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Control of Urban Stormwater Runoff by Detention and Retention

ABSTRACT

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Recognizing that stormwater management is still in its infancy, there is a need to examine the current state-of-the-art. A coordinated summary of the literature is used as the basis for identifying a sampling of the literature pertinent to stormwater runoff legislation, policy, design, and management. Additionally, special concerns in urban stormwater runoff control are discussed, and a historic overview of detention and retention is given. Specific summaries are provided for water-quality performance of detention and retention facilities based on field, laboratory, and computer modeling studies. Guidelines for planning and designing water-quality features of these facilities and their operation and maintenance aspects are included.

KEYWORDS: Detention, drainage, erosion, flood, hydrology, runoff, sediment, stormwater, urban hydrology, water management, water quality.

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by Richard H. McCuen, Stuart G. Walesh, and
Walter J. Rawls[1]

INTRODUCTION

During the 1960's, professional journals contained numerous technical reports on the hydrologic effects of urbanization. Many of them showed the increase in peak discharges and volumes, as well as the effect on unit hydrograph characteristics, that resulted as both the percent imperviousness and the degree of channelization increased and the flood plains were encroached upon. Recognizing that urbanization had detrimental flooding impacts, hydrologists in the 1970's turned their attention toward reducing the amount of increase and managing the increased stormwater runoff. As part of the environmental movement of the late 1960's and early 1970's, the effect of urbanization on water quality received much attention in the professional literature. Thus, during the 1970's, numerous articles appeared on the planning, management, and design of stormwater control methods and the management of both stormwater quantity and quality. During that decade, some State and local governments developed policies aimed at providing order to the elements involved in controlling stormwater runoff. The stormwater runoff process, which includes legislation, policy, planning, design, and management, will continue to evolve during the 1980's.

Since urbanization has an impact on water quantity and quality characteristics, it may be of interest to examine, at least superficially, the urbanization process and the intent of stormwater management practices. Watershed development includes a change in land use that often entails removing natural vegetation or covering topsoil, grading the surface, and covering part of the watershed with impervious material. The loss of natural vegetation represents a loss of interception storage that exists with natural vegetation. Grading reduces both infiltration and depression storage. Similarly, the depression storage on impervious surfaces is less than on pervious land uses, and covering a watershed with

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impervious materials will obviously eliminate infiltration in these areas. The losses of natural storage, that is, interception, subsurface, and depression, result in increased peak discharge rates and runoff volumes that are apparent in urbanized watersheds. The transition from a natural to an urbanized state is an especially troublesome period. It is often characterized by runoff, which is especially high in pollutant loadings. Even after the land has been stabilized, urban areas are known to have higher pollutant loadings than most natural land uses, resulting from activities characteristic of urban watersheds. As urbanization increases, the change in time characteristics of runoff is partly responsible for increased flooding problems.

In order to mitigate the detrimental effects as a watershed is developed, State and local governments have proposed and adopted several stormwater control alternatives. Although these measures may differ in content, the underlying intent should be to offset the effects of urbanization on the hydrologic cycle. Specifically, the stormwater management measures should be designed to minimize hydrologic effects, to replace the natural storage that is lost because of urban development, and to neutralize the effects of changes in time characteristics. For most parcels of land, stormwater control methods, if properly designed and managed, should be able to eliminate the detrimental effects of urbanization.

During the 1970's, detention and retention (D/R) facilities became popular as major elements in urban stormwater control systems. The original motivation for this evolving use of storage-oriented facilities seems to have been cost savings, which are sometimes achieved relative to the traditional conveyance-oriented systems. An apparent second motivation for the growing use of D/R facilities has been their aesthetic, recreational, and other values.

Because of growing concern with control of nonpoint source pollution in unsewered or separately sewered areas, a potential third reason for considering utilization of D/R facilities has been the enhancement of the quality of urban stormwater runoff. However, relatively little experience in planning, design, operation, and maintenance is available, and what is available, along with the research and development studies, is scattered about in varying institutions and the literature.

Report Objectives

Because of the diverse journals in which technical reports have been published and the varied technical backgrounds of those interested in stormwater management, a state-of-the-art analysis and a literature summary should be of interest to all involved in stormwater management, including hydrologists, engineers, and planners, as well as legislators and managers. Such a summary should provide a convenient source for identifying a sampling of the literature pertinent to the specific aspect of stormwater management that is of interest to the individual.

This report provides abstracts of some articles on stormwater management that have appeared in professional publications. In addition to the state-of-the-art analysis, special concerns in stormwater runoff control are discussed. Following a historic overview of detention and retention control, some ideas, information, and data reported in the literature are cited and summarized in the following categories: Water-quality performance of D/R facilities based on field, laboratory, and computer modeling studies and guidelines for planning and designing water-quality features of these facilities and their operation and maintenance.

Table 1 lists authors of selected references abstracted in Appendix B and identified according to selected keywords. Other references on stormwater management, which were not abstracted, are included in Appendix A and in References Cited.

Terminology

Because urban and suburban development most often increase the potential for damage from storm runoff, the term "stormwater management" has evolved to identify techniques that attempt to limit the potential damage. Several management techniques have been used to mitigate the hydrologic effects of increased development, with both structural and nonstructural methods currently being used. Structural techniques are construction related, whereas nonstructural include legal and administrative procedures. A structure that creates a reservoir is the most popular method of controlling runoff. Several terms have been applied to these structures, including detention basins, retention storage, onsite ponds, and stormwater management basins. Detention implies a relatively short period for detaining stormwater runoff and retention a longer period, but it is not always clear how they differ. Onsite ponding refers to storage methods that control runoff on the site where it is generated, and it can be applied to both detention and retention storage. Stormwater management basin, which is a more general term, can refer to both surface and subsurface storage. It is frequently used in the literature because it avoids the ambiguities of the other terms; also, results of reports in which the other terms are used are applicable to all types of structural storage, including rooftop and parking lot storage.

Table 1.--Authors of selected references that are abstracted in Appendix B and identified here by keywords

Abstract No.	Authors	Water quality	Economics	Policy	Design	Planning	Management	Sediment	Data collection	Coastal areas	Modeling	Case study	Urban land use	Agricultural land use	Nonstructural management	Sewer systems	Porous pavement
1.	Alley	X							X	X	X	X	X				
2.	Baker				X		X				X		X				
3.	Bedient and Amandes	X	X		X		X		X		X	X	X				
4.	Bedient, Harned, and Characklis	X				X	X		X		X	X	X				
5.	Bouthillier and Peterson				X	X		X			X				X		
6.	Brandt, Conyers, Ettinger, et al.		X				X	X			X	X	X				
7.	Butler and Maher	X	X	X		X	X						X		X		
8.	Calabrese	X	X			X	X			X	X	X	X		X	X	
9.	Cordero				X	X	X	X				X	X				
10.	Curtis and McCuen			X	X	X	X	X			X		X				
11.	Davis, McCuen, and Kamedulski	X		X			X	X			X	X	X	X			
12.	Day and Ho	X							X	X		X		X			
13.	Dendion, Delleur, and Talavage		X			X	X				X	X	X			X	
14.	Diniz (1979)	X				X					X						
15.	Diniz (1980)	X			X						X		X				X
16.	Freund and Johnson	X					X	X	X		X	X	X			X	
17.	Gburek and Urban	X			X				X		X	X	X				X
18.	Grigg, Botham, Rice, et al.		X	X		X							X		X		
19.	Grigg, Duda, and Morris	X		X		X	X			X		X	X		X		
20.	Guy	X	X	X	X	X	X	X					X			X	
21.	Hawkins, Meloy, and Pavon	X		X											X		
22.	Henry and Ahern		X		X	X	X		X		X					X	
23.	Jackson and Ragan				X								X				X
24.	Kamedulski and McCuen (1978)			X			X	X	X		X	X	X				
25.	Kamedulski and McCuen (1979)			X	X						X		X				
26.	Krishnamurthi and Balzer	X		X	X			X									
27.	Krishnamurthi and Lenocker					X				X	X		X				
28.	Lai				X					X	X	X	X			X	
29.	Lakatos and Wiswell					X					X	X	X			X	
30.	Lockwood				X						X		X		X	X	
31.	Looper			X	X				X	X	X	X	X			X	
32.	McCuen (1979a)			X		X		X	X		X	X	X				
33.	McCuen (1979b)			X	X			X			X		X				
34.	McCuen (1980)	X					X	X	X		X	X	X				
35.	Manz			X		X	X			X	X	X	X		X		
36.	Mariles, Bribiesca, and Mora		X		X	X					X		X			X	
37.	Mattraw, Hardee, and Miller	X							X		X	X	X			X	
38.	Moodie, Scholes, and Thompson	X				X		X	X			X	X				
39.	Myers and Ho					X			X	X	X	X					
40.	Nawrocki and Pietrzak		X	X				X					X				
41.	Novitski (1977)	X		X				X		X		X					
42.	Novitski (1978)	X		X				X		X		X					
43.	Patrick	X				X	X	X		X		X		X			
44.	Pennel					X	X			X			X				
45.	Peterson, Bubenzer, and Madison	X				X	X	X		X		X		X	X		
46.	Pitt	X	X					X	X				X		X	X	
47.	Ports				X			X					X		X		
48.	Putt and Johnson				X		X				X		X				
49.	Reuter and Fox	X	X	X											X		
50.	Schluchter and Teubner					X				X	X	X					
51.	Simons, Li, and Ward	X			X	X		X			X		X				
52.	Slyfield					X				X	X		X				
53.	Smolenyak	X				X		X		X	X	X	X	X			
54.	Ward, Haan, and Barfield				X			X			X		X	X			
55.	Weber and Wilson	X			X			X	X								
56.	Widseth		X		X							X	X	X		X	
57.	Willison et al.	X	X	X				X							X		
58.	Woodward, Welle, and Moody				X				X	X	X	X		X			
59.	Wu and Ahlert	X				X		X		X	X	X	X				
60.	Wycoff		X		X	X					X		X			X	
61.	Wycoff, Scholl, and Kissoon	X	X	X					X				X				
62.	Wycoff and Singh				X	X			X		X		X				

Settling efficiency, trap efficiency, and similar words have varied, with inconsistent meanings and interpretations in erosion-sedimentation literature. According to Malcolm and New (*1975*),[2] settling efficiency is "the fraction of particles of a certain size that will be trapped in the basin under design conditions at peak outflow." Trap efficiency is "the fraction of material removed from all runoff passing through the reservoir during its life." The definition of trap efficiency, as used in this report, is based on all runoff passing through the reservoir during a period of time. Trap efficiency is expected to markedly exceed settling efficiency for the design conditions because most runoff events will be less severe than the design event.

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[2] The year in italic after authors' names refers to References Cited, p. 35.

Because of regional variation in hydrologic problems, various laws and policies have evolved during the 1970's, the decade of the infancy of small-scale stormwater management. These have produced a wide variety of design methods. The lack of consistency in applying design methods has led many, especially the nonengineer, to question the value of stormwater management on small watersheds. This doubt was further intensified by some ambiguous research results, with some studies suggesting that stormwater management may actually create problems (McCuen, 1979; Malcolm, 1980). Thus, the area of design methods is a topic of special interest, especially as it relates to comparing the different available design methods.

In spite of the questions concerning the value of stormwater management, its use has increased exponentially because, in part, studies have almost without exception suggested that it has economic benefits. Case studies have shown that downstream flood damage may be reduced. Added benefits result because lower peak discharges mean smaller conveyance systems are required. Benefits that are not easily translated into economic terms include positive environmental impacts. In many instances, the economic factors are influential in decisions concerning stormwater management legislation. For this reason, it may be useful to examine the literature that specifically addresses the economic impacts of stormwater management.

In recent years, developmental pressures have been very great in coastal areas. Thus, there is now a special interest in examining the value of stormwater management in these areas. Because of the low slopes and high water tables in coastal areas, there is considerable concern that traditional structural methods of control may not be applicable. Thus, coastal area stormwater management will receive considerable attention in the 1980's, and a review of existing literature is especially necessary.

Design methods, economics, and coastal area analysis are of special concern to those involved in formulating both legislation and policies. Therefore, they are examined here in more detail.

Design for Controlling Flow Rates

Cordero (9)[3] described a simplified method for estimating the volume of storage and release rate from a detention structure, both of which are functions of the drainage area. Such methods, though easy to apply, reflected the state-of-the-art in both stormwater design and policy at that time. However, as policies improved, the design methods became more complex in both the

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[3] Numbers in parentheses refer to abstracts in Appendix B.

conceptual development and the application. Bouthillier and Peterson (5) reported on a method of computing storage requirements by using a graphic relationship of the ratio of the maximum allowable outlet rate to the maximum inflow rate versus the ratio of the required reservoir volume to the total inflow volume.

As suggested previously, the storage in detention and retention basins is intended to offset the natural storage that has been lost because of development. Therefore, the next generation of design methods included hydrograph analysis. Wycoff and Singh (62) described a technique that was typical of the simple hydrograph model. It reflects the effect of land-use changes on both the time and flow rate characteristics of the hydrograph. This generation of design and planning methods did not require routing, which for some design problems may be considered as a limitation.

Baker (2) reported on a method in which the rate of outflow is dependent on the depth of impounded water; thus, a linear routing equation is used to route the flow through the detention basin. In the solution procedure, an attempt is made to increase the accuracy of estimates by means of an iterative method, in which rainfall of various durations is used to determine the critical rainfall duration that requires the largest storage volume.

In the design of a detention and retention basin, the discharge rate is dependent on the inflow, the outlet structure configuration, and the basin storage characteristics, all of which in turn are dependent on the discharge rate. Thus, an iterative procedure that allows for this interdependent relationship should improve the accuracy of estimates for the required volume of storage and the flow rate. Bondelid and McCuen (1979) described a method that is representative of the latest generation of design methods. It has the added features of allowing for multistage riser designs and of being computerized.

Although everyone is concerned with the accuracy of prediction, it is difficult to assess the accuracy of any technique because an adequate data base for comparison does not exist. Thus, it is only possible to compare the various design and planning methods using synthetic data. Donahue et al. (1981) compared various levels of design and planning models, with the results indicating a very noticeable range of proposed storage volumes and release rates. Thus, in order to provide consistent estimates, it may be prudent to select one method for all designs in a region. This policy would result in consistent estimates and eliminate institutional conflicts that arise from overly flexible policies. It must be recognized, however, that the true design cannot be known and that, if the method selected is inherently biased in concept, then all designs will produce inaccurate answers. The latest generation of models is probably sufficiently accurate so that in the trade-off between design accuracy and consistency of estimation, it would be best to identify in stormwater management policy statements a single procedure to be used for the design of stormwater management basins.

Economics of Stormwater Management

Some early studies demonstrated that detention and retention basins could provide economic benefits, such as reduced cost for downstream conveyance systems (Leach and Kittle, 1966). Guy (20) indicated that stormwater management, especially when well coordinated with natural drainage, may result in lower initial costs of storm drainage systems; however, he pointed out that the cost of maintenance may increase. Reuter and Fox (49) provided a methodology for evaluating the economic costs of nonstructural pollution-control techniques; nonstructural alternatives should increase the effectiveness of structural pollution controls while reducing the costs of achieving environmental quality objectives.

When a comprehensive methodology has not been developed to assess the economic benefits and costs of a storm drainage system that includes one or more stormwater management techniques, it is difficult to generalize about costs. Several studies have provided economic comparisons of stormwater management alternatives; such comparisons may provide some help in evaluating the economic impact of stormwater management alternatives. Henry and Ahern (22) calibrated formulas for estimating sewer pipe costs. The results indicated that sewer system costs for subdivisions were reduced when storage was incorporated. Rawls and McCuen (1978) also provided regression equations for estimating the cost of storm sewer systems, which were calibrated from actual projects throughout the United States. They also provided a simple relationship between detention basin cost and project drainage area that was based on 34 stormwater detention projects in the Washington, D.C., area. Bedient and Amandes (3) compared costs of a variety of management alternatives to evaluate their relative effectiveness. Calabrese (8) developed cost-effectiveness data on various management practices and used the method for establishing the least-cost combination of management practices for a case study in Florida.

Brandt et al. (6) made a comprehensive cost study on the Seneca Creek watershed near Washington, D.C. In this study, costs were compared to effectiveness for many erosion and sediment control systems. Drainage costs in streams were also assessed.

The results indicated that sediment damages from uncontrolled erosion on urban construction sites could each potentially cost $1,500 per acre ($607 per ha).

Butler and Maher (7) also examined the economic impacts for downstream sites. They concluded that the external costs of upstream development require that both flooding and water-quality aspects of stormwater runoff be managed basinwide. Site-by-site action will probably not provide adequate control at a reasonable cost.

Grigg et al. (18) provided the most comprehensive analysis of the impacts of urban drainage and flood control projects. The measurement of tangible benefits is described; however, they concluded that a direct objective technique for quantifying intangibles was not available. They provided guidelines for selecting the proper discount rate and for estimating flood damage.

Stormwater Management in Coastal Areas

As indicated earlier, developmental pressures are currently greater in coastal areas than in most other areas. Because of both environmental and economic reasons, government is especially concerned about the hydrologic impact of development. Unfortunately, very few publications provide conclusions that can be transferred to other areas. Also, most studies concentrate on the problems created by development but fail to show conclusively that an intensive stormwater management program will eliminate the problems.

Day and Ho (12) conducted research to determine whether natural wetlands in south Louisiana can remove nutrients from agricultural runoff. Grigg et al. (19) assessed the magnitude of the stormwater runoff and flooding problem in the North Carolina coastal zone, described the existing management programs, and made recommendations for improving stormwater management programs. In another study, Patrick (43) examined water-quality problems in Louisiana's coastal zone that might be handled using management techniques. Flooding problems in coastal areas are compounded by tidal surges. Myers and Ho (39) examined an approach to tide frequency assessment, using the Delmarva coast as an example.

A gradual evolution has occurred in the state-of-the-art of stormwater management and in actual practices (Poertner, 1974). It is briefly described here to demonstrate that it is time to consider using D/R for enhancing the quality of stormwater runoff in urban and urbanizing areas.

Impact of Urbanization: Water Quantity and Quality

Urbanization usually increases the volume of stormwater runoff while decreasing the runoff time. The net effect of these two processes usually is a marked increase in peak runoff rates and stages. Although such natural factors as land slope and the underlying soil type are important in determining the hydrologic-hydraulic response, land use superimposed on that soil by man's activities will markedly alter the response.

In addition to increasing the quantity of runoff, often with adverse consequences, urbanization can also increase the variety and amount of potential water pollutants washed from the land surface and eventually into the receiving waters. This is the result of two factors that tend to have an additive effect. First, urbanization increases the variety and availability of potential water pollutants. Examples include soil and other materials that are loosened and exposed as a result of demolition and construction, the introduction of human litter, residue of careless material storage and handling, and street deicing materials and sand. Second, as urbanization increases the volume and rate of stormwater runoff, it provides a more effective means of transporting the newly exposed potential pollutants from the land surface into the surface waters. Additionally, stream channel erosion is a principal reason why stormwater management began and is legislated.

Controlling the Quantity of Runoff

The state-of-the-art of stormwater management has developed to the point that there are two fundamentally different approaches to controlling the quantity of stormwater runoff. Selected characteristics of these two approaches to stormwater management are illustrated in figure 1.

Conveyance-oriented approach. The first of the two approaches is the more traditional "conveyance-oriented" stormwater system. Systems designed in accordance with this approach provide for the collection of stormwater runoff followed by the immediate and rapid conveyance of the runoff from the collection area to the discharge point so as to minimize damage and disruption. The principal components of conveyance-oriented stormwater systems are culverts, storm sewers, and channels that are supplemented with stormwater inlets and catch basins.

Storage-oriented approach. A potentially effective but less common approach to stormwater control is the "storage-oriented" system. Its function is to provide for the temporary storage of stormwater in or near the site, with subsequent slow release

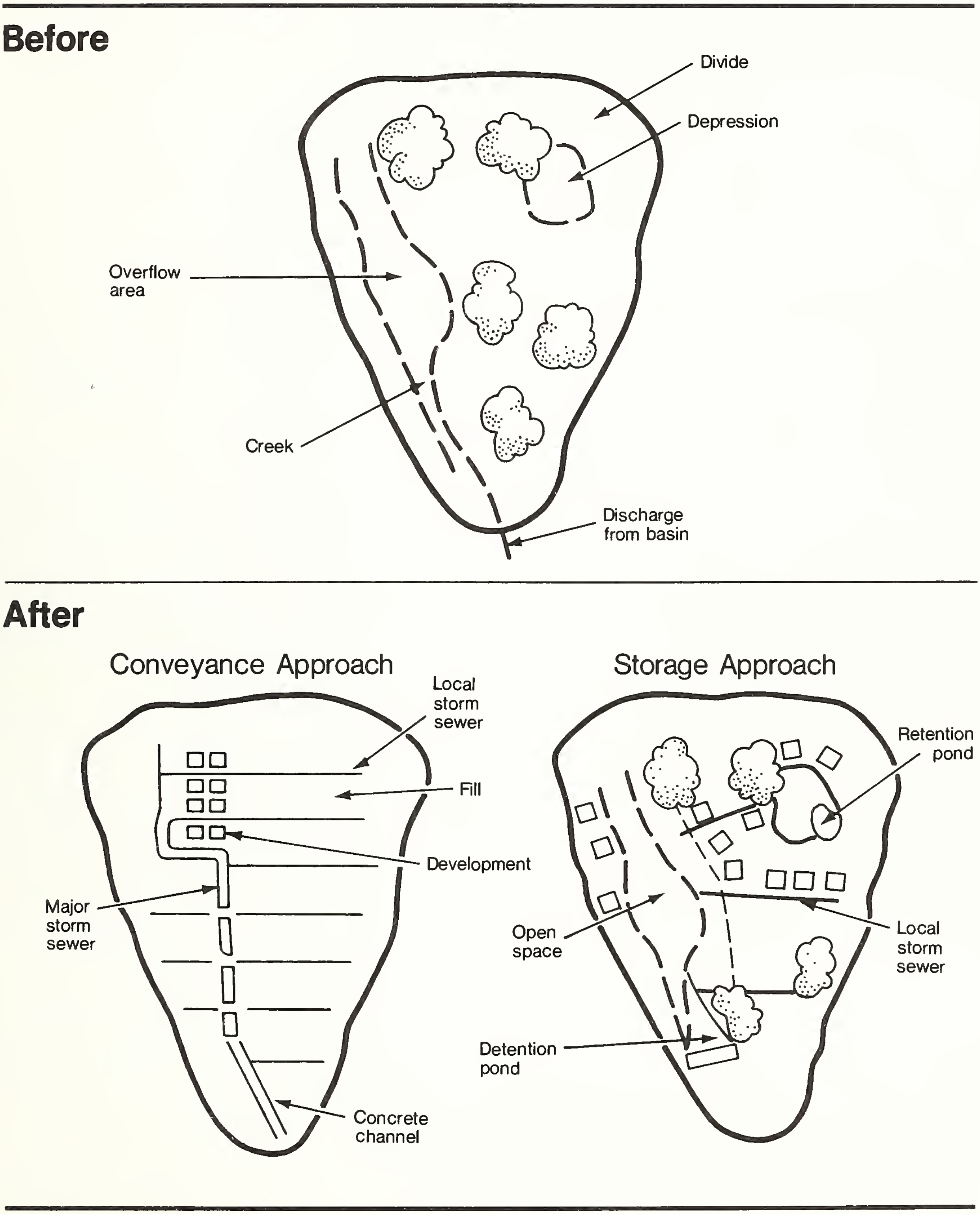

Figure 1.--Characteristics of two approaches to stormwater management.

to downstream storm sewers or channels. This approach minimizes damage and disruption both within and downstream of the site. One or more D/R facilities are the principal elements in a storage-oriented system. These principal elements are often supplemented with culverts, storm sewers, inlets, and catch basins.

Comparison of features. Principal advantages of the traditional conveyance-oriented approach to stormwater control are applicability to both existing and newly developing areas, rapid removal of stormwater from the service area, minimal operation and maintenance requirements and costs, and accepted analysis and design procedures. Principal advantages of the storage-oriented approach are possible cost reductions in newly developing urban areas, prevention of downstream adverse flooding and pollution associated with stormwater runoff, and potential for multipurpose uses.

Potential Economic Advantage of the Storage-Oriented Approach

The original motivation for using the newer storage-oriented approach over the traditional conveyance-oriented approach apparently was that the former may offer cost advantages. Poertner (1974) and Donohue & Associates, Inc. (1978, 1979) presented cost comparison data for several engineering studies, each of which indicated a significant reduction in stormwater control costs when D/R was used in lieu of conveyance-oriented systems, particularly when the latter utilized storm sewers and concrete-lined channels.

A complete comparison of conveyance-oriented and storage-oriented systems must consider other costs and benefits, such as the reduction in available land with the storage-oriented system and increased land values for areas contiguous to D/R facilities. Therefore, cost analyses must be conducted on a case-by-case basis. Nevertheless, there are already enough documented cases of the economic advantage of storage-oriented systems to suggest that D/R facilities should always be considered for controlling the quantity of stormwater runoff.

Recreation and Aesthetic Values of D/R Facilities

D/R facilities are being increasingly planned, designed, and used as multipurpose developments. In addition to their primary stormwater control function, they can provide, or be part of, a site for such recreation activities as fishing, boating, tennis, jogging, ski-touring, sledding, and field sports. A well-planned, designed, and operated D/R facility will also have aesthetic value for contiguous and nearby residential areas.

Mandatory D/R Facilities

Need for control. In addition to the obvious erosion and sedimentation problems often associated with urbanization, it is becoming increasingly apparent that urban stormwater runoff contributes a significant part of some pollutants to the surface waters. For example, Colston (1974) compared the quality of urban runoff with that of secondary municipal sewage treatment effluent on the basis of weight per unit area per year for Durham, N.C. On an annual basis, the urban runoff contributed 91 percent of the chemical oxygen demand, 89 percent of the ultimate biochemical oxygen demand (BOD), and 99 percent of the suspended solids. Many Public Law 92-500 "208" studies also concluded that urban stormwater runoff was a major contributor of pollutants to surface waters. For example, in southeastern Wisconsin, urban stormwater runoff accounts for 54 percent of the suspended solids, 27 percent of the 5-day BOD, and 32 percent of the total phosphorus carried from the land surface to the surface waters (Bauer, 1978).

It appears as though controlling the quality of runoff—at least the first and most important increment of control—should focus on suspended solids, partly because erosion and sedimentation are problems in urbanizing areas. Furthermore, many pollutants, such as phosphorus, pesticides, heavy metals, and bacteria, are carried by soil particles (e.g., Betz Environmental Engineers, 1976; Whipple, 1979; and Davis, 1979). Therefore, successful erosion and sediment control is also likely to lead to significant control of all these pollutants.

Potential effectiveness of D/R facilities. Many measures have been suggested for controlling urban area nonpoint source pollution in general and erosion sedimentation in particular. The use of D/R is one of these measures. The state-of-the-art of using D/R facilities to control the quality of urban stormwater runoff is discussed in the following sections. Inasmuch as D/R facilities are being increasingly used for controlling the quantity of runoff because of the cost advantages and for recreational and aesthetic values, they also should be considered for controlling the quality of water, an important third function.

Historic Overview Summary

The evolution of using D/R facilities in urban stormwater management is shown in figure 2. Beginning with the single use of quantity control, D/R facilities have evolved so that they can serve three compatible functions, namely, quantity control, recreation, aesthetic, and other supplemental uses, and quality control.

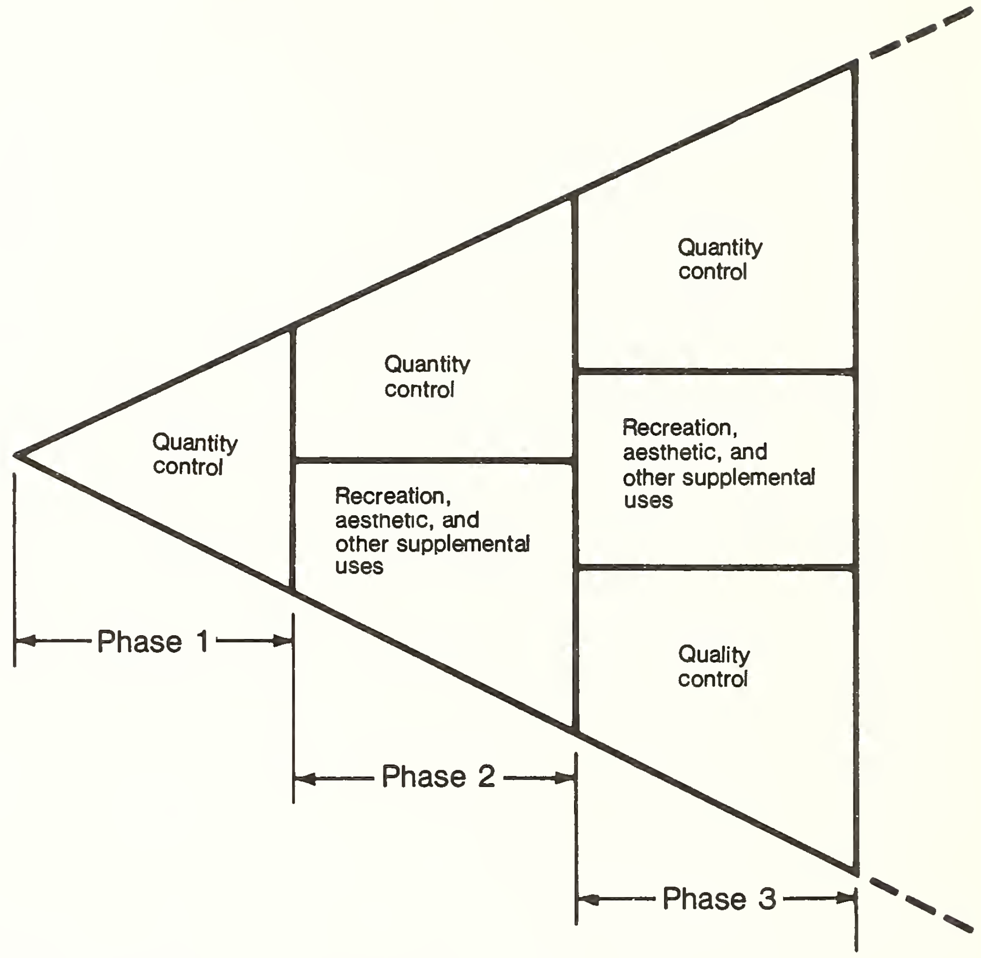

Figure 2.--Historic development of using D/R facilities.

SCS Empirical Trap Efficiency Relationship

The Soil Conservation Service, U.S. Department of Agriculture, has developed graphs of percent sediment trapped versus the ratio of impoundment volume and inflow volume. These trap efficiency curves are based on a study of sedimentation data for relatively large retention reservoirs (Brune, 1953, and Geiger, 1963, as cited in Chen, 1975).

For detention, as opposed to retention facilities, 5 and 10 percent reductions in trap efficiency are suggested for incoming suspended sediments that are, respectively, coarse and fine textured. These adjustments in the trap efficiency curves are intended to account for the increased likelihood of flows directly through a detention facility as opposed to a retention facility.

The trap efficiency curves suggest that D/R facilities, like those used increasingly in urban stormwater management, could capture essentially all the sediment that enters them. There are two qualifications in using the trap efficiency curves. First, they apply to long-term sediment trapping as opposed to individual runoff events. Second, the curves are based on sediment trap data for impoundments that are generally larger than the typical D/R facility and, therefore, may not actually reflect the behavior of the latter.

Sedimentation Basin-Retention Pond in Montgomery County, Md.

Davis (1978) reported on a field monitoring study of the hydrologic and sediment-trap performance of the sedimentation basin-retention pond in Montgomery County, Md. During the study, the mildly sloped, 45-acre (18-ha) tributary watershed was being developed for a complex of government structures. Watershed soils were reported as "deep, well-drained, and moderately erodible."

The sedimentation basin-retention pond had an area of 1.3 acres (0.53 ha) at the permanent pool level. Eight acre-feet (9,867 m^3) of water and sediment storage volume—equal to 2.1 inches (5.3 cm) of runoff from the tributary watershed—were available between the bottom of the basin and the crest of the nonperforated circular riser of the riser and barrel service spillway. A 4-inch (10.2-cm)-diameter port in the vertical riser maintained the normal pool 18 inches (46 cm) below the crest of the riser. This provided up to 2.4 acre-feet (2,960 m^3) of net available storage—equivalent to 0.64 inch (1.63 cm) of runoff from the tributary area—at the outset of a runoff event.

Inflow and outflow data for 10 storms from June through August 1977 were analyzed. Storm durations ranged from 0.83 to 14.25 hours, rainfall volumes varied from 0.08 to 2.2 inches (0.20 to 5.60 cm), and average intensities ranged from 0.04 to 0.94 inch (0.10 to 2.39 cm) per hour. Construction and development proceeded in the tributary watershed during the monitoring period as indicated, with a general increase in impervious pavement of 14 to 39 percent and in rooftops of 8 to 10 percent and a decrease in exposed soil area from 44 to 3 percent.

Settling efficiency for the 10 storms ranged from 88.1 to 99.7 percent. About 92.6 percent of the total sediment that entered the facility during the 10 storms was trapped. Except for the largest storm, totaling 2.2 inches of rain in 3.9 hours, the peak discharge at the outlet was about 9 percent of the peak discharge entering the facility. In summary, the sediment basin-retention pond was very effective both in trapping sediment and in attenuating peak flows.

Davis emphasized the importance of the amount of storage available between the normal pool level and the crest of the service spillway. A hood fitted to the top of the riser on the riser and barrel service spillway was very effective in preventing floating debris, which is especially likely to be present during construction activities, from escaping from the pond. Davis favored nonperforated to perforated risers for sediment control based on observed performance of both. Perforated risers permit suspended sediment to pass through the facility and, under some rainfall-runoff situations, result in a "negative" trap efficiency, that is, sediment outflow may exceed sediment inflow, especially during periods of low flow.

Mitigation of erosion and sedimentation problems in urbanizing areas, according to Davis, requires a two-pronged approach—erosion control on disturbed areas and sedimentation control in the form of sediment basin-retention pond facilities.

Multipurpose Retention Facility in Milwaukee, Wis.

Cherkauer (1977) monitored the quantity and quality of runoff from two adjacent urban watersheds, approximately 2.9 square miles (7.5 km^2), in the Milwaukee, Wis., area for 2 years. These watersheds were similar in area, drainage density, total relief, channel gradient, percentage of main channel improved, and percentage of watershed developed.

The most significant difference between them was that one contained a 48-acre (19.4-ha) retention facility normally containing 308 acre-feet (379,955 m^3) of water with an average depth (quotient of volume and depth) of 6.5 feet (2 m). The retention facility received runoff from the upstream 52 percent of the watershed and was multipurpose in that it served stormwater control, recreational, and aesthetic purposes. Water-quality parameters monitored were chloride, sodium, calcium, magnesium, and total dissolved solids, as well as sediment.

The retention facility had the expected effect of significantly reducing peak flows at the watershed outlet while significantly extending the time of hydrograph recession. The monitoring of chloride, sodium, and total dissolved solids was used as an indicator of the effect of winter road salting, which was practiced in the watershed for deicing purposes. The monitoring indicated that the retention facility reduced the transport and concentration of chloride from the watershed during winter runoff events. This was explained as a combination of the dilution effect on the incoming saltwater and the tendency of the denser incoming saltwater to move to the bottom of the retention facility, displacing and forcing out of the retention facility the overlying stored water with less concentration. However, average concentrations of pollutants in runoff from the watershed containing the retention facility were larger. Therefore, the apparent effect of the retention facility was to reduce the annual variability in salt concentrations.

Calcium and magnesium concentrations were monitored to serve as an index of the behavior of substances transported from the soil to the surface water system. The mass transport and concentration of these substances from the watershed containing the retention facility were larger—factor of two or more—during runoff events of late summer and fall when the quality of base flow dominated the lake quality. The runoff events flushed the stored base flow from the retention facility and increased downstream concentrations. Although calcium and magnesium are of relatively little practical importance in assessing surface water quality, the behavior of these soil-derived constituents in a drainage system containing a retention facility suggests that the retention facility may store soil-derived pollutants during base-flow periods and cause abrupt and potentially adverse increases in downstream concentrations during an ensuing runoff event. An example of such a pollutant would be certain creosote compounds that have entered the shallow aquifer from a poorly managed creosote operation. In summary, if the soil and, therefore, the base flow are polluted, the effect of that pollutant on the receiving surface waters may be aggravated if a retention facility is introduced.

Unfortunately the quantity and quality of lake inflow were not determined coincident with lake overflow characteristics, and, therefore, it is not possible to directly demonstrate the effect of the facility on water quality. Also, other water-quality parameters of interest, such as sediment, dissolved oxygen, fecal coliform, and phosphorus, were not included in the analysis.

Underground Detention Facility in Milwaukee, Wis.

An underground detention tank in Milwaukee, Wis., was evaluated as a method for abatement of pollution from combined sewer overflow (Milwaukee and Consoer, Townsend, & Associates, 1975). The tank received most of the combined sewage from the 570-acre (230.7-ha) tributary area. Relief and interceptor sewers captured some of the combined sewage before it reached the detention tank and transported it past the tank.

Because this facility received a combination of stormwater runoff and sanitary sewage, as opposed to only stormwater runoff, the results of the study are not directly used in design for control of stormwater runoff. A study by Dalrymple et al. (1979) suggests that stormwater runoff may have better suspended solids settling characteristics than combined sewage. Therefore, the results of this combined sewage detention study for suspended solids may provide a conservative estimate of what could be expected from stormwater runoff.

The tank had inside dimensions of 420 by 75 by 16 feet (128 by 23 by 5 m) and a capacity of 3.9 million gallons (14,761.5 m^3 liters), which is equivalent to 0.25 inch (0.64 cm) of runoff from the tributary area. Combined sewage flowed by gravity to the tank and entered through a bar screen with 1.5-inch (3.8-cm) openings. The tank contained several rotary mixers operated only to resuspend solids for pumping out the tank after a rainfall-runoff event.

Inflow-outflow data were insufficient to directly determine suspended solids and biochemical oxygen demand (BOD) removal efficiencies. Therefore, a computer model was developed and calibrated using the inflow-outflow data. The sedimentation equation, as discussed by Fair and Geyer (1954), was used in the model to represent suspended solids and BOD.

Historic hourly rainfall data for 3 years (wet, normal, and dry) were input to the model to test the effect of variable tank size. The size of the storage tank significantly affected predicted suspended solids and BOD removal. For example, the modeling indicated that increasing the tank size from 1 million gallons per square mile (1,461 m^3/km^2) or 0.058 inch (0.15 cm) of runoff to 7 million gallons per square mile (10,227 m^3/km^2) or 0.406 inch (1 cm) of runoff would increase suspended solids removal from about 35 to 90 percent. This is based on the quantity of suspended solids and BOD reaching the tank—not all of it did since some was taken from the drainage area by relief and interceptor sewers. However, interceptor capacity was set at 8 million gallons per day (0.35 m^3/s), which was small compared to peak runoff rates during storms.

A model run for 1972 was used to test the effect of pump-out rates on settling efficiency, with the conclusion that settling efficiency was relatively insensitive for the range of pump-out time examined. Decreasing the pump-out time from 96 to 24 hours for the facility increased overall suspended solids removal efficiency from about 68 to 72 percent and increased overall BOD removal efficiency from about 65 to 70 percent.

Sediment Ponds in Idaho

Bondurant et al. (1975) discussed the sediment removal efficiency and other characteristics of two sediment ponds in Idaho based on measurements taken over several years. The first and larger basin measured 60 by 500 by 5 feet (18 by 152 by 1.5 m) and served an area of 6,000 acres (2,400 ha). The total volume was 3.44 acre-feet (4,244 m^3), which is equivalent to only 0.007 inch (0.02 cm) of runoff from the tributary area. The second basin measured 300 by 40 feet (91 by 12 m), with a depth ranging from 2 to 4 feet (0.61 by 1.2 m), and served an area of only 70 acres (28 ha). The total volume was about 0.8 acre-foot (987 m^3), which is equivalent to 0.15 inch (0.38 cm) of runoff from the tributary area.

Longitudinal bottom profiles and sediment characteristics (percent clay, silt, sand, and density) at the smaller basin revealed a pattern of more sediment and more sandy sediment at the inlet end. Periodically determined settling efficiencies varied from 56 to 96 percent and were greatest during higher flow rates because heavier sediment was carried in. Three years of data collected for the larger basin showed annual trap efficiencies of 65, 68, and 74 percent.

Ponds in the Woodlands Development, Texas

Davis (1979) monitored low flows and stormwater runoff from parts of the Woodlands, a new urban development near Houston, Tex., for 2-1/2 years. The study area contained two closely spaced artificial lakes in series with a total drainage area of 820 acres (328 ha) and a total volume of 110 acre-feet (135,709 m^3). The investigations focused on pathogenic and indicator bacteria and included some limited laboratory and field studies of the effect of detention. A few suspended solids and turbidity analyses were also run.

Data for five rainfall events in March (two events), April, September, and October 1975 indicated large reductions in peak concentrations of suspended solids and turbidity from the upper reaches of the upstream lake to a point in the downstream lake. For example, an approximately 4-inch (10-cm) rainfall in April produced an upstream peak suspended solids of 2,660 mg per liter, whereas the downstream peak was only 356 mg per liter—an 87 percent reduction. Similarly, peak turbidity was reduced from 900 to 210 Jackson Turbidity Units (J.T.U.)—a 77 percent reduction.

Additional data for these five rainfall events indicated significant reductions in pathogenic, fecal coliform, and fecal streptococci bacteria. Most reductions in peak bacterial concentrations were in the range of one to three orders of magnitude. Peak concentrations of fecal coliform bacteria in the downstream lake were generally reduced to about 100 to 1,000 colonies per 100 ml. Davis hypothesized that the reductions in pathogen and indicator bacteria were caused by a combination of die-off and settling processes.

Laboratory settling experiments were conducted with 5-gallon (18.9-liter) samples of stormwater runoff. One of a pair of the samples was continuously agitated and the other was not. Samples were periodically drawn from both samples at a depth of 5.9 inches (15 cm) and analyzed for indicator and pathogen bacteria. Although some reductions of 50 percent or more were achieved for indicator bacteria after 30 minutes, the results were inconsistent and, therefore, inconclusive.

Other conclusions were that indicator and pathogen bacteria both exhibit a first flush phenomenon during stormwater runoff events, and the times of peak bacterial concentration correlate closely with the peaking times of solids and turbidity. Finally, fecal coliforms, as opposed, for example, to total coliforms, appear to be the best indicators of pathogens in stormwater runoff.

D/R Basins for Sediment Control at a Maryland Construction Site

Oscanyan (1975) described the use of two lakes in series (retention facilities) and two sediment basins (detention facilities) in a 65-acre (26.3-ha) multiuse recreation facility in Maryland. All four D/R facilities were intended to serve as sediment traps during construction.

The upstream lake had a tributary area of 37 acres (15 ha) and a surface area of 0.9 acre (0.36 ha). The downstream lake had a tributary area of 75 acres (30.4 ha), which included the 37-acre (15-ha) tributary to the upstream lake, and a surface area of 2.0 acres (0.81 ha). The larger of the two sediment basins had a tributary area of 15 acres (6.1 ha) and a surface area of 0.3 acre (0.12 ha), and the smaller basin had a tributary area of 2.5 acres (1.0 ha) and a surface area of 0.2 acre (0.08 ha). Volumes of the lakes and basins were not given.

A modest sediment inflow-outflow sampling program carried out in the D/R facilities during construction indicated that the two lakes and one of the sediment basins removed over 99 percent of the incoming suspended sediment. However, the second sediment basin trapped only about 30 percent of the sediment during rainfall-runoff events and had a negative efficiency during some rainfall-runoff events. Based on the widely differing sediment trapping performance, Oscanyan concluded that factors enhancing sediment trapping include (1) a high ratio of D/R surface area to stored volume of water at the design storage elevation, (2) a long, narrow shape with flow through the long dimension to prevent short circuiting, and (3) minimized turbulence.

Lake in Urban Watershed in Maryland

McCuen (1980) summarized input-output mass transport quantities and trap efficiencies for 11 parameters. The study focused on runoff from a 148-acre (59.2-ha) urban watershed in Montgomery County, Md., containing a shopping mall, apartment complexes, highways, and townhouses under development. Watershed runoff passed through a 5.9-acre (2.36-ha) lake, with outflow controlled by a vertical 24-inch (61-cm)-diameter corrugated metal pipe. The 11 water-quality parameters were sampled during "several storm events"; the number and distribution of sampling were not indicated. The monitoring data were used to develop equations for inflow and outflow transport as a function of flow rate. Design storms were then used to calculate inflow and outflow hydrographs for 2-, 10-, and 100-year recurrence intervals. The hydrographs were in turn combined with the equations to compute mass inflow, mass outflow, and settling efficiencies for each of the 11 parameters.

The resulting theoretical settling efficiencies were very high for most potential pollutants. For example, for design storm recurrence intervals of 2, 10, and 100 years and storm durations of 0.5, 1.0, 2.0, and 6.0 hours, settling efficiencies ranged from about 20 to 70 percent for orthophosphate, about 75 to 90 percent for 5-day biochemical oxygen demand, and over 95 percent for lead. However, the settling efficiency for total phosphorus was low, being between 2 and 22 percent. As expected, settling efficiency tended to decrease with increasing severity of the design storm and with increasing duration within any recurrence interval.

Artificial Marsh-Pond System in Upton, N.Y.

Small (1976) presented input-output concentration data collected for over 30 parameters from August 1975 through August 1976 for an artificial marsh-pond system. This outdoor system, which is located in Upton, N.Y., received sanitary sewage that had been degritted, screened, and aerated. The marsh-pond system was part of an experiment to develop natural systems for treating sanitary sewage prior to discharging it to the ground water. Although the marsh-pond system received "weak raw sewage or the equivalent of secondary or primary treated sewage," the study is unique, particularly because an artificial marsh and a pond in series were used.

The upstream marsh part of the system covered 0.2 acre (0.08 ha) and was excavated, lined with an impermeable membrane, backfilled with 4 to 6 inches (10 to 15 cm) of muck, and planted with cattails. Water depth in the artifical marsh was controlled so as not to exceed 2 inches (5 cm). The downstream pond was 5 feet (1.5 m) deep and was excavated, lined, and stocked with carp and other tolerant fish. Because of the carp, algae were the only vegetation supported in the pond. During the 13-month sampling period, the application of sewage to the artificial marsh varied from 50,000 to 100,000 gallons per day per acre (4.68 x 10^5 to 9.35 x 10^5 liters/ha/da).

The quality of the flow was significantly enhanced by passage through the marsh system. This may be illustrated by comparing average inflow-outflow concentrations of selected parameters. For example, the average concentration of suspended solids in the inflow was 353 mg per liter and the average concentration in the outflow was 43 mg per liter, an 88 percent reduction in average values. Inflow concentrations of suspended solids ranged from 50 to 4,300 mg per liter, whereas the range in effluent concentrations was 14 to 100 mg per liter. Similarily, the average concentration of biochemical oxygen demand was reduced from 170 to 19 mg per liter, an 89 percent reduction, the average concentration of total phosphorus was reduced from 7.2 to 2.1 mg per liter, or 71 percent reduction, and the geometric mean of fecal coliform bacteria was reduced from 1,560 to 50 colonies per 100 ml.

Natural Marsh at Brillion, Wis.

Inflow to and outflow from a 385-acre (154-ha) natural marsh at Brillion, Wis., with a 19-square mile (49-km^2) drainage area were monitored for 15 months (Fetter et al., 1978). The marsh received surface runoff from the primarily urban watershed, and because of a municipal waste-water treatment plant, secondary effluent accounted for from 2 to 50 percent of the estimated monthly flows into the marsh. The average depth of the marsh was about 1.5 feet (46 cm), and the estimated theoretical detention time, based on average annual runoff, was 48 days.

A comparison of inflow and outflow concentrations averaged over the study period for various potential pollutants indicated that significant reductions occurred. For example, percent reductions for biochemical oxygen demand concentrations were 80, coliform bacteria 86, nitrate 51, chemical oxygen demand 44, turbidity 44, suspended solids 29, total phosphorus 13, and orthophosphate about 6. A mass balance analysis indicated a net phosphorus reduction attributed to the marsh of 32 percent for the 15-month study.

Wayzata Wetland in Minnesota

A study was conducted on the Wayzata wetland in the Minnehaha Creek Watershed District in Minnesota.[4] The goal was to determine the effectiveness of wetlands in removing potential pollutants from incoming streams and thus preventing these substances from entering and impairing the quality of lakes. The wetland removed 77 percent of the total phosphorus and 94 percent of the total suspended solids that entered during the study period. Based on a biological assessment, no negative impacts on wildlife or vegetation were noted.

Natural Marsh at Green Lake, Wis.

A study culminated in a management plan for Green Lake, a 7,346-acre (2,938-ha) lake in a preglacial valley about 75 miles (121 km) northwest of Milwaukee, Wis. (Donohue & Associates, 1978). Green Lake water quality was deteriorating as indicated primarily by increases in nuisance algae and other aquatic plants. The observed water-quality degradation and the shift toward a eutrophic status were attributed to an increased influx of nutrients.

One of the recommended management measures was to investigate the feasibility of an artificial marsh on Silver Creek where it enters the east end of Green Lake in order to trap incoming suspended sediment and phosphorus. The recommendations were based, in part, on monitoring the nutrient trap effect of County Park Marsh through which flow enters the west end of the lake. Grab samples were taken over a period of 1 year during both wet and dry weather. During the monitoring period, 71 percent of the total phosphorus entering the marsh was trapped and prevented from entering the lake.

Artificial Marshes in Wisconsin

Studies on several artificial marshes and a natural marsh at Brillion, Wis., suggested significant seasonal patterns (Spangler et al., 1977). Primary and secondary effluent was passed through the artificial marshes composed of bulrushes, and over an 18-month period approximately one-third of the total phosphorus in the incoming flow was removed by the marsh. The variable seasonal phosphorus accumulation pattern was "accumulation over long periods in spring and summer and discharge of phosphorus in sudden spurts either in autumn or winter. Accumulation in the artificial marshes seems to be associated with high rates of biological activity. Discharge occurs after cold weather kills the flora."

The authors suggested that the water-quality enhancement effect of a marsh could be improved by harvesting vegetation and by pumping water from or diverting it around the marsh during expected flushing periods.

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[4] Wenck, N. C. Use of wetlands for non-structural methods of storm water treatment. (Abstract) Paper presented at 10th Ann. Water Resources Seminar, Minneapolis, Minn., 1977. [Unpublished. Abstract on file (S. G. Walesh).]

WATER-QUALITY PERFORMANCE OF D/R FACILITIES BASED ON LABORATORY STUDIES

Runoff Quality From Durham, N.C.

Colston (1974) studied a 1.67-square-mile (4.33-km^2), mixed land-use urban basin in Durham, N.C. The study area did not have a storm sewer system. Drainage was provided by street gutters, swales, small pipes, and culverts. Thirty-six storms were sampled. For most pollutants, concentrations had a standard deviation of 70 to 80 percent.

Laboratory experiments were conducted on stormwater samples using chemical oxygen demand (COD), suspended solids, and turbidity as water-quality indicators. The objective was to explore the factors affecting the physical-chemical treatment of stormwater runoff. Laboratory sedimentation tests were conducted in 1,500-ml beakers, some with and some without pH adjustment and various coagulants.

Fifteen minutes of natural sedimentation under quiescent conditions produced average COD, suspended solids, and turbidity removals of 61, 77, and 53 percent, respectively. Fifteen minutes of natural sedimentation under quiescent conditions using alum as a coagulant produced higher average COD, suspended solids, and turbidity removals of 84, 97, and 94 percent, respectively. Colston stated "within the choices of treatment alternatives, plain sedimentation is a reasonable, relatively inexpensive alternate to chemical treatment of urban land runoff."

After completion of these jar tests, larger batch-scale coagulation, flocculation, and sedimentation tests were run on stormwater runoff. The test apparatus consisted of a 10-foot (3.05-m)-tall Plexiglas cylinder with a 6.25-inch (16-cm)-inner diameter. The test results produced depth versus time relationships for difference in percent removal of suspended solids. These relationships were in turn used to construct curves of percent suspended solids removed versus overflow rate. These relationships are for ideal quiescent settling and "would have to be adjusted depending on the relative efficiency of a designed sedimentation basin." Even at an overflow rate of up to 6,000 gallons per day per square foot (2.444×10^5 liters/m^2/da), over 90 percent of suspended solids can be removed by sedimentation according to the settling curves in the report.

Unfortunately, these large-scale tests were not run as plain sedimentation, that is, without coagulants or coagulation aids. Based on the results of the jar tests, a smaller maximum allowable overflow rate for a given desired percent removal would be expected.

Runoff Quality From Toronto, Canada

Dalrymple et al. (1979) reviewed literature on the settling properties of sanitary sewage, combined sewage, and stormwater runoff and then performed laboratory suspended solids tests on a few samples of Toronto, Canada, stormwater runoff.

Studies reported in the literature were used to develop a particle-size distribution graph for sanitary sewage, combined sewage, and stormwater. The graph suggests that particle sizes in potential stormwater runoff are significantly larger than in combined sewage. This assumes that stormwater runoff will similarly transport all the solids on the street just as in street washing. Thus, all other things being equal, better settling should be achieved with stormwater runoff than with combined sewage.

Laboratory settling tests were run on stormwater runoff collected at an outfall in Toronto. The sample was thought to be higher in clay and silt content relative to most stormwater runoff. In one run, 1 hour of settling reduced suspended solids by 80 percent from an initial concentration of 337 mg per liter. In another run, 1 hour of settling reduced suspended solids by 87 percent from an initial concentration of 323 mg per liter. Based on their laboratory tests, Dalrymple et al. suggested that the settling characteristics of stormwater runoff might be improved by storage prior to settling to provide agglomeration of small particles.

WATER-QUALITY PERFORMANCE OF D/R FACILITIES BASED ON COMPUTER MODELING STUDIES

Computer Modeling Studies of Hypothetical D/R Facilities

Curtis and McCuen (1977) reported on factors that influence the effectiveness of a D/R facility in controlling both flow and sediment. They developed a computer model consisting of a soil detachment transport submodel, a D/R reservoir sedimentation submodel, and a reservoir routing submodel. All analyses used a 2-year, 6-hour design storm. Sensitivity studies were run leading to the observations that settling efficiency increased with increased proportion of heavier soil particles, decreased depth of D/R, decreased initial volume of water in D/R, and decreased size of orifices in an outlet control structure (a perforated riser pipe). Peak outflow was decreased by all these factors that increased settling efficiency except particle size distribution. Because of timing effects, it is possible that multiple D/R in a watershed could increase flow at the watershed outlet.

Kamedulski and McCuen (1979) used a calibrated hydrologic-erosion-sedimentation model to evaluate the consequences of various detention policies. All modeling was based on design storms as opposed, for example, to a series of historic storms. Peak flow reduction through a D/R facility decreased within increased recurrence interval, increased urbanization, and increased storm durations—all because of the increased volume of inflow. Settling efficiencies decreased in a similar fashion.

Most D/R policies constrain one point on the discharge-probability relationship that may result in significant overdesign or underdesign for other possibilities. The general trend suggested by this modeling study was that if a D/R facility is designed for a given recurrence interval, it will be overdesigned for more severe events and underdesigned for less severe events. Of interest is the very high, generally 85 percent or greater, settling efficiencies predicted for all situations. This was explained by a dominance of heavy, larger soil particles and long flow lengths.

Settling Efficiency Equation

Haan and Ward (1978) developed a digital computer model to simulate the passage of a hydrograph and sedimentgraph through a D/R basin. A limited amount of data was available to verify the model. Model input included inflow hydrograph, inflow sedimentgraph or inflow sediment mass, a stage-discharge-area relationship, sediment particle size distribution, and specific gravity. The initial modeling resulted in developing an equation for settling efficiency as a function of D/R capacity, inflow volume, average detention time, storm duration, peak inflow and outflow rates, and percentage of sediment particles smaller than 5 microns at the peak inflow rates.

Potential Adverse Downstream Flooding and Erosion Effects

Malcolm[5] investigated the effect of a D/R facility receiving flow from a 360-acre (146-ha) watershed on channel bank and bottom erosion downstream of the facility. A hypothetical D/R facility was designed to reduce peak watershed outflow for the selected design storm from 500 to 150 cubic feet per second (14 to 4.2 m^3/s). A digital computer model was used to develop inflow-outflow hydrographs.

In addition to before and after hydrographs for the design storm condition, before and after graphs of tractive force versus time were also constructed. The tractive force graphs indicated that the effect of the storage facility was to reduce the maximum tractive force by about one-half but to double the time of persistence of tractive force above the scouring threshold. This suggests the counter-intuitive conclusion that D/R will not necessarily reduce downstream channel bottom and bank erosion but may actually aggravate it by increasing the duration of tractive forces and by concentrating those forces in and near the channel.

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[5] Malcolm, H. R. Culverts, flooding, and erosion. Paper presented at Engin. Found. Conf., Water Problems in Urban Areas, Henniker, N.H., 1978. [Unpublished. Copy on file (S. G. Walesh).]

GUIDELINES FOR PLANNING AND DESIGNING WATER-QUALITY FEATURES OF D/R FACILITIES

Planning and Designing to Control Quantity and Quality of Runoff

Whipple (1979) noted that D/R facilities can be planned and designed to control both the quantity and quality of urban runoff. The few large storms that typically occur in a year cause the most flood damage, whereas runoff from the large number of small storms carry most of the pollutants. Therefore, dual-purpose D/R facilities should be sized and provided with outlet works that detain as much runoff as possible from small storms and hold it long enough to provide ample time for settling. Dual-purpose D/R facilities should also be designed to safely detain as much runoff as possible from a large storm but release it from the D/R facility as soon as possible to provide room, if needed, for storage of runoff from a subsequent flood. Maintenance will be even more important for dual-purpose D/R facilities than for single-purpose facilities.

SCS Sediment Basin Concepts and Aids

The Soil Conservation Service reported design guidelines for the outlet control structure of a permanent or temporary facility intended to trap sediment (USDA, no date; USDA, 1975). The principal elements of this structure were (1) a turf-covered earthen embankment with a trapezoidal cross section, (2) a pipe principal spillway passing beneath the structure provided with a metal riser and trash rack at the upstream end, and (3) an emergency spillway.

This type of hydraulic control structure is frequently modified to serve the dual purpose of controlling large volumes of runoff associated with large infrequent rainfall events while effectively trapping sediment and adsorbed pollutants during smaller but more frequent rainfall and snowmelt events.

Design Procedures for Sedimentation Aspects of a D/R Facility

Malcolm and New (1975) presented a procedure for designing the sedimentation aspects of a D/R facility. Necessary design criteria include selection of the recurrence interval and the size of the smallest particle to be settled.

(1) It is first necessary to select a recurrence interval. A 10-year recurrence interval is suggested for the settling performance of the D/R facility, with a more severe condition being selected for the hydrologic-hydraulic and structural design of the entire D/R facility.

(2) It is also necessary to select the size of the smallest particle to be settled, with a given settling efficiency at peak outflow. A 40- to 80-micron particle is suggested to be removed at 70 percent efficiency. (Note: 1 micron = 0.001 mm.)

The design process, which is described in detail and illustrated with an example, consists of sizing the following components:

(1) A shallow inlet zone is sized to spread the incoming flow across the width of the basin.

(2) The settling zone is sized based on the design flow; the design particle size and trap efficiency must also be sized. Hazen's (Fair and Geyer, 1954) theory of sedimentation tank design is used to determine the minimum allowable plan area of the settling zone.

(3) The sediment storage zone, which lies beneath the settling zone, is sized to contain the total volume of settled sediment that will be trapped during the life of the facility or between sediment removal operations.

(4) The perforated metal riser and the piped spillway, which passes beneath the earthen or other dam forming the outlet structure, must also be sized. The riser diameter is based on a weir flow analysis; the number, size, and location of perforations in the riser area are based on an orifice flow analysis, and the size of the main pipe is based on an inlet control approach.

Oscanyan (1975) also described and illustrated with an example a procedure for designing the sedimentation aspects of a D/R facility.

He provided a schematic plan and section drawings of a sedimentation basin that complements those described by others (USDA, no date; USDA, 1975). Important elements of the basin are an earthen dam or embankment, a settling zone on top of a sediment storage zone, a metal riser, and a pipe spillway that passes beneath the earthen embankment.

The design of a combination sedimentation basin-stormwater control facility was not discussed by Oscanyan. However, this sedimentation basin design procedure could be integrated with a design procedure for determining the volume of storage and the outlet control works needed to regulate a large quantity of runoff such as would be generated by a large storm.

Chen (1975) described a design procedure that is similar to the two preceding procedures in that it is based on settling efficiency as determined by settling velocity of particles. An illustrative example is not provided. Useful design aids given by Chen include a table of dry weights of settled sediment, a table of settling velocities for a range of suspended sediment sizes from fine clay to coarse sand, and a graph of settling efficiency versus outflow rate (unit overflow rate based on plan area) for the same range in suspended sediment sizes.

Operation and Maintenance Aspects of D/R Facilities

A systematic maintenance program is required for the safe operation and proper functioning of a D/R facility intended to control the quantity or quality of stormwater runoff. In such areas as northeastern Illinois where D/R of stormwater has been practiced or required for quantity control for a decade or more, there are indications that proper maintenance has not been provided. Inadequate maintenance prevents the D/R facility from functioning as designed and creates safety hazards, flood risks, nuisances, and aesthetic problems.

Operation and maintenance suggestions based on experience in Madison, Wis., were made by Schoenbeck.[6/] The planning and design process should include operation and maintenance needs by providing ease of access and movement for trucks, front-end loaders, and mowers. Consideration should be given to providing protective grates on outlet control structures to minimize entrapment of debris and to prevent children from being washed into the outlet control structure.

Madison crews check outlet control structures during and after every runoff event and are experimenting with a weather forecasting service to provide advance information as to the expected occurrence and magnitude of runoff events. Madison has experimented with weirs and other outlet control structures intended to trap sediment.

Highland Park, Ill., (Highland Park, 1978) allows use of a D/R facility as a temporary sediment trap during construction of land-development projects provided the facility is restored to its design storage capacity. The continued proper functioning of D/R facilities is encouraged by requiring a maintenance procedure for such facilities as part of the plan submitted for land development. Furthermore, the city engineer is required to inspect every D/R facility at least once every 5 years and to serve notice if repairs or maintenance is required.

As a result of the Maryland Sediment Control Act of 1970, the Montgomery (County) Soil Conservation District must approve sediment control plans prior to undertaking land-development projects. The District's responsibility includes controlling offsite erosion and sedimentation and, therefore, use is made of D/R facilities. Formal maintenance responsibility arrangements must be made prior to construction. If facilities are constructed on public land, the head of the government unit must submit a letter indicating responsibility for maintenance. For facilities constructed on private land, the owner must sign a maintenance statement.

[6/] Schoenbeck, R. H. Maintenance and operation of detention in systems. Presentation at Storm Water Detention Systems Inst., Univ. Wis. Ext., Madison, 1979.

FURTHER CONSIDERATIONS

With the exception of a few field and laboratory studies on the effects of D/R facilities on removing suspended sediment from stormwater runoff, few field or laboratory studies have been conducted on using D/R to enhance stormwater runoff. Therefore, the effectiveness of D/R facilities in removing nonpoint source pollutants, other than sediment, has not been convincingly demonstrated in the field.

D/R facilities have, in many instances, been effective in controlling the quantity of stormwater runoff while also offering economic, recreation, and aesthetic benefits. Suspended solids trap efficiencies in excess of 90 percent have been reported for the few available field studies. Although the state-of-the-art is rudimentary, it appears that with additional effort leading to increased knowledge, D/R facilities can be planned, designed, constructed, and operated to control the quality of stormwater runoff.

Effect of D/R Facilities on Pollutants Other Than Suspended Solids

Based on the results of very few field and laboratory studies, there are indications that D/R facilities may significantly reduce the concentration of pollutants other than suspended solids. Examples of these pollutants or pollution indicators are biochemical oxygen demand, chemical oxygen demand, pathogenic and indicator bacteria, turbidity, and chloride. The solids appear to be a transporter of pollutants, such as phosphorus, pesticides, heavy metals, and bacteria. Therefore, suspended solids should be the primary target. The explicit successful control of suspended solids in D/R facilities is likely to result in the removal of other nonpoint source pollutants.

Factors That Affect Performance of D/R Facilities

Field, laboratory, and computer modeling studies indicate that D/R facilities can easily achieve suspended solids trap efficiencies of 70 percent or more. Trap efficiency is improved by or increased with (1) volume available for temporary storage of stormwater, (2) presence of a restricting outlet control device such as a metal riser, (3) reduction in emptying time between runoff events, (4) increased fraction of larger soil particles, (5) minimized short circuiting, (6) large surface area for a given storage volume, (7) introduction of a coagulant such as alum and coagulant aids, and (8) outlet control configuration that minimizes velocity in the D/R facility near the outlet.

Just as D/R facilities reduce the long-term variation in stream flows in downstream reaches, they may also reduce the long-term variation in stream water quality, that is, in the concentration and transport of potential pollutants. Although a leveling of water quality may be generally desirable, there may be adverse effects.

Some design guidelines are available for the sedimentation aspects of D/R facilities for use by practicing engineers. These aids are based on a combination of plain sedimentation basin design procedures drawn from the field of sanitary engineering and empirical sediment trap efficiency studies for large reservoirs. Because incorporation of water-quality enhancement features in D/R facilities is relatively new, engineers should proceed with caution and make full use of the few aids that are available.

Integrating Quantity- and Quality-control Concepts

Preliminary engineering investigations of D/R facilities intended to achieve quantity and quality control with supplemental recreation and aesthetic benefits should draw on experience already gained in the following three areas: Hydrologic-hydraulic design of flood control D/R facilities, empirical and theoretical sedimentation design procedures, and use of vegetative filters. One D/R facility concept that integrates these three areas of experience is a series configuration consisting of, in downstream order, a sedimentation basin, a vegetative filter, and a retention reservoir (fig. 3).

Possibility of Increased Downstream Erosion

Based on preliminary studies, the construction of a D/R facility intended to reduce downstream flooding and pollution may under certain conditions actually increase downstream erosion and sedimentation by increasing the duration of erosive forces, by concentrating those forces in or near the channel, and by reducing the sediment load in the D/R discharge. Designers should carefully assess this possibility and its consequences.

The "Little Additional Expense" Idea

In terms of land acquisition and construction costs, relatively little additional expenditures are likely to be required to add effective water-quality control components to a planned D/R facility. D/R facilities intended to control stormwater quantity with supplemental recreation and aesthetic benefits have typically been of such size and configuration that relatively little additional earthwork and components would be required.

Potential Inspection and Maintenance Problems

The short experience with operating D/R facilities, most of which were intended to control the quantity and not the quality of runoff, suggests that periodic and storm-related inspection and maintenance are vital to effective operation. One problem that has occurred is accumulation of sediment and debris. Because D/R facilities intended for both quantity and quality control will, by design, accumulate even more sediment and debris, it follows that systematic inspection and maintenance will become even more essential.

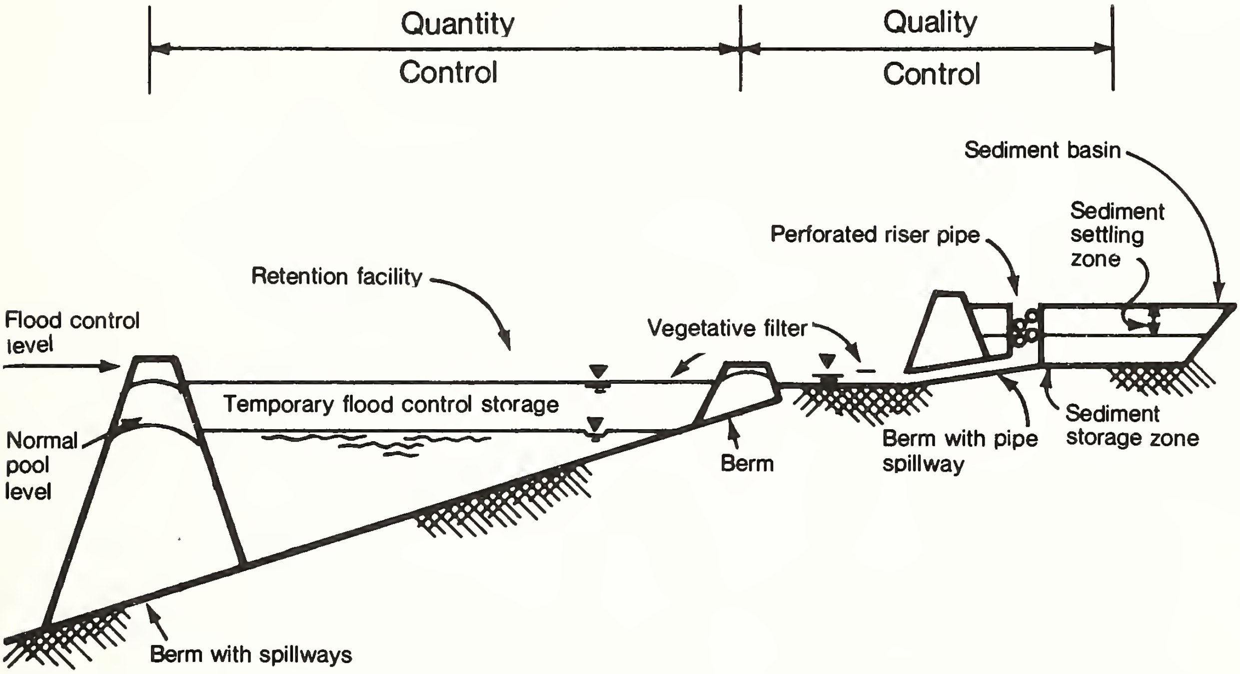

Figure 3.--Integrating quantity- and quality-control concepts.

Proper inspection and maintenance of D/R facilities may be accomplished by the municipal staff or may be carried out by the owner, when required by legal agreement or municipal ordinance. Inspection and maintenance responsibilities should be formalized prior to beginning construction.

D/R facilities are one of many structural and nonstructural measures potentially available for managing the quantity and quality of stormwater runoff. Even if significant advances are made in the state-of-the-art of D/R facility knowledge, other management measures may be more appropriate in a given situation.

"Go Slow" in Mandating D/R Facilities

Given the limited knowledge, the local, State, and Federal government units should go slow in mandating D/R for controlling the quality of stormwater runoff in urban and urbanizing areas. Premature rulemaking and regulations are likely to result in action but little progress. More is likely to be accomplished in advancing the state-of-the-art and in achieving significant control of nonpoint source pollutants by (1) additional research and development projects and pilot studies and (2) encouraging the control of nonpoint source pollutants but not dictating the means.

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APPENDIX A - ADDITIONAL REFERENCES

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APPENDIX B - ABSTRACTS OF SELECTED REFERENCES[1]

1. Alley, W. M. 1980. A simple lumped-parameter runoff quality model. In Kuo, C. Y., ed., National Symposium on Urban Stormwater Management in Coastal Areas, pp. 236-243. Amer. Soc. Civ. Engin., New York, N.Y.

Abstract: The state-of-the-art of urban runoff modeling is far in advance of urban runoff-quality modeling. Whereas, a physically based, distributed parameter approach to rainfall-runoff modeling has been successfully performed in many studies, such approaches toward runoff-quality modeling have rarely proved successful. In recognition of this fact, a single runoff-quality model has been developed. It is a lumped-parameter model in that no spatial variations in model parameters are accounted for. It has been linked with a more complex distribution routing rainfall-runoff model. The structure of the runoff-quality model and its application to a small urban drainage basin along the coast of south Florida are described. The model utilizes exponential constituent accumulation and washoff equations for runoff-quality simulation and a modified-Rosenbrock direct search algorithm to identify model parameters. An option is included in the model to account for wetfall contributions. The model is limited in its applicability to watersheds and constituents for which runoff loads originate predominantly from effective impervious surfaces and for which constituent concentrations tend to decrease with time from start of storm. The model was calibrated and verified for storm-runoff loads of total nitrogen from a small urbanized watershed in south Florida; standard errors of approximately 60 percent were found during model verification. The potential importance of accounting for wetfall contribution when determining model parameters for total nitrogen was demonstrated in this application.

2. Baker, W. R. 1977. Stormwater detention basin design for small drainage areas. Public Works Jour., Mar. 1977, pp. 75-79.

Abstract: Control and management of stormwater runoff have resulted in associated problems causing an increasing source of concern for public works engineers. A detention basin is one of the most effective methods of reducing the rate of runoff. The author employed hydrographs to develop a model to design detention basins for small drainage areas. A modified version of the rational method was utilized to generate the inflow hydrograph. This method represented a simple procedure that yielded acceptable design results when applied to small drainage areas (i.e., up to 200 acres in area).

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[1] For keywords, refer to table 1, p. 4.

3. Bedient, P. B., and C. B. Amandes. 1978. Monitoring, modeling and management of non-point sources in Houston, Texas. In Haan, C. T., ed., International Symposium on Urban Storm Water Management, pp. 151-157. Univ. Ky., Lexington.

Abstract: The Department of Environmental Science and Engineering at Rice University has undertaken a coordinated research effort with the City of Houston Health Department on stormwater sampling and management. A comprehensive stormwater quality and low flow sampling program was designed for the Brays Bayou watershed and tributaries in order to define pollutant loads (TSS, TP, NO_3, NH_3, BOD, DO) and potential impacts. The main objective of the study was to organize the City of Houston's sampling effort in order to differentiate the impact of point sources versus stormwater runoff. Load-runoff relationships were developed as a function of land-use type and were used in a predictive model (HLOAD) for multiple or individual storm events. Stormwater responses were predicted using a hydraulic formulation such as STORM in concert with the HLOAD methodology. Results from four watersheds were satisfactory for TSS, TP, TKN, and COD. Total annual load calculations indicated 85-90 percent was due to non-point source runoff. For a variety of stormwater management practices, including channel modification, detention storage, and land-use controls, STORM and HLOAD models were used to characterize the effects of storm flows and receiving water quality. Both present and projected land-use patterns were input to investigate the effects of future development in the watershed. Cost data for a variety of management alternatives will be estimated and compared to evaluate relative effectiveness.

4. Bedient, P. B., P. A. Harned, and W. G. Characklis. 1978. Stormwater analysis and prediction in Houston. Amer. Soc. Civ. Engin., Environ. Engin. Div. Jour. 104(EE6):1087-1100.

Abstract: Analyses of available stormwater hydrologic and water-quality data for several Houston, Tex., area watersheds yielded direct linear relationships between pollutant mass loading rates and cumulative storm runoff volume. These relationships were then used to rank the watersheds on a pollutant-load-per-unit-runoff basis and to calculate total annual pollutant loads for each area. Further, a plot of dimensionless cumulative flow versus the dimensionless cumulative flux provided a quantifiable means to evaluate the first flush, allowing comparison of this effect between watersheds. Finally, the developed load-runoff relationships provided the basis for a simple, yet effective method of predicting pollutant mass flows for individual or sequential storm events.

5. Bouthillier, P. H., and A. W. Peterson. 1978. Storage requirements for peak runoff control. In Haan, C. T., ed., International Symposium on Urban Storm Water Management, pp. 13-18. Univ. Ky., Lexington.

Abstract: Storage of storm runoff is becoming a common part of the design of land development because most environmental control authorities have imposed limits on the peak rate of runoff. The objective of such regulations is to reduce erosion by flows that would exceed those occurring before development. A method of computing storage requirements for storm runoff is presented. A plot of the ratio of the maximum allowable outlet rate to the maximum inflow rate versus the ratio of the required reservoir volume to the storage is given. A bottom outlet is used; its rate varies as the square root of the head on the outlet. Curves are provided for triangular and for cusp-shaped hydrographs. Computations are based on total runoff (coefficient of runoff x rainfall) and a chosen base length of hydrograph. Allowable peak outlet rates may be assumed or set by regulatory agencies. Examples are given using Edmonton rainfall data. The range of options provided, viz, return storm period, base length of hydrograph, and runoff coefficients, should enable wide applicability of this method. In considering the uncertainties of rainfall intensity and patterns, this method is believed to be sufficiently accurate for most applications.

6. Brandt, G. H., E. S. Conyers, M. B. Ettinger, and others. 1972. An economic analysis of erosion and sediment control methods for watersheds undergoing urbanization. 181 pp. The Dow Chemical Company, Midland, Mich.

Abstract: Economic benefits are expected from controlling erosion and sediment during urban construction, but control costs for urban erosion have not been previously related to benefits. In this study, costs are compared to effectiveness for many erosion and sediment control systems. Potential soil losses were calculated with the universal soil loss equation. Damage costs in streams were assigned to specific construction sites by equations incorporating estimated cost constants and sediment delivery ratios for various "legs" along a drainage path. Specific damage values were determined for numerous downstream sediment problems. The Seneca Creek watershed, located 20 miles northwest of Washington, D.C., was used as a model watershed for the study. Control practices presently being used in the watershed include sediment basins, diversion berms, level spreaders, grade stabilization structure, sodded ditches, seeding, and straw mulch tacked with asphalt or disked. This conventional system is estimated to cost $1,125 per acre and to control 91 percent of the potential erosion.

Control systems incorporating large sediment basins can boost control to 96 percent at less total cost. Multipurpose impoundments design with sediment forebays for chemical flocculation can boost urban sediment control to 99 percent. In addition, such structures contribute very significantly to controlling sediment from agricultural and idle land. Sediment from these nonurban sources must be controlled to significantly reduce the sediment pollution problem. Urban construction sites can contribute large quantities of sediment per unit area, but they constitute a minor part of the total sediment pollution problem because total acreage is generally small compared with other land that contributes sediment. Sediment damages from uncontrolled erosion on urban construction sites in the Seneca watershed could potentially reach $1,500 per acre. This estimated damage value applies to specific conditions prevailing in the watershed where 300 tons of sediment could erode per acre of uncontrolled development during an 18-month construction period. The estimated maximum soil erosion rate approaches 200 tons per acre per year or 128,000 tons per square mile per year. However, downstream damages would be caused by only a part of this total potential sediment. Sediment delivery and transport ratios determine damage distribution along a stream and are a major source of uncertainty in this economic analysis.

7. Butler, R. V., and M. D. Maher. 1978. The economics of urban stormwater management. 18 pp. Ctr. for Econ. Theory and Econometrics, Rice Univ., Houston, Tex.

Abstract: Recent studies have shown that urban flooding and water-quality problems are due in part to the effects of upstream urbanization. Economic analysis suggests that upstream development will continue and the problem will worsen because upstream residents have no incentive to alter their behavior that causes stormwater problems. The consequences of the increased runoff they generate are borne by others - by affected downstream residents and by the general taxpayer if traditional government protection programs are used to lessen damage downstream. The major policy implication of this analysis is that treatment and mitigation efforts should focus on the source of the problem as well as the site of damage. The costs of upstream development require that both flooding and water-quality aspects of stormwater runoff be managed basinwide, since uncoordinated community-by-community action cannot simultaneously implement controls upstream, upland, and downstream. In addition, the efficient management strategy must consider both flooding and water quality simultaneously. Since the pollution and flooding problems are produced jointly, joint treatment should be planned. Several policy instruments for basinwide control are discussed.

8. Calabrese, M. M. 1980. Optimization of stormwater management practices. In Kuo, C. Y., ed., National Symposium on Urban Stormwater Management in Coastal Areas, pp. 183-194. Amer. Soc. Civ. Engin., New York, N.Y.

Abstract: In recent years, stormwater has been a principal source of pollution to receiving waters. Major research efforts have been directed in this area, primarily as a result of the water pollution acts and amendments. Yet there remains a need for more stormwater management data, especially cost performance, and the planning methodology to optimally select management practices based on the cost performance data. The objectives of this research were to develop cost-effective data on various management practices and to use these data to find optimal combinations of stormwater management practices for storm sewer systems. The optimal combination of structural and nonstructural management practices for wet weather pollution control was determined using linear programing methods. The selection is a most critical element of stormwater management research, because stormwater removals must be related to lake productivity, and the best combination of management practices must be specified to achieve desired water-quality improvement. Combinations of computer analyses and mathematical programing were used to analyze the data. The research culminating in the computer program "MANAGE" described in this paper reveals a methodology for the choice of an optimal combination of stormwater management practices. However, more work is needed to estimate localized cost efficiencies for stormwater management practices. Incorporating mathematical programing methods in this work saves time and money, since it eliminates guesswork and allows one to select a combination of practices that will remove a maximum amount of pollutants at least cost. The program was beneficial in establishing the least cost combination of management practices in the Lake Eola watershed, Orlando, Fla.

9. Cordero, C. T. 1972. Management of runoff from minor storms in Montgomery County, Maryland. 7 pp. Amer. Soc. Agr. Engin., St. Joseph, Mich. (Preprint.)

Abstract: The purpose of this paper is to present briefly the action taken by and in Montgomery County, Md., to relieve some of the problems connected with stormwater runoff in a rapidly urbanizing area. First, the procedure by which the criteria were developed and a synopsis of the criteria are given. Then, several examples of how the criteria were applied are briefly described. Finally, an assessment is made of how well the program is succeeding so that others can benefit.

10. Curtis, P. C., and R. H. McCuen. 1977. Design efficiency of stormwater detention basins. Amer. Soc. Civ. Engin., Water Resources Planning and Mangt. Div. Jour. 103(WR1):125-140.

Abstract: In addition to increasing flood runoff, urban development has significantly increased sediment loads in streams. Although many suggestions for sediment and runoff control have been proposed, stormwater detention has been one of the more cost efficient. Because detention facilities have not been used extensively in the past, a data base is not available for determining the effect of design factors on sediment trap efficiency and runoff control characteristics. A mathematical model, which includes erosion, sedimentation, and detention facility components, was developed from principles of hydraulics and classical settling mechanics. The model was used to examine the effect of (1) detention basin location, (2) soil particle size distribution, (3) basin depth, (4) initial storage, and (5) orifice diameter. An understanding of the relative importance of these factors may lead to a better design of stormwater detention facilities.

11. Davis, W. J., R. H. McCuen, and G. E. Kamedulski. 1978. The effect of stormwater detention on water quality. In Haan, C. T., ed., International Symposium on Urban Storm Water Management, pp. 211-218. Univ. Ky., Lexington.

Abstract: Recent studies have indicated that nonpoint sources of pollution are often a major contributor to the degradation of stream quality. Although stormwater detention basins have been effective in controlling both runoff rates and sediment loads, the effectiveness of detention facilities has not been documented. Montgomery County, Md., has completed a Section 208 research study of the effectiveness of a functional sedimentation control basin and a stormwater management basin as examples of local nonpoint source pollution control structures. These structures are recommended for strategic use in a plan for areawide waste treatment management developed by the Metropolitan Washington Council of Governments for the Washington, D.C., area. The study included monitoring of rainfall and water-quality parameters in basin inflow and outflow, as well as detention basin and land-use characteristics. Analysis of measured data provided relationships of inflow sediment and pollutant loadings to land use and rainfall. Trap efficiencies for sediment and pollutant loads were evaluated and related to rainfall, land use, and basin design characteristics. With the measured data, a hydraulic-hydrologic model was calibrated and used to examine the effect of stormwater detention on sediment and other pollutant loads. The model was employed to examine the effect that variation of basin design characteristics would have on efficiency of the structures. Monitoring installations and data collection are described, data analysis techniques and results are presented, and the model, its calibration, and operation are discussed.

12. Day, J. W., and C. L. Ho. 1978. Assimilation of agricultural runoff by a swamp forest wetland. 127 pp. Agr. and Mech. Col., Ctr. for Wetlands Resources, La. State Univ., Baton Rouge.

Abstract: The general objective of this research is to determine whether natural wetlands in south Louisiana can remove nutrients from agricultural runoff. We are specifically interested in an area of swamp forest near Lac des Allemands. This lake is now highly eutrophic, principally because of agricultural runoff. Under natural hydrologic conditions, runoff from higher areas would percolate through the swamp. Now, because of an extensive network of drainage canals, the nutrient-laden runoff flows directly into water bodies causing the eutrophication problem. This problem affects both fresh and estuarine waters and is beginning to threaten commercial fisheries. Earlier studies in Louisiana have shown that when fishery wastes were applied to wetlands, the wastes were assimilated and productivity of wetland vegetation was increased by as much as 50 percent. If the research proposed here is successful, it will show the utility of natural treatment for nonpoint source runoff. Thus, a widespread cause of deterioration of water quality in south Louisiana may have an economical solution.

13. Dendion, S. A., J. W. Delleur, and J. J. Talavage. 1978. Systematic planning of urban storm-drainage utilities. In Haan, C. T., ed., International Symposium on Urban Storm Water Management, pp. 229-234. Univ. Ky., Lexington.

Abstract: A computer program package is developed that integrates and interfaces an urban growth simulation model, LANDUSE, and an urban hydrology model, a modified version of STORM. Alternate growth scenarios can thus be directly related to the corresponding storm-drainage systems. If these systems are designed to achieve specified standards of performance, then a useful comparison among several possible urban growth patterns can be performed. Although an urban area encompasses several natural watersheds, the hydrologic models simulate one watershed at a time. The different watersheds that partition an urban agglomeration create a treelike or dendriform configuration. The planning of a global storm-drainage system for such a conglomerate of basins can be efficiently accomplished by coordinating the interactions among the different basins. A model for these interactions is developed.

The planning variables are the drainage network capacity, the placement and size of the storage facilities, and the size of a central treatment facility. An example of application is shown for a medium-size community in Indiana.

14. Diniz, E. V. 1979. Water-quality prediction for urban runoff, an alternative approach. Stormwater Mangt. Model Users' Group Mtg. Proc. 1979, pp. 112-134. Proj. Off. H. C. Torno, Washington, D.C.

Abstract: The accurate prediction of stormwater quality resulting from nonpoint sources of pollution has recently become of noteworthy interest. In general, stormwater quality is a function of the total pollutant accumulation on all surfaces exposed to rainfall. However, the rainfall intensity and washoff capacity of the pollutants are also important factors. After pollutants have been dislodged from exposed surfaces, overland flow and channel hydraulics determine the pollutant concentrations evidenced at a downstream observation of sampling site. Recent studies have indicated that pollution accumulation rates are affected by several factors, including land use, population density, impervious area, traffic intensity, condition of surface area, total overland flow length, time from last rain, street-sweeping frequency, climate, and season. A water-quality prediction strategy, as normally formulated, requires the compilation of a data base, calibration of a predictive model, simulation of existing and future conditions, analysis of these predictions, and use of the results in planning decisions. Consequently, the data base provides a foundation on which both the analysis and subsequent decisions will be carried out. Because of the importance of valid data to the overall strategy, numerous investigators have attempted to compile data that could be used to develop predictive correlations between land use, watershed characteristics, runoff, and water quality. The result of these efforts is a very comprehensive data base for areas throughout the United States. Unfortunately, the data collection and analysis procedures utilized by each investigator are rarely uniform, and consequently different sets of data must be carefully processed to be comparable.

15. Diniz, E. V. 1980. Quantifying the effects of porous pavements on urban runoff. Natl. Symp. on Urban Hydrol., Hydraul., and Sediment Control, Lexington, Ky., Proc. 1980, pp. 63-70.

Abstract: Porous pavements have been suggested as a means to reduce volume of runoff as well as peak flows resulting from urbanization. The use of porous pavements allows for infiltration into the ground from paved areas that would otherwise be impermeable. Porous pavements can also be used to reduce the overload on existing storm sewers. The effects on runoff quantity and quality from porous pavements have been quantified by a modeling scheme, in which the pavement and subgrade are considered as two hydraulically connected control volumes forming a single system. Inflows to the system are direct rainfall and an overland flow hydrograph from contributing impervious areas. Outflows from the system include vertical seepage, horizontal drainage, evaporation, and surface flow in the case of a surcharged porous pavement. Model input requirements include physical dimensions of the porous pavement, rainfall intensities, and impermeabilities of the pavement, subgrade, and natural ground. A depth storage function for the pavement and subgrade is also necessary. A comprehensive temporal accounting of flow and storage in each element of the system is output from the model.

16. Freund, A. P., and C. D. Johnson. 1980. Comparison and relationships of stormwater quality and basin characteristics: Madison, Wisconsin. In Haan, C. T., ed., International Symposium on Urban Storm Runoff, pp. 143-155. Univ. Ky., Lexington.

Abstract: The physical and hydrologic characteristics of three large, diverse urban catchments in Madison, Wis., are examined, and relationships are developed between rainfall, discharge, sediment, and nutrients using regression analysis. The developed relationships provide a basis for comparing the behavior of each basin as related to its physical characteristics. The results of a street debris sampling program undertaken in each of the monitored urban basins are reported, and implications for stormwater management are briefly explored.

17. Gburek, W. J., and J. B. Urban. 1980. Storm water detention and groundwater recharge using porous asphalt. Initial results. In Haan, C. T., ed., International Symposium on Urban Storm Runoff, pp. 930-940. Univ. Ky., Lexington.

Abstract: Data collected and observations made during the first 2 years of operation of the Willow Grove facility allow us to assess the potential of porous asphalt pavement for storm water detention and groundwater recharge. To date, the porous asphalt plot has produced no surface runoff from either high-intensity or long-duration rainstorms to which it has been subjected—7.0 inches per hour for 6 minutes (25-year return period) and 0.37 inch per hour for about 8 hours (5-year return period), respectively. Generally, 70 to 90 percent of the rainfall appears as percolate below the plot on both the monthly and the individual storm basis, although commonly no percolate appears during individual events of up to about 0.3 inch. Groundwater beneath the porous asphalt plot responds relatively rapidly to rainfall, usually within about 6 hours, and at the center of the plot it rises approximately 5 feet per inch of rainfall. A very localized groundwater mound is formed by every storm that causes percolate, but this mound forms and dissipates rapidly. Concentrations of both the critical inorganic and organic water-quality parameters within the percolate leaving the porous asphalt plot are well below acceptable drinking water standards; the percolate seems to pose no groundwater contamination threat. Field testing of the strength of the porous asphalt plot showed that the plot as constructed is able to support light to moderate traffic. Observations during severe weather conditions indicate that the porous asphalt layer does not seem to be affected by freeze and thaw conditions and remains relatively skid-resistant during both wet and freezing weather. Finally, the initial results clearly show that groundwater is recharged under the porous asphalt plot throughout the year, whereas that under the adjacent grass cover plot is recharged slightly or not at all during the growing season.

18. Grigg, N. S., L. H. Botham, L. Rice, and others. 1976. Urban drainage and flood control projects: Economic, legal and financial aspects. Colo. State Univ., Fort Collins, Hydrol. Paper No. 85, 76 pp.

Abstract: Techniques for evaluating minor and major Urban Drainage and Flood Control (UDFC) projects are described. Economic, political, engineering, financial, and legal problems must be resolved prior to implementation of proper levels of these projects. The measurement of tangible benefits is described, though a literature review revealed no direct objective techniques for quantifying intangibles. However, some methods for establishing the relative rankings of intangible contributions show promise for improving evaluation techniques. The legal problem of establishing benefits is described, and a copy of recently enacted Colorado legislation is included. Information on estimating flood damage and selecting discount rates is presented for use by the analyst. Careful coordination of land-use and drainage-control measures is stressed. Related recent legislation and regulations are included.

19. Grigg, N. S., A. M. Duda, and J. Morris. 1980. Stormwater management in coastal North Carolina. In Kuo, C. Y., ed., National Symposium on Urban Stormwater Management in Coastal Areas, pp. 33-34. Amer. Soc. Civ. Engin., New York, N.Y.

Abstract: The objective of this paper is to assess the magnitude of the stormwater runoff and flooding problem in the North Carolina coastal zone, to describe existing management programs, and to provide recommendations for improving stormwater management programs. The discussion is based on the practical aspects of a fragmented and pluralistic approach to stormwater management in the coastal zone, including three levels of government, several categories of problems, and the multiple objective approach to problem solutions. North Carolina approaches the stormwater management problem realistically by seeking multiple objectives through multiple means. We cannot expect that new comprehensive stormwater management legislation or extensive new management programs will be approved by the General Assembly in the near future. The only alternative is to make midcourse corrections in our various existing programs at the local, State, and Federal level to insure that they are coordinated and more effective.

20. Guy, H. P. 1978. Sediment management concepts in urban storm water system design. In Helliwell, P. P., ed., International Conference on Urban Storm Drainage, pp. 523-534. Univ. Southampton, England.

Abstract: Storm drainage systems can be designed that will greatly reduce peak rates of runoff and the amount of sediment and pollutants normally transported from urbanizing and urban areas to receiving water bodies. Decreased peak flow rates reduce the potential for serious channel enlargement and additional sediment problems downstream from the development. Optimum design can be achieved through effective land-use planning that is well coordinated with natural drainage. This in turn will minimize excavation and soil exposure during construction and provide a maximum of individual and (or) community onsite storm water detention storage. The resulting storm drainage system would usually have a lower initial cost and result in a more esthetically pleasing neighborhood than generally exists with conventional designs, but it could cause loss of convenience and be more costly to maintain.

21. Hawkins, R. A., B. F. Meloy, and J. L. Pavon. 1979. Procedure for the establishment of statewide wasteland allocations. Stormwater Mangt. Model Users' Group Mtg. Proc. 1979, pp. 83-92. Proj. Off. H. C. Torno, Washington, D.C.

Abstract: State regulatory agencies are faced with the problem of developing effluent limitations for industrial, semipublic, and municipal dischargers which assure that water-quality standards are met and that the economic burden of environmental protection is shared as equitably as possible among all dischargers to a stream segment. In the past, emphasis has been

placed on the development of sound, technical, water-quality modeling procedures and the calibration and verification of the water-quality models. The purpose of this paper is to present the minimum treatment requirements that have been established for dischargers by the U.S. Environmental Protection Agency and a procedure that allows regulatory agencies to decide where limited resources for water-quality sampling and field investigation should be placed in developing defensible waste load allocations.

22. Henry, J. G., and P. A. Ahern. 1976. The effect of storage on storm and combined sewers. 105 pp. Canada-Ontario Agreement Research Program, Ottawa, Ontario, Canada.

Abstract: The effect of storage on storm and combined sewers has been investigated for a residential subdivision of approximately 100 acres under development in southern Ontario. The storage methods examined were (1) ponding of rainfall on flat roofs, (2) onsite storage of roof runoff, (3) storage of flows from street gutters at catch basins, and (4) holding reservoirs as part of the sewer network. A hydrograph model for estimating stormwater runoff from residential areas has been developed and incorporated in a computer program. The model was used to determine the outflow hydrograph at the storm sewer outfall from the subdivision for a synthetic 2-year design storm. An alternate design, replacing the separate sanitary and storm sewers by combined sewers, was carried out and the outflow hydrograph from a combined sewer network was determined. The effects of different storage methods on the outflow hydrograph were tested for both the separate and combined systems. Substantial reductions in peak flow were found to occur as the level of storage was increased, with holding reservoirs providing the greatest reductions. Cost data from the original separate system design were used to calibrate formulas for estimating sewer pipe costs. The total costs of systems incorporating various storage options were compared. A combined sewer system was found to be slightly less expensive than the separate system, and small savings in subdivision sewer costs resulted when storage was incorporated.

23. Jackson, T. J., and R. M. Ragan. 1974. Hydrology of porous pavement parking lots. Amer. Soc. Civ. Engin., Hydraul. Div. Jour. 200(HY12), Proc. Paper 11010, pp. 1739-1752.

Abstract: Numerical solutions of the Boussinesq equation were used to examine the hydrologic behavior of porous pavement systems incorporating subdrains in open-graded base courses placed on impermeable membranes. A series of numerical experiments showed that substantial control of the runoff hydrograph from parking lots could be obtained through utilizing porous pavements. The numerical experiments conducted with synthetic design storms were used to develop equations and graphs for use by engineers designing porous pavement systems for runoff control.

24. Kamedulski, G. E., and R. H. McCuen. 1978. The effect of maintenance on stormwater detention basin efficiency: Water Resources Bul. 14(4):1146-1152.

Abstract: Stormwater detention is an effective and popular method for controlling the effects of increased urbanization and development. Detention basins are used to control both increases in flow rates and sedimentation. Although numerous stormwater management policies have been proposed, they most often fail to adequately consider the maintenance of the basin. Sediment accumulation with time and growth of grass and weeds in the emergency spillway are two maintenance problems. A model that was calibrated with data from a stormwater detention basin in Montgomery County, Md., was used to evaluate the effect of maintenance on the efficiency of the detention basin. Sediment accumulation in the basin caused the peak reduction factor to decrease while it increased as vegetation growth in the emergency spillway increased. Thus, the detention basin will not function as intended in the design when the basin is not properly maintained. Thus, maintenance of detention basins should be one component of a comprehensive stormwater management policy.

25. Kamedulski, G. E., and R. H. McCuen. 1979. Evaluation of alternative stormwater detention policies. Amer. Soc. Civ. Engin., Water Resources Planning and Mangt. Div. Jour. 105(WR2):171-186.

Abstract: Mathematical modeling is quick, inexpensive, and effective in evaluating existing stormwater detention policies and examining alternative policies. The model was calibrated with data collected from a watershed in Montgomery County, Md. The data base included measured precipitation and both sediment and flow into and from the detention basin. Model studies indicate that many existing stormwater management (SWM) policies do not meet their intent because the volume-duration frequency concept that has long been used in hydrologic design is ignored. SWM policies often fail to specify a duration for detention basin design and limit the design frequency to a single return period. A detention that is designed using a policy based on a single return period will not limit the entire flood frequency curve to that of the before-development conditions, and thus the policies do not satisfy the intent of a SWM. Also, less costly designs are possible if both basin volume and outlet characteristics are considered simultaneously.

26. Krishnamurthi, N., and J. L. Balzer. 1978. Design storm for sedimentation ponds. 12 pp. Environ. Quality Depart., Utah Internatl. Inc., San Francisco, Calif.

Abstract: The Office of Surface Mining and Reclamation has adopted a 10-year, 24-hour precipitation event as the design storm for sedimentation ponds to limit sediment concentrations in effluents. The authors believe that the design storm approach using the frequency analysis is seldom warranted and often leads to overdesign and undue costs. They discuss the physical process of precipitation that causes runoff and how it should be considered in developing criteria for the design of sedimentation ponds. They recommend that the Office of Surface Mining revise the design principles of sedimentation ponds for both environmental and economical reasons and that they increase emphasis on limiting the sediment volume flowing past a mining facility rather than limiting its concentration in the effluent. It is their hope that these recommendations could affect EPA effluent regulations in the future.

27. Krishnamurthi, N., and W. T. Lenocker. 1980. Comparison of HEC 1 and TR 20 Programs. In Kuo, C. Y., ed., National Symposium on Urban Stormwater Management in Coastal Areas, pp. 92-98. Amer. Soc. Civ. Engin., New York, N.Y.

Abstract: Determination of peak flows in an ungaged watershed has been of interest to practicing engineers because of increased interest in flood plain management programs at the local, State, and Federal levels. Since the 1960's, research institutions and academic universities have developed many rainfall-runoff simulation models for the ungaged watersheds. Some of the notable, commonly used models are (1) Stanford Watershed Model, (2) HEC 1, (3) U.S.G.S.-Dawdy Model, (4) TR 20, (5) USDAHL, and (6) ILLUDAS. Although these models are well documented as to the purpose of programs, identification of variables, and explanation of input and output procedures, very little work has been done on comparing them. The objective of this paper is to compare two of these models—HEC 1 and TR 20—as to their accuracy and the resources needed. The HEC 1 program was developed by the Hydrologic Engineering Center of the U.S. Army Corps of Engineers to handle flood hydrograph computations for precipitation and runoff on a complex, multisubbasin, multichannel river basin. The TR 20 program was developed by the Soil Conservation Service of the U.S. Department of Agriculture to compute surface runoff from any synthetic or natural rainstorm. Detailed descriptions of these programs and the input parameters are explained in their user's manuals. Based on preliminary testing, the authors believe that if rainfall and runoff data are available, the HEC 1 program is best suited to calibrate the input parameters of a rainfall-runoff simulation and to predict the peak flow of floods. However, the coefficients of Snyder and Clark for the HEC 1 program are not readily available for many ungaged watersheds. For such watersheds, TR 20 programs can be best utilized through use of soil survey maps.

28. Lai, C. 1980. Urban storm sewer flows in coastal areas. In Kuo, C. Y., ed., National Symposium on Urban Stormwater Management in Coastal Areas, pp. 244-254. Amer. Soc. Civ. Engin., New York, N.Y.

Abstract: Analyses and management of urban stormwater in coastal areas have become increasingly important in recent years. Urban basins are generally small and consist of a large percentage of impervious surface. Many sewers in coastal areas have small conduit slopes and tide-affected flows. Additional features, such as rapid change of discharge due to subtropical rainstorms, are common to the sewers of southern coastal areas. Storm sewers in the Miami, Fla., area exhibit a number of these flow characteristics typical of urbanized southern coastal areas. Accurate simulation of this class of flows remains difficult, and general, rational, and reliable deterministic methods for solving such flow problems are needed. The purpose of this paper is to examine and explore methods for analyzing the transient flows of urban storm sewers in southern coastal areas. The study considers three general cases: (1) Full-pipe or closed conduit flow, (2) free-surface or open-channel flow, and (3) two-phase or mixed flow. For ease of formulating a workable approach, storm sewer configurations in southeast Florida are used to develop the numerical solution technique. Numerical schemes for simulating these three types of flow have been investigated, and a computer model for full-pipe flow has been applied to a storm sewer flow in south Miami, Fla. The simulated discharge hydrograph generally compares well with the measured one; however, some refinement in low discharge analysis seems necessary. The use of a rigid water column theory for full-pipe flow is adequate for most sewers. "Minor losses" contribute significantly to hydraulic loss in the flow simulation. A U-shaped flow control device may be used advantageously to obtain a point discharge in a sewer pipe for the open-channel flow regime. In fact, some U-shaped constrictions have been installed for this purpose in south Florida sewers by the U.S. Geological Survey.

29. Lakatos, D. F., and K. C. Wiswell. 1978. Computer simulation of storm drainage system: A case study based on the use of the Penn State runoff model. In Haan, C. T., ed., International Symposium on Urban Storm Water Management, pp. 1-12. Univ. Ky., Lexington.

Abstract: Successful management of urban water resources depends on the ability of urban planners and managers to predict accurately the effects that increased urban development will have on stormwater runoff. The lack of simple methods for predicting watershed response to storm events is a major factor contributing to increased urban flooding. The Penn State Runoff Model is a simple, concise, stormwater simulation program, developed for the purpose of analyzing the timing of subarea flow combinations and their effect on downstream flow rates. Information on the manner of combining subarea flows provides the basis for evaluating flood-control altenatives for the source of the flooding problem rather than for the point of actual flooding. The Peak Flow Presentation Table, a major output of the model, lists the subwatershed flows that combine to form a flood flow downstream. The timing of peak flows from individual subareas determines the magnitude of aggregate flow downstream, which in turn determines the extent of flooding. The results of a storm drainage study illustrate the practicality of the Penn State Runoff Model in developing realistic control alternatives for storm-related flooding problems. This study involved development of detailed schematics of the storm drainage system and accumulation of flow and rainfall data required for use of the model. Evaluation of the various runoff-control alternatives revealed some situations where conventional control measures are required to alleviate the immediate problems. The planning and analysis had to be sufficiently comprehensive to insure that the control program did not place an unwarranted runoff burden on downstream properties.

30. Lockwood, G. 1980. New approach to storm drainage pipe design. Civ. Engin. 50, pp. 59-61.

Abstract: With a recently developed computer program, drainage swales can be designed to provide short-term storage of stormwater. Benefits of this approach to stormwater management include reduced sewer pipe size requirements, minimal pollution of streams and lakes from runoff, reduced flooding during peak storm periods, and, if desired, a recharged aquifer.

31. Looper, R. D. 1980. Calibration and application of a watershed planning model. In Kuo, C. Y., ed., National Symposium on Urban Stormwater Management in Coastal Areas, pp. 152-162. Amer. Soc. Civ. Engin., New York, N.Y.

Abstract: Accurate determination of the stormwater runoff process is critical to the overall effectiveness of a stormwater drainage master plan. For a stormwater drainage master plan consisting of 16 basins in Pinellas County, Fla., the Soil Conservation's TR-20 computer model was selected. This model was formulated to improve the quality of watershed project planning by providing a large degree of flexibility in developing input parameters and by quickly evaluating alternative drainage systems. However, in order to apply this model to a coastal area, calibration of various input parameters had to be accomplished. The TR-20 model utilizes synthetic unit hydrograph theory, which uses input parameters based on the physical characteristics of a watershed. Several of these parameters, such as rainfall, infiltration, soil moisture capacity, and time of concentration, required special attention because of the topography and hydrology of coastal areas. Verification of TR-20 parameters was accomplished by using the continuous event model, STORM, and the single event model, HEC-1. The calibration and application of the TR-20 watershed planning model to Alligator Creek Basin in Pinellas County, Fla., are described. Problems encountered with the HEC-1 model pertain mainly to the loss rate parameter relationship. By reconstituting observed runoff events, HEC-1 must optimize loss rate parameters when given estimates of starting values for input variables. These loss rate parameters are not directly comparable to those used in the SCS curve number runoff analysis. The principal difficulty in using the TR-20 model is trying to apply the model to develop basings. Although TR-20 provides a routing procedure for reservoirs and channels, closed conduit systems are not provided for. This limitation excludes TR-20 from being used to analyze sewered areas.

32. McCuen, R. H. 1979a. Downstream effects of stormwater management basins. Amer. Soc. Civ. Engin., Hydraul. Div. Jour. 105(HY11):1343-1356.

Abstract: Urbanization decreases the natural storage of a watershed, which changes the timing characteristics of the runoff. Stormwater management (SWM) basins are an attempt to put the storage lost through development back into the runoff process. Although SWM basins provide the proper volume of storage, they fail to return the timing characteristics to those that existed prior to development. The changes in storage and timing characteristics may adversely affect flow rates and bedload transport in downstream channel reaches. A study of a 2.12-square mile watershed in Montgomery County, Md., showed that a SWM basin increased both peak flows and bedload transport rates in the channel downstream from the facility. This results from both the change in timing characteristics and the increased duration of bank-full flow. These results indicate that SWM policies must require evaluation of SWM plans on a regional basis and not just use of onsite control criteria. Also, methods that can evaluate storage and timing changes must be used in the design of SWM facilities.

33. McCuen, R. H. 1979b. Stormwater management policy and design. Civ. Engin. Design Jour. 1(1):21-42.

Abstract: Stormwater management is recognized as a requisite to controlling storm runoff from developing areas. Numerous policies have been adopted to meet the intent of stormwater management. Unfortunately many are deficient in their failure (1) to lead to designs that meet the intent of stormwater management and (2) to provide the proper guidelines for translating policy into a design that affords the maximum benefit to society. Specific deficiencies of many policies include (1) the use of a single frequency, (2) neglect of storm duration, (3) inadequate consideration of maintenance, (4) insensitivity to the importance of soil characteristics, (5) lack of recognition of differences between water quality and quality control, and (6) lack of consideration of downstream effects of detention storage. The effect of these policy deficiencies is evaluated. Different hydrologic methods are being used to translate policy into design, including graphical, empirical, unit hydrograph, and conceptual models. These methods provide various designs and differ on other important criteria, including accuracy, training requirements, design cost, total cost, and their sensitivity to policy components. The different hydrologic methods are compared using these criteria.

34. McCuen, R. H. 1980. Water quality trap efficiency of stormwater management basins. Water Resources Bul. 16(1):15-21.

Abstract: Although the water quality of rivers has received much attention, the degradation of small streams in upland areas of watersheds has only recently been recognized as a major problem. Increases in nonpoint source pollution that accompany urban expansion are a principal cause of the problem. A case study is used (1) to examine the potential for stormwater detention as a means of controlling water quality in streams frequently used to control increases in discharge rates and (2) to reduce the level of pollutants in inflow to receiving streams. Data collected on a 148-acre site in Maryland show that a detention basin can trap as much as 98 percent of the pollutant in the inflow. For the 11 water-quality parameters, most showed reductions of at least 60 percent depending on storm characteristics.

35. Manz, P. E. 1980. Development of a dynamic stormwater management system. In Kuo, C. Y., ed., National Symposium on Urban Stormwater Management in Coastal Areas, pp. 163-172. Amer. Soc. Civ. Engin., New York, N.Y.

Abstract: Conventional stormwater drainage master plans are generally developed both to provide a solution to existing flood problems and to provide adequate drainage for anticipated future development in a watershed. The evolution and selection of drainage improvements are based on Ultimate Land Use (ULU) conditions, as envisioned at the present time. Any changes in the ULU conditions of a drainage basin or revision of the recommended improvement to a channel in the basin can make the stormwater master plan obsolete or inadequate. Extensive revisions and lengthy computations are required to update the master plan and maintain it as an effective tool in solving drainage problems. A systems approach was used to develop dynamic stormwater drainage master plans for Pinellas County, Fla. Computer programs were obtained or developed to digitize the basin, calibrate and develop the hydrology, and model the hydraulic characteristics of the basin. The strength of a dynamic master plan lies in its flexibility after the final plan is submitted. The client is provided with program decks on the computer models used and copies of all input files. As land-use patterns change, the master plan can be updated and checked to see whether the alternatives are still adequate. If the alternatives prove inadequate or other changes are proposed, they can be quickly evaluated and incorporated into the master plan. In this way the client always has a current master plan that can be an effective tool to use in urban planning. The advantages of dynamic stormwater master plans include the ability (1) to maintain a current plan by incorporating changes in the land-use pattern, (2) to quickly evaluate proposed changes to the plan at a specific location, (3) to rapidly evaluate downstream responses to changes in the plan, and (4) to obtain water-quality indications of the proposed changes.

36. Mariles, O. A., J. L. S. Bribiesca, and R. D. Mora. 1978. A numerical procedure to design drainage networks based on the hydraulic and storage capacities of the pipes. In Haan, C. T., ed., International Symposium on Urban Storm Water Management, pp. 333-346. Univ. Ky., Lexington.

Abstract: A numerical procedure based on finite difference computations has been developed by the authors to calculate at any time and at any site of a given network the hydraulic parameters, i.e., velocity and depth. In this way and taking into account the storage at registers and manholes, it is possible to simulate the entire network and to know the volume of stormwater that is not possible to manage inside the pipes. Since such a volume will produce a flood and cause a certain amount of damage, it is possible to associate the damage for several storms having different return periods with the expected damage for a certain design. In this way the expected damage associated with each design can be known. If the benefit of a design is assumed to be the expected avoided damage at actual conditions and with a certain design, two graphs can be drawn; the first one will be the cost of the design against its capacity and the second will be the benefit associated against its capacity. The selection of the right design becomes obvious.

37. Mattraw, H. C., Jr., J. Hardee, and R. A. Miller. 1978. Urban stormwater runoff data for a residential area, Pompano Beach, Florida. U.S. Geol. Survey, Tallahassee, Fla., Open-File Rpt. 78-324, 108 pp.

Abstract: The U.S. Geological Survey has measured rainfall, runoff, and runoff quality for three urban sewered basins in Broward County, Fla. Approximately 2 years of records have been collected for a 47-acre single-family residential area; a 58-acre, 3,000-foot secondary divided-highway segment; and a 28-acre commercial shopping center. The three homogeneous areas were gaged with an automatic, integrated instrumentation package or urban hydrology monitor. This monitor collects and synchronously records 36-second interval rainfall and water-level information. The collection time of 24 water-quality samples is also recorded. Discharge is computed from the difference in stage through a U-shaped construction Venturi flume placed in a sewer pipe. Approximately 100 rainfall-runoff periods per site were digitized from analog records and stored in an urban data management system. Sets of nutrient and heavy-metal water-quality data were collected for 30 or more storms at each of the 3 areas and stored in the system. Loads computed for the three areas indicate the importance of the hydraulic interconnection between impervious areas. Factors affecting stormwater runoff loads include land use, proportion of hydraulically interconnected impervious area, seasonal distribution of rainfall, and antecedent dry period. The variability within a basin is great, indicating the need for systematic collection of runoff-quality information for a variety of conditions prior to any satisfactory calibration of currently available models.

38. Moodie, A. R., J. D. Scholes, and D. G. Thompson. 1978. Design of a stormwater quality and quantity monitoring system for an urban catchment - an Australian case study. In Haan, C. T., ed., International Symposium on Urban Storm Water Management, pp. 135-142. Univ. Ky., Lexington.

Abstract: A preliminary investigation into stormwater runoff quality from an urban catchment in Melbourne, Australia, is discussed. Similarities with the results obtained by workers in the United States are noted. The results of the preliminary investigation are shown to be useful in designing and operating a stormwater quality and quantity monitoring system for the catchment. Aspects of the design of this system are outlined, such as the selection of subcatchments for instrumentation and the design of a device for constant proportional depth sampling in a large Parshall flume.

39. Myers, V. A., and F. P. Ho. 1980. Coastal tide frequency, Virginia to Delaware. *In* Kuo, C. Y., ed., National Symposium on Urban Stormwater Management in Coastal Areas, pp. 74-82. Amer. Soc. Civ. Engin., New York, N.Y.

Abstract: More than 2,000 miles of U.S. coast are at a risk from temporary inundations by storm-driven seawater. A judicious decision is important on the area of the coastal zone that will be occupied and on its rational use. Such decisionmaking can lessen the risk to life and property. Many aspects of risk assessment require knowledge—in probability terms—of the elevation and lateral extent of the space that storm-driven seawater is likely to occupy. The behavior of coastal storms is ultimately assessed from past experience. The longer the return period of flood heights to be determined, the larger the experience sample required. Local experience with hurricanes does not necessarily reveal the true risk. In this study, "experience" is enhanced by applying all the data of a region to each coastal point, by deriving data needed (storm tides) from data available (meteorlogical parameters), by computing with tested models, and by developing hypothetical storms that collectively represent the full range of possibilities. This summary paper illustrates this approach to coastal tide frequency assessment, using the coast from the Virginia-North Carolina border to Delaware Bay ("Delmarva" coast) as the example.

40. Nawrocki, M., and J. Pietrzak. 1976. Methods to control fine-grained sediments resulting from construction activity. 67 pp. Hittman Associates, Inc., Columbia, Md.

Abstract: This publication is the third in a series issued under Section 304(e)(2)(C) of Public Law 92-500 concerning the control of water pollution from construction activity. It was prepared for use by planners, engineers, resource managers, and others who may become involved in programs to effectively provide for sediment control. Standard erosion and sediment control measures are usually effective in preventing runoff of the *total* sediment load. These standard techniques, however, have been relatively ineffective in preventing runoff of the fine-grained fractions, such as the silts and clays. The objective of this study was to research practical, cost-effective methods that would reduce specifically the fine-grained sediment pollution derived from construction activities. The prime consideration was to use or adapt existing technology, as described in the current literature or data, to the fine-grained sediment pollution problem.

41. Novitski, R. P. 1977. Hydrology of the Nevin fresh-meadow wetlands. 14 pp. U.S. Dept. Int., Geol. Survey, Water Resources Div., Madison, Wis.

Abstract: Wetlands have been vanishing rapidly from Wisconsin. Approximately half of the original 5 million acres has been drained or affected by drainage. The fresh-meadow wetlands have been vanishing most rapidly because of agricultural and urban pressures. To preserve wetlands in the future, the Wisconsin Department of Natural Resources needs to evaluate the tangible values of these areas. With such an evaluation, the DNR may be able to predict the type and magnitude of disturbance that will be caused by proposed wetland changes. This project will attempt to define the hydrologic system that presently maintains the Nevin wetland and to monitor and explain changes that may occur. The water quantity and quality entering and leaving the area will be evaluated as to the effect of land-use changes, drainage, nutrients, sediment, municipal and local pumpage, and hatchery. Data will be collected on spring flows into wetlands, streamflow leaving wetlands, water level, precipitation, and evaporation. Water samples for analysis of sediment, pesticides, and total organics will be collected from water entering and leaving wetlands and from ground water in shallow aquifers in the study area. An inventory of hydrologic and geologic factors affecting wetlands and an analysis of the quantity and quality of water moving through wetlands and its related drainage basin will be made. Changes in quantity and quality detected by monitoring will be useful in evaluating those factors that may be affecting the wetlands.

42. Novitski, R. P. 1978. Hydrology of wetlands in Wisconsin. 23 pp. U.S. Dept. Int., Geol. Survey, Water Resources Div., Madison, Wis.

Abstract: Interest in the role of wetlands in the hydrologic system has intensified in response to increased environmental concern. However, little information is available concerning those hydrologic factors that affect wetlands, and conversely, the effects of wetlands on the hydrologic system. To manage wetlands as a significant element in the total environment will require a better understanding of their function in the hydrologic system and their effect on the quality of water moving through them. The initial purpose will be to classify wetlands according to their function in the hydrologic system.

In particular, the effect of the wetland on runoff, sedimentation, and chemical characteristics of lakes or streams and the wetland's relation to water levels and water quality in the ground water system will be defined. Several wetland areas, each representative of one wetland category, will be studied in detail. The hydrologic system near each wetland will be defined to determine direction of water movement, both vertical and horizontal, to determine areas of recharge and discharge, to determine the function of the wetland in the local system, and to define the effect of the wetland on flood flows, low flows, and sedimentation in associated streams in the local system. The chemical nature of water entering, within, and leaving the wetlands will be examined to determine the effect of the wetland on water quality.

43. Patrick, W. H. 1981. Effect of man's alterations on wetland and estuarine chemistry. 48 pp. La. State Univ., Agr. and Mech. Col., Sch. Agr., Baton Rouge.

Abstract: Objectives are (1) to determine whether specific lakes of Barataria Basin are a source or sink for nitrogen and phosphorus; (2) to characterize sediment profile and sediment water interfaces in shallow bays, lakes, and channels; (3) to determine the significance of sedimentation throughout Barataria Basin in relation to nitrogen, phosphorus, and carbon chemistry; (4) to determine the importance of mineral components of organic marsh soils in neutralizing plant toxins such as sulfide; and (5) to continue studying nitrogen reactions in wetland systems, nitrogen fixation in water-sediment and plant-soil systems using labeled nitrogen, and denitrification in natural systems. The information obtained from this study will be used by public agencies concerned with management of coastal lands and resources in such problems as dealing with eutrophication, agricultural runoff, waste-water management, water quality, and primary production of Louisiana's coastal zone. Identified benefits to date are as follows: (1) A trophic State index based on cluster and factor analyses of several aquatic parameters has been developed; (2) a study has examined the relationship between chemical and physical properties of marsh soils and the intriguing variations in plant growth; (3) the significance of sediment transport to marsh accretion and nutrient cycling has been demonstrated; and (4) a better understanding of the nitrogen cycle in a *Spartina alterniflora* salt marsh has resulted.

44. Pennel, A. B. 1980. Retention/detention basins in coastal areas. *In* Kuo, C. Y., ed., National Symposium on Urban Stormwater Management in Coastal Areas, pp. 299-302. Amer. Soc. Civ. Engin., New York, N.Y.

Abstract: Stormwater management is an integral part of urban planning and development. Urban growth translates directly to an increase in the percentage of impervious surfaces that generates higher runoff rates and volumes over a shorter period than was previously generated from the undeveloped condition. The traditional role of stormwater management was to remove the additional water from the developed site as rapidly and efficiently as possible to minimize flood hazard and inconvenience. Continued growth and development, competing with a renewed awareness of environment issues and concerns, have led to a reevaluation of stormwater management practices. Present practices are moving toward multiple objective concepts. These generally include the traditional flood protection along with the preservation or maintenance of the existing flow quality and quantity. Use of the retention and detention basin system serves as one of the basic tools in achieving these objectives. The practicality of retention and detention basins in coastal areas is a function of the optimization of design parameters relative to the value served. The design parameters of particular influence in this regard are ground water table elevations and tail water stages. Utilization of a model that accurately accounts for these parameters in an economical and timely manner is paramount to fulfilling the obligations and goals of stormwater management in coastal areas.

45. Peterson, J. O., G. Bubenzer, and F. Madison. 1977. Evaluation of the implementation of the White Clay Lake protection and management plan. 36 pp. Univ. Wis., Sch. Agr. and Life Sci., Madison.

Abstract: Implementing the plan to protect the water quality of White Clay Lake presents an opportunity to assess its effectiveness by applying simple sediment and nutrient control measures in an agricultural watershed. Techniques such as clear-water diversion, terracing, contour stripping, better manure handling systems, and streambank protection are useful soil and water conservation practices, but applying such techniques on a broad basis should be preceded by an evaluation of their effectiveness for water-quality protection. Major changes in water quality resulting from implementing conservation practices will be most easily noted in the incoming streams. Continuous monitoring of two streams that drain about 45 percent of the watershed provides 2 years of background data on waterflows, nitrogen, phosphorus, chloride, and sediment transport. Evaluation of the management plan implementation involves a continuation of current lake and watershed monitoring plus using sediment cores to delineate the history of lake infilling. Additionally, evaluation of the effect that marsh areas have on the quality of water entering the lake will help guide judgments about preserving these wetlands for protection of lake water quality.

46. Pitt, R. 1978. The potential of street cleaning in reducing nonpoint pollution. In Haan, C. T., ed., International Symposium on Urban Storm Water Management, pp. 289-301. Univ. Ky., Lexington.

Abstract: In this paper are briefly described the conclusions of an EPA-sponsored demonstration study of nonpoint pollution abatement through improved street-cleaning practices. An important aspect of the study was developing sampling procedures to test street-cleaning equipment performance in real-world conditions. These procedures and the experimental design are described in detail in the interim report. The accumulation rate characteristics of street dirt in the area studied are summarized. The results of performance tests for street-cleaning equipment and the factors thought to affect this performance are also summarized. These data are used to draw preliminary conclusions about elements that must be considered in designing an effective street-cleaning program. The study of urban runoff yielded information on overall flow characteristics, concentrations and total mass yields of monitored pollutants in the runoff, street dirt removal capabilities, and effects on deposition in the sewerage of various kinds of storms. These data are summarized here. Urban runoff water quality is compared with recommended water-quality criteria and the quality of sanitary waste-water effluent. Costs and labor effectiveness of street cleaning, runoff treatment, and combined runoff and waste-water treatment are also compared. Preliminary results from a study of airborne dust losses from street surfaces are summarized.

47. Ports, M. A. 1978. Erosion and sediment control design. 20 pp. Md. Water Resources Admin., Watershed Permits Sect., Annapolis.

Abstract: Since soil erosion and sedimentation by water are complex processes, a better understanding of them provides a sound basis for developing improved prediction and control methods for urban areas. The Universal Soil Loss Equation is an important technique for evaluating urban erosion rates, and various conservation practices are effective for controlling urban erosion and sedimentation. Design of control plans requires the selection of appropriate control practices. These topics are discussed and illustrated as they relate to solving urban problems in erosion and sedimentation.

48. Putt, R. A., and R. L. Johnson. 1978. Onsite stormwater retention. In Haan, C. T., ed., Internationl Symposium on Urban Storm Water Management, pp. 91-94. Univ. Ky., Lexington.

Abstract: Many urban areas have tried various stormwater detention and controlled release schemes to decrease peak flow rates for many reasons, including lower costs for smaller storm sewers and decreased downstream flooding. However, detention schemes have some disadvantages, such as land requirements and safety problems. An alternate method for reducing storm sewer requirements is to use retention and reroute part of the flow that would ordinarily be urban runoff into the soil for subsequent percolation into the ground water supply. Onsite retention methods can provide the same advantages of peak flow reduction as detention without the extra land requirements. Most stormwater runoff in developed areas is from impervious cover. Reduction of both runoff volume and rate can be accomplished by retaining part of the runoff from roofs using porous media "French drains." Modifications were made to the Runoff Block of the Stormwater Management Model (SWMM) from the Environmental Protection Agency. The computer program was changed to allow a fraction of the runoff from the impervious surface to be immediately directed to onsite retention units of specified volume. Overflow from the retention units during extreme storm periods was onto adjacent pervious surfaces. Using a hypothetical residential drainage area, retention volumes of 500 and 1,000 cubic feet per acre were studied. The fraction of impervious area was set at 0.30, and one-half of this area drained into the retention storage. The modified SWMM computer program showed that for a 5-year, 1-hour storm the total runoff volume with no retention was 363 cubic feet, which was reduced to 256 and 218 cubic feet for 500 and 1,000 cubic feet per acre of onsite retention, respectively. For the same storm event, the sum of the peak runoff rates of 132 cubic feet per second with no retention was reduced to 95 and 79 cubic feet per second, respectively, with 500 and 1,000 cubic feet per acre. Reduction of this magnitude could have a large impact on stormwater management strategies.

49. Reuter, F., and C. Fox, Jr. 1976. Evaluation of the cost-effectiveness of non-structural pollution controls: A manual for water quality management planning. 54 pp. CONSAD Res. Corp., Pittsburgh, Pa.

Abstract: A methodology is described for evaluating the economic costs of non-structural pollution control techniques such as land-use control. Used instead of or as a complement to structural pollution controls, non-structural alternatives can increase the effectiveness and/or decrease the costs of achieving environmental quality objectives. Included in the report are chapters on legal feasibility, social impacts, and alternative compensatory mechanisms for non-structural controls.

50. Schluchter, S., and M. Teubner. 1980. Coastal flooding of tidal estuaries. In Kuo, C. Y., ed., National Symposium on Urban Stormwater Management in Coastal Areas, pp. 275-278. Amer. Soc. Civ. Engin., New York, N.Y.

Abstract: Several different two-dimensional surge models are being used by Federal and private agencies to predict the magnitude of hurricane surges along the open coast; however, surge levels in estuaries can vary significantly from open coast values. Flood levels in these estuaries can be accurately and economically determined using a one-dimensional unsteady flow model. Such a model is considered in this report. It includes both dynamic and storage effects associated with the channel flow and the tidal flats, as well as the effects of multiple-connected river junctions. An area along the Texas coast was selected to demonstrate the model's capabilities. A one-dimensional unsteady flow model is briefly described. Some of its features include (1) its capability of handling a large number of rivers, tributaries, and canals at one time, (2) its adaptation to using more accurately determined input data involving cross-sectional parameters, and (3) its ability to use predetermined elevation hydrographs, either from an associated two-dimensional model or from measured data, as input elevations. Unfortunately, both the original one-dimensional model and the combined model have one main problem—insufficient surge data for calibration and verification. It is relatively easy to recreate existing tidal conditions, but to accurately determine storm surge elevations, more detailed data are required.

51. Simons, D. B., R. M. Li, and T. J. Ward. 1978. Estimation of sediment yield for a proposed urban roadway design. In Haan, C. T., ed., International Symposium on Urban Storm Water Management, pp. 309-315. Univ. Ky., Lexington.

Abstract: Roadways are one of the primary sources of sediment in urban environments. Soil erosion and the resultant sediment yield are important problems during construction and postconstruction of road surfaces. Increased soil erosion and sediment yield often result from scarification of the natural terrain and changes in drainage patterns caused by urban road construction. This increased sediment loading to streams and drainages affects water quality, riparian and aquatic ecosystems, and flooding potential due to aggradation of channels. Techniques have been developed to estimate erosion and sediment yield from roadways. One approach used complex computer simulation of physical processes that determine erosion and sediment yield. Although a useful technique, complex computer simulation is often difficult to comprehend for many field users. A simpler, more readily understood physical process computer simulation model has been developed. It is based on the same physical processes as the complex model but integrates and averages the processes to develop a physically realistic solution. In this paper, the simplified version of a roadway sediment yield model is given along with applications to selected roadway designs. Using this model and available roadway data, one can quickly estimate sediment yield from a proposed roadway design. Roadway components considered in the model include the road surface, cut and fill slopes, drainage ditches, and culverts. Impact of design alternatives, such as a roadway cross section, road gradient, road surfacing, and size and spacing of cross drains, can be determined by the model. Use of the simplified model in road design can alert the urban planners and roadway design engineers to potential erosion and sediment problems and help the designers avoid such problems.

52. Slyfield, R. E. 1978. Management of urban runoff by remote sensing in south Florida. In Haan, C. T., ed., International Symposium on Urban Storm Water Management, pp. 235-244. Univ. Ky., Lexington.

Abstract: A continuous urban area 100 miles long by 10 miles wide borders the southeast coast of Florida. Because of the unique character of this area—very flat topography, average elevation of about 5 feet above sea level, and very intensive tropical rainfall—immediate water management decisions are required. Consequently, the South Florida Water Management District, which operates the area's primary water management facilities, is constructing a remote sensing and control system. This system transmits vital hydrometeorological data via a terrestrial telemetry system to a control center where management decisions are made. Operational directions are then transmitted over the system to control facilities and executed remotely. Simultaneously these actions are monitored at the control center. Because the system's main function is to perform during periods of high stress, design requirements have been adapted to assure that it will be operational when needed most. Various innovative features are described that increase reliability. The system consists of a microwave backbone in a loop configuration and is capable of fully duplex transmission under computer control. Remote acquisition and control units (RACU's) contain environmental sensors and control elements that operate water-control facilites. RACU's also contain transceivers powered by either commercial or solar power. Many sensors are of unique design, and high accuracy requirements have been verified.

53. Smolenyak, K. J. 1980. Stormwater runoff modeling of a planned community. In Kuo, C. Y., ed., National Symposium on Urban Stormwater Management in Coastal Areas, pp. 378-387. Amer. Soc. Civ. Engin., New York, N.Y.

Abstract: The Tampa Palms development, which is located approximately 11 miles northeast of downtown Tampa, Fla., is a residentially oriented master-planned community of 5,400 acres, with an ultimate density of 13,000 units. Stormwater discharges from this property will enter the Hillsborough River, a potable source of water for the City of Tampa. In order to assess the effects of the development of the Tampa Palms property on the quantity and quality of stormwater runoff entering the receiving systems, the Storage Treatment Overflow Runoff Model (STORM) was employed. STORM, a widely used and proven hydrologic model (continuous simulation), was initially applied to the project in its current undeveloped condition. It used water-quantity and quality data collected from several monitoring stations strategically located at surface runoff sites throughout the property for model calibration. The proposed changes in land-use and drainage characteristics due to development were then incorporated into the model to predict future stormwater runoff quantity and quality conditions and to analyze potential impacts to receiving systems. The net impacts of stormwater discharges from the Tampa Palms property on the Hillsborough River should be minimal, because significant treatment of stormwater runoff will be achieved in the Tampa Palms drainage system and the pollutant loads (mass) from the developed property will only constitute a small percentage of the loads carried by the river. For all the pollutants modeled, total loads for the postdevelopment basins represent a minor to very minor percentage of the total loads for the Hillsborough River. In addition, stormwater discharges from the developed drainage system will be attenuated via controlled release and will increase the ability of the Hillsborough River to assimilate the loads.

54. Ward, A. J., C. T. Haan, and B. J. Barfield. 1977. Simulation of the sedimentology of sediment detention basins. 133 pp. Univ. Ky., Water Resources Res. Inst., Lexington.

Abstract: Sediment detention basins are widely used to control downstream sediment pollution from strip mining and construction activities. A mathematical model for describing the sedimentation characteristics of detention basins has been developed. It requires as inputs the inflow hydrograph, inflow sediment graph, sediment particle size distribution, detention basin stage-area relationship, and detention basin stage-discharge relationship. Based on this information, the model routes the water and sediment through the basin. In this process, the outflow sediment concentration graph, the pattern of sediment deposition in the basin, and the sediment trapping efficiency are estimated. Comparison of predicted results with measured sediment basin performance indicates that the model accurately represents the sedimentation process in detention basins. The authors describe the model, illustrate its use in design, explain how to process it on a digital computer, and present its program listing.

55. Weber, W. G., Jr., and C. Wilson. 1976. Evaluation of sediment control dams. 36 pp. Pa. Dept. Transp., Bur. Mater., Testing and Res., Harrisburg.

Abstract: Small dams in waterways have been extensively used by the Pennsylvania Department of Transportation in erosion control. Their performance was evaluated to determine how well they removed sediment from flowing water. Various methods of constructing these dams were compared. The results indicated that only minor amounts of suspended sediment were removed from the flowing water. However, the bottom transport was trapped by these dams. The rock dams generally were stable.

56. Widseth, R. A. 1978. Utilizing a storm sewer outlet. In Haan, C. T., ed., International Symposium on Urban Storm Water Management, pp. 317-322. Univ. Ky., Lexington.

Abstract: The University of Minnesota operates a college and an agricultural experiment station north of the City of Crookston in northwestern Minnesota. In 1970, the university installed an 11,000-foot-long storm sewer outlet to drain the campus area. This outlet crossed undeveloped university-owned farmland along its route, but it was not sized to serve this property because a need was not anticipated. Now 100 acres of this land have been sold for development and require storm sewer service. By using a stormwater detention basin and a controlled outlet, this development can be drained by the existing storm sewer for approximately one-seventh the cost of constructing a new outlet.

57. Willison, J., and others. 1977. Preventive approaches to stormwater management. 163 pp. U.S. Environ. Protect. Agency, NPS Br. (WH-554), Washington, D.C.

Abstract: This document was prepared for use by local agency administrators and others who may be involved in programs to abate pollution from urban runoff. The concept of source control has been discussed in the past, and this report lists many techniques that would be included in a Best Management Practice (BMP). The legal, financial, and institutional problems of implementing these practices are also discussed.

The objective of this study was to provide for local administrators a basic understanding of BMP and its techniques.

58. Woodward, D. E., P. I. Welle, and H. F. Moody. 1980. Coastal plains unit hydrograph studies. In Kuo, C. Y., ed., National Symposium on Urban Stormwater Management in Coastal Areas, pp. 99-107. Amer. Soc. Civ. Engin., New York, N.Y.

Abstract: A hydrologic study in 1975 indicated that the U.S. Soil Conservation Service (SCS) was not able to simulate recorded flood hydrographs or regional peak-flow frequency curves on the Delmarva Peninsula in Delaware, Maryland, and Virginia. The standard SCS unit hydrograph was used in these detailed hydrologic studies. The peak rate equation for this standard SCS unit hydrograph can be expressed as $q_p = 484QA/T_p$, where q_p is the peak discharge in cubic feet per second, 484 is a shape and units conversion factor, Q is the volume of runoff in inches, A is the drainage area in square miles, and T_p is the time to peak in hours. The 484 factor is referred to here as a dimensionless unit hydrograph peak factor. The studies to develop a dimensionless unit hydrograph for the Delmarva Peninsula are described. The standard SCS unit hydrograph was developed from small agricultural watersheds primarily in the Midwest. They are generally characterized by local relief of 50 to 100 feet with little or no natural storage. Since physical characteristics in the Midwest differ from those in the Delmarva Peninsula, it seemed necessary to develop a unit hydrograph specifically for the study area. The basic shape of the new hydrograph appears rational because when compared with the standard SCS unit hydrograph, the recession limb contains more volume and the peak rate is lower. Analysis of the August 3, 1967, storm on Murderkill River was used as a check on the reasonableness of the selected unit hydrograph.

59. Wu, J. S., and R. C. Ahlert. 1978. Prediction and analysis of stormwater pollution. In Haan, C. T., ed., International Symposium on Urban Storm Water Management, pp. 183-188. Univ. Ky., Lexington.

Abstract: In recent years, pollution from nonpoint sources has become increasingly important in water-quality planning and management. Stormwater pollution can be characterized in magnitude and in concentration of pollutants as intermittent and impulse-type discharges into receiving waters, causing shock-loading problems to the ecosystems of these water bodies. The classical approach, using critical low flow as the design criterion for water-quality management schemes, must include the effect of storm runoff. The state-of-the-art methodologies for predicting storm runoff loads are summarized. Four methods

to achieve different levels of prediction include zero order, rational, statistical, and descriptive, i.e., average annual storm load, storm load per event, and storm load distributions within events. The authors' ongoing efforts are to develop an analytical method for assessing stormwater impacts as to biochemical oxygen demand and sediment on receiving water quality. The receiving water body is represented by a completely mixed reactor and a settling basin during storm runoff. Surface runoff and pollutant loads enter the receiving stream at an average uniform rate over each time interval, i.e., a stepwise, steady state approach to input variables. Deposition or resuspension of sediment or both are limited by the sediment transport capacity of the stream. Model equations and analytical solutions are presented, with the Assunpink Basin of New Jersey as the illustrative example.

60. Wycoff, R. L. 1978. Computer-aided hydraulic design of storm drains. In Haan, C. T., ed., International Symposium on Urban Storm Water Management, pp. 315-321. Univ. Ky., Lexington.

Abstract: Conventional hydraulic design of closed conduit storm drains usually consists of selecting conduit sizes based on open channel flow computations. Conventional design of highway culverts, on the other hand, uses the available static energy head at the culvert site. A computer-aided design procedure is presented, whereby the hydraulic equations of culvert flow are utilized to size branching, closed conduit, and storm drainage networks. By this method, the available static energy head is used as efficiently as possible. The design algorithm selects a pipe size array that will carry the design flows without overtopping while minimizing the largest conduit size selected. The pipe size array obtained by applying the computer-aided design procedure to an example network is compared with the pipe size array obtained by open channel flow design procedures. In general, the computer-selected sizes are smaller than the open channel sizes, resulting in construction cost savings.

61. Wycoff, R. L., J. E. Scholl, and S. Kissoon. 1979. 1978 needs survey - cost methodology for control of combined sewer overflow and stormwater discharges. 474 pp. U.S. Environ. Protect. Agency, Munic. Constr. Div., Off. Water Program Oper., Washington, D.C.

Abstract: The major objective of this project is to develop updated nationwide cost estimates for controlling pollution from combined sewer overflow and urban stormwater runoff on a State-by-State basis. A secondary objective is to establish the National Combined Sewer System Data File. This file contains

information on every known combined sewer system in the Nation, including location, sewer system and receiving water characteristics, and status of current combined sewer overflow planning.

62. Wycoff, R. L., and V. P. Singh. 1976. Preliminary hydrologic design of small flood detention reservoirs. Water Resources Bul. 12(2):337-349.

Abstract: Flood detention reservoir design is a common water resources problem for engineers and others. In this paper, a method is described by which the volume of flood storage required for a single reservoir or a series of reservoirs may be estimated without using numeric flood-routing techniques. An idealized model based on triangular hydrographs was developed to define the major relationship among the variables. A generalized equation was then obtained by multiple linear regression analysis of computed flood-routing data. The effect of storage distribution on flood peak reduction efficiency was then investigated by means of a computer model study of equal-sized reservoirs located in series. This resulted in a relationship between number of reservoirs and peak reduction efficiency and, together with the generalized storage volume equation, formed a proposed procedure for the preliminary hydrologic design of small flood detention reservoirs.

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