residential

storm water management

objectives, principles & design considerations

published jointly by
ULI—the Urban Land Institute
ASCE—the American Society of Civil Engineers
NAHB—the National Association of Home Builders

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New York, New York 10017

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ULI—the Urban Land Institute is an independent, nonprofit organization incorporated December 14, 1936 to improve the quality and standards of land use and development.

The Institute is committed to conducting practical research in the various fields of real estate knowledge; identifying and interpreting land use trends in relation to the changing economic, social and civic needs of the people; and disseminating pertinent information leading to development of land.

ULI receives its financial support from membership dues and sale of publications and contributions for research and panel services.

 Printed in the United States of America. Library of Congress Catalog Number: LC75-34759

Acknowledgements

An undertaking such as this required the cooperative participation by a significant number of representatives from each of the organizations. The need for a report on residential storm water management originated in the NAHB Land Use and Engineering Committee in 1971. An initial survey and interim report completed in 1973 by the NAHB Research Foundation and its staff was the basis for initiation of the joint effort among NAHB, ASCE and ULI. This initial effort was reviewed by each organization. As a result of that review, a revision was prepared by Carl F. Izzard under a grant from the Urban Land Research Foundation. This revision was then reviewed by the committees of NAHB, ASCE & ULI; a further draft, including a discussion of legal implications by Ruth M. Wright of Boulder, Colorado, was prepared with the participation of staff members from NAHB, ULI and the NAHB Research Foundation. The draft was further reviewed and modified with additions from members of the ASCE review committee. Special acknowledgement needs to be given to the Urban Water Resources Research Council of ASCE, especially Messrs. Izzard, Jens and Jones, for providing leadership and counsel as well as a testing ground for the concepts set forth in this report. Without the willing and diligent participation of all those involved, this joint effort could not have been brought to fruition.

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Foreword

Publication of this report under the joint auspices of the American Society of Civil Engineers, the National Association of Home Builders and ULI—the Urban Land Institute is a continuation of the unique cooperative effort which resulted in a previous jointly sponsored publication, *Residential Streets: Objectives, Principles, and Design Considerations.* This report is a second jointly sponsored and reviewed report which represents the attitudes and concerns of the three organizations on a subject of common interest and importance—the setting of objectives, principles and design considerations to be applied to the development of storm water management systems to serve residential communities.

The content of this report evolved, as did its predecessor, from an assessment of current practices to a guide toward a more creative and thoughtful approach to storm water runoff management. While not rejecting past practice, it clearly identifies and articulates a new underlying philosophy and approach which diverges significantly from the past.

It is hoped that this report will stimulate communities of all sizes, in all locales, to rethink current storm water management practices and to adopt those which are responsive to local conditions and supportive of the basic objectives and principles presented herein.

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INTRODUCTION

The Need for Change

The basic philosophy of storm water management in residential, and for that matter, all kinds of development, is open to challenge and revision. Nationwide experience with the effects of narrow and inadequate philosophies on past practices indicates that storm water has rarely been well managed, and has in fact often been mismanaged. To some extent, at least in residential developments, past approaches, development patterns and public policies inadvertently encouraged the very approaches this report seeks to modify. Simply stated, past philosophy sought maximum convenience at an individual site by the most rapid possible elimination of excess surface water after a rainfall and the containment and disposal of that water as quickly as possible through a closed system. The cumulative effects of such approaches have been a major cause of increased frequency of downstream flooding, often accompanied by diminishing groundwater supplies, as direct results of urbanization; or have necessitated development of massive downstream engineering works to prevent flood damage. The downstream urban flooding problem has become acute during the past thirty years as communities have grown and as curbed roadways (paved channels) have been installed in both new suburban areas and throughout older areas that formerly provided runoff-retarding storage in roadside swales or ditches. Amelioration of the unfortunate results of past urbanization requires very large investments to construct additional flood control works. Where flood control is infeasible, the flooding hazard reduces property values and may lead to abandonment, which is unacceptable to community leaders.

The entire process of storm water runoff management is currently undergoing a significant redirection, if not a revolution. This is evidenced by a new emphasis on the desirability of detaining or storing rainfall where it falls, on-site, which sometimes requires tradeoffs with short-term localized inconvenience. These kinds of solutions applied to individual sites or developments often have beneficial cumulative effects by attenuating both peak runoff and total short-term runoff. If fully applied throughout a drainage basin, they would reduce major facilities investments required to protect against flood hazards in the lower portion of the drainage basin.

The Problem

In an undeveloped area, the storm water management system is provided by nature. The cycle begins with rainfall—the storm. Some of the water stands where it falls on leaf or plant, and evaporates; some is absorbed into the ground near the surface and feeds trees and plants, ultimately to be returned to the atmosphere by transpiration; some percolates deeply into the ground and replenishes the groundwater supply. The remainder gradually or quickly collects into rivulets, accumulating both in quantity and speed as it hurries down the watershed through drainageways and streams to its ultimate destination—the river and then the sea, to begin the cycle again (Figure 1).

All of us have been exposed to this simple explanation but its seeming simplicity belies its complexity. Nature's inability to accommodate severe storms without significant damage, even where urbanization has not occurred, is quite apparent. The natural drainage systems in an undeveloped area are not static in design, but are constantly changing. Streams change course, banks erode, vegetation and soil permeability change with seasons, lakes fill in with sediment and disappear. The stripping of ground and tree cover by fire may change an entire system, forcing new natural accommodations throughout the system. Urbanization has required new drainage systems because man was both unwilling to suffer inconvenience where it could be avoided and because he would not tolerate the loss of life or property. In an urbanizing area, those concerns often have been translated into storm water management system requirements for convenience and safety, without recognition of other significant considerations. This has meant that no matter how large the rainfall or its duration, the drainage system was expected to remove runoff as quickly as possible, to restore maximum convenience in the shortest possible period of time. At the same time, fears of loss of life and of damage to possessions have encouraged a search for 100 percent protection against the worst storm that nature might generate.

It is the premise of this report that these two objectives are not mutually achievable without extremely high "cost". Where we have sought maximum convenience as our first choice in the upper and middle reaches of a watershed, we have created imbalanced systems, and increased hazard and risk of damage along the lower reaches. The need is obvious — to strike a realistic balance between elimination of inconvenience and protection against hazard. Past practice has not always achieved such a balance. In fact, it more often than not has encouraged acceleration of imbalance as areas urbanized.

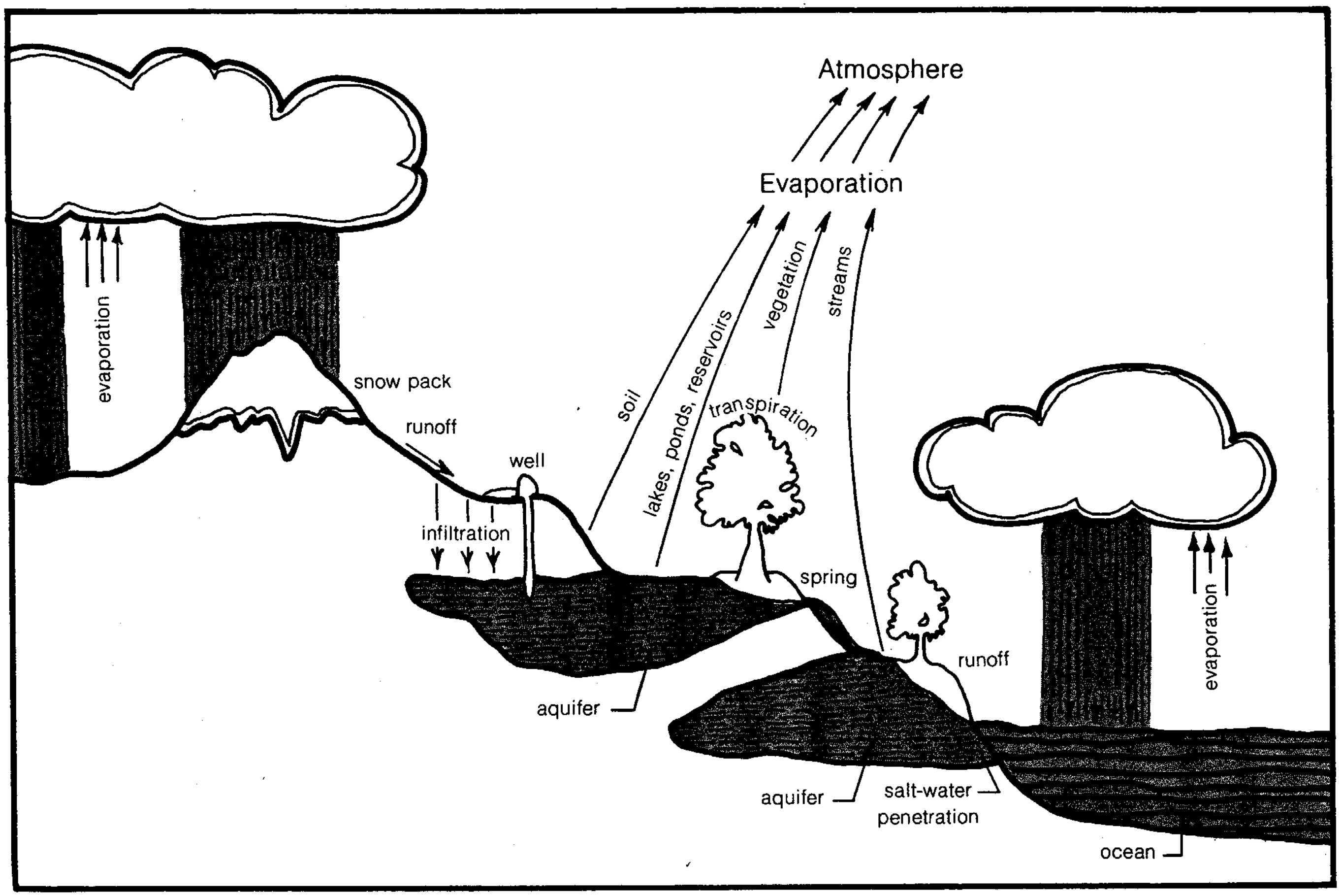

Figure 1 Hydrologic Cycle

New Development Patterns Provide New Opportunities

Every parcel of land is part of a larger watershed. Ideally, a storm water runoff management solution for each development project should be based on, and supportive of, a plan for its entire drainage basin. This is not a revolutionary idea, but only recently have data collection and data handling technology made this economically possible in a meaningful way. Even in the absence of such basin-wide plans, new approaches to residential land planning, which have been evolving since about 1955, have made it possible to apply more creative approaches to storm water management within a project.[43, 49] With their application, the net effects of incremental urbanization can avoid most negative impacts and may produce benefits, enhancing opportunities for future implementation of an overall basin-wide drainage plan.

Before 1945, most residential development involved small parcels of land and often proceeded on a lot-by-lot basis. Development was easily accommodated using the then-prevalent philosophy of maximum convenience and rapid downstream disposal of surface water. The pace of urbanization was slow and the cumulative impact of drainage decisions was difficult to assess, if it was even considered.

The major residential boom in the post 1945 era, relying on total subdivision of land into individual lots, often with complete stripping of natural site features and replacement by an "efficient" design, was the logical extension of that approach. Beginning in the late 1950's, however, some proposed residential developments clustered dwellings and created common open space, seeking to preserve and enhance natural site attributes. These various innovative concepts of land planning, which have now become grouped under the common title Planned Unit Development, present opportunities for storm water management consistent with the emerging new philosophy advocated by this report. Traditional subdivision design practices will also benefit from the new storm water management approaches, but not always to the same degree.

Note: Reference numbers shown at various points in the text refer to references provided on page 63 of this report.

The Basic Concepts

It is almost impossible to summarize the development of this report into a concise series of statements of objectives, principles, and design considerations. The ideas are far reaching and deal with many levels of concern. Following, however, are at least some of the basic concepts upon which these principles and objectives are built.

- The water falling on a given site should, in an ideal design solution, be absorbed or retained on-site to the extent that after development the quantity and rate of water leaving the site would not be significantly different than if the site had remained undeveloped. This objective may conflict with present statutory and case law in some locales, which does not reduce its validity.
- Optimum design of storm water collection, storage and treatment facilities should strike a balance among capital costs, operation and maintenance costs, public convenience, risk of significant water-related damage, environmental protection and enhancement, and other community objectives. The optimum balance among these factors is dynamic, changing over time with changing physical conditions and value perceptions.
- Just as the importance of water quality is being increasingly recognized, a major new emphasis needs to be placed on the identification and application of "natural" engineering techniques to preserve and enhance the natural features of a site. and to maximize economic-environmental benefit. "Natural" engineering techniques are those which capitalize on and are consistent with natural resources and processes. Engineering design can be used to improve the effectiveness of natural systems, rather than negate, replace or ignore them.
- Among the new trends in basic philosophy that should be pursued, are concurrent recognition of the convenience drainage and overflow or flood conveyance elements of drainage systems, the use of on-site detention storage and "blue-green" [18] development, the increased use of storage to balance out handling or treatment of peak flows, the use of land treatment systems for handling and disposal of storm water, and perhaps most important a recognition that temporary ponding at various points in the system, including on the individual lot, is a potential design solution rather than a problem in many situations.
- A continuing recognition that there is a balance of responsibilities and obligations for collection, storage and treatment of storm water to be shared by individual property owners and the community as a whole.
- A new recognition that storm water is a component of the total water resources of an area which should not be casually discarded but rather should be used to replenish that resource. Storm water problems signal either misuse of a resource or unwise land occupancy.
- A growing emphasis on the recognition that every site or situation presents a unique array of physical resources, occupancy requirements, land use conditions, and environmental values. Variations of such factors within a community generally will require variations in design standards for optimal achievement of runoff management objectives.

The above key concerns, while not all-inclusive, embody a basic philosophy that should receive wide dissemination and due consideration. Although this report focuses primarily on residential design practices, these concepts should be considered and applied to entire drainage basins in which any development may proceed. Therefore, underlying the points made above is another basic idea that is already well perceived and that is being implemented:

- Reevaluation of the approach to basin-wide runoff management is a universal need. It is the responsibility of, and should be an objective of, the public sector.

Responsible solutions for individual developments in the absence of basin-wide plans will be more difficult to achieve particularly where current practices are based on traditional drainage concepts. For example, if current practices allow upstream development to use traditional drainage approaches that increase runoff, a development relying on new concepts might be unable to accommodate the amount of excess runoff thereby generated without additional significant costs. The approaches suggested herein should allow development to proceed on individual projects in the absence of a basin-wide plan since the strategy for retention and attenuation of peak runoff and total runoff to values not significantly different from predevelopment levels would normally be compatible with any future plan that might evolve for a watershed. Unfortunately, this can probably only be achieved at an initially higher cost for the project. Therefore, development of basin-wide plans should be pursued.

A Note for Readers

An area of concern as complex as that of storm water management defies translation into simple terms that would be easily and completely understandable by all the audiences to whom this is addressed. It would be misleading not to have included a significant amount of technical material, which will be of more specific value to engineers attempting to apply the concepts embodied herein, but which may confuse and cloud the understanding of the less initiated reader. To the greatest extent possible, Objectives and Principles and to a lesser extent Design Considerations are described in a manner that will achieve general comprehension without ignoring the complexities and technical concerns. At the same time, there are significant amounts of technical information and references which can be useful to the engineer seeking to apply this report in actual practice.

Like all documents seeking to serve a wide audience but dealing with technical terms that have of necessity acquired very precise meanings for use in design formulae, the participants in the preparation of this report are very concerned about the choice of words and the definition of terms. The obvious temptation when trying to espouse new thinking is to establish new and never before used nomenclature. Even the use of the word *storm* can be questioned because it does not clearly define the true nature and complexities of natural events, each of which is unique. The term "storm" is often applied to synthetic events that for convenience are used in derived equations that sometimes approximate real events.

This report prefers to avoid such precise definitions during general discussion and to accept them, of necessity, when they are part of a technical discussion. This dichotomy will be more apparent to the technically trained reader than to the non-technical audience.

A Definition of "Storm Water Runoff System"

The term "storm water runoff system" is used frequently and will be used herein, as described below.

First of all, a storm water runoff system is composed of both natural and man-made elements. In the past, designers have often failed to capitalize upon natural elements and have at times ignored them when a constructed element was installed.

Secondly, these components include not only those which contain and convey storm water, but also those which absorb, store and otherwise use storm water rather than dispose of it.

Thirdly, the storm water runoff system is a single system having two purposes: (1) the control of storm water runoff to prevent or minimize damage to property and physical injury and loss of life which may occur during or after a very infrequent or unusual storm; and (2) the control of storm water to eliminate or minimize inconvenience or disruption of activity as a result of runoff from more frequently occurring, less significant storms. Some individual components of the drainage system may operate only in fulfillment of the first purpose. This dual purpose is characterized in much of the technical literature as "major" and "minor" functions.[18, 29] Many American and foreign cities have revised their drainage design approaches to embrace the dual function approach.

Fourthly, within a single system, there are components that are designed primarily to obtain convenience at the smallest scale of the system at the individual site or intersection, during minor or frequent storms. During an infrequent or major storm, the capacities of many of the convenience-oriented components will be exceeded and flow capacity must be provided by other components designed to provide safety and minimize damage throughout the system, from the individual site to the discharge point of the drainage basin or watershed. It must be recognized and emphasized that a total storm water runoff system, subjected to an infrequent major storm, cannot be expected to prevent inconvenience and minor property damage. A design that would eliminate all such stress would be fundamentally unreasonable and almost certainly infeasible. Expected damages from such a major runoff event would include minor erosion and scour, damage to lawns and vegetation, and damage to unwisely located structures, but flooding or undermining of buildings or essential facilities should not occur.

Most of our Nation's past urban drainage construction expenditures have been for small pipes and inlets that cannot intercept and transport the total runoff volume from infrequent storms. The designer's attention should focus upon controlling and safely routing all foreseeable runoff, especially that which cannot find its way into storm sewer pipes. Such a focus often will lead to wiser land occupancy practices, and minimize expensive drainage works construction, while mitigating potential damages from runoff.

Using This Report

In the next 25 years, more money may be spent for storm water management than has been spent for drainage during the entire history of the Nation. This will amount to billions of dollars, not including funds that will be expended to maintain water quality, which also is an increasing national concern. Much, if not most, of this investment will be private funds expended during the development of land for urban uses. Ultimately, however, all costs (capital, debt and maintenance) are borne by all citizens. Public investments should be made wisely in furtherance of the quality of life so highly valued. It is the opinion of ASCE, NAHB, and ULI that the application of the Objectives, Principles, and Design Considerations contained in this report, with due regard for unique and particular circumstances and conditions found in various areas of the country, will be a significant step in the right direction.

For the concepts in the report to achieve wide application there will be a need to induce institutional changes even beyond the design professions and the regulatory institutions of governments. Changes also are necessary in the financial institutions which fund development based on their approval of a project's design, in the insuring institutions and their perceptions of the insurability of this approach, and in the legal professions in relationship to the preexisting body of land use law regarding rights, responsibilities and liabilities. The implication of the above statement, that change may be precluded by institutional constraints, is real. The importance of encouraging application of worthwhile new approaches should provide the impetus to achieve necessary changes.

It is hoped that this report will motivate creative rethinking and updating of drainage design practices. Anyone disagreeing with any part of this report is encouraged to advise the publishers of that disagreement, including their detailed reasons and alternative recommendations. Such information will help guide future revisions and enhance the document's value to our Nation.

OBJECTIVES

- To provide a clear understanding of residential storm water runoff systems, including their intended functions and the impacts of alternative philosophies or policies on the design and effectiveness of storm water runoff systems.

Residential storm water runoff systems must fulfill two objectives: (1) they must prevent significant loss of life and property due to runoff from any foreseeable rainfall event; (2) they must provide an acceptable degree of convenient access to property during and following frequent rainfall events. Both of these objectives must be accommodated in the design process with the understanding that some protection components of the storm water runoff system may have to operate only infrequently. It must also be understood that providing protection against a given event, e.g. against the worst storm water runoff of record, does not guarantee that a greater runoff event will not occur during the useful life of the property. Similarly the enlargement of storm water runoff system components providing access convenience is generally an infeasible approach to fulfillment of property protection objectives.

- To promote a philosophy for the design of residential storm water runoff systems which anticipates the impact of alternative design solutions within both the land subdivision and the overall drainage basin.

Residential storm water runoff systems are not restricted in their design or impact to the immediate tract of land which they serve. Each is a part of a basin-wide drainage system and must, at a minimum, accommodate storm water flowing into the tract from upstream sources and mitigate the impacts of the outflow on downstream properties.

- To provide a methodology for determining the type and degree of analyses necessary to derive the optimum design solution.

To a large degree it is only in recent years that the cumulative impact of subdivision drainage in a basin has been assessed with a concern for basin-wide runoff management.

- To provide guidance toward identification and selection of alternative solutions to drainage problems which utilize and preserve, to the extent possible, desirable existing natural systems.

This has led some local ordinances to require that storm water runoff rates after development not exceed pre-development runoff peaks, both to aid in erosion control and to decrease the probability of downstream flooding. This goal rarely is fully attainable.

- To encourage the design of systems which will minimize potential erosion and sedimentation problems.

- To encourage the design of systems which respond to the need to maintain or enhance ground water resources, including ground water quality, except where land stability might be impaired.

Practices suggested herein should not increase localized capital costs for development of quality storm water systems. They should reduce cumulative downstream drainage construction costs by comparison with the effects of past practices that forced rapid runoff from land developments. The suggested practices are not new but their optimum implementation often requires reevaluation of the basic philosophy of storm water runoff system design. Changes in philosophy may produce additional alternatives for design solutions which this document may not cover. It is hoped that additional alternatives will achieve the primary goals of safety, economy and the enhancement of residential environments.

- To encourage the design of systems which will reduce capital and environmental costs to the community.

- To encourage the design of systems which will minimize potential pollution from residential surface drainage.

- To encourage system designs which conserve materials.

- To encourage continuing development of additional methods and practices designed to enhance storm water management contributions to life and environmental quality.

- To encourage continuous improvement of regulatory practices and policies, at all levels of government.

- To summarize recent advances in practice for the benefit of professionals not routinely involved in drainage design.

The design of residential storm water systems can utilize various methodologies to arrive at solutions or alternatives for the drainage plans. Differences in runoff management philosophies and in environmental conditions should be carefully evaluated in selecting methodologies to be used. The scale of development and the size and physical characteristics of the drainage area affect selection of methods, as do climatic characteristics. While certain methods may be desirable for assessing small sites with simple drainage patterns, they may be inappropriate for larger sites with more complex patterns. Conversely, the methods available for assessing large scale or basin-wide storm water systems may be too complex, costly and/or inefficient to be useful for smaller sites, and often fail to consider important micro-scale details and alternatives. No one method or solution is possible for all areas. This document will suggest some logical methods of analysis for selection of optimum localized approaches to storm water management. Inherent in the philosophy regarding those choices is the basic need for practical conservation of natural systems while providing for safety and convenience in land development.

PRINCIPLES

General

Future problems can be minimized or avoided if all political jurisdictions within a drainage basin collaborate to define and implement optimum analytical methodologies, standards and regulations pertaining to drainage systems and land development.[51]

- Local government should study and develop master plans for each drainage basin within its jurisdiction which may be impacted by development. Optimally, contiguous communities will collaborate to master-plan drainage basins that extend across jurisdictional boundaries.

- All individual land development proposals should include storm water runoff system plans that will be compatible with any basin-wide master drainage plans, and that anticipate and provide for potential effects of upstream development on the proposal area and on downstream areas.

The design of a storm water system must consider convenience and safety both at the subdivision level and at the drainage basin level. Cumulative basin-wide effects of proposed land development practices should provide the basis for decision-making, rather than the generally minimal incremental effects of individual land developments.

- Storm water runoff systems should be designed to assure provision of both major and minor components which will serve specific access convenience and property protection objectives.

Storage

- The design of permanent and temporary ponding and/or storage should be an integral part of the overall development planning process, and should consider opportunities within the open space and landscaped areas for the creation of such facilities.

When provision of storage is being considered, the designer should verify that attenuation of the runoff peak will not aggravate any potential downstream peaking conditions.

- Storm water runoff systems should be designed to facilitate aquifer recharge when it may be advantageous to compensate for ground water withdrawals. Conversely, designs should avoid recharge where groundwater effects might be harmful.

- Design of permanent storage facilities should consider safety, appearance, recreational use and effective, economical maintenance operations, in addition to the primary storage function.

Storage should not be created by happenstance or strictly in response to aesthetics. Storage must be rationally planned to accomplish its intended functions. Improperly located storage may create its own flooding problems or aggravate others.

Open Channels

- Natural overland flows, and open channel and swale routings should be the preferred alignments for major components of a residential drainage system.

Open channels and swales should harmonize with the natural features of the site. They should relate closely to individual lots so that occupants will not be tempted to use them for disposal of lawn clippings or other debris or wastes. Provisions must be made for maintenance on a routine basis to assure that open channels can function at or near design capacity. The utilization of open channels must be carefully evaluated. They may become depositories for debris if installed in neighborhoods not having a strong pride of ownership. The *blue-green* approach can help make a channel into an aesthetic focal point and discourage its abuse.

- Open channels and swales should be routed and designed to avoid or minimize safety hazards.

- Alignment of open components of a drainage system must be coordinated with the design of lot and street patterns and grades.

Generally, street and lot patterns and grades should be designed around natural drainage routings, if excessive land development expenses are to be avoided and environmental values preserved and enhanced.

Streets and Curbs

- Storm water management systems, street layout, lotting patterns, and the horizontal and vertical locations of curbs, inlets and site drainage and overflow swales should be concurrently designed.

Residential streets may be broken down into five classifications which may be utilized in the determination of safety and convenience associated with storm drainage considerations.[34] Each of the five classes — place, lane, subcollector, collector and arterial — has its own limitations on the depth of flow in gutters and spread of water across the pavement. Arterial streets should remain as free of water as is practical. The incidence of high traffic volumes and speeds and probable pedestrian traffic preclude any appreciable spread of water from the standpoint of both safety and convenience.

- The depth of flows in gutters and the allowable spread of water across the pavement should be consistent with the classification of the street based upon its anticipated use and traffic load.

Depth and velocity of runoff flows in the gutters (if any) on places and lanes must be given careful consideration due to the likely presence of children shortly after the end of the rainfall. Prudence suggests that safe velocities for pedestrians, especially small children, will be substantially less than ten feet per second.

- Appreciable amounts of runoff usually should not be permitted to flow across an intersection under normal rainfall conditions.

- The maximum velocity of flow, in the deepest part of the gutter under "convenience" design conditions, should not exceed ten feet per second.

Storm Water Inlets

- The number and spacing of inlets should be carefully regulated.

Consideration should be given to:
1. Inlet hydraulic capacities as limited by gutter gradients and cross sections.
2. Peak flow and time of concentration.
3. Erosion, debris and potential inlet blockage.

- Inlet design should consider pedestrian and bicycle safety as well as hydraulic efficiency.

Grated inlets will generally prove more hazardous and more subject to debris blockage than properly designed side-opening inlets.

- Sediment traps should not be designed into the inlet box. Inlet boxes should be self-scouring, even under low-flow conditions.

Enclosed Systems

The use of enclosed components should be minimized to the extent consistent with (1) the ability of the existing natural systems to accommodate storm runoff, and (2) the degree to which the local public will accept and act responsibly toward open channels.

- Enclosed components of a storm water runoff system should help manage storm water, not just dispose of it.

- Energy dissipators and other outfall protection should be designed and installed where enclosed drains discharge onto erodible soils.

- Conduit sizes of enclosed components of a drainage system should be selected by use of computed hydrologic and hydraulic data.

Other

- Erosion from storm water runoff should be minimized by appropriate design within the system, but erosion control or prevention generally should be achieved at the source if downstream sedimentation problems are to be avoided.

Siltation (sedimentation) ponds should be installed at the start of construction, but only where the soil's particle sizes and specific gravity are sufficiently large to assure entrapment of a significant proportion of eroded materials. Where sedimentation ponds foreseeably will have only limited effectiveness, erosion control at the sediment source should be emphasized. Direct flows from parking lots, streets, and roofs to natural water courses should be minimized. Where practical the outflow from small parking lots and roofs should be sheeted across turf. Detention storage should be incorporated in their design, whenever feasible.

- Construction, amortization, maintenance and operating costs are integrally related over time and their initial *present value* should be minimized.

DESIGN CONSIDERATIONS
STORM WATER RUNOFF
ANALYSIS CONSIDERATIONS

Storm water runoff is the water flowing over ground surfaces during and immediately following a rainfall. In specialized cases storm water runoff may be augmented by ground water flow and melting ice and snow. The runoff passing a particular point is the total rainfall at that point less the amounts of infiltration, transpiration, surface storage and other losses.

The primary goal of storm water runoff management is to assure the provision of facilities to control storm water runoff in ways which will minimize hazards to life. In addition, such systems should reduce inconvenience and minimize hazards to property. Achievement of such a system requires careful estimation of hydrologic factors at controlling design points in the system and includes the siting of property improvements in relation to all potential hazards. The primary factors are discharge rates, runoff volume, flow velocities, stage-discharge characteristics, maintenance of downstream flow conditions and water quality.

Initial planning for a residential subdivision should begin with a study of the total drainage area. The major components of the system (which should be readily identifiable; e.g. streams, large depressions, existing lakes and ponds) should be located and their potentials for storm water management assessed. Utilization of storage facilities should be given particular attention, as they can often significantly reduce the in-place cost of the system. Storage facilities are not inherently beneficial unless they are properly located and designed. Improperly designed or located ponds or recreational lakes may be undesirable.

In this initial planning phase, existing plans for storm water management—or the lack of such plans—should be assessed both as to the effect of the subdivision drainage on basin-wide drainage and vice-versa. Preliminary decisions should identify acceptable levels of temporary inconvenience to residents, such as ponding at inlets or limited storage in swales or depressions.

It may be desirable or necessary to estimate amounts of runoff at various design points within the system prior to planning street layouts and system details. Runoff estimates can range from a single point estimate—e.g. peak flow rate at the discharge point(s) from the proposed subdivision—to normal or integrated hydrographs, which account for varying flows, over time, at various points in the drainage system.

The selection of controlling design points depends upon the methodology employed to evaluate rainfall and runoff rates, on the component of the system under consideration, and on the specific local terrain and its existing or planned development characteristics. The major components of the system are outfalls, storage ponds, reservoirs, large channels (open or closed), emergency overflow routes, natural streams and others. The minor components include inlets, drainage swales, storm sewers and feeder pipes, and minor drainage-way crossings.

The degree of sophistication used in the runoff analyses depends on the size and complexity of the drainage area under consideration, the available flexibility in site improvements to avoid flooding losses, the nature of potential losses, and the types of drainage facilities to be incorporated in the design. It should be emphasized that sensitive planning in the development of a storm water runoff system which maximizes the use of natural elements can dramatically reduce initial capital costs and future maintenance costs of the system. The storm water runoff system design should also be correlated with the earliest design and layout of the street system. The street system is an integral component of the storm water runoff system and its coordination with drainage design is essential to conserve costs, avoid problems, and enhance the neighborhood.

There are a wide range of analysis techniques available for guiding the design of storm water runoff systems. The choice of technique must be suited to the size and complexity of the area, the degree of safety and convenience sought, and the cost factors involved. Regardless of the techniques selected to guide the design the following factors must be considered:*

1. Rainfall
   a. historic
   b. predictable future
   c. bases for design
2. Drainage Area Characteristics
   a. at the site
   b. downstream
   c. upstream
   d. basin-wide
3. Land Use Characteristics
   a. present
   b. future—short term
   c. full development
4. Design Options
   a. on site detention/storage
   b. overland flow
   c. channel capacity; volume/storage
   d. storage, detention, routing
5. Risk Analysis
   a. to life
   b. to property
      (i) on the site
      (ii) downstream
      (iii) upstream
6. Costs
   a. initial
   b. amortization
   c. operation
   d. maintenance
   e. replacement
   f. inconvenience
   g. flood damage

* Local government should develop basin-wide drainage studies to which individual sites can relate their specific designs.

Review of Analysis Techniques

The quantification of expected rainfall generally is a prerequisite to storm water runoff analyses. Rainfall estimation permits approximation of runoff discharge rate, volume and stage.

A rainfall event is a random occurrence—no two events are alike. All analysis techniques must therefore begin with a description of historical rainfall events which will be used in the analysis. Ideally, an analysis would be able to accurately describe the management of a wide variety of natural rainfall events with all their differences and complexities. The degree of refinement of analysis techniques and data precludes this ideal.

Rainfall quantification is achieved through an analysis of historical records and translation into a synthesized description which approximates a natural event. This description has three parameters: intensity—how much water; duration—in how much time; and frequency—how often this situation occurs. More sophisticated analysis techniques will use many sets of parameters. The National Weather Service publishes reports on rainfall frequency, intensity and duration for many cities. Their local offices can provide up-to-date information and references.

The following section is a brief summary of the prime analysis and design techniques currently used in the design of urban storm water runoff systems. Past designs of storm water runoff systems have most commonly been based on the Rational Method for rainfall runoff analysis, and steady rate flow equations for sewer flow analyses.[16, 52] The limitation of these approaches in the design of relatively complex urban systems under dynamic flow conditions is well recognized.[25] A number of mathematical models have been developed recently to aid the design engineer in his task. The decision as to what level of sophistication is desirable and, indeed, achievable must be made for each project. There are no hard and fast rules as to what the "optimum" technique might be in a general sense. The decision must be made in the light of the size of the drainage basin, type of development under consideration, terrain variables, natural stream systems, aesthetic goals, drainage codes, data availability and so on. The primary techniques of practical importance are reviewed below with their merits and problems briefly noted.

Quantitative estimates of runoff in a given drainage system or from a watershed or drainage area can be made by using one of four basic techniques, or combinations thereof.

Hydrologic Simulation Models

For decision-makers, designers and operators, a comprehensive mathematical computer simulation program that models quantity (flows) and quality (concentrations) during the total urban rainfall runoff process can be an invaluable tool. Such a model can give a good representation of the physical system. It can also serve to evaluate the physical and cost effects of alternate schemes of storm water management or pollution abatement procedures.

An urban runoff model in its elementary form is simply a group of mathematical expressions that simulate the processes of the conversion of rainfall to runoff. Additionally, it may realistically reflect dry weather flow, infiltration, treatment and storage, and water quality parameters. Models can range from the crude approximations of the Rational Method to the solution of many simultaneous differential equations. Nearly all applications of detailed models require a high speed digital computer.

The physical characteristics of the tributary area and the drainage system (size, slope, land use, imperviousness, sewer characteristics) must be embodied to some degree in the input to all models. The extent of data and processing required varies with the model employed. Much of the data reduction is relatively straightforward (e.g. tabulation of diameters, slopes, lengths of a sewer system).

Many models are designed such that if all input parameters are reasonably accurate, the physics of the processes are simulated well enough to secure satisfactory results without calibration. However, neither the input data nor the numerical methods are accurate enough for most specific areas. Additionally, there are computational procedures within some models that have been developed from limited data. This is particularly true of the quality components of models. Consequently, it is normally essential that some local verification-calibration data be available for a specific application site to lend reliability to the predictions of any urban runoff model. Calibration of most models against measured rainfall amounts and associated runoff flows can be accomplished through adjustment of the input parameters. Quality measurements, to be of calibration value, require time-related flow measurements.

There are three categories of models: planning, design/analysis, and operation. Such models have somewhat different characteristics and various models overlap on objectives to some degree.

Planning models give an overall assessment of the urban runoff problem and may also provide estimates of the effectiveness and costs of alternative storm runoff management procedures. Relatively large time steps (hours) and long-term simulation periods (months and years) generally characterize these broad-objective models. Minimum data requirements and low mathematical complexity are typical. Long-term planning models may also generate initial conditions for input to design models. The effects of urbanization are readily computed.

Design models generally involve the simulation of selected storm events with short-time steps such as minutes (the shortest interval for which Weather Service data is generally available is 5 minutes) and short simulation periods (hours). Several of these can be used for a complete description of flow, storage and pollution routing from the point of rainfall through the total drainage system and into the receiving waters. As with planning models, design models can be used to arrive at least-cost abatement procedures for both quantity and quality problems. Data requirements can be moderate to very extensive depending on the particular model involved.

Operational models help resolve actual control decisions during a storm event. From telemetered rain and flow gauge signals as inputs to the model, estimated system responses are projected a short time into the future. In-system storage, regulator settings, or diversions, or combinations of these, may then be employed as control options. Informational needs for operations models are much greater than for either planning or design models. A number of models have been developed and variations and improvements are almost continuously evolving, making it difficult to characterize them in any lasting way. However, several comparisons of model characteristics were reported in 1974 and 1975, and the reader is referred to them for details.[3, 4, 13, 26, 27, 50]

Quality aspects will become increasingly important with the growing emphasis on minimizing the ecological impact of all developments on their surroundings. In those models accommodating water quality considerations, components considered range from erosion rates and sediment loads to biochemical oxygen demand, nitrogen and phosphates.

Hydrologic modeling is as much an art as a science and thus can never be, and need not be, perfect or complete. Discussions of the current (1974-75) use of storm water models are in Huber APWA, 1975; and McPherson and Schneider WRR, 1975; and each of these has a good coverage of related recent literature.[13, 27]

Unit Hydrograph Techniques

A unit hydrograph is the runoff hydrograph resulting from one inch of excess rainfall applied to a given drainage basin over some specified time interval.

Hydrographs for a given storm can be computed from the unit hydrographs through a simple scaling and lagging operation. The unit hydrograph itself is derived either from analysis of historic records or through a regression equation(s) based on watershed characteristics such as area, length and slope. Although unit hydrograph techniques have been widely used for rural watersheds, their use in urban areas is limited by data availability. Several regions in the country have performed the necessary studies, however, to enable acceptable synthetic unit hydrographs to be derived for given development patterns.[12, 22, 32, 40] Reliability of these hydrographs reportedly is good in the regions for which they were developed.

Unit hydrograph techniques yield the total runoff hydrograph at various locations within the drainage system and can be combined with suitable reservoir simulation techniques to evaluate the operation of storage as a control measure in the system.

Regression Models

Regression models, of which many exist, seek to relate a causal factor such as rainfall and/or watershed characteristics with an effect such as peak discharge, runoff volume or annual mean flows, through statistical correlation.[32] Their applicability to urban storm water systems is minimal, mainly because of the lack of adequate historic data for regression analysis and because of the constantly changing watershed characteristics where urbanization is in process. These models do not in general predict the total hydrograph and are of limited use whenever storage in the system is being considered.

Empirical Formulas

A wide range of empirical formulas to relate runoff to rainfall have been developed over the years. The oldest of these is the Rational Method, which together with its derivatives, forms the basis for much of urban hydrology as currently practiced. The Rational Method is presented below in some detail, since it is the most popular method and may be useful in the detailed design of the minor components where a high degree of accuracy is not required.

In the Rational Method, the peak of runoff, Q, in cubic feet per second, is computed as:

$$Q = CiA$$

in which C = runoff coefficient representing the characteristics of the drainage area.

i = average intensity of rainfall in inches per hour for a duration equal to the time of concentration, t, for a selected rainfall frequency.

t = time in minutes after the beginning of rainfall for runoff to peak at the point under consideration.

A = size of drainage area in acres.

Guidance for selection of coefficient C is provided by Table 1 which shows commonly used values in accordance with the type of development and local soil characteristics. A composite C value should be weighed in proportion to the acreage in each part of the subdrainage area.

Common practice in determining the time of concentration, t, to a given design point has been to specify a fixed time for the flow to reach the first inlet and then to add the time of flow in the pipe system to that point. The time of concentration in overland flow can be estimated from Figure 2, which was extrapolated by Wright-McLaughlin Engineers.[51] In determining the time of concentration for downstream locations, paved gutter, swale or channel velocities may be estimated by making a preliminary estimate of their discharges and using open-channel flow charts published by the Bureau of Public Roads.[5] Travel time is then computed using these velocities.

Appropriate values of rainfall intensity, i, may be available from local studies or obtained from the intensity/frequency/duration data.[46, 47] Coefficients usually used in the Rational Method must be revised if the method is used to forecast peak runoffs from very infrequent rainfall events.

For more definitive information regarding the Rational Method and its appropriate application, several works are available.[7, 25, 32, 52]

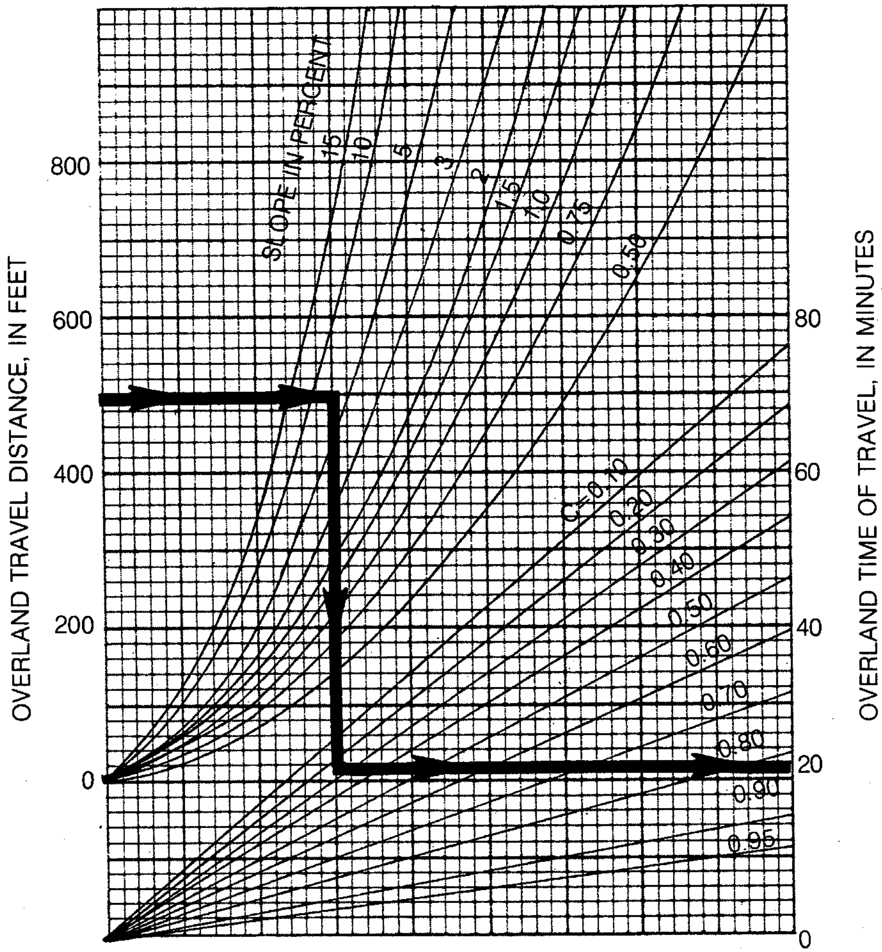

Figure 2
Relation of overland time of travel to overland travel distance, average overland slope, and coefficient C —for use in Rational Method.

Source:
Wright-McLaughlin Engineers/
"Airport Drainage,"
Federal Aviation Administration
Washington, DC 1965.

Table 1

RUNOFF COEFFICIENTS

Description of Area	Runoff Coefficients
Business	
Downtown	0.70 to 0.95
Neighborhood	0.50 to 0.70
Residential	
Single Family	0.30 to 0.50
Multi-units, detached	0.40 to 0.60
Multi-units, attached	0.60 to 0.75
Residential (suburban)	0.25 to 0.40
Apartment	0.50 to 0.70
Industrial	
Light	0.50 to 0.80
Heavy	0.60 to 0.90
Parks, cemeteries	0.10 to 0.25
Railroad yard	0.20 to 0.35
Unimproved	0.10 to 0.30

Character of Surface	Runoff Coefficients
Pavement	
Asphalt or Concrete	0.70 to 0.95
Brick	0.70 to 0.85
Roofs	0.70 to 0.95
Lawns, sandy soil	
Flat, 2 percent	0.05 to 0.10
Average, 2 to 7 percent	0.10 to 0.15
Steep, 7 percent or more	0.15 to 0.20
Lawns, heavy soil	
Flat, 2 percent	0.13 to 0.17
Average, 2 to 7 percent	0.18 to 0.22
Steep, 7 percent or more	0.25 to 0.35

The coefficients in these two tabulations are only applicable for storms of five to ten year return frequencies, and were originally developed when many streets were uncurbed and drainage was conveyed in roadside swales.

For recurrence intervals longer than ten years, the indicated runoff coefficients should be increased assuming that nearly all of the rainfall in excess of that expected from the ten year recurrence interval rainfall will become runoff and should be accommodated by an increased runoff coefficient.

The runoff coefficients indicated for different soil conditions reflect runoff behavior shortly after initial construction. With the passage of time, the runoff behavior of sandy soil areas will tend to approach that of heavy soil areas. If the designer's interest is long-term, the reduced response indicated for sandy soil areas should be disregarded.

Source: *Design and Construction of Sanitary and Storm Sewers*, ASCE Manual of Practice No. 37, 1970. Notes revised by D. Earl Jones, Jr.

STORAGE CONSIDERATIONS AND CRITERIA

One of the primary factors to consider in storm water runoff management is storage. The availability or absence of facilities for temporary or permanent runoff storage is an important element in selecting the analysis methodology and establishing the underlying philosophy for design. As important as storage is, it should not be seen as the cure-all for storm drainage design. It is likely that in many instances the storage capacity required to assure both maximum safety and convenience will not be economically feasible; but, this amount may still be desirable.

Provision of storage can reduce peak runoff rates; aid in the replenishment of the water supply; provide an attenuation mechanism if storm water is to be treated; lessen the possibility of downstream flooding, stream erosion, and sedimentation; and can be used in the development of upstream areas to avoid increasing the runoff peaks which impact existing downstream facilities.

Storage occurs naturally on a small scale in most drainage areas. Natural storage is provided during overland flow in surface depressions and on wetted vegetation. Greater storage is possible where larger depressions and swales exist in the drainage area and where highly pervious recharge areas exist. Much natural storage is temporary, of small volume, and can be lost through development. This volume can be replaced by using swales, by revegetation and by utilizing special inlets that meter the outflow from planned ponding areas. Where detention storage is used, overflow routing must be provided with sufficient hydraulic capacity to assure freedom from significant downstream damages in the event of improbable runoff peaks. Large scale temporary retention storage can be used to replace storage loss due to the increase of impervious surfaces associated with development.

Rooftop and parking lot ponding are just two methods for temporarily storing and then slowly releasing this outflow of storm water. In addition, the design of percolation ground storage facilities and dry ponds may be utilized to accommodate large amounts of storm water.

Permanent storage (ponds, reservoirs and stream channels) provides maximum amounts of storage with the greatest amount of certainty. The "blue-green" approach to development, where practical, provides such storage in an economical manner consistent with environmental protection and enhancement.[18, 31]

Degrees of Storage

Different degrees of storage should be considered in residential design. The lowest degree is the natural storage provided by surface depressions and by foliage and ground cover interception of rainfall. To take advantage of this storage, natural ground cover should be maintained. Temporary, usually small volume storage can be provided for in the design of swales, pipes, and channels upstream from embankments. Outlets from temporary storage can be choked or otherwise controlled to attenuate peak outflow, but safety and protection of adjacent and downstream properties should be assured by conscious design of overflow capacity and siting of damage-susceptible improvements. Facilities may be designed specifically for storage. Roof-top and parking lot ponding, recharge basin storage and normally dry ponds, may be employed in a storm water runoff management system. Permanent storage, especially as provided by use of the "blue-green" approach may be particularly useful. The comparative amounts of storage that may be achieved using different combinations of facilities will vary. The designer of storage should determine that the cost of storage provisions will not exceed benefits accrued and that the designs will be economical to maintain. The residential storage system should be coordinated with watershed and regional storage plans for flood control, water supply and recreation.

Factors to Consider

Permanent ponds and lakes have multiple benefits including short-term and long-term enhancement of property values and the landscape; possibilities for boating, ice skating, fishing and swimming; and habitat for resident and migratory wildlife. Proper maintenance and protection from health and safety hazards and positive control of visual appearance must be integral parts of storage design and planning. Permanent storage sites must be evaluated to assure their capability to retain water and to determine if an adequate natural or artificial supply of water is available year round to replace evaporation and infiltration losses.[31] Eutrophication, or declining water quality, can be a very serious problem in shallow lakes.[35]

Excessive lowering of the water surface during dry spells can decrease the aesthetic and recreational value of storage. Siltation of permanent ponds may result in loss of storage capacity or undesirable weed growth. Control of erosion is a major consideration in the design, construction and maintenance of storage facilities. General information on residential lakes is available from the U.S. Geological Survey (USGS).[35]

Temporary storage in "dry ponds" can be used effectively in areas designed specifically for that purpose; water can accumulate in these areas during and for a short period after storms. Since these facilities are designed to completely drain after the storm, they can serve a dual purpose. Golf courses, recreation fields and parks are examples of compatible uses. Temporary storage can also be obtained in parking lots, on rooftops or in underground seepage pits. Reference[31], sponsored by the Office of Water Resources Research and published (1974) by the American Public Works Association on "Practices in Detention of Urban Storm Water Runoff" can be consulted as a current investigation of some of the concepts, techniques, applications, costs, problems and legal aspects of urban storm water storage.

Parking lot storage has been combined with percolation trenches filled with coarse gravel which intercept some runoff from the lot. Some experimental parking areas on non-cohesive sub-grades are being constructed with a porous pavement that allows direct recharge of ground water. These types of storage may prove advantageous in some built-up areas where large amounts of open spaces are not economically available.[31, 48]

Rooftop Ponding

The structural capability of the roof system must be considered when designing a temporary rooftop storage system. A three-inch water depth is equivalent to a load of 15.6 lbs./sq. ft. which is less than most current building code requirements for live loads. Overflow mechanisms should be provided so that there is no danger of overloading during major storms. Special considerations of roof watertightness may be necessary since storage may be effective only if the water is detained for a significant period of time. Many flat roofs already pond significant amounts of water, although not by design, which should be considered when evaluating drainage conditions in established commercial areas.

Parking Lot Ponding

Parking lot ponding should be arranged so that pedestrians can reach their destinations without walking through ponded water. The ponding should be relegated to those portions farthest from the use served or to overflow parking areas, and should be a reasonable portion of the total area so that sufficient parking remains available for use. The maximum design depth of ponding can vary depending upon the location. A seven-inch design depth is not unreasonable where access to parked vehicles will not be impaired. An overflow outlet should be provided so that runoff from major storms will be limited to a seven-inch depth. Debris may accumulate at outlet drains, which may reduce the capacity of the drain and become unsightly, so provisions must be made for periodic cleaning. Thought should be given to the use of semi-paved/semi-grassed areas for overflow parking which will permit infiltration of rainfall and reduce the total runoff associated with parking lot pavements.

Percolation Storage

Under favorable conditions of a deep, permeable subsoil, runoff may be discharged into trenches back-filled with sands and gravels chosen and placed in accordance with sound graded filter principles. So long as the system does not become clogged by sediment, it will accomplish the dual purpose of disposing of at least part of the storm water and of recharging ground water storage. Percolation tests must be run on the stratum at the bottom of the proposed trench. The rate of percolation will then control the outflow from the trench (exfiltration) provided the ground water table is below the trench. An excess of inflow rate over percolation rate will result in temporary storage of water in the voids in the filter materials. Design of percolation storage must consider the potential effects of clogging of voids over a period of time and reduced load carrying capacity of pavement subbase in a saturated condition. An overflow channel should be provided to carry off excess storm water when the percolation trench capacity is exceeded. Under appropriate conditions, piped storm drains can be open-jointed or perforated to permit exfiltration.

Lakes and Ponds

The design criteria for storm water runoff storage in lakes and ponds are numerous. Hydrographs of runoff from both frequent and unusual storms must be evaluated. For major installations, stream flow measurements in advance of the planning stage may be desirable.

The retaining structure, usually an earth dam except where storage is created by further excavation of a low point in the site, must be designed and constructed according to the best accepted practices for such structures. The outlet works:

- must be designed to release the allowable flow in the downstream channel at the storage level established for the minor storm;
- must include an overflow spillway to handle potential peak runoff from major storms so as not to cause serious damage to adjoining and downstream properties; and
- must provide for draining of the lake or pond.

Adequate provision must be included for energy dissipation and erosion protection where outlet works discharge into the outfall channel. The outlet channel must be capable of handling the released flows without being damaged during a minor storm event and, where practical, within acceptable damage limits during a major storm. It is often completely impractical to avoid damages from a rare major storm.

The probable quantities of sediment coming off the watershed during the life of the facility should be estimated, taking into account the degree of erosion control likely to be achieved during and after construction. Temporary structures may be necessary to trap sediment before it enters the storage facilities during the construction phase. Planning of the facility must recognize loss of storage capacity from silting or anticipate occasional sediment removal. In the case of permanent lakes the maintenance of a minimum level should be ensured by the inflow from the watershed (or by other augmentation) during prolonged dry periods and by the capability of the pool bottom to retain water.

The design of storage facilities to meet these criteria requires the services of engineers experienced in hydrology, hydraulics and earth structures. Aesthetic considerations suggest the services of a landscape architect. The engineering economy aspects of the design are especially important since considerations of alternative design possibilities as they affect the costs of construction and maintenance, reduced to average annual costs, can substantially lower the ultimate cost to the public.

"Blue-Green" Storage

Where streets must cross drainageways, there is an opportunity to utilize the roadway embankment as an effective dam for only moderate additional cost. Such dams are the heart of the "blue-green" development approach.[18, 35] Embankment quality and stability must be assured as for any dam, but the entire roadway and embankment may serve as the overflow spillway. This necessitates continuous erosion protection from the upstream point on the embankment face, where approach velocities become significant, to below the downstream toe of the embankment. Such dams may be used to provide a chain of lakes as neighborhood focal points that enhance long term neighborhood values and stability. Potential overflow areas usually should be developed as green spaces. If left substanially open to public access and view, the blue-green spaces created can enhance entire neighborhoods rather than just immediately adjacent properties.

Other Storage Considerations

In creating urban ponds or lakes, certain special considerations are worthy of mention.

- Access to and along shorelines may be effectively limited to desired locations by planting thorny decorative shrubs.
- Lake bottoms within ten feet of the shore should be so graded that water depth normally will not exceed eighteen inches, to simplify immediate rescue of small children.
- Extensive areas of shallow water, especially in upper reaches of the lake, should be avoided to prevent undesirable weed growth.
- Dense plantings of shrubs that will act as barriers to automobiles are appropriate where vehicles might otherwise run into the lake, especially at night.
- Paved walkways roughly paralleling the shoreline, low-level night lighting, fixed benches, floored rain shelters and sensitive landscaping can add considerably to the charm of a lake or pond setting, and to the desirability of the surrounding neighborhood. Massive plantings of seasonally colorful shrubs, such as azaleas, redbud, dogwood or Japanese maple, can help publicize an area and create particular pride of ownership throughout the neighborhood.

STREETS AND CURBS

The primary purpose of residential streets is to provide vehicular access to homes and community facilities. Vehicles using the streets will vary from routine automobile traffic to larger delivery and service trucks and emergency police and fire vehicles. Streets also have several secondary functions. One is to provide routes for pedestrian and bicycle traffic; another, more relevant, is to collect and convey storm water runoff.

Planning a drainage system should be done simultaneously with street layout and gradient planning, and careful consideration should be given to the following:

- The functions of streets as parts of the storm water management system.
- Street slopes in relation to storm water capacity and flow velocity in gutters and/or street swales.
- The location and sizing of street culverts. Culverts may be sized to create temporary upstream storage if there is proper consideration of earth bank stability and potential overflow effects during major flood conditions.
- Location of streets in relation to natural streams, storage ponds and open channel components of the system.
- Location and capacity of inlet points to pipes in relation to gutter slopes, the spread of water across streets and the flow of water across intersections.
- Coordination of street grades with lot drainage. Positive slope away from all sides of the house must be accomplished. Lot drainage becomes difficult when there is less than 1½ to 2 percent (usually from 14 to 24 inches) fall from the earth grade at the center rear of the house to the street curb at the lowest front corner of the lot.

Table 2

DRAINAGE ADVANTAGES AND DISADVANTAGES OF STREET CROSS SECTIONS

Type of Cross Section	Advantages	Disadvantages
Normal crown with curb and gutter.	• Center lane clear during minor storms. • Traffic barrier on both sides. • Driveway ramps behind curb keep water confined.	• Curb and gutter increases cost. • Must have longitudinal grade to assure drainage. • Concentrates water and increases downstream flooding.
Cross slope	• Reduces number of inlets and manholes. • Decreases earthwork. • Fits better with natural topography. • Traffic barrier on both sides.	• Water from streets intersecting on high side must be picked up as it will overflow intersection rather than "run around corner." • Maximum width of sheet flow. • Hazardous if sheet flow from rain or snow melt freezes. • Flow capacity can be achieved in only one gutter.
Asymmetrical crown	• No cross flow until crown is overtopped. • Lessens hazard of icing. • Fits better with natural topography. • Traffic barrier on both sides.	• Limited flow capacity on upper side. • Allows less cross fall than section above. • Rides "funny"
Drainage Swales	• Lowest cost where usable. • Allows for infiltration of runoff in channels. • No water confined on pavement so freer movement of traffic during storms. • Can be merged into the natural topography. • Fewer underground storm drains. • Slows down the runoff because of much lower velocities in the grass-lined channel and because considerable storage must be filled before overflow.	• Not advisable where small lots require frequent driveway culverts. • More of a maintenance problem on shoulders and channel. • May require wider right-of-way to accommodate flat side slopes on drainage swales. • Less adaptable to sidewalks, but compatible with off-street walk systems.

Street and Curb Cross Sections

There are typical street cross sections in common usage. The advantages and disadvantages of each from the drainage standpoint are summarized in Table 2.

The most commonly used cross section is a center crown sloping at a rate of one-quarter inch per foot toward a swale or curb and gutter, on each side of the street. Sidewalks, if present, can be placed against the curb or, as is more common, more desirable and necessary in wet or snowy areas, can be separated from the curb by a planting area.

On a sidehill section, the street section can be designed with a straight crown or with a crown at the one-third point with a slope toward each curb. This section should not be used on collector streets where speeds are higher because the ridge tends to make car control more difficult. The cross slope on roadway sections should not exceed five percent in any case.

A street cross section with drainage swales replacing curb and gutter, and often with no sidewalks, is currently being used for many residential streets. This approach is compatible with development concepts which utilize path and walkway systems and low traffic volume streets such as cul-de-sacs, loops and courts.[34] Such practice is a return to urban practice, common to the early part of this century, which provided about 40 acre-feet of streetside storage per square mile. Elimination of that storage and installation of curbs during the past 35 years has created significant urban flooding problems where none previously existed, by accelerating downstream runoff peaking.[53]

Since slip forming of curbs and of curbs and gutters often is generally used for construction economy, it is important that uniform curb and gutter sections be used as much as possible. The hydraulic capacities of the straight and battered curbs are about the same and they lend themselves to side-opening curb inlets. The rolled or mountable curb has a lower hydraulic capacity and requires a transition to a vertical face to accommodate a side-opening curb inlet; flexibility in accommodating field changes in driveway locations is a characteristic of rolled curbs that should be considered where their limited hydraulic capacity is not a significant issue.

Hydraulic Capacity

The hydraulic capacity of a street section to convey water can readily be calculated by the Manning Equation in the following form as developed by Izzard:

$$Q = 0.56 \frac{Z}{n} d^{8/3} S^{1/2}$$

In this equation the symbols are defined as follows:

- Q = discharge in cfs
- Z = $1/S_x$ where S_x is the cross slope of the pavement
- d = depth of water in feet at face of curb
- S = longitudinal grade of street
- n = Manning's roughness coefficient

Experiments have proved that this form of the equation is more accurate than would be obtainable by computing the hydraulic radius based on the wetted perimeter and the area of the cross section. The equation applies directly to a section having a straight cross slope.

The compound section, with the gutter having a Z-value of 12, is widely used for streets because the hydraulic capacity for a given spread of water on the pavement is substantially increased. (About 30 per-width.) This is because the velocity at any point on the cross section is directly proportional to the two-thirds power of the depth, which is increased by steepening the gutter cross slope.

Since more water is concentrated close to the curb the compound section also increases the capacity of inlets to intercept flow. To facilitate computation of inlet capacity, the compound section can be converted to an equivalent straight cross slope having the same capacity as the compound section for a given depth "d" measured from the gutter flow line.

The equivalent straight-slope section can be computed by the following equation:

$$Z_3 = Z_1\left[1 + (Z_2/Z_1 - 1)\left(\frac{T\text{-}W}{T + W(Z_2/Z_1 - 1)}\right)^{8/3}\right]$$

in which

- Z_3 = reciprocal of cross slope of equivalent section
- Z_1 = reciprocal of cross slope of gutter
- Z_2 = reciprocal of cross slope of pavement
- W = width of gutter in feet (this often will be identical to the width of the depression of a curb opening inlet since it is impractical to extend the inlet depression appreciably beyond the gutter width.)
- T = top width of water surface

By using this value of Z_3 in the previous equation and the same value of "d" as for the compound section, the exact Z for the latter is found. The first equation given can be directly applied to a compound section by use of Nomographs.[8]

Estimating Runoff in Streets

The peak flow contributed to a gutter or swale is normally estimated by the Rational Method. Drainage areas are subdivided so that runoff contributed to each gutter or swale can be computed at the end of a block or at other points where an inlet or pick up point is required. Inlets are usually sized so that a portion of the flow is bypassed; the actual flow in the next reach of gutter includes this bypass flow. The flow reaching the second inlet is a portion of the flow contributed from its drainage subarea plus the flow bypassing the first inlet. The low point or sump inlet catches the remaining flow from both directions and must be sized accordingly.

Locations and required capacities of inlets and swales are established by computing estimated flow rates, depth and velocity of flow, and spread across street. The design of sump inlet capacity may provide a degree of outflow control from the sump storage, safely obtained, through localized temporary ponding.

Under conditions prevailing during a major storm, the storm drain system will be surcharged and the rest of the flow will be carried on the lawns, the streets, etc. Inlet capacity in this case is indeterminate but is probably somewhat less than the inlet would handle under sump conditions because of debris blockage and surcharge back pressures. It is probably safe to assume that the flow on the street would be the difference between the total runoff and the capacity of the storm drain surcharged to the level of the gutter. Since debris blockage of inlets is most likely during extreme runoff events, emergency overflow routing and analyses for runoff extremes should assume that no more than 50 percent of pipe capacity is available under these circumstances.

Criteria for Spread of Water Across Street

The allowable spread of water across the street from the curb is limited by the criterion of maintaining two clear ten-foot moving lanes of traffic for collector streets during minor storms. One clear lane should be maintained on subcollectors, and lanes and places may have a spread equal to one-half of their width. These criteria are fully justifiable in humid areas, but may be difficult to meet in arid areas where:

- available slope is limited,
- runoff may contain considerable suspended solids,
- drainage essentially is by surface flow, and
- the public accepts the resulting inconvenience.

When a steep cross slope is used (five percent is suggested as a limit), a ten-foot spread would produce an excessive depth at the curb making it difficult to intercept the flow except with a very long curb opening inlet.

Consequently with pavement cross-sloped from three to five percent, the depth of flow at the curb should not exceed six inches.

Flow Across Intersections

The most critical situation exists where a street on a grade intersects with another street, especially a collector or subcollector. Even when the flow on the grade is severely limited, great care must be taken to provide inlets which will intercept virtually all the flow from a minor storm. Full interception may be impossible for a major storm.

A "T-intersection" requires special care because houses directly below a steep "T" stem are particularly subject to intersection overflow damage during major storms. Overflow of "T" intersections can be somewhat impeded by:

- elevating the through-curb;
- installing a higher-then-normal roadway crown on the through street; and
- using a straight-faced through-curb of 7½ inch or greater height. In severe situations, a decorative wall (low) placed behind the through-curb and landscaped will provide practical control, often more economically and assuredly than inlet construction.

Flow across collector streets should not be allowed during frequent storms. Controlled flow across subcollectors is acceptable and there are no design limitations placed on flow across lanes and places. During major storms, permissible flow across intersections will be a function of the street's traffic-carrying importance and the availability of convenient alternative access.

Ponding at Low Points in Grade

Some ponding of water at low points in the grade is inevitable, even during a minor storm, and in some cases may be desirable. However, because of the driving hazard and splashing of water on pedestrians, ponding should be minimized. This is done best by intercepting most of the flow before it gets to the bottom of the grade. In picking up most of the flow prior to the sump location, a large percentage of sediment will also be removed from the flow. This prevents sediment deposition in the gutter as velocity is checked on the decreasing grade. A curb-opening inlet at the low point in the grade is an efficient structure but must be of ample size because this is the point where debris is most likely to accumulate. Effective performance during a major storm should be assured by considering:

- damage from water overtopping curb and sidewalk
- methods of minimizing damage
- relative sizing of inlet and pipe
- overflow mechanisms

Maximum Velocity in Gutters

Water flowing down steep grades can be dangerous. For example, water flowing at ten feet per second can exert a force of 100 pounds against a flat, one-foot wide object placed across the flow. A 20-pound push at shoe level will sweep a grown man off his feet, so gutter flow can be very hazardous to a child. Aside from the safety hazard, such flows are difficult to intercept at inlets and can create difficulties, such as shooting across an intersecting street or overriding curbs and causing severe localized erosion and sometimes damage to downhill properties.

A recommended criterion is that the velocity in the deepest part of the gutter be limited to ten feet per second. This velocity is readily computed by the Manning equation using the depth at a point six inches from the face of the curb as the hydraulic radius.[41] The mean velocity for the entire cross section is not a good measure. If the calculated velocity exceeds ten feet per second, the allowable discharge in the gutter must be reduced until velocity is within the limit. The designer is then faced with the problem of where and how to reduce the runoff entering this gutter. Additional inlets could be installed upstream, but this is expensive. If possible, some way should be found to divert runoff to some path other than the steep street, preferably by a revised street layout. Future street resurfacing which will reduce capacity should be considered in the calculations.

NATURAL DRAINAGE

Natural drainage flow techniques serve very useful functions in the control and management of storm water runoff. The primary function is to provide an opportunity for natural infiltration of storm water to the ground water supply system. Secondly, it helps to control the velocity of runoff flows, which is a necessary factor in the control of erosion and sedimentation. Thirdly, and perhaps most important, natural drainage techniques can extend the time of concentration of storm water runoff, thereby contributing to the ultimate goal of maintaining the rate of runoff at or near the levels existing prior to development. As noted earlier, street swales can provide up to about 40 acre-feet of runoff storage per square mile, thereby contributing significantly to runoff attenuation.

The achievement of the goals stated above is important. Urban and suburban areas have experienced a rise in the frequency of severe flooding and an increase in the amount of hazard and damage associated with floods at or near past levels. An important factor in this phenomenon is the rate at which storm water runoff reaches the receiving streams from developments in the drainage basin. Natural storm water runoff systems can help to control that rate and release the accumulated runoff over a longer period, thus contributing to a reduction in the rate and volume at given points in the lower reaches of the receiving streams. This is especially important where older areas downstream of new developments either have inadequate storm drainage systems or a combined sanitary and storm sewer system. Specific reduction in the amount of runoff contributed from each new development in the upper and middle reaches of a drainage basin will reduce the cumulative runoff impact of development thereby contributing to reduction of hazard and/or reduction in the need for costly supplemental systems in the downstream areas. Natural drainage systems must be properly maintained to assure their continued performance at the designed capacity. It must be noted that open channel flows in residential storm water management systems are not completely "natural" systems, although they rely heavily on existing natural features and qualities of the development site. Virtually all development will increase the amount of storm water that becomes runoff during and after an event because of the impervious surfaces used in development. Increases in runoff which change the dynamic equilibrium of natural areas used in the system mandate specific engineering solutions to conserve these natural systems and the predevelopment characteristics of the area. The creation of swales, alteration of small channel capacity or direction, changing of ground cover and the lining of existing channels with other materials, natural or man-produced are necessary in some parts of the system to achieve the desired objectives.

These alterations or improvements will have to be maintained if the total system is to function properly. The maintenance of swales and open channels in the interior areas of residential development is most critical during construction. Debris from this source, including plastic wrapping materials and other nonbiodegradable substances, can diminish the capacity of the system or effect changes in the flow characteristics of the runoff which tend to cause erosion and sedimentation. After construction, internal maintenance problems within residential areas will not be significantly higher if property owners understand that their normal maintenance responsibilities are integrally related to regular public maintenance efforts. The primary problem areas for roadside swales or open channels are along major arterials bordering residential areas or areas where non-residential uses contribute large quantities of man-made debris.

An awareness of potential problems is the first step towards their prevention, but should not be an overriding cause for rejection of a system which would produce benefits that exceed potential maintenance disadvantages.

The characteristics, function and maintenance of open channel elements should be evaluated prior to the final design of the total network which forms a residential storm water management system.

Overland Flow

In planning an open channel system, overland flow distances should be made as long as possible consistent with other constraints and requirements. Overland flow should be over and through turf or other flow retardants such as ground cover or forest litter. This is one reason why natural woods should be preserved whenever possible. Slopes of overland flow areas should be as flat as possible, but maintaining natural topography and ground cover should take precedence over regrading to achieve flat slopes.

Overland sheet flow is a significant factor affecting the peak rate of runoff reaching the first collecting channel. Gently sloping turf areas shorter than 100 feet will probably not detain runoff significantly during intense rainfalls. The runoff rate from meaningful overland flow areas will be substantially less than the rate at which rain is falling. Minor surface depressions due to irregularities in grading add further to the storage potential. In addition, the retarded passage of water provides additional time for infiltration into the soil (if permeable), thus reducing the quantity of runoff. On paved surfaces, such as on parking areas, the storage in overland sheet flow is only about one-fifth as much as on turf, but is still a significant factor. On steeper slopes, whether pavement or turf, the velocity increases and storage decreases, so that less time is required for runoff rates to become equal to the rate at which the rain is falling. Most presently available mathematical models for computing runoff include the length and other characteristics of overland flow as essential inputs.

Hydraulics for Swales and Open Channels

When runoff reaches swales and open channels, principles similar to those for overland flow should be applied. If feasible, they should be wide and shallow with a rough surface and on as flat a grade as topography will permit. In this way, storage will further retard runoff and reduce the peak flow. Flat slopes may present the problem of marshy low areas after a storm. A minimum slope should be established, based on soil permeability and the capacity of the swale or channel.

The Manning Equation is almost universally used in calculating open channel flow. Numerous aids to facilitate computations are available including computer programs. A very useful publication for those not having access to a computer is *Design Charts for Open Channel Flow.*[5] This publication includes consideration of flow in open channels and swales on mild and steep slopes. Velocity of flow in open channels and swales is dependent on rate of flow, slope, surface roughness, and cross section and can be calculated using the Manning Equation. Suface roughness and consequent velocity will depend on the quality of maintenance. Well-mown grass will have a different surface roughness coefficient than tall grass.

Control of Erosion

In designing channels for erosion control, the velocity must be estimated and compared to the allowable velocity for the material on which the water is flowing. Table 3 indicates the allowable velocities for grass channels. It should be noted that the quantity of water which can be carried in well-established, dense turf swales without erosion is surprisingly large, even for steep slopes. For urban residential drainageways, flow velocities for erosion potential evaluations should be based upon the ten-year frequency runoff event, which generally is a practical break-point between initial cost and excessive maintenance cost.

However, when the allowable velocity for a turf channel is exceeded, there are a number of alternatives to consider as shown in Table 4. They include: lining channel with an impervious material; drop structures or other velocity and erosion control measures; gravel or rip-rap bottoms; and gabions (rock enclosed in wire baskets).

The probable performance of the open channels and swales should be evaluated for major storm runoff with respect to the depth and spread of water and the erosion potential. Antecedent flow conditions resulting from previous storms are an important consideration. Open channels and swales may suffer damage during major storms, even if properly designed. The potential for incurring these infrequent maintenance costs should be balanced against the initial cost of attempting to make them "flood proof" during the design process.

It is important that open channels be constructed in accordance with plans. When intermittent channels are sodded to the depth of the expected flow, they can immediately provide protection for minor storms. It is not practical to establish turf in a drainage channel by seeding and mulching unless jute mats, or similar protective materials, are placed over the seed bed.

Flow and Erosion in Natural Streams

Maintenance of streams in their natural condition is a desirable goal. A natural stream normally adjusts its cross section and slope so that they are in approximate equilibrium and flowing bankful at the average annual peak flow rate. For greater flows, the banks are overtopped and flow also occurs on the flood plain. If the flood plain is then constricted due to development, more flow will be concentrated in the channel, probably disturbing its equilibrium and resulting in more than normal erosion. Similarly, additional erosion may result if the peak discharge is increased, even if the flood plain is not constricted. Limiting the minor storm discharge from a residential or other development to pre-developed flow rates is a means of controlling the peak discharge. The two concepts, of storage and the use of natural open channel flow, assist in this objective.

Table 3 **Permissible velocities for swales, open channels and ditches with uniform stands of various well maintained grass covers.**

Cover	Slope Range Percent	Permissible Velocity on:[a] Erosion-Resistant Soils (fps)[b]	Permissible Velocity on:[a] Easily Eroded Soils (fps)[c]
Bermudagrass	0-5 5-10 Over 10	8 7 6	6 5 4
Buffalograss Kentucky bluegrass Smooth brome	0-5 5-1 Over 10	7 6 5	5 4 3
Grass mixture	0-5 5-10	5 4	4 3
Lespedeza Weeping lovegrass Yellow bluestem Kudzu Alfalfa Crabgrass	0-5	3.5	2.5
Common lespedeza[d] Sundangrass[d]	0-5	3.5	2.5

Original table from *Handbook of Channel Design for Soil and Water Conservation,* Soil Conservation Service, U.S. Department of Agriculture Publication No. SCS-TP-61 March 1947, revised June 1959.

[a]Velocities in excess of 5 fps to be used only where good cover and proper maintenance can be assured.
[b]Defined as CL, CH, OH, GM, GP, GC and GW (Unified Soil Classification System Designation).
[c]Defined as ML, SM, SC, MH and OL (Unified Soil Classification System Designation).
[d]Annuals, used on mild slopes or as temporary protection until permanent cover is established.

Source: *Slope Protection for Residential Developments*, National Academy of Sciences, Washington, D.C. 1969.

Table 4 ALTERNATE METHODS OF CONTROLLING EROSION IN OPEN CHANNELS

Type of Control	Advantages	Disadvantages
1. P. C. or asphaltic concrete or soil cement paving.	Permanent if carefully constructed and maintained.	High cost. Speeds up runoff.
2. Drop structures across channel at intervals so that slope of channel between drops restricts allowable velocity for turf.[41]	Satisfactory if drops are well-designed and built. Does not speed up runoff.	Unsightly, if natural material is not used. May have maintenance problems.
3. Lining with crushed rock or gravel sized for requirements.[1]	Satisfactory if well-designed. Can harmonize with landscape. Can allow both infiltration into permeable soil and exfiltration of ground water.	Can be costly if rock or gravel are not available locally.
4. Rip-rap.[42]	Permanent if carefully placed and maintained.	Can be costly. Can be unattractive.
5. Rock enclosed in galvanized wire baskets (gabions). This generally requires wide shallow channels so that drops will not be over-ridden and channels destroyed during unusual extreme flow events.	Permanent if carefully placed. Can allow infiltration on permeable soil. Aesthetically pleasing—becomes invisible. No limit to range of flow.	Can be costly.

UNDERGROUND PIPE SYSTEMS

Layout of the Storm Drain System

The layout of the storm drain system for residential areas should make maximum use of existing open channels and natural streams, before resorting to enclosure of runoff in underground pipes. Former practice tended toward enclosing small streams in conduits which was not only costly, but also concentrated the flow downstream and increased the peak rates of discharge. The preferred approach is to leave natural streams undisturbed and to limit peak runoff conditions. Erosion of the stream channel usually is not accelerated when this is accomplished. As recommended in this report, runoff will be collected in swales or open channels and curb and gutter sections and carried as far as practical before entering an underground pipe system. The underground pipe system consists of a series of inlets, pipes, and manholes. Output from computer simulation models of runoff or empirical techniques may be used in the detailed design of the system. Decisions made in the planning stages of the residential development, some of which are listed below, will have a great influence on the final form and cost of the underground pipe system.

- Planning of both minor and major components with appropriate design rainfall recurrence intervals.
- Limitation of peak runoff rates after development.
- Type and amount of storage.
- Use and incorporation of natural drainage such as overland flow, street swales, open channels and natural streams.
- Assurance that all contributory upstream areas will be similarly regulated or initially assessed and developed, so projected conditions may be relied upon.

Pipe Location and Alignment

The pipe system is usually in the street right-of-way, but portions may be in easements along lot lines when that route provides the best outlet path to a natural stream. One common location within the right-of-way is behind the curb. This method connects inlet boxes with the least amount of pipe and junctions.

There is no reasonable objection to the pipe being laid on horizontal and vertical curves conforming to the curvature of the street. The horizontal and vertical alignment of storm drain pipes must be coordinated with the location of all other uilities. In cases where joint trenching of electrical, telephone, CATV, gas and possibly water lines is allowed, it is much easier to coordinate the locations of utility lines during construction. Since storm drains are generally constructed early in a residential project, require gravity profiles, are located at shallow depths, and require trench backfill density control, the opportunity for joint trenching with other utilities rarely exists. As most localities now require electrical power and telephone lines to be underground, there no longer are possible conflicts with utility poles behind curbs.[33]

Culverts

With the emphasis on keeping surface runoff in street swales and open channels, culverts may be required for street crossings. Driveways crossing properly designed street swales should not automatically require culverts, as vehicles should be able to cross the swale. When required, culverts preferably should have flared end sections for good appearance and hydraulic characteristics.[9] Precast or pre-fabricated flared end sections for pipes are available.

Any culvert will cause an increase in water level in the upstream channel. This backwater can flood property and overflow into the streets. The frequency with which this is allowed to happen should depend on the amount of damage, including delays to traffic, caused by the backwater.

Where storage is required to control peak discharge, a road fill can provide a dam for temporary impounding of storm water.[18, 35] Legal and physical requirements for such temporary ponding are constraints to be considered.

Culverts may also require energy dissipators at the outlet if the stream bed is erodible. These can range from simple placement of rip-rap to elaborate concrete stilling basins. Similar structures may also be required on storm drain outlets.[6, 45]

Materials

Storm drain pipes are most commonly plain or reinforced precast concrete; however, other materials may be used.[16] There has also been good experience using carefully controlled installations of unreinforced cast-in-place concrete pipe, which may also provide initial construction cost savings. Corrugated metal pipe can be used for short runs, but its high resistance factor often requires a larger pipe size for equivalent flow capacity which weighs against its use for long lines, unless grades are very steep or unless the invert and sides are lined with asphalt to give a smooth interior. Where culvert hydraulics are governed by inlet control, concrete and corrugated metal pipes may be interchanged size for size.

Curb opening inlets are usually reinforced concrete, often with precast units for top slabs and other parts. Concrete block can also be used for walls if the inlet opening is short. On longer openings, the structural problem of carrying the top slab across the opening with no intermediate supports and very limited thickness of slab allowable, may require cantilevering the slab off the rear wall of the reinforced concrete inlet box.

Manholes can be brickmasonry or reinforced concrete and are frequently built as precast concrete units. Fiberglass units are seeing limited use.

Hydraulics

The usual hydraulic practice is to select the pipe size for the accumulated runoff rate at each inlet or manhole assuming that the pipe is just barely flowing full. For the water to accelerate to the uniform flow velocity computed from the Manning Equation, water must back up into the inlet to a depth above the pipe equal to the outflow velocity head plus the inlet lateral entrance loss. Standard practice also requires that the hydraulic gradient, or pressure head line, be computed for the full length of the pipe system, usually starting at the downstream end. The pressure (head) losses at junctions must also be computed.[37] Guide vanes and other geometric improvements within the junction or manhole can be used to minimize pressure losses. The pressure losses become particularly significant for velocities in excess of eight feet per second. The pressure line should be kept close to the crown of the pipe for the design discharge of the minor rainfall. Surcharging the pipe with the pressure line above the crown of the pipe but still remaining about 0.5 feet below ground level is acceptable.

During a major rainfall, the underground system will be under pressure with the pressure line probably at the surface of the water in the gutter. Since the pipe slope is usually about the same as the street slope, the pipe will be carrying only the discharge for that slope, the remainder of the storm water being on the surface of the street. When testing a tentative design for performance under major storm runoff conditions, it may be necessary to increase the size of one or more reaches of pipe to avoid incurring excessive damage costs resulting from overflowing the street. Other alternatives for disposing of the excess flow may be more economical.

The minimum pipe size required should be based on hydraulic considerations rather than arbitrary standards; it should be noted that if a less than 15-inch pipe is satisfactory, then the storm sewer is probably unnecessary, since a curbed 26-foot wide roadway will handle more than three times the flow of a 15-inch pipe on the same grade. Consideration should be given to hydraulic capacity of a pipe given its size, slope and roughness characteristics, tendency to become clogged, self-scouring velocities and ability to clean the pipe and remove obstructions. The use of street swales to collect water, and criteria which allow more flow in gutters prior to initial pick-up, will mean that the initial minimum pipe size will generally be larger than under the old philosophy of "get it into pipes as quickly as possible."

The minimum allowable velocity to keep small particles of sediment moving in a pipe is about two feet per second. It is advisable to have a minimum pipe slope of about 0.1 percent in the approach to a junction box. While the thrust of the storm water management program includes keeping sediment out of the system as much as possible, some sediment load may be unavoidable. With a heavy sediment load, coarser particles may settle out where there is a reduction in transport capacity because of decreasing grade.[21]

The use of an inlet box as a sediment trap is ill-advised. Experiments have shown that the turbulence created by the falling jet moves sediment beyond the box. In addition, catch basins are costly to clean out, and the pipe system usually has the capacity to carry away the sediment anyway. If trapping of sediment becomes necessary, it should be done by designing a sediment trap located at a point where the pipe capacity to transport sediment is reducing. The trap should be accessible for cleaning with mechanical equipment. Storm water loaded with abrasive sediment particles can cause wear on a concrete pipe at high velocities, so the entrance of such sediments should be minimized. The duration of storm water flow is relatively short and infrequent so abrasion by particles that do get into the pipe may not be serious. There is little that can be done to slow down water on a steep grade, other than building a vertical drop structure to dissipate excess energy.

Difficulty with high velocity flow is more likely to occur when the energy gradient (the position of pressure head plus the velocity head) is allowed to rise well above the ground surface at a manhole where the pipe slope decreases abruptly. A hydraulic jump can occur which would check the velocity and result in conversion of velocity head to pressure head sufficient to blow off the manhole cover or the whole top of the manhole. This is a particular problem where pipe alignments cause flow through inlet boxes, which are often shallow, as the intended inlets may instead function as outlets.

Manholes

The principal purpose of manholes is to provide access for cleaning and inspection. They usually should not be more than 500 feet apart on small pipes; spacing may be greater for larger pipes and unlimited for 66-inches and larger. Maintenance and safety requirements will dictate spacing on the big pipes. Inlet boxes should also have manhole openings to provide access. If storm drain pipes run through inlet boxes, they can be used for inspection and maintenance and can be counted when determining minimum spacing. This practice is only recommended where there is no likelihood of soil movements or external live loads on the inlets. Where pipes are routed through inlet boxes both pipes and boxes usually must be at least one foot below conventional depths to offset hydraulically adverse head recoveries, turbulence and entrance losses, to assure functioning of the inlets.

STORM WATER INLETS

Storm water inlets are located at the transition between open surface flow and a closed conduit system. They are either constructed as part of the street's curb and gutter system, located in street swales or used to drain open areas. The inlets should remove runoff from surfaces when the flows exceed the criteria for velocity, spread of water across streets, or flow across intersections. Inlets in street swales also remove flow when it exceeds swale capacity. Drainage of open areas is often picked up by an inlet in a depressed area.

In utilizing natural systems effectively, the employment of inlets should be delayed as long as possible because as soon as the runoff enters the pipe system, it is carried rapidly downstream.

Grate Inlets

Grate inlets consist of metal bars or a grid encased in a frame. When grate inlets are placed in the street, the bars are usually aligned with gutter flow for maximum hydraulic efficiency. This allows the intercepted water to fall between the bars. The bars of the grate may be placed at right angles to the curb for the safety of cyclists. When this is done, water hitting the bars may be projected upward, causing some of the flow to be deflected away from the inlet. The efficiency of both applications is improved by depressing the grate below the plane of the gutter within the transition area. This creates a sump condition and the small amount of ponding helps reduce approach velocity abating the tendency of the water to be deflected beyond the inlet.

Grate inlets are often placed in street swales and other overland flow areas, when it is necessary to intercept the flow due to velocity or the lack of a satisfactory route for continued flow. Grate inlets are also used to drain parking lots. The design of these inlets must account for any expected reduction in inlet interception capacity due to clogging by grass cuttings, and water borne debris.

Periodic maintenance to assure the capacity of the inlet is necessary. Grate inlets in unpaved areas should be placed according to the most efficient design, as it is not likely that bicycle traffic will be a factor in this type of installation. Grate inlets on urban streets are not recommended.

Curb Opening Inlets

The capacity of an inlet to intercept water flowing down the street depends to a large degree on the distribution and velocity of water in the gutter cross-section. On a continuous grade, an inlet will intercept only that flow within its hydraulic reach. In the case of the curb opening inlet, the width, length and depth of the depressed section of the gutter in front of the opening is very important. Steepening of the cross slope of the gutter enables gravity to begin turning the flow into the opening, but because of the inertia of the flow considerable opening length is necessary.

The vertical height of the opening should be not greater than six inches in order to eliminate the possibility of a child being washed into the inlet basin. This places a restriction on hydraulic capacity for major storm conditions when most of the street may be flooded. The outlet pipe would probably be flowing full by that time and would limit the inflow anyway. The opening preferably should be clear for the entire length on continuous grades.

A sediment trap formed by lowering the floor of the inlet box below the elevation of the outlet pipe is unnecessary and undersirable since there is too much turbulence for effective trapping, and cleaning is costly.

Capacity of Curb Opening Inlets

The most authoritative data on capacity of curb opening inlets is contained in a circular published by the Federal Highway Administration (FHWA).[8] That report includes charts for estimating the interception ratio Q_1/Q for inlets five, ten and fifteen feet long, and curb widths of one, two and three feet when used on street sections with cross slopes ranging from 0.015 to 0.06 ft./ft. and roadway grades up to four percent. The charts, as published, are based on full scale tests by Colorado State University. Extension of the charts to steeper grades has been developed and is awaiting publication.

Curb Opening Inlets at Sump Locations

Curb opening inlets at a low point in the grade (sump) operate efficiently, since the water is trapped at the opening. Charts are available for estimating the capacity of inlets five, ten and fifteen feet long in terms of the depth of ponding over the inlet lip.[8] It also has a procedure for determining when a given inlet will restrict flow to the point where backwater will occur in the approach gutters, thus increasing the width of ponding. For major storms, the restriction caused by the outflow pipe may govern.

Curb Opening Inlets—Deflector Type

The state-of-the-art literature contains references to the use of deflector vanes on the surface of the depressed gutter in front of an inlet to force more water into the curb opening. The only experimental data available on deflector vanes were based on a steep crown slope $S_x = 0.055$ with a narrow range of water depth and with water spread only twice the width of the depression. These results are not applicable to flatter cross slopes, and are applicable least of *all* to large ratios of water spread to curb width. The Colorado experiments on which the charts in *FHWA's Drainage of Highway Pavements* were based demonstrated conclusively that the interception ratio is a function of water spread to curb width.[8]

The use of deflector vanes is not recommended, since they complicate construction and in the past have been rendered inoperative when buried by street resurfacing.

OTHER DESIGN CONSIDERATIONS

Soil Erosion

Control of erosion *during residential construction* requires an examination of the entire site to pinpoint potential problem areas, such as steep slopes, highly erodible soils, soil areas that will be unprotected for long periods or during peak rainy seasons and natural drainageways. Steps should be taken to assure erosion control in these critical areas. After a heavy storm the effectiveness of erosion control measures should be evaluated. Periodic maintenance and cleaning of the facilities is also important.

Control of erosion *after construction* consists primarily of minimizing bottom and side scouring of natural drainageways. This can be accomplished by proper initial design which limits velocities and specifies correct drainageway linings and structures, and by proper routine maintenance and repair of the system.

Some of the basic concepts for controlling erosion during and after construction are:[2, 7, 30, 54]

- Earth slopes: Erosion of cut or fill slopes is usually caused by water concentrations at the top of the slope flowing down an unprotected bank. Runoff should be diverted to safe outlets. Slopes should be protected from erosion by quick establishment of vegetative cover, benches, terraces ,slope protection structures, mulches, or a combination of these practices as appropriate.
- Waterways or Channels: Waterways should be designed to avoid serious erosion problems. Wide channels with flat side slopes lined with grass or other vegetation will usually be free from erosion. Where channel gradients are steep, linings or grade control structures may be required. Space limitations may make it necessary to use concrete or stone linings. Every effort should be made to preserve natural channels.
- Structures for Erosion Control: Erosion may be controlled by the use of grade control structures, energy dissipators, special culverts, and various types of pipe structures. Structures are expensive and should be used only after it has been determined that recommended vegetation, rock revetment or other measures will not provide adequate erosion control.
- Existing Vegetation: Good stands of existing vegetation adequate to control erosion should be preserved wherever possible.
- Soil Treatment, Seeding and Mulching: The ability of the soil to sustain vegetation intended for erosion control must be ascertained. The admixture of a fine textured topsoil may be warranted to assure success of more attractive, lower maintenance vegetation. Liming and fertilization should be done according to recommendations based upon soil test information. After the soil has been prepared, the correct seed mixture, sod, ground cover and mulch should be applied.
- Outfall Design: The outfall pipe should be designed and located so as to minimize erosion; especially if the outfall is to an overland flow area with a steep slope or is elevated above the base flow of the receiving streams. An energy dissipator may be necessary.

Siltation and Sediment Control

Proper control of soil erosion during and after construction is the most important element of siltation and sediment control. However, it is physically and economically impractical to entirely eliminate soil erosion. Secondly, erosion is a natural function and is required in certain portions of the drainage system in order to provide future stream capacity. Therefore, provisions should be made to trap eroded material at specified points. Some measures that can be implemented are:[11, 30, 54]

- Temporary ponds which store runoff and allow suspended solids to settle out can be used during construction and may be retained as part of the permanent storage system after construction.
- Protection of inlets to the underground pipe system can be accomplished during construction by placing hay bales around the structure.
- Egress points from construction sites should be controlled, so that sediment is not carried off-site by construction traffic.

Storm Water Runoff Pollution

As storm water runoff flows over surfaces, it picks up pollutants and carries them downstream. The magnitude of the pollution load has been the subject of recent investigations by the Environmental Protection Agency (EPA) and others.[2, 38] It is generally conceded that the magnitude is sufficient to warrant serious examination of alternate methods of controlling and treating storm water runoff pollution.

Documentation of pollution loads in streams before and after construction is a necessary first step prior to embarking on extensive runoff treatment programs. Measurements might include suspended solids, Biochemical Oxygen Demand (BOD), dissolved oxygen and the concentrations of toxic materials, bacteria and nutrients. Under ideal conditions the measurement of pollution should be coordinated with simultaneous collection of data on rainfall and runoff. Pollution loads are the result of:

- soil erosion and dissolving of minerals in the natural ground cover;
- overland flow which picks up fertilizer, animal droppings, and organic material, and
- flow on parking lots, roofs and streets which carries petroleum products, trash, dust fall and debris from cars and trucks into the drainage system.

Three basic methods of treatment can be used:

- The first controls pollution loads at their source. For example, proper erosion control and sediment control will reduce the suspended solids levels. Also, periodic street cleaning will reduce pollution loads.

- Storm water runoff can be treated at the source. Temporary storage of runoff to allow suspended solids to settle out is one example. Diversion of runoff to land treatment areas for spraying or controlled overland flow is another. The fact that most runoff pollution results from the "first flush" of runoff should be considered when planning source treatment facilities.
- Treatment of storm water runoff at a centralized plant downstream is the third alternative. This is probably the most costly method because of the vast volume of water requiring treatment. Consideration may be given to storage facilities enabling storm water to be released to treatment plants at a gradual rate after the runoff peak has passed.
- Treatment of runoff to reduce pollution loads is probably unnecessary for most low-density residential development, but the availability of pertinent information is limited. It seems obvious that the cost of such treatment will be high, so it follows that treatment should not be considered unless there is documentation of the need and a demonstration that the benefits from treatment will be consistent with its costs.

Maintenance

Adequate provision for short- and long-term maintenance of the residential storm water system is an important design consideration. Maintenance and replacement needs and costs should be part of the economic analyses.

Maintenance requirements for the type of system suggested in this document may be different from those for a fully enclosed pipe system. Mowing, trash and sediment removal, replacement of sod and repair of eroded areas will become parts of the maintenance program. Conversely, less pipe inspections, repair and cleaning will be required.

When planning an on-site storage system, determination must be made about long-term ownership and/or maintenance and operation of the facility. The choices will generally be between public and private organizations and the final decision will be dependent on local conditions.

Encroachment into Potential Flood Plain Areas

No consideration of residential storm drainage is complete without recognition of potential flood hazard exposure. These potential hazards are obvious along major rivers and streams but can also occur along tributaries and drainageways and in headwater areas as will be discussed later.

Management of major drainage basins and rivers is usually controlled by other than local governments; however, local government should be concerned with controls for development in all other areas subject to flooding.

The Federal Insurance Administration (FIA) is currently involved in a two-staged effort to delineate and map some floodplains and their potential flood elevations for many communities as part of an effort to provide insurance for structures located in areas of potential hazard. The first stage provides a gross delineation of the floodplain, to permit subsidized insurance for properties already located within a hazard zone and a basis for planning future land uses in such areas. The second phase provides more accurate and detailed mapping of the floodplain to guide future land use practices and determine insurance rates for structures permitted to locate in a designated hazard zone. It will take years to complete this mapping effort, and it is uncertain whether it will be possible to identify and map all potential flood hazard areas. Thus it is necessary for all involved in the process of land development to recognize and consider any potential flood hazards associated with the land being developed.

In a subsequent discussion of basic legal aspects of urban drainage and flood control, potential liabilities associated with land use and development are outlined. The direction of liability may be shifting, by placing increasing culpability on parties involved in the approval of land uses in a hazardous area or in the creation of hazards. The availability from FIA and others of hazard information and delineated potential hazards makes it easier to assess liability for improper location or land use.

As a result of FIA actions and Federal regulations relating to flood hazards, local governments have been stimulated to provide new regulations for their jurisdictions. These regulations cover areas delineated by FIA and may cover tributary and headwater areas not currently mapped. The new regulations do not prohibit all development in potential flood hazard areas but rather require that development be consistent with wise floodplain management to qualify for insurance or loans from federally regulated or insured institutions.

Within flood hazard areas, there are often locations where occupancy is fully justifiable under certain conditions. The Minimum Property Standards (MPS) of the Department of Housing and Urban Development recognize this and permit floodplain occupancy provided the finished first floor of a dwelling is no lower than the 100-year frequency flood elevation and the building site grades adjacent to the dwelling area are no lower than the 50-year frequency flood level.

In practice, the use of the 50-year frequency flood elevation as a limit to acceptable encroachment upon a flood plain may justifiably be varied. Where the difference in elevation between the 50-year and 100-year frequency flood levels is less than eight inches, it often will be fully justifiable to occupy sites having elevations below the 50-year frequency flood elevation, sometimes as low as the 20-year frequency flood elevation, if dwellings will have their floors at or above the 100-year flood elevation and the dwellings will have no basements. This justification reflects the typical low-flow velocity of floodwaters in such locations and the minimal effect of buildings upon flooding depths upstream from such locations. Where the difference in elevation between the 50-year and 100-year frequency flood levels is more than eighteen inches, residential encroachment upon the flood plain to the 50-year frequency flood elevation generally is unwise since potential flooding depths and fast-flow velocities could cause severe damage to properties. Where properties may potentially be flooded for more than a few hours, more stringent encroachment limits than the 50-year frequency flood elevation may be appropriate because the social displacements and flooding damages will usually be greater than from short-term flooding of similar depth. Of course, technical justification of a variation will not necessarily be acceptable to regulatory authorities.

The economic benefits that may be derived from occupancy of portions of a designated special flood hazard area, or other areas subject to flooding, may be appreciably greater than probable future flooding losses. There is a statutory provision for Federal acceptance of alternative land use and control measures applicable to such locations, but the burden of developing alternative measures and demonstrating their assured fulfillment of Federal loss mitigation objectives is upon the local community. The community must demonstrate conclusively that the economic and social benefits derived from occupancy will be greater than, and of overriding importance relative to, the potential flooding losses. For locally-suggested alternative measures to be given credence, proponents of the alternative measures should clearly explore whether immediate costs and adverse effects upon property values, tax revenues and public facilities (including utilities), attributable to adoption of generally promulgated land use and control measures, are greater than the probable future flooding losses discounted to present value. Locally-suggested alternative measures should also demonstrate how their implementation would mitigate future flooding losses, and to what degree. Regardless of whether flooding is caused by inadequate drainage or by streamflow, the derivation and support of locally-suggested alternatives optimally requires interaction and close cooperation among all local interests.

Selection of appropriate types of dwelling units for construction in areas exposed to flooding may significantly reduce potential flooding losses, by comparison with potential losses using other dwelling types. Where the occupancy will be in a community that is generally exposed to flooding, or in a substantially developed area in which it is not feasible or reasonable to forego building upon vacant sites, selection of the merchantable building type having the lowest flooding loss expectancy is appropriate. In such situations, the probable market response to a change in building type should be carefully assessed during decision making. Based upon the Federal Insurance Administrations' Depth-Damage curves,[10] the relative flooding loss characteristics of common types of residential buildings are as follows:

Building Type	**Ratio of Damage***
Two-story dwelling without basement	1.0
Split level dwelling	1.15
Two-story dwelling with basement	1.2
One-story dwelling without basement	1.5
One-story dwelling with basement	1.65
Mobile home	2.3

*Base level is two-story dwelling without basement

As shown, substitution of a building type with a lesser loss potential could reduce potential average annual flooding losses to levels comparable to loss expectancies outside of other designated special flood hazard areas. Where such an alternative relationship can be demonstrated, there would seem to be a persuasive argument for acceptance.

Additional loss mitigation can be effected by reducing land occupancy densities, thereby reducing the total value of exposed property per acre, and by floodproofing, to reduce the losses expected from any given level of potential flooding. Floodproofing[17, 19, 44] involves a series of construction modifications either to exclude water from entering buildings or to reduce the potential for water damage if water does enter buildings. In some situations, floodproofing can reduce potential flood losses by as much as 60 percent by minor initial increases in construction costs.

The potential for flood hazards and the issues of encroachment into flood plain areas discussed above tend to presume a continuation of past practices in runoff management in upstream tributary areas. A major objective of this publication is to encourage new approaches to storm water runoff management which would attenuate peak runoff thus reducing frequent flood hazard threats in the middle and lower reaches of a drainage basin. Thus, application of the objectives, principles, and design considerations set forth in this publication may in themselves provide further justification for cautious variations of limitations on land use in flood hazard areas.

Potential Flood Hazards in Tributary and Headwater Areas

The prior discussion has been concerned with flooding associated with overflow of channels, streams and rivers into adjacent, generally identifiable, flood hazard areas. There is considerable potential for water damage associated with unwise siting and drainage practices which are often overlooked and are often a source of residential flooding in tributary and headwater areas. These hazards generally are foreseeable, are usually the result of poor application of good design practices, and can be avoided without significant increase in development or construction costs.

Streets, highways and railroad crossing drainageways or streams are commonly elevated, on embankments, with culverts or small bridges passing beneath them to accommodate runoff flows. When the runoff flow is too great to pass through the culvert or bridge, or when the culvert or bridge is blocked by debris, the embankment will act as a dam causing runoff to accumulate upstream and possibly overflow the embankment. The depths of potential flows over roadway embankments are variable and should be computed, but most commonly are from one to two feet. The potential for residential flooding upstream from drainageway-crossing embankments can be eliminated if dwelling floors and openings into dwellings are higher than potential runoff overflow elevations at embankments. Failure to recognize such conditions is a widespread source of residential flooding. A proper application of the *blue green* concept discussed elsewhere should eliminate this hazard.

One common but easily overlooked source of residential flooding occurs where runoff from small areas will naturally follow a lot line swale between dwellings. Even though a drainage area may be very small, the quantity of foreseeable funoff will be frequency-related. The worst foreseeable flows should be anticipated during design. Appropriate designs for such locations will consider both the size of the swales and the elevations at which buildings are sited. There is always a potential for water-related damage, from storm water runoff or ground water, to structures improperly sited or improperly graded. Thus, detention ponding on individual sites, as suggested elsewhere in this publication, may be impractical or unwise because of such local problems as impermeable soils, expansive soils or seasonally high ground water. Under such conditions, positive drainage of individual building sites may be essential.

Some relationships between basement construction and flood hazard exposure should be emphasized. Typical basement construction is incompatible with on-site detention ponding where site soils are more than slightly permeable and where detention ponding might contribute to the rise of ground water to building footing elevations. The most commonly observed cause of residential basement flooding is entry or penetration of storm water runoff due to the failure to drain runoff quickly and positively away from buildings. Where soils are essentially impermeable, protective slopes around a dwelling can be used to assure quick and positive drainage of runoff away from the dwellings either to off-site locations or to ponding storage areas on-site with controlled outfall.

Again, it should be emphasized that the flood or water damage hazards described here would be the result of improper site-specific application of recommended design approaches suggested earlier in this publication. Proper application of on-site detention, and proper use of swales and other engineering techniques should avoid creation of residential flood hazards.

LEGAL IMPLICATIONS

Homebuilders and developers are familiar with zoning, subdivision regulations and building codes. Storm water law is another control which the public sector has placed on the use and development of land or which has arisen through liability imposed by courts when the acts of one land owner have adversely affected the property of another. Storm water law, like storm water engineering, can be divided into two areas—floods and drainage—even though they obviously belong to the same system of surface water runoff.

Regulating the Flood Plain

The flood plain is usually defined as that area bordering a watercourse which would be inundated by a flood of a certain magnitude. The magnitude used in establishing the federal flood hazard areas is the "one-hundred-year flood", that is, a flood which has a statistical one percent chance of occurring or being exceeded in any one year. Often this flood plain is further subdivided into a "floodway" and a peripheral area.

Billions of dollars have been spent on flood protection works. In spite of this, nationwide flood losses have continued to escalate. The response to this dilemma has been a change in philosophy in dealing with flooding. Instead of attempting to keep rivers away from people by damming and channelizing them, the trend is towards keeping people away from rivers by preventing further unwise encroachment onto the flood plains. This is not to say that no development should occur at all, but rather that development must be consistent with good flood plain management. The greatest impetus has come from the federal government through its National Flood Insurance Program, the Flood Disaster Protection Act of 1973 (PL 93-234, amending 24 U.S.C. Ch. 50).

Briefly, it works in the following manner. First, special flood hazard areas are identified and designated on maps by the federal government. If the community has become a "participating community" by adopting adequate land use measures and other controls for its flood plains, those buildings which already exist in the flood hazard areas are eligible for heavily-subsidized flood insurance. Flood insurance for new construction, however, will not be subsidized; instead, premiums will reflect the actual flooding risks to the property. The crux of the program is that flood insurance is *required* before the vast majority of lending institutions in the United States can make, increase, extend or renew any loan secured by improved real estate located or to be located in one of these special flood hazard areas. For the developer, this means he must investigate whether or not the property he proposes to develop is or is likely to be in a federally-designated special flood hazard area. If it is, and the community has failed to become a "participating community" by adopting acceptable land use controls, residential financing will probably be unavailable. If the land is within a "participating community," the developer must investigate what controls the community has placed on the land and what the flood insurance costs would be. A federal rate map identifies applicable insurance rates. Occupancy and insurance costs can be mitigated by taking certain precautions (such as raising the elevation of the building), but may still make construction in that location less feasible. Therefore not only how the building is constructed, but whether the building should be built at that site at all, is an initial consideration affected by the National Flood Insurance Program. Another site, outside of the hazard area, may be financially more advantageous for development.

Additionally, even if the federal government has not designated an area, both state and local laws should be consulted. Some states and communities have adopted flood plain regulations and maps on their own initiative, or areas in addition to the federally-designated areas might be locally controlled, such as on smaller tributaries of the main stem. Local land use controls may be in the form of building codes, subdivision regulations, or specific flood plain regulations. Since the floodway is supposed to be adequate for the safe passage of the floodwaters through the community, building restrictions within it are severe. In the peripheral area, sometimes called the low-hazard zone or flood storage area, development is usually permitted within certain less restrictive design parameters and precautions. Since the federal requirements are minimum, local flood plain controls can be more restrictive. It behooves a developer to find out what they are. Some regulations declare that a building which is not in compliance with the flood plain regulations is a public nuisance which can be enjoined or even abated. In addition, where such development is the proximate cause of injury to the person or property of another, and the non-compliance could constitute negligence, the owner or developer might be liable for damages in a tort action.

Drainage Law

While flood plain regulation is of fairly recent vintage, drainage law dates back to ancient times. Here we are looking at the respective rights and duties of the "upper" landowner versus the rights and duties of an adjoining "lower" landowner. The "upper" land lies at a higher elevation, and water drains down onto the "lower" land. This relationship is based on the lands in their natural, unaltered state.

There are basically two doctrines which have been adopted by various state courts: the "common enemy rule" and the "civil law rule". Under the "common enemy rule" the lower landowner may take any measures necessary to keep water off his land, even to the point of turning the water back onto the upper land. The upper owner can similarly protect his property from the "enemy" by diverting water around his property causing greater quantities at higher velocities to flow onto his neighbor's land. In its pure form it would be a might-makes-right situation.

Therefore, courts have modified the rule to require that such acts be reasonable *vis-a-vis* each other. The "civil law rule" states that the upper land owner has an easement over the lower land for the natural drainage off of his land. The key word is "natural", meaning the same quantity and velocity as drained from the upper land in its undeveloped state. It was felt that, in its pure form, the law would substantially restrict development of the upper land, so again courts have modified it to accommodate reasonable use of the upper property. Finally, both of these doctrines, which are based on the property-law concepts of dominant versus servient lands, have been rejected by some courts. These courts focus on "reasonable use" alone, based on tort-oriented law. While these modifications tend towards the same results, the practical questions of predictability and proof requirements remain substantially different.

The developer will want to protect himself from possible exposure to a potential liability suit for damages, or from a time-consuming and costly injunction action. Under any of the doctrines mentioned above, his best protection is to develop in such a manner as to keep the runoff as close as possible to runoff conditions in the natural state—in quantity, velocity, and location. If he has obtained the hydrologic, soils, and other data recommended for good engineering design, and has developed his project accordingly, the same facts will protect him from liability because he can prove that he has not materially changed the natural drainage conditions and has acted in a reasonable, non-negligent manner.

Some communities have established special assessment districts or storm drainage fees for the purpose of constructing drainage improvements. The developer should also investigate how these might affect the property. The basis for the fee may be the difference between the amount of runoff which was generated from that property in its developed condition. Here again if the same amount of runoff has been maintained, by on-site ponding or other techniques, the fee may be negligible. If, on the other hand, the natural permeability has been reduced by extensive paving, he may be committing the property to be subjected to high drainage fees. Or the fee may reflect the cost of flood control works which are necessary to remove the property from a flood hazard zone. This may affect not only how he constructs, but whether he constructs there at all.

Conclusion

From a legal point of view, as from an engineering point of view, the developer must accept the fact that every piece of property involves storm water runoff in either a major or minor way and as both a contributor and recipient. It is imperative, before purchase or development, to get the physical facts and to investigate the local, state and federal laws which could affect the property. The storm water aspects of the property may be one of the controlling factors on how to develop or even whether to develop that site at all. However, after having done his homework, and developed the property in a responsible and reasonable manner, the developer can rest assured that he has good protection from liability.

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