174

NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM
SYNTHESIS OF HIGHWAY PRACTICE **174**

STORMWATER MANAGEMENT FOR TRANSPORTATION FACILITIES

TRANSPORTATION RESEARCH BOARD
National Research Council

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STORMWATER MANAGEMENT FOR TRANSPORTATION FACILITIES

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NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

Systematic, well-designed research provides the most effective approach to the solution of many problems facing highway administrators and engineers. Often, highway problems are of local interest and can best be studied by highway departments individually or in cooperation with their state universities and others. However, the accelerating growth of highway transportation develops increasingly complex problems of wide interest to highway authorities. These problems are best studied through a coordinated program of cooperative research.

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PREFACE

A vast storehouse of information exists on nearly every subject of concern to highway administrators and engineers. Much of this information has resulted from both research and the successful application of solutions to the problems faced by practitioners in their daily work. Because previously there has been no systematic means for compiling such useful information and making it available to the entire highway community, the American Association of State Highway and Transportation Officials has, through the mechanism of the National Cooperative Highway Research Program, authorized the Transportation Research Board to undertake a continuing project to search out and synthesize useful knowledge from all available sources and to prepare documented reports on current practices in the subject areas of concern.

This synthesis series reports on various practices, making specific recommendations where appropriate but without the detailed directions usually found in handbooks or design manuals. Nonetheless, these documents can serve similar purposes, for each is a compendium of the best knowledge available on those measures found to be the most successful in resolving specific problems. The extent to which these reports are useful will be tempered by the user's knowledge and experience in the particular problem area.

FOREWORD

By Staff
Transportation Research Board

This synthesis will be of interest to highway design engineers, maintenance engineers, environmental personnel, administrators, and others responsible for the design, operation, and maintenance of stormwater management for highways and ancillary facilities. Information is presented on the basic hydrology needed to assess stormwater impacts and on the effectiveness of stormwater management techniques.

Administrators, engineers, and researchers are continually faced with highway problems on which much information exists, either in the form of reports or in terms of undocumented experience and practice. Unfortunately, this information often is scattered and unevaluated, and, as a consequence, in seeking solutions, full information on what has been learned about a problem frequently is not assembled. Costly research findings may go unused, valuable experience may be overlooked, and full consideration may not be given to available practices for solving or alleviating the problem. In an effort to correct this situation, a continuing NCHRP project, carried out by the Transportation Research Board as the research agency, has the objective of reporting on common highway problems and synthesizing available information. The synthesis reports from this endeavor constitute an NCHRP publication series in which various forms of relevant information are assembled into single, concise documents pertaining to specific highway problems or sets of closely related problems.

Designers of highway facilities must consider stormwater management requirements within the context of both localized runoff impacts and downstream effects of runoff. This report of the Transportation Research Board describes the management of both stormwater quantity and quality. Stormwater quantity includes an overview of methods of estimating runoff and management control practices. Stormwater quality management includes discussions of the most prevalent pollutants and best management practices (BMP) to minimize pollutants from transportation facilities. Various types of structural and nonstructural methods are described, including their design considerations and efficiencies. Several stormwater management models are described, with special concern for highway applications. Highlights from the 1990 National Pollutant Discharge Elimination System (NPDES) permits are presented.

To develop this synthesis in a comprehensive manner and to ensure inclusion of significant knowledge, the Board analyzed available information assembled from numerous sources, including a large number of state highway and transportation departments. A topic panel of experts in the subject area was established to guide the researcher in organizing and evaluating the collected data, and to review the final synthesis report.

This synthesis is an immediately useful document that records practices that were acceptable within the limitations of the knowledge available at the time of its preparation. As the processes of advancement continue, new knowledge can be expected to be added to that now at hand.

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Frank D. McCullagh, Engineer of Design, Transportation Research Board, assisted the NCHRP project 20-5 Staff and the Topic Panel.

Information on current practice was provided by many highway and transportation agencies. Their cooperation and assistance were most helpful.

STORMWATER MANAGEMENT FOR TRANSPORTATION FACILITIES

SUMMARY

Traditionally, the practice of routine highway drainage design has been to remove storm runoff from the roadway. However, in recent years it has become generally recognized that urban stormwater runoff, including runoff from highways, may carry constituents that potentially contribute to the degradation of water quality in receiving water bodies. For example, solids, nutrients, heavy metals, oil and grease, pesticides, and bacteria have been found in stormwater runoff associated with highway construction, operation, and maintenance activities.

The U.S. Environmental Protection Agency (EPA) stormwater regulations promulgated in November 1990 required permits for major municipal and industrial (including transportation) stormwater discharges by late 1992, in accordance with the provisions of the National Pollutant Discharge Elimination System (NPDES) program. The impact of the NPDES permit requirements on transportation operations will be mainly in the following three areas:

- Highway storm sewers that convey runoff to a municipal system that is subject to permitting;
- Construction projects disturbing an area greater than five acres; and
- Facilities such as maintenance shops, material handling facilities, and contractor batch plants.

In addition, many states and localities have established stormwater rules and regulations that affect transportation activities. It is therefore recommended that management of both the quantity and quality of stormwater runoff be included as integrated elements of highway drainage design.

One of the key requirements in the EPA and in many states' stormwater regulations is the use of "best management practices" (BMPs) for controlling stormwater quantity and quality. These BMPs include both nonstructural and structural measures. Nonstructural measures refer to such practices as street sweeping, controlled use of fertilizers and pesticides, deicing compound management, and effective traffic handling and regulation for traffic volume reduction. Structural BMPs include the following:

- Storage controls such as detention and retention basins;
- Infiltration practices such as infiltration basins and trenches, and porous pavements;
- Vegetative controls such as grassed swales and vegetative filter strips; and
- Wetlands.

Based on limited literature data, the following BMPs are found to be cost effective in controlling highway runoff pollution:

- Wet detention ponds,
- Extended dry detention ponds,
- Infiltration basins,
- Grassed swales, and
- Wetlands.

This synthesis discusses pollutant removal mechanisms, design guidelines, and maintenance and safety considerations of the various BMPs, as well as recent advances in hydrologic and stormwater analysis methodologies, especially advances in computer usage.

A stormwater management program cannot be successful without a well-designed and executed institutional framework. Issues such as funding, manpower, and infrastructure maintenance are especially important. Furthermore, transportation agencies may find it necessary in many cases to coordinate their stormwater management activities with other agencies and localities so that an effective regional stormwater management plan can be implemented.

CHAPTER ONE

INTRODUCTION

The term "stormwater management" commonly refers to a local or regional plan for pollution abatement and for mitigating or preventing the impacts of flooding caused by increased runoff resulting from urbanization. The urbanization process, which includes transportation activities, causes the conversion of highly pervious surface areas to less pervious areas, sometimes resulting in flooding, soil erosion, sedimentation, stream bank erosion and channel enlargement, and pollution of surface and subsurface waters. Stormwater management includes a number of nonstructural and structural practices, including detention and retention by storage, to reduce or mitigate the adverse runoff and water quality effects caused by urbanization.

This synthesis addresses management of runoff from transportation facilities to reduce the probability of flooding caused by construction of the facility and the abatement of pollution from stormwater runoff. Nine papers on related topics have been published as *Transportation Research Record 1017: Surface Drainage and Highway Runoff Pollutants* (*1*). Management of highway runoff on wetlands is discussed in *National Cooperative Highway Research Program (NCHRP) Report 264* (*2*). *NCHRP Synthesis 70* (*3*) discusses the role of sedimentation basins in sediment control and provides criteria for the design of these basins.

The impetus for stormwater management came with a growing perception that the effect of providing for rapid disposal of rainfall runoff from developing areas has been increased frequency of flooding in downstream areas, and realization that many water quality problems in surface waters stem from nonpoint as well as point sources of pollution. It is apparent that water quality goals for surface waters cannot be achieved by separation of combined sewers or tertiary treatment of sewage, but will require abatement of pollution from nonpoint sources as well.

Where existing developed areas are downstream of more recent development, as is the predominant sequence of development in the United States, massive investments in flood control works or storm sewer outfalls from developing areas are sometimes required to reduce flood damage. Where flood control is infeasible, flooding reduces property values and may lead to abandonment. The alternative to downstream flood control works or the abandonment of flood hazard areas is to provide flood protection by stormwater management in the upstream developing areas. Where pollution abatement as well as flood control is an objective, as is now required by the Environmental Protection Agency (EPA) National Pollutant Discharge Elimination System (NPDES) regulations (see Appendix A), additional or alternative stormwater management measures may be required to provide source control of storm runoff pollution.

Highway construction, operation, and maintenance contribute a variety of pollutants to surface and subsurface water. Solids, nutrients, heavy metals, oil and grease, pesticides and bacteria can all be associated with highway runoff (*4*). Although the impacts of highway runoff pollution on receiving waters may or may not be significant, it is generally recognized that responsible agencies may be required by federal and state regulations to apply the Best Management Practice, or BMP, available in order to reduce pollutant loads entering a water body. One of the primary objectives of environmental impact statements (EIS) is the quantification of possible pollutants emanating from the operation and maintenance of highway and other transportation facilities, so that sound judgements can be made as to the overall usefulness of the facility (*4*).

Recent years have witnessed increased emphasis on water quality as part of stormwater management, as opposed to the traditional focus on quantity. With the expected implementation of the EPA stormwater permit regulations and the existence of some state and local regulations (*5*), it is imperative for transportation agencies to include stormwater management as part of standard operations.

This synthesis on stormwater management for transportation facilities is an overview of the current practice with regard to stormwater runoff characteristics, management of runoff, pollution abatement, and regulations. Chapter Two is a summary of these practices, including a description of how stormwater runoff affects development downstream of the facility and the process for containment and storage of stormwater runoff. This chapter also describes the sources of highway runoff pollutants and how these affect water bodies. Chapter Three presents a detailed discussion on managing stormwater quantity, including methods for estimating precipitation and runoff, highway drainage models, and methods for managing stormwater runoff. Methods for managing the impact of stormwater on water quality, including BMP design, maintenance, and safety considerations are contained in Chapter Four. Brief descriptions of stormwater management models to evaluate both quantity and quality as tools for planning and decision making are provided in Chapter Five. Chapter Six presents the institutional aspects of stormwater management, including federal regulations and regulations from several states. The last chapter offers some conclusions and recommendations for further research. Appendix A is a summary of the National Pollutant Discharge Elimination System (NPDES) rules for transportation facilities and other facilities including the rules for general permits. Appendix B is a glossary of terms used in this synthesis.

CHAPTER TWO

OVERVIEW OF STORMWATER MANAGEMENT

THE PROBLEM

Prior to 1960, stormwater concerns were primarily related to drainage problems (*6*). Both localized and general flooding are common problems in urban areas, with flood losses amounting to billions of dollars annually in the United States. Flooding is a natural phenomenon, but mounting flood losses are the result of intensive use of floodplains where there is inadequate provision for runoff. Stormwater management programs are initiated to reduce the frequency and severity of flooding experienced as upstream areas are developed. Records of increasing flood losses are the result, no doubt, of a continuing increase in the value of development on floodplains, but they also may result in part from better and more systematic data collection and record keeping.

During the 1960s, stormwater pollution began to be investigated. Urban runoff was found to be a significant source of pollution loads entering the nation's water bodies (*7,8,9*). Many studies were conducted under the auspices of the 1972 Clean Water Act: Section 208 and later Section 205j. The EPA National Urban Runoff Program (NURP) data-gathering effort covered 28 sites nationwide and provided information on the efficiencies of several structural and nonstructural control measures. The primary objective of NURP was to assemble an appropriate data base and develop analytical methodologies that would allow the examination of (*6*):

- The quality characteristics of urban runoff, and similarities or differences at different urban locations;
- The extent to which urban runoff is a significant contributor to water quality problems across the nation; and
- The performance characteristics and the overall effectiveness and utility of management practices for the control of pollutant loads from urban runoff.

Results of the NURP program suggested the following:

Characteristics of Urban Runoff. Heavy metals (especially copper, lead, and zinc) are by far the most prevalent priority pollutants found in urban runoff. Other significant constituents include total suspended solids, oxygen-demanding substances, bacteria, and nutrients.

Impacts on Receiving Water. The effects of urban runoff on receiving water quality are highly site-specific. They depend on the type, size, and hydrology of the water body; the urban runoff quantity and quality characteristics; the designated beneficial use; and the concentration of the specific pollutants that affect that use.

Control Effectiveness. Detention basins and other control measures, such as grass swales, were found to be more effective than street sweeping. Wetlands are considered a promising technique for control of urban runoff quality.

More recent studies have dealt with further examination of the impact of highway runoff on receiving waters and the design and effectiveness of control measures. For example, significant impact on dissolved oxygen levels was observed downstream of urban areas during wet weather (*10*). Stormwater from urban and agricultural areas has also been found to affect the water quality in coastal waters (*11*). Much still remains to be accomplished with regard to control measures, especially in the area of long-term performance and proper design criteria for cost-effective control practices.

The 1987 amendments to the Clean Water Act established regulatory controls over urban stormwater discharges, including a requirement for permits for stormwater discharges from industries and municipalities. EPA has recently issued stormwater management guidelines regarding the permit system that directly affect transportation facilities. Details of the permit system and its impact on highway agencies are discussed in Chapter Six.

STORMWATER QUANTITY ISSUES

The Effects of Development on Runoff

A widely held opinion regarding the impact of urban development on stormwater runoff is stated succinctly by the American Public Works Association (*12*), "A review of various impacts of urbanization studies clearly indicates that hydrologic loads can increase markedly — by multiples — as urban development occurs." Although runoff peaks and volumes *can* increase markedly with urbanization and the frequency of flooding *can* increase, the hydrologic impact of urbanization cannot always be generalized because of the many factors that influence runoff. In the case of urbanization, these factors include the location, character, and intensity of the development in the watershed, the size of the developed area relative to the size of the watershed, and the flood-frequency of the event under consideration. Sauer et al. (*13*) completed a study of all available literature, primarily those reports that relate to the magnitude and frequency of peak discharge, and an analysis of all available data for drainage basins affected by urbanization. The following statement is quoted from his report to the 61st Annual Meeting of the Transportation Research Board (*14*):

> In the process of urbanizing a basin, man converts natural pervious areas to impervious surfaces. These areas cause an increased volume of runoff because infiltration is reduced, the surface is usually smoother thereby allowing more rapid drainage, and depression storage is usually reduced. In addition, the drainage system is often altered by enlarging, straightening, and smoothing the channels, and the installation of storm sewers and curb-and-gutter systems. The resulting drainage system usually facilitates more rapid runoff with a resultant increase in flood peaks. Some aspects of urbaniza-

> tion, however, can result in decreased flood potential. One example is the rapid runoff from an urbanized lower part of a watershed before the upper part can significantly contribute runoff to the lower reaches. Another example is the use of detention ponds in some cities to reduce flooding by storing the water in designated areas and releasing it at a slower rate. The construction of culverts, bridges, storm sewers, and roadway embankments may result in temporary water storage behind these structures that reduces peak discharges. Obviously, there are many factors that must be considered when evaluating the effects of urbanization on flood potential. To make a blanket statement that urbanization increases floods in all cases would not be accurate. In fact, the data accumulated for this study show that for a number of basins the urban flood-frequency curve is below an equivalent rural curve. Also, there are several instances where the two flood-frequency curves cross; the low-order flood being increased by urbanization and the high-order floods decreased.

Sauer also states:

> The results of the literature review supported the generally held concept that urbanizing a natural drainage basin usually causes runoff volume to increase and basin response time to decrease. In addition, peak discharges are generally increased for those watersheds which do not have significant in-channel detention storage. These increases are usually most dramatic for low-order floods which occur frequently, and become less pronounced as flood magnitude increases.

The reports referenced above (*13,14*) are based on the only comprehensive study undertaken to date of all available urban hydrologic data. The results indicate that, while development and urbanization indisputably alter the hydrology of the developed area, it is inaccurate to assume that floods of all frequencies will be increased by development of any nature. It may be more accurate to assume that where the number and magnitude of low-order floods are already a problem, the problem will grow as development continues in the flood-prone area and upstream.

There is still a need for good field data that can be used to model the effects of development on the hydrology of a watershed. The rainfall-runoff process is very complex and the variables are so numerous that data collection efforts would necessarily be extensive, intensive, and expensive. Sauer and others (*13*) found data from only 199 sites in the entire United States suitable for use in a study of flood frequency in urban areas. Obviously, data from a great many more sites would be necessary to adequately describe the effects of the many processes that affect the rainfall-runoff relationship in urban areas.

Most investigators, however, agree that the percent of impervious cover, although permanently affecting the basin hydrology, does not have the same effect on the rainfall available for runoff for all storm events. As storm intensity and magnitude increase, the percentage of rainfall that infiltrates the ground, is trapped in surface depressions, or is lost by evaporation or other means, becomes less and less (even for a rural basin) until the amount of these losses has little or no effect on the volume of rainfall available for runoff. This implies differences between the magnitude of the effect of a given rainfall despite the degree of urbanization. However, the improvements in the hydraulic efficiency of the drainage systems found in urban areas remain in effect and continue to speed the runoff past a point in the stream. This means that the bulk of the runoff passes a point in the stream in a shorter period of time. The rate of flow, and consequently the peak flow, is appreciably higher for urban areas with no retention controls than that for an undeveloped condition. Figures 1 and 2 illustrate the combined effects of increased imperviousness and storm sewerage on the mean annual flood (a flood discharge with a one-year return period) for a drainage area of one square mile, as reported by Leopold (*15*).

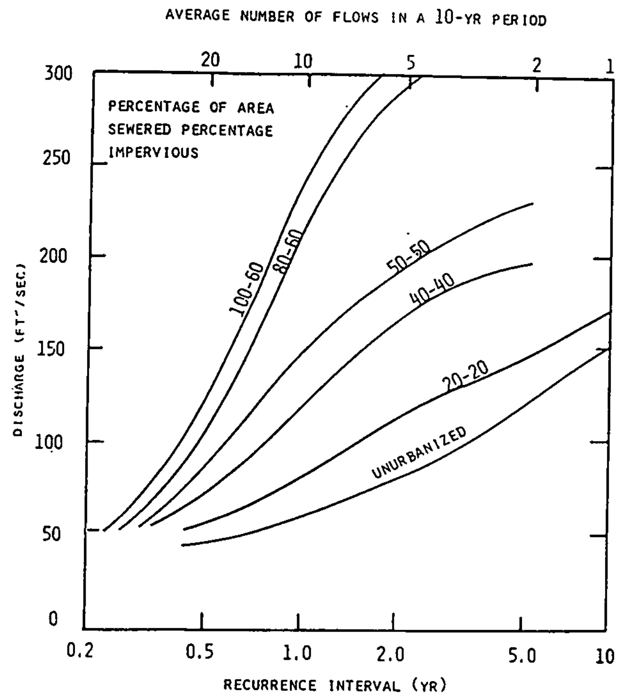


FIGURE 1 Flood frequency curves in various states of urbanization (*15*).

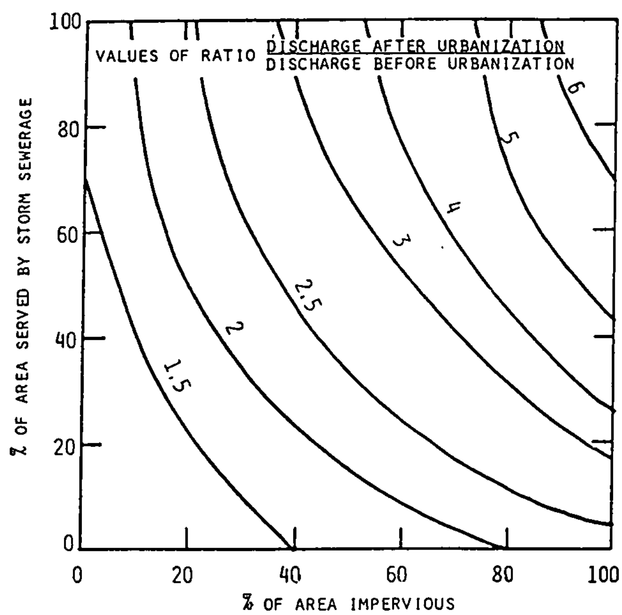


FIGURE 2 Effect of urbanization on mean annual flood (*15*).

Both manual and computer methods used to compute runoff rates and volumes require rainfall as an input, either as a uniform intensity or as a hyetograph. Typically, they require the selection of a design storm and assume that the resulting runoff rate and volume are of the same recurrence interval. Much has been written about the limitations in both the design storm concept (*16,17*) and the assumption that rainfall of a selected frequency will produce runoff of the same frequency. Many question the assumption, inherent in the models, that growth patterns are predictable. The models are mathematical relationships that attempt to describe the runoff phenomenon in some measure of physical terms. In a paper presented at an ASCE Research Conference on urban runoff quantity and quality, Van Sickle (*18*) pointed out that:

> The models were developed and verified, generally, using data from the well-known Chicago, Baltimore, and British catchments which are fairly well-documented. As a result, the numerical values for the constants in the relationships are not known for other areas, and no satisfactory measure of the reliability of the verified values when transferred to other hydrologic regions has been developed. They may be useful research tools, but how valuable are they for use in areas where no test data are available to verify assumed constants? And if they cannot be reliably verified, what incentive is there for practicing engineers to use them?

Similar sentiments toward the use of mathematical or computer models have been expressed by others, for example, M. J. Lowing (*19*).

In recent years, through efforts primarily made in North America and Europe, more field data are becoming available for model testing and verification. From a practical standpoint, however, a model should not be more complicated than necessary and should be tested against solid data before being used for planning and design.

Urban runoff models are discussed in more detail in Chapter Five.

The Effects of Storage

Considerable controversy has brewed over the years regarding the efficiency of small detention and retention facilities in reducing flood peaks and volumes, i.e., small dams versus large dams. It is possible that uncontrolled releases from storage could change the timing of runoff from a segment of a watershed so as to actually increase rather than decrease peak flow rates downstream. For this reason, stormwater management plans should be specific regarding the total storage and the general location of storage planned for the watershed. A report prepared for the American Public Works Association (APWA) (*12*) and other recent literature present case studies to illustrate the need for overall system planning and to demonstrate that storage at some locations is more effective in attenuating peak flows downstream than at other locations. Generalized statements regarding the most effective locations cannot be made because of differences in watersheds and development patterns. A basinwide planning approach is therefore generally encouraged. Optimal storage locations can be determined and the choice between on-site and regional facilities can be made without compounding flooding problems.

Because of potential liability for damages which could result from uncontrolled releases, an independent study may be warranted wherever significant storage is proposed in conjunction with a highway project. This could be particularly applicable where the local agency has not established priorities for construction or defined storage requirements for the various segments of the watershed.

One of the effects of man-made storage imposed on any stream system is change in the stream regime both upstream and downstream of the storage. In-stream reservoirs invariably cause deposition and consequently, aggradation upstream of the reservoir. The magnitude of the problems created by upstream aggradation depends on the volume of bedload carried by the stream, the detention time, and especially the land-use upstream of the reservoir. Storage can cause either degradation or aggradation downstream of the reservoir, depending on the sediment loads contributed by downstream tributaries. Generally, degradation will occur immediately downstream of reservoirs because of sustained periods of flow and the fact that the sediment transport capacity exceeds the sediment load in the reservoir releases (*20*).

The effect of extensive urbanization in a watershed, i.e., where a sizable proportion of a watershed is urbanized, is generally erosion of the streambed and enlargement of the channel. Therefore, the net effect of storage in an urbanized watershed could be beneficial to the stream regime (*19*). The use of storage as a stormwater management measure was implemented in Montgomery County, Maryland, and in Virginia in some of the earlier stormwater management programs, for the specific purpose of abating the adverse effects of urbanization on stream regime. Documents by Lowing, Pagan, and Zulovs et al. (*19,21,22*) are recommended for further reading on the subject of stream equilibrium, but the subject warrants further study in the context of urbanized watersheds.

STORMWATER QUALITY ISSUES

Sources of Highway Runoff Pollutants

Materials accumulate on the highway surface, median areas, and adjoining right-of-way as a result of highway use, maintenance, natural contributions, and pollution fallout. The magnitude of these constituents on roadways is affected by the following variables (*23*):

- Traffic characteristics (speed, volume, braking);
- Climate conditions (intensity and form of precipitation, wind, temperature);
- Maintenance policies (sweeping, mowing, repair, deicing);
- Surrounding land use (residential, commercial, industrial, rural);
- Percent pervious and impervious areas;
- Age and condition of vehicles;
- Anti-litter laws and regulations covering vehicle emissions;
- Use of special additives in vehicular operation;
- Vegetation types on the highway right-of-way; and
- Accidental spills.

Table 1, taken from a Federal Highway Administration (FHWA) study (*24*), provides a list of common highway runoff constituents and their primary sources.

Highway Runoff Quality Data

One of the first comprehensive studies on street and roadway runoff pollution was conducted by the American Public Works

TABLE 1
COMMON HIGHWAY RUNOFF CONSTITUENTS AND THEIR PRIMARY SOURCES (*24*)

Constituent	Primary Sources
Particulates	Pavement wear, vehicles, atmosphere, maintenance
Nitrogen, phosphorus	Atmosphere, roadside fertilizer application
Lead	Leaded gasoline (auto exhaust), tire wear (lead oxide filler material), lubricating oil and grease, bearing wear
Zinc	Tire wear (filler material), motor oil (stabilizing additive), grease
Iron	Auto body rust, steel highway structures (guard rails, etc), moving engine parts
Copper	Metal plating, bearing and bushing wear, moving engine parts, brake lining wear, fungicides and insecticides applied by maintenance operations
Cadmium	Tire wear (filler material), insecticide application
Chromium	Metal plating, moving engine parts, brake lining wear
Nickel	Diesel fuel and gasoline (exhaust) lubricating oil, metal plating, bushing wear, brake lining wear, asphalt paving
Manganese	Moving engine parts
Bromide	Exhaust
Cyanide	Anticake compound (ferric ferrocyanide, Prussian Blue or Sodium ferrocyanide, Yellow Prussiate of Soda) used to keep deicing salt granular
Sodium, Calcium	Deicing salts, grease
Chloride	Deicing Salts
Sulphate	Roadway beds, fuel, deicing salts
Petroleum	Spills, leaks or blow-by of motor lubricants, antifreeze and hydraulic fluids, asphalt surface leachate
Polychlorinated byphenyls, pesticides	Spraying of highway right-of-ways, background atmospheric deposition, PCB catalyst in synthetic tires
Pathogenic bacteria (indicators)	Soil litter, bird droppings and trucks hauling livestock and stockyard waste
Rubber	Tire wear
Asbestos	Clutch and brake lining wear

Association (APWA)(*25*). The study provided estimates of street litter accumulation rates for various land uses. The main component of street litter was found to be dust and dirt (less than 1/8 in. (0.32 cm) in size). It was also found that approximately three percent of the total dust and dirt was soluble, which contributed to runoff pollution. Based on weighted average amounts, the APWA report estimated that the pollution potential of biochemical oxygen demand (BOD) from street litter was about five percent of secondary treatment effluent BOD. The APWA study also found that the amount of BOD and chemical oxygen demand (COD) in dust and dirt were directly proportional to traffic intensity.

Many other studies were conducted during the 1970s to characterize highway runoff pollution, dealing with such items as rubber loss from tire wear (*26*), heavy metals and grease and oil in street runoff (*27*), and fate and transport of highway deicing salts and their effect on the environment (*28*). A brief review of these and a number of other studies is given in FHWA Report No. FHWA/RD-81-042 (*23*).

The most extensive study to date on highway runoff pollution and its effect on the environment was sponsored by the Federal Highway Administration. The study, spanning from the mid 1970s to the mid 1980s, was conceived as a multiphase research project having the following objectives (*24*):

- Phase 1: Identify and quantify the constituents of highway runoff.
- Phase 2: Identify the sources and migration paths of these pollutants from the highways to the receiving water.
- Phase 3: Analyze the effects of these pollutants in the receiving waters.
- Phase 4: Develop the necessary abatement/treatment methodology for objectionable constituents.

Results of the Phase 1 study were reported in a six-volume FHWA document series entitled *Constituents of Highway Runoff* (*23*). Table 2 presents a summary of highway runoff quality data collected at six sites in Wisconsin, Pennsylvania, Colorado, and Tennessee during 1976–1977 under the Phase 1 effort.

During the Phase 2 study, four sites located in Milwaukee, Wisconsin; Sacramento, California; Harrisburg, Pennsylvania; and Efland, North Carolina were selected for further sampling. Results of the Phase 2 research are described in a four-volume report entitled *Sources and Migration of Highway Runoff.* Table 3 is a summary of highway runoff composite quality data for all four monitoring sites. Average highway surface constituent loads were estimated and are given in Table 4.

The FHWA studies showed that, in general, the amount of runoff

TABLE 2
SUMMARY OF HIGHWAY RUNOFF QUALITY DATA FOR ALL SIX MONITORING SITES[a] 1976-1977 (*23*)

	Pollutant concentration (mg/L)		Pollutant loading (lb/acre)	
Parameter[b]	Average[c]	Range	Average[c]	Range
TS	1147	145 - 21640	51.8	0.04 - 535.0
SS	261	4 - 1656	40.0	0.008 - 96.0
VSS	77	1 - 837	3.7	0.004 - 28.2
BOD_5	24	2 - 133	0.88	0.000 - 4.1
TOC	41	5 - 290	2.1	0.002 - 11.5
COD	147	4 - 1058	6.9	0.004 - 34.3
TKN	2.99	0.1 - 14	0.15	0.000 - 1.04
NO_2+NO_3	1.14	0.01 - 8.4	0.69	0.000 - 0.42
TPO_4	0.79	0.05 - 3.55	0.047	0.000 - 3.6
Cl	386	5 - 13300	13.0	0.008 - 329.0
Pb	0.96	0.02 - 13.1	0.058	0.000 - 0.48
Zn	0.41	0.01 - 3.4	0.022	0.000 - 0.12
Fe	10.3	0.1 - 45.0	0.50	0.000 - 3.5
Cu	0.103	0.01 - 0.88	0.0056	0.000 - 0.029
Cd	0.040	0.01 - 0.40	0.0017	0.000 - 0.14
Cr	0.040	0.01 - 0.14	0.0028	0.000 - 0.29
$Hg{\cdot}10^{-3}$	3.22	0.13 - 67.0	0.00059	0.000 - 0.00214
Ni	9.92	0.1 - 49.0	0.27	0.007 - 1.33
TVS	242	26 - 1522	9.34	0.01 - 44.0

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

[b] TS = Total Solids
SS = Suspended Solid
VSS = Volatile Suspended Solid
BOD = Biochemical Oxygen Demand
TOC = Total Organic Carbon
COD = Chemical Oxygen Demand
TKN = Total Kjeldahl Nitrogen
NO_2+NO_3 = Nitrites + Nitrates
TPO_4 = Total Phosphorus
Cu = Copper
Cd = Cadmium
Cr = Chromium
$Hg{\cdot}10^{-3}$ = Mercury
Ni = Nickel
TVS = Total Volatile Solids
Pb = Lead
Cl = Chlorine
Zn = Zinc
Fe = Iron

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

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

constituents increases as the average daily traffic increases and that total solids is a good index parameter that relates well with all other quality parameters.

The FHWA studies also showed that priority pollutants, such as metals and cyanide, were present in the highway environment and that they migrated via runoff during storm events. A significant number of organic priority pollutants were present in the highway environment. However, the major portion of the priority pollution loads in the highway runoff was attributed to metals, for example, lead, zinc, and copper.

The 1976–77 FHWA sampling also found no significant concentrations of pesticides/herbicides in highway runoff. The geometric mean concentration of polychlorinated biphenyls (PCBs) was found to be 0.33 μg/l, which is well below the point discharge standard. On the other hand, sizable concentrations of coliform bacteria were observed at all sites.

The AASHTO study (*20*) also cited results of a statistical analysis of the data reported in the APWA study (*25*); the latter showed that the amounts of BOD and COD in dust and dirt samples, unaffected by rainfall, are directly proportional to traffic intensity, as shown in Figure 3.

Using data compiled from U.S., European, and Australian sources, a more recent paper (*29*) presents a summary of storm event mean pollutant concentrations and loadings in urban runoff, including the highway component, as shown in Table 5. Urban highway runoff can be seen as a significant source of pollution, discharging high metal and hydrocarbon loadings to receiving waters. In fact, one study (*30*) showed that some 50 percent of solids, 40 to 75 percent of metals, and 70 percent of the total pathogens in receiving water input budgets can be derived from highway runoff sources.

Effects of Highway Runoff on Receiving Waters

The stormwater pollution loads entering a receiving water body are transient in nature and are highly variable from storm to storm. Their effects on receiving water quality are site-specific and depend on such factors as the type, size, and hydrology of the water body, as well as the stormwater quantity and quality (*6*). For instance, for small streams the stormwater generated pollutant loadings pass through the system quickly and their effect may last for only minutes or hours after the storm event. For large rivers it may take

TABLE 3
SUMMARY OF HIGHWAY RUNOFF COMPOSITE QUALITY DATA FOR ALL FOUR MONITORING SITES—OVERALL MONITORING PERIOD (WINTER AND NONWINTER) (*24*)

	Pollutant concentration (mg/L)		Pollutant loading (lb/mi/event[a])	
Parameter[b]	Minimum	Maximum	Minimum	Maximum
pH	4.90	7.95		
TS	68	57,000	0.85	17,400
TVS	10	510	0.25	12,000
SS	6	2,160	0.22	6,080
VSS	4	317	0.04	915
Pb	ND	6.30	ND	20.3
Zn	0.036	2.90	0.0004	7.52
Fe	0.30	115	0.012	150
Cr	ND	0.19	ND	0.556
Cu	ND	0.59	ND	1.93
Cd	ND	0.06	ND	0.010
Ni	ND	0.22	ND	0.66
Hg	ND	0.001	ND	0.001
As	ND	0.03	ND	0.13
Na	2.1	22,500	0.02	12,600
Ca	4.0	450	0.92	202
Cl	2.0	35,000	0.07	13,500
Oil & grease	1	21	0.3	69
PO_4-P	0.03	4.45	0.01	11.5
TKN	ND	9.80	ND	15.5
NO_2+NO_3	ND	9.00	ND	8.67
TOC	4	182	2.45	425
COD	16	660	4.92	1930
SO_4	ND	180	ND	51

[a]Both directions irrespective of number of lanes.

[b]As = Arsenic Na = Sodium Ca = Calcium PO_4-P = Total Phosphate
Other symbols are as defined in Table 2.

ND = Not detectable.

Metric units: To convert lb/mi to kg/km multiply by 0.2819.

days for the pollutants to pass through and the loading effects extend much beyond the period of intense runoff.

Results of the EPA Nationwide Urban Runoff Program (NURP) (*6*) indicate that heavy metals and bacteria in urban runoff may cause water quality problems for receiving streams and rivers and more intense problems for lakes and estuaries. Possible long-term problems may arise due to the buildup of priority pollutants in the sediments, contributed wholly or in part by urban runoff.

A recent study of rural highway runoff sponsored by the Federal Highway Administration (*31*) reported results of an extensive field monitoring program aimed at collecting data on impact of highway runoff. Three sites, two streams and one lake, all receiving highway runoff, were selected in Wisconsin and North Carolina for the study. The field sampling program included continuous highway runoff measurements, discrete storm event monitoring, receiving water sampling, laboratory and field bioassays, and other pertinent information.

The following is a summary of the results of the three-year (1980–83) field study (*31*):

- Annual pollutant loadings from the highway right-of-way (ROW) were a very small percentage of the total watershed loads. This was expected because the highways sampled were in mostly rural or undeveloped areas and the ROW accounted for only 1.5 to 3.0 percent of the total watershed area.
- No adverse impact of highway runoff on the receiving water was observed at any of the three sites. A few discrete samples collected at one site exceeded the EPA chronic criterion.
- Laboratory bioassay experiments showed no acute toxic effect of undiluted highway runoff on several selected organisms. However, algal bioassay tests yielded significant inhibition of growth due to metals in highway runoff.

The fact that the highway sections tested in the FHWA study were designed with a flush-shoulder, grassy-ditch drainage system might have led to the above observations. The study also reaffirms the highly variable and site-specific nature of water quality effects of stormwater.

The 1986 National Water Quality Inventory (*32*) provides a

TABLE 4
SURFACE CONSTITUENT LOADINGS AT THE SITES MONITORED (POUNDS PER HIGHWAY MILE,[a] ALL LANES) (*24*)

Parameter	Milwaukee I-94		Sacramento Hwy 50		Harrisburg I-81		Efland I-85	
	Range	Mean	Range	Mean	Range	Mean	Range	Mean
Gross material[c]	112-1,900	669	ND-214	ND[b]	31.6-75.8	53.7	3.86-747	224
Litter[d]	746-13,400	4,070	93.2-379	245	2.46-4.98	3.72	1,600-7,090	4,040
TS[e]	2,440-66,400	18,100	282-433	360	32.9-40.0	36.5	40.5-1940	566
TVS	146-6,550	1,400	22.0-36.4	26.6	12.3-12.6	12.5	7.24-122	41.3
TOC	25.1-1,140	228	5.98-12.1	8.72	--	3.77	--	4.28
COD	106-3,660	1,020	16.5-56.8	33.8	--	8.11	--	14.3
Pb	3.64-293	64.8	0.914-2.23	1.43	0.032-0.056	0.044	0.058-1.90	0.593
Zn	1.74-96.1	18.2	0.158-0.342	0.23	0.042-0.054	0.048	0.024-0.646	0.208
Fe	8.86-4,290	1,200	9.70-13.8	12.4	0.324-0.532	0.428	0.722-41.6	12.2
Cr	0.026-5.46	1.68	0.026-0.075	0.043	0.002-0.004	0.003	0.002-0.036	0.013
Cu	0.138-36.1	6.75	0.032-0.040	0.037	0.006-0.010	0.008	0.004-0.112	0.036
Cd	0.008-0.426	0.115	0.0005-0.002	0.001	0.0006-0.0009	0.0008	0.002-0.004	0.003
Ni	0.032-6.05	1.45	0.008-0.026	0.020	0.006-0.012	0.008	0.002-0.030	0.010
As	0.004-0.044	0.017	0.0002-0.004	0.002	--	ND[b]	--	ND[b]
$Hg*10^{-3}$	0.1-4.0	0.3	0.01-0.02	0.02	--	ND[b]	--	ND[b]
NO_2+NO_3	0.05-0.318	0.170	0.018-0.176	0.117	0.138-0.316	0.227	0.042-0.064	0.049
TKN	1.45-36.8	8.53	0.366-0.730	0.521	0.296-0.348	0.322	0.194-1.36	0.773
PO_4-P	1.02-23.7	5.46	0.176-0.228	0.205	0.022-0.024	0.023	0.042-1.18	0.368
Ca	666-4,130	1,930	0.694-5.47	3.76	--	3.32	--	0.414
Na	6.35-110	37.2	0.264-0.934	0.521	0.720-0.899	0.810	0.394-0.624	0.497
Cl	4.75-91.4	25.4	0.408-1.82	0.922	1.44-1.76	1.6	0.646-1.00	0.826
SO_4	3.82-16.8	9.79	0.542-6.04	2.25	2.45-2.80	2.63	0.688-0.854	0.771
Oil & Grease	17.0-730	167	0.720-4.09	1.73	0.614-1.72	1.17	0.478-0.690	0.548
Rubber	60.7-648	206	--	43.0	--	1.38	--	1.27

[a]Both directions
[b]Median
[c]Gross material is defined as very large litter that can be picked up by hand (e.g.,hub caps, tire fragment)
[d]Litter is defined as particles larger than 3.35 mm not including gross material
[e]Total solids are defined as particles less than 3.35 mm.
ND = Not detectable   Metric units: To convert lb/mi to kg/km multiply by 0.2819.

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

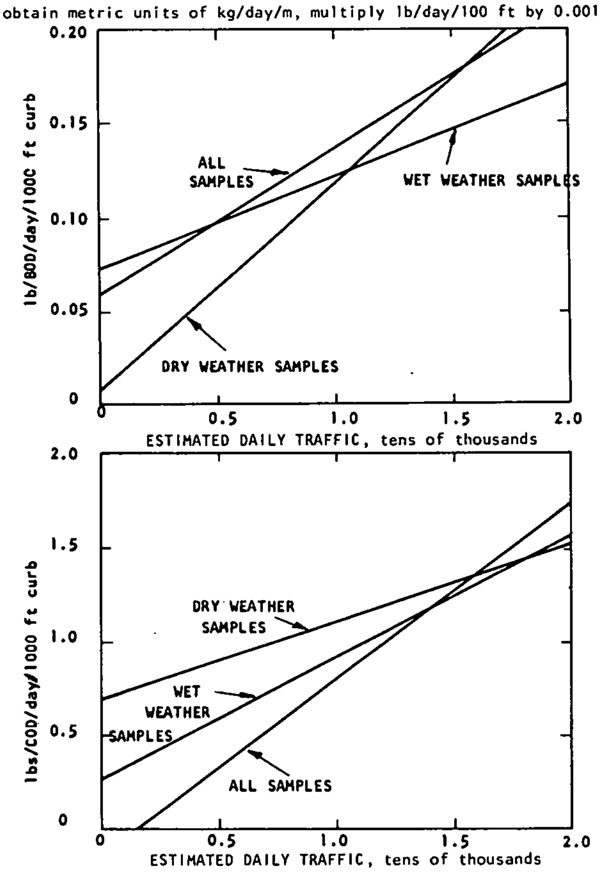


FIGURE 3 Effect of traffic on BOD and COD on street dust and dirt (*23*).

general assessment of water quality that was derived from biennial reports submitted by the states under Section 305(b) of the Clean Water Act. Based on 37 states that provided information on sources of pollution, stormwater pollution from urban and agricultural areas was the cause of impairment to beneficial use for 65 percent of the rivers and streams, 76 percent of the lakes, and 45 percent of the estuaries. The assessment concluded that runoff pollution from agricultural and urban areas is suggested by the states as the leading cause of water quality impairment. These sources of pollution will be even more significant as point sources of pollution are being controlled.

In summary, runoff from transportation facilities including highways and maintenance centers can be expected to contain priority pollutants that might contribute to water quality impairment under certain circumstances. It appears that an integrated physically based and statistically based simulation approach may provide a reliable means to examine water quality fluctuations due to urban runoff loadings from all sources in general, and to highway runoff loadings in particular (*33*).

TABLE 5
POLLUTANT DISCHARGES IN URBAN AREAS (*29*)

	Mean Pollutant Concentrations (mg/L)								Mean Pollutant Loadings (kg/ha/yr)					
Sewer	TS	TVS	BOD	COD	NH_4	Pb	PAH[a]	E.Coli[b]	TS	TVS	BOD	COD	NH_4	Pb
Separate Storm Sewer Runoff	21-582	26-149	7-22	33-265	0.2-4.6	0.03-3.1	29-200	10^2-10^4	347-2340	90-127	35-172	22-703	1.2-25.1	0.09-1.91
Combined Storm Sewer Overflow	237-635	N/A[c]	43-95	120-560	2.9-4.8	0.15-2.9	12-215	10^4-10^6	1230-4917	N/A	505-1345	1760-3256	52-85	N/A
Highway Runoff	28-1178	18-86	12-32	128-171	0.02-2.1	0.15-2.9	365-60000	10-10^3	121-6289	45-851	90-172	181-3865	0.8-6.1	0.65-13.0
Roof Runoff	12.3-216	40-88	2.8-8.1	57.9-80.6	0.4-3.8	0.001-0.030	N/A	10^2	--	--	--	--	--	--
Gully Pot Liquors	15-840	185	6.8-241	25-109	0.7-1.39	0.06-0.85	N/A	10-10^2	--	--	--	--	--	--
Residential Areas	112-1104	28-124	7-56	37-120	0.3-3.3	0.09-0.44	N/A	10-10^3	620-2300	N/A	5-76.8	22-761	N/A	0.06-1.91
Commercial Areas	230-1894	75-85	5-17	74-160	0.03-5.1	0.1-0.4	N/A	10^2-10^4	50-840	N/A	43-87	1000-1029	N/A	0.17-6.84
Light Industrial Areas	45-375	35-72	8-12	40-70	0.2-1.1	0.6-1.2	N/A	10	400-1700	N/A	N/A	N/A	N/A	2.2-7.0

[a] ng/L

[b] MPN/100mL

[c] N/A = No data available

CHAPTER THREE

MANAGEMENT OF STORMWATER QUANTITY

INTRODUCTION

The highway drainage engineer traditionally has been concerned with how to direct runoff away from highways as rapidly as possible. Practices that accomplish this, while alleviating localized problems in the vicinity of the highway, can contribute to the increased frequency of downstream flooding. Beginning in the 1970s, much more attention was given to a watershed approach, i.e., treating local stormwater drainage problems as part of the total urban storm drainage system. This systems approach led to on-site or source control techniques, such as storage or infiltration facilities, to address flooding as well as water quality concerns.

Today's highway drainage plans should address both quantity and quality concerns. Issues related to stormwater quantity are discussed in this chapter. It should be noted that estimation of pollutant masses can not be made until the quantity of runoff is obtained.

Generally speaking, the most important parameters of stormwater quantity are the peak flow and the corresponding hydrograph resulting from a specific or design storm event. The peak flow usually is used to size drainage structures such as storm sewers and culverts, while the hydrograph provides the estimate for required detention storage. Hydrologic and hydraulic principles are, therefore, important tools for transportation engineers in dealing with stormwater quantity problems.

There is an abundance of literature regarding hydrologic and hydraulic principles applicable to highway drainage design and analysis. Several FHWA reports, *Hydrology for Transportation Engineers* (*34*), which has been superseded by another FHWA report entitled *Hydrology* (*35*), *Design of Urban Highway Drainage—The State of the Art* (*36*) and *FHWA Hydraulic Engineering Circular No. 12: Drainage of Highway Pavements*, provide good reference materials on the subject.

COMPUTING RUNOFF

In determining stormwater runoff for designing drainage or storage facilities, it is usually necessary to select a design storm event. Important characteristics of a design storm include its frequency of occurrence, duration, storm intensity, and spatial and temporal distribution.

Intensity-Duration-Frequency Curves for Rainfall

The frequency of occurrence, or return period, of rainfall selected for a hydrologic design determines the degree of protection the structure would provide. Therefore, the selection of a design frequency should be made on the basis of balancing the cost of providing a certain degree of protection against the potential inconvenience or damages associated with the design. A risk analysis can be performed and a risk-based design procedure can be used to select the appropriate frequency. As a general approach to selecting design frequency, Jens (*36*) states that:

> The relative hazards to persons, property and traffic associated with each of the runoffs related to rainfalls of several selected frequencies should be used in storm drainage design. Mitigation of drainage-related damages or losses is theoretically balanced as a benefit against the associated drainage costs. In practice, judgement has largely been relied upon to choose the design rainfall frequency. . . .
>
> Urban highways such as the interstate system should use high drainage standards. At locations where water can pond on the roadway and create a hazard to life, traffic and property, as in sag vertical curves, underpasses and depressed sections, the roadway drainage system should be designed for a relatively infrequent rainfall event (perhaps five times the recurrence interval of locations where water cannot pond). At such locations the flow should include bypass amounts from upstream inlets and tributary areas with facilities designed to a lesser standard. At locations where water cannot pond, inlets for roadway and bridge drainage should be designed so that spread on the pavement from a 10-year rainfall event will be limited to the highway shoulder. Roadside and median ditches should be designed to convey at least the runoff from a 10-year rainfall event without encroachment on the shoulders.
>
> Urban highways other than interstate should preferably also be provided with drainage systems based upon at least a 10-year rainfall. . . .
>
> Detention storage should be considered where economies can be achieved or downstream flooding problems would otherwise be worsened by drainage from the highway development.

Most local ordinances require that a 10-year storm be used as a minimum for design of detention storage.

The U.S. National Weather Service, which is under the National Oceanic and Atmospheric Administration (NOAA), has compiled and processed rainfall data collected throughout the country and published a series of technical reports providing information on rainfall intensity-duration-frequency relationships. The following reports are most widely used:

- U.S. Weather Bureau, Technical Paper No. 40 (TP-40) "Rainfall Frequency Atlas of the United States for Duration from 30 Minutes to 24 Hours and Return Period from 1 to 100 Years" (*37*). The report provides maps covering the 1-, 2-, 5-, 10-, 25-, 50- and 100-year frequencies and 30 min, 1-hr, 3-hr, 6-hr, 12-hr and 24-hr durations. These maps can be used to generate rainfall intensity-duration-frequency curves for localities, such as the one shown in Figure 4 (*38*).
- NOAA, NWS HYDRO-35 "Five to 60 Minute Precipitation Frequency Data for Eastern and Central United States" (39). This report augments TP-40 by providing 5- to 60-min rainfall values for eastern and central United States.

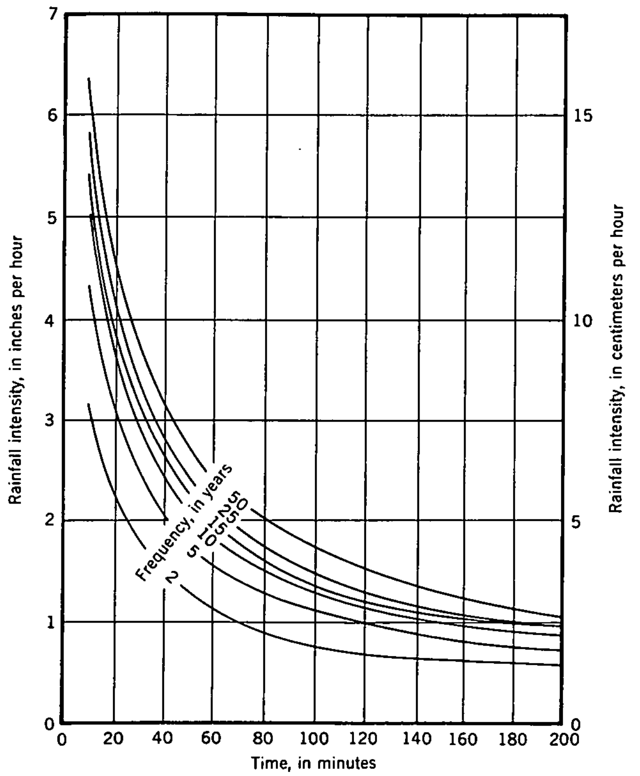


FIGURE 4 Intensity-duration rainfall curves, Boston, MA (*38*).

• NOAA, National Weather Service "Precipitation-Frequency Atlas of the Western United States, Atlas 2, Volumes I-XI" (*40*). Atlas 2 was published in 1973 to refine information for western United States.

TP-40 and HYDRO-35 also outline procedures for estimating rainfall values for durations other than the ones listed. For example, Table 6 lists the adjustment factors suggested by NOAA for obtaining X-minute estimates from 1-hr values.

TABLE 6
ADJUSTMENT FACTORS TO OBTAIN X-MINUTE ESTIMATES FROM 1-HR VALUES (*36*)

Duration (min)	5	10	15	20
Ratio to 1 hr	0.29	0.45	0.57	0.79

Temporal and Spatial Distribution of Rainfall

The temporal distribution of rainfall, or the hyetograph, describes the temporal pattern of a storm event and is required for computing storm runoff hydrographs. The choice of an appropriate design hyetograph is very important because of its significant effect on the shape and peak magnitude of the resulting hydrograph, as demonstrated by many in the literature, including Akan and Yen (*41*).

The temporal distribution of rainfall is highly variable from location to location and from storm to storm. A number of distribution patterns have been developed based on statistical analysis of storm data or by subjective designation. Examples of these distributions include the Soil Conservation Service (SCS) curves, the U.S. Army Corps of Engineers' balanced hyetograph method, the Chicago method, the Huff quartile distributions, and the more recent triangular hyetographs proposed by Yen and Chow. Several of the more commonly used distributions, and some recent developments are described below.

SCS Distributions (42,43)

SCS developed four synthetic 24-hour rainfall distributions (I, IA, II, and III) from National Weather Service rainfall data. Figure 5 shows the four distributions and Figure 6 shows their approximate geographic boundaries. Type IA is the least intense and Type II the most intense rainfall. Distributions of shorter durations can be derived from the 24-hour distribution. For example, SCS suggests that the 6-hour distribution can be obtained by taking the most intense 6-hour rainfall rates from the 24-hour curve.

The Huff Distribution (44)

The Huff method was based on a study in central Illinois involving 261 heavy storms (exceeding 0.50 in) with durations of 3 to 48 hr. The storms were divided into four groups on the basis of the time quartile in which the heaviest rainfall occurred, with 10 percent to 90 percent probability levels determined for each quartile. These levels represent the percentage of storms having that particular time distribution or one above it. The 50 percent level is the median curve (see Figure 7). The time distributions are expressed in probability terms because of the variability of the distribution from storm to storm, and they can be used to design for various levels of risks. The median curve, however, is recommended for most applications.

The probability levels represent particular storm types. For example, with the 10 percent level in first quartile storms, 80 percent of the total storm occurs in the first 20 percent of the storm duration. Huff associates this condition with short-duration storms, such

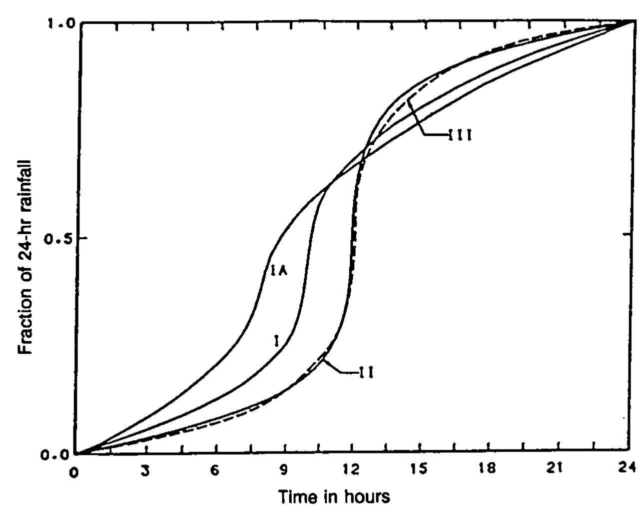


FIGURE 5 SCS 24-hour rainfall distributions (*43*).

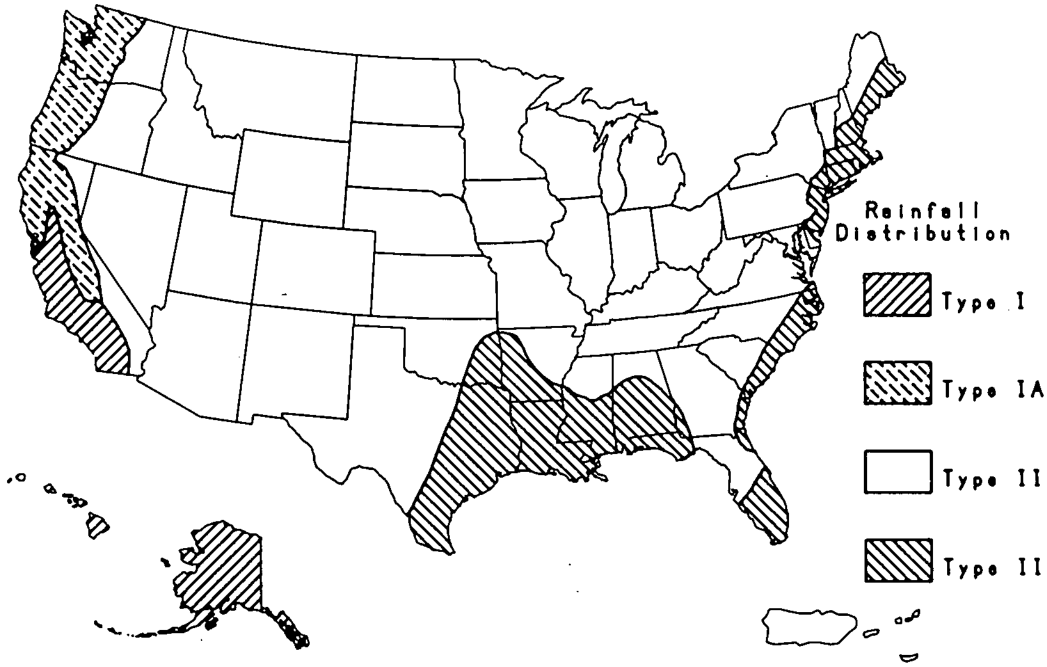


FIGURE 6 Approximate geographic boundaries for SCS rainfall distributions (*43*).

as the passage of an intense prefrontal squall line in which light rain falls for substantial periods following the initial major rain burst.

Within each quartile, the time distributions are expressed as cumulative percentages of storm rainfall and cumulative percentages of total storm duration. This technique was used by Huff to allow valid comparisons between storms and to simplify analyses of data.

Huff suggested a trend in regard to the relation between storm duration and quartiles. The long duration storms tended to have a fourth-quartile classification, whereas short duration storms fell predominately in the first and second quartiles. Overall, however, the effect of storm duration was minor and somewhat inconsistent.

Yen and Chow Rainfall Time Distribution (45)

Yen and Chow, in a document prepared for the Federal Highway Administration (FHWA), reported results of statistical analyses of more than a quarter of a million rainstorms over three hundred locations in the United States. They proposed the use of triangular and trapezoidal hyetographs with localized parameters which can be obtained statistically.

In the report, the authors presented maps showing parameters for the triangular hyetograph for all parts of the United States. These parameter values were obtained by analyzing the moments of the rainfall data.

Recent Developments

If sufficient data are available, it is always desirable to derive temporal distribution of storms that would reflect local conditions. In recent years several regionalized hyetographs have been developed. For example, Huff's distribution was found to be applicable for the region including Ohio, Illinois, and Texas (*46*) and regional curves were derived for Pennsylvania (*47*) and Virginia (*48*).

The Virginia study conducted by Yu et al. (*48*) was based on statistical analyses of some 1,400 storms and yielded the following main conclusions:

- The temporal distribution of Virginia storms differs significantly from the commonly recognized distribution curves such as the Huff quartile curves and the SCS curves. In general, the Virginia curves show a shorter time to the peak rainfall and a lower rate of increase near the mid-portion of the storm duration.
- One statewide rainfall time distribution curve is adequate for Virginia for storms of 6-hr or longer durations (see Figure 8).
- Virginia storms of 6-hr or longer durations are predominantly second and third quartile types according to Huff's classification. Shorter duration storms are mostly first and second quartile types.
- No regional difference was observed for storms of medium or long durations (6-hr or longer). However, for short duration storms (mostly thunderstorms), there were significant regional differences in rainfall time distributions, so regional curves are needed.

In summary, the selection of a storm hyetograph in computing runoff has a significant effect on the resulting hydrograph. Also, the commonly used SCS distribution tends to provide more conservative estimates when compared with temporal distributions derived from local data (*49,50,51*).

Another factor affecting design rainfall intensity is the areal distribution of rainfall. Point rainfall values should be adjusted by applying reduction factors converting point rainfall to the average over the area of interest. An example of such an area-depth curve is given in Figure 9 (*38*).

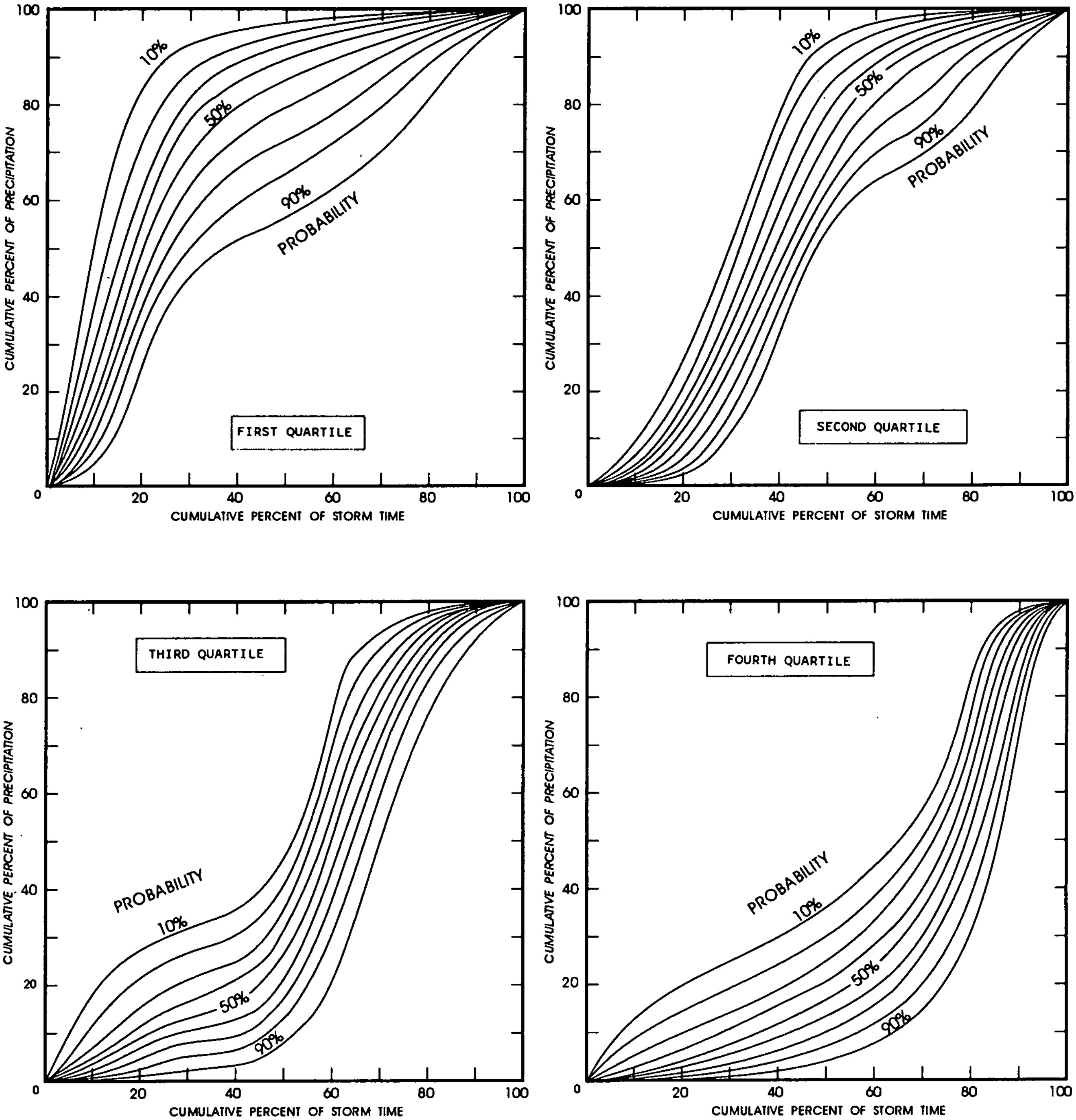


FIGURE 7 Huff time distribution of storms.

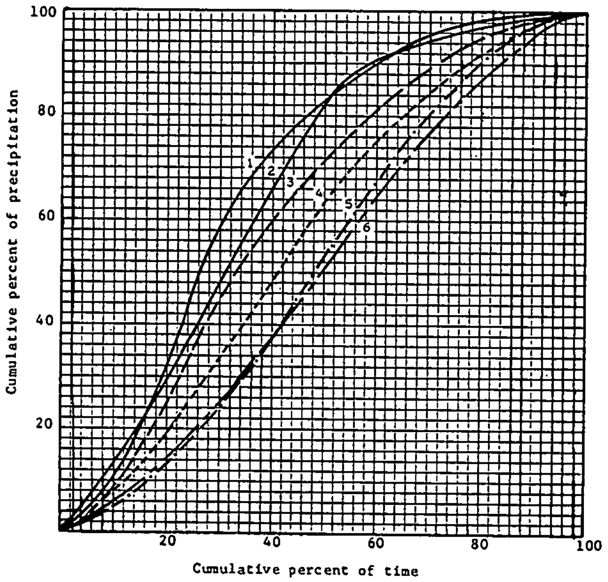
METHODS OF ESTIMATING RUNOFF

Basically, there are two methods used to estimate runoff. These are the statistical analysis of runoff records to establish peak flow frequency or relationship between peak flow and pertinent parameters; and the use of mathematical descriptions of the rainfall-runoff process or computer models to estimate runoff peaks and/or hydrographs.

The accuracy and reliability of statistical methods depend on the extent of available runoff data. Rainfall-runoff equations and models are limited by their underlying assumptions, the physical processes represented, and the proper calibration of each parameter.

Statistical Analysis

Statistical analysis of runoff records may be carried out for an individual site at which a gauging station has been maintained or



1. D ≤ 1 hr Piedmont Region*
2. D ≤ 1 hr Mountain Region**
3. 1 hr < D < 6 hr Piedmont Region
4. 1 hr < D < 6 hr Mountain Region
5. 6 hr < D < 18 hr Statewide
6. D > 18 hr Statewide

* Mid-Virginia
** Shenandoah, southwest Virginia

FIGURE 8 Rainfall time distributions for Virginia (*47*).

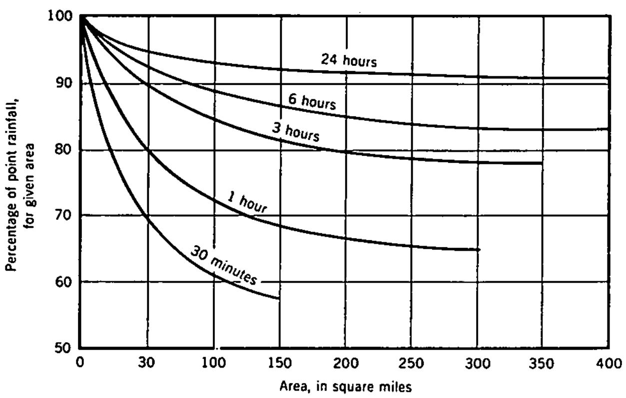


FIGURE 9 Area-depth curves (*38*).

the analysis may consist of a regression analysis of all stations in a homogeneous hydrologic region. Analyses of streamflow records have been completed and published by the U.S. Geological Survey (USGS) for rural watersheds in all states. Typically, flood-frequency characteristics are first defined using flow data collected at gauging stations. Multiple regression techniques are then used to relate frequency characteristics to basin characteristics. An example of the derived relationship is (*52*):

$$Q_T = aA^bS^cRF \qquad (1)$$

where

Q_T = flow for T-year return period
A = drainage area
S = slope
RF = regional factor to account for regional variations in basin terrain characteristics
a,b,c = regression coefficients

More recently, the U.S. Geological Survey, in cooperation with the Federal Highway Administration, conducted a nationwide study of flood magnitude and frequency in urban watersheds (*53*). Multiple regression techniques were used to relate peak flows to a number of pertinent parameters. The following is an example (*54*):

$$Q_2 = 13.2A^{0.2}(13 - BDF)^{-0.43}RQ_2^{0.73} \qquad (2)$$

where

Q_2 = two-year peak flow
A = drainage area
BDF = Basin Development Factor
RQ_2 = corresponding 2-year peak flow from an identical rural basin in the same region as the urban watershed.

Similar equations were developed for almost 200 urban watersheds throughout the United States. The basin development factor (BDF) is an index of the prevalence of four drainage elements: storm sewers, channel improvements, impervious channel linings, and curb-and-gutter streets. The values of BDF range from zero ("not prevalent") to 12 ("full development").

Rainfall-Runoff Methods

Rainfall-runoff methods commonly require rainfall input, such as a rainfall hyetograph; these methods assume that the frequency of the calculated runoff is equal to the frequency of the input rainfall. In general, these methods can be categorized as follows:

- Empirical Formulas, such as the Rational Formula, which treat the watershed as a single unit or "lumped system." Rainfall is assumed to be uniformly distributed over the entire basin and only peak flow is computed at the outlet.
- Hydrograph Methods, such as the unit hydrograph approach, which compute hydrographs at the watershed outlet from given rainfall hyetographs.
- Computer Simulation Models, such as the ILLUDAS model, which simulate various processes responsible for transforming rainfall to runoff.

Empirical or Peak-Flow Formulas

The Rational Formula. The most frequently used rainfall-runoff method in urban hydrology is the Rational Method, first referred to in American literature in 1889 by Kuichling (*55*). Although frequently criticized for its simplicity and underlying assumptions, the Rational Formula has become the standard method for computing peak flow in all parts of the world.

The Rational Formula is:

$$Q = CIA \quad (3)$$

where Q is the peak runoff rate (ft^3/s), C is a dimensionless runoff coefficient representing characteristics of the watershed, I is the average rainfall intensity for a duration equal to the time of concentration and for the probability of recurrence chosen for design (in./hr), and A is the drainage area (acres) (*36*).

The runoff coefficient C characterizes antecedent precipitation, soil moisture, infiltration, detention, ground slope, ground cover, evaporation, shape of the watershed, and other variables. Typical C value for storms of 5- to 10-year return periods are given in Table 7 (*54*).

Details of the use of the Rational Method can be found in numerous publications (*36,38,54,56*).

SCS TR-55 Method. The U.S. Soil Conservation Service developed a graphical procedure for estimating peak discharge for urban watersheds. The peak discharge is computed by: (*43*)

$$q_p = q_u A_m Q F_p \quad (4)$$

TABLE 7
TYPICAL C COEFFICIENTS FOR 5- TO 10-YEAR FREQUENCY DESIGN (*53*)

Description of Area	Runoff Coefficients
Business	
Downtown areas	0.70 - 0.95
Neighborhood areas	0.50 - 0.70
Residential	
Single-family areas	0.30 - 0.50
Multiunits, detached	0.40 - 0.60
Multiunits, attached	0.60 - 0.75
Residential (suburban)	0.25 - 0.40
Apartment dwelling areas	0.50 - 0.70
Industrial	
Light areas	0.50 - 0.80
Heavy areas	0.60 - 0.90
Parks, cemeteries	0.10 - 0.25
Playgrounds	0.20 - 0.35
Railroad yard areas	0.20 - 0.40
Unimproved areas	0.10 - 0.30
Street	
Asphaltic	0.70 - 0.95
Concrete	0.80 - 0.95
Brick	0.70 - 0.85
Drives and Walks	0.75 - 0.85
Roofs	0.75 - 0.95
Lawns; sandy soil:	
Flat, 2%	0.05 - 0.10
Average, 2-7%	0.10 - 0.15
Steep, 7%	0.15 - 0.20
Lawns; heavy soil:	
Flat, 2%	0.13
Average, 2-7%	0.18 - 0.22
Steep, 7%	

where
q_p = peak discharge (cfs);
q_u = unit peak discharge (cfs);
A_m = drainage area (acres);
Q = runoff (in.); and
F_p = pond and swamp adjustment factor.

For a selected rainfall frequency, the 24-hour rainfall (P) is obtained from frequency maps or local data. The total runoff is then determined by using the SCS Curve Number (CN) method as described in the SCS Hydrology Handbook (*57*).

The SCS runoff equation is (*43*):

$$Q = \frac{(P - I_a)^2}{[(P - I_a) + S]} \quad (5)$$

in which
Q = runoff (in.)
P = rainfall (in.)
S = potential maximum retention after runoff begins (in.) and
I_a = initial abstraction, including surface storage, interception, and infiltration prior to runoff (in.).

The relationship between I_a and S was developed empirically from watershed data. This relationship was found to be $I_a = 0.2S$.

S is related to the soil and cover conditions of the watershed through the Curve Number or CN. CN varies from zero to 100 and is related to S by:

$$S = \left(\frac{1000}{CN}\right) - 10 \quad (6)$$

Runoff volumes for given rainfall amounts are computed for various CN numbers and are shown graphically in Figure 10.

The CN numbers are determined by hydrologic soil group, cover type, treatment, hydrologic condition, and antecedent moisture condition. Table 8 lists CN numbers for urban areas (*42*). SCS Technical Release 55 (*43*) also provides tables of CN numbers for agricultural lands and rangelands. A complete list of hydrologic soil groups in the U.S. can be found in both editions of TR 55 (*43,58*) and in Supplement A of the SCS Handbook (*57*).

SCS also provides means of estimating composite CN numbers for cases when not all of the impervious areas are directly connected to the drainage system, as illustrated in Figures 11 and 12.

With CN known, I_a can be determined from Eq. (6). The peak flow can be found by using figures provided by SCS (an example is given in Figure 13) and Eq. (4).

Finally, if adjustment due to pond and swamp areas is needed, the adjustment factors (F_p) are given in Table 9 (*43*).

Hydrograph Methods

Peak flow formulas provide estimates of design flows for sizing storm sewers and culverts. However, the entire runoff hydrograph is needed for computing the runoff volume required for designing storage facilities.

Many methods are available for determining the runoff hydrograph from a given rainfall. A simple yet sometimes practical method is the Modified Rational Method. This method basically

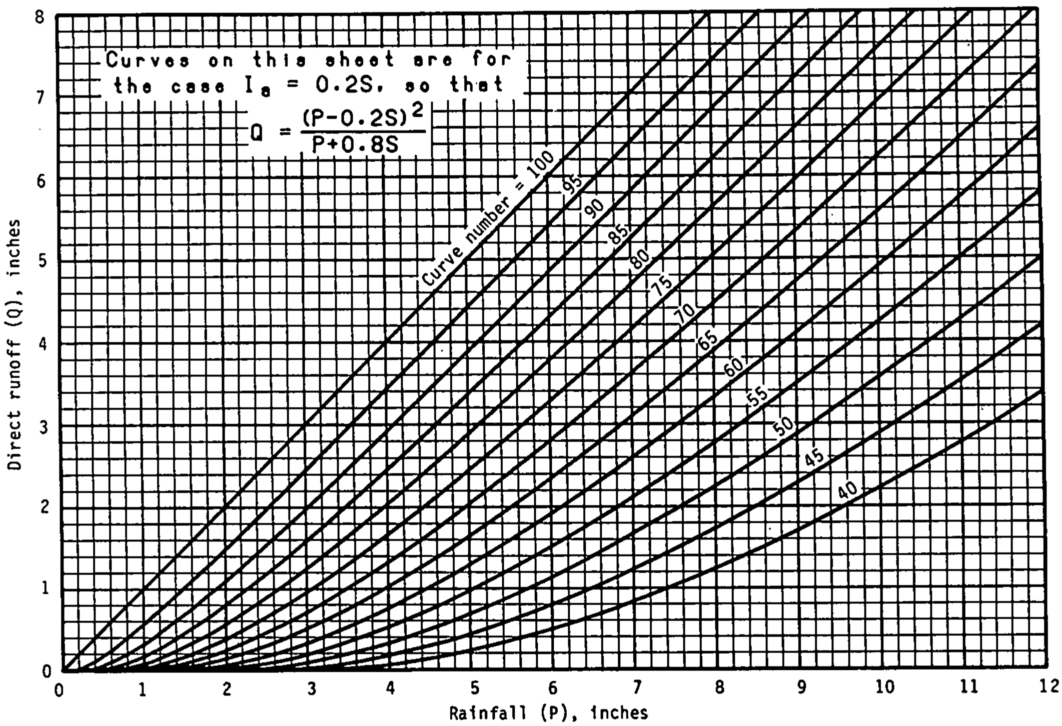


FIGURE 10 SCS rainfall-runoff curves (*43*).

assumes a triangular hydrograph shape with the peak flow computed by the Rational Method and the time to peak and recession time both equal to the time of concentration (*59*).

A similar method is the Inlet Hydrograph Method, which modifies the recession time by considering the travel time in channels or sewers (*60*).

The Kinetic Wave method provides an estimate of overland and channel flow velocity as a function of slope and type of surface, both easily determined factors (*58*). Some of the more commonly used hydrograph methods are described below.

Unit Hydrographs. The Unit Hydrograph Method is one of the most widely used methods of computing runoff hydrographs from given rainfall hyetographs. Sherman (*61*) in 1932 originally proposed the unit hydrograph theory by defining the unit hydrograph as "basin outflow resulting from one inch (one centimeter) of direct runoff generated uniformly over the drainage area at a uniform rainfall rate during a specific rainfall duration."

The basic assumptions of the unit hydrograph application are that the watershed behaves as a linear system in transforming rainfall excess to runoff and that the relationship between rainfall and runoff is steady or time-invariant (*62*). Although questions as to the validity of the unit hydrograph assumptions in real world situations have been raised, the method is still commonly used and generally provides satisfactory results.

The development of unit hydrographs for gauged watersheds and the general rules and limitations in using the unit hydrograph approach are described in many basic hydrology textbooks such as those by Viessman (*54*) and Bedient and Huber (*62*). Other references include the FHWA Report No. HEC-19 *Hydrology* (*35*) and the AASHTO *Model Drainage Manual* (*63*).

Synthetic Unit Hydrographs. For ungauged areas, unit hydrographs can be determined by using a synthetic unit hydrograph procedure. These techniques relate unit hydrograph parameters such as peak flow, time to peak, and base time to watershed characteristics such as size, slope, and channel length. Several commonly used synthetic unit hydrograph techniques are described below:

Snyder's Method: Snyder's synthetic unit hydrograph method (*64*) expanded by Taylor and Schwartz (*65*), relies on correlation of lag time and peak discharge with various physiographic watershed characteristics, as described by the following equations:

$$t_l = C_t\,(LL_{ca})^{0.3} \tag{7}$$

where

t_l = the lag time between the centroid of unit rainfall excess to the peak of the unit hydrograph (hours)
C_t = a coefficient dependent on watershed slope and storage
L = length of main stream channel from outlet to divide (mi)
L_{ca} = length along the main channel from outlet to a channel point nearest the watershed centroid (mi).

$$Q_p = \frac{640\,C_pA}{t_l} \tag{8}$$

where

Q_p = peak discharge (cfs)
C_p = coefficient accounting for flood wave and storage conditions
A = watershed area (sq mi)
t_l = lag time (hours)

TABLE 8
RUNOFF CURVE NUMBERS FOR URBAN AREAS[a] *(56)*

Cover description		Curve numbers for hydrologic soil group			
Cover type and hydrologic condition	Average percent impervious area[b]	A	B	C	D
Fully developed urban areas (vegetation established)					
Open space (lawns, parks, golf courses, cemeteries, etc.)[c]					
Poor condition (grass cover < 50%)		68	79	86	89
Fair condition (grass cover 50% to 75%)		49	69	79	84
Good condition (grass cover > 75%)		39	61	74	80
Impervious areas:					
Paved parking lots, roofs, driveways, etc. (excluding right-of-way)		98	98	98	98
Streets and roads:					
Paved; curbs and storm sewers (excluding right-of-way)		98	98	98	98
Paved; open ditches (including right-of-way)		83	89	92	93
Gravel (including right-of-way)		76	85	89	91
Dirt (including right-of-way)		72	82	87	89
Western desert urban areas:					
Natural desert landscaping (pervious areas only)[d]		63	77	85	88
Artificial desert landscaping (impervious weed barrier, desert shrub with 1- to 2-inch sand or gravel mulch and basin borders)		96	96	96	96
Urban districts:					
Commercial and business	85	89	92	94	95
Industrial	72	81	88	91	93
Residential districts by average lot size:					
1/8 acre or less (town houses)	65	77	85	90	92
1/4 acre	38	61	75	83	87
1/3 acre	30	57	72	81	86
1/2 acre	25	54	70	80	85
1 acre	20	51	68	79	84
2 acres	12	46	65	77	82
Developing urban areas					
Newly graded areas (pervious areas only, no vegetation)[e]		77	86	91	94
Idle lands (CNs are determined using cover types similar to those in table 2-2c).					

[a] Average runoff condition, and $I_a = 0.2S$.

[b] The average percent impervious area shown was used to develop the composite CNs. Other assumptions are as follows: impervious areas are directly connected to the drainage system, impervious areas have a CN of 98, and pervious areas are considered equivalent to open space in good hydrologic condition. CNs for other combinations of conditions may be computed using Figure 2-3 or 2-4.

[c] CNs shown are equivalent to those of pasture. Composite CNs may be computed for other combinations of open space cover type.

[d] Composite CNs for natural desert landscaping should be computed using figures 2-3 or 2-4 based on the impervious area percentage (CN=98) and the pervious area CN. The pervious area CNs are assumed equivalent to desert shrub in poor hydrologic condition.

[e] Composite CNs to use for the design of temporary measures during grading and construction should be computed using Figure 2-3 or 2-4, based on the degree of development (impervious area percentage) and the CNs for the newly graded pervious areas.

The hydrograph shape is adjusted so that it contains 1 in. of direct runoff. To provide additional assistance in constructing the unit hydrograph, the Corps of Engineers developed curves relating time widths for points on the hydrograph located in 50 and 75 percent of peak discharge to the peak discharge (66).

The time base of the Snyder's synthetic unit hydrograph for a large area can be computed by:

$$T = 3 + \left(\frac{t_l}{8}\right) \tag{9}$$

where

T = base time of the synthetic unit hydrograph (days)
t_l = lag time (hours)

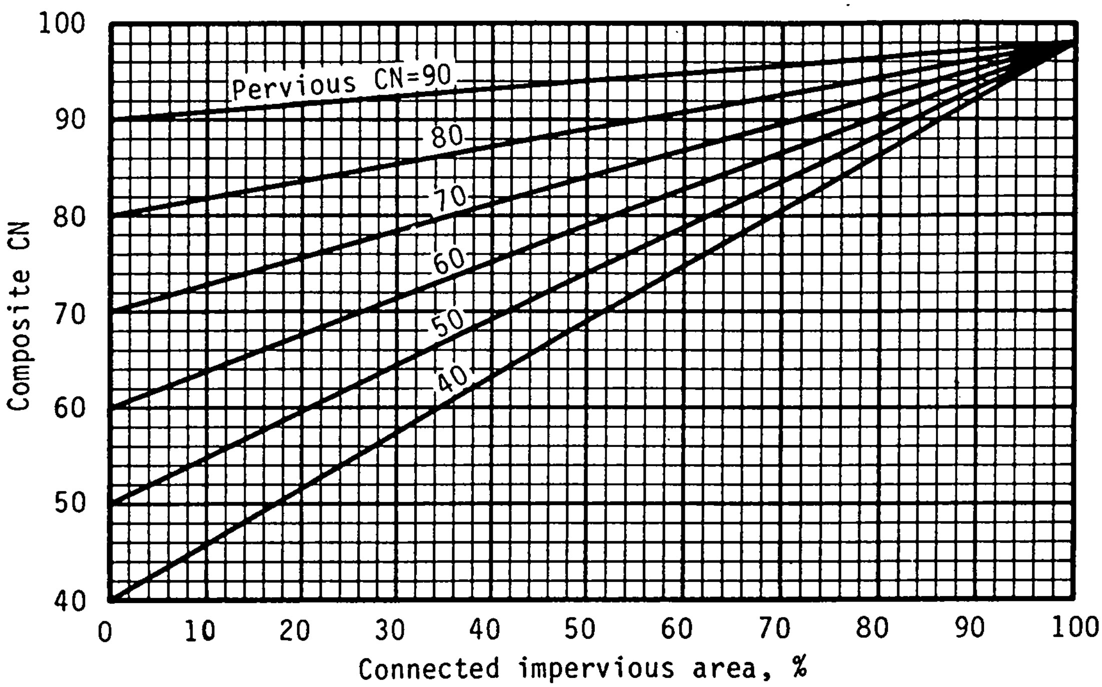


FIGURE 11 Composite CN with connected impervious area *(43)*.

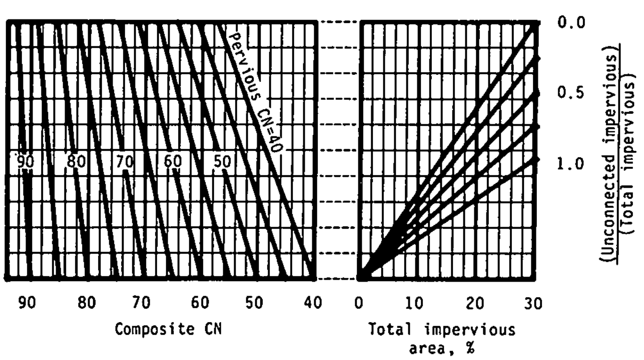


FIGURE 12 Composite CN with unconnected impervious area *(43)*.

For a smaller area, the base time can be taken as three to five times the time to peak *(66)*.

SCS Method: The Soil Conservation Service developed a synthetic unit hydrograph procedure based on a dimensionless hydrograph (Figure 14). The peak flow is determined by appoximating the unit hydrograph as a triangular shape with base time equal to 8/3 times the time to peak, i.e., *(67)*:

$$q_p = \frac{484A}{t_p} \qquad (10)$$

where

q_p = peak discharge (cfs)
A = watershed area (sq mi)
t_p = time to peak (hour) which can be computed as

$$t_p = \frac{D}{2} + t_l \qquad (11)$$

in which

D = rainfall duration and
t_l = lag time (hours).

SCS also developed an equation for computing t_l, the lag time:

$$t_l = \frac{L^{0.8}(S + 1)^{0.7}}{1900\,Y^{0.5}} \qquad (12)$$

where

t_l = lag time (hours)
L = length from outlet to divide (feet)
S = potential maximum retention as defined in equation
Y = average watershed slope in percent.

Clark Method: The Clark Hydrograph Method considers the discharge a function of the translation and storage characteristics of the watershed *(68)*. The translation is represented by the time-area diagram, the development of which is shown in Figure 15. The dashed lines in Figure 15a are travel time isochrones that divide the watershed into a number of subareas. Plotting the subareas against the travel time gives the time-area histograms, which essentially represent incremental runoff versus time, as shown in Figure 15b *(66)*. Routing the incremental runoff histogram through a linear reservoir, which represents the storage effect of the watershed, yields the Clark Unit Hydrograph.

For a linear reservoir,

$$S = KQ \qquad (13)$$

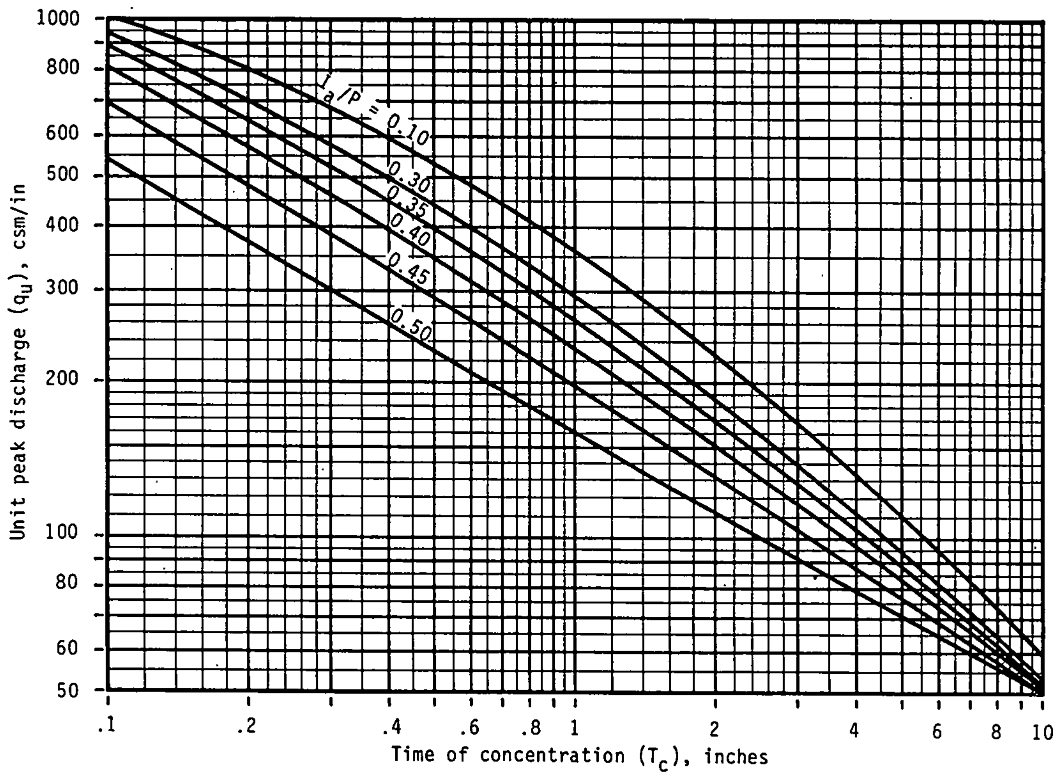


FIGURE 13 Unit peak discharge for SCS Type II rainfall distribution (*43*).

TABLE 9
ADJUSTMENT FACTORS (F_p) FOR POND AND SWAMP AREA THAT ARE SPREAD THROUGHOUT THE WATERSHED

Percentage of pond and swamp area	F_p
0.0	1.00
0.2	0.97
1.0	0.87
3.0	0.75
5.0	0.72

where

S = storage (ft^3)
K = storage coefficient
Q = outflow (cfs).

The routing equation is the continuity equation

$$I - Q = \frac{dS}{dt} = K\frac{dQ}{dt} \tag{14}$$

where

I = inflow (cfs).

For an incremental time Δt between time $t - 1$ and t, Equation (14) can be used to solve for Q_t, i.e.,

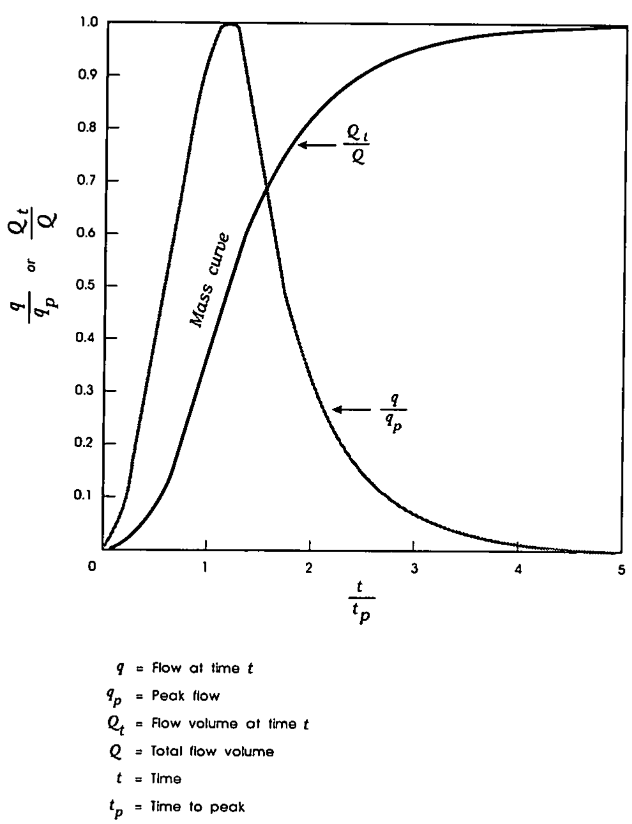


FIGURE 14 SCS dimensionless hydrograph (*67*).

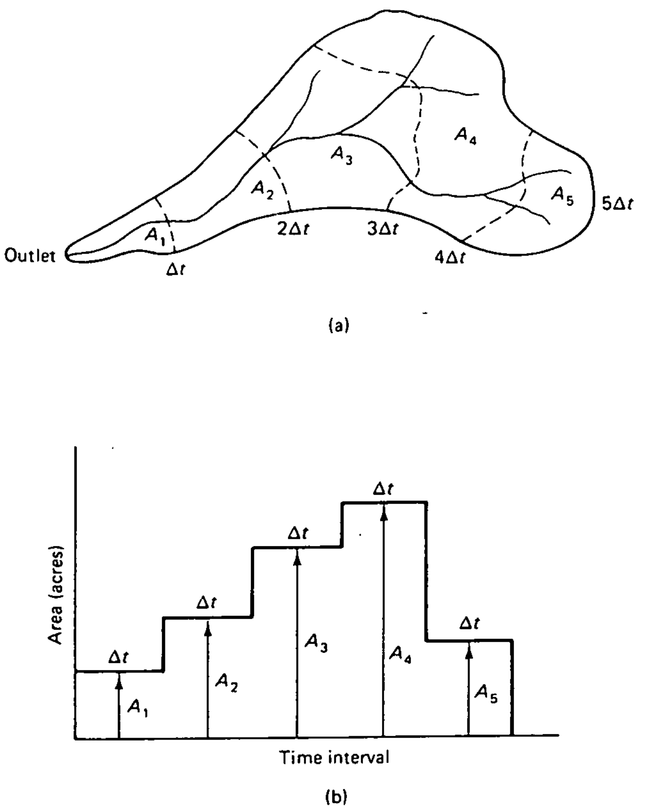


FIGURE 15 Development of time-area histogram for use with Clark's Method. (a) isochrones spaced t apart (shown as dashed line) and (b) time-area histogram (*66*).

$$Q_t = C_0\bar{I} + C_1 Q_{t-1} \tag{15}$$

in which

Q_t = discharge at time t
Q_{t-1} = discharge at time $t - 1$
I = average inflow during Δt

and

$$C_0 = \frac{2\Delta t}{2K + \Delta t} \tag{16}$$

$$C_1 = \frac{2K - \Delta t}{2K + \Delta t} \tag{17}$$

The storage coefficient K has the unit of time, and can be approximated by the lag time of the watershed. It can also be estimated by letting $I = 0$ in equation (14), and therefore, $K = -Q/(dQ/dt)$, and can be evaluated at the inflection point on the recession limb of the hydrograph (*66*).

USGS Dimensionless Unit Hydrograph. The U. S. Geological Survey has developed a dimensionless hydrograph procedure for estimating the average runoff hydrograph for a specific peak discharge. For a given design frequency, the peak discharge Q_p can be determined by using regression equations developed by USGS for locations throughout the United States. The runoff hydrograph can then be obtained by using a dimensionless hydrograph as shown in Figure 16 (*69*).

In Figure 16, LT is the basin lag time, which is defined as the elapsed time from the center of the rainfall excess to the center of the resultant runoff hydrograph. USGS has developed regression equations for estimating the basin lag time (*69*).

The dimensionless hydrograph can be changed into a hydrograph width relationship by computing the width of the dimensionless hydrograph at selected values of the dimensionless discharge ordinates, as shown in Figure 17.

The relations in Figure 17 are useful to estimate the elapsed time for which a given discharge will be exceeded. For example, to estimate the inundation time of a roadway by a 100-year flood, the ratio of overtopping discharge Q to the 100-year peak discharge Q_p is computed. With known Q/Q_p, one can use Figure 17 to find the ratio W/LT. Multiplying W/LT with the estimated lag time for the basin yields the inundation time (*69*).

The USGS has cooperated with state highway agencies, the Federal Highway Administration (FHWA) and other state and federal agencies to provide estimates of flood peak discharges, flood hydrographs, and frequencies. For example, the USGS collaborated with the Ohio Department of Transportation and the FHWA in studying 30 urban watersheds in Ohio from 1974 to 1985. A report titled "Estimating Peak Discharge, Flood Volumes and Hydrograph Shapes of Small Ungauged Urban Streams in Ohio" resulted from the study (*70*). The data reported by Sauer (*69*) included basins having drainage areas between 0.1 and 500 square miles for rural areas, and less than 50 square miles for urban areas.

A project for the development of the AASHTO Model Drainage Manual has been completed by Georgia Technology-Transfer Center, under the direction of the AASHTO Task Force on Hydrology and Hydraulics. The manual summarizes recommended policies and procedures for the hydraulic design of bridges and highway drainage structures and systems. The manual is available from AASHTO (*63*).

Many other synthetic hydrograph procedures have been developed. Examples include the Colorado Unit-Hydrograph Procedure

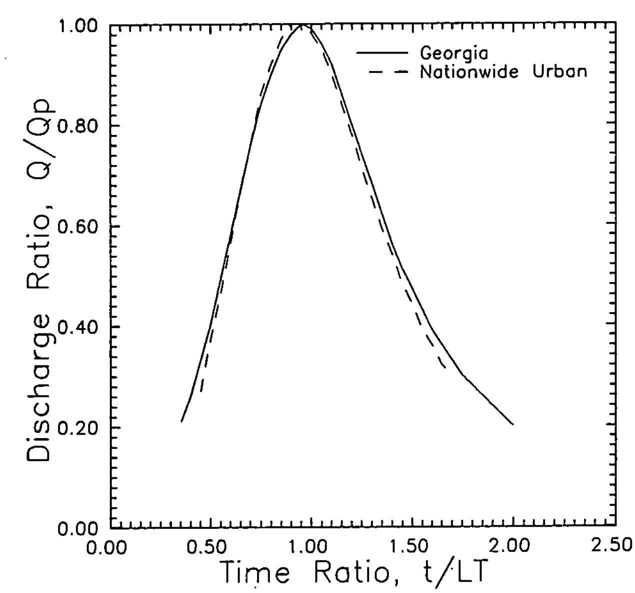


FIGURE 16 USGS dimensionless hydrographs (*69*).

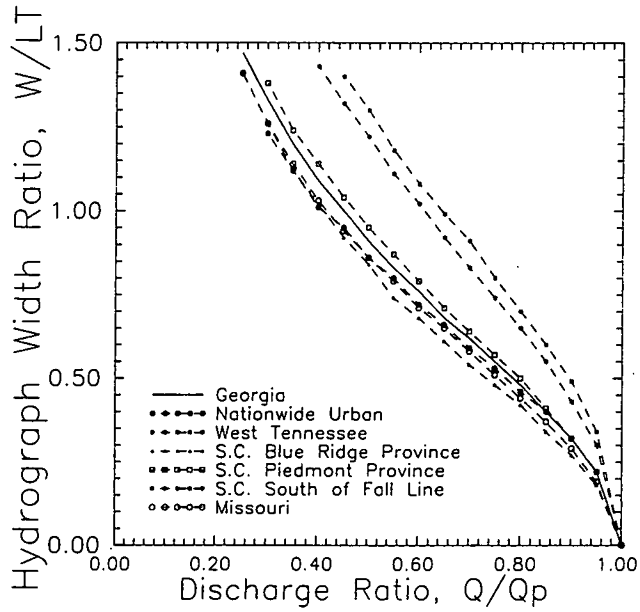


FIGURE 17 Hydrograph width relations (*69*).

(CUHP); the Epsey Synthetic Unit Hydrograph and the Santa Barbara Urban Hydrograph Method (SBUH). Descriptions of these methods can be found, for example, in Viessman et al. (66) and Wanielista (*71*). Descriptions of rainfall-runoff models are given in Chapter Five.

STORMWATER QUANTITY MANAGEMENT PRACTICES

Measures for controlling urban storm runoff can be classified into two major categories: structural and nonstructural. Structural measures are those requiring the construction of certain facilities, such as detention basins for temporarily storing storm runoff, thus reducing and delaying runoff peaks. Nonstructural measures include such practices as land use management to strategically locate impervious areas so that the resulting total hydrograph peak is less severe. Table 10 lists some of the measures for reducing and delaying urban storm runoff recommended by the Soil Conservation Service (*42*).

Figure 18 illustrates how storage facilities, such as detention basins, can be used for flood control. The inflow hydrograph is specified by selection of an appropriate design storm and the use of one of the rainfall-runoff models, such as STORM or the unit-hydrograph method. The outflow hydrograph is also specified so that the peak discharge is below the maximum flow permitted. The shaded area then represents the storage volume required to produce the specified outflow from the given inflow hydrograph.

Of the measures listed in Table 11, detention basins or ponds, either dry or wet, are the most commonly used practices for controlling storm runoff, i.e., for attenuating flood peaks and flood volumes. According to a survey conducted by the American Public Works Association (APWA) Research Foundation in 1980, two-thirds of the facilities reported from 325 communities throughout United States and Canada were dry basins or wet ponds (*12*). Table 11 is taken from the APWA Report.

Since the 1980 APWA survey, the number of stormwater management facilities has increased rapidly. For example, it was estimated that more than 3,000 detention ponds were in use in the metropolitan Washington, D.C. area in 1989, compared to a national total of about 12,000 in 1980. Detention basins have now become a common element in small and large drainage master plans throughout the United States (*72*); however, they may not be appropriate for certain areas, and they must be properly designed and maintained or serious problems may result.

Other measures (Table 10) used to attenuate flood peaks are intended to encourage infiltration and avoid accelerating runoff to the extent practicable. These measures include check dams, weirs, artificial channel meanders, porous pavement, grass swales, and infiltration trenches and basins. Of these, grass swales and infiltration trenches and basins are especially useful in controlling stormwater runoff from highways.

A brief discussion of the more commonly used measures for controlling stormwater quantity at transportation facilities is presented below. Many of the measures also provide certain water quality benefits and are now considered "Best Management Practices" (BMPs). These measures are discussed in more detail, emphasizing the quality aspects, in Chapter Four.

Detention Facilities: Types and Design Considerations

Natural Depressions. Open space and grassed areas can be made into a ponding area for stormwater with installation of controls such as weirs and small-diameter pipes.

Parking Lot Storage. Although considered impractical by some, shallow ponding could be allowed in parking lots to provide some detention benefits. The depth of water allowed to inundate the parking lot should be such that inconvenience caused to pedestrians is minimal. This method is used in some other countries, but strict safety measures to maintain certain depths are enforced.

Blue-Green Storage. The Blue-Green storage concept refers to a version of detention ponding in which stormwater is stored in urban drainageways traversing roadways (*12*). Usually the drainageways are designed to use roadway embankments as dams and control structures so that stormwater runoff will pond upstream of these points and be released at a prescribed rate.

Plaza and Mall Storage. Pedestrian plazas and malls can be designed in such a way that shallow ponding storage is provided with depth of water not exceeding a few inches. An example of such a design is shown in Figure 19 (*12*).

Park Storage. In a dual drainage system, described by Wisner et al. (*73*), the major system (streets) is designed with street low points at locations where stormwater can be directed to parks by shallow open channels. The minor system (underground sewers) consists of oversized pipes that provide storage volumes and will work together with the major system in reducing flood peaks during large storm events. Wisner et al. compared park storage favorably with several other commonly used storage alternatives, as shown in Table 12. For residential areas with an average imperviousness of 30 percent, it was found that complete detention of the 100-year storm runoff could be accomplished with no more than 2.5 percent of the total area of a development required for use by such a dual drainage system.

Underground Storage Tanks. In highly developed areas where surface ponding is inappropriate due to topographic limitations or

TABLE 10
MEASURES FOR REDUCING AND DELAYING URBAN STORM RUNOFF[a]

Area	Reducing Runoff	Delaying Runoff
Large flat roof	1. Cistern storage 2. Rooftop gardens 3. Pool storage or fountain storage 4. Sod roof cover	1. Ponding on roof by constricted downspouts. 2. Increasing roof roughness a. Ripples roof b. Gravelled roof
Parking lots	1. Porous pavement a. Gravel parking lots b. Porous or punctured asphalt 2. Concrete vaults and cisterns beneath parking lots in high value areas 3. Vegetated ponding areas around parking lots 4. Gravel trenches	1. Grassy strips on parking 2. Grassed waterways draining parking lot. 3. Ponding and detention measures for impervious area a. Rippled pavement b. Depressions c. Basins
Residential	1. Cisterns for individual homes or groups of homes 2. Gravel driveways (porous) 3. Contoured landscape 4. Groundwater recharge a. Perforated pipe b. Gravel (sand) c. Trench d. Porous pipe e. Dry wells 5. Vegetated depressions	1. Reservoir or detention basin 2. Planting a high delaying grass (high roughness) 3. Gravel driveways 4. Grassy gutters or channels 5. Increased length of travel of runoff by means of gutters, diversions, etc.
General	1. Gravel alleys 2. Porous sidewalks 3. Mulched planters	1. Gravel alleys

[a]Source: Soil Conservation Service (43)

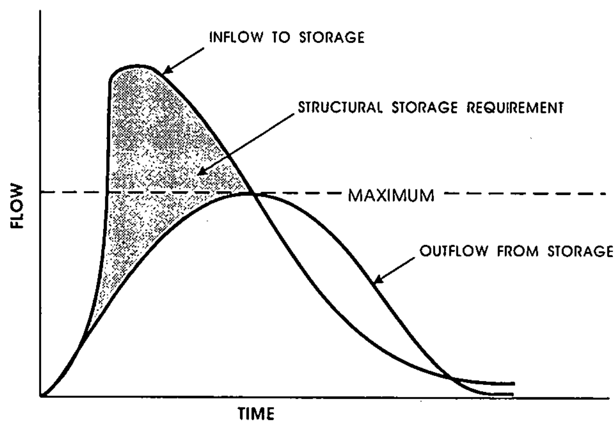


FIGURE 18 Storage as a means of flood control.

high cost of available land, underground storage tanks or oversized pipes and manholes can be constructed for on-site control of stormwater runoff.

Detention Ponds. As mentioned earlier, detention ponds are the most common type of storage facility used for controlling stormwater runoff peak discharges. The majority of detention ponds in use are dry ponds, which release all the water temporarily detained during a storm and, therefore, are dry between storm events. Wet ponds are those designed to maintain a permanent pool by using, for example, a riser pipe to control release of flow.

In designing detention ponds, the following factors must be determined:

- Storage volume required, which is checked by hydrologic routing;
- Pond geometry, i.e., width, depth, length;
- Other features such as side slopes and forebay; and
- Maintenance and safety requirements.

Referring to Figure 20, one can use the mass balance equation:

$$\frac{dS}{dt} = i - q \qquad (18)$$

where

S = storage volume
t = time
i = inflow
q = outflow

To obtain the storage volume required for reducing the peak inflow to the prescribed level, one can use the following equation:

TABLE 11
DETENTION FACILITIES IN USE IN THE UNITED STATES AND CANADA (*12*)

Type of Facility	Total in Use No.	Total in Use %	Ownership: Private No.	Private %	Public No.	Public %
Dry Basin	6,053	47.8	4,913	81	1,140	19
Parking Lot	3,134	24.7	2,982	95	152	5
Pond	2,382	18.8	1,199	50	1,183	50
Rooftop Storage	694	5.5	644	93	50	7
Underground Tank	160	1.3	142	89	18	11
Oversized Sewer	135	1.0	83	61	52	39
Underground Tunnel	9	0.1	8	89	1	11
Other	116	0.9	64	55	52	45
Totals	12,683	100.	10,035	79	2,648	21

FIGURE 19 Depressed parkway in downtown Denver, CO; multiple-purpose use, passive recreation and stormwater storage. (Photo courtesy of Urban Drainage and Flood Control District, Denver, Colorado.)

$$S = \int_0^T (i - q)dt \tag{19}$$

where
T = the time when inflow hydrograph intersects the outflow hydrograph on the recession limb

As an approximation to Eq. (19), inflow and outflow hydrographs can be assumed to take a triangular shape, as shown in Figure 21. The storage volume required is then (*12*)

$$S = \frac{1}{2} b(i - q) \tag{20}$$

where
i = peak inflow rate
q = allowed peak outflow rate
b = time base of the inflow hydrograph

The triangular hydrograph procedure, described originally by Boyd (*74*), gives a preliminary design storage volume for the detention pond and was found to compare favorably with more complete design procedures involving reservoir routing.

TABLE 12
COMPARISON OF PARK STORAGE WITH OTHER ALTERNATIVES (*73*)

Item	Valley Storage	Wet Pond	Dry Pond	Park Storage
Storage	continuous	continuous	frequent	rate
Aesthetics	not important	very important	very important	less important
Maintenance	low	high	moderate	very low
Accident Prob.	low	moderate	low	very low
Facility cost	high	moderate	moderate	low
Land cost	none	high	high	none
Landscaping cost	low	high	medium	medium
Planning	less important	very important	very important	very important
Experience	extensive	adequate	adequate	limited
Modeling	medium	medium	medium	complex

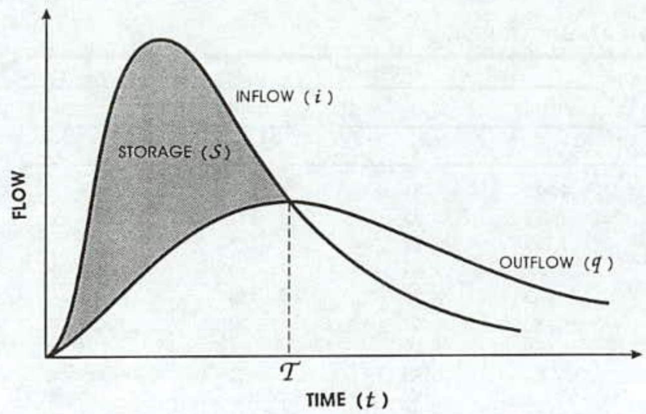


FIGURE 20 Determination of required storage volume.

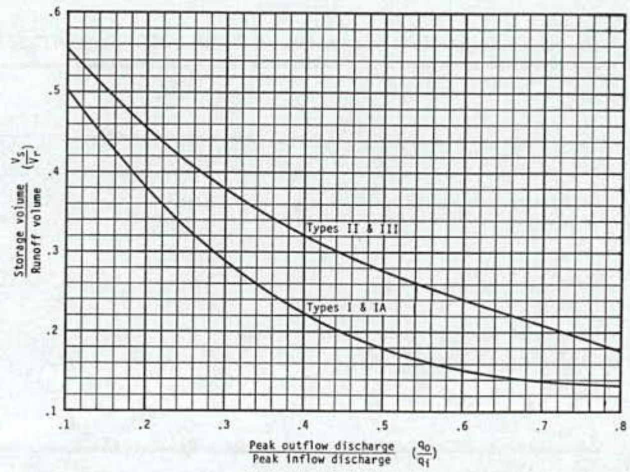


FIGURE 22 Approximate detention basin routing for rainfall types I, IA, II and III (*43*).

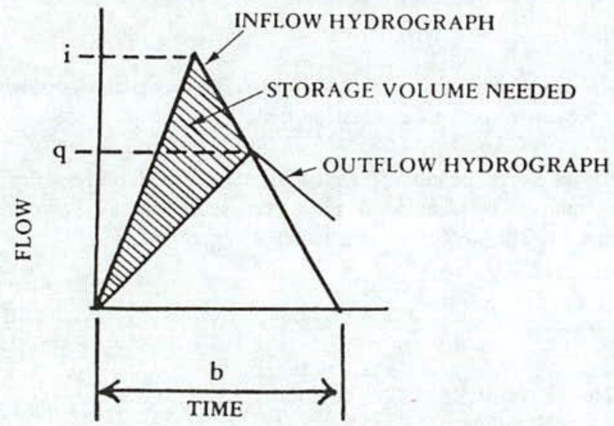


FIGURE 21 Assumed triangular shapes of inflow and outflow hydrographs for preliminary design (*12*).

SCS Detention Basin Design Procedure

SCS, in its TR-55 Second Edition Report (*43*), described a manual method for quick estimates of temporary detention on peak discharges. The method was based on average storage and routing effects for many structures. A dimensionless figure relating the ratio of basin storage volume V_s to input runoff volume V_r with the ratio of peak outflow discharge q_o, to peak inflow discharge q_i as shown in Figure 22.

The procedure for using Figure 22 in estimating the detention storage required is described as follows (*43*).

1. Determine q_o the peak outflow discharge. Usually q_o is set as the pre-development peak discharge corresponding to a specific rainfall frequency required by regulations. The most commonly designated rainfall frequency is 10 years.

2. Estimate q_i the post-development peak discharge with given rainfall frequency and type, by using the SCS method described earlier in the chapter and represented by Eq. (4). Also the Tabular Hydrograph method as described in TR-55 can be used.

3. Compute q_o/q_i and determine V_s/V_r from Figure 22.

4. Determine V_s by:

$$V_s = V_r\left(\frac{V_s}{V_r}\right) \tag{21}$$

Alternative Storage Design Methods

The methods described above are based on the design storm concept, which does not typically address the question of antecedent moisture conditions. Depending on the antecedent moisture condition, the rainfall frequency may or may not be equal to the frequency of stormwater runoff, causing possible discrepancies in the design approach.

Two other approaches to determining storage volume have been proposed recently:

1. The Derived Distribution Approach. Loganathan et al. (*75*) described a statistical approach in which distributions are derived for variables such as runoff, storage volume, and overflow based on distributions of different storm variables.

2. The Continuous Simulation Approach. In the Continuous Simulation analysis, a model accepts time series of rainfall records and generates runoff sequences using a continuous soil moisture accounting strategy. The final output from such a model includes both peak discharge and required storage frequency curves from which design decisions can be made (*76*).

After the required storage volume is obtained and the preliminary design, including pond geometry and outlet structure, is completed, it is necessary to route the design inflow hydrograph through the detention basin to check the adequacy of the design.

Hydrologic Reservoir Routing

The most commonly used method for routing a given inflow hydrograph through a detention pond is the storage indication or modified Puls method. The method is based on the continuity equation as described by Eq. (18) and expressed below for an incremental time interval Δt, i.e.,

$$\frac{\Delta S}{\Delta t} = \frac{I_1 + I_2}{2} - \frac{O_1 + O_2}{2} \tag{22}$$

in which

$\Delta S = S_2 - S_1$,

S = change in storage over time Δt.

S_2 = storage at the end and S_1 is the storage at the beginning of Δt.

I = inflow

O = outflow

Subscript 1 refers to the beginning and subscript 2 refers to the end of the time interval Δt.

Equation (22) can be rearranged as follows:

$$I_2 + I_1 + \left(\frac{2S_1}{\Delta t} - O_1\right) = \frac{2S_2}{\Delta t} + O_2 \tag{23}$$

in which the only unknown for any time increment is the term on the right side.

To solve Eq. (23) a storage indication curve, based on given storage-outflow relationship for a specific outflow structure, is obtained. With the aid of the storage indication curve, Eq. (23) can be solved successively for time increments over the inflow hydrograph to obtain the outflow hydrograph.

The storage indication method is incorporated into computer models such as the SCS TR-20 and now into many microcomputer-based models.

There is abundant literature regarding detention pond design and operations. The APWA Report *(12)* provides excellent coverage of detention pond planning, design, and management. Detention pond design with emphasis on water quality aspects is discussed in Chapter Four.

Infiltration Practices

Infiltration practices are those that enhance the infiltration of surface runoff into the subsurface so that the potential of surface flooding is reduced. Groundwater recharge is also a benefit resulting from infiltration practices. Examples of infiltration practices include infiltration trenches, infiltration basins, porous pavement, vegetative buffer strips, and swales.

Infiltration Trenches

Infiltration trenches are stone-filled trenches that allow rainwater to fill the stone voids and then to infiltrate into the surrounding soil column. For soils with inadequate permeability, a perforated pipe may be installed in the infiltration trench to carry the water to a drainage system. Filter fabric is commonly placed around all sides of the trench to prevent clogging of the voids. Infiltration basins, infiltration wells or dry wells, and infiltration pits are variations of the infiltration trench design.

Because of the relatively small storage capacity an infiltration trench can offer, its flood-peak reduction benefit is limited. However, for small storm events these devices may be quite effective and, therefore, would be more useful in controlling water quality.

In some cases, clogging by solids has been found to be of concern for infiltration practices.

Substantial information on infiltration trench design can be found in a report prepared by Caltrans titled, "Underground Disposal of Storm Water Runoff" *(77)*.

Porous Pavement

The porous pavement concept, which includes open-graded friction courses, is more than 10 years old. Porous pavement uses the natural infiltration capacity of the soil to absorb rain water after storing it in a porous base consisting of sand or large diameter open-graded gravel. If infiltration into the soil is undesirable or if soil permeability is low, a perforated pipe can be provided to transport rainwater to a drainage system.

A porous pavement system can be designed to store up to several inches of rainwater to delay runoff from the site and to attenuate peak discharge to an acceptable level.

Porous pavement applications designed primarily to control runoff have been experimental. A computer program, PORPAV, was developed for the analysis of flow and storage in porous pavement facilities. Such analysis would allow comparisons to be made of the hydraulic response of alternative pavement designs.

More detailed discussion of porous pavement design and performance is found in Chapter Four.

Swales

Swales are vegetated open channels that allow conveyance and infiltration of storm runoff. Wanielista et al. *(71)* used a mass balance of input and output waters in a triangular swale system to derive an expression for estimating the length of a swale necessary to infiltrate all the input rainfall excess.

$$L = \frac{KQ^{5/8}S^{3/16}}{N^{3/8}f} \tag{24}$$

where

L = length of swale (m or ft)

S = longitudinal slope (m/m or ft/ft)

Q = average runoff flow rate (m^3/s or cfs)

N = Manning's roughness coefficient (for overland flow)

f = infiltration rate (cm^3/hr or in^3/hr)

K = constant that is a function of side slope parameter A (1 vertical/Z horizontal) and is defined as:

Z (Side slope) (1 vert./Z horiz.)	K (SI units) ($f = cm^3/hr$, $Q = m^3/s$)	K (English units) ($f = in^3/hr$, $Q = cfs$)
1	98,100	13,650
2	85,400	11,900
3	71,200	9,900
4	61,200	8,500
5	54,000	7,500
6	48,500	6,750
7	44,300	6,150
8	40,850	5,680
9	38,000	5,285
10	35,670	4,955

Wanielista et al. (*71*) found that for most watersheds, the length of a swale necessary to infiltrate 3 in. of runoff was excessive or at least twice the distance available. Consequently, a berm or on-line detention may be needed to make the swale approach more practical.

Integrated Approaches

For special situations, such as in highly populated and congested areas, a combination of several management practices may be needed to achieve overall control that would satisfy the designed level of stormwater management. This concept is much like the grouping of a number of unit operations in a water or wastewater treatment plant for the purpose of achieving a certain level of treatment efficiency.

An example of such an integrated system is an "Experimental Sewer System" (ESS) installed in Tokyo and described by Fujita (*78*). The ESS consists of the following unit operations:

1. Porous pavement
2. Infiltration inlet
3. Infiltration trench
4. Circuitous sewer pipe
5. Storage manhole

A schematic diagram of an ESS is shown in Figure 23.

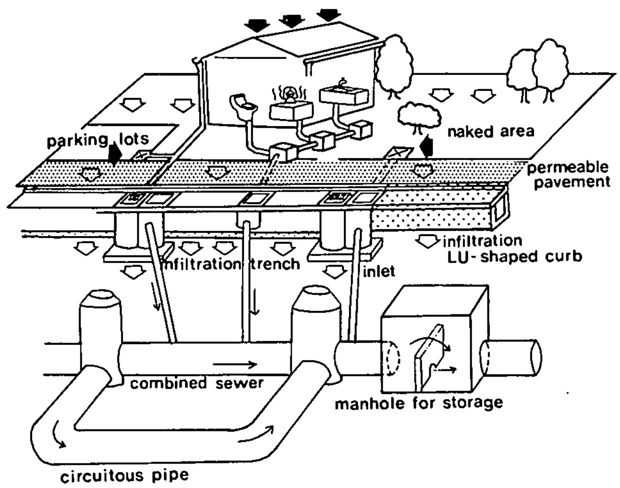


FIGURE 23 Conceptual layout of ESS (*108*).

CHAPTER FOUR

MANAGEMENT OF STORMWATER QUALITY

INTRODUCTION

Field sampling studies conducted both in the U.S. and in foreign countries have found highway runoff to contain certain priority pollutants, such as hydrocarbons, metals, nutrients, and pathogens. These pollutants result from traffic using the facility, as well as from highway maintenance activities. Information regarding the impact of highway runoff on receiving waters is scarce, but some general observations can be made based on available literature (*79*):

- Highway runoff does have the potential to adversely affect the water quality and aquatic biota of receiving waters.
- The significance of these adverse effects is variable by highway, receiving water, and runoff event.
- Runoff from urban highways with high average daily traffic (ADT) volumes may have a relatively high potential to cause adverse effects.
- Runoff from rural highways with low ADT volumes has a relatively low potential to cause adverse effects.

The EPA nationwide Urban Runoff Project (*6*) and other similar studies also indicated that a large amount of the total stormwater pollution load usually is produced by a relatively small stormwater runoff during the initial stages of the runoff event, known as the "first flush" phenomenon. Consequently, managing stormwater quality may require the control of minor or frequent storm events rather than major or less frequent events. For example, stormwater detention for flood control usually requires a 10-year storm as the design storm, whereas for quality control a 1-year storm event may be more appropriate.

Stormwater management for pollution abatement includes measures to control pollution at the source and measures to abate pollutants in the stormwater runoff. Measures to control pollution at the source include street sweeping, catch basin cleaning, and the control of solid wastes such as trash and organic wastes. Other measures for the control of pollution at the source include the controlled use of chemicals such as fertilizers and pesticides, and the reduction of traffic-generated pollutants by the use of lead-free gasoline and effective traffic handling and regulation. Measures to abate pollutants from stormwater runoff include grassed waterways and vegetative filter strips; infiltration by the use of wells, ponds, trenches, and seepage areas; land treatment by spreading, sprinkler irrigation, and overland flow; slowing the runoff to facilitate infiltration and deposition by the use of check dams, rock-lined channels, baffles, sedimentation, retention and detention ponds; diversion of the first flush or generally pollutant-laden initial runoff from storms; and the use of wetland areas to filter and settle out pollutants.

In this chapter the various stormwater management practices, commonly referred to as best management practices (BMPs), are reviewed and design guidelines are discussed, with special reference to applications in controlling highway runoff pollution.

BEST MANAGEMENT PRACTICES: TYPES AND EFFICIENCIES

In general, BMPs can be divided into two categories: nonstructural and structural. Nonstructural BMPs include predevelopment planning and modifying maintenance and operation practices. Structural BMPs are those involving construction of certain devices, such as detention ponds, infiltration trenches, and porous pavements (*80*).

Nonstructural Measures

In highway practice, nonstructural measures include the following (*79*):

Curb Elimination

Curb systems act as traps for particulates and other pollutants, accumulating pollutants between storms. Omission of the curbs allows winds and vehicle-generated air turbulence to scatter the pollutants along the shoulder and rights-of-way, reducing the pollutant load available to the runoff. It also allows runoff to filter directly over vegetated shoulders.

Litter Control

Existing litter control programs and regulations were designed primarily for aesthetic and safety objectives. However, they also achieve pollutant reduction benefits through limitation of potential pollutant sources.

Deicing Chemical Management

Proper storage and handling of deicing chemicals, coupled with sound application practices will provide significant reduction for potential ground and surface water contamination. Covered storage and handling facilities designed to prevent wash off and loss of deicers along with good housekeeping will effectively mitigate potential pollution from these facilities.

Pesticide/Herbicide Management

Use of pesticides and herbicides by state highway agencies (SHAs) typically is limited in scope and strictly controlled. The benefits of these controlled-use programs are shown by the low percent of total pollutant load attributed to pesticides/herbicides.

Structural Measures

Detention Ponds

The concept of using stormwater detention basins to reduce runoff pollution gained widespread attention as a result of studies authorized by Section 208 of the 1972 Clean Water Act. The dual-purpose detention pond design approach allows the pond to reduce flood damages downstream and to reduce non-point pollution from storm runoff (*81*). The EPA Nationwide Urban Runoff Project (*6*) further demonstrated the water quality benefits of wet detention basins.

Dry Ponds

Dry ponds are depressed areas that store runoff during storm events. They are usually designed to reduce the peak flow from an area to the predevelopment level to prevent downstream flooding. As mentioned in Chapter Three, the most commonly used design flood is the 10-year peak flow. However, dry ponds are not very effective in removing pollutants; they are basically designed for controlling quantity, not quality. Because of the short detention times, many particulate pollutants do not have enough time to settle out of the runoff, and the ones that do settle to the bottom of the pond are very easily resuspended by the next storm event. Pollutant removal efficiency for dry ponds reported in the literature ranged from 0 to 20 percent for all pollutants as an average. Therefore dry ponds, though efficient in controlling stormwater quantity, are not generally recommended if water quality control is needed.

Figure 24 shows a typical dry pond serving a residential area, and Figure 25 shows a vertical-walled dry pond that serves a shopping mall.

Extended Dry Ponds

The outlet structure of a dry pond can be modified to provide a retention outlet sized for slow release of the runoff from a designated "BMP storm." A BMP storm is a small and frequent storm, such as the 2-year storm, which is designated by some regulations or ordinances as appropriate for water quality purposes.

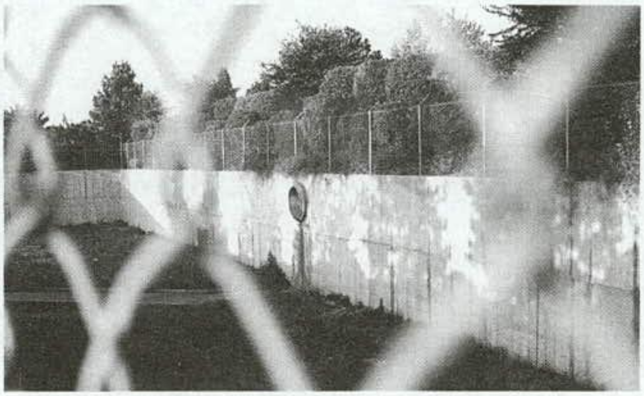


FIGURE 25 Vertical-walled dry pond serving a shopping mall.

The pollutant removal efficiency for extended dry ponds depends on how long and how much of the runoff is detained. In general, a moderate to high removal rate (40 to 70 percent) can be achieved for particulate pollutants such as suspended solids. For dissolved pollutants such as nutrients, the removal efficiency is very low.

Wet Ponds

Wet ponds, by maintaining a permanent pool, allow particulate pollutants time to settle out and dissolved pollutants to be removed by biological uptake or other decay processes. Consequently, the water quality benefits of wet detention ponds are well documented. For example, long-term average removal rate estimates by Driscoll (*82*) range from around 50 percent to more than 90 percent for total suspended solids (TSS), from 40 to 60 percent for nutrients, and 40 to 45 percent for zinc. Several studies conducted in the Washington metropolitan area and summarized by Schueler and Helfrich (*83*) show moderate efficiency for a wet pond. Moderate to high removal rates for wet ponds were also reported in studies in Florida (*84*), North Carolina (*85*), and Virginia (*86*).

Figure 26 depicts a wet pond near an office complex that attracts

FIGURE 24 A typical dry pond in a residential area.

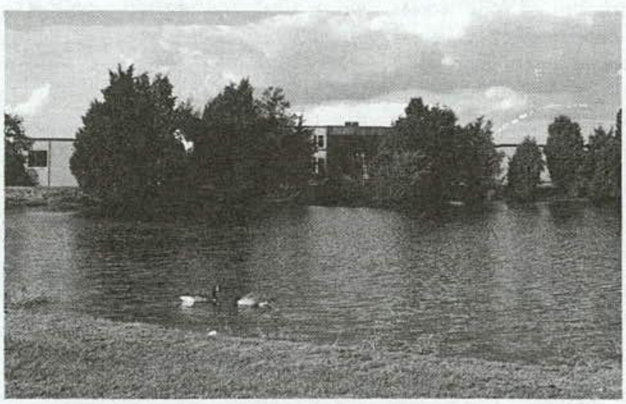


FIGURE 26 Wet pond near an office complex.

some wildlife. Figure 27 shows a wet pond in a residential area. Note the vegetation growth around the fringe and the riser pipe in the foreground.

Infiltration Facilities

Infiltration trenches and basins, and porous pavements function in a similar fashion. These practices allow stormwater runoff to filter through the soil column where pollutant removal by physical (sedimentation, adsorption, etc.), chemical (reaction), and biological (root uptake, transformation, etc.) processes take place. Infiltration facilities can achieve a relatively high degree of removal of particulates as well as dissolved pollutants if properly designed. Since clogging by sediment is a major concern for infiltration facilities, some type of pretreatment device, such as a vegetative filter strip, is usually included as part of the infiltration system.

Infiltration Trenches and Basins

These measures are trenches or basins in which coarse sand or gravel is placed. Filter fabric can be used to line the trench or basin to prevent voids from clogging and fines from surrounding soil from leaking into the voids. Basins are the most economical and efficient infiltration system for highway runoff drainage. Trenches and pits are suitable for some situations, including many parking lots.

Moderate to high pollutant removal rates can be expected of infiltration trenches and basins. For example, Schueler (*87*) reported removal efficiencies of 80 to 100 percent suspended sediment, 60 to 80 percent nutrients and 80 to 100 percent metals and bacteria can be removed by a properly designed infiltration trench or basin.

Figures 28 and 29 show examples of an infiltration trench and an infiltration basin.

Porous Pavement

Porous pavement is a fairly innovative practice in controlling stormwater runoff. It generally consists of a layer of open-graded

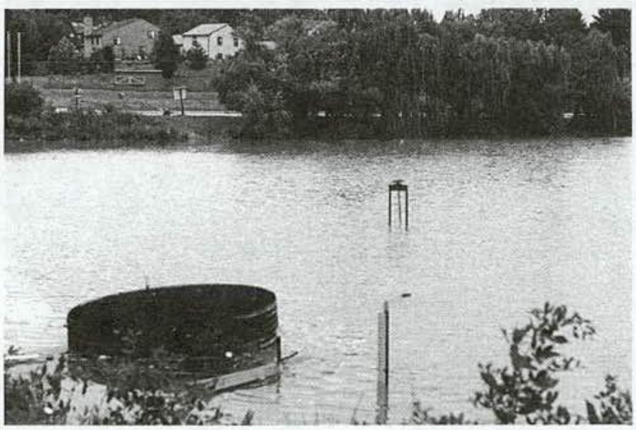


FIGURE 27 Wet pond in a residential area.

FIGURE 28 An infiltration trench at a parking lot.

FIGURE 29 Close look at an infiltration trench and basin.

asphalt mix on top of a deep base filled with large size crushed stone aggregate to form a reservoir for detaining rainwater. A filter fabric may be installed at the bottom of the stone aggregate to prevent the reservoir from clogging. For low permeability soils, perforated pipes may be installed to provide subsurface drainage.

Studies suggest that porous pavement performs adequately in reducing ponding and therefore hydroplaning effects (*88*). It works well on sandy soils in non-frost areas. Additional costs for the construction are offset by the reduced costs for conventional highway drainage construction.

Very little information has been accumulated on water quality benefits of the porous pavement. In a recent study, the Arizona Department of Transportation constructed a 3,000 foot stretch of an urban highway with porous pavement (*89*). Preliminary findings indicate satisfactory drainage performance but also vertical deformation of the pavement surface.

Several studies have been conducted by Maryland and by Virginia on porous pavement performance in terms of water quality benefits. These studies and one being conducted at a Fauquier County site by the Virginia Department of Transportation have shown some positive results (*90*, and personal communication from D.C. Wyant).

Figure 30 illustrates a porous pavement surface. Figure 31 shows a comparison of porous and conventional pavements during a storm.

Vegetative Filter Strip

Vegetative (wood or more often grass) filter strips are low-cost practices that have been found to offer some water quality benefits. Studies conducted in Virginia in an urban setting (*86*) and in agricultural areas (*91*) have shown moderate pollutant removal efficiency, especially for particulate pollutants such as suspended sediment. A level spreader, which is an earthen or concrete trench situated on a contour, is usually needed as a component of a filter strip for the purpose of spreading stormwater runoff evenly onto the strip. Otherwise channels may form, the strip will be short-circuited and lose its removal efficiency. Figure 32 shows a level spreader/vegetative filter strip system in Charlottesville, Virginia, and Figure 33 shows the system with a fairly even sheet flow (*86*).

Vegetative filter strips, either left in place or constructed, can be used as a first stage practice, preceding another practice so that a high overall performance is achieved. For example, runoff from a parking lot can be made to pass over a filter strip before entering an infiltration trench. Not only will the combined removal be higher, but the infiltration trench is less likely to be clogged by particles.

The level spreader/vegetative filter strip system, shown in Fig-

FIGURE 30 Porous pavement surface.

FIGURE 31 Porous pavement (foreground) compared with conventional pavement (background) during a storm.

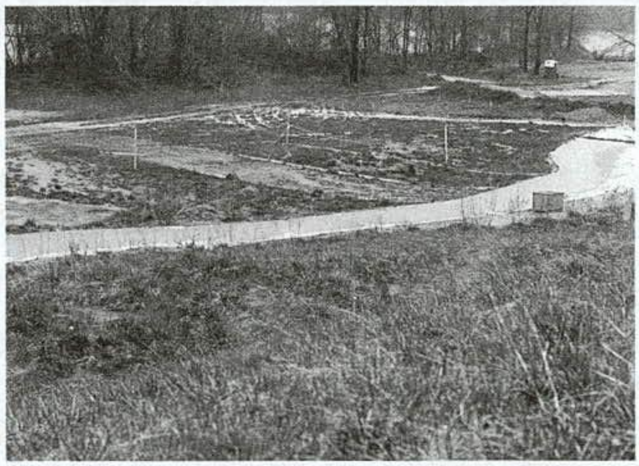


FIGURE 32 Level spreader/vegetative filter strip system (*86*).

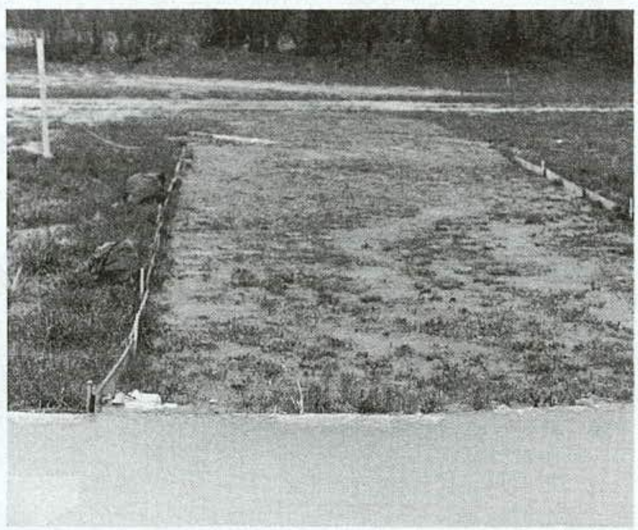


FIGURE 33 Vegetative filter strip with sheet flow looking down from the level spreader (*86*).

ures 32 and 33, tested by Yu et al. (*86*), gave removal rates comparable to a wet pond, i.e.:

Pollutant	
Total suspended solids	70%
Total phosphorous	40%
Zinc	40%
Lead	25%
Nitrate-nitrite	10%

Grassed Swales

Grassed swales are a common practice in residential areas and highway medians. Because conventional design of swales does not allow much time for runoff water to be detained, they have limited efficiency in controlling runoff quantity and quality. However, grassed swales can be designed with enhanced filtering capacity and, therefore, can be used as a preferred method of treating highway runoff.

Figure 34 shows a grassed swale in a highway median. Figure 35 shows the same swale with monitoring devices, i.e., flow barriers and weir, equipment boxes and rain gauge. The swale is being studied in connection with an FHWA HPR project through the Virginia Department of Transportation.

FIGURE 34 Grassed swale in a highway median.

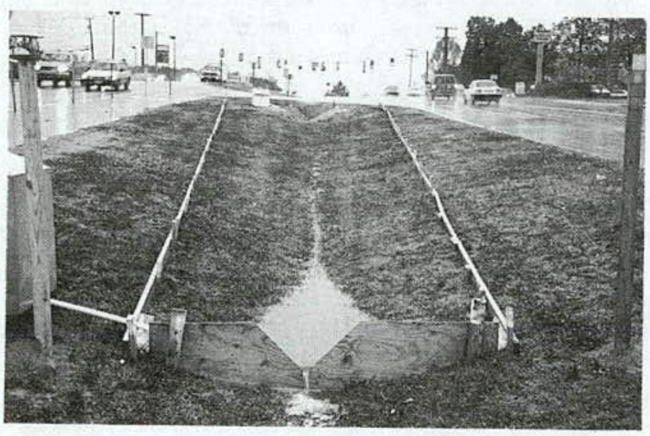


FIGURE 35 Grassed swale with monitoring devices during a storm event.

Wetlands

Wetlands have long been used for treatment of municipal wastewater as reported by Boyt et al. (*91*). Many studies have demonstrated the cost effectiveness of wetlands as an alternative for wastewater treatment.

Using wetlands to treat urban runoff is a recent idea. A study conducted in Minnesota (*92*) examined the use of natural marshes to filter nutrient-rich urban runoff water and significant removal of nutrients and suspended solids was observed. However, relatively little information is available, for example, regarding the cost effectiveness of using natural or artificial marshes as a management practice. The potential impact of stormwater runoff on the receiving wetland must be thoroughly evaluated before the wetland can be used as a BMP.

A study conducted by the U.S. Geological Survey (USGS) in cooperation with the Florida Department of Transportation was intended to examine the efficiency of a detention pond/wetland system in treating highway runoff. The system, described by Martin and Smoot (*93*), receives runoff from a four-lane highway and the adjacent residential area. Stormwater runoff enters the detention pond first and then the wetland before discharging into the receiving water (Figure 36).

Martin and Smoot reported that the wetlands system was quite efficient in removing metals: lead, 73 percent; zinc, 56 percent; and suspended solids, 66 percent. Results for nutrients were low, ranging from 17 percent for total phosphorous to 21 percent for total nitrogen.

Another study conducted by Scherger and Davis (*94*) of a natural wetlands area in Michigan showed good removal efficiency for solids (76 percent to 93 percent), moderate rate for total phosphorus (40 percent to 60 percent), and low rate for nitrogen (20 percent to 30 percent).

Comparative Removal Efficiencies

Two tables were prepared to provide summary information on pollutant removal efficiencies of urban BMPs. Table 13 is a list of comparative pollutant removal efficiencies of selected BMPs. The table was prepared based on results reported in the literature

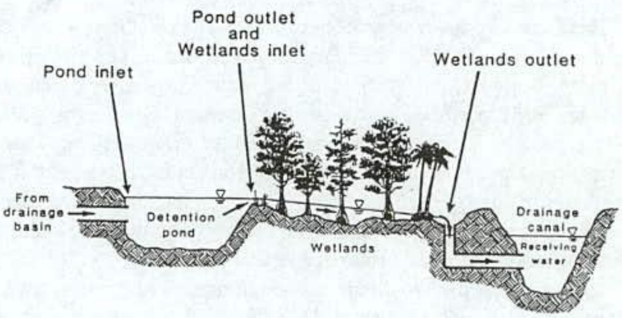


FIGURE 36 Profile schematic view of the detention pond and wetlands (*93*).

TABLE 13
COMPARATIVE POLLUTANT REMOVAL EFFICIENCIES OF URBAN BMPs (Removal efficiencies in %)

BMP	Total Sus. Solids	Total Phosphorus	Total Nitro.	Total Lead	Total Zinc	Data Source
Detention Ponds						
Dry Ponds	14	20	10	-5	-10	Ref. (83)
Ext. Dry Ponds						
4-6 hr detent.	29	40	25	29	25	Ref. (83)
6-12 hr detent.	70-74	13-56	24-60	24-61	40-57	Ref. (83)
Wet Ponds						
a/A* <0.1%	0-32	0-18				Wet Pond
0.1-1%	5-66	29-36				data from
1-2%	60-91	34-79		57	51	(6, 85,86,
2.85%	81	54				93)
7.51%	93	45				
Infiltration Trenches**	90+	30-70	30-70	15-80	15-80	Ref. (79)
Porous Pavements**	82-95	65	80-85	90+	90+	Ref. (87)
Vegetative Buffer Strip with Level Spreader	70	40		25	51	Ref. (86)
Grassed Swales with Check Dams**	20-40	20-40	20-40	0	0	Ref. (87)
Wetlands	60-90	20-60	20-30	73	56	Ref. (93)

* a/A = pond surface area/watershed area ratio
** Estimates based on very limited data

cited in this section. Table 14 is a summary of monitored wet detention pond pollutant removal efficiencies. The location, name, and basin-to-watershed area ratio of the wet ponds are also given.

BEST MANAGEMENT PRACTICES: DESIGN CONSIDERATIONS

There are two basic approaches to the determination of design guidelines for a BMP. One is performance based, i.e., to derive rules for design based on field or laboratory experiment data on how the BMP performs in removing pollutants. Obviously, good design guidelines can only be clearly defined when long-term performance data under a variety of environmental conditions are available. By using statistical analysis, one can relate BMP performance to certain BMP parameters, such as dimensions or configurations, and then derive rules for design.

The other approach to obtaining design rules is to examine theoretically the key mechanisms that would affect the performance of a BMP. By so doing, certain pertinent parameters can be defined as design variables that can be verified by actual performance data. Modeling analysis can also be made to compare the relative importance of the parameters. This will lead to the determination of design guidelines. For example, from theoretical considerations the pollutant removal efficiency of a wet detention pond can be related to the residence time, which in turn is related to the length-to-width ratio of the pond. A modeling analysis can be made to compute removal efficiencies for various length-to-width ratios and the ratio leading to the best efficiency is then used as part of the design guidelines.

At the present time, field data on long-term BMP performance are still scarce, except perhaps for wet ponds. Consequently, most design guidelines recommended in the literature have been based on a combination of the two approaches.

In this section, design guidelines for selected BMPs are discussed. The selection was based on available information regarding effectiveness and potential applications in managing highway runoff pollution. The BMPs selected are:

- Extended Dry Detention Ponds
- Wet Ponds
- Infiltration Trenches

TABLE 14
SUMMARY OF MONITORED WET DETENTION POND POLLUTANT REMOVAL EFFICIENCIES

Location	Basin	Basin Watershed Area Ratio (%)	TSS	TP	DP	TKN	PB	ZN
USEPA NURP Detention Basins (6)								
			55	66		15	65	51
Lansing, Mich.	Grace No.	0.01	0	0	0			
Lansing, Mich.	Grace So.	0.04	32	12	23			
Ann Arbor, Mich.	Pitt	0.09	32	18	0			
Ann Arbor, Mich.	Traves	0.31	5	34	56			
Long Island, N.Y.	Unqua	1.84	60	45				
Washington D.C.	Westleigh	2.85	81	54	71			
Lansing, Mich.	Waverly Hills	1.71	91	79	70			
Glen Ellyn, Ill.	Lake Ellyn	1.76	84	34				
Florida Detention Pond (93)								
Orlando, Fla.	Highway Pond	0.47	66	38	72	20	40	39
Washington Urban Runoff Detention Pond (95)								
Washington D.C.	Burke	11.5	37	59				
Virginia Urban Pond (87)								
Charlottesville, Va.	Four Seasons	1.46	77	70	63	53	57	51
North Carolina Urban Ponds (85)								
Charlotte, N.C.	Waterford	0.59	41	29		22		22
Charlotte, N.C.	Runaway Bay	0.74	62	36		21		32
Charlotte, N.C.	Lakeside	7.51	93	45		32		80

- Porous Pavements
- Vegetative Filter Strips
- Grassed Swales
- Wetlands

Detention Ponds

Removal Mechanisms

Pollutants are removed in a detention pond mainly through the following mechanisms:

Particle Settling. Particulate pollutants are removed by gravitational settling. Therefore, the removal rate for particulates should relate to the inflow *particle size distribution* of the pollutant and the *detention time*, which is affected mainly by the size of the pond, the geometry, and the design of the outlet structure.

Decay. For nonconservative pollutants such as BOD and bacteria, biodegradation and die-off will occur, respectively.

Biological uptake. Dissolved nutrients are primarily removed by biological activities of the aquatic vegetation in the pond.

For most detention ponds, the dominant factors influencing removal efficiency are the settling velocity (or size distribution) of the pollutants and the basin volume.

Driscoll (*82*) reported a typical settling velocity distribution of urban runoff suspended solids based on the EPA NURP study data, as shown in Table 15. The table suggests that 80 percent of the suspended solids in urban runoff have settling velocity less than or equal to 7.0 ft/hr.

Using the typical size distribution, Driscoll developed long-term regional performance curves for total suspended solids as depicted in Figure 37. The performance curves were derived based on the classical sedimentation theory. The "short-circuiting" parameter, which is related to the degree of mixing in the pond, was assumed to be 3, indicating "good" performance.

It should be noted that Figure 37 applies to suspended solids only. The detention pond should be designed for removing all the pollutants. However, the settleability of various pollutants differs from one another. For example, Whipple and Hunter (*96*) performed column settling tests and found that hydrocarbons and lead settle out similar to suspended solids (TSS), but phosphorus, zinc, copper, nickel and BOD exhibit quite different settling patterns.

TABLE 15
TYPICAL SETTLING VELOCITY DISTRIBUTION OF SUSPENDED SOLIDS IN URBAN RUNOFF (*82*)

Size Group (in 20% Increments)	Average Settling Velocity (ft/hr)
1	0.03
2	0.30
3	1.50
4	7.00
5	65.00

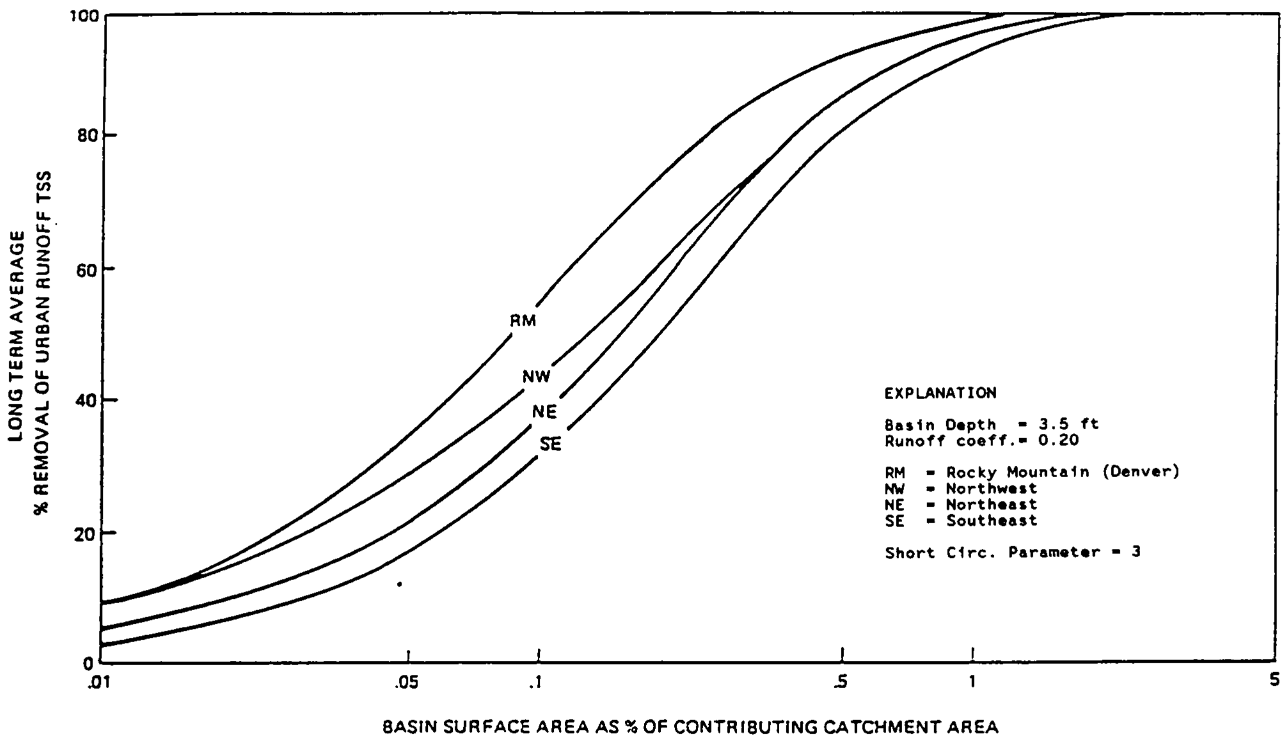


FIGURE 37 Regional differences in detention basin performances (*82*).

For example, below are percent settled estimated from Whipple and Hunter's data assuming a settling time of 12 hours:

Pollutant	Percent settled after 12 hr
TSS	55
Hydrocarbons	57
Lead	50
Total phosphorous	40
BOD	25
Copper	25
Nickel	25
Zinc	20

The different settling characteristics of various pollutants are further illustrated by data collected by Wu et al. (*85*), as shown in Figure 38.

The same observations were obtained in the Metropolitan Washington Council of Governments (MWCOG) NURP study. In the MWCOG study, both laboratory column tests and field monitoring of two detention pond sites were conducted. Figure 39 shows the removal rates for various pollutants obtained by the settling column tests (*87*). The same trend was also observed for the field test results.

In summary, design of detention ponds based on particle settling should consider the following:

- Particle size distribution in the inflow water is a very important design consideration. As it is site-specific and may vary from storm to storm, an examination of the typical particle size distribution in highway runoff for various areas will enhance design.

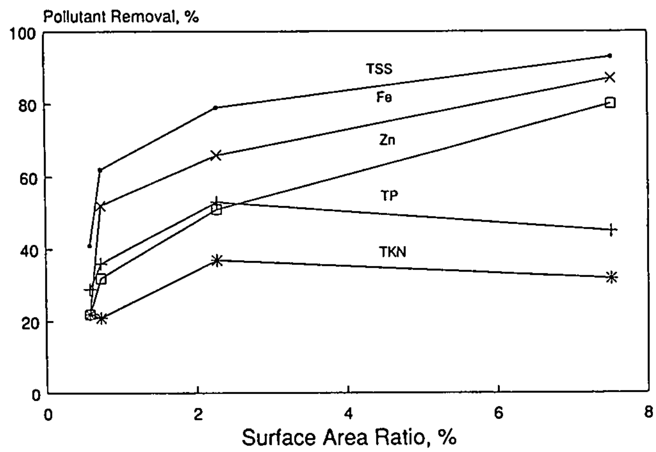


FIGURE 38 Summary of field monitoring data (*115*).

- Suspended sediments, lead, and hydrocarbons may exhibit similar settling characteristics, while phosphorous and the other pollutants may be grouped into another category.
- Detention time is an important design parameter which is related to pond size configuration, and auxiliary devices such as inlet/outlet structures and baffles. There also seems to be a point of diminishing return between 6 and 12 hours of detention time (See Figure 39).

In general, the kinetic process for decay and biological uptake by plants are both enhanced by longer detention time in a pond. Therefore, the detention time can be considered as the key design

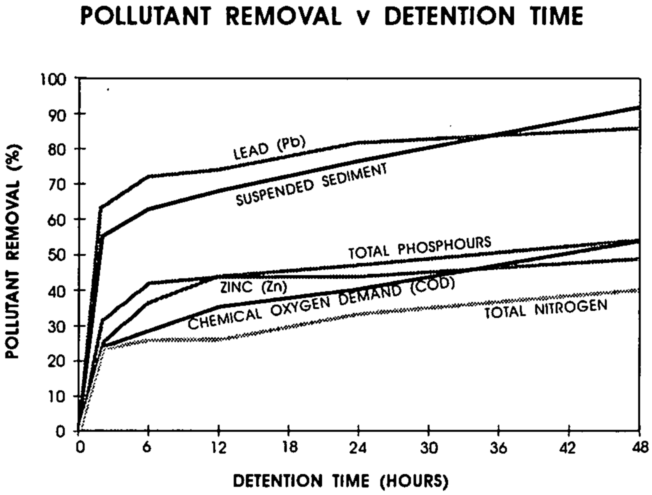


FIGURE 39 Removal rate versus detention time for selected pollutants (*89*).

factor. Longer detention time (24 to 36 hours) may be preferred if biological uptake is desired.

Example Design Guidelines

Extended Dry Ponds

Schueler (*83,87*) recommended some guidelines for designing BMPs. Highlights of the design considerations for extended dry ponds are:

- Volume should store runoff quantity produced by a 1-in. storm.
- For optional pollutant removal, 24 hours of detention is desirable.
- Smaller storms (0.1 to 0.2 in. of runoff) should be detained for at least 6 hours.
- A two-stage design is recommended: an "upper" stage of the pond is to remain dry normally and a "bottom" stage is regularly inundated with its volume set to store about 0.5 in. of runoff.
- Marshes should be established at the bottom stage.
- The outlet control device should be designed to set water levels and should withstand partial clogging.
- A low flow channel is desirable.

A schematic diagram of a design for an extended dry pond is shown in Figure 40.

Figures 41 and 42 show two examples of the outlet structure design for an extended dry pond.

Wet Ponds

By maintaining a permanent pool, wet ponds achieve particulate and dissolved pollutant removal through enhanced particle settling, decay processes, and biological uptake. In addition to the particulate settling-based design approach, biological and other decay processes should also be included in deriving design guidelines. In general, wet pond design methodology could include the following approaches:

Solids Settling Design. Based on sedimentation theory, the method uses the particle size distribution and thus, the settling velocity as a key parameter. Pond size and configuration are designed so that particle settling is optimized. Figures 41 and 42 illustrate the basic design considerations, as described in the previous paragraphs for extended dry pond design.

Lake Eutrophication Model Design Method. Hartigan (*97*) proposed that a wet pond be considered as a small eutrophic lake that can be simulated by empirical models to evaluate lake eutrophication. Hartigan used the "input-output" phosphorus retention model developed by Walker (*95*) as the design tool. The Walker model relates phosphorus removal rate to such variables as the inflow total phosphorus concentration, the second order decay rate, mean lake depth, and the hydraulic residence time. By changing the wet pond volume and other geometry characteristics, one can obtain the removal rate desired. This design approach generally leads to larger required pond volumes (*87*).

Detailed Hydraulics/Water Quality Modeling Approach. A wet pond can also be modeled in a more detailed fashion, analogous to a lake. Flow patterns, pollutant transport and transformation processes in a pond can be simulated under a variety of trail design conditions so that some guidelines can be obtained. For example, the geometry of the pond can be changed, or a baffle installation could be tried and their effect on the removal rate can then be examined by using a model (*86*).

To compare the solids settling design method with the lake eutrophication model method, Hartigan (*97*) plotted average total phosphorus removal rates computed from each model against (T) the average residence time. (T) can be computed from the ratio of permanent pool storage volume (VB) to the product of mean storm runoff (VR) times the average number of storms per year. Figure 43 shows the comparison. Hartigan reported that the eutrophication method would result in a permanent pool requirement three times larger than that from the solids settling method to achieve the same removal efficiency.

The detailed modeling analysis approach can be used, for example, to make refinements of the pond design. Figure 44 depicts the results from a two-dimensional pond modeling study of effects of the length-to-width ratio of particulate removal efficiency (*87*).

Another example application of the two-dimensional model is a study on the use of baffles to prevent short-circuiting and to increase the removal efficiency of a wet pond, as shown in Figure 45(a) and 45(b). A longitudinal baffle was shown to improve the removal efficiency by 10 to 20 percent (*98*).

Table 16 summarizes design recommendations for detention ponds based on recommendations found in the literature (*85-87,90,97*).

As an example of highway applications, a wet detention pond can be constructed within a loop ramp of the interchange as shown in Figure 46 (*79*). The guidelines listed in Table 16 can be followed and pollutant removal performance curves, such as those shown in Figure 38, can be used to check the design alternatives. A recommended schematic of a wet pond is shown in Figure 47 (*87*).

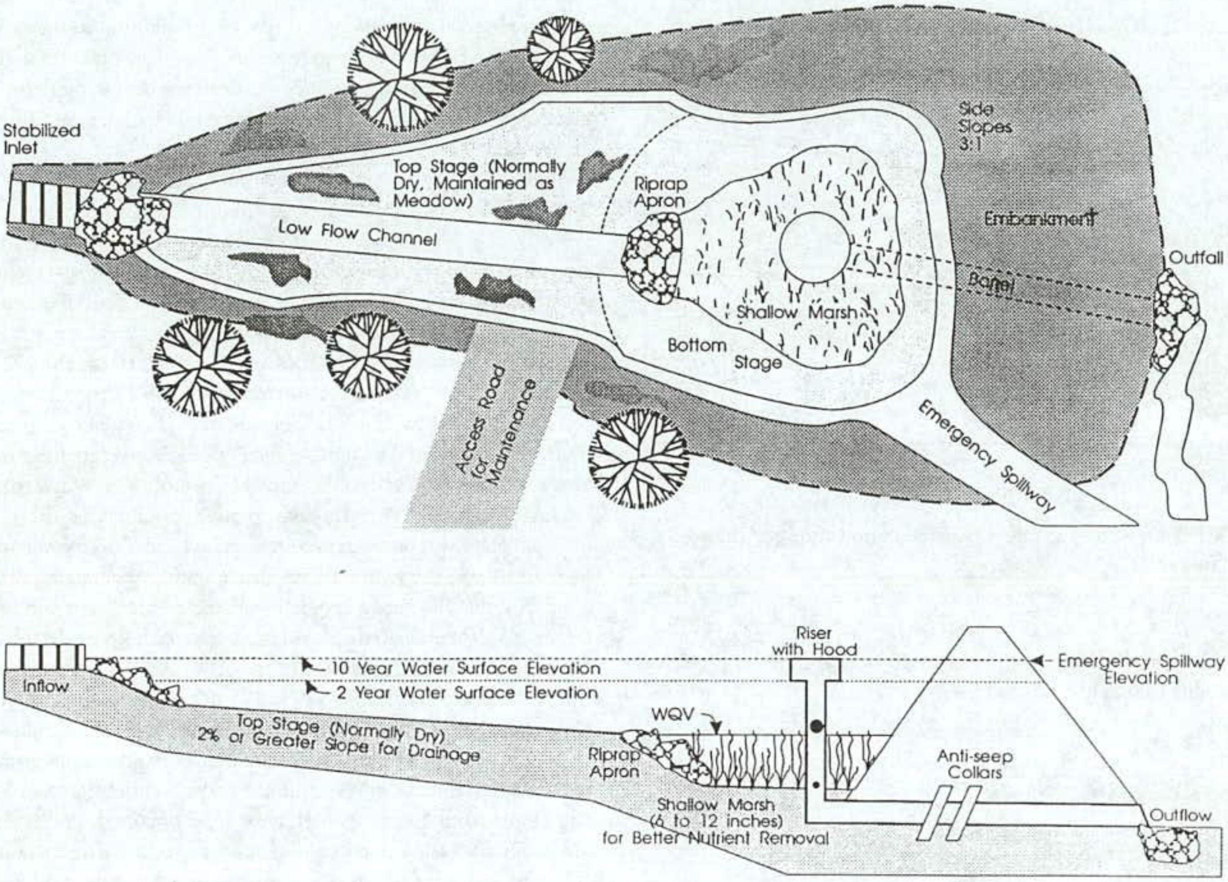


FIGURE 40 Schematic of extended detention pond design features (*87*).

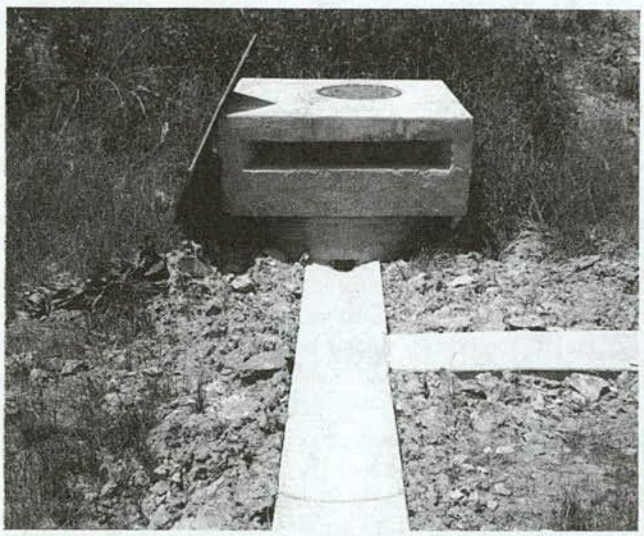


FIGURE 41 Extended dry pond outlet design (photo by R. Kaighn).

Infiltration Trenches (or Basins)

Removal Mechanism

From the viewpoint of pollution of the surface waters, infiltration trenches or basins can be considered 100 percent effective in removing pollutants from surface stormwater runoff. However, impact on groundwater of the exfiltrated water from infiltration facilities should be considered. In this case, pollutants are removed through settling and adsorption while being temporarily detained in the infiltration facility. Further removal is accomplished through the physical, chemical, and biological processes taking place when water is percolated through the soil column.

Information on pollutant removal by infiltration through soil is limited. However, studies on land treatment of municipal wastewater have provided some estimates (*79*):

Total suspended solids	99%
Nutrients	30–70%
Metals	15–80%

Design Considerations

A typical cross-section of an infiltration trench is shown in Figure 48. The size of the trench is determined by the amount of

FIGURE 42 Extended dry pond outlet design (photo by R. Kaign).

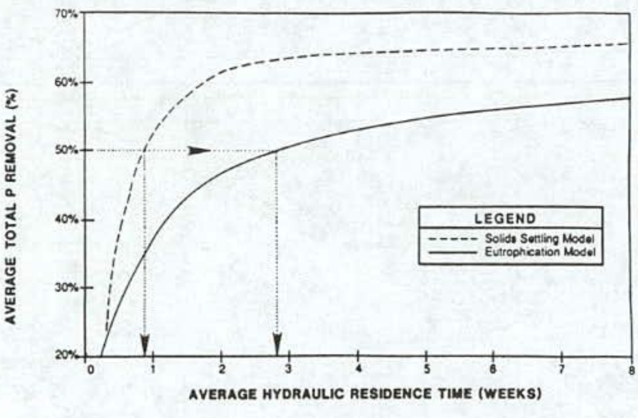


FIGURE 43 Comparison of wet detention basin design models: northern Virginia (*97*).

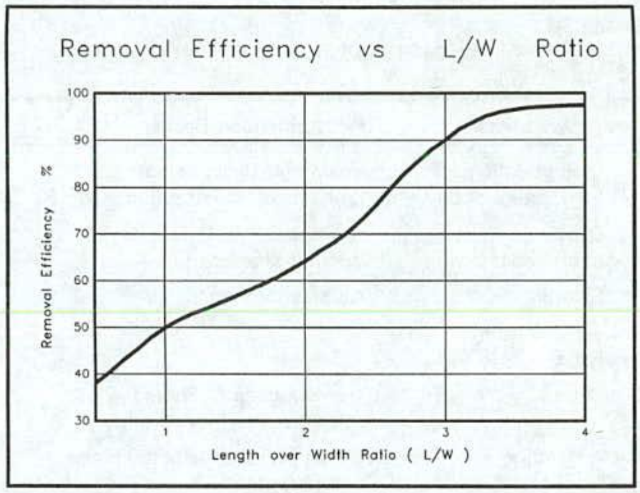


FIGURE 44 Removal efficiency versus length over width ratio for a wet pond (*86*).

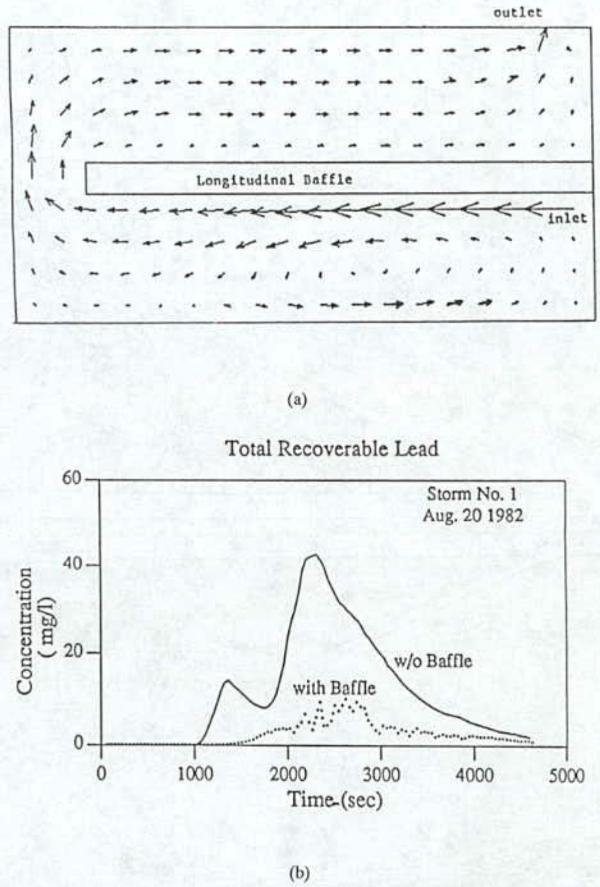


FIGURE 45 Flow pattern (a) and removal efficiency (b) of a wet pond with a longitudinal baffle (*129*).

storage volume required. Sizing rules for storing either 0.5 inches or 1.0 inches of runoff per impervious area in the contributing watershed have been recommended (*87*). The trench depth is usually between 3 and 10 ft. Filter fabric is placed around all sides of the trench to prevent clogging and soil fines from leaching into the stone reservoir. Buffer strips should be placed between the runoff producing area and the trench for solids removal.

Infiltration trenches may be best suited for highway median strips or right-of-way areas with inflow via overland flow paths (*79*).

TABLE 16
SUMMARY OF WET POND DESIGN RECOMMENDATIONS
(*85,86,87,90,97*)

Design Parameter	Recommended Design
1. Storage Volume (permanent pool)	Volume of Basin at least 2.5 times mean storm runoff volume
2. Depth (permanent pool)	Average 3-9 feet. Use large depth if practical
3. Side Slopes	No steeper than 3H:1V
4. Length/Width Ratio	At least 3:1
5. Baffles	Use as needed. Should maximize the flow length.
6. Vegetation	Marsh establishment near inlet and perimeter
7. Sediment Forebay	Shallow forebay for sedimentation and vegetation is preferred

Other suitable areas for infiltration trenches include the bottom of grass channels and interchange loops. An example of a median strip infiltration trench design is shown in Figure 49 (*87*).

It should be noted that soil permeability is an important consideration in infiltration trench or basin application. A minimum soil infiltration rate of 0.5 in/hr (SCS Hydrologic Soil Groups A or B) is preferred.

Figures 50 and 51 depict actual installations of infiltration trenches. Figure 50 is a good design with a long vegetative buffer strip leading to the trench, while the trench in Figure 51 is not a very good design because the strip on either side of the trench is too short. In both figures, the monitoring well can be seen.

Porous Pavements

Removal Mechanisms

The pollutant removal mechanism of a porous pavement facility is much like that of an infiltration trench. Some pollutants will be trapped in the asphalt pores and the stone reservoir base, but most of the removal will take place when runoff percolates into the

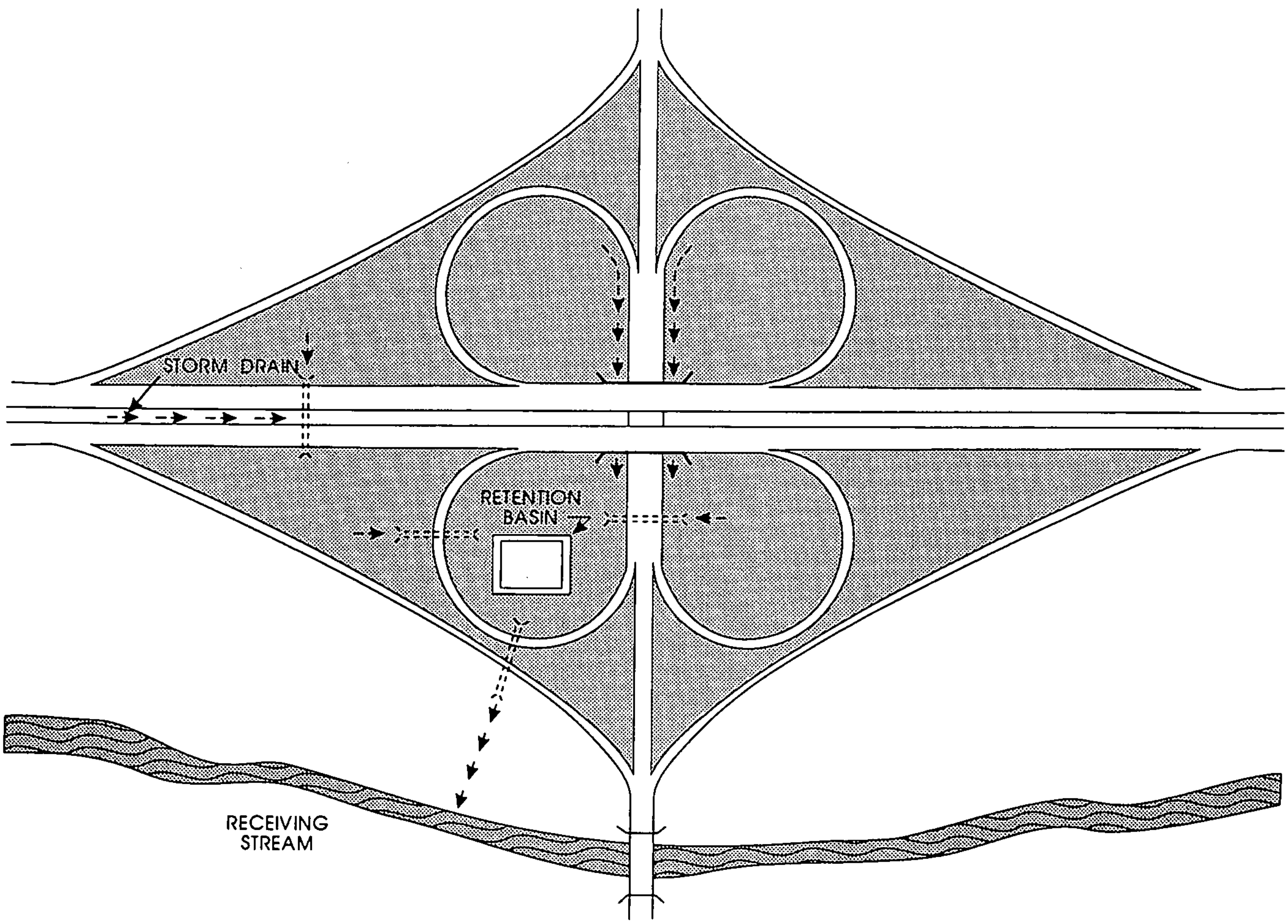


FIGURE 46 Example of highway wet detention basin design (*79*).

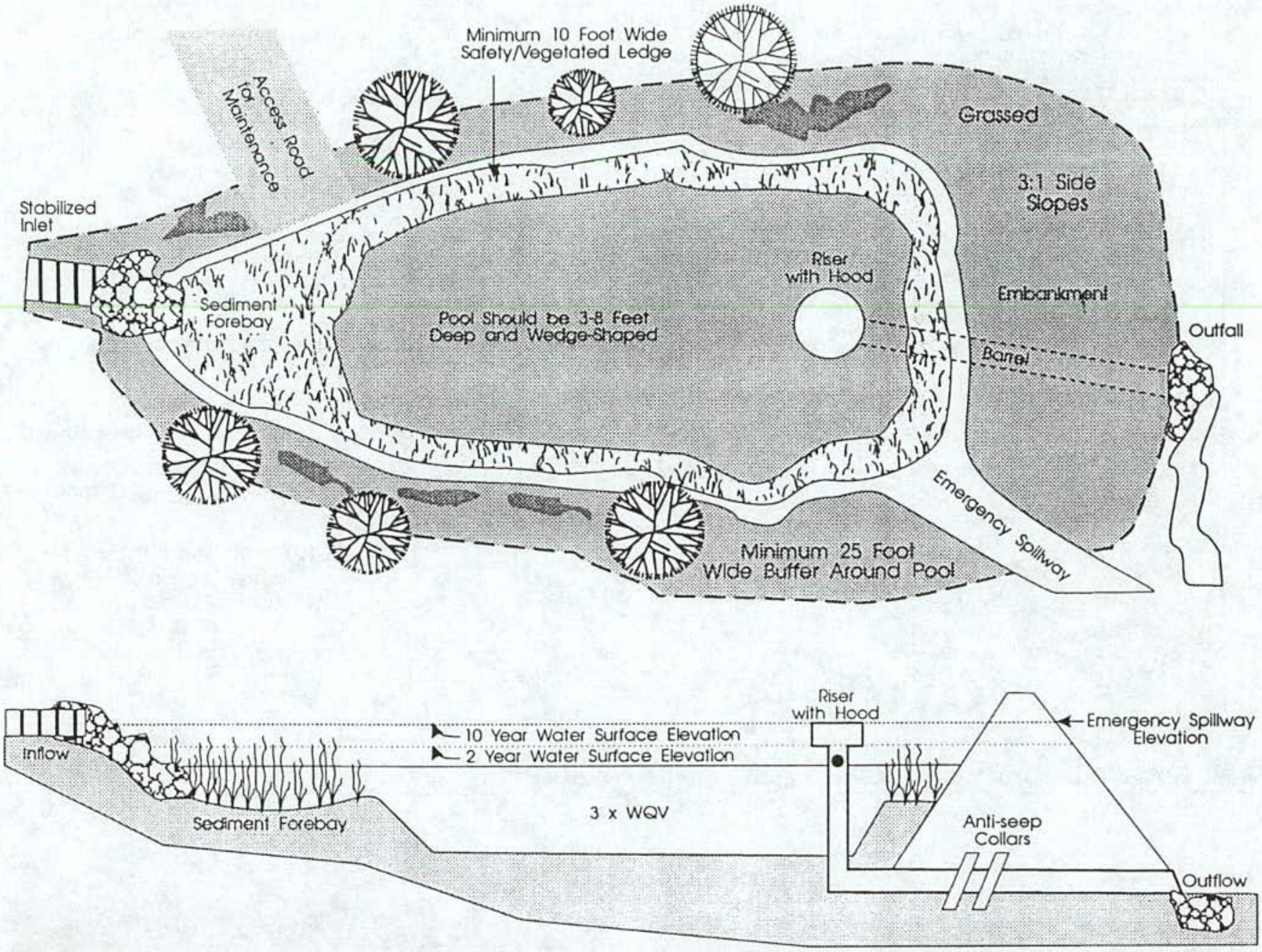


FIGURE 47 Schematic of wet pond.

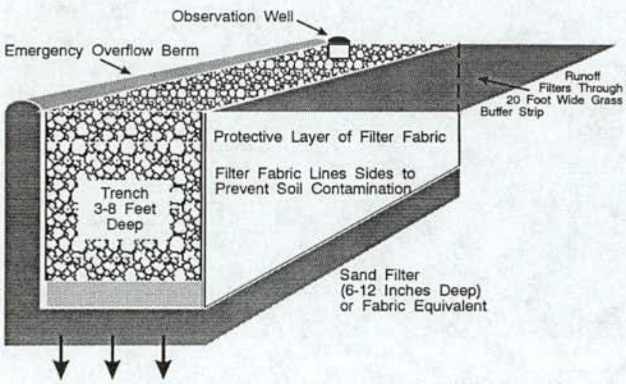


FIGURE 48 A typical cross-section of an infiltration trench with monitoring well (*147*).

subsoil. To avoid structural problems associated with wet pavement foundations, porous pavements may be suitable for parking lots only, in warm (never freezing) climates with sandy substrates, or where collection pipes are installed to drain the runoff to a holding area.

Very few prototype tests of water quality benefits of porous pavements have been conducted. Schueler (*87*) reports estimates of long-term removal rates based on field tests conducted in Maryland and Virginia:

Suspended solids	82–95%
Total phosphorous	65%
Total Nitrogen	80–85%
Chemical oxygen demand	82%
Zinc	99%
Lead	98%

Porous pavements have also been found effective in removing urban stormwater pollution in other countries. In Japan, for example, more than 300,000 square meters (about 3.23 million ft^2) of porous pavement surfaces were installed in Tokyo and a 3-year monitoring study has found the systems to be quite effective (*99*).

Design Considerations

A typical porous pavement cross-section is shown in Figure 52 (*88*). The depth of the stone reservoir should be designed so that,

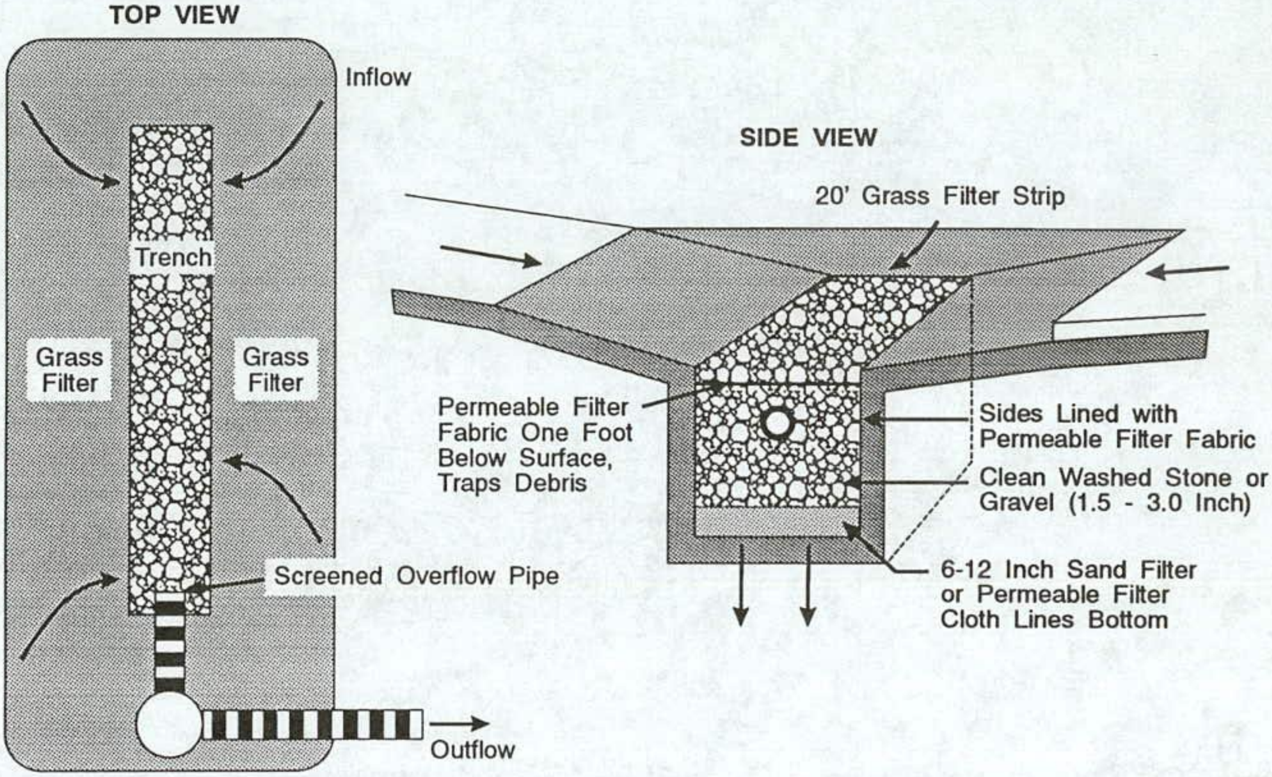


FIGURE 49 Example of highway median strip infiltration trench design (*87*).

FIGURE 50 Infiltration trench with long vegetative buffer strip.

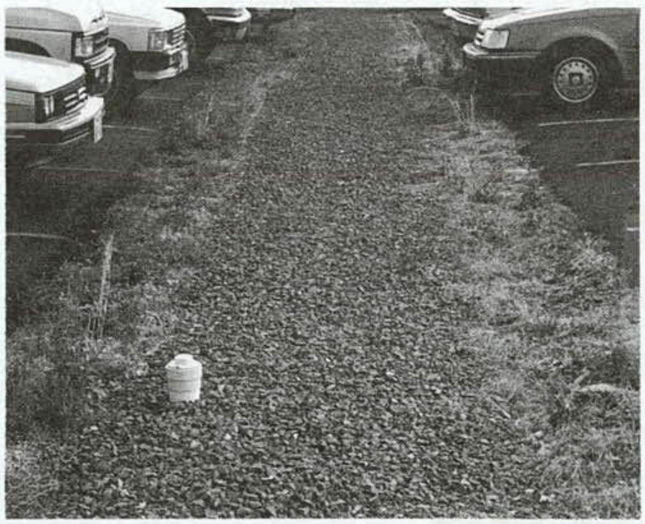


FIGURE 51 Infiltration trench with very short filter strips.

as a minimum, the first 0.5 inches of runoff is detained for no longer than 72 hours, or the average time interval between storm events. Underground drains to a holding pond may be needed for soils with low permeability.

Due to concerns regarding the durability of porous pavements and the complexity involving construction specification changes, porous pavement as a BMP is usually recommended for low-traffic roads or parking lots. More studies are needed so that water quality benefits and the durability of porous pavements can be fully documented.

Vegetative Filter Strips

Removal Mechanism

As shown in Figure 53, a vegetative filter strip (VFS) refers to either a grass or a wooded area graded to a mild slope so that runoff is evenly distributed (sheet flow, as shown in Figure 32) over the filter strip by a level spreader installation. The VFS will only function properly when sheet flow is maintained.

Referring to Figure 54, where a level spreader/vegetative filter strip installation is depicted, the system essentially functions as two BMPs, namely, a mini-detention pond when runoff is retained in the level spreader, and a vegetative filter strip when runoff spills over the weir and onto the grass strip. Although usually having a small volume and depth (3 ft in this case), the level spreader does not act as a flow-through basin until it overflows. It is expected, therefore, that a fair amount of pollutants will be trapped at the bottom of the level spreader due to settling.

The vegetative filter strip, or VFS, serves to slow down overland flow, allowing sediments and pollutants to settle out or infiltrate. Figure 54 is a simplified representation of the level spreader system. Mechanisms associated with pollutant removal for a system include:

- Sedimentation and filtration, removing primarily solids and metals; and
- Adsorption, precipitation and plant uptake, removing primarily nutrients.

High solids removal by vegetative filter strips have been reported in literature. For example, a 2-year monitoring study conducted in Virginia (*86*) yielded removal efficiency for various pollutants by a level spreader/vegetative filter strip system as shown in Figure 55.

Design Considerations

It can be observed in Figure 55 that filter length is an important design parameter. A filter length of at least 60 ft is desirable. However, other factors, such as slope, runoff velocity, particle size distribution, and flow depth are all significant factors in determining the overall pollutant removal rate of a filter strip.

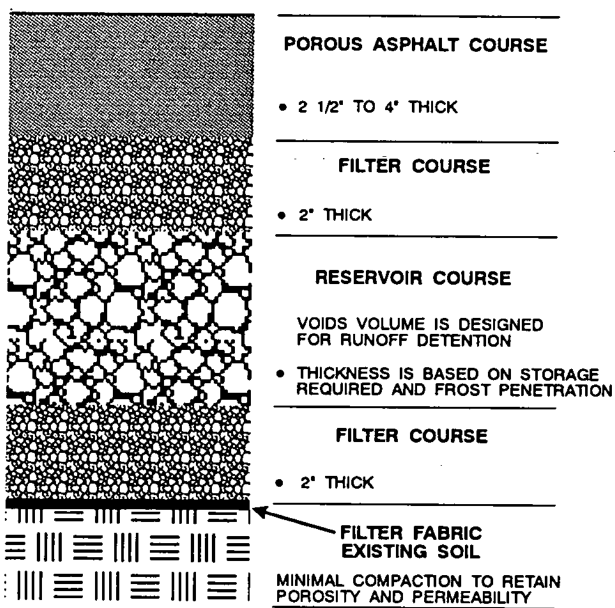


FIGURE 52 Typical section of porous pavements (*88*).

Wong and McCuen (*100*) developed a nomograph for sizing the filter length for given slope, runoff velocity, and desired solids removal efficiency, as shown in Figure 56. Such charts are very useful, especially with additional pollutants, such as nutrients and metals included when data are available.

Grassed Swales

Grassed swales are similar in many respects to vegetative buffer strips, except that they are usually designed for hydraulic efficiency and therefore provide very little in water quality benefits, especially with respect to soluble pollutants.

However, the removal efficiency of a swale can be enhanced if runoff is slowed and detained by the installation of a check-dam as shown in Figure 57 (*87*).

Some general design considerations have been offered by Dorman et al. (*79*):

- Pollutant removal efficiency is directly related to length of grassed channels. A length of at least 100 ft should be used if possible.
- Depth of flow should be shallow. Side slopes should be as flat as practicable.
- Channel erosion should be minimized.

For example, Vermont's Agency of Transportation uses the following criteria for designing grass-lined swales:

> A minimum ratio of 100 linear ft of grass-lined swale per acre of impervious surface, at a slope of less than 5 percent, and a channel velocity of less than 2 fps, for the runoff from a 10-year--24-hour storm.

Extensive literature is available regarding design guidelines for ensuring channel stability.

Wetlands

Removal Mechanism

Wetlands are complex ecosystems characterized by high floral productivity and nutrient needs, high decomposition rates, low oxygen content in the sediments and substrates, and large adsorptive surfaces in the substrates (*79*).

Removal mechanisms of wetlands include physical processes such as *sedimentation* for particulate pollutants; *adsorption* for ammonium ions, phosphate, metals and viruses; *chemical precipitation* for metals; *filtration* for organic matter, phosphorus bacteria, and solids; *volatilization* for oils, chlorinated hydrocarbons, and mercury; and *biological processes* such as nutrient uptake (*101*).

Very little scientific information is available regarding design criteria for wetlands used for stormwater treatment. The limited literature findings suggest that important factors to be considered in wetland design and management are pretreatment (for example, a detention pond upstream of a wetland) for solids removal and wetland hydrology (*101*). One example of a wet pond/wetland combination is the system built by the Florida Department of Transportation near Orlando, as shown in Figure 36 and described by Martin and Smoot (*93*). Figure 58 is a picture of the Orlando

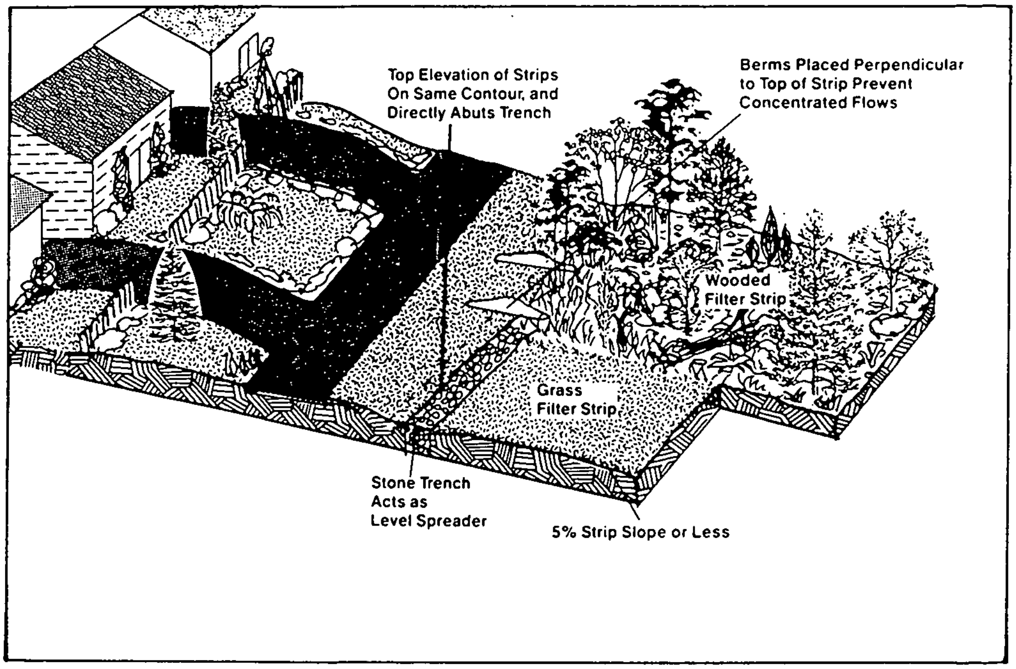


FIGURE 53 A schematic diagram of vegetative filter strips (*87*).

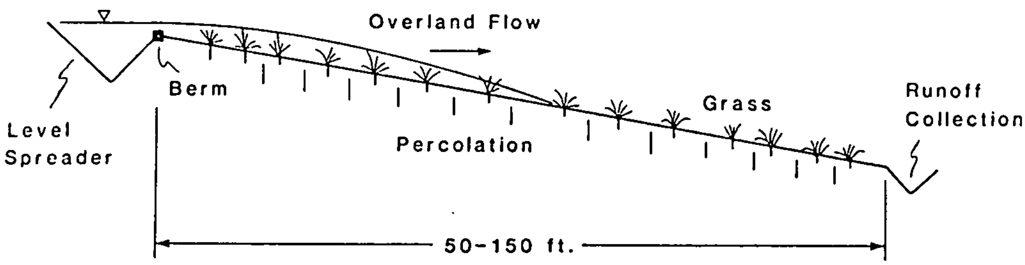


FIGURE 54 The level spreader/vegetative filter strip system (*86*).

pond, with the wetland in the background and a diagonal baffle installed for enhancing pond removal efficiency.

A set of design guidelines for wetlands was developed by the state of Maryland as listed in Table 17 (*102*). An example highway application of constructed wetlands as a stormwater BMP is shown in Figure 59.

More recently, FHWA issued Report No. FHWA-IP-90-010: "A Guide to Wetland Functional Design" in July of 1990 as a conceptual guide on wetland functional design. This report was intended to be a starting point in providing information on wetland functional replacement mitigation. Such wetland functions include hydrology; nutrient removal / transformation; sediment / toxicant retention; groundwater recharge; and acquatic and bird habitat diversity. FHWA also indicated that the conceptual guide should be "augmented with site specific and project specific design information."

MAINTENANCE AND SAFETY CONSIDERATIONS

General

Maintenance of stormwater management structures is an extremely important aspect of any stormwater management program. Adequate long-term performance of a stormwater management practice depends heavily on its routine inspection and proper maintenance. For example, dry detention ponds will lose their flood control and pollutant removal efficiency due to excessive weed growth and debris accumulation. Infiltration facilities may be clogged without routine cleaning.

When stormwater management regulations were first introduced at the local or regional level a few years ago, maintenance requirements were often not clearly defined and emphasized. For example, a developer may build a stormwater management facility to satisfy the local ordinance. Sometime later, the developer may sell the

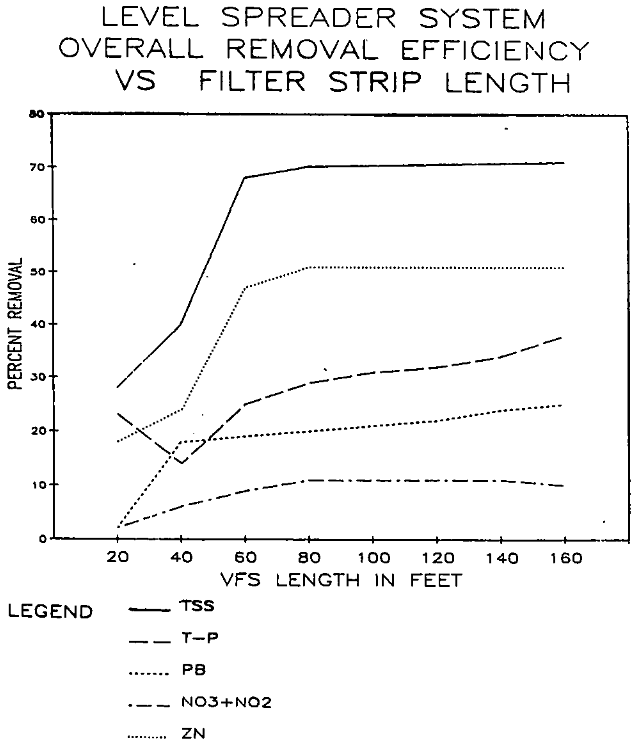


FIGURE 55 Level spreader/vegetative filter strip pollutant removal efficiency (*116*).

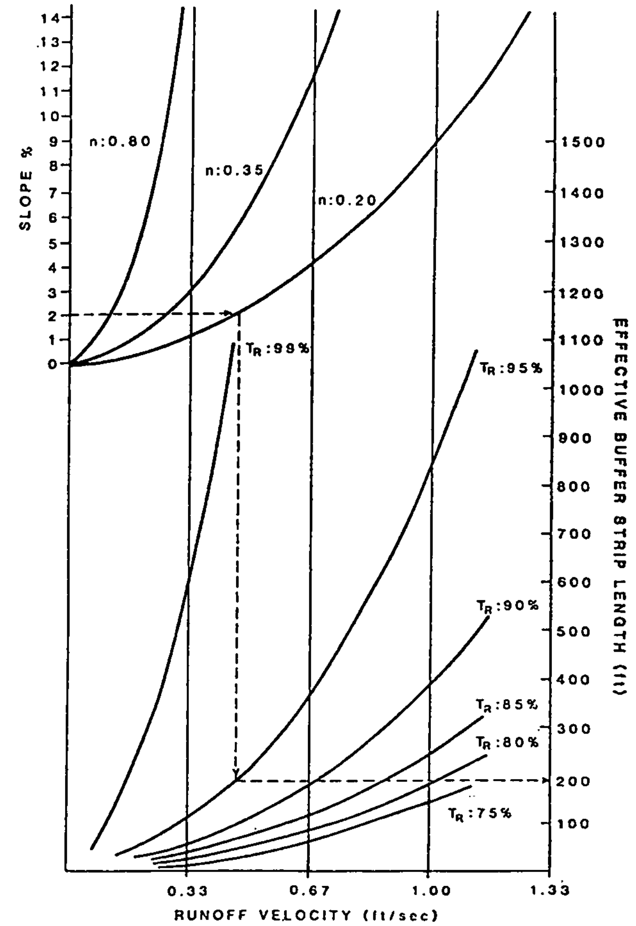


FIGURE 56 Effective buffer length determination for various trap efficiencies (T_R) (*100*).

property without passing on the maintenance responsibilities to the new owner. Many facilities either fail or function poorly due to lack of maintenance.

Recent federal and state regulations both recognize the importance of maintenance. For instance, the Virginia Stormwater Management Regulations state that:

> A schedule of maintenance inspections shall be incorporated into the local ordinance. Ordinances shall also provide that in cases where maintenance or repair is neglected . . . the locality has the authority to perform the work and to back-charge the owner. . . .
>
> Responsibility for the operation and maintenance of stormwater management facilities, unless assumed by a governmental agency, shall remain with the property owner and shall pass to any successor or owner.

Public safety is also a major area of concern, especially in the case of wet detention ponds. The issue of responsible ownership is an important one and should be considered when wet ponds are selected as a stormwater management practice.

Maintenance Considerations

Maintenance of Dry and Wet Detention Ponds

For detention ponds the most important routine maintenance tasks include:

Mowing. The side-slopes, embankment and emergency spillway of a detention pond should be mowed regularly for weed control (*87*). The frequency of mowing will depend on the site conditions and could vary between once per month to twice a year during growing seasons.

Debris and Litter Removal. Debris and litter should be removed, especially around the outlet of the pond so that clogging is prevented. Removal can be made during mowing operations, but should also be done if clogging occurs after heavy rain.

Permanent Erosion Control. Control measures such as riprap protection, regrading and revegetation may be necessary for preventing erosion to the embankment, emergency spillway, and side-slopes of a detention pond (*87*).

Other maintenance requirements include structural repair and sediment removal on an as-needed basis, as well as control of insects and odors, which may be necessary in many cases.

Ponds should be inspected regularly. Recommended frequency of inspection ranges from once a year (*87*) to at least twice a year and after any storm that causes the capacity of the facility to be exceeded, as specified in the Virginia Stormwater Regulations.

Maintenance of Infiltration Facilities

Clogging is a most common problem with all types of infiltration facilities such as trenches, basins, and porous pavement. If an infiltration facility has a clogging problem, the surface layer of the

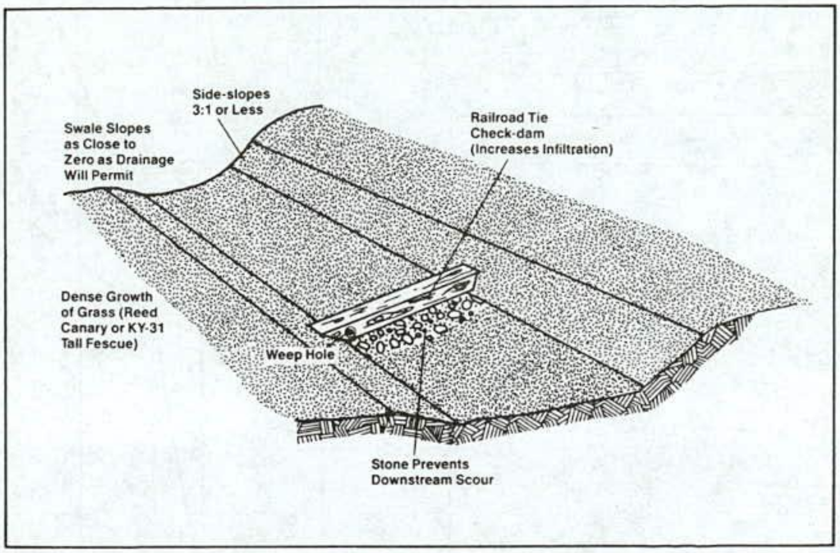


FIGURE 57 Swale with check-dam (*87*).

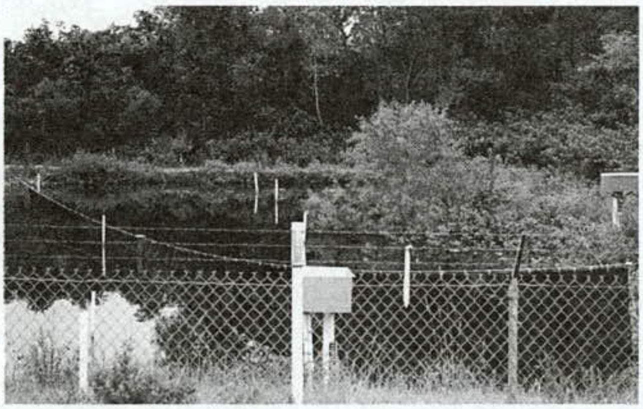


FIGURE 58 Detention pond wetland system in Orlando, Florida (pond with diagonal baffle in foreground, wetland is the background beyond the trees).

aggregate and the filter fabric covering the top of the trench should be replaced (*79*). Rehabilitation of the entire trench may be necessary if clogging becomes a serious problem at the bottom of the trench (*87*). For porous pavements, routine cleaning by vacuum sweeping should be considered for removing clogging materials.

In the case of vegetative buffer strips and swales, sedimentation of solids can hinder the effectiveness of grass in retarding flow and trapping pollutants. Clogging of soil pores could also be a problem. Periodic removal of sediment and seeding for maintaining a dense vegetative cover would be routine maintenance needs for buffer strips and swales.

Maintenance of Wetland Systems

Information regarding maintenance of wetlands for treating stormwater runoff pollution is relatively scarce. Dorman et al. (*79*) suggested that the following activities should be included as maintenance needs for wetlands used for treating highway runoff:

TABLE 17
WETLAND DESIGN GUIDELINES (*102*)

- **Water flow into pond must exceed infiltration rate of basin or a liner should be installed**
- **25% of the wetland area should be 2-3 ft deep**
- **75% of the wetland area should be under one ft deep**
  - **25% should be 6-12 in. deep**
  - **50% should be under 6 in. deep**
- **Locate discharge outlet in deep area of wetland**
- **Included a 3-ft deep forebay having at least 10% of the total basin volume**
- **Wetland perimeter should be bordered by 10–20-ft wide zone that is temporarily flooded at most storms**
- **Incoming stormwater should flow into the shallow, vegetated area of the wetland**
- **Length to width ratio should be at least 2:1**
- **Wetland should be able to detain the one-year storm for 24 hours**

- Periodic sediment removal within wetland,
- Introduction of certain vegetative species,
- Harvesting or burning of vegetation,
- Toxic monitoring, and
- Mosquito control.

Other maintenance items include repair as needed of channels, berms, and hydraulic control structures of the wetland systems.

Safety Considerations

For wet detention ponds, public safety is an important consideration. For example, wet ponds on the roadside could "constitute a

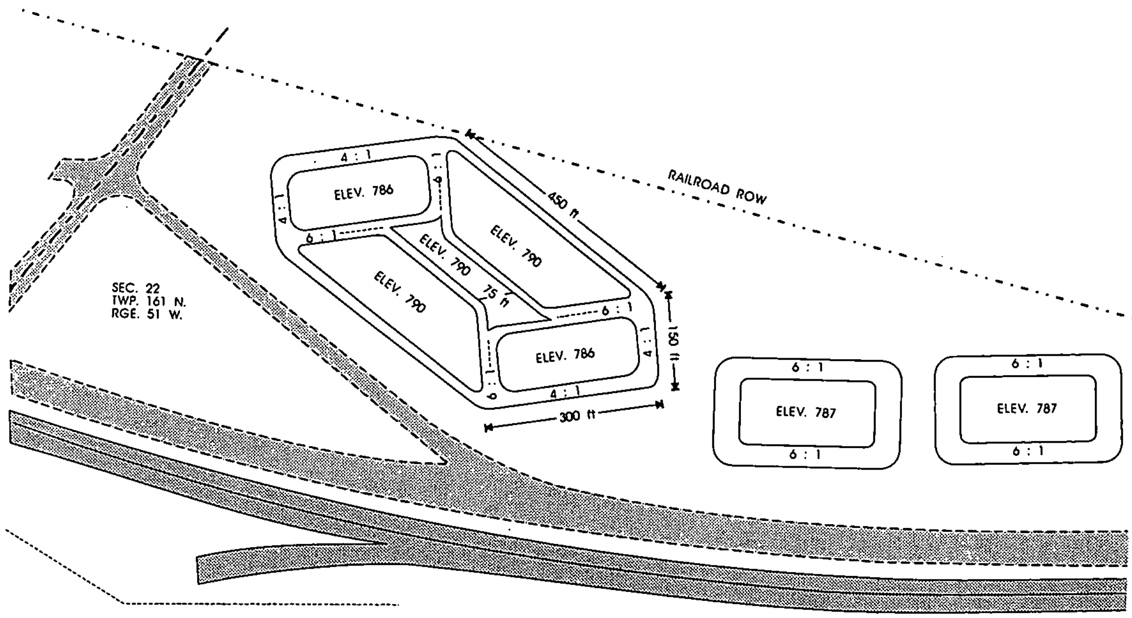


FIGURE 59 Example of highway application of artificial wetlands as stormwater BMP (*79*).

roadside hazard in ran-off-the-road incidents" (*79*). The authors also state that: "Highway safety should be a first consideration in choosing the location of a detention basin, particularly in an interchange area where traffic barriers are especially hazardous to traffic."

The following are a few measures that can be considered when designing safety features for wet detention ponds:

- Fence in pond to prevent access.
- Provide shallow (2 ft deep) safety ledge around pond.
- Build fence around large outlet structures.
- Post warning signs.

More detailed discussions on maintenance and safety issues are available in works by Schueler (*87*) and Dorman et al. (*79*).

CHAPTER FIVE

STORMWATER MANAGEMENT MODELS: TOOLS FOR PLANNING AND DECISION MAKING

INTRODUCTION

The discussion of stormwater management (SWM) models is limited to those that describe both stormwater quantity and quality. These models range in complexity from simple, single-purpose equations to complicated, multiple-featured computer programs. Properly calibrated and verified models can provide accurate descriptions of the stormwater quantity and quality changes for given conditions. By using the models, one can investigate and compare design options, and choose an optimal design. Models can also be used, for example, to estimate the impact of certain growth patterns on strategies for local stormwater master planning. The designer can assume various growth patterns and evaluate alternatives by using the model to simulate their consequences.

In stormwater management studies, categories include models for:

- Predicting stormwater pollution loads,
- Simulating the rainfall-runoff process,
- Describing the fate and transport of stormwater-generated pollutants,
- Describing BMP pollutant removal mechanisms, and
- Developing stormwater management strategies, for example, models for strategically locating detention ponds.

It should be noted that models are developed based on the knowledge of the basic stormwater quantity and quality processes and therefore are not substitutes for actual field data that describe these processes directly.

SWM MODEL DESCRIPTIONS AND COMPARISONS

Models for Predicting Storm Runoff Pollutant Loading

One of the key elements of a stormwater management strategy is the estimation of stormwater pollution loadings that will, for example, provide the information needed for comparing the impact of various development subareas. This is a rather difficult matter, in view of the fact that in many cases only a finite number of storm events are sampled, and that only discrete grab sampling data are obtained. Moreover, the mass loadings of pollutants in storm runoff are affected not only by the drainage basin characteristics such as land use, slope, and imperviousness, but also by various hydro-meteorological factors such as rainfall intensity and duration, flow rate, and antecedent conditions. To differentiate these factors and to obtain definitive estimates of storm runoff pollution loadings, it is best to have a substantial amount of data, taken at short-time intervals, and at various environmental conditions. However, budgetary and time constraints usually make detailed sampling infeasible, if not impossible. Consequently, it is often necessary to employ less-sophisticated methodology for the computation of pollution loadings.

Levels of Prediction

Several levels of analysis can be used to estimate storm runoff pollution loads. They range from a rather simplistic average annual loading to a complete distribution of loadings over the entire hydrograph for a single storm event, i.e. the pollutograph analysis. In general, the following levels of prediction can be defined:

Level I Total Annual Load or Average Annual Load

The total annual load is defined as the cumulative yield for a given year of a certain pollutant in storm runoff for a given area, usually expressed in terms of pounds per unit area per year. The average annual load may be defined as the long-term average of total annual loads. The average annual load can be converted to either average daily load for the entire year (wet and dry weather combined) or average daily load for the wet periods only.

Level II Mean Event Load or Mean Event Concentration

The average load for a specific event can be obtained by taking the average of the temporal distribution of pollution loads. Similar analysis can be made with regard to the pollutant concentration.

Level III Pollutographs

The pollutograph depicts the continuous variation of pollution loadings with respect to time. Therefore, the within-event distribution of loads can be obtained.

Level I prediction may be used for preliminary screening of stormwater management alternatives. Long-term loadings are useful in assessing long-term or steady-state impacts of storm runoff on receiving water quality. For example, long-term average stormwater pollution loadings may be used to evaluate the progress of siltation of river channels or to examine the extent of lake eutrophication due to stormwater-induced nutrient inputs. On the other hand, the analysis of short-term "shock-loading" of storm runoff would require a Level II or Level III type of analysis. An example could be the evaluation of the depletion of dissolved oxygen levels in a receiving stream after a rain storm.

The Simple Method

In rainfall-runoff analysis using the Rational Method, as described in Chapter Three, one uses a runoff coefficient to convert the rainfall rate into an estimate of the peak rate of runoff from a certain area. The same approach can be used to estimate the average pollutant loading rate in storm runoff by the Simple Method (*88*). An average or representative pollutant concentration is obtained and then multiplied by the average runoff to give the average loading estimate, i.e.,

$$L = K \times C \times R \tag{25}$$

where

L = average loading rate, in pounds per hour
C = average or representative concentration in milligrams per liter,
R = runoff rate in cubic feet per second, and
K = units conversion factor

This method is somewhat crude and can only provide approximate estimates of event or long-term average loadings, such as the average annual loading. However, it is easy to apply and its accuracy can be enhanced when the C value is modified if more stormwater quality data are available. If runoff is computed, then the average concentration can be obtained by:

1) Using values obtained by sampling of storm events. Average of flow-weighted average concentrations are computed from storm event data. More accurate loading estimates can be made if the sampling program covers a variety of storm events with different intensity/duration and frequencies. Examples of this approach can be seen in Whipple et al. (*103*) and in Scheuler (*88*). Table 18 presents the average, flow-weighted C values for selected pollutants measured during the EPA Nationwide Urban Runoff Project Study and several other studies (*87*).
2) Using an equation statistically developed relating the average concentration to various watershed characteristics and hydrological parameters considered to affect pollutant concentration. For example, AVCO (*104*) developed regression equations relating average pollutant concentrations to variables such as length of main stream, average land slope, sewered area, and residential density. Heaney et al. (*105*) proposed "loading factors" for prediction of annual average loading rates as a desktop procedure.

USGS Nationwide Regression Equations

Recently the USGS, using the EPA NURP study and the USGS data bases, derived regional regression equations relating 11 storm runoff pollutant loads to watershed demographic and physical characteristics, and to storm-specific and climate variables (*106*). The pollutants covered include solids, chemical oxygen demand, nitrogen and phosphorus species, cadmium, copper, lead, and zinc.

Regression models were developed for both storm runoff mean concentrations, and mean seasonal and mean annual pollutant loads for urban areas throughout the United States.

These models, together with those described as The Simple Method, provide straightforward, simple tools for preliminary planning and design of stormwater management facilities.

Rainfall-Runoff Models

Rainfall-runoff models (or hydrologic models) in general attempt to simulate on a computer the entire rainfall-runoff process in a basin or watershed. Such simulation models incorporate mathematical equations describing various component processes in the rainfall-runoff relationship.

Pioneering efforts in developing computer models for simulating watershed behavior were made in the 1960s by the U.S. Army Corps of Engineers, Harvard University, and Stanford University. The Stanford Watershed Model, developed by Crawford and Linsley (*107*), served as the basis for many later models, notably the Hydrologic Simulation Program-FORTRAN (*108*). During the past two decades, a large number of hydrologic models, ranging from lumped parameter-event models to distributed parameter, continuous simulation models have been developed. A few of the commonly used models are reviewed in this report. More detailed descriptions of hydrologic models and their reviews can be found in, for example, Viessman et al. (*66*), Bedient and Huber (*62*), Fleming (*109*), Kibler (*110*) and Whipple et al. (*111*).

All computer models must be properly calibrated and verified before they can be used for planning and design purposes. Calibration involves adjusting model parameters so that the model can closely reproduce the observed data. Verification involves checking the accuracy of the calibrated model in reproducing other sets of observed data. Model parameters can be further fine-tuned in the verification process.

Since in many situations field data are rather limited, care must be taken to choose an appropriate model that can be calibrated and verified with the available data, i.e., one that has a smaller number of parameters or is less data-intensive. Current consensus among practitioners is that the simplest model that satisfactorily describes the watershed behavior for the given data should be used.

Table 19 gives a list of the commonly used or referenced hydrologic models (*112-125*).

With so many models available for rainfall-runoff simulations, the user must consider a number of factors in choosing an appropriate model. Important factors include model characteristics such as lumped parameter vs. distributed parameters, event simulation vs. continuous simulation, model capability and very importantly, data requirements for the model.

Lumped parameter models assume that a watershed acts as a "black box" in transforming the input (rainfall) into the output (runoff); therefore spatial variation in watershed processes is neglected. The unit hydrograph is a good example of the lumped parameter approach. Distributed parameter models, such as the Stanford Watershed Model, consider the spatial variation of various hydrologic processes such as areal distribution of rainfall; and nonuniform distribution of infiltration rates in a watershed in computing runoff from rainfall.

Event models simulate single-storm watershed responses to given rainfall data, while continuous models are based on long-term balances of inputs to and output from a watershed, thereby accounting for soil moisture changes between storm events. Examples of event models include HEC-1 and UCURM (*118*), whereas HSPF and STORM are examples of continuous models.

An event model is appropriate for obtaining the design hydrograph for a given design storm. Distributed models, while theoretically more satisfying, require a substantial amount of data for their calibration and verification. Consequently, lumped parameter, event simulation models are most frequently used in drainage design practices.

Figure 60 illustrates a typical lumped parameter, event simulation model of the rainfall-runoff process applied to a sub-basin (*66*). The precipitation hyetograph is input uniformly over the sub-

TABLE 18
URBAN C VALUES FOR USE WITH THE SIMPLE METHOD (mg/L) (*87*)

Pollutant	New Suburban NURP sites (Wash,D.C.)	Older Urban Areas (Balt.)	Central Business District (Wash,D.C.)	National NURP Study Average	Hardwood Forest (Northern Virginia)	National Urban Hgwy Runoff
Phosphorous						
Total						
Ortho	0.26	1.08	-	0.46	0.15	-
Soluble	0.12	0.26	1.01	-	0.02	-
Organic	0.16	-	-	0.16	0.04	0.59
	0.10	0.82	-	0.13	0.11	-
Nitrogen						
Total	2.00	13.6	2.17	3.31	0.78	-
Nitrate	0.48	8.9	0.84	0.96	0.17	-
Ammonia	0.26	1.1	-	-	0.07	-
Organic	1.25	-	-	-	0.54	-
TKN	1.51	7.2	1.49	2.35	0.61	2.72
COD	35.6	163.0	-	90.8	>40.0	124.0
BOD (5-day)	5.1	-	36.0	11.9	-	-
Metals						
Zinc	0.037	0.397	0.250	0.176	-	0.380
Lead	0.018	0.389	0.370	0.180	-	0.550
Copper	-	0.105	-	0.047	-	-

basin area, and precipitation losses are abstracted, leaving an excess precipitation hyetograph that is convoluted with the prescribed unit hydrograph (e.g., Clark Unit Hydrograph) to produce a surface runoff hydrograph for the sub-basin. The sub-basin hydrograph is then routed downstream and combined with others to eventually give the outflow hydrograph for the watershed.

Routing techniques used to track the peak flow through a system of connected storm drainage systems, including natural drainage elements include:

- The Modified Puls, a method based on a nonvariable discharge-storage relationship, that provides outflow hydrograph characteristics related to and based on time during the total event, as well as the storage-outflow relationship for the drainage element (*59*, p.102) and
- The Muskingham Method, based on a variable discharge-storage relationship. This method allows for a critical evaluation of the way in which system storage effects adjust the volumes of flow through the system, and therefore affect the time of peak flow occurrence at the downstream end of the reach (*59*, p.102).

A brief description of some of the commonly used rainfall-runoff models is given below:

HEC-1

HEC-1 is a general flood hydrograph package with the following capabilities (*62*):

- Optimal estimation of unit hydrograph, loss rate, and streamflow routing parameters from measured data.
- Simulation of watershed runoff and streamflow from historical or design rainfall.
- Computation of damage frequency curves and expected annual damages for various locations and multiple flood control plans.
- Simulation of reservoir outflow for dam safety analysis.

HEC-1 offers four methods for computing rainfall losses, namely, initial and constant loss; exponential loss function; SCS curve number method; and the Holtan's equation. Surface runoff can be computed by either an input unit hydrograph, the Clark Hydrograph Method, the Snyder Unit Hydrograph Method, the SCS Method, or the kinematic wave method for overland hydrograph.

Flood routing in HEC-1 can be accomplished by either the Muskingum Method, the Modified Puls Method, or the kinematic wave method for channel routing.

HEC-1 is one of the most widely used methods for watershed simulation and flood event analysis. Detailed documentations of the model are available from the Hydrologic Engineering Center, Corps of Engineers, in Davis, California (*119*).

SCS TR-20

The SCS TR-20 (*121*) models computer runoff hydrographs using SCS procedures, routes them through channel reaches and

TABLE 19
COMMONLY USED OR REFERENCED HYDROLOGIC MODELS

	Model	Developer (Ref.)	Year	Remarks
1.	Chicago Hydrograph Method	Tholin (112), Keifer (113)	1959, 1970	Urban event model
2.	Stanford Watershed Model	Crawford & Linsley (107)	1966	Continuous Distributed Model, Data-Intensive
3.	MITCAT	Bravo, et al. (114)	1970	Urban event model
4.	SWMM	Metcalf & Eddy, CDM (115, 116) University of Florida (115)	1971, 1981 1987	Stormwater Management Model Quantity/Quality
5.	UCURM	Papadakis & Preul (118)	1972	Cincinnati Urban Runoff Model Quantity/Quality
6.	HEC-1	Corps of Engineers (119)	1973	Flood Hydrograph Package
7.	ILLUDAS	Illinois St Water Survey (120)	1974	Illinois Urban Drainage Area Simulator
8.	SCS-TR20	SCS (121)	1975	Watershed Hydrologic Model
9.	STORM	Corps of Engineers (122)	1974	Storage, Treatment, Overflow, Runoff Model; Quantity/Quality
10.	Penn St.	Aron, Lakatos (123)	1976	Urban Runoff Model
11.	HSPF	Hydrocomp, EPA (124)	1980	Hydrologic Simulation Program - FORTRAN; Quantity /Quality
12.	DR3M	USGS (125)	1982	Distributed Routing Urban Model

Inclusion in this list indicates that these models are part of current practice. It does not constitute an endorsement by the Transportation Research Board, the Federal Highway Administration, or the American Association of State Highway and Transportation Officials.

reservoirs, and combines hydrographs at confluences. For each sub-basin, the area, runoff curve number, and time of concentration are required. Routing procedures include the convex routing method or a simple routing coefficient. TR-20 is particularly suited to examining the effects of detention storage in a watershed.

DR3M

The USGS Distributed Routing Rainfall-Runoff Model, or DR3M, (*125*) is an event model intended primarily for urban applications. The model considers four types of model segments of a basin, namely, the overland flow segments, detention storage facilities, channels, and nodes. Overland flow routing is by unsteady overland flow hydraulics, channel routing is by kinematic wave methods, storage routing can be done by either a linear reservoir analysis or the Modified Puls Method.

ILLUDAS

ILLUDAS (*120*) is an event simulation model that can handle a detailed storm-sewer system and can be run in either a design mode or an analysis mode. Runoff is generated using a time-area curve. ILLUDAS requires input rainfall, pipe configurations, and sub-basin areas to calculate flows at various points in the sewer system, both under open channel and surcharged conditions.

Many studies have been conducted for the purpose of comparing the various models. For example, Heeps and Mein (*126*) and Marsalek et al. (*127*) compared several urban runoff models with respect to their modeling approaches and simulation performances. More extensive reviews and comparisons of models can be found in Brandstetter (*128*) and Lager and Smith (*129*).

In recent years the use of microcomputers has spread to all corners of our society, and the water resources profession is no exception. Many hydrologic and stormwater management computer models developed for mainframe applications are now compatible with microcomputers. With systems such as HEC-1, SWMM, ILLUDAS, and the SCS models, drainage design, like other hydrologic design and analysis, is now accomplished in a microcomputer environment.

Highway Drainage Models

Highway drainage has long been a major area of concern for transportation engineers. This is not only due to the obvious effect on highway safety and the social and economic impact that can result from inadequate drainage, but also to the complexity of the various physical processes involved. The importance of highway drainage can be illustrated by the fact that about 20 to 25 percent of highway construction dollars are spent for erosion control and drainage structures such as culverts, bridges, channels, and ditches (*130*). The percentage may be even higher as federal and some state stormwater management regulations take effect.

This synthesis discusses the various aspects of highway drainage design, the emphasis is therefore placed on modeling and those aspects relating to management of stormwater quantity as well as quality.

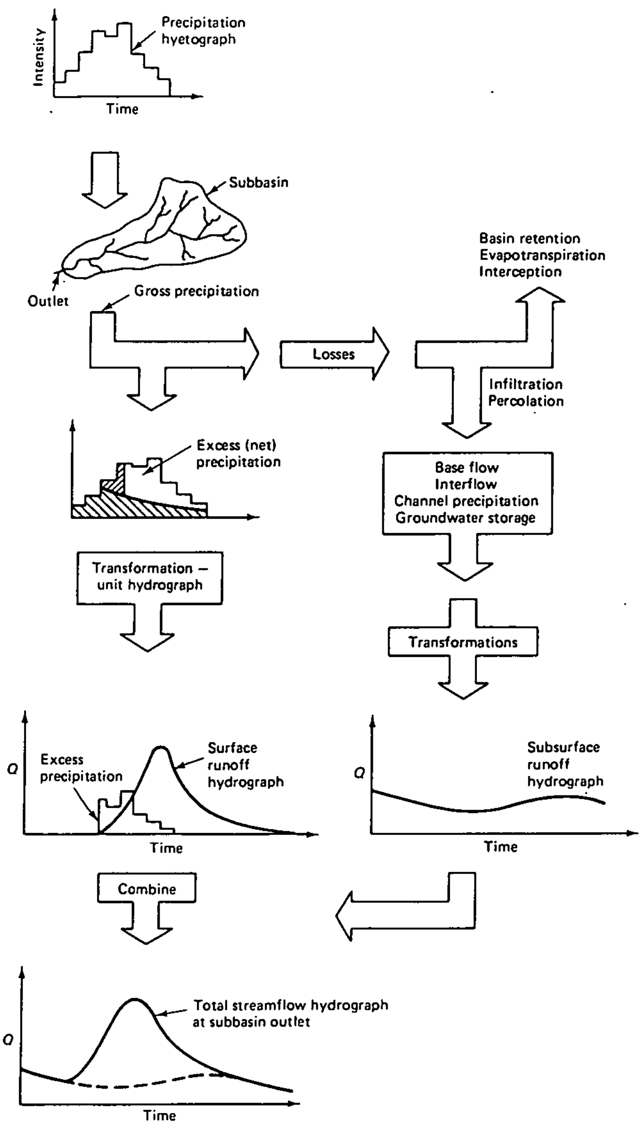


FIGURE 60 Typical lumped parameter event-simulation model (*66*).

Existing Drainage Modeling Practices.

The prevailing highway drainage design practice in all states is to follow the various reports issued by the Federal Highway Administration (FHWA) on drainage design. Examples of these publications include:

FHWA Hydraulic Design Series:
No. 3 "Design Charts for Open Channel Flow"
No. 5 "Hydraulic Design of Highway Culverts"

FHWA Hydraulic Engineering Circulars:
No. 12 "Drainage of Highway Pavements"
No. 15 "Design of Roadside Channels with Flexible Linings"
No. 19 "Hydrology"

Other reports by FHWA dealing with drainage practices include *Design of Urban Highway Drainage—The State of the Art* (*36*), and the AASHTO *Model Drainage Manual* (*63*).

In general, a state issues a drainage design manual that combines hydrologic design and hydraulic design and incorporates into it materials provided in the FHWA reports.

As mentioned earlier in this chapter, many states have a cooperative agreement with the U.S. Geological Survey for the latter to provide estimates of flood frequency and magnitude for design purposes. According to a survey conducted by Grigg (*131*), the Rational Method is used extensively by states for estimating peak flows and the Rational triangular hydrograph is usually used when a hydrograph is needed. Some states use the SCS method while others use a watershed model such as HEC-1 for peak flow and hydrograph computations.

With respect to hydraulic design in general, hydraulic charts, tables, and nomographs are used. Many states also use models for certain hydraulic analysis and design. For example, Wyoming uses a computer program called HYDRA for its storm sewer design and analysis (personal communication with M. Wacker, 1987). Virginia uses HEC-2, as well as other water surface profile programs, for its open channel hydraulics computations (personal communication with C.F. Boles, III, 1985). During the past few years, the use of computer models for drainage design and analyses by the states has steadily increased.

Recent Advances in Highway Drainage Model Development

With the rapid advances in computer technology, especially with the increased availability of microcomputers, more highway drainage design and analyses are carried out on computers. The increasing use of computer-aided drafting and design (CADD), computer-aided management (CAM), and the Geographical Information System (GIS) has augmented the effectiveness of computer applications. The following is a brief description of some of the recent advances in highway drainage model development.

FHWA Urban Storm Drainage Model

FHWA developed an urban highway storm drainage model for use in the evaluation of existing drainage systems and the design of new systems in 1983 (*132*). The FHWA Urban Storm Drainage Model, written for the mainframe computer, consists of the following four modules:

Precipitation Module: generates single-peak synthetic hyetographs and performs statistical analyses on long-term precipitation data.

Hydraulics/Quality Module: consists of three computer programs: the Inlet Design Program, the Surface Runoff Program (simulates time-varying runoff quantity and quality), and the Drainage Design Program (sizing the subsurface drainage system).

Analysis Module: simulates unsteady, graduate-varied flow in the major drainage system of the highway right-of-way. Its primary purpose is to analyze the performance of the drainage system under extreme storm events.

Cost Estimation Module: estimates the total annual costs associated with the construction and maintenance of a highway drainage system.

The survey of states (*131*) yielded no information regarding application of the Urban Storm Drainage Model; however, some of its features have been employed in other computer models.

HYDRAIN-Integrated Drainage Design Computer System

In order to provide highway drainage engineers with an integrated microcomputer package that would satisfy most drainage design needs, the FHWA organized a Pooled Fund Project (PFP) in 1984 with funding contributed by participating states. From this effort the HYDRAIN package was developed. Phase I of the project was completed in 1988 when the number of participating states had grown to 23. The project effort is still continuing.

The HYDRAIN Package consists of the following programs (*133*):

HYDRO Program: generates design flows or hydrographs from rainfall. It offers many hydrologic analysis options such as the Rational Method, USGS Regression Method, Log Pearson Type III Method, and Snyder's Unit Hydrograph.

PFP-HYDRA Program: a very powerful and flexible storm and sanitary sewer system analysis and design program adapted from the program HYDRA, which was aquired by the FHWA. The following are some of PFP-HYDRA's capabilities:

- Models Sanitary Flow. PFP-HYDRA "generates" sanitary flow based on the traditional peaking factor concept.
- Models Storm Flow and Offers Choice of Methods. PFP-HYDRA is capable of "generating" storm flow based on either the rational method or hydrologic simulation methods. This may be particularly advantageous for engineers who wish to compare design or analysis results based on different methods.
- Models Costs. Cost estimating capabilities are included that allow for consideration of dewatering, traffic control, sheeting, shrinkage of backfill, costs of borrowing, bedding costs, surface restoration, rock excavation, pipe zone and other costs.

PFP-HYDRA has been expanded by Yu and Li (*134*) to offer hydraulic gradeline computations, and a pressurized flow routine with additional hydrograph options (Clark, SCS) has also been added by Yu et al. (*135*).

CDS (Culvert Design System) Program: allows the user to prepare a hydraulic design for a culvert, or analyze an existing or proposed culvert.

Water Surface Profile (WSPRO) Program: Developed by USGS for bridge waterway analysis to compute the water surface profile, WSPRO was downloaded to the microcomputer by the USGS and FHWA and incorporated into HYDRAIN.

HY8 Program: HY8 is an interactive culvert hydraulic analysis program that uses the FHWA analysis methods (HDS-5, Hydraulic Design of Highway Culverts) for circular, rectangular, elliptical, arch, and user-defined geometry.

In addition, a HYDRAIN System Shell was developed for the purpose of controlling the entire system of the PFP programs, as shown in Figure 61.

The HYDRAIN Package is still being modified and improved to suit Pooled Fund member states' needs. For example, HYDRAIN will include a module called HYCHNL which uses the procedures of HEC-15 for roadside channel design. The package is available through the McTrans Center at the University of Florida and should prove useful for drainage design and analysis.

Comprehensive Stormwater Management (SWM) Models

Several SWM models not only generate stormwater pollutant loads, but also describe the fate and transport of the pollutants in the overland or conveyance systems. Many SWM models have been developed during the past two decades that exhibit a wide range of complexity in simulation algorithms, solution techniques, data requirement, and other characteristics.

The physical processes typically simulated by an SWM model can be seen in Figure 62.

As seen Figure 62, the major components of an SWM model are:

Overland Flow Component: Quantity and quality, including pollutant accumulation and washoff and transport over land surface.

Drainage System Component: Quantity and quality, including channel or pipe flow transport, and storage routing (such as detention ponds).

Receiving Water Component: Quantity and quality, including fate and transport of pollutants and receiving water response. Most SWM models do not include this component.

A schematic diagram of the various SWM model components is shown in Figure 63. To date, the most commonly used or referenced stormwater management models are SWMM (*115,116,117*), STORM (*122*), and HSPF (*124*). These models are briefly described below.

SWMM

The EPA Stormwater Management Model (SWMM) is one of the most comprehensive models for planning and design. SWMM essentially simulates all the quantity/quality processes shown in Figure 62. The model can handle complex sewer networks, including pumps and gates. It can also simulate backwater and surcharging conditions. The water quality simulation in SWMM is based on a pollutant buildup and wash-off mechanism. Major conventional pollutants, such as solids, nutrients, organics, and oil and grease are simulated. As an urban runoff model, it provides for continuous and event simulation for a variety of catchments, conveyance, storage, treatment, and receiving streams. Both water quantity and quality can be simulated and flow routing can be performed by nonlinear reservoir methods, kinematic wave methods, or with the full St. Venant equations in the SWMM EXTRAN Block (*62*). The program is well documented and supported; user group meetings are held on a regular basis.

STORM

The U.S. Army Corps of Engineers model, STORM, (*122*) is a watershed model that simulates the processes depicted in Figure 62, except for the sewer hydraulics component. The model computes runoff based on a runoff coefficient scheme and simulates six conventional pollutants: (1) suspended and (2) settleable solids, (3) biochemical oxygen demand (BOD), (4) total nitrogen, (5) orthophosphorous and (6) fecal coliform. The pollutant simulation algorithm is similar to that of SWMM. The program performs continuous simulation using continuous hourly rainfall data, but individual storm events may also be analyzed. Rainfall loss is

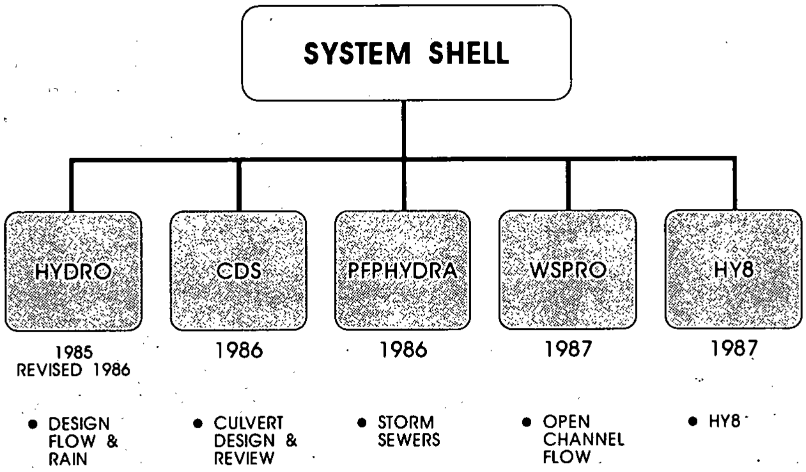


FIGURE 61 HYDRAIN layout (*100*).

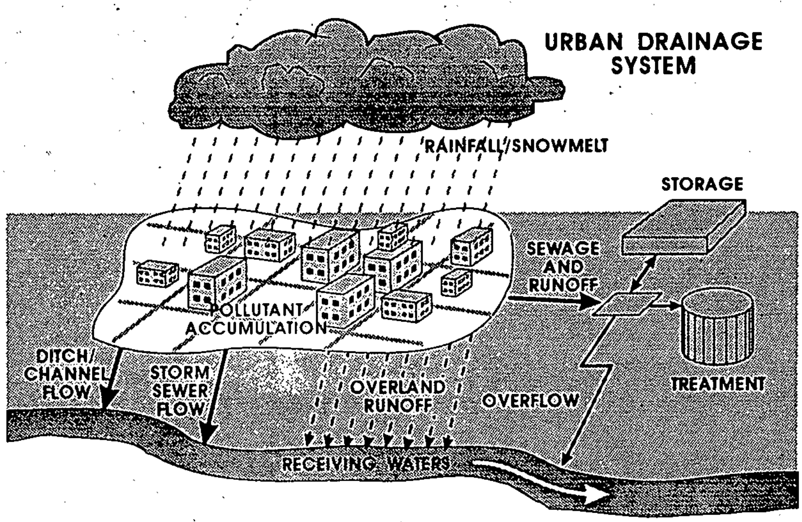


FIGURE 62 Processes simulated by a SWM model (*87, modified*).

estimated using a weighted runoff coefficient on SCS methods. Downstream storage and treatment processes can be simulated but there is no channel or pipe routing. STORM can be used to estimate overflow event statistics based on a given treatment level for the storm runoff generated. The model is easy to implement and is less data-intensive than SWMM.

HSPF

HSPF was developed from the Stanford Watershed Model and modified to include water quality considerations, kinematic wave routing, and variable time steps. The water quality algorithm was based on sediment detachment and transport mechanisms. Pollutants are related to the sediment. HSPF can be run either as an event model or as a continuous, distributed parameter model that performs a variety of simulations of hydrologic and water quality processes on or under the land surface, in channels, and in reservoirs (*62*). HSPF has a nonpoint source pollutant module and is very data-intensive.

VAST

VirginiA STorm Model or VAST, was developed at the University of Virginia (*136*). An event model that can be applied to multiple catchment basins, VAST combines techniques used in STORM, SWMM and HEC-1 to compute rainfall abstractions, generate overland flow hydrographs, combine and route outflow from upstream sub-basins through the channel downstream, and compute pollutant washoff from sub-basins. The model also routes hydrographs and pollutographs through detention basins according to the storage-indication and advection/dispersion algorithms, respectively. VAST is composed of three primary and two auxiliary computer programs. The primary program simulates stormwater runoff, pollutant loadings of suspended solids, settleable solids,

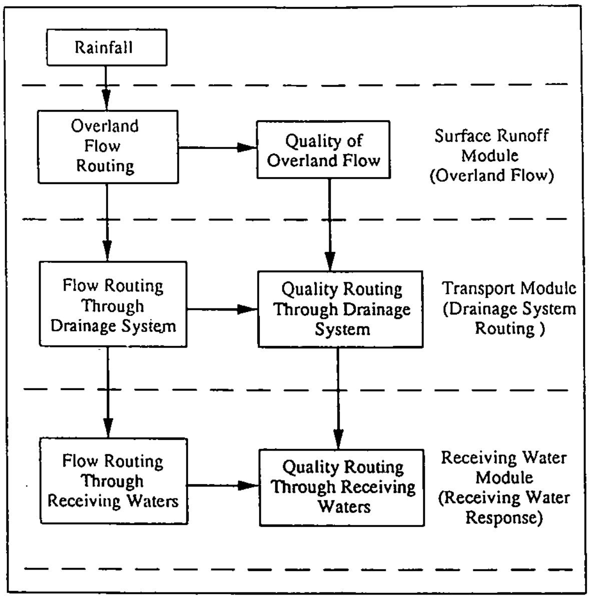


FIGURE 63 Components of a comprehensive stormwater management model (*80*).

BOD, total nitrogen, orthophosphate, fecal coliforms, and loadings for four additional user specified pollutants.

The auxiliary programs present results generated by VAST in graphical form on a computer video monitor. These programs can optionally present field data with simulation results to assist users in the calibration and verification processes.

A comparison of the various features in HSPF, STORM, SWMM, and VAST is presented in Table 20.

Models for BMP Evaluation

In order to simulate the effect of BMP practices, Kuo et al. (*137*) modified the ILLUDAS Model (*120*) to make it a continuous model, capable of simulating water quality. The algorithm used by STORM was incorporated into ILLUDAS. Several BMP features were considered. An optimization routine was also included in the model for the purpose of sizing and locating detention basins in a watershed.

More recently, The Northern Virginia Planning District Commission (NVPDC) (*138*) developed a computer program to perform regional stormwater management (SWM) and BMP analyses. The program uses an optimization routine to select the most cost-effective locations for regional SWM and BMP facilities in small undeveloped watersheds.

Model Calibration and Verification.

A model should be calibrated and verified before it can be used as a planning or design tool. Calibration involves minimizing differences between observed data and computer results by adjusting certain model parameters. Verification is the process of checking the model calibration using a different set of data. Usually the verification results will provide feedback for further adjusting of model parameters.

The objective of both the quantity and quality calibration is to fit the model to average watershed conditions. Therefore, the emphasis will be on results integrated over the entire calibration data (three or four storm events) rather than on any single storm events.

The standard error of estimate (SEE) is a commonly used statistic to measure the fit between observed and predicted data. It is computed from predicted and observed data points. The criteria for acceptable SEE values depend on factors such as density of monitoring network, equipment accuracy, and subjective decision of the model. Usually, an SEE of less than five percent to 10 percent is desirable.

For the calibration process, a set of model parameters that yields the best SEE for all storm events will be accepted as calibrated model parameters. The verification of a model will usually involve supplying data for one or two storm events.

Statistically, model reliability increases when the amount of data for calibration and verification increases. However, more than resource limitations dictate the amount of data that can be gathered. It is not uncommon to find monitoring efforts that last a year in duration and produce five or six sets of storm runoff data. In such a case, the common practice is to use three or four events for model calibration, and one or two for model verification.

Highway Applications

Highway application of stormwide management models may be primarily in the following areas:

- Estimating stormwater pollution concentration and loads in highway runoff and runoff from transportation facilities such as maintenance shops.
- Designing best management practices (BMPs) as required by stormwater permits. Examples include sizing detention ponds, determining swale lengths, and others.
- Analyzing BMP performances and maintenance needs.

The choice of stormwater management models will depend on the following factors:

- Level of detail of needed information
- Resource requirements for using a certain model, e.g., data required for model calibration and verification, hardware/software specifications, and personnel needed for running and maintaining the model.
- Other factors, such as model documentation and support service.

Major stormwater management models, such as SWMM and HSPF are very complex in model structure and are data-intensive. Most highway applications probably will not require the use of such models. Simpler and less data-intensive models such as The Simple Method and VAST could be used.

Since the model HYDRAIN is being used by many highway agencies at the present time, it may be desirable to expand HYDRAIN to include a runoff quality submodel and a BMP design

TABLE 20
COMPARISON OF MODELING CAPABILITIES

Item	HSPF (E,C)[a]	STORM (C)	SWMM (E,C)	VAST (E)
Infiltration loss techniques	Stanford watershed model, infiltration as function of soil moisture and permeability	Runoff coefficient	(1) Horton model (2) Modified Green-Ampt model	(1) Horton model
Runoff modeling techniques	Manning's equation and storage routing	Modified rational formula	Storage routing using Manning's equation and continuity equation	(1) Input unit hydrograph
Sewer routing	Yes	No	Yes	No
Nonpoint source pollutant accumulation and washoff modeling technigues	Sediment detachment and transport; pollutant is related to sediment	Based on pollutant accumulation and washoff	Based on pollutant accumulation and washoff	Based on pollutant accumulation and washoff
Number of pollutants	10	6	10 (6 plus 4 user specified)	
Storage/treatment analysis	Yes	Yes	Yes	Being added
Executable on microcomputer	Yes	Yes	Yes	Yes
Program output can be graphically presented	Line printer	Line printer	Line printer	Line printer and video monitor
Level of program documentation	High	Moderate	High	Moderate
Ease of implementation	Difficult	Easy	Difficult	Easy
Data requirement	Very high	Moderate	High	Moderate
Source	EPA	COE	EPA	UVA

[a]E = Event; C = Continuous

and analysis submodel. Many algorithms regarding runoff quality and BMP design in existing models could be incorporated into HYDRAIN without a great effort. By so doing, a "complete" quantity–quality computer package could be available to highway agencies for their stormwater management applications.

CHAPTER SIX

INSTITUTIONAL ASPECTS OF STORMWATER MANAGEMENT

INTRODUCTION

A stormwater management (SWM) program cannot be successful without a well-designed and executed institutional framework. Important elements of an SWM program include **motivation**, either through regulations or other concerns such as health hazards; **organization**, and **implementation issues** such as funding, labor, and infrastructure maintenance. These aspects, especially those relevant to highway agencies, will be discussed in this chapter.

During the past two decades stormwater programs have evolved from urban drainage and erosion control types to comprehensive types dealing with both quantity and quality issues. The 1972 federal Clean Water Act (CWA) initiated the "areawide" water quality planning programs (Section 208) which formally included stormwater pollution (non-point source) as a target for planning. Section 208 studies (later the Section 205j studies) have provided useful data for characterizing stormwater pollution. The EPA Nationwide Urban Runoff Project (*6*) expanded the data base and initiated monitoring studies for BMPs.

The 1987 Water Quality Act (WQA) amendment to the CWA was first to require states to develop comprehensive programs for the control of stormwater runoff (Section 319). The WQA also mandates the EPA to develop stormwater permit regulations, which will add certain stormwater discharges to be regulated on the National Pollutional Discharge Elimination System (NPDES). The EPA finalized the permit regulations and promulgated the rules on October 31, 1990.

With the 1987 WQA as the major driving force, stormwater management will become an element of the standard responsibilities of states, localities, and industries including transportation-related activities.

In the following sections, a brief review of the various levels of regulations (federal, state and local) will be given. Important issues with respect to stormwater management, such as institutional framework, implementation problems such as funding and maintenance infrastructure will be discussed.

STORMWATER MANAGEMENT REGULATIONS

Federal Regulations

Pre-1987 Water Quality Act Regulations

The most important piece of legislation regarding stormwater (or nonpoint) pollution control before 1987 was the 1972 Clean Water Act. Specifically, the 1972 CWA required that (139):

- To the extent practicable, waste treatment management shall be on an areawide basis and provide control or treatment of all point and nonpoint sources of pollution, including in place or accumulated pollution sources (Section 201a).
- States must develop, implement and enforce water quality standards which would ensure waters to be fishable and swimmable (Section 303).
- States must develop areawide water quality management plans which shall describe the regulatory and nonregulatory programs, activities and Best Management Practices (BMPs) which the agency has selected as the means to control nonpoint source pollution (Section 208).

The point source control program (NPDES) of the 1972 CWA has been quite successful, as evidenced by the completion of many waste allocation programs under the NPDES Permit System. In general, however, the areawide water quality management plans regarding nonpoint source control were not effective. The main problem, as Thompson (*140*) observed, was that while Section 208 provided states with adequate authority to control stormwater runoff, it did not clearly require adequate program implementation. Consequently, many 208 plans simply "remained on the shelves after they were completed."

In defense of the 208 programs, however, one must note that 15 to 20 years ago, there were not even adequate data for characterizing stormwater pollution, let alone for evaluating BMP performance or deriving design criteria. There was very little scientific basis to work with so that appropriate guidelines for implementation could be developed. Furthermore, the 208 studies did provide useful information regarding characteristics of stormwater pollution and potential receiving water impacts. Even today, we still do not have enough scientific data on, for example, long-term performance of a number of the BMPs.

The 1987 Amendments of the Clean Water Act

In February 1987, Congress passed the Water Quality Act (WQA), which contains a key provision i.e., Section 405, specifically addressing stormwater discharges. Highlights of Section 405 requirements include (141):

> Stormwater discharges associated with industrial activity must comply with sections 301 and 402 of the Clean Water Act (requiring control of the discharge of pollutants that utilize the Best Available Technology (BAT)), but permits for discharges from municipal separate storm sewer systems must require controls to reduce the discharge of pollutants to the maximum extent practicable (MEP) and must include a requirement to effectively prohibit non-stormwater discharges into the storm sewer.
>
> Five types of stormwater discharges are required to obtain a permit:
>
> A. A discharge with respect to which a permit has been issued prior to February 4, 1987;
>
> B. A discharge associated with industrial activity;
>
> C. A discharge for municipal separate storm sewer systems serving a population of 250,000 or more (a large system);

D. A discharge from a municipal separate storm sewer system serving a population of 100,000 or more, but less than 250,000 (a medium system); or

E. A discharge for which the EPA or a state with an approved NPDES program determines that the stormwater discharge contributes to a violation of a water quality standard or is a significant contributor of pollutants to the waters of the United States.

Since 1987, EPA has been preparing for the formal promulgation of the NPDES stormwater permit regulations. In November 1990, EPA issued the Final Rules (139) which require the stormwater discharges listed above under Section 405 of the 1987 WQA to prepare a water quality management plan to include extensive inventory, sampling, analysis and implementation of water quality control strategies. Plans must address wet weather pollution as well as illicit connection pollution.

The Final Rules defined discharges "associated with industrial activity" which include: "Transportation facilities, Standard Industrial Classification (SIC) 40, 41, 42 (except 4221-25), 43, 44, 45, and 5171 including vehicle maintenance shops, material handling facilities, equipment cleaning operations and airport deicing operations, etc."

In summary, transportation activities are included in the EPA stormwater regulations. Under the federal rule several possible scenarios exist for permit requirement, i.e., the transportation activity is considered as a separate "industrial discharge", as a co-permittee for or part of a municipal system permittee, or as a part of a "general permit" program.

A detailed summary of the 1990 federal rules, with emphasis on those rules affecting transportation activities, is attached to this synthesis as Appendix A.

Wetland Regulations

One of the key provisions in the Clean Water Act which impact highway agencies is the Section 404 permitting requirements for highway construction. When a highway construction activity results in wetlands being filled in and built on, the highway agency is required as part of the permit conditions to create artificial wetlands to compensate for the loss of natural wetlands. The U.S. Army Corps of Engineers is the Section 404 permit granting agency.

The implications of the 404 permit requirements to stormwater management for highways may include the following scenarios:

- Construction of stormwater BMPs may result in filling in or building on existing wetlands.
- Highway stormwater runoff may be discharged into existing wetlands.
- The possibility of using constructed wetlands as a stormwater BMP, as described in Chapter Four, although care must be taken in properly designing such a system and also in dealing with negative perceptions of such systems by citizens and environmental groups.

State and Local Regulations and Practices

Stormwater management programs have generally been implemented by local governments by zoning and regulation of development and by separate ordinances requiring the installation of stormwater management measures with land development. The objective of most stormwater management programs is to limit runoff from developed sites to predevelopment flow rates and volumes. According to a survey conducted in 1983 by Hawley and McCuen (*142*) of state, regional, and local governmental agencies nationwide, the most common goal of the stormwater management (SWM) programs is flood control. Another common goal is sediment and erosion control. Nonpoint source pollution control regulations are not generally found in local programs, but this may change in the near future due to the EPA and also state or local stormwater regulations.

On the other hand, the EPA 208 studies and the Nationwide Urban Runoff Program, among others, have certainly generated awareness and attracted attention from the general public. A number of states and localities have already enacted legislations or ordinances for stormwater management. A few examples are described below:

Florida's Stormwater Program

Through the 208 program, it was recognized that stormwater, whether from agriculture, forestry or urban land, was the primary source of pollutant loading to Florida's receiving waters. To meet the CWA objectives it would be necessary to implement stormwater programs to reduce the delivery of pollutants from stormwater discharges (*143*).

The first official Florida stormwater regulation was adopted in 1979 and was revised in 1981 as Chapter 17-25, Florida Administrative Code. According to Livingston (*143*), the revised code established requirements for stormwater permits for all new discharges and for existing discharges that were modified to increase flow or pollutant loading.

The Florida Department of Environmental Regulation set a stormwater treatment objective of at least 80 percent of the average annual pollutant load for discharges to Class III (fishable/swimmable) waters. Higher rates are required for Class II (shellfish harvesting) and Class I (potable supply) waters.

Maryland's Stormwater Program

Maryland interprets state sediment and erosion control laws to authorize imposing such requirements as are appropriate to control off-site stream channel erosion. In practice, developers are required to install stormwater management measures to prevent stream channel erosion from increased flows after development.

In 1984, most stormwater management efforts up to that time had mainly focused on the control of the increased peak flows due to urbanization. However, the Maryland Stormwater Management Act, passed in 1982, states that "the primary goal of the state and local programs will be to maintain after development, as nearly as possible, the predevelopment runoff characteristics." The intent of this statement was clearly to include water quality into the stormwater management plan (*144*).

Maryland requires infiltration practices to be considered first among all other stormwater management practices to provide urban runoff control from proposed developments (*144*). Infiltration trenches, for example, are in widespread use in Maryland. Much useful information regarding field performance and design guidelines have been generated through such efforts in Maryland.

New Jersey's Stormwater Management Program

The New Jersey Stormwater Management Act, enacted in 1981, requires all municipalities to prepare and implement a stormwater management plan and ordinance within one year from the date of promulgation of stormwater regulations by the New Jersey Department of Environmental Protection (NJDEP).

The NJDEP adopted the stormwater management regulations in 1983. These regulations define Phase I planning for municipalities, which involves the adoption of an ordinance. Phase II planning consists of detailed watershed studies to encourage a broader approach to planning. For both phases, design standards require the construction of dual-purpose detention basins rather than the conventional, quantity control basins (*81*).

Pennsylvania's Stormwater Management Program

The Pennsylvania Stormwater Management Act, or Act 167, was enacted in 1978, which requires the Department of Environmental Resources to, among others:

- Coordinate the management of stormwater in the Commonwealth.
- Designate "watersheds" in consultation with counties for preparation of watershed plans.
- Develop guidelines for stormwater management (promulgated in 1985).
- Review and approve county watershed plans.

Watersheds were delineated by the Department of Environmental Resources and approved by the Environmental Resources and approved by the Environmental Quality Board.

The 1978 Stormwater Management Act mainly addressed the stormwater management issue from a quantity standpoint. Water quality concerns were incorporated into later versions of the regulation as more technical and other information became available.

Virginia's Stormwater Management Program

Virginia's water quality management has always been the responsibility of the State Water Control Board (SWCB), as authorized by the State Water Control Law (SWCL). SWCL does not explicitly address stormwater or nonpoint source (NPS) pollution control, but it requires SWCB to establish policies and programs for effective areawide water quality control and management (*145*).

Recognizing the importance of NPS pollution, SWCB completed a number of planning efforts including a series of technical studies on NPS pollution impacts and control, and most importantly the development of BMP handbooks in 1979. In the years following 1979, these handbooks served as important documents for the State Nonpoint Source Pollution Control and Abatement program.

In implementing the NPS pollution controls, the SWCB decided to adopt a "voluntary" rather than regulatory approach. Another facet in Virginia's stormwater program is the division of management responsibilities among state agencies. The Division of Soil and Water Conservation (DSWC) in the Department of Conservation and Historic Resources, which manages the erosion and sediment control (ES) program, was delegated the agricultural and part of the urban NPS programs. In 1988, DSWC developed the Virginia NPS Pollution Management plan and has "overall statewide responsibility for implementing" the plan and coordinating the activities of other agencies (*140*).

Virginia established a comprehensive stormwater regulation in 1990, which went into effect as of January 1, 1991. Below are a few highlights of the rules:

- State agencies and localities are required to develop stormwater management programs with the key objective of maintaining post-development runoff quantity and quality equal to or better than the predevelopment characteristics.
- Minimum criteria are set which must be met by all stormwater management programs.
- Provision for long-term responsibility for the maintenance of BMPs will be required.
- Stormwater management program should be integrated with erosion and sediment control, flood plain management and other land development laws.

Wisconsin's Nonpoint Source Pollution Abatement Program

Wisconsin established its Nonpoint Source Pollution Abatement Program in 1978. The program is administered by the Department of Natural Resources and focuses on NPS pollution within priority watersheds, which are identified through a systematic ranking procedure.

The Wisconsin program calls for the identification of water quality objectives within the priority watershed area based on potential water uses, an inventory and assessment of NPS pollution, and the development of implementation strategies. These strategies include educational activities, design of control measures, and financial assistance.

The Wisconsin program has been described as a systematic approach to solution of the NPS problem. Twenty-six priority watersheds were designated during 1978-85 and progressed to various stages of program development (*143*).

Regional and Local Programs

In addition to state programs, a number of regional or local stormwater programs have also been instituted nationwide. Several of these programs are briefly described below:

The Chesapeake Bay Program

The Chesapeake Bay is one of the prime water resources on the East Coast. The U.S. EPA has identified that NPS pollution is a major contributing factor to the water quality degradation of the Chesapeake Bay. A consortium was established in 1985 by the governors of the states that drain to the Bay (Delaware, Maryland, Pennsylvania, and Virginia), and the EPA for managing water quality of the Bay. One of the key activities of the effort was to reduce the NPS pollution loadings into the Bay to reach a goal of 40 percent reduction by 1992.

The Occoquan Watershed Program

The Occoquan Reservoir in Fairfax County, Virginia is a public water supply for approximately 700,000 people in suburbs adjacent to Washington, D.C. The reservoir was found to be affected by stormwater runoff nutrient inputs.

As part of the planning authorized by the 1972 CWA, the Metropolitan Washington Council of Governments (MWCOG) designated the Northern Virginia Planning District Commission (NVPDC) to coordinate development of an areawide water quality control plan for the Occoquan watershed. The Occoquan Basin NPS Management Program was signed in 1982 in which the use of BMPs was suggested.

The NVPDC's efforts have resulted in a substantial data base on NPS pollution and also a number of very useful publications on BMP design guidelines such as Schueler's manual for planning and design (*87*) and NVPDC's evaluation (*138*).

The Puget Sound Program

The Puget Sound Basin in western Washington State is a complex estuary-bay system. The Basin is drained by more than 10,000 rivers and streams and has a population of more than 2.9 million. Problems of pathogenic, toxic sediment, and nutrient-related water pollution have been found in the Sound. In 1985, the Puget Sound Water Quality Authority (PSWQA) was established by the state legislature to develop a plan to improve aquatic resource management. Nonpoint source control is an important component of the plan (*140*).

The Puget Sound Water Quality Management Plan was completed in 1987, establishing a cooperative local watershed planning process that uses existing and new state programs to address problems that require statewide control. State guidelines have been provided for controlling NPS pollution from various sources.

INSTITUTIONAL ASPECTS

Organization

In general, stormwater management is well suited to be carried out at the local level because flood control and quality control are largely local in their effects (*81*). Watershed areas, however, usually encompass more than one political jurisdiction. Since local governments cannot control activities outside their boundaries, regional planning organizations need to coordinate multi-level programs, disseminate technical information and foster cooperation among local jurisdictions (*140*). The Stormwater Management Districts in Florida, the Northern Virginia Planning District Commission, and the Puget Sound Water Quality Authority are good examples of regional organizations.

Centralized state program control may be preferred so that conflicts between government levels can be resolved and redundancies in coverage be eliminated. In this case, the state water quality management agency would be in charge of the overall state stormwater management program (*137*). The state can provide technical guidance and financial assistance to local or regional stormwater management efforts.

Design Criteria

Design criteria are an important driving force in achieving stormwater management program goals and objectives. Guidelines should be provided as part of a stormwater management regulation in the following areas:

- Control facilities: Minimum requirements for quantity and quality control.
- Major pollutants to be included in design analyses: Different pollutants have different settling and decay characteristics and therefore may require different design or selection of controls.
- Methodology for Analyses: Hydrologic and water quality analyses methodologies which are recognized, e.g., acceptable stormwater management models if modeling is needed.
- General Strategies: Regional facility versus on-site facilities, for example.

Traditionally, the design storm approach has been used for designing flood control facilities. Even though a design storm is to be used for design, opinions differ as to what frequency of occurrence or return period and duration should be designated for the design storm. The selection has been made on a somewhat subjective basis depending on the acceptable risk of flooding and cost considerations. Currently, the most commonly used design frequency for flood attenuation purposes is between 5 years and 50 years, with the 10-year frequency being most often cited for storage design.

For water quality control purposes, the most important storm events are the smaller, more frequent type of storms. The concept of a "design storm" for water quality is not easily defined, for a critical event for one pollutant may not be the critical event for another pollutant. Consequently, the current approach is to subjectively choose a small storm, say of 2-year frequency, as the design storm. The selection is based on the premise that storms of 2-year frequency or less would generate a majority portion of the stormwater runoff pollutional masses.

A number of the existing or proposed stormwater management design criteria are given below:

Florida (*143*)
BMP Treatment Volume Requirement (Discharges to Class III Waters)

Wet Detention: Detention of the first in. of the runoff or the runoff volume calculated by using an imperviousness which is equal to 2.5 times the actual drainage area imperviousness, whichever is greater. For commercial and industrial land uses pretreatment of up to 0.5 in. runoff by infiltration BMPs is required.

Swales: Infiltrate 80 percent of the runoff generated by a 3-yr, 1-hr storm (typically about 2 in. of runoff)

New Jersey (*80*)

Quantity: Control of flood hydrographs of 2-yr, 10-yr, and 100-yr floods to predevelopment levels at the site is required.

Quality: A "settleability" design storm is defined as 1 1/4 in. of rain in 2 hr, on the one-yr, 24-hr storm.

Maryland (*146*)

Quantity: Control of the peak discharge for a 2-yr, 24-hr storm to the predevelopment level for certain counties. Control of the peak discharges for a 2-yr, 24-hr, and a 10-yr, 24-hr, storm event to the respective predevelopment levels.

Quality: Wet detention pond shall provide for 24-hr detention period for detaining and releasing the volume of runoff from the 1-yr. frequency storm.

North Carolina (*147*)

Wet Pond Design Criteria: Runoff from a one-inch design storm shall not draw down to the permanent pool level in less than two days and more than five days. An 85 percent removal rate of solids is required.

Vegetative Filter Strip Design Criteria: The slope and width of the vegetative filter shall be determined so as to provide a non-erosive velocity of flow through the filter for a 10-yr, 24-hr storm with a 10-yr, 1-hr intensity.

Virginia (*147a*)

Quantity: The predevelopment 2-yr storm velocity and the predevelopment 10-yr storm runoff peak discharge shall be maintained.

Quality: Facilities shall be designed to achieve NPS pollutant reduction for the first 0.5 in. of runoff.

The above examples of design criteria illustrate the diversified approach to and complexity involved in establishing design criteria for stormwater management facilities, especially from a water quality standpoint. It is expected that design guidelines will be modified from time to time when more information and data on BMP performance become available.

Actually, the quality of the receiving waters serves as the ultimate judgment of the effectiveness of the BMPs. Therefore a water quality-based design approach appears to be a logical one. However, in practice the establishment of receiving water standards under wet-weather conditions is difficult (*148*), which makes the water quality-based design less appealing at this time.

Funding Issues

Funding for stormwater management programs including the construction and operation and maintenance cost for the BMP facilities is critical for the programs to succeed. A continuous and stable source of funding is needed to fund all aspects of the stormwater management program. Maintenance cost is especially important in that it is needed to prolong the useful life of the facility and to ensure that the facility functions as it was designed to.

Historically, many localities have funded stormwater control facilities with general revenues from property taxes (*149*). These revenues, though stable, cannot be relied on as a continuous source of funding because maintenance of BMP facilities may be a low-priority budget item in days of tight budgets. Property taxes for stormwater management may not be equitable either because high property-taxed neighborhoods may actually generate relatively small amounts of stormwater runoff and pollutants.

Other funding ideas have been proposed and discussed, such as bonds, grants from federal and state governments, and other types of taxes (*138*). The most promising funding mechanism, however, may be through a "stormwater utility" concept. The American Public Works Association (*59*) has recommended user charges on the utility approach as the best method of financing stormwater management.

Shaver (*149*) describes the basic concepts of the utility approach are that:

- All properties contribute to or benefit from the stormwater system.
- Users (i.e., properties that generate stormwater) should pay in relation to the level of service provided or amount of service consumed.
- Charge systems are designed to reflect the amount of runoff from properties and commonly are based on Rational Method Coefficient.

Livingston (*143*) reports that the City of Tallahassee implemented Florida's first stormwater utility in October 1986 and many other local governments have or are following this example.

STORMWATER MANAGEMENT AND TRANSPORTATION AGENCIES

Traditionally, the practice of routine highway drainage design has always been to "remove storm runoff from the roadway." The same philosophy prevails in highway drainage design manuals throughout the country today. Some changes have resulted from the 1987 Clean Water Act and the EPA and state rules. For some states, stormwater management rules are already in effect and transportation activities in those states are subject to regulation by those rules.

The EPA stormwater permit regulations classify certain transportation facilities as "industrial activities" and could be required to apply for stormwater discharge permits. A state's rules would most certainly require the state department of transportation's compliance with certain provisions because road building is a major construction and land-disturbing activity. Highway facilities will usually qualify for a general permit with EPA rules summarized in Appendix A.

Even without a statutory requirement, a state highway agency would usually propose a highway drainage scheme that is compatible with local stormwater management planning and objectives. On the other hand, a linear facility such as a highway often must intercept and discharge flows that originate outside the highway rights-of-way and the highway agency should not assume nor be asked to assume a disproportionate share of the responsibility for the attenuation of peak flow rates or volumes downstream of the highway. In this case, the stormwater utility concept based on amount of contributed runoff may appear to be a fair way of dividing responsibilities.

A few cases describing how the state transportation agencies were dealing with the stormwater management issue in 1991 are given below:

California

According to a survey by V. Racin of Caltrans hydraulic engineers from various highway districts, "quality" is generally perceived as important and a short- and long-term highway drainage design objective. Caltran's *Highway Design Manual* was modified in 1988 to reflect "water quality as a design objective."

Maryland

Maryland's Water Resources Administration has issued stormwater management guidelines for state and federal projects (*146*). In principle, no state or federal agency shall develop any land without having provided appropriate stormwater management measures that control or manage runoff. These guidelines are updated on a periodic basis. Detailed design criteria and recommendations regarding stormwater management facilities are given in the guidelines provided to the Maryland Department of Transportation.

North Carolina

North Carolina's stormwater runoff disposal regulations target the coastal counties as areas for which strict control of stormwater runoff must be maintained (*147*). Consequently, when building roads in the designated coastal areas, the North Carolina Department of Transportation must employ best management practices to minimize water quality impacts.

Virginia

The Virginia Stormwater Management Rules require state agencies such as the Virginia Department of Transportation (VDOT) to submit stormwater management plans for approval by the regulatory agency, i.e., the Virginia Division of Soil and Water Conservation (VDSWC). VDOT actually has been an active member on the State's Task Panel in drafting the stormwater rules.

Also VDOT will cooperate with the VDSWC to study the feasibility of using highway rights-of-way for the construction of BMPs such as detention basins (*138*).

1992 Survey of State DOTs on Stormwater Management Practices

A nationwide survey of state DOT strategies for stormwater management was conducted by the Virginia Transportation Research Council. Some of the preliminary findings, obtained mostly through telephone calls, are assembled and listed in Table 21.

It appears the best strategy for the DOTs is to work with either an NPDES state agency or directly with the EPA to obtain a general permit. The general permit can be used to cover all highway projects in a state and therefore, greatly reduces the resources needed for permit application. Furthermore, a DOT "Stormwater Manual of Design and Specification" could be used for satisfying permitting requirements which again will save labor and other resources.

TABLE 21
SURVEY OF STORMWATER MANAGEMENT PRACTICES

FHWA Region/State	NPDES Permit Strategy	Stormwater BMPs Used: Ponds	Infiltration Facilities	Swale/ Vegetative	Wet-lands	Remarks
Region 1						
Massachusetts	General Permit					
New Jersey	General Permit	X	X	X		
Region 3						
Maryland	General Permit	X	X			
Virginia	General Permit	X		X		Design manual used to satisfy state regulations
Region 4						
Florida	General Permit	X	X	X		
Georgia						
Region 5						
Illinois	General Permit		Not in place yet			Co-permitted with Milwaukee and Madison
Wisconsin	General Permit					
Region 6						
Arkansas	General Permit	X	X			
Texas	General Permit	X		X	X	
Region 7						
Kansas	General Permit					
Missouri	General Permit					
Region 8						
Colorado	Group Permit					
Utah	General Permit					
Region 9						
Arizona	Individual Permit (Tuscon & Phoenix)					
California	Group Permit / Individual Permit		Types not dictated			Group permits in LA & SF, Individual permits other areas
Region 10						
Oregon						
Washington	General Permit	X		X	X	

CHAPTER SEVEN

CONCLUSIONS AND RECOMMENDATIONS

The following conclusions and recommendations are drawn from the text.

• Highway construction, operation, and maintenance may contribute a variety of pollutants to surface and subsurface water. Solids, nutrients, heavy metals, oil and grease, pesticides and bacteria can all be associated with highway runoff. Although the impacts of highway runoff pollution on receiving waters may or may not be significant, it is generally recognized that responsible agencies should apply the "best management practice" (BMP) available in order to reduce pollutant loads entering a water body. One of the primary objectives of environmental impact statements (EIS) is the quantification of possible pollutants emanating from the construction, operation, and maintenance of highway and other transportation facilities.

• Recent years have witnessed increased emphasis on water quality as part of stormwater management, as opposed to the traditional focus on quantity. With the federal and many state and local stormwater regulations now in place, it may be necessary for transportation agencies to include stormwater management as part of their standard operations.

• With the rapid advances in computer technology, especially in the realm of microcomputers, highway drainage design and analyses increasingly are carried out on computers. The proliferation of microcomputers is, in a sense, revolutionizing all engineering practices, including highway drainage. The increasing use of computer-aided drafting and design (CADD), computer-aided management (CAM), and the Geographical Information System (GIS) is a good example. Many microcomputer-based highway drainage programs are presently available. A Pooled Fund group involving many state transportation departments has developed an integrated highway drainage design package called HYDRAIN, which is being distributed for general use.

• Stormwater management for pollution abatement includes nonstructural measures to control pollution at the source and structural measures to abate pollution from contaminants transported in the stormwater runoff. Measures to control pollution at the source include street sweeping, catch basin cleaning, and the control of solid wastes such as trash, organic wastes, and dead animals. Other measures for the control of pollution at the source include the controlled use of chemicals such as fertilizers, growth inhibitors, soil sterilants, and pesticides, and the reduction of traffic-generated pollutants by the use of lead-free gasoline and effective traffic handling and regulation. Pollutants in stormwater runoff from streets and highways are derived principally from accumulations of debris along curb lines and other vertical or near-vertical barriers. Therefore, designs that avoid the use of curbs and other barriers effectively eliminate this source of pollution.

• Structural measures or best management practices (BMPs) to abate pollution from contaminants transported in stormwater runoff include grassed waterways and vegetated filter strips; infiltration by the use of wells, ponds, trenches, and seepage areas; land treatment by spreading, overland flow, sprinkler irrigation, and sheet flow; slowing the runoff to facilitate infiltration and deposition by the use of check dams, sedimentation, retention and detention ponds; diversion of first flush or highly contaminated initial runoff from storms; diversions from critical or sensitive watersheds; and the use of natural or artificial wetlands to filter and settle out contaminants.

• Source control measures such as curb elimination, litter control, and control of chemical usage such as deicing compounds and fertilizers, should always be considered in highway practices to reduce the need for structural control.

• Based on studies sponsored by EPA, FHWA, and state and local agencies, wet and extended dry detention ponds appear to be effective in removing particulate pollutants in stormwater runoff. Wet ponds can also be designed to provide biological as well as physical/chemical removal of nutrients. Vegetative control measures, swales and buffer strips, for example, are quite effective in removing particulates such as metals during minor storm events. Infiltration trenches and porous pavements may be good measures for small and low traffic areas, such as parking lots. Information on wetlands is scarce. However, the limited data collected thus far indicate promising pollutant removal effectiveness of wetlands, especially for metals. The potential impact of stormwater runoff on wetland habitats must be carefully studied and mitigated before wetlands can be considered as a BMP. Research is needed in the area of BMP effectiveness, especially field performance regarding water quality benefits.

• In selecting the appropriate BMPs, local or site-specific conditions usually would weigh heavily, together with other factors such as cost effectiveness, space requirements, maintenance and aesthetics, and other environmental concerns. For highway applications, the following control measures have been recommended, according to the order of priority in making a selection:

1. Vegetative measures, e.g., grassed swales, buffer strips
2. Wet detention basins
3. Extended dry detention basins
4. Infiltration basins and trenches
5. Wetlands

Sometimes, a combination of control measures could prove to be most cost effective, such as a wet detention pond linked with a wetland system.

• Maintenance of BMPs is a key to the successful long-term performance of any control measure. Routine and special maintenance requirements of BMPs should be an integrated element of an overall stormwater management plan. Safety considerations can be very important in certain situations.

• Transportation activities are included in the newly promulgated EPA stormwater regulations. Under the federal rule, the transportation agency may be required to obtain an individual stormwater discharge permit for industrial discharge, or it may be considered a co-permittee for a part of a municipal system. In view of the federal, and in many cases, the state and local regulations, a transportation agency should plan a stormwater management strategy that will comply with the various regulations and also minimize its implementation costs. In this regard, collaborations with local or state agencies to achieve some cost-sharing arrangement would seem to be a prudent approach.

REFERENCES

1. *Transportation Research Record 1017: Surface Drainage and Highway Runoff Pollutants*, Transportation Research Board, National Research Council, Washington, D.C. (1985).
2. Kobriger, N.P., et al., *NCHRP Report 264: Guidelines for the Management of Highway Runoff on Wetlands*, Transportation Research Board, National Research Council, Washington, D.C. (November 1983).
3. Ree, William O., *NCHRP Synthesis of Highway Practice 70: Design of Sedimentation Basins*, Transportation Research Board, National Research Council, Washington, D.C. (June 1980) 53 pp.
4. *Constituents of Highway Runoff, Vol. 1: State-of-the-Art Report*, Report No. FHWA/RD-81/042, Federal Highway Administration, Washington, D.C. (1981) 111 pp.
5. Cox, W. E., and L. M. Henson, Control of Nonpoint Source Pollution in Virginia: An Assessment of the Local Role. *Bulletin 158*, Virginia Water Resources Research Center (November 1987) 90 pp.
6. United States Environmental Protection Agency, *Results of the Nationwide Urban Runoff Program: Executive Summary*, NTIS PB84-185545, Washington, D.C. (1983) 24 pp.
7. Yu, S. L., W. Whipple and J. V. Hunter, "Assessing Unrecorded Organic Pollution from Agricultural, Urban, and Wooded Lands," *Water Research*, Vol. 9 (1975) pp. 849-852.
8. Bryan, E. H., "Quality of Stormwater Drainage from Urban Land Areas in North Carolina," *Report No. 37*, North Carolina Water Resources Research Institute (1970).
9. Field, R., and E. J. Struzeski, "Management and Control of Combined Sewer Overflows," *Journal of Water Pollution Control Federation*, Vol. 44, No.7 (1972).
10. Heaney, J. P., and W. C. Huber, "Nationwide Assessment of Urban Runoff as Impact on Receiving Water Quality," *Water Resources Bulletin* (1984).
11. United States Environmental Protection Agency, "Chesapeake Bay: A Framework for Action," EPA Chesapeake Program, Annapolis, MD (1983).
12. APWA Research Foundation and the Institute for Water Resources of the American Public Works Association, "Urban Stormwater Management," *Special Report No. 49*, American Public Works Association (1981).
13. Sauer, V. B., W. 0. Thomas, Jr., V. A. Stricker, and K. V. Wilson, *Flood Characteristics of Urban Watersheds in the United States—Techniques for Estimating Magnitude and Frequency of Urban Floods*, Report No. FHWA/RD-81/178, Federal Highway Administration, Washington, D.C. (1981).
14. Sauer, V. B., et al., "Magnitude and Frequency of Urban Floods in the United States," a paper prepared by the U.S. Geological Survey Water Resources Division in cooperation with the Federal Highway Administration for presentation to the 61st Annual Meeting of TRB, January 1982.
15. Leopold, L. B., *USGS Circular No. 554: Hydrology for Urban Land Planning*, U.S. Government Printing Office, Washington, D.C. (1968).
16. McPherson, M. B., "The Design Storm Concept," a paper presented by the Institute of Stormwater Detention, University of Wisconsin (April 14, 1977).
17. "Guide for Collection, Analysis, and Use of Urban Stormwater Data," A Conference Report by William M. Alley, The Engineering Foundation, U.S. Geological Survey, and the ASCE Urban Water Resources Council, American Society of Civil Engineers (1976).
18. Van Sickle, Donald, "Storm Drainage Planning for Growth Areas," *Proceedings of a Research Conference, Urban Runoff Quantity & Quality*, cosponsored by The Engineering Foundation and the ASCE Urban Water Resources Research Council, American Society of Civil Engineers (1974).
19. Lowing, M. J., "Urban Hydrological Modeling and Catchment Research in the United Kingdom," *ASCE Urban Water Resources*, No. IHP-4 (July 1976).
20. "Hydraulic Analyses for the Location and Design of Bridges," prepared by the Task Force on Hydrology and Hydraulics, Highway Subcommittee on Design, American Association of State Highway and Transportation Officials (1982) 122 pp.
21. Pagan, Alfred R., "An Important Legal Decision Involving Increased Runoff After Land Development," *International Symposium on Urban Storm Runoff*, University of Kentucky (July 23-26, 1979).
22. Zulovs, George, D. G. Weatherbe, and J. Marsalek, "Urban Runoff Control Technology," *Civil Engineering* (August 1982) pp. 50-52.
23. "Constituents of Highway Runoff," *Vol. 1, State-of-the-Art Report*, No. FHWA/RD-81-042, Federal Highway Administration (1981) 111 pp.
24. "Sources and Migration of Highway Runoff Pollutants," *Vol. 1 Executive Summary*, Report No. FHWA/RD-84/057, Federal Highway Administration (1984) 24 pp.
25. American Public Works Association, "Water Pollution Aspects of Urban Runoff," *Water Pollution Control Research Series WP-20-15*, Federal Water Pollution Control Authority (1969).
26. Dannis, M. L., "Rubber Dust From the Normal Wear of Tires," *Rubber Chemistry and Technology*, Vol. 47, No. 4 (1974).
27. Pitt, R. E., and G. Amy, *Toxic Material Analysis of Street Surface Contaminants*, Report No. EPA-R2-73-283, United States Environmental Protection Agency (1973).
28. Adams, F. J., "Highway Salt: Social and Environmental Concerns," paper presented to Highway Research Board, Fifth Summer Meeting (1972).
29. Ellis, J. B., "Pollutional Aspects of Urban Runoff," in *Urban Runoff Pollution*, edited by H. C. Torno et al., NATO ASI Series, Springer-Verlag (1985) pp. 1-38.
30. Perry, R., and A. E. McIntyre, "Impact of Motorway Runoff Upon Surface Water Quality," in *Effects of Land Use on Fresh Water*. Edited by J. Solbe, Water Research Centre, Medmenhan, UK (1985).
31. Rexnord Inc., "Effects of Highway Runoff on Receiving Waters," *Vol. 1: Executive Summary*, Report No. FHWA/RD-

84/062, Federal Highway Administration, Washington, D.C. (1985) 24 pp.

32. United States Environmental Protection Agency, Office of Water, *National Water Quality Inventory 1986*, A Report to Congress, available from Government Printing Office, Washington, D.C.
33. Medina, M. A., "State-of-the-Art, Physically Based and Statistically Based Water Quality Modeling," in *Urban Runoff Pollution*, edited by H. C. Torno et al, NATO ASI Series, Spring-Verlag (1985) pp. 499-586.
34. Grigg, N. S., *Hydrology for Transportation Engineers*, Report No. FHWA-IP-80-1, Federal Highway Administration, Washington, D.C. (1980) 736 pp.
35. *Hydrology*, Report No. 19/FHWA-1P-84-G, Federal Highway Administration, Washington, D.C. (1984) 650 pp.
36. Jens, Stifel W., *Design of Urban Highway Drainage—The State of the Art*, Report No. FHWA-TS-79-225, Federal Highway Administration, Washington, D.C. (1979).
37. "Rainfall Frequency Atlas of the United States for Durations from 30 Minutes to 24 Hours and Return Periods from 1 to 100 Years," *U.S. Weather Bureau Technical Paper No. 40*, National Oceanic and Atmospheric Administration, Washington, D.C. (1961).
38. "Design and Construction of Sanitary and Storm Sewers," *Manual of Engineering Practices, No. 37*, American Society of Civil Engineers, New York (1969).
39. National Oceanic and Atmospheric Administration, "Five to 60 Minute Precipitation Frequency Data for Eastern and Central United States," *National Weather Service HYDRO-35*, Silver Spring, MD (1977).
40. National Oceanic and Atmospheric Administration, "Precipitation–Frequency Atlas of the Western United States," *Atlas 2, Volumes I-XI*, Silver Spring, MD (1973).
41. Akan, A. 0., and B. C. Yen, "Effect of Time Distribution of Rainfall on Overland Runoff," *Proceedings, Third International Conference on Stormwater Drainage*, Goteburg, Sweden (1984) pp. 193-202.
42. "A Method for Estimating Volume and Rate of Runoff in Small Watersheds," *U.S. Soil Conservation Service Technical Paper 149*, United States Soil Conservation Service, Washington, D.C. (1973) 40 pp.
43. "Urban Hydrology for Small Watersheds," *U.S. Soil Conservation Service Technical Release 55*, 2nd ed. United States Soil Conservation Service, Washington, D.C. (1986) 146 pp.
44. Huff, F. A., "Time Distribution of Rainfall in Heavy Storms," *Water Resources Research*, Vol. 3, No. 4 (1967) pp. 1007-1019.
45. Yen B. C., and V. T. Chow, *Local Design Storms: Vol. 11, Methodology and Analysis*, Report FHWA/RD-82/064, Federal Highway Administration, Washington, D.C. (1983).
46. Bonta, J. W., and A. R. Rao, "Regionalization of Storm Hyetographs," *Water Resources Bulletin,* Vol. 25, No. 1, AWRA (1989) pp. 211-217.
47. Aron, G., D. J. Wall, E. L White, C. N. Dunn, and D. M. Kotz, "Pennsylvania Storm Intensity-Duration-Frequency Charts PDT-IDF," Pennsylvania Department of Transportation, Harrisburg, PA (1986) 56 pp.
48. Yu, S. L., P. A. Hamilton, and C. E. Kent, "Temporal Distribution of Rainfall in Virginia," Virginia Transportation Research Council, Charlottesville (1984) 69 pp.
49. Yu, S. L., and D. Benelmouffok, "Dynamics of Runoff from High-Intensity, Short-Duration Storms," Virginia Transportation Research Council, Charlottesville (1985) 51 pp.
50. Aron, G., "Sensitivity of Storm Runoff Hydrographs to Hyetograph Shape," *Proceedings, International Conference for Centennial of Manning's Formula and Kuichling's Rational Formula*, University of Virginia, Charlottesville (1989) pp. 1-9.
51. Paine, J. N., "Effects of Hyetograph Shape on Detention Pond Sizing," *Proceedings, International Conference for Centennial of Manning's Formula and Kuichling's Rational Formula,* University of Virginia, Charlottesville (1989) pp. 36-44.
52. U.S. Geological Survey, "Techniques for Estimating Magnitude and Frequency of Floods in Virginia," *USGS Water Resources Investigations 78-5,* United States Geological Survey, Richmond, VA (1978) 83 pp.
53. Sauer, V. B., W. D. Thomas, V. A. Stricker and K. V. Wilson, "Flood Characteristics of Urban Watersheds in the United States," *US Geological Survey Water-Supply Paper 2207*, United States Geological Survey, Washington, D.C. (1983).
54. Viessman, W., Jr., G. L. Lewis and J. W. Knapp, *Introduction to Hydrology*, 3d ed., Harper & Row (1989) 780 pp.
55. Kuichling, E., "The Relation Between the Rainfall and the Discharge of Sewers in Populous Districts," *Transactions of ASCE*, Vol. 20 (1889) pp. 1-60.
56. Searcy, J. K., *Drainage of Highway Pavements*, U.S. Department of Transportation, Federal Highway Administration, Washington, D.C. (1969).
57. U.S. Soil Conservation Service, "Hydrology," *Supplement A to Section 4, Engineering Handbook*, United States Department of Agriculture, Washington, D.C. (1968).
58. U.S. Soil Conservation Service, "Urban Hydrology for Small Watersheds," *Technical Release 55*, United States Department of Agriculture, Washington, D.C. (1975).
59. *Urban Stormwater Management*, American Public Works Association, Chicago, IL (1981) 285 p.
60. Yen, B. C., "Inlet Hydrographs," Section V of *Storm Sewer System Design*, Department of Civil Engineering, University of Illinois, Urbana (1978).
61. Sherman, L. K. "Stream-Flow from Rainfall by the Unit-Graph Method," *Engineering News Record 108,* (1932) pp. 501-505.
62. Bedient, P. B., and W. C. Huber, *Hydrology and Flood Plain Analysis*, Addison-Wesley Publishing Co., Reading, MA (1988) 650 p.
63. *Model Drainage Manual 1991*, American Association of State Highway and Transportation Officials, Washington, D.C.
64. Snyder, F. F., "Synthetic Unit Graphs," *Transactions of the American Geophysical Union*, Vol. 19 (1938) pp. 447-454.
65. Taylor, A. B., and H. E. Schwartz, "Unit Hydrograph Lag and Peak Flow Related to Basin Characteristics," *Transactions of the American Geophysical Union*, Vol. 33 (1952) pp. 235-246.
66. Viessman, W., Jr., G. L. Lewis and J. W. Knapp, *Introduction to Hydrology*, 3d ed., Harper & Row (1989) 780 pp.
67. Mockus, V., "Use of Storm and Watershed Characteristics in Synthetic Hydrograph Analysis and Application," U.S. Soil Conservation Service, United States Department of Agriculture, Washington, D.C. (1957).

68. Clark, C. O., "Storage and the Unit Hydrograph," *Transactions of the ASCE* (1945) pp. 1419-46.
69. Sauer, V. B., Dimensionless Hydrograph Method of Simulating Flood Hydrographs, Presented at 68th Annual Meeting, Transportation Research Board (1989) Washington, D.C.
70. U.S. Geological Survey, "Estimating Peak Discharges, Flood Volumes, and Hydrograph Shapes of Small Urban Streams in Ohio," *USGS Water Resources Investigation Report 86-4197*, USGS, Columbus, OH (1986) 52 pp.
71. Wanielista, M., *Hydrology and Water Quality Control*, Wiley (1990) 565 p.
72. Jones, J. E., and D. E. Jones, Where Is Urban Stormwater Management Today? paper presented at the International Conference on Rational Formula and Open Channel Hydraulics, University of Virginia, Charlottesville (1989).
73. Wisner, P. E., A. M. Kassem, and P. W. Cheung, "Parks Against Storms", *Proceedings, Second International Conference on Urban Storm Drainage*, Urbana, IL (1981) pp. 322-330.
74. Boyd, M. J., "Preliminary Design Procedures for Detention Basins," *Proceedings, Second International Conference on Urban Storm Drainage*, Urbana, II (1981) pp. 370-378.
75. Loganathan, G. V., J. W. Delleur and R.I. Segarra, "Planning Detention Storage for Stormwater Management," *ASCE Journal of Water Resources Planning and Management*, Vol. 111, No. 4 (1985) pp. 382-398.
76. Ormsbee, L. E., "Detention Basin Design Using Continuous Simulation", *Proceedings, ASCE Symposium on Engineering Hydrology*, Williamsburg, VA (1987) pp. 376-381.
77. California Office of Transportation Laboratory, *Underground Disposal of Stormwater Runoff*, FHWA75-80-218, Federal Highway Administration, Washington, D.C. (1980).
78. Fujita, S., "Experimental Sewer Systems for Reduction of Urban Storm Runoff," *Proceedings, Third International Conference on Urban Storm Drainage*, Goteborg, Sweden (1984) pp. 1211-1220.
79. Dorman, M.E., J. Hartigan, F. Johnson, and B. Maestri, *Retention, Detention and Overland Flow for Pollutant Removal from Highway Stormwater Runoff: Interim Guidelines for Management Measures*, FHWA/RD-87-056, Federal Highway Administration, Washington, D.C. (1988) 189 pp.
80. Finnemore, E.J., "Stormwater Pollution Control: Best Management Practices," *Proceedings, ASCE Environmental Engineering Division*, Vol. 108, No. EE5 (1982) pp. 835-851.
81. Whipple, W. Jr., R. Knapp, and S. Burke, "Implementing Dual-Purpose Stormwater Detention Programs," *Journal of Water Resources Planning and Management*, Vol. 113, No. 6, ASCE (1987) pp. 779-792.
82. Driscoll, E. D., *Methodology for Analysis of Detention Basins for Control of Urban Runoff Quality*, EPA Report 440/5-87-001, United States Environmental Protection Agency (1986) 72 pp.
83. Schueler, T. R., and M. Helfrich, "Design of Extended Detention Wet Pond Systems," *Proceedings of Engineering Foundation Conference on Current Practice and Design Criteria for Urban Duality Control*, ASCE, Potosi, MO (1989) pp. 180-200.
84. Martin, E. H., "Effectiveness of an Urban Runoff Detention Pond-Wetlands System," *Journal of Environmental Engineering*, ASCE (1988).
85. Wu, Jy S., B. Holman, and J. Dorney, "Water Quality Study on Urban Wet Detention Ponds," *Proceedings, Engineering Foundation Conference on Current Practice and Design Criteria for Urban Quality Control*, ASCE, Potosi, MO (1989) pp. 280-289.
86. Yu, S. L., W. K. Norris, and D. C. Wyant, "Urban BMP Demonstration Project in the Albemarle / Charlottesville Area," *Final Report to Virginia Department of Conservation & Historic Resources*, University of Virginia, Charlottesville (1987) 120 pp.
87. Schueler, T. R., "Controlling Urban Runoff: A Practical Manual for Planning and Design Urban BMPs," Metropolitan Washington Council of Governments, Washington, D.C. (1987)
88. Smith, Harry A., *NCHRP Synthesis of Highway Practice 180: Performance Characteristics of Open-Graded Friction Courses*, Transportation Research Board, National Research Council, Washington, D.C. (1992) 44 pp.
89. Meier, W. R., Jr., and E. J. Elnicky, *Porous Pavement for the Control of Highway Runoff*, Report FHWA-AZ88-227, Arizona Department of Transportation (1988) 38 pp.
90. Schueler, T., R. Magill, M. P. Sullivan and C. Wiegand, "Comparative Pollutant Removal Capability, Economics and Physical Suitability of Urban Best Management Practices in the Washington, D.C. Metropolitan Area," Paper presented at Nonpoint Pollution Abatement Symposium, Marquette University, Milwaukee, WI (1985).
91. Boyt, F. L., S. E. Bayley, and J. Zolter, "Removal of Nutrients from Treated Municipal Wastewater by Wetland Vegetation," *Journal of Water Pollution Control Federation*, Vol. 49 (1977) pp. 789-799.
92. Barten, J. M., *1981 Clear Lake Water Quality and Treatment Marsh Assessment, Final Report*, EPA Grant #S804691-01-0, (1982).
93. Martin, E. H., and J. L. Smoot, *Constituent-Load Changes in Urban Stormwater Runoff Routed Through a Detention Pond-Wetlands System in Central Florida*, USGS Report 854310, Tallahassee, FL (1986).
94. Scherger, D. A., and J. A. Davis, Control of Stormwater Runoff Pollutant Loads by a Wetland and Retention Basin, *Proceedings, International Symposium of Urban Hydrology, Hydraulics and Sediment Control*, University of Kentucky, Lexington, KY (1982) pp. 109-123.
95. Walker, W. W., Jr., "Phosphorus Removal by Urban Runoff Detention Basins," *Lake and Reservoir Management Society*, Washington, D.C. (1987) pp. 314-328.
96. Whipple, W., Jr., and J. V. Hunter, "Settleability of Urban Runoff Pollution," *Journal of Water Pollution Control Federation*, Vol 53, No. 12 (1981) pp. 1726-1731.
97. Hartigan, J. P., Basis for Design of Wet Detention Basin BMPs, *Proceedings, Engineering Foundation Conference on Design of Urban Runoff Quality Controls*, ASCE, Potosi, MO (1988) pp. 122-143.
98. Yu, S. L., Y. Wu, and J. Benelmouffok, *Modeling the Effect of Baffles on the Hydrodynamic and Pollutant Removal Characteristics of a Detention Pond*, Report to USGS, University of Virginia, Charlottesville, VA (1989).
99. Fujita, S., "Experimental Sewer Systems: Application and Effects," *Proceedings, Fourth International Conference in Urban Storm Drainage*, Lausanne, Switzerland (1987) pp. 357-362.
100. Wong, S. L., and R. H. McCuen, "The Design of Vegetative

Buffer Strips for Runoff and Sediment Control," in *Stormwater Management in Coastal Areas*, Department of Natural Resources, Annapolis, MD (1982).

101. Livingston, G. H., "The Case of Wetlands for Urban Stormwater Management," *Proceedings, Engineering Foundation Conference on Design of Urban Runoff Quality Controls*, ASCE, Potosi, MO (1988) pp. 467-489.
102. "Guidelines for Constructing Wetland Stormwater Basins," Maryland Department of Natural Resources, Annapolis, MD (1987).
103. Whipple, W., Jr., S. L. Yu, and J. V. Hunter, "Runoff Pollution from Multiple Family Housing," *Journal of American Water Resources Association*, Vol. 14, No. 2 (1978) pp. 288-301.
104. AVCO Economics Systems Corp., *Storm Water Pollution from Urban Land Activity*, Federal Water Quality Administration Publication No. 11034FKLO7/70 (1970).
105. Heaney, J., W. W. Huber, and S. J. Nix, *Storm Water Management Model: Level I Preliminary Screening Procedures*, EPA-600/2-76-275. US EPA, Cincinnati, OH (1976) 77 pp.
106. Driver, N., and G. D. Tasker, *Techniques for Estimation of Storm-Runoff Loads, Volumes and Selected Constituent Concentrations in Urban Watersheds in the U.S.*, USGS Open-File Report 88-191, Denver, CO (1988) 80 pp.
107. Crawford, N. H., and R. K. Linsley, "Digital Simulation in Hydrology, Stanford Water Model IV," *Technical Report 39*, Civil Engineering Department, Stanford University, Stanford, CA (1966).
108. Johanson, R. C., J. C. Imhoff and H. H. Davis, *User's Manual for Hydrological Simulation Program-FORTRAN (HSPF)*, EPA-600/9-80-015, US EPA, Athens, GA (1980).
109. Fleming, G., *Computer Simulation Techniques in Hydrology*, American Elsevier Publishing Co. (1975).
110. "Urban Stormwater Hydrology," *Water Resources Monograph 7*, edited by D.F. Kibler, American Geophysical Union, Washington, D.C. (1982).
111. Whipple, W., N. S. Grigg, T. Grizzard, C. W. Randall, R. P. Shubinski and L. S. Tucker, *Stormwater Management in Urbanizing Areas*, Prentice-Hall, Englewood Cliffs, NJ (1983).
112. Tholin, A. L., and C. T. Keifer, "Hydrology of Urban Runoff," *Proceedings, ASCE Journal of the Sanitation Engineering Division*, Vol. 85, No. SA2 (1959) pp. 47-106.
113. Keifer, C. T., J. P. Harrison, and T. 0. Hixson, *Chicago Hydrograph Method Network Analysis of Runoff Computations*, Preliminary Report, City of Chicago, Bureau of Engineering (1970).
114. Bravo, C. A., M. H. Harley, F. E. Perkins, and P. S. Eagleson, *A Linear Distributed Model of Catchment Runoff, Report No. 123*, Hydrodynamics Laboratory, Massachussetts Institute of Technology, Cambridge, MA (1970).
115. Metcalf & Eddy, Inc., University of Florida, and Water Resources Engineers, Inc., *Stormwater Management Model for EPA*, EPA Reports #11024DOC07/71-10/71 (1971).
116. Huber, W. C., J. P. Heaney, S. J. Nix, R. E. Dickinson and D. J. Polmann, *Storm Water Management Model User's Manual, Version Ill*, EPA-600/2-84-109a, United States Environmental Protection Agency, Athens, GA (1981).
117. Roesner, L. A., R. P. Shubinski and J. A. Aldrich, *Stormwater Water Management Model User's Manual Version Ill: Addendum I, EXTRAN*, EPA-600/2-84-109b, United States Environmental Protection Agency, Athens, GA (1981).
118. Papadakis, C. N., and H. C. Preul, "University of Cincinnati Urban Runoff Model," *Proceedings, ASCE Journal of the Hydrologic Division*, Vol. 98, No. HY10 (1972) pp. 1789-1804.
119. "HEC-1 Flood Hydrograph Package: User's Manual," United States Army Corps of Engineers, Hydrologic Engineering Center, Davis, CA (1973, 1981, 1985).
120. Terstriep, M. L., and J. B. Stall, "The Illinois Urban Drainage Area Simulator, ILLUDAS," *Bulletin 58*, Illinois State Water Survey, Urbana, II (1974).
121. United States Soil Conservation Service, "Computer Program for Project Formulation, Hydrology," *Technical Release No. 20*, U.S. Department of Agriculture, Washington, D.C. (1975).
122. United States Army Corps of Engineers, "Urban Storm Water Runoff, STORM," Computer Program 723-S8-L2520, Hydrologic Engineering Center, Davis, CA (1974).
123. Aron, G., and D. F. Lakatos, "Penn State Urban Runoff Model: User's Manual," *Research Publication 96*, Institute for Research on Land and Water Resources, Pennsylvania State University, University Park (1976).
124. "Hydrocomp Simulation Package FORTRAN, User's Manual," United States Environmental Protection Agency, Athens, GA (1980).
125. Alley, W. M., and P. E. Smith, *Distributed Routing Rainfall-Runoff Model-Version 11, User's Manual*, USGS Open-File Report 82-344, United States Geological Survey (1982).
126. Heeps, D. P., and R. G. Mein, "Independent Comparison of Three Urban Runoff Models," *Proceedings, ASCE Journal of the Hydrologic Division*, Vol. 100, No. HY7 (1974) pp. 995-1010.
127. Marsalek, J., T. M. Dick, P. E. Wisner, and W. G. Clark, "Comparative Evaluation of Three Urban Runoff Models," *Water Resources Bulletin*, AWRA, Vol. 11, No. 2 (1975) pp. 306-328.
128. Brandstetter, A., *Comparative Analysis of Urban Stormwater Models*, Battelle Memorial Institute (1974).
129. Lager, J. A., and W. G. Smith, *Urban Stormwater Management and Technology—An Assessment*, US EPA Rep. EPA-670 / 2-74-040, United States Environmental Protection Agency (1974).
130. Garber, N. J. and L. A. Hoel, *Traffic and Highway Engineering*, West Publishing Co., St. Paul, MN (1988) 959 p.
131. Grigg, N. S., *Hydrology for Transportation Engineers*, Report No. FHWA-IP-80-1, Federal Highway Administration, Washington, D.C. (1980) 736 pp.
132. Camp, Dresser and McKee, Inc., *Urban Highway Storm Drainage Model*, seven volumes, FHWA-RD-81-011 to -017, Federal Highway Administration (1983).
133. GKY & Associates, Inc., *HYDRAIN-Integrated Drainage Design Computer System*, six volumes, FHWA No. RD-88-120 to -125, Federal Highway Administration, McLean, VA (1988).
134. Yu, S. L., and J. Li, *Microcomputer Software for Storm Drain Hydraulic Gradeline Computation*, Final Report, Virginia Transportation Research Council, Charlottesville (1987) 45 pp.
135. Yu, S. L., Y. Win and M. Woolfolk, *Pressurized Flow Simu-*

lation Model: Model Enhancement, Final Report, Virginia Transportation Research Council, Charlottesville (1990).

136. Yu, S. L. and T. Tisdale, A New Microcomputer Model for Stormwater Management. Paper presented at the Conference on Stormwater and Water Quality Modeling, Environmental Protection Agency, Toronto, Canada (1986).
137. Kuo, C. Y., G. V. Loganathan, W. E. Cox, S. P. Shregtha, and K. J. King, "Effectiveness of BMP's for Stormwater Management in Urbanized Watersheds," *Bulletin 159*, Virginia Water Resources Research Center, Blacksburg, VA (1987) 121 pp.
138. "Evaluation of Regional BMP's in the Occoquan Watershed," Northern Virginia Planning District Commission, Annandale, VA (1990).
139. "National Pollutant Discharge Elimination System Permit Application Regulations for Storm Water Discharges: Proposed Rule," *Federal Register 40 CFR Parts 122,123,124 and 504*, United States Environmental Protection Agency (1988).
140. Thompson, P., "Poison Runoff: A Guide to State and Local Control of Nonpoint Source Water Pollution," Natural Resources Defense Council, Inc., New York, NY (1989) 484 pp.
141. Gallup, J. D., and Y. Weiss, "Federal Requirements for Storm Water Management Programs," *Proceedings, Engineering Foundations, Design of Urban Runoff Quality Controls*, ASCE, Potosi, MO (1988) pp. 100-106.
142. Hawley, M. E., and R. H. McCuen, "Elements of a Comprehensive Stormwater Management Program," *Journal of Water Resources Planning and Management*, Vol. 113, No. 6, ASCE, Potosi, MO (1987) pp. 793-809.
143. Livingston, E. H., "State Perspectives on Water Quality Criteria," *Proceedings, Engineering Foundation Conference, Design of Urban Runoff Quality Controls*, ASCE, Potosi, MO (1988) pp. 49-66.
144. "Standards and Specifications for Maryland Water Resources Administration, Infiltration Practices," Maryland Department of Natural Resources, Annapolis, MD (1984) 125p.
145. Cox, W. E., and L. M. Heerson, "Control of Nonpoint Source Pollution in Virginia: An Assessment of the Local Role," *Bulletin 158*, Virginia Water Resources Research Center, Blacksburg, VA (1987) 90 pp.
146. "Stormwater Management Guidelines for State and Federal Projects," Maryland Water Resources Administration, Annapolis, MD (1986).
147. *Stormwater Runoff Disposal, 15NClC24.1000*, North Carolina Department of Natural Resources, Raleigh (1988).
148. Huber, W. C., "Technological, Hydrological and BMP Basis for Water Quality Criteria and Goals," *Proceedings, Engineering Foundation Conference, Design of Urban Runoff Quality Control*, Potosi, MO (1989) pp. 68-83.
149. Shaver, H. E., "Institutional Stormwater Management Issues," *Proceedings, Engineering Foundation Conference, Design of Urban Runoff Quality Control*, ASCE, Potosi, MO (1988).

APPENDIX A
OVERVIEW OF THE ENVIRONMENTAL PROTECTION AGENCY STORMWATER PROGRAM NATIONAL POLLUTANT DISCHARGE ELIMINATION SYSTEM (NPDES)

STORM WATER PROGRAM

BACKGROUND

The 1972 amendments to the Federal Water Pollution Control Act (FWPCA, also referred to as the Clean Water Act or CWA) prohibit the discharge of any pollutant to waters of the United States from a point source unless the discharge is authorized by a National Pollutant Discharge Elimination System (NPDES) permit. Efforts to improve water quality under the NPDES program traditionally have focused on reducing pollutants in discharges of industrial process wastewater and from municipal sewage treatment plants. Efforts to address storm water discharges under the NPDES program have generally been limited to certain industrial categories with effluent limitations for storm water.

In response to the need for comprehensive NPDES requirements for discharges of storm water, Congress amended the CWA in 1987 to require the Environmental Protection Agency (EPA) to establish phased NPDES requirements for storm water discharges. To implement these requirements, EPA published the initial permit application requirements for certain categories of storm water discharges associated with industrial activity, and discharges from municipal separate storm sewer systems located in municipalities with a population of 100,000 or more on November 16, 1990, (55 FR 47990). Storm water discharge permits will provide a mechanism for monitoring the discharge of pollutants to waters of the United States and for establishing appropriate controls.

ENVIRONMENTAL IMPACTS

Pollutants in storm water discharges from many sources are largely uncontrolled. The "National Water Quality Inventory, 1990 Report to Congress" provides a general assessment of water quality based on biennial reports submitted by the States under Section 305(b) of the Clean Water Act. The Report indicates that roughly 30% of identified cases of water quality impairment are attributable to storm water discharges. The States identified a number of major sources of storm water runoff that cause water quality impacts including separate storm sewers, construction, waste disposal, and resource extraction.

INDUSTRIAL FACILITIES COVERED

EPA has defined the term "storm water discharge associated with industrial activity" in a comprehensive manner to address over 100,000 facilities (see Attachment VII for a complete definition). All storm water discharges associated with industrial activity that discharge through municipal separate storm sewer systems or that discharge directly to waters of the U.S., are required to obtain NPDES permit coverage, including those which discharge through systems located in municipalities with a population of less than 100,000. Discharges of storm water to a sanitary sewer system or to a Publicly Owned Treatment Works (POTW) are excluded. Facilities with storm water discharges associated with industrial activity include: manufacturing facilities; construction operations disturbing 5 or more acres; hazardous waste treatment, storage, or disposal facilities; landfills; certain sewage treatment plants; recycling facilities; powerplants; mining operations; some oil and gas operations; airports; and certain other transportation facilities. Operators of industrial facilities that are Federally, State or municipally owned or operated that meet the description of the facilities listed in 40 CFR 122.26(b)(14)(i)-(xi) must also submit applications.

TRANSPORTATION ACT OF 1991

The Transportation Act of 1991 provides an exemption from storm water permitting requirements for certain industrial activities owned or operated by municipalities with a population of less than 100,000. Such municipalities must submit storm water discharge permit applications for only airports, powerplants, and uncontrolled sanitary landfills that they own or operate, unless a permit is otherwise required by the permitting authority. The Transportation Act of 1991 also revises group application deadlines for facilities that are owned or operated by municipalities with a population of less than 250,000. See Attachment II for revised deadlines.

9th CIRCUIT COURT DECISION

The 9th Circuit United States Court of Appeals' opinion in NRDC v. EPA (June 4, 1992) and the opinion in AMC v. EPA (May 27, 1992), affirmed and upheld the basic structure and direction of the national storm water program. In "NRDC", the Court upheld the definition of "municipal separate storm sewer system," the standards for municipal storm water controls, the scope of storm water requirements for oil and gas operations, and EPA's decision not to provide public comment on Part 1 group industrial permit applications. On the question of deadlines, the Court noted that the storm water application deadlines clearly exceeded statutory requirements, but refused to "roll back" the current regulatory deadlines. The Court also emphasized, however, that any further regulatory extension would be illegal. In two other areas the Court invalidated and remanded for further proceedings two regulatory exemptions from the definition of "storm water discharges associated with industrial activity": (1) the exemption for construction sites disturbing less than 5 acres of land (category x), and (2) the exemption of certain "light" manufacturing facilities without exposure of materials and activities to storm water (category xi). In response to these two remands, the Agency intends to conduct further rulemaking proceedings on construction activities under 5 acres and light industry without exposure as ordered by the Court. EPA will not require permit applications for construction sites disturbing less than 5 acres of land and category xi facilities without exposure until this further rulemaking is completed. In "AMC," the Court upheld EPA's regulation of storm water discharges from inactive mines.

INDUSTRIAL APPLICATION OPTIONS

The November 16, 1990, storm water regulation presents three permit application options for storm water discharges associated with industrial activity. The first option is to submit an individual application consisting of Forms 1 and 2F. The second option is to participate in a group application. This option, however, is no longer available as the deadlines have passed. The third option is to file a Notice of Intent (NOI) to be covered under a general permit in accordance with the requirements of an issued general permit. The following overview briefly outlines each of these three options and the subsequent attachments provide a more detailed explanation.

A. INDIVIDUAL APPLICATIONS

Operators of facilities with storm water discharges associated with industrial activity who did not participate in a group application or did not obtain coverage under a general permit, must submit an individual application consisting of Form 1 and Form 2F. The information required in Form 2F includes a site drainage map, a narrative description of the site identifying potential pollutant sources, and quantitative testing data. There are specific requirements for construction activities and oil and gas operations and mining operations. See Attachment I for additional information.

B. GROUP APPLICATIONS

The group application procedure was an option available for facilities that have similar industrial operations, waste streams and other characteristics. Group applications reduced the burden on the regulated community by requiring the submission of quantitative data from only selected members of the group. The group application was submitted in two parts. Part 1 of the application identified all participants, provided facility specific information and proposed a representative sampling subgroup. Part 2 of the application consists of sampling data from each member of the sampling subgroup identified in Part 1 of the application. See Attachment II for additional information.

C. GENERAL PERMIT - NOI REQUIREMENTS

Industrial storm water dischargers that submit an NOI to be covered by the general permit are not required to submit an individual permit application or participate in a group application, provided the discharger is eligible for the permit and an individual permit application is not required by the Director on a case-by-case basis. Submitting an NOI represents a significantly less burden than submitting an individual application or participating in a group application. The NOI requirements for general permits usually address only general information and typically do not require the collection of monitoring data. Submittal of an NOI is only possible where applicable general permits have been issued by the permitting authority. EPA has finalized general permits for construction and industrial activity in the 12 States without NPDES authorization (57 FR 41176, September 9, 1992 and 57 FR 44412, September 25, 1992). As of March 1993, 35 of the 39 authorized NPDES States have general permit authority. See Attachments III, IV and V for additional information.

INDUSTRIAL PERMIT APPLICATION DEADLINES

Type of Application	Deadline	
▲ Individual	October 1, 1992	
▲ Group	Part 1	Part 2
All industrial activities except those owned or operated by a municipality with a population of less than 250,000.	September 30, 1991	October 1, 1992
Industrial activities owned or operated by a municipality with a population of less than 250,000.	May 18,1992	May 17, 1993
▲ General Permit NOI	October 1, 1992 (for EPA's general permits)	

MUNICIPAL APPLICATIONS

"Municipal separate storm sewer" is defined as any conveyance or system of conveyances that is owned or operated by a State or local government entity designed for collecting and conveying storm water which is not part of a POTW. The application requirements do not apply to discharges from combined sewers (systems designed as both a sanitary sewer and a storm sewer). Municipal separate storm sewer systems that are addressed by the November 16, 1990, regulations include storm sewer systems located in 173 cities with populations of 100,000 or more; located in 47 counties identified by EPA as having populations over 100,000 in unincorporated, urbanized areas; and systems that are designated by the Director based on consideration of the location of the discharge with respect to waters of the United States, the size of the discharge, the quantity and nature of the pollutants discharged to waters of the United States, the interrelationship to other regulated storm sewer systems, and other factors. The operator of a designated system will be notified by the Director. Under the November 16, 1990, storm water rule, those municipal separate storm sewer systems identified must submit a two-part application. The first part requires information regarding existing programs and the means available to the municipality to control pollutants. In addition, part one requires a field screening analysis of major outfalls to detect illicit connections. Building on this information, the second part requires a limited amount of representative quantitative data and a description of a proposed storm water management plan. See Attachment V for a detailed explanation of the two-part application process.

MUNICIPAL APPLICATIONS DEADLINES

	Part 1	Part 2
Large Municipalities (over 250,000)	November 18, 1991	November 16, 1992
Medium Municipalities (100,000 - 250,000)	May 18, 1992	May 17, 1993

ATTACHMENT I

INDIVIDUAL APPLICATION REQUIREMENTS

These requirements address storm water discharges associated with industrial activity that are not authorized by a general permit and that are not included in a group application.

Application Forms

- Applicants for discharges composed entirely of storm water must submit **Forms 1 and 2F**
- Applicants for discharges composed of storm water and process wastewater must submit **Forms 1, 2C, and 2F**
- Applicants for new sources or new discharges composed of storm water and non-storm water must submit **Forms 1, 2D, and 2F**
- Applicants for discharges composed of storm water and nonprocess wastewater must submit **Forms 1, 2E, and 2F**
- Authorized NPDES States may establish their own forms which are at least as stringent as EPA's forms.
- Forms are available from State permitting authorities for facilities located in NPDES authorized States, or from EPA Regional Offices for facilities located in States without NPDES authorization.

Form 2F Requirements

- Site map showing topography and/or drainage areas and site characteristics.
- Estimate of impervious surface area and the total area drained by each outfall.
- Description of significant materials exposed to storm water, including current materials management practices.
- Certification that outfalls have been tested or evaluated for the presence of non-storm water discharges that are not covered by a NPDES permit.
- Information on significant leaks and spills in last 3 years.
- Quantitative testing data for the following parameters:
  - Any pollutants limited in an effluent guideline to which the facility is subject
  - Any pollutant listed in the facility's NPDES permit for process wastewater
  - Oil and grease, pH, BOD_5, COD, TSS, total phosphorus, nitrate plus nitrite nitrogen, and total Kjeldahl nitrogen
  - Certain pollutants known to be in the discharge
  - Flow measurements or estimates
  - Date and duration of storm event.

Individual Application Requirements for Construction Activities

- Provide a narrative description of:
  - Location and nature of construction activity (including a map)
  - Total area of the site and area to be excavated
  - Proposed measures to control pollutants in storm water discharges during and after construction operations
  - Estimate of runoff coefficient and increase in impervious areas after construction
  - Name of receiving water.
- No quantitative sampling.
- Application deadline
  - 90 days prior to date when construction begins.
- EPA has not developed a standard form for these discharges at this time (Form 2F is not required).

Application Requirements for Oil & Gas Operations and Mining Operations

- Operators of oil & gas facilities are not required to submit a permit application unless the facility:
  - Has had a discharge of a reportable quantity for which notice is required under CERCLA or CWA in the past 3 years, or
  - Contributes to a violation of a water quality standard.
- Operators of active and inactive mining sites are not required to submit permit applications unless the discharge has come into contact with any overburden, raw material, intermediate or finished products, byproducts, or waste products located onsite (inactive coal mining operations released from SMCRA performance bonds and non-coal mining operations released from applicable State or Federal reclamation requirements after December 17, 1990, are not required to submit permit applications).

Available Guidance

Guidance Manual For The Preparation of NPDES Permit Applications for Storm Water Discharges Associated with Industrial Activity (Order #PB92199058), available from NTIS, *(703) 487-4650*; *NPDES Storm Water Sampling Guidance Document*, available from the Storm Water Hotline, *(703) 821-4823*.

Deadline

October 1, 1992, or 180 days prior to commencement of a new discharge.

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ATTACHMENT II

GROUP APPLICATION REQUIREMENTS

Facilities that discharge storm water associated with industrial activity had until September 30, 1991, to file Part I of the group application in lieu of submitting a complete individual application or an NOI to be covered by a general permit. The Transportation Act of 1991, however, extended the group application deadlines for certain industrial activities owned or operated by a municipality with a population of less than 250,000. Facilities that are part of the same effluent guideline subcategory or with similar activities and operations were eligible to submit a group application. EPA received 1,243 Part I group applications coverings approximately 60,000 facilities.

The group application was submitted in two parts. Part 1 of the application was due by September 30, 1991, and Part 2 of the application was due by October 1, 1992. These deadlines applied to all industrial activities except those owned or operated by a municipality with a population of less than 250,000. For these facilities, Part 1 of the application was due by May 18, 1992, and Part 2 of the application is due by May 17, 1993. Both parts were submitted directly to U.S. EPA Headquarters, Office of Wastewater Enforcement and Compliance (EN-336), 401 M Street, SW, Washington, DC 20460, regardless of whether or not the included facilities are in a NPDES authorized State. The Transportation Act also addressed municipally owned or operated industrial activities that were denied by EPA from the group application process. Such facilities must submit an individual application or be covered by a general permit within 180 days after the denial was made, or by October 1, 1992, whichever is later.

EPA is currently taking both parts of the application and formulating model permit language. The complete applications and model permit language will then be distributed to every NPDES authorized State or EPA Region (if the State is not NPDES authorized) in which participants are located. The State then reviews the application and model permit language. The State may consider the application and model permit language when issuing permits (either individual or general). The State may ask each or any of the applicants for more information on their facility and/or discharge if the State needs additional information. EPA Regional Offices will follow these same steps for participants located in States without NPDES authorization.

Part 1

- A list of participants by name, location, and precipitation zone
- A summary of each participant's industrial activities
- An explanation of why the participants are sufficiently similar
- A list of significant materials stored outside by each participant and materials management practices
- A list of representative dischargers that will submit test data in Part 2.

Part 2

- Quantitative testing data must be submitted by those facilities identified as "samplers" in Part I of the application.

  For groups of 4 to 20 members, 50 percent of the facilities must submit data; for groups with 21 to 99, a minimum of 10 dischargers must submit quantitative data; for groups with 100 to 1,000 members, a minimum of 10 percent of the facilities must submit data; for groups with greater than 1,000 members, no more than 100 facilities must submit data; there must be 2 dischargers from each precipitation zone in which 10 or more members of the group are located, or 1 discharger from each precipitation zone in which 9 or fewer members are located. Testing requirements are described under 40 CFR 122.26(c)(1)(i)(E) and 40 CFR 122.21(g)(7).

Additional Information

A model group application accompanied by detailed information on how to complete both Part 1 and Part 2 group applications is available from the Storm Water Hotline, *(703) 821-4823*. Technical support with regard to sampling procedures is also available from the hotline *(NPDES Storm Water Sampling Guidance Document)*.

Deadlines

- All Industrial Activities Except Those Owned Or Operated By A Municipality With A Population Of Less Than 250,000

  Part 1 - September 30, 1991
  Part 2 - October 1, 1992

- Industrial Activities Owned or Operated By A Municipality With A Population Of Less Than 250,000

  Part 1 - May 18, 1992
  Part 2 - May 17, 1993

ATTACHMENT III

EPA GENERAL PERMIT REQUIREMENTS (GENERAL INFORMATION)

On September 9 and 25, 1992, EPA issued general permits for construction and industrial activities (57 FR 41176 and 44412) which are intended to initially cover the majority of storm water discharges associated with industrial activity in 12 States and 6 territories without authorized NPDES programs. As of March 1993, 35 of the 39 authorized NPDES States have authority to issue general permits. Facilities in authorized NPDES States should contact their State permitting agencies to determine the status of the general permitting program. The following tables (Attachments III, IV and V) outline conditions in EPA's general permits for industrial activities and construction activities.

Areas of Coverage

- Region I— MA, ME, NH; Indian lands in MA, NH, ME. Region II—PR and Indian lands in NY. Region III—DC, Federal facilities in DE. Region IV— FL; Indian lands in FL, MS, NC. Region VI—LA, NM, OK, TX. Region VII—SD; Indian lands in CO, MT, ND, SD, UT (except Goshute Reservation and Navajo Reservation lands), WY; Federal facilities in CO; Ute Mountain Reservation in CO, and NM. Region IX— American Samoa and Guam; AZ; Territories of Johnston Atoll, and Midway and Wake Island; Indian lands in CA, and NV; Goshute Reservations in UT and NV, Navajo Reservations in UT, NM, and AZ, Duck Valley Reservation in NV and ID. Region X—AK, and ID; Indian lands in AK, ID (except Duck Valley Reservation lands), and WA; Federal facilities in WA.

Types of Discharges Covered

- EPA's general permits cover the majority of storm water discharges associated with industrial activity. Storm water discharges associated with industrial activity that cannot be authorized by EPA's general permits include those:
  - With an existing effluent limitations guideline for storm water
  - That are mixed with non-storm water, unless the non-storm water discharges are in compliance with a different NPDES permit
  - With an existing NPDES individual or general permit for the storm water discharges
  - That are or may reasonably be expected to be contributing to a violation of a water quality standard
  - That are likely to adversely effect a listed or proposed to be listed endangered or threatened species or its critical habitat
  - From inactive mining, or inactive oil and gas operations or inactive landfills occurring on Federal lands where an operator cannot be identified (industrial permit only).

NOI Requirements

- A facility must submit a Notice of Intent (NOI) to be authorized by the general permit.
- NOI's do not require the collection of discharge sampling data.
- Facilities which discharge to a large or medium municipal separate storm sewer system must also submit signed copies of the NOI to the operator of the municipal system.
- Operators of construction activities must also submit signed copies of the NOI to State or local agencies approving sediment and erosion or storm water management plans under which the construction activity is operating.

Deadlines for NOI's

- On or before October 1, 1992 for existing industrial activities
- For facilities or construction activities which begin industrial activity after October 1, 1992, an NOI shall be submitted at least 2 days prior to the commencement of the industrial activity.
- NOI's must be sent to the following address:

  Storm Water Notice of Intent
  P.O. Box 1215
  Newington, VA 22122

Special Conditions

- Prohibition on most types of non-storm water discharges as a component of discharges authorized by this permit. (These discharges should already have an NPDES permit.) However, EPA's permits authorize certain types of non-storm water discharges.
- In the event there is a release(s) of a hazardous substance in excess of reportable quantities established under the CWA or CERCLA (see 40 CFR 117.3, 40 CFR 302.4) the discharger must:
  - Notify the National Response Center and the Director, and modify the storm water pollution prevention plan.

Pollution Prevention Plan Requirements

- Operators of all facilities covered by EPA's general permits must prepare and implement a storm water pollution prevention plan.

ATTACHMENT IV

EPA INDUSTRIAL GENERAL PERMIT (SPECIFIC REQUIREMENTS)

Contents of NOI for Industrial Activities

- Street address or latitude/longitude
- SIC Code or identification of industrial activity
- Operator's name, address, telephone number, and status as Federal, State, private, public, or other entity
- Permit number(s) of any existing NPDES permit(s)
- Name of receiving water(s)
- Indication of whether the owner or operator has existing quantitative data describing the concentration of pollutants in storm water discharges
- A certification that a storm water pollution prevention plan has been prepared for the facility (for industrial activities that begin operations after October 1, 1992).

Pollution Prevention Plan Requirements for Industrial Activities

The Pollution Prevention Plan is considered to be the most important requirement of the General Permit. Each industrial facility covered by the general permit must develop a Plan, tailored to the site specific conditions, and designed with the goal to control the amount of pollutants in storm water discharges from the site.

- **Pollution Prevention Team** - Each facility will select a Pollution Prevention Team from its staff, and the Team will be responsible for developing and implementing the Plan.
- **Components of the Plan** - The permit requires that the Plan contain a description of potential pollutant sources, and a description of the measures and controls to prevent or minimize pollution of storm water. The description of potential pollutant sources must include:
  - A map of the facility indicating the areas which drain to each storm water discharge point
  - An indication of the industrial activities which occur in each drainage area
  - A prediction of the pollutants which are likely to be present in the storm water
  - A description the likely source of pollutants from the site
  - An inventory of the materials which may be exposed to storm water
  - The history of spills or leaks of toxic or hazardous materials for the past 3 years.

  The measures and controls to prevent or minimize pollution of storm water must include:

  - Good housekeeping or upkeep of industrial areas exposed to storm water
  - Preventive maintenance of storm water controls and other facility equipment
  - Spill prevention and response procedures to minimize the potential for and the impact of spills
  - Test all outfalls to insure there are no cross connections (only storm water is discharged)

  - Training of employees on pollution prevention measures and controls, and record keeping.

  The permit also requires that facilities:

  - Identify areas with a high potential for erosion and the stabilization measures or structural controls to be used to limit erosion in these areas
  - Implement traditional storm water management measures (oil/water separators, vegetative swales, detention ponds, etc) where they are appropriate for the site.

- **Inspection/Site Compliance Evaluation** - Facility personnel must inspect the plant equipment and industrial areas on a regular basis. At least once every year a more thorough site compliance evaluation must be performed by facility personnel
  - Look for evidence of pollutants entering the drainage system
  - Evaluate the performance of pollution prevention measures
  - Identify areas where the Plan should be revised to reduce the discharge of pollutants
  - Document both the routine inspections and the annual site compliance evaluation in a report.
- **Consistency** - The Plan can incorporate other plans which a facility may have already prepared for other permits including Spill Prevention Control and Countermeasure (SPCC) Plans, or Best Management Practices (BMP) Programs.
- **Deadlines** - The plan must be prepared on or before April 1, 1993, and the facility must be in compliance with the plan on or before October 1, 1993.
- **Signature** - The plan must be signed by a responsible corporate official such as the president, vice president or general partner.
- **Plan Review** - The plan is to be kept at the permitted facility at all times. The plan should be submitted for review only when requested by EPA.

Semi-Annual Monitoring/Annual Reporting Requirements

- EPCRA Section 313 facilities
- Primary metal industries Standard Industrial Classification (SIC) 33
- Land disposal units/incinerators/BIF's
- Wood treatment facilities
- Facilities with coal pile runoff
- Battery reclaimers

Annual Monitoring/No Reporting Requirements

- Airports with at least 50,000 flight operations per year
- Coal-fired steam electric facilities
- Animal handling/meat packing facilities

- Additional facilities, including:
  - SIC 30 and 28 with storage piles for solid chemicals used as raw materials that are exposed to precipitation
  - Certain automobile junkyards
  - Lime manufacturing facilities where storm water comes into contact with lime storage piles
  - Oil handling sites at oil fired steam electric power generating facilities
  - Cement manufacturing and cement kilns
  - Ready-mix concrete facilities
  - Shipbuilding and repairing facilities

Additional Monitoring Requirements

- Testing parameters for facilities are listed in the general permits.
- At a minimum, all dischargers must conduct an annual site inspection of the facility.

Alternative Certification

- A discharger is not subject to the monitoring requirements for a given outfall if there is no exposure of industrial areas or activities to storm water within the drainage area of that outfall within a given year.
- The discharger must certify, on an annual basis, that there is no exposure to storm water, and such certification must be retained in the storm water pollution prevention plan. Facilities subject to semi-annual monitoring requirements must submit this certification to EPA in lieu of monitoring data.

Numeric Effluent Limitations

- Coal pile runoff: 50 mg/l Total Suspended Solids (TSS) and 6-9 pH

Available Guidance

Storm Water Management for Industrial Activities, Developing Pollution Prevention Plans and Best Management Practices, available from NTIS (703) 487-4650, order number PB 92-235969; *Summary: Storm Water Management for Industrial Activities, Developing Pollution Prevention Plans and Best Management Practices* (October 1992), available from the Storm Water Hotline, (703) 821-4823.

ATTACHMENT V

EPA CONSTRUCTION GENERAL PERMIT REQUIREMENTS (SPECIFIC REQUIREMENTS)

Coverage

- Storm water discharges from construction sites that are authorized by this permit include those that will result in the disturbance of 5 or more acres of land.

Contents of NOI for Construction Activities

- Street address or latitude/longitude
- The name, address, telephone number of the operator(s) with day to day operational control and operator status as Federal, State, private, public, or other entity
- Permit number(s) of any existing NPDES permit(s)
- Name of receiving water(s)
- Indication of whether the owner or operator has existing quantitative data describing the concentration of pollutants in storm water discharges
- An estimate of the project start date and completion dates and estimates of the number of disturbed acres
- A certification that a storm water pollution prevention plan has been prepared for the facility

Deadlines for Notification

- An NOI shall be submitted at least 2 days prior to the commencement of construction (commencement of construction is defined as the initial disturbance of soils associated with clearing, grading, or excavating activities or other construction activities) at any site that will result in the disturbance of 5 or more acres total land area.

Pollution Prevention Plan Requirements for Construction Activities

The Pollution Prevention Plan is considered to be the most important requirement of the General Permit. Each construction activity covered by the general permit must develop a Plan, tailored to the site specific conditions, and designed with the goal to control the amount of pollutants in storm water discharges from the site.

- **Components of the Plan** - The permit requires that the Plan contain a site description, and a description of the measures and controls to prevent or minimize pollution of storm water. The site description must include:
  - A description of the nature of the construction activity
  - A sequence of major construction activities
  - An estimate of the total area of the site and of the area to be disturbed
  - An estimate of the runoff coefficient of the site after construction is complete
  - Any existing data on the quality of storm water discharge from the site
  - The name of the receiving water
  - Any information on the type of soils at the site; and
  - A site map indicating drainage patterns and slopes after grading activities are complete, areas of soil disturbance, the outline of the area to be disturbed, the location of stabilization measures and controls, and surface waters at the discharge points.

- **Measures and Controls** - Measures and controls to prevent or minimize pollution of storm water must include three different types of controls: erosion and sediment controls, storm water management controls and other controls:

  - Erosion and Sediment Controls

    - Stabilization (seeding, mulching, etc.) - Disturbed areas where construction has permanently or temporarily ceased must be stabilized within 14 days of the last disturbance or as soon as practicable in semi-arid and arid areas. (Areas which will be redisturbed within 21 days do not have to be stabilized).

    - Structural Controls - Sites with common drainage locations that serve 10 or more disturbed acres must install a sediment basin where it is attainable (where a basin is not attainable, sediment traps, silt fence or other equivalent measures must be installed. Sediment basins must provide 3,600 cubic feet of storage per acre drained. Drainage locations which serve less than 10 disturbed acres must install either a sediment basin, sediment trap or silt fence along the down slope and side slope perimeter.

- Plan shall be completed prior to submittal of an NOI and updated as appropriate.

- For construction activities that have begun after October 1, 1992, the plan shall provide for compliance with the terms and schedule of the plan beginning with the initiation of construction activities.

Available Guidance

Storm Water Management for Construction Activities, Developing Pollution Prevention Plans and Best Management Practices, available from NTIS (703) 487-4650, order number PB 92-235951; *Summary: Storm Water Management for Construction Activities, Developing Pollution Prevention Plans and Best Management Practices* (October 1992), available from the Storm Water Hotline (703) 821-4823.

ATTACHMENT VI

MUNICIPAL APPLICATION REQUIREMENTS

The CWA requires that NPDES permits for discharges from municipal separate storm sewer systems include a requirement to effectively prohibit non-storm water discharges into the storm sewers, and controls to reduce the discharge of pollutants to the maximum extent practicable (including management practices, control techniques and system design and engineering methods, and other provisions appropriate for the control of such pollutants). EPA or authorized NPDES States may issue system-wide or jurisdiction-wide permits covering all discharges from a municipal separate storm sewer system. The November 1990 storm water final rule established requirements for a two-part permit application designed to facilitate development of site specific permit conditions. The permit application requirements provide municipal applicants an opportunity to propose appropriate management programs to control pollutants in discharges from their municipal systems. This increases flexibility to develop appropriate permit conditions and ensures input from municipalities in developing appropriate controls.

Part 1

- General information (name, address, etc.)
- Existing legal authority and any additional authorities needed
- Source identification information
- Discharge characterization including:
  - Monthly mean rain and snow fall estimates
  - Existing quantitative data on volume and quality of storm water discharges
  - A list of receiving water bodies and existing information on the impacts of receiving waters
  - Field screening analysis for illicit connections and illegal dumping.
- Characterization plan identifying representative outfalls for further sampling in Part 2
- Description of existing management programs to control pollutants from the municipal separate storm sewer and to identify illicit connections
- Description of financial budget and resources currently available to complete Part 2.

Part 2

- Demonstration of adequate legal authority to control discharges, prohibit illicit discharges, require compliance, and carry out inspections, surveillance, and monitoring
- Source identification indicating the location of any major outfalls and identifying facilities that discharge storm water associated with industrial activity through the municipal separate storm sewer
- Discharge characterization data including
  - Quantitative data from 5-10 representative locations in approved sampling plans
  - For selected conventional pollutants and heavy metals, estimates of the annual pollutant load and event mean concentration of system discharges

- Proposed schedule to provide estimates of seasonal pollutant loads and the mean concentration for certain detected constituents in a representative storm event
- Proposed monitoring program for representative data collection.

▲ Proposed management program including descriptions of:

- Structural and source control measures that are to be implemented to reduce pollutants in runoff from commercial and residential areas
- Program to detect and remove illicit discharges
- Program to monitor and control pollutants from municipal landfills, hazardous waste treatment, disposal, and recovery facilities; EPCRA Section 313 facilities; and other priority industrial facilities
- Program to control pollutants in construction site runoff.

▲ Estimated reduction in loadings of pollutants as a result of the management program

▲ Fiscal analysis of necessary capital and operation and maintenance expenditures.

Available Guidance

Guidance Manual for the Preparation of Part 1 of the NPDES Permit Application for Discharges from Municipal Separate Storm Sewer Systems and *NPDES Storm Water Sampling Guidance Document*, available from NTIS *(703) 487-4650*, order number PB 92-114578; *Guidance Manual for the Preparation of Part 2 of the NPDES Permit Applications for Discharges from Municipal Seperate Storm Sewers Systems*, available from the Storm Water Hotline, (703) 821-4823.

Deadlines

▲ Large Municipal Systems With A Population Of 250,000 Or More:

(55 FR 48073, Novemer 16, 1990, Appendices F and H)

Part 1 - November 18, 1991
Part 2 - November 16, 1992

▲ Medium Municipal Systems With A Population of 100,000 to 250,000:

(55 FR 48074, November 16, 1990 Appendices G and I)

Part 1 - May 18, 1992
Part 2 - May 17, 1993

ATTACHMENT VII

STORM WATER DISCHARGE ASSOCIATED WITH INDUSTRIAL ACTIVITY

The discharge from any conveyance which is used for collecting and conveying storm water and which is directly related to manufacturing, processing or raw materials storage areas at an industrial plant. The term does not include discharges from facilities or activities excluded from the NPDES program under 40 CFR Part 122. For the categories of industries identified in subparagraphs (i) through (x) of this subsection, the term includes, but is not limited to, storm water discharges from industrial plant yards; immediate access roads and rail lines used or traveled by carriers of raw materials, manufactured products, waste material, or by-products used or created by the facility; material handling sites; refuse sites; sites used for the application or disposal of process waste waters (as defined at 40 CFR 401); sites used for the storage and maintenance of material handling equipment; sites used for residual treatment, storage, or disposal; shipping and receiving areas; manufacturing buildings; storage areas (including tank farms) for raw materials, and intermediate and finished products; and areas where industrial activity has taken place in the past and significant materials remain and are exposed to storm water. For the categories of industries identified in subparagraph (xi), the term includes only storm water discharges from all the areas (except access roads and rail lines) that are listed in the previous sentence where material handling equipment or activities, raw materials, intermediate products, final products, waste material, by-products, or industrial machinery are exposed to storm water. For the purposes of this paragraph, material handling activities include the: storage, loading and unloading, transportation, or conveyance of any raw material, intermediate product, finished product, by-product or waste product. The term excludes areas located on plant lands separate from the plant's industrial activities, such as office buildings and accompanying parking lots as long as the drainage from the excluded areas is not mixed with storm water drained from the above described areas. Industrial facilities (including industrial facilities that are Federally, State, or municipally owned or operated that meet the description of the facilities listed in this paragraph (i)-(xi) include those facilities designated under the provision of 122.26(a)(1)(v). The following categories of facilities are considered to be engaging in "industrial activity" for purposes of this subsection:

(i) Facilities subject to storm water effluent limitations guidelines, new source performance standards, or toxic pollutant effluent standards under 40 CFR Subchapter N (except facilities with toxic pollutant effluent standards which are excepted under category (xi) of this paragraph);
(ii) Facilities classified as Standard Industrial Classifications 24 (except 2434), 26 (except 265 and 267), 28 (except 283 and 285) 29, 311, 32 (except 323), 33, 3441, 372;
(iii) Facilities classified as Standard Industrial Classifications 10 though 14 (mineral industry) including active or inactive mining operations (except for areas of coal mining operations no longer meeting the definition of a reclamation area under 40 CFR 434.11(l) because the performance bond issued to the facility by the appropriate SMCRA authority has been released, or except for areas of non-coal mining operations which have been released from applicable State or Federal reclamation requirements after December 17, 1990 and oil and gas exploration, production, processing, or treatment operations, or transmission facilities that discharge storm water contaminated by contact with or that has come into contact with, any overburden, raw material, intermediate products, finished products, byproducts or waste products located on the site of such operations; (inactive mining operations are mining sites that are not being actively mined, but which have an identifiable owner/operator; inactive mining sites do not include sites where mining claims are being maintained prior to disturbances associated with the extraction, beneficiation, or processing of mined materials, nor sites where minimal activities are undertaken for the sole purpose of maintaining mining claim);
(iv) Hazardous waste treatment, storage, or disposal facilities, including those that are operating under interim status or a permit under Subtitle C of RCRA;
(v) Landfills, land application sites, and open dumps that receive or have received any industrial wastes (waste that is received from any of the facilities described under this subsection) including those that are subject to regulation under Subtitle D of RCRA;

(vi) Facilities involved in the recycling of materials, including metal scrapyards, battery reclaimers, salvage yards, and automobiles junkyards, including but limited to those classified as Standard Industrial Classification 5015 and 5093;
(vii) Steam electric power generating facilities, including coal handling sites;
(viii) Transportation facilities classified as Standard Industrial Classifications 40, 41, 42 (except 4221-25), 43, 44, 45, and 5171 which have vehicle maintenance shops, equipment cleaning operations, or airport deicing operations. Only those portions of the facility that are either involved in vehicle maintenance (including vehicle rehabilitation, mechanical repairs, painting, fueling, and lubrication), equipment cleaning operations, airport deicing operations, or which are otherwise identified under paragraphs (i)-(vii) or (ix)-(xi) of this subsection are associated with industrial activity;
(ix) Treatment works treating domestic sewage or any other sewage sludge or wastewater treatment device or system, used in the storage treatment, recycling, and reclamation of municipal or domestic sewage, including land dedicated to the disposal of sewage sludge that are located within the confines of the facility, with a design flow of 1.0 mgd or more, or required to have an approved pretreatment program under 40 CFR 403. Not included are farm lands, domestic gardens or lands used for sludge management where sludge is beneficially reused and which are not physically located in the confines of the facility, or areas that are in compliance with Section 405 of the CWA;
(x) Construction activity including clearing, grading and excavation activities except: operations that result in the disturbance of less than five acres of total land area which are not part of a larger common plan of development or sale;
(xi) Facilities under Standard Industrial Classification 20, 21, 22, 23, 2434, 25, 265, 267, 27, 283, 285, 30, 31 (except 311), 323, 34 (except 3441), 35, 36, 37 (except 373), 38, 39, 4221-25, (and which are not otherwise included within categories (ii)-(x))

Note: The Transportation Act of 1991 provides an exemption from storm water permitting requirements for certain facilities owned or operated by municipalities with a population of less than 100,000. Such municipalities must submit storm water discharge permit applications for only airports, power plants, and uncontrolled sanitary landfills that they own or operate, unless a permit is otherwise required by the permitting authority.

APPENDIX B
GLOSSARY

Basin Development Factor (BDF): An index of the prevalence of discharge elements such as storm sewers and channel improvements, used in the U.S. Geological Survey flood frequency equations.

Best Management Practices (BMPs): Measures, either structural or non-structural, for controlling stormwater or nonpoint source pollution.

Continuous Simulation Model: Model based on long-term water balance equations.

Design Storm: A storm of a specific duration and frequency of occurrence that is selected for sizing a hydraulic structure such as a culvert, a drain pipe, or an emergency spillway.

Detention Ponds: Depressed areas that detain stormwater runoff for flood control and, in some cases, water quality control purposes.

Distributed Parameter Model: A model that attempts to describe physical processes of rainfall-runoff mechanisms in space and time.

Dry Detention Pond: A detention pond that stores stormwater runoff during wet weather and remains dry between storms.

Dry Well: An open-bottomed structure that is used for disposal of stormwater into the soil column.

Floodplain: The alluvial land on either side of a stream that is subject to inundation by floods.

Hyetograph: A graph of rainfall intensity versus time.

Hydrograph: A graph of runoff rate versus time.

Infiltration Basin: An infiltration facility which looks like a dry pond and is designed to detain stormwater and infiltrate it through the bottom of the basin.

Infiltration Trench: An infiltration facility where a trench is excavated and then filled with a stone aggragate. Stormwater is stored in the voids of the fill material until it is infiltrated.

Level Spreader: A small concrete or vegetated trench that is situated on the contour and is used to distribute stormwater runoff evenly onto a vegetative filter strip.

Lumped Parameter Model: A model that aggragates spatially distributed parameters in the rainfall-runoff process.

Model Calibration: Process of parameter estimation using given data.

Porous Pavement: An infiltration practice in which a stone reservoir is placed under a layer of porous asphalt concrete that allows water to infiltrate into the stone reservoir.

Retention Ponds: Ponds designed to store stormwater runoff for an indefinite period of time. Water is allowed to evaporate and/ or to infiltrate into the soil column.

Stormwater Management: Activities dealing with the control of stormwater quantity as well as quality; activities of both technological and institutional nature.

Swale: A roadside or median stormwater conveyance channel that is used to transport runoff.

Synthetic Unit Hydrograph: Unit hydrograph for ungauged basins based on theoretical or empirical methods.

Unit Hydrograph: A graph of runoff versus time produced by a unit excess rainfall over a given duration.

Vegetative Filter Strip: A vegetated (usually grass) area that is designed to accept stormwater sheet flow.

Wet Detention Pond: A detention pond in which a permanent pool is maintained by placing the outlet structure at a prescribed elevation above the bottom of the pond.

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