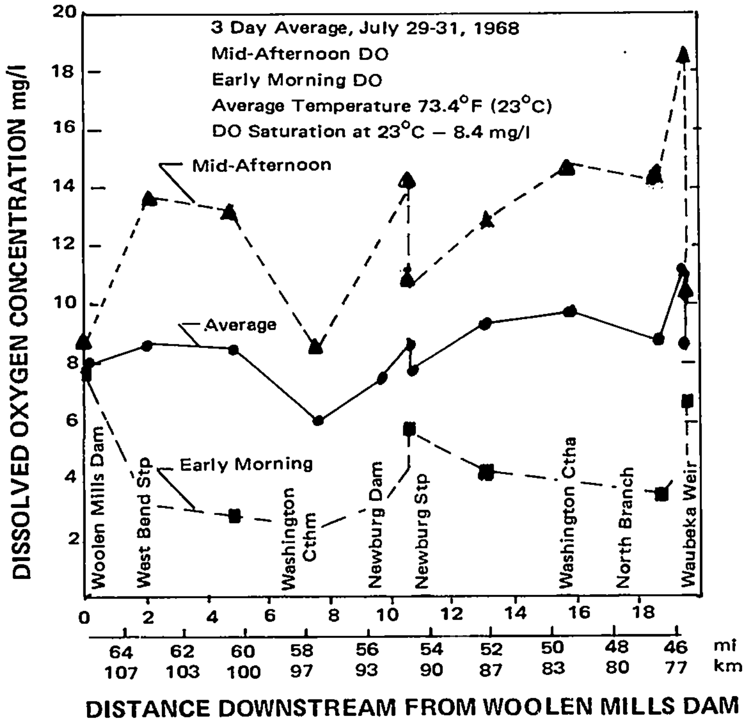


Figure 77. Measured dissolved oxygen profile. West Bend-Waubeka reach of the Milwaukee River, summer 1968.

Source: Southeastern Wisconsin Regional Planning Commission, "A Comprehensive Plan for the Milwaukee River Watershed: Inventory, Findings and Forecasts," Waukesha, Wisconsin, December, 1970.

Miscellaneous Receiving Water Impacts

The foregoing discussion has emphasized the impacts of biodegradable organic contaminants and nutrients on receiving waters. Other important receiving water impacts may be attributable to such other factors as temperature changes, chlorides, pesticides, heavy metals, and other toxic materials.

Temperature effects can be attributed to deforestation activities, stream channelization, and the impoundment of flowing water. (94) It has been found that average temperature elevations about 4°C (7°F) above ambient summer temperatures in a marine environment caused almost barren conditions where few animals and almost no micro-algae or seagrasses existed, between 3 and 4°C (5.4 and 7°F), serious depletion occurred in the biota, and between 2 and 3°C (3.6 and 5.4°F), damage to the summer biota occurred. (108)

In Minneapolis-St. Paul, higher runoff chloride concentrations due to winter snow and ice control activities were noted. Mean winter concentrations were found to be around 300 mg/l while summer runoff concentrations were approximately 24 mg/l. Annual contributions to the lake system amounted to 5.1 mg/l. It was found that high chloride concentrations provided a stimulus to the growth of blue-green algae, a major local lake nuisance. High level lake concentrations also cause an incomplete turnover of domestic lakes that prevent the oxygen rejuvenation of deep lake water. (96)

Runoff has been found to be the major transport mode for various herbicides (109) and pesticides. (110) The soil insecticides such as dieldrin, and herbicide Trifluralin, have been found to accumulate in fish and snails in concentrations above those found in the water. (92) A representation of the pesticide residues found in a number of water bodies is shown in Table 129.

TABLE 129. PESTICIDE RESIDUES MEASURED IN VARIOUS RECEIVING WATER BODIES

	Concentration in mg/l						
Location	**Dieldrin**	**Endrin**	**DDT**	**DDE**	**DDD**	**Heptachler**	**BHC**
Great Lakes Region*							
St. Lawrence River: Massena, N.Y.	ND	ND	ND	.002	ND	ND	ND
Lake Erie: Buffalo N.Y.	ND	ND	ND	ND	ND	ND	ND
Detroit River: Detroit Michigan	ND	ND	ND	ND	ND	ND	ND
St. Mary's River: Sault Ste. Marie, Michigan	ND	ND	ND	ND	P	ND	ND
Lake Superior: Duluth, Minn.	ND	0.022	0.026	P	0.005	ND	ND
Lake Michigan: Milwaukee, Wis.	ND	ND	ND	ND	ND	ND	ND
Maumee River: Toledo Ohio	ND	ND	ND	ND	0.006	ND	ND
St. Joseph River: Benton Harbor, Mich.	P	0.29	ND	ND	0.013	ND	0.003
Grand River: Grand Haven, Mich.	P	ND	ND	ND	0.009	ND	ND
Detroit River, Grosse Ponte, Mich.	ND	ND	ND	ND	0.012	ND	ND
Fox River: Green Bay, Wis.	ND	.007	ND	ND0.007		ND	ND

ND — indicates none detected.
P — indicates presumptive. Data are reported as presumptive in instances where the results of chromatography were highly indicative but meet all requirements for positive identification and quantification.

*Agricultural Pollution of the Great Lakes Basin, Combined Report by Canada and the United States, July 1, 1971.

Polychlorinated biphenyls were also found to accumulate in snails and fish increasingly as the number of chlorine substituents increased. (92) Many of these materials show some toxic effects on various receiving water biota at sustained low-level concentrations.

The effects of heavy metals buildup in receiving waters are not well understood. Their toxicity is well established and their unabated discharge is a cause for concern. (90) Dangerously high lead concentrations have been measured in snow melt runoff (96) as well as urban storm runoff. (111) Other significant metals have been noted, as well.

Receiving Water Components

Various analyses have been performed to assess the impact of runoff on receiving water bodies, both hypothetical and based on actual data. The results of these analyses on the transient and longer-term effects of biodegradable contaminants and their effects on dissolved oxygen levels, nutrients and nutrient impacts, and miscellaneous contaminants, point to an array of consistent conclusions:

- Direct and indirect urban runoff contributions can be a significant source of pollution.
- The pollutant percent loadings in sewers and in non-sewered urban runoff provides one estimate of the annual distribution of various pollutants in major wastewater flows across the country, as shown in Table 130.

TABLE 130. POLLUTANT PERCENT LOADINGS IN SEWERS AND IN NON-SEWERED URBAN RUNOFF

	PERCENTAGES OF INDIVIDUAL COMPONENTS IN EACH STREAM			
	Combined Sewers	Sanitary Sewers	Storm Sewers	Non-Sewered Urban Runoff
BOD_5	28.6	61.2	4.5	5.6
COD	27.7	48.0	10.8	13.5
SS	26.3	28.6	20.1	25.1
N	29.3	63.2	3.3	4.2
P	28.1	61.2	4.8	5.9
Inorg. DS	29.4	70.6	0	0
		% Coliforms/yr		
Total MPN Coliforms	29.2	70.1	0.3	0.4

Source: Bostian, H.E., "The Relative Magnitudes of Municipal Water Pollution Problems," an unpublished EPA paper, September, 1974.

This table shows that approximately 40 percent of the BOD, 50 percent of the COD, and 60 percent of the suspended solids are associated with combined sewers, storm sewers, and non-sewered urban runoff flows.

- Under given wet-weather conditions, direct and indirect storm runoff can govern the quality of receiving waters because of their shock impact characteristics.

- High levels of dry-weather treatment may not insure receiving water quality under wet weather conditions.

- The abatement of runoff-related pollution may be more cost-effective than providing higher levels of dry-weather flow in many circumstances.

Hence, direct and indirect runoff should not be casually dismissed if effective means of insuring receiving water quality are to be achieved. Urban runoff in its many forms is an important aspect of urban wastewater pollution and it warrants careful consideration as a necessary added dimension in local, regional, and national water resources planning.

SECTION VI

DATA NEEDS

One of the essential features of the study has been the development of an analytical framework that provides the quality and quantity characterization of direct stormwater runoff pollution. The informational outputs from this type of activity can reveal not only the total magnitude of pollutional loads entering receiving waters but also holds the key to identifying the relative effects and relationships of the various existing pollutional sources. Based on this knowledge of relative pollutional contributions from the many sources, alternative plans for abatement and control can be identified and evaluated in terms of program costs and related benefits. Such an analysis will provide a basis for the reduction of the pollutional impact on receiving waters in an efficient fashion.

To accomplish these objectives it is necessary to bring into use various analytical tools. Such tools are necessary due to the extremely complex nature of the component parts of the many physical processes that constitute runoff phenomenon and the high level of interaction between these processes. In view of this complexity it is extremely difficult, if not impossible, to provide meaningful information regarding the above objectives without taking advantage of various analytical techniques that are available.

The state of the art methodology for providing the needed informational outputs requires a large amount of data. This section of the report will present a critical review of existing data and discuss the data requirements for using and validating the tools at our disposal that can provide the results necessary for the evaluation of stormwater runoff pollution.

EXISTING DATA

The existing data sources have been reviewed in detail in the foregoing sections. These data can best be described as:

- Collected for purposes that are extremely different from one data set to the next,
- Collected for types of pollutants that are inconsistent from test to test,
- Collected with sampling devices that are not comparable with one another,
- Collected under physical conditions that are quite dissimilar, and
- Collected using measurement and sampling techniques that are incommensurable.

Other generalizations concerning existing data can be made. For the most part the data results are reported in terms of (arithmetic) average values. However, the wide range of values reported and relatively large standard deviations suggests that average and mean values may not be reliable measures of central tendency. Other measures of central tendency such as the mode, median, or geometric mean should be considered in these instances.

Much of the data that reports pollutional loadings by land use types, geography, city, etc., uses the overall average value for a complete data set when individual average values do not differ "significantly" from the overall values. This can be very misleading, since "significance" is as much dependent on the discriminating power of the statistical test being used as well as the real difference in the average values being tested.

This high level of variability represents an underlying weakness of the existing body of information. The inconsistencies, variation and diversity in the data impose limitations on its usefulness and as such should be used with caution. Although this weakness is present, the data discussed and used in this report are the best available at this time.

DATA REQUIREMENTS

Before specific gaps in existing data can be addressed, the issue of consistency must be considered. Adding to the available voluminous data, more data than is collected in a piecemeal, uncoordinated manner will only compound current problems. Future efforts at data acquisition must be carefully planned and executed in terms of the uses to which the data are to be applied.

Since the problem is basically one of national scope, any solution attempted at other governmental levels will fall short of the goal of insuring that the data sets collected in the future are not only commensurable with one another, but also that the scope of other data collected is adequate for the state-of-the-art analysis techniques. USEPA has just published a report which establishes a handbook of accepted standards and specifications for data acquisition for urban stormwater discharges. (75)

Physical-Geographic Data

1. Validation of the assumption (the estimating function) that land use distribution may be estimated by population density.

2. Validation of the techniques for estimating the percentages of pervious and impervious area in an urban area as well as the validation of the technique for decomposing the impervious areas into street and non-street impervious area.

3. Validation of the methods used for estimating total curb or gutter length.

An alternative to validating these three estimating techniques would be to develop in each urban area of concern actual data for the three variables being estimated. These variables are of such a nature, however, to make this a burdensome, time consuming task, a task that would be open ended, with a real possibility that the end results would be incomparable. Thus it appears that validation and refinement, is necessary, if the estimating techniques would be the logical choice.

These validations should take the form of a carefully planned experimental design that would take into account possible underlying influencing parameters such as climatology, legal restrictions, and possibly terrain. Based on this design, selected urban areas would then have the actual values of these variables measured and compared, statistically, to the values produced by the estimating techniques. This comparison will result in either a validated estimating technique or guidelines for refining the method.

Pollutional Loadings by Source

1. Streets

As reported in Section III, Application of Street Surface Contaminant Data, calibration factors have been prepared that produced reasonable estimates for individual runoff events, but only for selected pollutant types. This calibration process applied measured annual average runoff discharge pollutant concentrations to reported pollutant to solids relationships and on this basis adjusted the dust and dirt (solids) values on the street.

This approach, however, neglects the possibility of error in the analytical tool that "transports" the loadings from the street to the point of measurement. If this tool underestimates the transport mechanism, and loadings from other sources, such as rooftops, are also underestimated or even ignored, then application of this calibration procedure will allocate a disproportionate share of the pollutant loading to the street source. This has the obvious result of placing too strong an emphasis on streets as a point of control.

It would appear more logical to develop a standard "in-situ" method for measuring street pollutional loadings, since once the pollutants have entered the collection system the loadings from the different sources are mixed together. Thus, no matter how accurately the runoff pollution is measured, the results will not trace the pollutants back to the respective source. This method would have to be fairly simple and not require more time than local jurisdictional people would be willing or able to give.

2. Non-Street Impervious (Rooftops, Sidewalks, Parking Lots, etc.)

The only data that have been used for estimating pollutional loadings for this source has been the reported dustfall data. Dustfall data is not representative of other than rooftop surfaces, and does not address possible pollutants on these surfaces from other than dustfall sources, such as animal droppings, decomposition of debris, etc. In light of the fact that non-street impervious areas have been shown to be significant contributors to the total runoff pollutant discharge it is warranted to establish quantitatively the pollutional loadings for this source. This would preferably be done by land use categories with consideration given to where the runoff from these sources is directed, i.e., storm or sanitary sewers, open culverts, etc.

3. Pervious Areas (Soil Loss)

By applying the Universal Soil Loss Equations to individual events, pervious areas have been shown to be potentially significant contributors of sediment and other nutrients such as nitrogen and phosphorus. The use of these equations to estimate soil loss for short term events needs to be validated for use with small urban parcels or other methods should be developed.

Controlled Removal Effects

The effects of controlled removal are crucial to the evaluation of stormwater runoff. This is especially true with the increased use of vacuum and combined brush-vacuum street cleaning systems, as this equipment has been demonstrated to be very efficient in removal of the finer particles that contain most of the pollutant loadings. Thus, the equipment efficiency combined with the frequency of cleaning can drastically reduce the pollutant loadings in a given urban area.

Some street cleaning frequency data, stratified by population ranges and climatic zones, is available. The data is sparse in some places and additional data are needed. Data on equipment efficiency, however, is very much lacking. This is exhibited by the wide range of values reported in the available test data. This wide range of values is mostly caused by the fact that efficiency is almost totally dependent on equipment conditions and operation. Additional data will not improve this situation unless some effort is made to maintain equipment at specified minimum levels and to standardize optimum equipment operation.

Rainfall Events

Analytical efforts to date have assumed uniform rainfall distribution over an entire area. This assumption needs to be tested by performing sensitivity analysis on the evaluation tools being used. This could be done by selecting a number of areas and in each area measure the actual rainfall in enough locations to accurately reflect the true rainfall distribution and scale the hypothetical statistical analysis of rainfall density by the true rainfall pattern. If the analysis tools are in fact sensitive to the true rainfall distributions then the methodology must be modified.

Transport Mechanism (Pollutant Removal)

Negative exponential decay functions have been used very successfully to describe the street pollutant removal phenomenon. The function contains a critical parameter that is dependent on the street surface characteristics. The function has been well tested and documented.

This same function has been used to describe the non-street impervious runoff. This is a logical application of the function since both processes are physically analogous. However, representative values for the type surface parameter are not available. Thus, the application of the function needs to be validated and from this process determine the necessary parametric values for rooftop surfaces.

Direct Measures At Receiving Water Sites

This data will be used to verify directly several components of the modelling effort that evaluates the stormwater runoff phenomenon. It includes measuring runoff quantities continuously over the time period of various types of rainfall events combined with an adequate number and type of individual samples. The sampling plan for extracting these individual samples must be such that the relationship between flow quantity and pollutant loadings can be established. Since technology does not exist for continuous sampling of pollutants in runoff flow, this continuity must be approximated by judiciously selecting discrete points over the life of the rainfall event at which to procure a sample.

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APPENDIX

DATA MANAGEMENT FOR STREET SURFACE SOLIDS ACCUMULATIONS

Three sources of data on street surface accumulations exist. These are the results of studies by APWA for Chicago, (15) by URS Research Company in various cities across the country (43) and by Biospherics, Inc. for Washington, D.C. (6) Each of these studies explored the pollutional potentials of street surface accumulations. Land-use was acknowledged as a means of classifying and characterizing the results of field measurements except in the case of the studies in Washington, D.C., where the contribution from vehicular traffic was investigated in some detail. The selection of sampling sites was based on the assumption that land-use effects could be minimized. Even so, two sites in commercial areas were acknowledged in this study as having strong land-use influences.

Some variation in field measurement technique occurred in each study. The largest and most susceptible component to the effects of runoff was taken to be the dust and dirt fraction of the total street accumulation. In one case, this was defined as the fraction passing a 3.2 mm (0.125 in) screen, (15) in another, it was assumed to be the fraction passing the U.S. No. 6 sieve (43) and in the last, it was defined as being less than 6.35 mm (0.25 in) in size. (6)

Field measurements were generally taken by sweeping, in some instances they were obtained by a combination of sweeping and vacuuming, and in other cases they represented a combination of sweeping, vacuuming and flushing with water. As may be expected, each of these sample collection methods could yield somewhat different tresults. The most significant of these relates to the use of flush samples.

An array of the types of samples collected in each of the aforementioned studies is shown in Table A-1.

The most consistent sampling accomplished to date has been through sweeping and, in some instances, vacuuming. Measurements taken on this basis account for 90 percent of available samples collected at identified land use sites, while 10 percent included flush sampling components.

The geographical distribution of the field observations of dust and dirt accumulations is presented in Table A-2.

TABLE A-1. DISTRIBUTION OF AVAILABLE LAND USE RELATED SAMPLES BY MAJOR SAMPLING CHARACTERISTICS

Sample Location	Sample Type	Single-Residential	Multiple-Residential	Commercial	Industrial	Total
Chicago	Sweeping	60	93	126	55	334
	Flush	—	—	—	—	—
Many Cities	Sweeping	13	8	10	12	43
	Flush	8	6	7	8	28
Washington	Sweeping Vacuuming	—	—	22[1]	—	22
	Flush	—	—	14[1]	—	14
Total	Sweeping (Vacuuming)	73	101	158	67	399
	Flush	7	6	21	8	42
		80	107	179	75	441

[1] Data available in separate dust and dirt and flush fractions.

TABLE A-2. DISTRIBUTION OF AVAILABLE LAND USE RELATED DUST AND DIRT SAMPLES BY GEOGRAPHICAL AREAS

Location	Single-Family Residential	Multiple-Family Residential	Commercial	Industrial	Total
Great Lakes—Upper Mississippi	62	95	128	57	342
Chicago, Ill.	(60)	(93)	(126)	(55)	(334)
Milwaukee, Wis.	(2)	(2)	(2)	(2)	(8)
New England—Mid Atlantic—Ohio	3	0	22	2	27
Bucyrus, Oh.	(3)	(0)	(0)	(2)	(5)
Washington, D.C.	(0)	(0)	(22)	(0)	(22)
S. Atlantic Gulf—Lower Mississippi	0	0	0	0	0
Arkansas—White—Red Texas Gulf	0	0	0	0	0
California—Great Basin Upper Colorado—Lower Colorado—Rio Grande	8	6	8	8	30
San Jose, Calif.	(4)	(2)	(4)	(4)	(14)
Phoenix, Az.	(4)	(4)	(4)	(4)	(16)
Pacific NW—Missouri Basin	0	0	0	0	0
Totals	73	101	158	67	399

The major geographical categories shown are cited in terms of the water resources regions identified by the Water Resources Council. Individual cities included within the data set are also identified. The majority of all samples have been collected in the Great Lakes area, in Chicago, Illinois, and Milwaukee, Wisconsin. The remainder of the identified regions are represented by considerably less field observation data. Although statistical comparisons of aggregated data for some of the regions are possible, few land use-related comparisons could be reasonably accomplished due to small sample sizes or non-existent data. The addition of flush sample data would not alter this circumstance meaningfully. Reaggregation of the data into four major regions -- Northwest, Southwest, Northeast and Southeast -- would still result in an inadequacy of data for the Northwest and Southeast regions. Thus, it appears that specific comparisons on a regional basis, are not warranted.

GLOSSARY

BOD /removal efficiency: Measurement of the BOD data is used in sizing of waste treatment facilities and for measuring the efficiency of some treatment processes. The rate at which dissolved oxygen will be required can also be calculated from BOD data.

catch basin: A chamber or well, usually built below grade at the curb line of a street, for the admission of surface water or drainage to a sewer or subdrain, having at its base a sediment sump designed to retain grit and sediment below the point of overflow.

combined sewer: A sewer receiving both intercepted surface runoff and municipal sewage.

combined sewer overflow: Flow from a combined sewer in excess of the interceptor or regulator (preset diversion) capacity that is discharged into a receiving water.

confidence interval: Provides a method of stating both how close the value of a single term is likely to be to the value of a parameter and the chances of its being that close.

core city (central city): The major jurisdiction of 50,000 inhabitants or more within the SMSA. In addition to the county or counties containing such a city or cities, contiguous counties are included in an SMSA if, according to certain criteria, they are socially and economically integrated with the central city.

demographic: Science of the condition, general movement and progress of population in civilized countries. The dynamic balance of a population, expecially with regard to density and capacity for expansion or decline.

depression storage: Watershed capacity to retain water in puddles, ditches, depressions and on foliage.

detention time: The theoretical time required to displace the contents of a tank or unit at a given rate of discharge (theoretically defined as volume divided by rate of discharge).

direct pollution: The processes by which urban runoff that may be accumulated and collected into a separate storm sewer collection system and may suffer impairments in its quality.

direct runoff: The runoff that enters stream channels promptly by flow over the ground surface or through the ground without entering the main water table, or that portion of the runoff which is directly associated with causative rainfall or snow melt.

dissolved oxygen: Usually designated as D.O. The oxygen dissolved in sewage water or other liquid usually expressed in mg/l or percent of saturation.

D.O. deficit: The difference between the actual oxygen content of the water and the saturation content at the water temperature. The process of reoxygenation and deoxygenation go on simultaneously. If deoxygenation is more rapid than reoxygenation, an oxygen deficit results. The amount of dissolved oxygen at any time can be determined if the rates of reoxygenation and deoxygenation are known.

D.O. sag: A graphical representation of the decreasing dissolved oxygen concentration against distance downstream. This curve is attributed to active biological decomposition which begins immeidately after discharge. This decomposition utilizes oxygen. Finally, the critical dissolved-oxygen point, at which the rate of oxygen utilized for waste decomposition equals the rate of atmosphere reaeration, is reached on this curve. Downstream from this point, the rate of reaeration is greater than the rate of utilization and dissolved oxygen begins to increase.

dominant soil characteristics: The following soil properties are of the most significance: 1) sheer strength, 2) density, 3) compressibility, 4) permeability, 5) color, 6) composition (grain size, shape, plasticity, mineralogy), 7) structure of soil.

dry-weather flow: The flows in a combined sewer that result from domestic sewage discharges with no significant contribution by stormwater runoff.

dust and dirt: The portion of street refuse which is smaller than 0.32 cm (0.125 in).

erosion: (1) The wearing away of the land surface by running water, wind, ice, or other geological agents, including such processes as gravitational creep. (2) Detachment and movement of soil or rock fragments by water, wind, ice, or gravity. (3) The spattering of small soil particles caused by the impact of raindrops on wet soils. The loosened and spattered particles may or may not be subsequently removed by surface runoff.

evapotranspiration: The unit amount of water used on a given area in transpiration, building of plant tissue, and evaporated from adjacent soil, snow, or intercepted precipitation in any specified time.

first flush: The condition, often occurring in storm sewer discharges and combined sewer overflows, in which a disproportionately high pollutional load is carried in the first portion of the discharge or overflow.

frequency of storm (design storm frequency): The anticipated period in some time frame (ex. yrs.), which will elapse, based on average probability of storms in the design region, before a storm of given intensity and/or total volume will recur; thus, a 10 year storm can be expected to occur on the average once every 10 years. Sewers designed to handle flows which occur under such storm conditions would be expected to be surcharged by any storms of greater amount or intensity.

hydrograph: A graphical representation of liquid flow versus time with time on the horizontal axis.

hyetrograph: An intensity-time graph for rainfall derived from direct measurements.

impervious: Not allowing or allowing only with great difficulty, the movement of water. Impermeable. Waterproof.

indirect pollution: Refers to runoff as a diluent to other wastewater flows.

infiltration: The water entering a sewer system and service connections from the ground, through such means as, but not limited to, defective pipes, pipe joints, connections, or manhole walls. Infiltration does not include, and is distinguished from, inflow.

interevent time: The period between points of time or events.

land use: Differentiating the spatial arrangements and activity patterns of the urban area. From a variety of research studies it became clear that quantityt and quality of runoff could be related to the intensity and spatial separations of land use.

litter: Material which can be removed by sweeping street surface.

non-point discharge: Flow from an area from which pollutants are exported in a manner not compatible with practical means of pollutant removal. (example: croplands)

nutrients: A nutritious substance or component. A chemical element or inorganic compound (as a nitrate) taken in by a green plant and used in organic synthesis.

overflow: (1) The flow discharging from a sewer resulting from combined sewage, storm wastewater, or extraneous flows and normal flows that exceed the sewer capacity. (2) The location at which such flows leave the sewer.

permeability: The flowrate in gpm - cp/ft^2 promoted through a granular bed by a differential pressure equal to one foot of liquid head per foot of bed thickness. (cp = viscosity in centipoise)

pervious: Allowing movement of water.

point discharges: Flows from a location at which pollutants are released in quantity and concentration compatible with practical means of pollutant removal. (example: sewage effluent)

pollutograph: A time-concentration or time-mass emission graph of a particular pollutant carried by urban runoff.

reaeration: The process entraining air in liquids such as wastewater effluents, streams, etc. Reaeration is proportional to the dissolved oxygen deficit; its rate will increase with increasing deficit.

runoff: That portion of the precipitation on a drainage area that is discharged from the area in stream channels. Types include surface runoff, groundwater runoff, or seepage.

runoff coeffient: The fraction of the flow calculated to have reached the ground from rain gauge data which reaches some arbitrarily chosen downstream point. The coefficient may be measured from actual data or estimated from the topography of the drainage area.

runoff event: A particular occurrence at which runoff occurred.

separate sanitary sewer: A sewer that carries liquid and water-carried wastes from residences, commercial buildings, industrial plants and institutions, together with minor quantitites of ground, storm and surface waters that are not admitted intentionally.

separate storm sewer: A sewer that carries stormwater and surface water, street wash and other wash waters, or drainage, but excludes domestic wastewater and industrial wastes. Also called storm drain.

SMSA: Except in the New England states, a SMSA (standard metropolitan statistical area) is a county or group of contiguous counties which contain at least one city of 50,000 inhabitants. In the New England states, SMSA's consist of towns and cities instead of counties. The complete title of an SMSA identifies the central city or cities. For a detailed description of the criteria used in defining SMSA's; see the Bureau of Budget, Standard Metropolitan Statistical Areas: 1967, U.S. Government Printing Office, Washington, D.C. 20402.

SWMM: Storm Water Management Model: A model developed by the EPA specifically for simulation of urban quantity and quality processes.

tertiary treatment: A third stage of treatment of sewage and other wastes, following primary and secondary treatment, for the purpose of further improving the quality of the treated waters by the removal or modification of constituents which have not been removed or modified by previous treatment steps.

universal soil loss equation: Predicts the short-term rates of soil loss for localized areas. This equation takes into account the influence of the total rainfall energy for a specific area rather than rainfall amount. The universal equation is as follows: $A = RKLSCP$ where A is the average annual soil loss in tons/acre, R is the rainfall factor, K is a soil-erodibility factor, LS is a slope length and steepness factor, C is a cropping and management factor, and P is the supporting conservation practice, such as terracing, strip cropping, and contouring.

urban/urbanizing: The area included within and adjacent to a municipality or other urban place of 5,000 or more population.

wet-weather flow: A combination of storm flow as well as infiltration/inflow which occurs as a result of a storm with or without sanitary industrial flow. This total flow, in older or poorly constructed systems, can be many times the dry-weather flow.

TECHNICAL REPORT DATA

(Please read Instructions on the reverse before completing)

1. REPORT NO.	2.	3. RECIPIENT'S ACCESSION NO.
EPA-600/2-77-064c		

4. TITLE AND SUBTITLE	5. REPORT DATE / 6. PERFORMING ORGANIZATION CODE
NATIONWIDE EVALUATION OF COMBINED SEWER OVERFLOWS AND URBAN STORMWATER DISCHARGES Volume III: Characterization of Discharges	5. August 1977 (Issuing Date) 6.
7. AUTHOR(S) Manning, Martin J., Sullivan, Richard H., and Kipp, Timothy M.	8. PERFORMING ORGANIZATION REPORT NO.
9. PERFORMING ORGANIZATION NAME AND ADDRESS American Public Works Association Research Foundation 1313 East 60th Street Chicago, Illinois 60637	10. PROGRAM ELEMENT NO. 1BC611 11. CONTRACT/~~GRANT~~ NO. 68-03-0283
12. SPONSORING AGENCY NAME AND ADDRESS Municipal Environmental Research Laboratory—Cin., OH Office of Research and Development U.S. Environmental Protection Agency Cincinnati, Ohio 45268	13. TYPE OF REPORT AND PERIOD COVERED FINAL 14. SPONSORING AGENCY CODE EPA/600/14

15. SUPPLEMENTARY NOTES Project Officer: Richard Field, (201) 321-6674, (8-340-6674). See also EPA-600/2-77-064a, Volume I, "Executive Summary," and EPA-600/2-77-064[b], Volume II, "Cost Assessment and Impacts."

16. ABSTRACT

An analysis was made of existing data to charaterize the pollutional strength of urban stormwater runoff and combined sewer overflows. Published and unpublished data were evaluated.

Extensive evaluation was made of census track data to develop data concerning land use and population densities in urban areas to assist modelling of urban stormwater discharge.

Utilizing the developed data, an analysis of receiving water impacts was made.

It was found that much of the available data was developed with consideration of the quantity of flow at the time quality was being considered. A wide variety of methods used to sample flows further complicates the use of much reported data.

The estimated runoff pollutional contributions were found to exceed any contribuitions of treated sanitary flows at the time of a storm event. Thus, runoff pollution can govern the quality of receiving water due to the shock effect and long term buildup of solids.

This report is submitted in partial fulfillment of EPA Contract 68-03-0283 by the American Public Works Association.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
Water pollution, Combined sewers	Separated sewers, Urban drainage, Urban runoff, Water pollution control, Water pollution effects, Pollution sources, Urban stormwater runoff, Storm sewer discharges, Combined sewer overflows, Receiving water impacts	13B

18. DISTRIBUTION STATEMENT	19. SECURITY CLASS *(This Report)*	21. NO. OF PAGES
RELEASE TO PUBLIC	UNCLASSIFIED	290
	20. SECURITY CLASS *(This page)*	22. PRICE
	UNCLASSIFIED	

EPA Form 2220-1 (9-73)

☆ U.S. GOVERNMENT PRINTING OFFICE: 1978—757-140/1319