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DETENTION SYSTEMS FOR SMALL URBANIZING
WATERSHEDS: A RUNOFF MANAGEMENT ALTERNATIVE.

THE UNIVERSITY OF OKLAHOMA, PH.D., 1977

THE UNIVERSITY OF OKLAHOMA
GRADUATE COLLEGE

DETENTION SYSTEMS FOR SMALL URBANIZING WATERSHEDS: A RUNOFF MANAGEMENT ALTERNATIVE

A DISSERTATION
SUBMITTED TO THE GRADUATE FACULTY
in partial fulfillment of the requirements for
degree of
DOCTOR OF PHILOSOPHY

BY
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Norman, Oklahoma
1977

DETENTION SYSTEMS FOR SMALL URBANIZING WATERSHEDS:

A RUNOFF MANAGEMENT ALTERNATIVE

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ACKNOWLEDGEMENTS

Acknowledgements should be written decades after the events, which are being acknowledged. Then there is a more accurate perspective of who or what was invaluable to the effort. At this point in time, those who attest to their approval of this effort by signing their names to the second page are strong candidates for the eventual appreciation.

There are however, people, places and events of decades past that seem to have facilitated (often obscurely) my arrival at this beginning.

To parents, wondering where their children went.

To school counselors who never counseled and left their charges to find things out the hard but unforgetable way ...

To Greyhound Buses ....the cheap, smokey transporters of the poor ....taking the back streets to Detroit.

To draft notices and other unpleasant interruptions of unpleasant times....barely avoiding disasters and developing a new resolve.

To the New York, New Haven and Hartford Railroad....now dead.... but then a financial and mental respite along the way.

To dairy farms, paper routes, and the New England woods.... unpurchasable rewards.

To dreaming, without which the peanut butter on Ritz Crackers with dry corn flakes would never have been digestable....

With Ann & John IV in
Athens, Georgia 1977

DETENTION SYSTEMS FOR SMALL URBANIZING WATERSHEDS:
A RUNOFF MANAGEMENT ALTERNATIVE

BY: John F. Crowley III

Major Professor: Dr. Marvin W. Baker Jr.

As population increases so will the urban area which houses and serves it. This apparently inevitable expansion of urbanization causes hydrologic change in the watersheds where development takes place. The change usually involves increases in peak flows and total runoff during periods of precipitation. There are, as a result, two undesirable and mutually reinforcing effects associated with the hydrologic change. First, the likelihood of flooding is increased as a result of increased volumes and peak flows. Second, urbanization itself often results in the increased intensity of development in and adjacent to flood hazard areas.

Large scale engineering works, floodproofing, land use regulation, forecasting and temporary evacuation, and relief are the prevailing methods for reducing flood damages. Yet despite the billions of dollars invested in the prevailing methods, flood damages have been continuing to increase. This raises the question of whether or not the prevailing approaches are best suited for managing the volumes of stormwater runoff and reducing associated damage in the modern era of urban development.

This study develops an alternative management approach and initiates a preliminary examination of its potential effectiveness and feasibility. The proposal is based on the premise that the tenants of each locality are responsible for managing their own runoff and that the watershed is a system of local drainage spaces. Properly managed,

the watershed is a system of sub basins within which runoff is detained and released at rates which, when added to all other sub basin releases, do not exceed the natural drainage capacities of any channels below their respective confluences. Each subbasin, subsequently, is a smaller watershed within which more locally drained areas are subject to the same detention and release considerations.

The prevailing approaches are examined so that problems which may be associated with them can be circumvented while successful attributes can be retained. The result of these observations is the development of a set of desirable performance characteristics which become the basis for the proposed alternative. Techniques which reliably achieve local detention are surveyed and systems or networks of techniques which can be applied to total watersheds are developed. Release techniques which can be incorporated into the various detention devices are applied to an example watershed of 11.6 square miles which is located near the leading edge of an expanding urban area. This case study application is tested under the conditions of a 100 year storm.

The study concludes that the systematic application of local detention and release devices can effectively manage the volumes of urban stormwater runoff under relatively severe test conditions. Areas of further testing and research, problems associated with implementing the alternative, and the relationship of the approach to other considerations such as water quality are also outlined.

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In general these flood studies provided evidence for a pattern of declining death rates and increasing damage, despite substantial investment in technical means for coping with hazard. In so doing they raised serious questions as to the efficiency of the prevailing approach to natural hazard loss reduction."[1]

Robert Kates

PREFACE

Kates' statement underlines the principle reason for the investigation of an alternative proposal for runoff management in this thesis. The main contention is that the present approaches are beginning to be questioned and that there are reasons to believe that these methods may not result in the best solution when applied. Recognizing that there are questions and doubts, this study proposes a possible alternative management approach and initiates an exploration of its feasibility and potential effectiveness. If the investigation determines a potential effectiveness under modeled test conditions, further research will be worthwhile. Otherwise, the value of this study lies in its redirecting explorations in runoff management toward other potential alternatives. In the meantime, actual management of runoff must continue with the prevailing approaches despite the increasing number of questions about their respective effectiveness.

The proposed approach is a systematic application of small scale, local detention techniques throughout the entire watershed which trap

[1]Robert W. Kates, "Experiencing the Environment as Hazard," in Environmental Psychology, ed. by Harold M. Proshansky, William H. Ittelson, and Leanne G. Rivlin (New York: Holt, Rinehard and Winston, 1972).

and hold runoff. In order that these detention devices be emptied before the occurrence of subsequent storms, a method for controlled release is also part of the proposed approach. The study investigates this approach in light of its potential application to small urbanizing watersheds. Although Poertner surveys cities which have attempted to apply various detention structures as remedial treatments for existing flood problems, there is no evidence in either the literature or in the applied fields of urban design and engineering that a small scale, systems approach, using the entire watershed, has been previously explored.[2] Public Law 566 (1954 Watershed Protection and Flood Prevention Act) was enacted as a basin wide runoff control approach for agricultural and rural lands which are probably tolerant of different patterns of runoff accumulations than the more densely developed urban lands.[3]

The proposed approach is based on three premises. First, floods (which should be avoided) are accumulations of water which cause damage. As an urban drainage area is enlarged, the potential for larger accumulations of runoff increases. A damaging accumulation can be avoided by detaining contributing flows at locations above the confluences where the first potentially damaging volumes would otherwise tend to collect.

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[2]Herbert G. Poertner, Practices in Detention of Urban Stormwater Runoff (Chicago: American Public Works Association, 1974).

[3]A more complete discussion of the character and intent of Public Law 566 can be found in the Soil Conservation Service, Multiple-Purpose Watershed Projects Under Public Law 566 (Washington, D.C.: U.S. Department of Agriculture, 1972).

Second, land areas constitute the sources of contributing runoff. The amount of flow contributed is dependent on the area's physiographic character and its use. Responsibility for managing contributing flows can be equitably and efficiently distributed to the most local scale by making each owner accountable for the flow which his land area generates.

Third, every drainage area has a network of channels along which runoff is conveyed. These channels have a natural capacity which, when exceeded, causes overbank flow and potential flood damage. Therefore, the rate of runoff discharged from a drainage area should be equal to or less than the natural capacity of the channel network which serves it.

The proposed alternative also utilizes the prevailing approaches as a guide. Chapter Two notes the successful elements of the present approaches and places an emphasis on their problem characteristics which have lead to Kates' "questions" so that additional successful elements might be introduced in the alternative techniques. Chapter Three develops a series of goals and objectives to be achieved by the alternative proposal based on retaining the successful elements and avoiding the recognized problem areas of the present flood damage abatement methods. The balance of the investigation consists of articulating and modelling the systems of techniques which constitute the alternative proposal. The closing discussion develops conclusions, lists some of the problems in implementing the proposal, notes some of the basic relationships of the alternative to water quality planning, and gives suggestions on areas of related research.

From the point of view of effective contribution to land use planning the academic branches generally are much less potent and useful than the land use organizations (National Park Service, National Forest Service, and National Resources Planning Board). In such disciplines as economics, history, sociology, or biology, there is the same narrowness of approach and disinclination to accept and utilize the findings of other groups, that is apparent in land use organizations. Further, the academic line seldom in the past have oriented at all toward the research of the kind necessary to land use planning.[1]

K. C. McMurray

CHAPTER ONE

DETENTION SYSTEMS FOR SMALL URBANIZING WATERSHEDS: A RUNOFF MANAGEMENT ALTERNATIVE

Introduction

The purpose of this chapter is sixfold. First, the problem which stimulated the research is defined and second, the objective of the research, with regard to solving the problem, is delineated. Third, the subject itself is defined and fourth, the inquiry into the subject as a geographical issue is discussed. Fifth, the related literature is briefly examined and sixth, the structure and format of the inquiry is outlined.

The Problem

Urbanization changes the hydrologic response of the drainage basin by increasing the volume and accelerating the rate of stormwater runoff.[2]

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[1] K. C. McMurray, "Geographical Contribution to Land Use Planning," Annals of the Association of American Geographers, XXVI (June 1936), p. 91.

[2] Urbanization, as a primary cause of increased stormwater runoff problems is substantiated by most of the literature of flooding. Two

"Essentially every metropolitan area of the United States has a stormwater problem, whether served by a combined sewer system (approximately 29 percent of the total sewered population or a separate sewer system."[3] It is expected that the United States will continue to urbanize and thereby further aggravate the runoff problem in the future.[4]

The U.S. has spent billions of dollars in the development of flood damage abatement structures, yet annual flood losses continue to increase.[5]

> The basic philosophy of stormwater management in residential, and for that matter, all kinds of developments, is open to challenge and revision. Nationwide experience with the effects of narrow and inadequate philosophies on past practices indicates that stormwater has rarely been well managed, and has in fact often been mismanaged.[6]

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sources include William J. Schneider, David A. Rickert, and Andrew M. Spieker, Role of Water in Urban Planning and Management, U.S. Geological Survey Circular 601-H (Washington, D.C.: U.S. Geological Survey, 1973) and Northeastern Illinois Planning Commission, Regional Overbank Flooding and Stormwater Drainage Policy Plan, Second Draft for Public Review and Comment (Chicago: Northeastern Illinois Planning Commission, 1976).

[3] John A. Lager and William G. Smith, Urban Stormwater Management and Technology: An Assessment (Cincinnati, Ohio: National Environmental Research Center, Office of Research and Development, U.S. Environmental Protection Agency, 1974), p. 3.

[4] Paul R. Erhrlich, Anne H. Ehrlich, and John P. Holdren, Human Ecology (San Francisco: W. H. Freeman and Company, 1973), p. 41.

[5] Gilbert F. White, Wesley C. Calef, James W. Hudson, Harold M. Mayer, John R. Sheaffer, and Donald J. Volk, Changes in Urban Occupance of Flood Plains in the United States, Department of Geography Research Paper No. 57 (Chicago: The University of Chicago Press, 1958), p. 6.

[6] Urban Land Institute, The American Society of Civil Engineers, and the National Association of Home Builders, Residential Stormwater Management: Objectives, Principles, and Design Consideration (Published jointly by the ULI and NAHD, Washington, D.C. and the ASCE, New York City, 1975), p. 7.

The problem therefore is twofold. First, stormwater runoff problems have been significantly aggravated by urbanization and the present approaches to solving them are subject to question. Second, urbanization will continue to increase and further aggravate the runoff problem. This necessitates research and experimentation with alternative runoff management approaches.

The Objective

The objective of this thesis is to examine a possible runoff management alternative and to study its feasibility. It is proposed that by examining the problems associated in the literature with the traditional management approaches (Chapter Two) alternative goals and performance characteristics can be developed (Chapter Three). If the techniques for achieving a resultant alternative are in turn modeled in a case study watershed, feasibility can be examined. If the same case study model is tested under conditions which are more severe than those likely to actually occur in most watersheds, an apparent feasibility for the test case would indicate a greater likelihood that feasibility is achievable elsewhere. Subsequent research could then be directed toward modeling the same alternative approach in a diverse series of basins under varying conditions. The subject, introduced in the following section, is the developing and testing of an urban runoff management alternative.

Defining the Subject

If a title is appropriately encapsulating, an analysis of its content should provide a good vehicle for the subject's introduction and definition. Figure 1.1 is a content diagram of the title. Following a brief look at each of the content elements, the title will be reassembled as the sum of its explained parts.

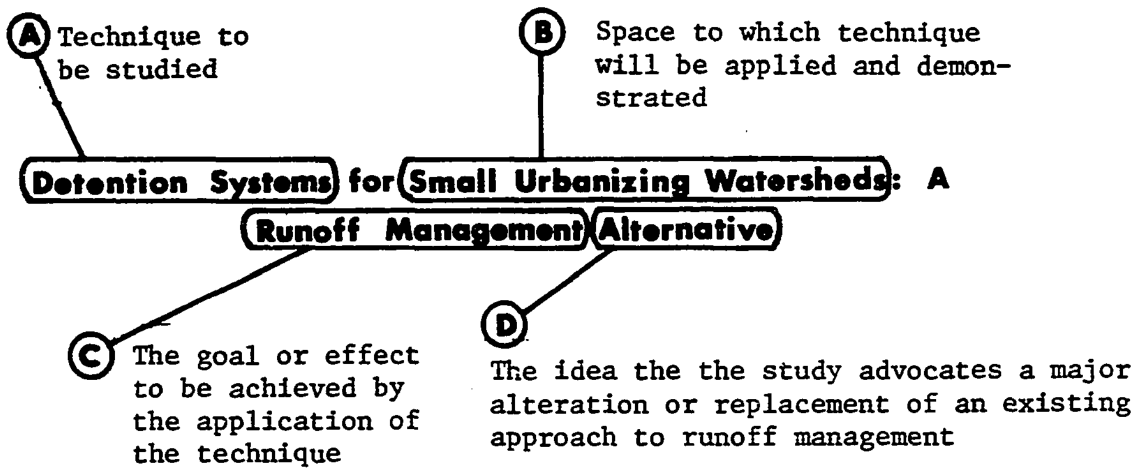
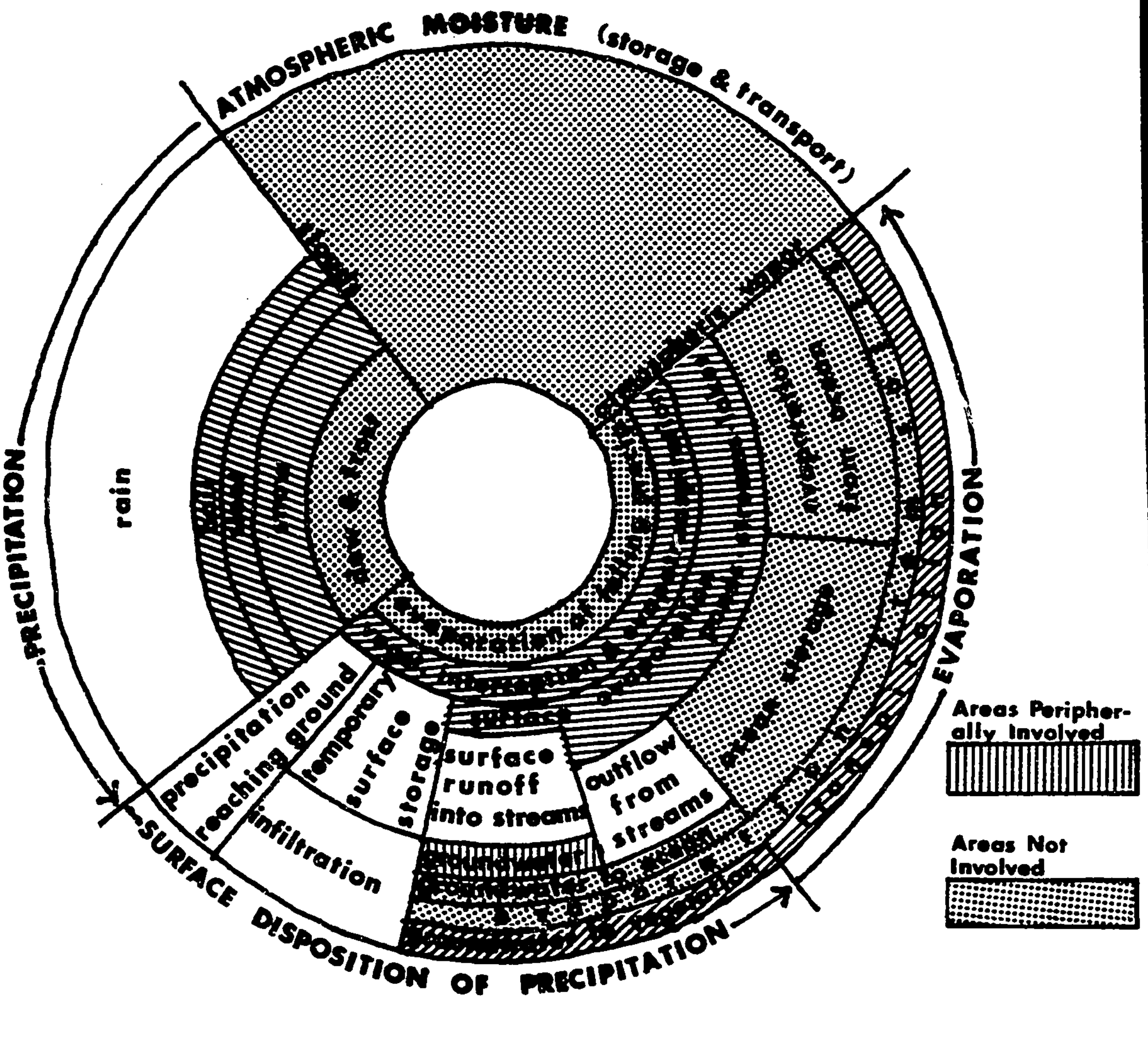


Fig. 1.1.--Content Diagram of the Title

<u>Detention Systems</u> (A)

The technique element of the study involves three components: a segment of the hydrologic cycle, an approach to managing that segment when it affects the man altered landscape, and the methods for achieving the management. Figures 1.2 and 1.3 show - schematic and section respectively - diagrams of the water cycle. The stippled areas cover those parts of the cycle which will not be considered. The lined areas represent those aspects of the cycle which will be involved peripherally. Evapotranspiration, for example, is an important consideration in moisture management. However, vegetative species, surface conditions, climate, and many other critical factors are so dynamic and un-

DIAGRAM OF THE HYDROLOGIC CYCLE



SOURCE: Adapted from Ven T. Chow, (Handbook of Applied Hydrology, 1964) p. 1-3.

Figure 1.2

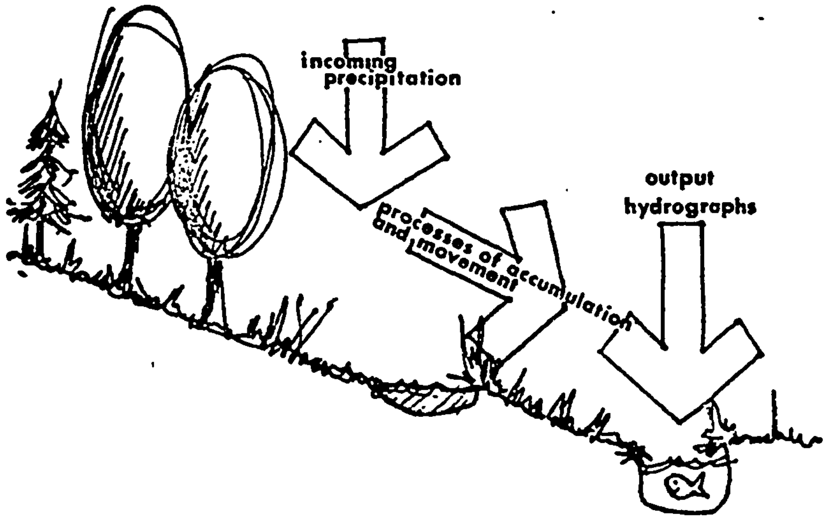


Fig. 1.3.—Section View of the Part of the Hydrologic Cycle Relevant to the Study

predictable that it is virtually impossible to attempt to quantify a plant's ability to remove specific amounts of moisture.[7]

Secondly, there is a wide spectrum of ways to manage precipitation once it reaches the surface. Each end of the continuum shown in Figure 1.4 represents opposing management extremes. Anyone utilizing techniques on the left side believes that precipitation is best managed when all moisture is quickly and efficiently gathered and removed from the surface. This could be called the maximized drainage approach. Anyone adhering to the techniques at the opposite end of the spectrum would manage precipitation by trapping all of it so that potentially harmful accumulations never occur; the water itself can

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[7]Gary Robinette, Plants/People/and Environmental Quality (Washington, D.C.: U.S. Government Printing Office, 1972). See particularly the sections on "The Engineering Uses of Plants", p. 33 and "The Climatological Uses of Plants," p. 67. Despite their unpredictability the concepts of evapotranspiration, plant interception and antecedent moisture will be considered later in the study as an area of potential buffering or establishing margins of safety in volume management.

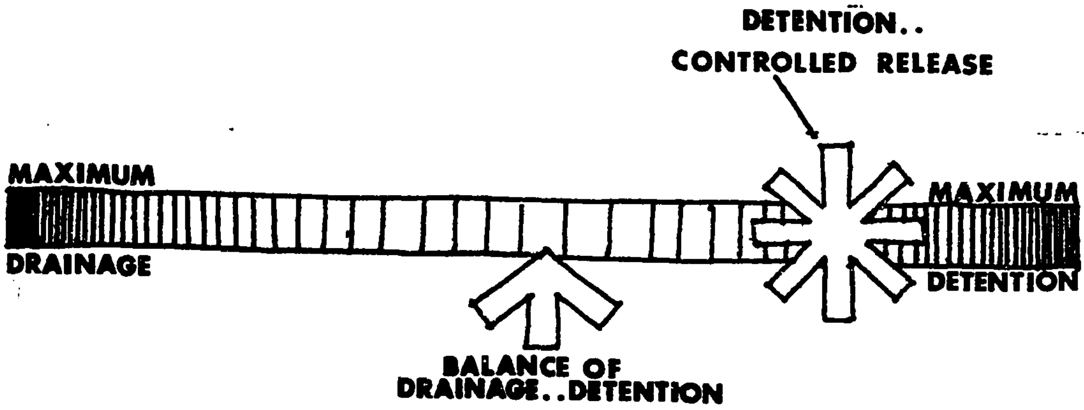

Fig. 1.4.--Precipitation Management Continuum

be put to local use as a resource (maximized detention). Between the two extremes are various combinations of drainage and detention techniques. The management approach used by this study involves a system which temporarily detains and predictably releases moisture (asterisk in Figure 1.4).

The final component involves the selection of techniques for achieving the above noted detention-release management system. Forest hydrologists, geologists, and especially civil engineers have been researching and developing precipitation management techniques for years.[8]

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[8]Historically there is evidence of the engineer/hydrologist since the beginning of civilization. Water and its control has always been a critical pursuit upon which great empires rose and fell. Witness

The study takes the techniques developed in the research areas and investigates their potential individual and systematic impacts on actual applications.

Small Urbanizing Watershed (B)

This title component designates the space within which the proposed technique application takes place. There are as many factors to consider here as there are words in the component. A small watershed is considered to cover an area of less than ten to twelve square miles.[9]

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the great underground aquaducts of Persia, the innundations of the Nile Valley, the Roman water tanks throughout the present day Middle East, Rome itself and the drainage of the Pontine Marshes, and the sophisticated systems of the Dutch Lowlands. More recently hydrologists are seen developing management techniques after the beginning of the Soil Conservation Service (1936), in the pilot efforts of the Muskingum Watershed of Southeastern Ohio, with the Tennessee Valley Authority, and ultimately with the Corps of Engineers. The programs of the Roosevelt administration of the depression era appear to be the stimuli for the principal surge of contemporary technique development in the U.S.

[9]Three reasons underlie the selection of the size of basin for this study. First, the 10 to 12 square mile module is an easy to manage common size unit. Secondly, the smaller the basin, the more likely it is for a storm to uniformly distribute moisture over it. The study assumes the uniform moisture distribution. Thirdly, a comprehensive general plan time frame commonly uses a twenty to twenty-five year duration (although it is constantly updated). It is realistic to consider

The term urbanizing is important in that the study addresses itself to those lands on the leading edge of a city's developed area. The watershed is a physically functioning whole into which the stimuli (detention and release techniques) are placed. Control of the entire ten to twelve square mile area is critical. Research in the area of water quality management has already begun to recognize the complete watershed as a planning module.[10] This study, however, addresses water quantity management.[11]

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areas of the 10 to 12 square mile size as workable land use planning modules for that period of time. The size is large enough to necessitate general (rather than detail) planning and small enough to allow computation and reasonably accurate land use projections. Further discussion on basin size is found in Chapter Six in the section on the selection of the case study area.

[10]An example of the growing realization that the watershed should be recognized as a planning and management module in water quality efforts is in The Water Pollution Control Act Amendments of 1972 (Public Law 92-500, 86 Stat. 816). This is particularly evident in Section 209 (86 Stat. 843) entitled "Basin Planning" and is implied in the term "areawide" in Section 208 (86 Stat. 839).

[11]It is necessary to limit the scope of the investigation to managing the volume of stormwater runoff because it is being made as a potential alternative to the prevailing flood abatement measures which are questionable. Water quality management, although closely related; requires a significantly different research approach and expertise. It is suggested in the concluding chapter that prior to the implementation of the alternative proposed in this study, research into its compatibility with water quality management efforts will have to be determined.

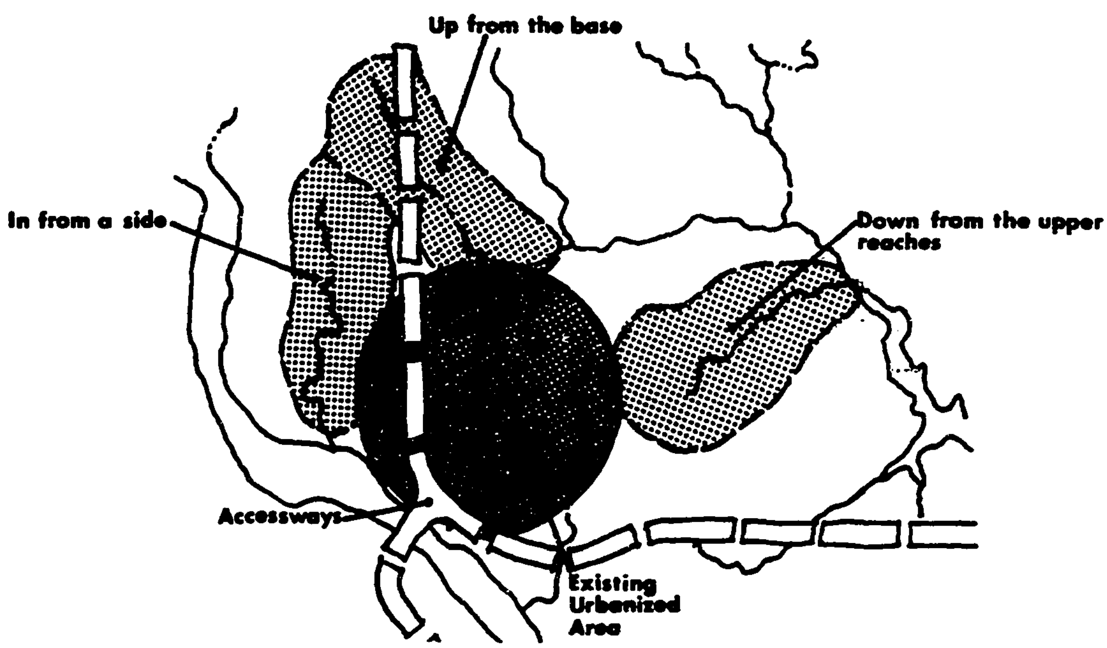

Fig. 1.5.--Position of Watershed Relative to Urbanized Areas - Examples of Potential Direction of Growth

Runoff Management (C)

The goal to be achieved by the methods being investigated in this study is to be able to manage the amount of precipitation which runs off the land during a rain. The inability to manage runoff can result in excessive amounts and overbank flows which create flooding. Another result of mismanaged runoff is the reduction or elimination of low flows in stream channels between rains. As a result, the objective of the proposed approach is to achieve an urban area which has a continuous low flow in its larger streams between rains and which is not subject to flooding during rains of a reasonable intensity and duration.[12]

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[12]The reasonable intensity and duration of rain considered to be maximum in this study will be a storm whose probable rate of occurrence

Alternative (D)

The "alternative" element in the title represents the idea that runoff management may be more effectively achieved by methods other than those which presently prevail. This study examines the possibility that local detention and controlled release is one of the more effective approaches which are speculated upon above.

Title Summary

This study examines the proposal that temporarily and locally detaining runoff from a 100 year storm may be the proper approach to the management of volumes of water in 10 to 12 square mile watersheds which are being urbanized. The limitations placed on the scope of the study facilitate a greater ability to focus on a specific type of event or process (urban runoff from a 100 year storm) in a certain sized space (10 to 12 square mile watershed). In that local runoff control is a major element in this management approach, it is likely that the same approach will be equally effective in watersheds of less than 10 square miles. On the other hand, if the controlled 10 to 12 square mile basins were all a part of a larger watershed the control of the latter would also be assumed. It would also be logical to assume that runoff management is accomplished in situations where the storms are less severe than the design storm. The investigation of these related aspects, however, is left for the additional research which is suggested at the conclusion of this study.

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is 1% in any given year (the 100 year storm). For further discussion of the design storm, see Appendix A.

The Geographical Nature of the Inquiry

Harvey's basic premise is "that geography always has been and always will be what those who call themselves geographers choose to do." This section briefly examines the geographical nature of a study in alternative methods for urban stormwater runoff.[13] A central issue/objective in such an investigation is the reduction or elimination of a flood hazard which would otherwise have a negative impact on a given space (small urbanizing watersheds). With regard to geographical legitimacy based on publications by those who are accepted by others as geographers, the section which follows reflects the literature on flood abatement from the fields of geography, geology, planning, and engineering. With regard to the specific investigation; its geographical nature is discussed in light of the integration and synthesis of the systematic sciences related to the subject of stormwater management, the spatial and network aspects of the watershed and drainage systems, and flood damage abatement and hazard research.

Integration and Synthesis

There are a number of highly specialized and systematic sciences involved in studies of urban hydrology. Hydraulics as analyzed and calculated by the engineer is reflected by Chow.[14] In addition, the geologist and agronomist methodically examine water, soils, and vegetation from the standpoints of sediment loading, erosion, effects on land form, and as elements in predicting water supplies and qualities.

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[13] David Harvey, Explanation in Geography (London: Edward Arnold, Ltd., 1969), p. 482.

[14] Ven T. Chow, Handbook of Applied Hydrology (New York: McGraw-Hill Book Company, 1964).

The application of the various land and hydrologic sciences are exemplified in the work of the geologists and soil scientists in the U.S. Geological Survey and U.S. Department of Agriculture. The applied sciences may be found in the form of extension programs, the Agricultural Stabilization and Conservation Service (A.S.C.S.), and the Soil Conservation Service (S.C.S.). The systematic sciences related to urbanization include political science, sociology, the physical and biological sciences, psychology, and economics. According to James "The system of procedures" or "point of view" with which the geographer approaches this subject is in extending the fields of systematic science by investigating actual implications through temporal-spatial models or in observations in time and space.[15] The geographical approach to the systematic science of hydrology is reflected by Chorley, while the geographical point of view on the various sciences encompassed by urbanization can be found in Berry, Detwyler, Carter, and others.[16] As a result it would seem that either the urban or the hydrological aspects of the subject of flood damage abatement can be investigated and examined from the geographical stand point.

The proposed approach relys on an integration of the physical-socio-economic aspects of the process of urbanization and the hydrological

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[15] D. W. Meinig, ed., On Geography: Selected Writings of Preston E. James (Syracuse, New York: Syracuse University Press, 1971), p. 6.

[16] Richard J. Chorley, Introduction to Geographical Hydrology (New York: Barnes and Noble, Inc., 1969), Brian J. L. Berry, The Human Consequences of Urbanization (New York: St. Martin's Press, 1973), Thomas R. Detwyler and Melvin A. Marcus, Urbanization and the Environment (Belmont, California: Duxbury Press, 1972), and Harold Carter, The Study of Urban Geography (New York: John Wiley and Sons, Inc., 1976).

processes in runoff and drainage. This is perhaps a synthesis of two "heterogeneous phenomena" as described by Hartshorne to be unique to the geographical approach and by Beaujeu-Garnier as being an important element in attempting to define what geographers do.[17] In addition, this causal relationship of two elements or processes (urban and hydrological) is expressed as being minimal to a geographical problem by Blaut.[18]

The Spatial and Network Aspects of the Watershed and Drainage System

The watershed space contains a hierarchical network which is the drainage system. The process of urbanization superimposes a development system on the pre-existing natural network and modifies, comes into conflict, or exists in harmony with it. The drainage basin as a physical system is introduced in most introductory physical geography

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[17] Richard Hartshorne, Perspective on the Nature of Geography (Chicago: Rand McNally and Company, 1959). The chapter which discusses integration is entitled "Is the Integration of Heterogeneous Phenomena a Peculiarity of Geography?" (p. 26-47). J. Beaujeu-Garnier, Methods and Perspectives in Geography (New York: Longman Inc., 1976). Beaujeu-Garnier's discussion of synthesis can be found in Chapter One entitled "What is Geography?" (p. 1-18). Note also that Beaujev-Garnier states that the University of Chicago, in creating a department of geography in 1903 (p. 3), began a scholarly tradition of occupying the central position between the natural and social sciences. The man-land relationship is evident in the hydrologic changes in an urbanizing watershed.

[18] J. M. Blaut, "Space and Process," in The Conceptual Revolution in Geography, Wayne K. D. Davies, ed. (Totowa, New Jersey: Rowan and Littlefield, 1972), p. 47. William D. Pattison, in "The Four Traditions of Geography" published in The Journal of Geography (Vol. 63 of May 1964, p. 211), classifies the traditionally accepted areas of geographical inquiry into earth sciences, spatial processes, man-land relationships, and aerial studies. An inquiry into the management of urban stormwater runoff would seem to fail to meet Pattison's geographical criteria for only one of the four traditional areas (areal studies).

texts with the more in depth examinations traditionally most visible in the works of Chorley.[19] The important consideration under this heading is that the drainage basin is a spatial module within which processes (temporal aspects) are investigated, modeled, and tested.

Flood Damage Abatement and Hazard Research

With the increase in urbanization there has been a corresponding increase in flood damage which may have provided an impetus for geographical concern. Geographers were involved in the early flood studies of the late 1930's and were later to comprise the major part of the body of those doing hazard perception research which developed in the early 1960's.

N.A. Hoyt and W. B. Langbein of the U.S. Geological Survey were early authors of flood studies.[20] The principle contributor to flood research from the geographical point of view was Gilbert Fowler White during his association with the University of Chicago.[21]

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[19]Richard J. Chorley is perhaps the most influential geographical hydrologist-geomorphologist found to be particularly useful in this study. The previously cited Introduction to Geographical Hydrology serves as a general source with Earth and Man: A synthesis of Hydrology Geomorphology, and Socio-Economic Geography (New York: Barnes and Noble, Inc., 1969) and other writings serving as sources for more specific information.

[20]Langbein in particular, was a prolific writer during the 1930 to 1960 period on the subject of floods. He collaborated with Hoyt on "Some General Observations on Physiographic and Climatic Influences on Flood," Transactions of the American Geophysical Union, XX (July, 1939), pp. 116-174. Some of Langbein's later publications included the titles "Flood Insurance" (1953) and "Flood Management Through Zoning,Insurance, and Forecasting" (1955).

[21]White's thesis of 1945 was a major research landmark and serves as a principle impetus for contemporary flood hazard abatement research Human Adjustment to Floods; Geographical Approach to the Flood Problem in the United States (Chicago: University of Chicago, Department of Geography Research Paper No. 29, 1945). White's other major contribu-

Kollmorgen also published during the formative flood research period on the economic aspects of flood control.[22]

Luna Leopold initiated his extensive involvement in flood research with a 1954 publication which discussed the large dam versus small dams and management approach controversey in flood abatement methodology.[23] Geographers such as White, Kollmorgen,Murphy and others may have played an influential part in the flood research involvement of the American Insurance Association following the disastrous urban floods of the early 1950's.[24]

Francis C. Murphy, of the Army Corps of Engineers (and converted to the geographical point of view by the University of Chicago) was

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tions (which are shown only by title and publication date for purposes of indicating the content development of flood research) include: "State Regulations of Flood Plain Use" (1940), "Changes in the Occupance of Flood Plains in the United States" (1958), "Action Program for the States: A New Attack on Flood Losses" (1959), "The Control and Development of Flood Plain Areas" (1960), "Flood Control, Flood Plain Regulation, and Flood Insurance " (1960), "Strategic Aspects of Urban Flood Plain Occupance" (1961), "Water, A Growing Crisis" (1961), "Papers on Flood Problems"(1961), "Choice of Adjustment to Floods" (1964), "Optimal Flood Damage Management: Retrospect and Prospect" (1965), and "A Flood Loss Reduction Program" (1968).

[22]W.M. Kollmorgen, "Settlement Control Beats Flood Control," Economic Geography, XXXVIX (July 1953), p. 208-215 and "Deliver Us From Big Dams," Land Economics, XXX (November, 1954), p. 333-346.

[23]Luna B. Leopold and Thomas Maddock, Jr., Flood Control Controversy; Big Dams, Little Dams and Land Management (New York: Ronald Press Company, 1954). The alternative proposal which is investigated in this study largely assumes the "little dams and land management position in the Leopold-Maddock book. Leopold is associated with the U.S. Geological Survey.

[24]The American Insurance Association, Studies of Flood and Flood Damage 1952-1955 (New York: The American Insurance Association, 1956). The opening and closing dates of the study corresponds with the Kansas City and western Connecticut Floods respectively.

an early influence on the development of concepts involving flood plain zoning.[25] Allison Dunham's 1959 "Flood Control Via the Police Power" remains as the dominant legal treatise concerning the constitutionality of flood plain regulation.[26] Sheaffer, and other University of Chicago geographers influenced research in the areas of flood plain and hazard mapping and flood proofing methods.[27]

The Tennessee Valley Authority was (and remains as) a major source of flood control research with J.K. Goddard serving as its investigator and author. Goddard is perhaps the most influential flood control researcher from the point of view of the engineer-geologist.[28]

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[25]Francis C. Murphy, Regulating Flood Plain Development (Chicago: University of Chicago, Department of Geography Research Paper No. 56, 1958).

[26]Allison Dunham, "Flood Control Via the Police Power," University of Pennsylvania Law Review, CVII (June, 1959), p. 1098-1132. The dominance of the Chicago school in flood research is further reinforced when noting Dunham was a professor in its law school.

[27]John R. Sheaffer collaborated with White and others on the book Changes in Urban Occupance of Flood Plains in the United States (Chicago: University of Chicago, Department of Geography Research Paper No. 57, 1958). Other Sheaffer publications listed by title and date only include: "Flood Proofing: An Element in a Flood Damage Reduction Program" (1960), "Flood Hazard Mapping -- Its Uses and Limitations" (1962), "Economic Feasibility and the Use of Flood Maps" (1964), and Introduction to Flood proofing; An Outline of Principles and Methods" (1967).

[28]An indication of the diversity of Goddard's research and its probable influence is gained through the titles of his publications which are listed in chronological order. They include: "Floods and How to Avoid Them" (1958), "Changing Concepts in Flood Plain Management" (1960 address), "Flood Damage Prevention in the Tennessee Valley" (1960), "Flood Plain Regulations to Avoid Flood Damage" (1960 address), "T.V.A.-Control on a Grand Scale" (1960), "Flood Proofing and Flood Damage Control" (1961), "Flood Damage Prevention and Flood Plain Management Improve Man's Enviornment" (1963), "Considerations in Preserving Reservoir Sites" (1965), "Beautification Opportunities are Inherent in Flood Damage Prevention Projects"(1966 address), "Emerging Program for Managing Flood Losses: (1966) and "Flood Hazards and Flood Plain Management" (1966).

The geographer is also highly visible in the research of cognition or perception of natural hazards which was developed during the early 1960's. Flood constituted a major consideration in natural hazard research and their perception is considered as an important prelude to the implementation of abatement or control measures. Kates' 1962 publication Hazard and Choice Perception in Flood Plain Management served as an initial catalyst for natural hazard research.[29] Burton and Kates subsequently collaborated during the early development of hazard perception research and continue to be dominant influences in that area of inquiry.[30]

The geographical nature of an inquiry into a proposed alternative for stormwater runoff management in a small urbanizing watershed is therefore based on three premises. First, that such an inquiry requires the synthesis of a number of systematic sciences relevant to it. It is an approach to or point of view on a subject as expressed by Harvey, Hartshorne, and James. Second, the area within which the subject of the inquiry exists is intrinsically spatial and contains natural, as well as man made, networks whose interactions and evolutions

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[29] R. W. Kates, Hazard and Choice Perception in Flood Plain Management (Chicago: University of Chicago, Department of Geography Research Paper No. 78, 1962).

[30] The works of Kates in collaboration with Ian Burton by title only and date of publication include: "The Flood Plain and the Seashore, a Comparative Analysis of Hazard Zone Occupance" (1964) and "Readings in Resource Management" (1965). Titles and dates of research done by Kates include: "Perceptual Regions and Regional Perception in Flood Plain Management: (1963), "The Synthetic Estimation of Flood Damages" (1963), "Flood Damage Synthesis: A Review of Present Practice and Presentation of New Techniques for Flood Damage Estimation in Slected Reaches of the Lehigh Valley, Pennsylvania" (1964), "Variation in Flood Hazard Perception: Implications for Rational Flood Plain Use" (1964), and "Experiencing the Environment as Hazard" (1976).

in time constitute process. These networks and processes are examined by urban geographers such as Carter and Berry and by physical geographers such as Chorley. Finally, research in the prevailing areas of flood damage abatement and natural hazard perception have an established geographical tradition through the works of White, Sheaffer, Murphy, Kollmorgen, Kates and Burton.

In the following section the remaining literature is surveyed by examining the major journals of the professions whose research fields are related to stormwater runoff management. Journals from the areas of civil engineering-hydrology, geology, and planning will be examined (in addition to geography) due to their close relationship with the subject of "Flood protection and assessment" according to Fabos and Caswell.[31]

Literature

In the discussion of the study's geographical nature, four research bodies were identified as being the major sources of flood related information. The Department of Geography of the University of Chicago, The Tennessee Valley Authority, The U.S. Geological Survey, and the Army Corps of Engineers were considered as important contributors through their respective investigators. Although these groups might be considered as being related to particular research disciplines (for example, geology and the U.S. Geological Survey), their publications may not be indicative of the research interests in

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[31]Julius Gy Fabos and Stephanie J. Caswell, Composite Landscape Assessment (Amherst, Massachusetts: Massachusetts Agricultural Experiment Station, 1977), p. 130.

the mainstream of their respective fields. This section briefly examines the patterns of flood related research in the principle journals of geography, planning, and engineering-hydrology.[32] Those publications previously associated with the above four bodies are precluded.

Geography

The "mainstream" journal, the Annals of the Association of American Geographers was traced from volume 1 in 1911 to the present.[33]

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[32]The geological journals are not considered here in the general literature section because much of the relevant published research in them were detailed investigations of very small aspects of hydrology and stream related landform processes. Generally, the Geological Survey Circular Series published by the U.S. Geological Survey (Washington, D.C.) constituted a more digested and applicable form of geological research material. Circular titles and dates include: "Urban Sprawl and Flooding in Southern California" (1970), "Flood Hazard Mapping in Metropolitan Chicago" (1970), "Real Estate Lakes" (1971), and "Extent and Development of Urban Flood Plains" (1974). The principle journals containing information about runoff management developments outside of the U.S. were the publications of the United Nations. The techniques reflected in the U.N. documents were generally the same as those developed earlier in this country. Journals surveyed in Geography were: Association of American Geographers, Annals of the Association of American Geographers, Washington, D.C., The Professional Geographer also published by the AAG, Economic Geography, published quarterly by Clark University. The planning journals surveyed were: American Institute of Planners, Journal of the American Institute of Planners, Washington, D.C., American Society of Planning Officials, Planners Advisory Service, Chicago, and the Urban Land Institute, Technical Bulletins, and other special publications, Washington, D.C. The engineering journals included: American Society of Civil Engineers, Proceedings, New York. Note also that within the Proceedings are a number of "Division Journals." These are cited independently and include: Journal of Hydraulics Division, Journal of the Irrigation and Drainage Division, Journal of the Urban Planning and Management Division, and Journal of the Water Resources Division. The Geological Society of America's Bulletin which is published in Boulder, Colorado, was surveyed as an indicator of geological research.

[33]Hereafter the text will refer to the Annals of the Association of American Geographers as "Annals".

The indicators of the profession's attitudes and concerns about urban flooding were considered to be the articles and papers from the annual conventions. Reviews and books received were included because therein was at least a potential for recognition of the subject. Due to changes in journal format, only the articles and proceedings consistently appeared throughout its publication life. In addition, indexes of The Professional Geographer, the Geographical Review, and Economic Geography were also examined. The criteria for being considered as directly relevant to the survey involved a significant examination of the interplay of urbanization and runoff changes resulting from it. For example, an article was considered relevant to the inquiry if it dealt with the urban land use interface with flooding or if it discussed flood abatement methodologies. Of the approximately 1050 articles published in the Annals since 1911, seven (.67%) can be considered generally related to the topic and of the seven, two (.19%) can be considered directly relevant. It is interesting to note that both occurred in the late 1920s and 1930s. Haas, in an article called "The Mississippi Problem: A Conflict in Economic Emphasis" throws a crude cost benefit question into the maze of engineering solutions for the Mississippian River flood system.[34] During the early part of the twentieth century the Mississippi River was viewed as a potentially valuable water transportation network as well as a hazard which caused major flood damages from time to time. Dams,

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[34]William Haas, "The Mississippi Problem, A Conflict in Economic Emphasis," Annals of the Association of American Geographers, XIX (March, 1929), p. 1-7.

levees, and improved channels were almost universally perceived as the controlling solution. The major Mississippi floods of the late 1920s may have stimulated Haas' examination of the accepted solutions and their real costs. In 1937 Andrew Ireland wrote on the "Physiographic Conditions Effecting Runoff and Soil Conservation in The Muskingum Drainage Basin of Ohio."[35] Its significance lies in the fact that the Muskingum Watershed Conservancy District was one of the first in the country. As a control effort on the upper reaches of the Mississippi it viewed the watershed as a unit to be comprehensively planned. The paper discusses the resettlement of towns and villages of the Muskingum Basin. Similar papers during this period may have been stimulated by programs of the Roosevelt era (the Tennessee Valley Authority, National Resources Planning Board, Soil and Conservation Service, Works Progress Administration, Civilian Conservation Corps and other projects under the National Recovery Act.) World War II may have briefly interrupted the growing geographical attention toward flooding problems. The next articles of any relevance to the topic do not show up until a few isolated ones are published in the middle 1950s and late 1960s.[36]

Although there were many more (Association of American Geographers) proceeding papers published than articles and there could have been a more frequent occurrence of closely related articles, the percentages

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[35]Andrew Ireland, "Physiographic Conditions Effecting Runoff and Soil Conservation in the Muskingum Drainage Basin of Ohio," Annals of the Association of American Geographers, XXVIII (March, 1938), p. 51-60.

[36]Influences which may have combined to stimulate some research in the geographical mainstream from the 1950s as where the severe flood years of 1952 and 1955, Gilbert White and the "Chicago School," and the expanding scope of urban renewal which could become instrumental in the clearance and reuse of hazard zones.

of occurrence of the two are virtually identical. Of the approximately 4050 papers, 36 (.89%) were generally related and 8 (.2%) were closely associated with the subject. The increases and decreases of relevant papers closely paralleled the patterns of the articles. The early 1900s group are general and descriptive. A simple listing of the titles and publication dates serves as a good indicator of the kind of topic covered. They include" "The Study of River Flow" (1905), "Notes on the Mississippi River Flood of 1903 and on the Floods of Other Years" (1905), "Drainage Modification in the Headwaters of the Chattahoochee and Savannah Rivers" (1905), "The Prospective Conquest of the Mississippi River" (1907), "Maximum and Minimum Hydrographs of the Mississippi River" (1909), "The Relationship Between Groundwater and Streams" (1911), and "Flood Producing Rains in the United States" (1916).

The only significant cluster of closely related papers occurs during the late 1930s with the research monies of the National Resources Planning Board apparently serving as an important impetus. Carlson's "Hydrology of the Valley of Mexico," although descriptive, relates watershed deforestation and downstream flooding of urban areas.[37] The late 1930s also saw the first discussions on reservoir severance lines. This was brought on by the land acquisition projects of the Tennessee Valley Authority and the resultant problems of protective watersheds and excess condemnation.[38] Although related to non urban

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[37]Fred A. Carlson, "Hydrology of the Valley of Mexico," Annals of the Association of American Geographers, XXV (March, 1935), p. 38-44.

[38]Donald Hudson, "The Setting for the Work of the Land Planning Division T.V.A.," Annals of the Association of American Geographers, XXIX (March, 1939), p. 77-87.

areas Guthe connected the dynamics of land use to those of runoff in 1939.[39] In addition, a 1941 Guthe's paper gives an excellent history of the development of public responsibility and attitude toward flooding.[40]

Outside of the generally related papers of the late 1950s and 1960s there are no other significant groups of relevant presentations from the "geographical mainstream" journals.

Little can be said of the patterns shown by book reviews since they are not listed in the "Annals" until the late 1940s. The percentage of 6 relevant articles out of 436 reviews (1.38%) is not much different from those of the articles and papers.

Of the 5530 literature events listed by the "Annals", 49 (.89%) can be considered worth looking into to gain information for the inquiry.

Planning

The "mainstream" journal of the planning profession is the Journal of the American Institute of Planners.[41] Two other serials

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[39]Otto Guthe, "Some Considerations of the Role of Land Use Flood Control," Annals of the Association of American Geographers, XXX (March, 1940), p. 56-62.

[40]Otto Guthe, "Watershed Management in the Federal Flood Control Program," Annals of the Association of American Geographers, XXXI (March, 1941), p. 56-65. Note that there is a distinct tendency for the relevant flood articles to appear in the March issue of the Annals.

[41]American Institute of Planners, Journal of the American Institute of Planners is published in Washington, D.C. From its beginning in 1925 until 1934 the Journal was entitled City Planning and was jointly published by the American City Planning Institute and the National Conference on City Planning. Between 1935 and 1944 (when it assumed its present name) the journal was published as The Planners' Journal.

also surveyed, are the publications of the Urban Land Institute (ULI) and the Planner's Advisory Service (PAS) published by the American Society of Planning Officials (ASPO).[42] Planning should be expected to be the field most closely associated with the application and testing of the land sciences, however, evidence of pilot efforts and studies in the area of flood control were uncommon. Of the thousands of articles, book reviews, and thesis abstracts of the "mainstream" publications, only ten significantly discuss in detail urban land use and runoff. "New Engineering Designs in Community Development" which peripherally mentions work done in the area of the flood abatement, is the only one to do so of the more than seventy Urban Land Institute technical bulletins written since 1945.[43] The Planners Advisory Service's bulletins include only two related publications of the more than three hundred written since 1945. Both papers involve the regulation of floodplains. The first is a 1953 effort followed by an update in 1972.[44]

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[42]The Urban Land Institute, a Washington, D.C. based, urban land economics interest group, researches and generally publishes its findings in a series called Technical Bulletins. The American Society of Planning Officials (Chicago) publishes a similar series of bulletins directed toward educating planning of practioners in the field on how to develop various projects and programs based on new available research. These constitute a chronologicall numbered series called the Planning Advisory Service. These technical information-research bulletins are the two most likely channels along which evolving flood management methodologies are passed to those most likely to apply them in planning solutions.

[43]Jack Newville, "New Engineering Designs in Community Development," Urban Land Institute Technical Bulletin No. 59, 1967.

[44]The two reports, both published by The American Society of Planning Officials (Chicago) are "Flood Damage Regulation" (PAS Information Report No. 53, August, 1953) for which the author was anonymous and John Kinsler and Thomas Lee, "Regulations for Flood Plains" (PAS Information Report No. 277, February, 1972). PAS Reports Nos. 307 and 308 "Performance Controls for Sensitive Lands: A Practical Guide for

If there were enough planning articles to establish a meaningful pattern, something other than a virtual lack of publication relating to the subject could be reflected upon. As will be noted in the next section, it is the field of civil engineering-hydrology which dominates the related research area.

Civil Engineering-Hydrology

The Proceedings of the American Society of Civil Engineering (ASCE) was surveyed as the indicator of the research and publication "mainstream" of civil engineering-hydrology.[45] As a field with many highly specialized areas of concentration there is a resultant proliferation of papers on a broad range of very limited topics. An important aspect of the engineering literature is that as techniques and subject areas become more sophisticated, specialized new "fragment journals" appear under the umbrella of the "Proceedings." As early as the late 1920s special divisions appear with their own publications. Relevant articles were most commonly found in the Journal of the Hydraulics Division with a fewer number of articles attributable to the Journal of the Urban Planning and Development Division.[46] The Water Resources and Management Division as well as the Irrigation and Drainage Division published related source materials on some occasions.

Local Administrators" written by Charles Thurow, William Toner and Duncan Erley (published in June, 1975) includes some material on methods for writing as well as examples of drainage ordinances.

[45]The Proceedings of the American Society of Civil Engineering which is published in Washington, D.C. by the society will be hereinafter referred to as the "Proceedings."

[46]There are a number of specialized journals or sub-journals within the ASCE "Proceedings" which are particularly relevant to the topic of runoff management. They include Journal of the Hydraulics Division,

The apparent patterns in the engineering literature are twofold. First, there is a large number of highly specialized pieces of research to sift through and it appears that the major segment of knowledge about flooding and runoff to date has been researched and developed by the engineers. Second, it is also apparent that each of the specialized research efforts relies very little on other related efforts within the engineering field. In other words, the failure of various academic professions to be interdisciplinary and exchange expertise could be applied in many respects to the specializations within civil engineering. This fragmented approach gives a good indication of the state of the art. In addition, there is a high rate of overlapping or replication of flood research in the engineering field.

It is apparent that the "state of the art" related to runoff is subject to rapid change. The pattern of replication is often the result of the constant reevaluation or updating process in engineering. It appears that a thorough examination of the engineering literature from 1970 gives a complete picture of the techniques of runoff abatement. This assumes that the methods are a filtered accumulation of all past efforts and therefore are those most acceptable and effective. In addition, it is after 1970 that the mathematic and computer models of basin runoff simulation appear to become important. Likewise, it appears that these models are survivors of discarded or improved earlier efforts.

Journal of the Irrigation and Drainage Division, Journal of the Urban Planning and Development Division, and Journal of the Water Resources Planning and Management Division. All of the division journals are published by ASCE in Washington, D.C.

As a summary of indicators, what can be seen in a survey of the literature? First, engineering is the principle source of a fragmented but sufficient amount of information on the subject of runoff and land use. Second, other than the "Chicago School" the geography and planning disciplines have done little if anything in the area of taking the engineering expertise and investigating the impacts and alternatives of the developed abatement measures. The contemporary city builds until it develops a severe drainage problem and then retains the services of a competent engineer to rid the system of that particular problem. Most often the remedial process calls for the acceleration and redirection of the troubling flow. Successful in their particular light, the reactive nature of these solutions usually results in unnecessary expense. Their cumulative effects on future development downstream are legally questionable, and their engineering utility commonly leaves little in community amenity. Figure 1.6 is a graphic summary of the incidence of relevant research publications outside of the four dominant research bodies noted in the section of the geographical nature of flood control inquiries.

Timeliness of the Research

The need for timeliness of this investigation is based on four contentions. First, that despite a constant reevaluation of and investment in the prevailing methods of flood damage abatement, floods are continuing to occur and are resulting in the losses of lives and an increasing amount of damage. The Johnstown, Pennsylvania floods of the spring followed by the Kansas City flood of September 1977 are recent examples.

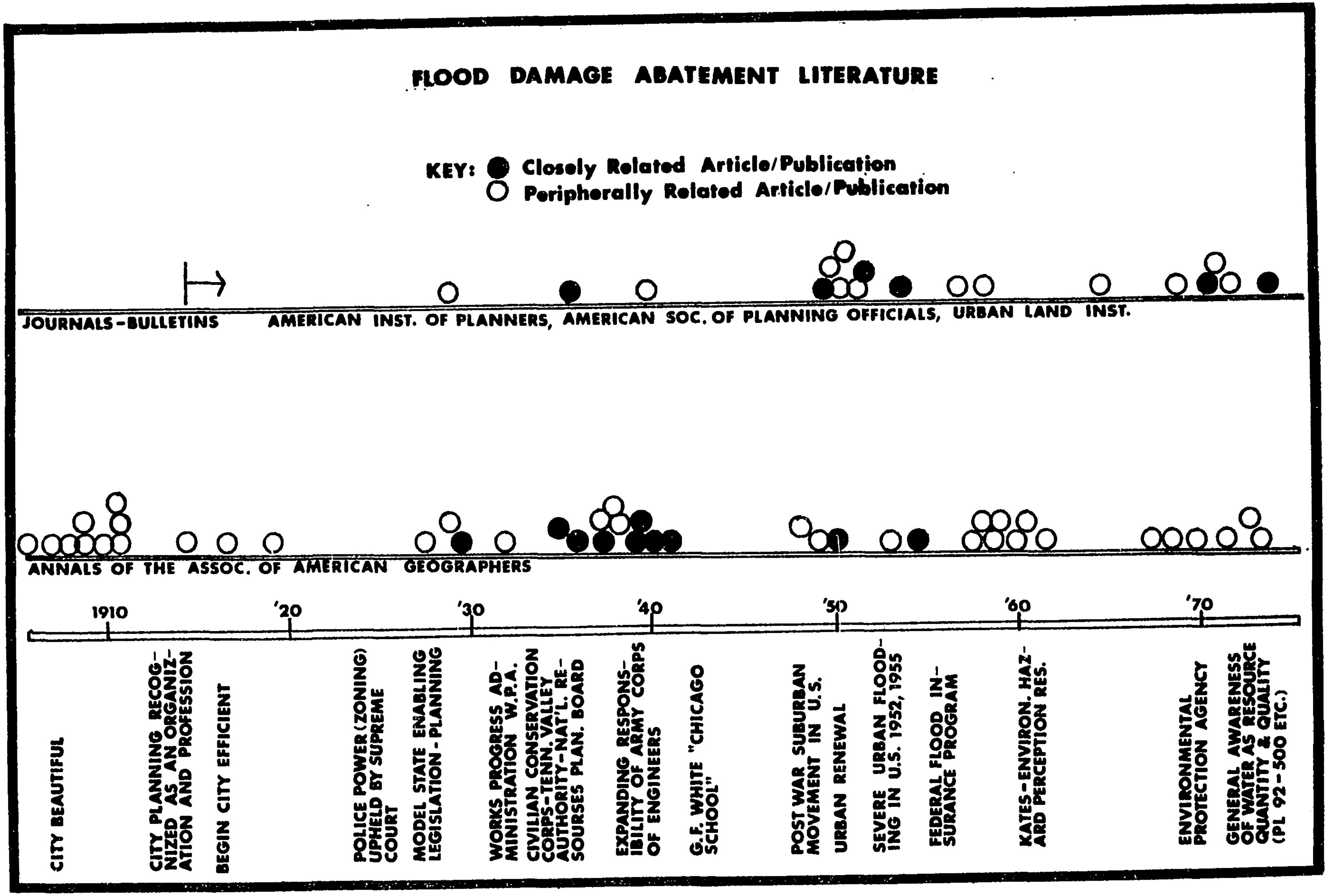
FLOOD DAMAGE ABATEMENT LITERATURE
KEY: Closely Related Article/Publication
Peripherally Related Article/Publication
JOURNALS-BULLETINS
AMERICAN INST. OF PLANNERS, AMERICAN SOC. OF PLANNING OFFICIALS, URBAN LAND INST.
ANNALS OF THE ASSOC. OF AMERICAN GEOGRAPHERS
1910
'20
'30
'40
'50
'60
'70
CITY BEAUTIFUL
CITY PLANNING RECOGNIZED AS AN ORGANIZATION AND PROFESSION
BEGIN CITY EFFICIENT
POLICE POWER (ZONING) UPHELD BY SUPREME COURT
MODEL STATE ENABLING LEGISLATION - PLANNING
WORKS PROGRESS ADMINISTRATION W.P.A.
CIVILIAN CONSERVATION CORPS-TENN. VALLEY AUTHORITY-NAT'L. RESOURSES PLAN. BOARD
EXPANDING RESPONSIBILITY OF ARMY CORPS OF ENGINEERS
G.F. WHITE "CHICAGO SCHOOL"
POST WAR SUBURBAN MOVEMENT IN U.S.
URBAN RENEWAL
SEVERE URBAN FLOODING IN U.S. 1952, 1955
FEDERAL FLOOD INSURANCE PROGRAM
KATES-ENVIRON. HAZARD PERCEPTION RES.
ENVIRONMENTAL PROTECTION AGENCY
GENERAL AWARENESS OF WATER AS RESOURCE QUANTITY & QUALITY (PL 92-500 ETC.)

Figure 1.6

Second, water is a resource upon which increasing demands are being placed during a time when poor arrangement of it is reducing its usable supply. A proposed management of runoff on a local scale is a necessary element in the larger schemes of water resource devlop- ment. These include harvesting icebergs and major river engineering projects which will distribute water for consumption by farms, cities, and industries thousands of miles away such as in the case of the Central Arizona Project or schemes to block and reverse Canadian rivers for use in the United States. The national concern about the future availability of water is reflected in a 1977 Associated Press article which noted researcher projections that by the year 2000, only three of the 19 major water regions in the U.S. could live comfortably with its supply.[47] A 1977 full page article in the New York Times addresses a potential world water resource crisis.[48]

Third, in a period of time when public capital is in short supply and present stormwater management solutions are both expensive and offer little in community amenity, there is a need to investigate potential solutions to flooding which may be less expensive. Solutions which localize more of the costs with the private sector and which may result in multiple usage of space are needed. It is contended that local detention and release networks potentially may fulfill both of the above requirements.

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[47]The Associated Press article by Roxinne Eruasti entitled "Severe Water Shortage Feared in the Future" examines the different region-based water availability problems in the United States. The article datelined Omaha, Nebraska, was published in The Norman Transcript, Norman, Oklahoma, on April 3, 1977.

[48]The article "Water, the Mistreated, Now Limited Resource" was written by Naomi Shepherd in the World section of The New York Times

Finally, the evidence that points toward the limited involvement of the geographer and the lack of involvement of the planner shows a definite need for an investigation. James best summarizes this contention in the statement: "Unfortunately much of the work of a geographic nature is done by scholars in other fields, by businessmen and engineers, in a way that reveals an ignorance of the concepts of modern geography and that makes crude and imprecise use of geographic method....."[49]

Method and Structure

In this study, each chapter will build upon the information developed in those previous to it. Chapter Two reveals the prevailing approaches to flood damage abatement and critiques them. The purpose is to determine what the weak points or shortcomings of the prevailing methods are and how to develop a series of goals of performance characteristics which circumvent the problem areas. Successful elements of the prevailing approaches are briefly noted so that they may be retained as much as possible in alternative methods. Chapter Three develops the performance characteristics which are to be sought by the proposed alternative. Chapter Four surveys the existing techniques for achieving the characteristics developed in Chapter Three (local detention and release methods). In addition, Chapter Four also discusses why some of the methods are not to be included. Chapter Five follows by considering the selected methods and building systems

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(March 13, 1977) as topical coverage of an international water conference at Mar de Plata (S.A.).

[49]D. W. Meinig, ed., On Geography: Selected Writings of Preston E. James, p. 7.

in an existing watershed and synthetically tests them under the conditions of a design storm (100 year storm) situation. A small area of the case study watershed is then planned in greater detail to demonstrate how each land owner might develop his property and fit it into the overall detention system. The concluding chapter summarizes the detention systems alternative and examines some of the potential problem areas impeding its actualization. The study is closed by relating the detention alternative to other natural resource management objectives and briefly lists areas where continued research is needed.

The entire process of storm water runoff management is currently undergoing significant redirection, if not revolution.[1]

Urban Land Institute, 1975

CHAPTER TWO

TRADITIONAL APPROACHES IN RUNOFF DAMAGE ABATEMENT

Introduction

Inevitably, rainfall occurs which produces large amounts of runoff whose accumulations exceed natural channel capacities and whose rates of flow erode and deposit elements caught in the path. When they occurred before man's settlement, it could be effectively argued that floods played a natural role in the evolution of the landscape. When man placed something that he valued where these overbank flows occurred, he or his possessions experienced flood damage, and he has since been attempting to avoid the recurrence of those losses. Although the return frequency of storm events of a given magnitude may remain constant, the urban surface (by reducing both permeability and the resistance to flow) increases the volume of runoff from lesser storms which occur more frequently. This causes their impact to be as severe as

[1]Urban Land Institute, the American Society of Civil Engineers, and the National Association of Home Builders, Residential Stormwater Management Objectives, Principles and Design Consideration, (Published jointly by the ULI and NAHB, Washington, D.C. and the ASCE, New York City, 1975), p. 7.

the larger, more infrequent storms.[2] As a result, man's efforts to reduce flood losses were counteracted by his expanding settlements which inherently increased the probability of recurrence of such damage.

Large scale, comprehensive, and expensive efforts to reduce flood loss in the U.S. can be traced to the 1930s when major federal involvement was initiated.[3] The creation of the Tennessee Valley Authority, the initiation of the Soil Conservation Service, and the notable expansion of the responsibilities of the Army Corps of Engineers are the major factors in this beginning. Ironically, the urban-suburbanization process, which is recognized as being the principle cause in the aggravation of the flooding problem, began to rapidly increase in the U.S. following the end of World War II a decade later. As a result, the past 40 years has seen the development and entrenchment of what now can be called the traditional methods for flood damage abate-

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[2]Julius Gy Fabos and Stephanie J. Caswell, Composite Landscape Assessment (Amherst, Massachusetts: Massachusetts Agricultural Experiment Station, (1977), p. 131. Fabos and Caswell studied flooding characteristics in southeastern New England streams during a METLAND (Metropolitan Landscape Planning Model) research project. "Research undertaken by the METLAND study in 1973 found that in the town of Wilmington (Mass.), floodplain urbanization between 1952 and 1971 increased the size of the floodplain for all return period floods" (p. 131). For example the study showed that the 50 year floodplain of 1952 became the 10 year floodplain in 1971. In the preliminary findings of a later study referenced by Fabos (p. 131) involving a time study (1951-1972) of 21 southeastern New England stream basins, four of the five basins thus far examined showed the 1952 100 year floodplain becoming the 25 year floodplain for 1971. In one case the 1952 100 year floodplain became a 5 year floodplain in 1971.

[3]Chapter 1 (pp. 1-35) of White's Human Adjustment to Floods is an excellent source on the history of flood problems and flood programs in the U.S.

ment. These traditional approaches have cost billions of dollars in program capital outlays. The problem is that as the capital outlays increase each year for flood prevention measures, the losses which are their target increase at greater rates.

Complicated flow charts listing the ways to reduce flood problems are common. They can all be reduced to 5 traditional methods recognized by White as early as 1945.[4] These methods are: engineering, floodproofing, regulating the use of the floodplain, forecasting and evacuation, and relief.

Engineering Works

The microclimate, shelter, food, power, and transportation properties of water have always served as attractions to settlement. As settlements expanded and safe development space was used up, development areas encroached on lands adjacent to rivers and streams. This resulted in the assumption of greater risks by those living in the developments which encroached on those more hazardous spaces. In addition, the settlements themselves increased the probability of the recurrence of the hazard as well as the area of the hazard zone.[5] The result of this process of increased risk and hazard zone expansion is an increased demand that flows be modified or contained in some way to

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[4] Ibid, p. 4

[5] Fabos and Caswell, Composite Landscape Assessment, p. 131.

afford protection for the occupants. The modifications of the flows and capacities of rivers and streams to protect settlement areas are included under engineering works. The most common examples of engineering works are levees, dams, and channel alterations.[6]

Levees, among the earlier protective works, merely increase the carrying capacity of the channel by increasing the cross sectional area. There are, however, four potential problems when using the levee as a device to abate or reduce flood loss.

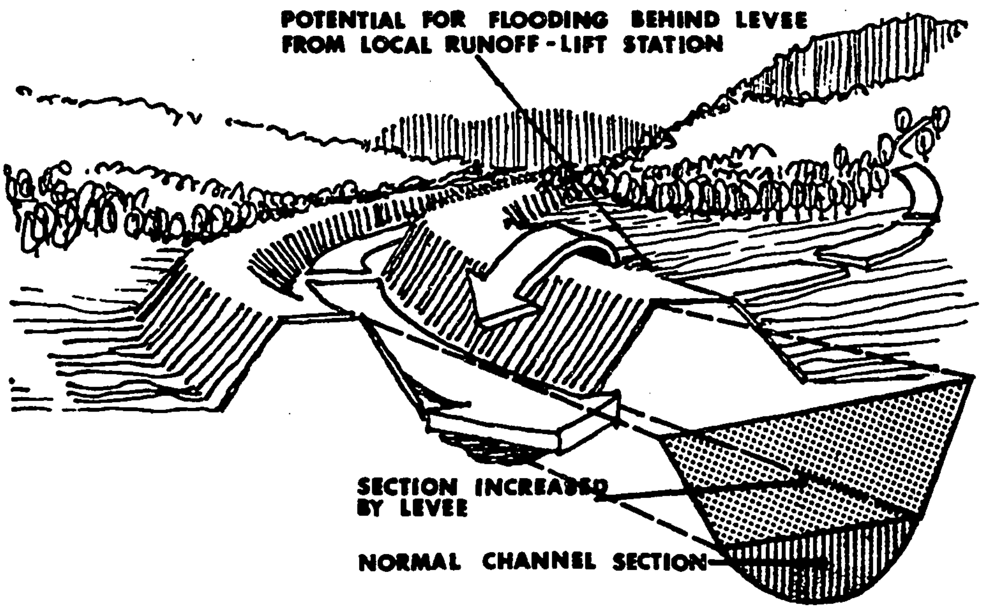

Fig. 2.1.--Perspective Section Through a Levee

First, the increased cross section carries larger amounts of flow from lands upstream of the area protected by the levee. If excessive runoff is produced in areas which are below the crest of the levee, a

[6]The common engineering term for channel alteration is channel improvements (straightening, widening, lining, etc.). The author uses alteration because, by definition, improvement would seem to indicate a positive change which may not be the case. Note also that many of the techniques inventoried in Chapter Four constitute engineering works of a much smaller scale.

pumping system must be incorporated to lift the water up to the elevation of the flow surface inside.[7] As a result, if the flow comes from the sides of a valley rather than from upstream, an urban levee can become a dam which actually inundates the area it was constructed to protect.

Second, the act of assumed protection itself can produce both a reduction in the perception of the potential hazard and encourage the occupance of the hazard area.[8] This in turn creates greater pressure for increased protection for the occupants of the hazard area. In the meantime, additional projects may have a much poorer cost-benefit ratio.[9] This argument also applies to large dams and major channel alteration projects.

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[7]The Dutch polders with windmills are a good example of the complex preindustrial engineering solution to water elevation change.

[8]Robert W. Kates, "Experiencing the Environment as Hazard," Environmental Psychology ed. by Harold M. Proshansky, William H. Ittelson, and Leanne G. Rivlin (New York: Holt, Rinehart and Winston, 1976), p. 415. Kates uses the term "prisoners of experience" to point to the concept that people in hazard zones tend to perceive the danger as less than reality, the further the occurrence of the hazard is (in time) from them. Protection may extend the period of time between experience and perception.

[9]Charles Abrams, Language of Cities (New York: The Viking Press, 1971), p. 76. Abrams defines cost-benefit analysis as "An analytic method designed to evaluate alternative programs (projects) in terms of their potential benefits and likely costs, and to aid decision-makers in choosing among them. When this method is applied in the environmental sciences, ideally it weighs the social, ecological, and aesthetic as well as economic factors and takes account of the indirect consequences of the different courses of action." A cost-benefit ratio is the result of summary of the analysis. A desirable ratio is one in which the costs are equal to or less than the potential benefits gained through a particular project or course of action. An in depth publication on the subject is Walter Isard's Ecologic-Economic Analysis for Regional Development (New York: The Free Press, 1972).

Third, the levee and dam alike may displace more land through coverage or inundation than that actually gained by the protective effort. As, in the case of the second argument above, subsequent encroachment in the protected areas create the added pressure for more protection which in turn covers more land.

The optimal use of land argument is the core of the fourth problem area. Historically, the river valleys have been the more fertile lands, particularly in arid climates where the water table and inundation (such as the Nile Valley) are critical. Water is a fixed, circulating resource which will become increasingly more in demand and higher in cost. As floodplains are encouraged to become urbanized by offering flood protection, agriculture is displaced to areas where the land may be less suitable for it and irrigation may become necessary. The act of protecting floodplains may be seriously counterproductive when considering the naturally subsequent displacement of a use for which it is better suited. Failure to protect the area could well result in the best use being the only choice.[10]

Dams have become the most visible effort associated with flood control related engineering works. Their protective principle is that increased flows above them are temporarily stored in flood pools gained by increasing the elevation of the lake behind the dam. There are three potential short comings in the use of large dams for flood control.[11]

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[10] Engineering works are used to protect agricultural lands also. The key issue in this case is to protect such land only in so far as it protects the particular kind of agriculture best suited to it.

[11] It should be noted that local detention also implies the use of some form of damming device. For purposes of delineation these traditional dams are defined as those which detain unimpeded flows

First, an argument which can be advanced against many lake projects in the U.S. proposed by the Corps of Engineers is that many of the locations where good cost-benefit ratios can be gained may already be dammed. If such is becoming the case and flood losses continue to increase, finding additional effective dam sites to stop the persistant recurrence of flood flows seems unlikely.

Second, the lake which results when a dam is constructed often serves as an attraction to development around it.[12] This (a modified and often worse form of urbanization) increases the volume and rate of flow from the watershed and potentially reduces the level of effectiveness of the dam's protection. Reduction of effectiveness, coupled with increased encroachment in the "protected" area below the dam, can place this measure in double jeopardy.

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from watersheds which are large enough to produce damaging flood accumulations above them. The case study (Chapter 6) in this thesis demonstrates that even in an 11 square mile watershed there will accumulate flows which can cause flood damage.

[12]The cost-benefit ratios which are developed to justify the construction of water supply and flood control reservoirs commonly include recreation potential as well as other "multiple uses." The development of recreation and leisure facilities implies the development of access to the lake from an existing highway or city. Recreation and transportation are in themselves, "attracted developments." However, they are often followed by second home subdivisions, tourist commercial developments and ultimately resorts. The development direction of nearby communities is commonly drawn by a lake amenity. Development implies the modification of the watershed which leads to higher coefficients of runoff. An example of the development of a water supply within commuting distance of a large city which resulted in the development and intensive use of a waterbased recreation area is Lake Thunderbird in Norman, Oklahoma. In this case the increased runoff from the recreation areas endangered water quality, but the same increased runoff peak flows could have reduced the ability of the lake to function for flood control purposes. (Further information can be gained through the State Department of Tourism and Recreation, Division of State Parks.) The second home subdivisions, commercial developments, and resort construction around Lake Sidney Lanier, (50 miles north of Atlanta,

Third, dams and lakes behind them have life expectancies. In fifty to one hundred years the lake fills in with sediment and/or the dam can deteriorate to the point where structural integrity is questionable. Normally, the flood pool does not silt in for a number of additional years because it is only a temporary impoundment. However, as the conservation pool fills in, pressure is commonly applied by the public to raise its level thus removing some of the capacity relied on for flood storage.[13]

Channel alteration can increase the ability of a given stream or river to convey greater flows through an area to be protected without overbank flow. This is achieved through any one or combinations of the following methods. Widening gives the channel a larger capacity. With straightening, the channel increases in gradient and realizes a reduction in resistance to flow, thus increasing the rate

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Georgia) is another example of "attracted development" (Further information can be gained through the Atlanta Regional Commission or The State Department of Natural Resources in Georgia).

[13]When a lake is constructed primarily for purposes of flood control, a critical measurement in its ability to temporarily impound flood flows is the height of its flood pool or the distance between the elevation of normal lake level and the top of the dam's flood gates. If, by demand for more storage, the permanent pool elevation is raised to half of the height of the flood pool, the flood storage capacity is reduced by up to 50% (depending on the surrounding watershed slopes). To increase the recreation potential at Lake Wister in southeastern Oklahoma (raise the water level above the level of tree stumps in the shallow ends of the lake) it was proposed that the permanent pool elevation be raised by eight feet. This would reduce the flood storage potential in a lake constructed primarily for that purpose by the Corps of Engineers. (The proposal was made in 1974 while the author was chief planner for the Division of State Parks). Presently, the City of Tulsa, Oklahoma is attempting to raise the permanent pool elevation at Lake Oolagah (north of the city) for increased municipal water requirements. The increased demand for water in industry or as a coolant for power generating plants has a significant potential for raising permanent pools and reducing flood storage. As lakes silt in fixed storage requirements will either generate pressure to raise lake levels or cause replacement construction (new lakes).

at which the water moves through it. Lining allows even the friction on a straight channel to be greatly reduced thus further increasing the velocity of flow. The problem with this approach is that it works so well that the runoff is conveyed downstream to some unfortunate recipient.[14] The interconnectedness of water systems becomes apparent when City X rapidly purges itself of its runoff and City Y is required to cope with the downstream demands of increased peak flows, volumes and velocities of flow. Does City X have the right to do this?

As early as the 1880's the Illinois courts were holding that farmers should not be drastically increasing or diverting runoff to their lowland neighbors. In Dayton v. The Drainage Commission in 1889, the court found that the owner of the dominant heritage (upper lands) may drain his lands, and even divert somewhat increased amounts of runoff across serviant heritages (lower lands) as long as it passed along natural drainageways. The law did not allow the dominant heritage to subject the serviant heritage to an unreasonable burden.[15] In a 1974 decision the Illinois Supreme Court stated in a "reasonable use" clause that the owner of the upper property has the right to gain benefit from the use of his land and thereby cause some increase in drainage.[16] The man on the lower property likewise has the right to

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[14]Presently the result of channel alteration and increased peak flows is commonly seen as the erosion and scouring which takes place at the end of a lined channel. In so far as streets, parking surfaces, and local storm drains constitute "improved" channeling of runoff, the obligation of neighborhoods downstream from newly developed areas to widen and line their formerly adequate channels is a local example of incurring costs due to drainage alterations. As regions urbanize, the same pattern can be seen to include entire cities being effected by the channel alterations of other cities.

[15]Dayton v. The Drainage Commission, 121 Ill. 271 (1889).

[16]Templeton v. Huss, 57 Ill. 2d. 134 (1974).

experience benefits and certainly be able to avoid losses on his land. Templeton v. Huss mirrors a growing opinion that there must be a balance among property owners' rights in matters of runoff. In modern urban situations such runoff increases are much more apparent and will likely lead to a future in which cities and major development corporations may be suing one another because of overly effective storm drains, channel alterations, and increases in the volume of runoff.[17]

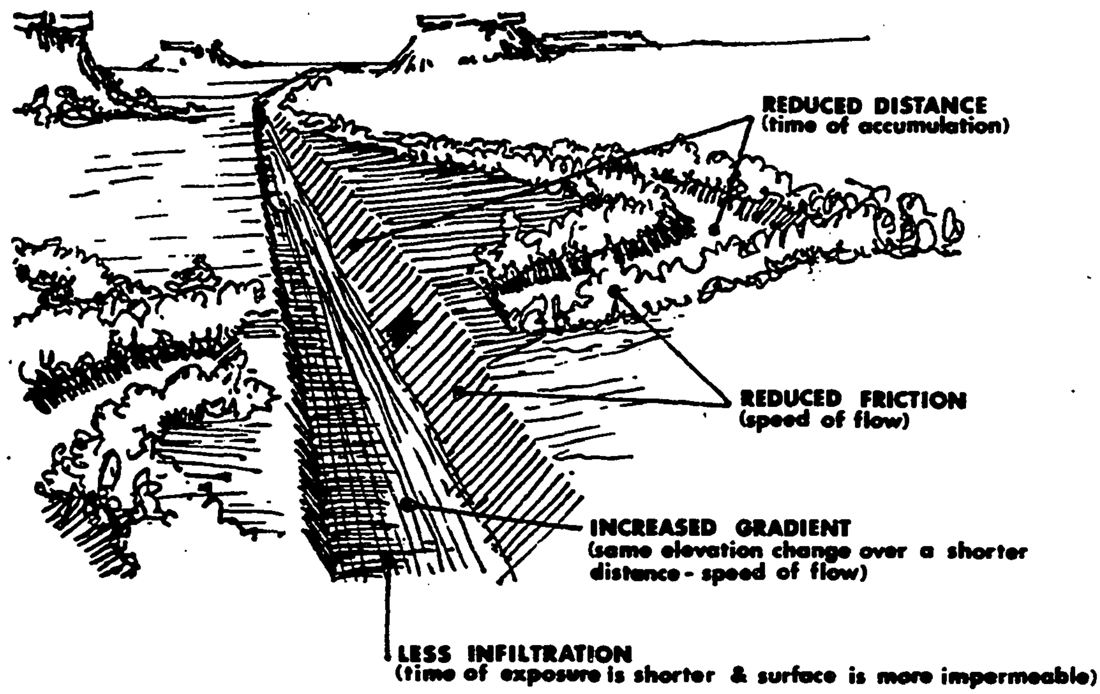

Fig. 2.2--Some Effects of Channel Alteration

[17]Charles Thurow, William Toner, and Duncan Erley, Performance Controls for Sensitive Lands; A Practical Guide for Local Administrators (Chicago: American Society of Planning Officials, Planning Advisory Service Reports Nos. 307 and 308, 1975). An indication of the new direction in ordinances enacted by cities to prohibit major changes in drainage characteristics is in the statement: "Under the concept of environmental performance standards, they (cities) are requiring that the amount of runoff from any specific development not exceed the carrying capacity of the natural drainage system" (p. 17).

There are a series of questions which can be posed to summarize some of the potential problems with the large scale engineering works approach to flood control. Does it temporarily protect an area which is encouraged by it to develop and subsequently require added protection? Does it inundate or cover a significant amount of land which could otherwise be more effectively used? Does its protection encourage the displacement of a more optimal land use which would otherwise have continued? Does a large area or region depend solely on it for protection? What happens when it becomes less effective in time or fails? Is it funded and constructed simply as a vehicle of local economic stimulation and political leverage?

With the large scale engineering works approach is the potential for highly visible accomplishment in terms of a politician's ability to channel funds toward his constituency (the large costs generally associated with levees and dams) as well as his ability to get things done (the obvious visual impact of a large construction project). This issue is mentioned at this point only to point out that the project scale and capital outlays for the traditional engineering approach to flood control can become more important to the decision than the functional effectiveness of the end product.[18]

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[18]The stimulation of local economics, the production of jobs, and the attraction of industry may be the assets of engineering works which could make it difficult to dislodge it as a flood control approach even if another nonstructural method was proven to be more effective. Edward Flattau discusses the challenge of giving the Army Corps of Engineers something else meaningful to do in an effort to redirect "porkbarrel" projects away from "ill conceived" water resource projects in "Plugging in the Barrel" (New Haven, Connecticut: The New Haven Register, January 30, 1977).

The aspects of engineering works which are potential assets which need to be retained and developed include their: predictable performances, technological improvement, and existing record of performance. Predictable performance underlines the idea that a dam or levee, or channel can be constructed to hold back or facilitate the flow of an amount of water which can definitely be calculated. The aging of lakes and structural improvements can be accurately predicted. Second, the process of building, using, evaluating and monitoring the performance of engineering works has lead to a present day level of sophisticated technology and materials. The continued development of engineering technology could result in the solution of many of the problems which are presently attributed to it. Finally, as an approach, the application of large scale engineering works for flood control has a performance record. Whether it is subject to question or not, levees and dams have been used throughout history while the developing alternatives are, at best, proven only under hypothetical conditions.

Floodproofing

Occupational floodproofing refers to two basic concepts.[19] The first is that any land use on a floodplain should be able to bear periodic flooding without damage. If a certain crop or pasture can withstand being under water for a certain number of days each year without significant damage, it is floodproof. Secondly, should it be necessary to have potentially damagable structures or other activities

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[19]A geographer researching in the area of practical flood problem solving is involved in the area of occupational floodproofing, John R. Shaeffer, Floodproofing: An Element in a Flood Damage Reduction Program, (Chicago: University of Chicago, Department of Geography Research Paper No. 65), 1960.

on the floodplain, their design and siting can be modified to withstand the inundations likely to occur there. Waterproof structures, local levees, and pumps are examples of floodproofing. The only criticism of this approach, when addressing the floodproofing of urban land uses, is that the advantages of the location should have to be such that the added expenses of modified designs are exceeded by the potential returns associated with the location. Generally floodproofing is a necessary solution for either urban uses which need to be located on floodplains or rural-agricultural uses which are best suited to be there.

Regulation of Land Uses on Floodplains

White's third measure states than an excellent way to avoid flood losses is to make sure that nothing which can be damaged is placed in its probable path. The literature often refers to this as keeping man away from the hazard as opposed to keeping the hazard away from man (engineering). One problem may lie in determining the magnitude of flood to which the regulation of land addresses itself.[20]

Another problem is that until recently there has been very little hydrologic data upon which to base the calculations to determine the

[20]The question here is philosophical. Various Federal, state, and local policies and laws generally accept the 100 year storm in a particular locality to be the event to which regulations are to be addressed. Yet there is little or no evidence in the literature related to the origins or reasonings for the selection of the 100 year storm other than perhaps the roundness of the number. Fabos and Caswell, in Composite Landscape Assessment state that "The majority of planners now adopt(s) the 100-year floodplain as a standard for flood protection" and then go on to note that in 19 years of development in some watersheds, the 100 year storm has become equivalent to the 5 year storm in runoff characteristics (p. 131). Footnote 2 in this chapter discusses this change process.

floodplain. Based on the probability of a storm of a certain intensity and duration, runoff must be computed based on those land uses which are most likely to develop in the future of the watershed.

Although, in most cases the courts have upheld the public's right to regulate floodplains, the actual figures and methods used to delineate them are often contested.[21] Platt as late as 1976, however, still expresses the potential unconstitutionality of the floodplain regulation matter.[22]

Another potential problem area is related to the philosophical question about where floodplain delineation should end. Are only these stream reaches where "significant" accumulations and damages occur to be delineated and regulated? The issue comes down to determining what constitutes damage. Should the criteria be $1 million of damage at one location on a major stream or should it be $1 worth of damage at one million locations on the extreme upper reaches of many small streams?

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[21]A paper by Beverly Scribner, "Urban Floodplain Regulation for Cities and Towns in Oklahoma: Its Legal Bases," (Unpublished paper, University of Oklahoma, Department of Regional and City Planning, 1976) provides a good overview of Oklahoma's legal ability to regulate floodplains. A broader legal treatise with a national stature is provided by Allison Dunham, "Flood Control via the Police Power," University of Pennsylvania Law Review (Philadelphia: University of Pennsylvania Press) CVII, June, 1959). Fred Bosselmann, David Callies, and John Banta provide a more extensive review of land regulation in The Taking Issue (Washington, D.C.: U.S. Government Printing Office, 1974).

[22]Rutherford Platt, "The National Flood Insurance Program: Some Midstream Perspectives," Journal of the American Institute of Planners, XLII No. 3, (1976), pp. 303-313.

Forecasting and Temporary Evacuation

White's fourth measure recognizes that another way of avoiding flood related losses is to get whomever or whatever is susceptable to damage out of the way before the flood develops. Here the potential problem is the reliance on the assumptions that there is adequate prior knowledge of the existence and potential magnitude of a developing flood and that those in its path are cognizant and cooperative in evacuation. The ability to adequately forecast floods in larger watersheds has been developed, although flash floods in small basins such as Bird and Joe Creeks in Tulsa, Lightning Creek in Oklahoma City or Peachtree Creek in Atlanta still occur with little warning.[23] In general, the literature in the area of hazard perception underlines many of the difficulties of convincing evacuees of an impending, but not yet perceived disaster.

Even if forecasting and evacuation are successful, there are two problems associated with the approach. First, although people and their portable belongings can be evacuated, the more expensive elements of settlement such as houses are left behind to result in the major part of the dollar losses. Secondly, evacuation itself is remedial and temporary; it does not stop the flooding itself. People are moved back and then once again inundated or evacuated during some future storm of similar or greater magnitude.

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[23]Further information about floods in these areas which have resulted in extensive damage to residences during the past few years can be obtained as follows: in Tulsa, Oklahoma, through the Tulsa District of the Army Corps of Engineers or the Tulsa Metropolitan Area Planning Commission and in Atlanta, Georgia, through the Atlanta Regional Commission.

Relief

The last traditional loss abatement measure is addressed to the rather charitable act of helping the victims of flood damges. In that such relief might facilitate resettlement elsewhere and subsequent public acquisition of the hazard area, a further loss avoiding solution is possible. Normally, however, flood relief is remedial in nature.

A second criticism of the relief approach in particular, and the evacuation approach in general, contests the equity of the public bearing the recurring expenses. Ignorance on the part of those who move into flood-prone areas can no longer be claimed as an excuse. Most state laws, as well as the 1973 Flood Disaster Protection Act, require notification about and often the posting of hazard areas prior to sales or loans. Another point brought out in earlier writings on the philosophy of floodplain occupance is that its appropriate use is that type of activity whose potential returns outstrip the risk of loss due to location.[24] That is when a person chooses to occupy a floodplain, he has elected to take a calculated risk and therefore has little right to be reinstated at public expense. This also applies to the pressuring for public capital outlay for protective engineering works which tend to widen the margin between private returns and loss risks. As with evacuation, relief is remedial.

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[24] White, Human Adjustment to Floods, p. 31.

In discussing the problems associated with the prevailing flood control methods, there is a danger that the reader might interpret this to mean that all of the traditional methods always are inappropr-ate. The author has been cautioned against eliminating the traditional techniques in clearing the way for an alternative approach which is developed in the next chapter.[25] As noted, smaller scale, localized engineering works are in fact suggested in the proposed alternative.

Floods of magnitudes greater than the design event will inevitably occur necessitating the continued improvement of forecasting evacuation, and relief techniques. Federally subsidized insurance and relief programs are still necessary for those who presently live in hazard zones which are not as yet protected either by the traditional engineering works or by the as yet undeveloped alternative approaches. The land use regulation of the floodplain will continue to be necessary to prevent improper development and perhaps to encourage through the law and tax policy, optimal use of those lands.

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[25] Interview with J. Lee Rogers, C.E. Norman, Oklahoma, July 12, 1977.

CHAPTER THREE

THE DETENTION SYSTEMS ALTERNATIVE FOR MANAGING URBAN RUNOFF

Introduction

The continuing trend in flood loss statistics points toward increasing rates of runoff management failures. Chapter Two presents some of the reasons why the prevailing approaches might be subjected to question. If the problem areas are understood, measures may be taken either to correct or avoid them. This chapter attempts to develop an alternative approach by retaining the positive aspects while correcting or avoiding the problem areas of the prevailing approaches. Goals or desirable effects are established with the sum total of these goals and effects constituting the alternative proposal for management. The problems for which alternative solutions are proposed are the scale of the traditional engineering works, the public cost-private benefit dilemma, the area-wide reliance on single projects, the hydrologic alterations of urbanization, and the legal problems of having to avoid excessive amounts of runoff (undue burden).

The Scale of Engineering Works

There are two basic problems included under this heading. The first is that the large protective works, which are presently developed, cover vast acreages of otherwise valuable lands. The alternative might be to develop many smaller devices on sites that are less usable or only temporarily used for protective measures. The second problem is that large reservoir or levee areas are necessarily situated at the bases of large contributing watersheds. Many of the losses related to flood runoff are attributable to the much smaller watersheds upstream from the present flood structures. An example provided by the City of Tulsa, is one of major flood losses adjacent to small urban area streams, rather than along the highly controlled Verdegris and Arkansas Rivers.[1] The key to the solution is to get the runoff management efforts distributed upstream at least to the points where the first damaging flows can accumulate.[2]

The Dilemma of Public Costs-Private Benefits

Traditional management efforts can be attacked on the basis that they tend to benefit those given direct protection even though the costs are distributed among those not requiring the protection. The counter-attack coming from those being protected, is that such protection was in large part necessitated by those who altered the hydrologic patterns of the contributing watershed. The solution may be to make all residents of contributing watersheds directly responsible for eliminating hydrologic change. This is to say that everyone must control his own runoff.[3] The implication therefore is highly localized costs and benefits gained through systems of management devices at the sources of runoff.

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[1]Reference is made to the local urban flooding on Joe and Bird Creeks which is discussed in Chapter Two (footnote # 23).

[2]The definition of damaging accumulations is still beset by the argument concerning $1 million damage in one place versus $1 damage in a million places, as presented in Chapter Two.

[3]As noted in Chapter Two (footnote #17) Thurow, Tone, and Erley discuss the trends in zoning and drainage ordinances toward an attitude of local control of generated runoff in <u>Performance Controls for Sensitive Lands; A Practical Guide for Local Administrators</u>, p. 17.

Area-Wide Reliance on Single Projects

The question of what happens when Lake X fills in or the dam on Lake Y collapses during a period of stress can generate significant criticism of large flood control projects. A breach in a levee near Vicksburg, Mississippi which inundates hundreds of square miles of "protected" lands is perhaps solved by localized management throughout the Missouri and Ohio River Basins. The advantage is twofold. First, the failure of a single local structure causes little or no damage when compared to the failure of a dam on a 100 square mile reservoir. Secondly, localization facilitates the development of many different forms of management devices. Their respective weaknesses and life expectancies tend to overlap less, thereby giving a greater resilience to the system (management ecology).[4]

Urbanization and Hydrologic Change

It is generally agreed that urbanization increses the probability of overbank flow by increasing the volume and reducing the lag time between the precipitation and stream response. The approach in the past has been to recognize this phenomenon, project its magnitude, and, as much as possible, catch and store the discharge before it does additional damage. A solution lies in the area of counteracting the urban phenomenon of increased flood probability. Management which best simulates the controlling properties of the natural watershed may be the answer to this problem. In fact, overbank flows which inevitably happen in natural watersheds are usually compensated for by adjustments

[4]The term ecology here implies that the greater the number and types of methods relied on to manage a natural system, the more stable the management system is because of the failure of a single device due to a particular stress, the entire network will not fall. The term is used as a parallel to the ecology of natural communities.

in floodplain and channel morphology. These properties strongly suggest that the presettlement situation was far more resilient and adaptable to overflows than the urban hydrologic situations. The management proposal of this study actually advocates going slightly beyond the simulation of the runoff retention characteristics of the natural watershed. Instead, the urban hydrologic change will result in increasing the retention qualities of the watershed rather than drastically reducing them (see Figure 3.1)

Generation of Excessive Runoff

The growing criticism revolving around the generation of excessive runoff (undue burden) is that the cumulative effects of accelerated drainage are becoming much more perceptable and are beginning to cause significant damage. A measure which is designed to reduce damage in one area and actually increase damage in another is counterproductive. The opinions of the courts cited in Chapter Two point to a definite need for a change away from expedited drainage and toward detention. In this case, however, excessive detention potentially violates the riparian rights of those downstream who have historically depended upon a certain rate of flow. The solution is probably found in the detention and release of precipitation from detention facilities at an acceptable rate. Legally, the rate can probably equal the historic runoff rate or that amount discharged by the same area prior to settlement. Rationally, the flow should not exceed the capacity of any section of the natural channels below the point of detention.[5]

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[5]The term natural channel capactiy is used recognizing that to alter the channel is to fall into the traditional approach which has been questioned in Chapter Two and which should be avoided if at all possible.

Figure 3.1 shows a management continuum and the relationships of the various points along it to solutions as well as potential violations of water related rights.

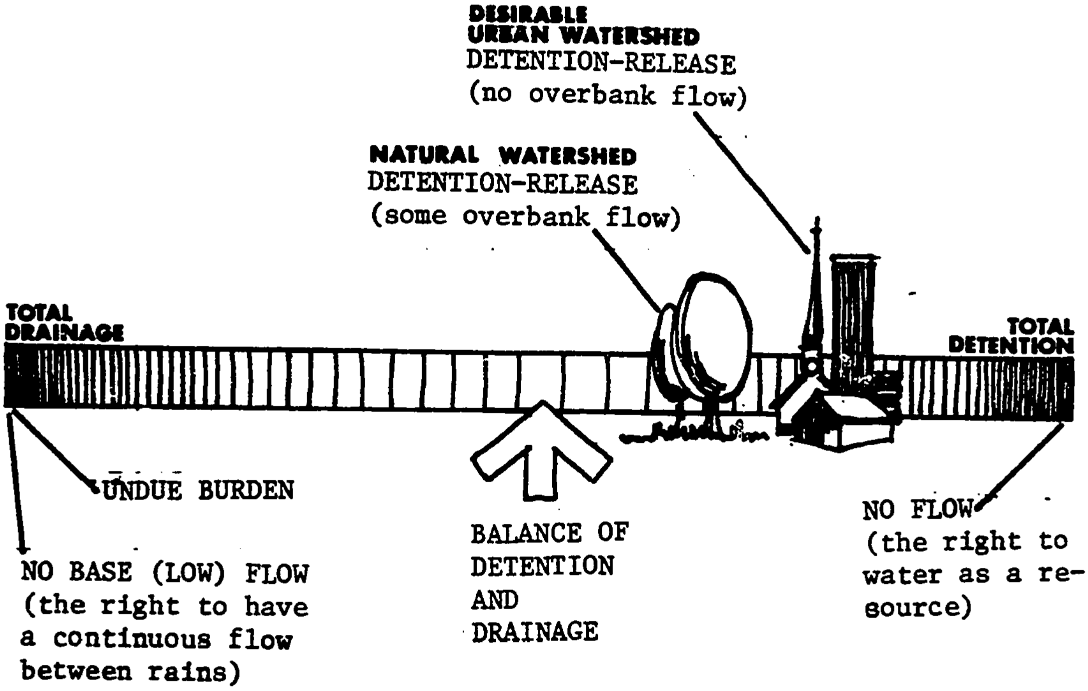

Fig. 3.1.--The Runoff Management Continuum

The Goals to be Achieved by the Proposed Approach

After examining the five problem areas and retaining the positive aspects of the prevailing flood control methods, a series of goals to be met by the proposed alternative are developed.

1. The controlling facility must be situated locally so as to intercept and retain runoff before it reaches a volume and velocity which can cause damage. For example, if the 135,000 cubic feet of runoff from an acre during a 6 inch rain causes damage, interception and storage of some of that volume must be accomplished with the acre.[6]

2. At least the minimum amount of local detention should be achieved through the use of facilities which contain and release their storage in a dependable manner. The designer should be able to calculate and rely on a specific performance. This is similar to the known volume of storage and the reliable rate of release achieved by large scale dams. Beyond the minimum requirements of detention, other less reliable detention techniques should be encouraged as a margin of safety.

3. The network of local techniques should be varied and designed to suit a particular site so that a particular weakness of one will not be common to all of the facilities. This "management ecology" approach should prevent the failure of a large number of facilities when the watershed is placed under a particular kind of natural hazard stress.

4. The controlling facilities should be such that each does not cover up a large area of otherwise usable land or should be designed so that between storms it can be used for other purposes (multiple use).

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[6]The figure 135,000 cubic feet is based on a 65% runoff rate (common to residential subdivisions).

5. Once a proper level of detention is achieved, the necessary rate of release from the facility should not be such that the cumulative release rates from all facilities exceeds the natural capacity of any downstream channel. A computable coordination of release from all facilities in a given watershed is perhaps best achieved based on a function of the area which drains into each facility. For example, if a certain detention structure stores the runoff from 3 percent of the area of the watershed, its rate of release should be equal to or less than 3 percent of the most limited natural channel capacity between it and the mouth of the watershed.

6. The detention device must be designed to release its storage so that it will be drained within a reasonable time. The facility must be adequately drained so that it can begin storage of runoff produced by subsequent storms. In addition, in as much as possible, the rate of release should be slow enough to facilitate ground water recharge and low flows without impairing the function of flood storage.

7. A consideration should be made to develop techniques and systems of detention which can be phased into use with the prevailing methods. A period of transition during which the proposed methods are evaluated is necessary.

With these goals in mind, the literature of the design professions (engineering, landscape architecture, and planning) was surveyed for detention and release techniques. The survey sought to realize all of the techniques, regardless of their suitability for reliable control or size of drainage area. Chapter Four includes the results of the technique survey and a subsequent examination of their respective suitabilities.

The new creek bed is ditched straight as a ruler; it has been 'uncurled' by the county engineer to hurry the runoff. On the hill in the background are contoured strip-crops; they have been 'curled' by the erosion engineer to retard the runoff. The water must be confused by so much advice.[1]

Aldo Leopold

CHAPTER FOUR

DETENTION TECHNIQUES

Introduction

To this point, the inquiry has concentrated on introducing urban runoff management and on attempting to solve the recognized short-comings of the traditional management approaches. The second part of the study addresses the methods for achieving the detention management alternative.

This chapter inventories and discusses individual detention techniques, their strong and weak points, and their possible impact on land use. There are four subtopics covered under detention techniques. First, all of the techniques are placed in a diagrammed position to give perspective to their relationships with all other techniques. As a result, they are shown at once with their relative positions offering the reader an introductory definition of each. Second, certain techniques are eliminated from further consideration. Those techniques are briefly explained and reasons for their elimination are given. Third, the methods being considered further, are introduced and

[1]Aldo Leopold, Sand County Almanac (Oxford: Oxford University Press, 1966), p. 126.

explained. Each includes areas of potential strengths or weaknesses as well as a discussion of impacts (if any) on land use patterns. Finally, methods for controlling the release of detained runoff are presented. Detention implies a temporary holding and subsequent release of what is detained.[2] Release is treated apart from detention because more than one method can be applied to any one technique.

Field research and a literature survey serve as the sources for all of the techniques to be discussed. Field application and research of the Soil Conservation Service (S.C.S.) of the U.S. Department of Agriculture has been the principal source of water management techniques in rural areas since its founding in 1936. Many of these previously rural methods developed in pioneer efforts such as the Muskingum watershed of Ohio are equally applicable to urban situations. In the 1960's, the S.C.S. actually began to apply its previously developed techniques to critical watersheds in urban areas.[3] The principle concern of S.C.S.'s pilot urban effort (Montgomery County, Maryland) has been sedimentation and water quality control. Quantity control is closely related. The publications of the American Society of Civil Engineers (A.S.C.E.) are the major sources of experimental

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[2]Detention is defined in Webster's Third New International Dictionary of the English Language Unabridged as"...enforced delay... period of temporary custody..." (Springfield, Mass.: G. & C. Merriam Company, Publishers, 1961), p. 616.

[3]The Montgomery County, Maryland,area outside of Washington, D.C., is noted as the first major urban pilot effort by S.C.S. It centers largely on the Rock Creek watershed and parts of the Potomoc. S.C.S. is now given an urban water and soil role. Presently the Montgomery County District remains as an example area where public officials and engineers go annually seeking guidance and new ideas.

and developing techniques.[4] A publication of the American Public Works Association (A.P.W.A.) is an excellent source for techniques presently being applied in certain areas of the country.[5]

All of these techniques are placed in perspective. Their placement will be based on the literature's discussion of each relative to others.[6] Two basic criteria were found common to all methods. First, each tended to be inherently suited for a certain runoff area size. For example, an underground vault (cistern) works well at the scale of an individual or small group of buildings. Large reservoirs are suited for watersheds of 50 or more square miles. Therefore each technique can be placed along an area size continuum such as Figure 4.1.

It logically follows that in a study which addresses "small urbanizing watersheds," detention techniques which are best suited for runoff areas larger than 10 to 20 square miles should not be considered further. The asterisk on the continuum respresents this cutoff point.

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[4]The A.S.C.E. is the professional society for civil engineers and is headquartered in New York City. The main professional journal is The Proceedings which has developed a number of relevant subdivisions such as Irrigation and Drainage, Urban Planning and Development, and particularly Hydraulics.

[5]Herbert G. Poertner, Practices in Detention of Urban Stormwater Runoff, Special Report No. 43 (Chicago: American Public Works Association, 1974.)

[6]An additional research project could be initiated to check the placement judgement of the author. A number of hydrologists, engineers, and planners could be asked to place all of the techniques on the two dimensional space introduced below. A point central to all of the locations assigned by the "experts" could be considered as a consensus position. As it stands, each technique is discussed in various publications and studies, usually in relationship with other techniques. An example is that cisterns are more suitable to small sites than channel impoundments and are generally much more controllable. All of the techniques are placed on plane as a result of the many relationships noted in the literature.

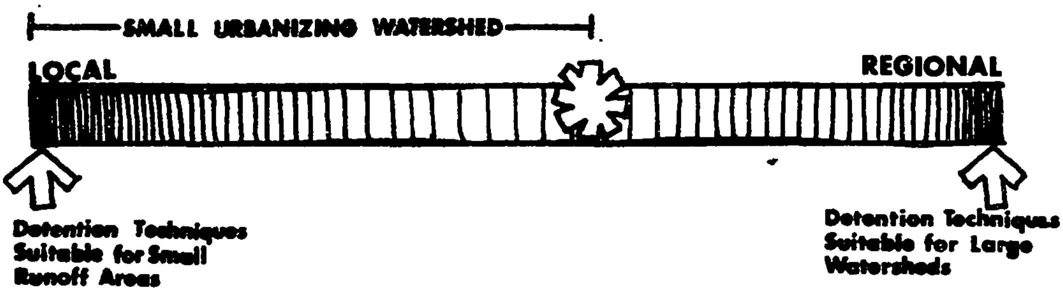

Fig. 4.1.--Detention Technique Suitability Based on Runoff Area Size

The second common criteria involves the varying levels of controllability.[7] One of the most important aspects of modeling detention is the ability to compute and rely on a predictable amount of storage in and rate of release from the detention element. The effectiveness of a detention system is measured by its discharge hydrograph. The hydrograph is based on the runoff being discharged from the study area.[8] If a

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[7]The terms controllability and controlment, referring to the ability to restrain or hold in check, are used interchangeably in the study.

[8]If the volume of runoff from a watershed which is managed by a detention system does not exceed the capacities of the stream channels in that watershed, the detention system is considered to be effective. The resultant hydrograph would have a rising limb which would cease to rise at the point where channel capacity is reached. The line of the hydrograph would then travel parallel to the base until the stored volume is discharged. The line then drops back to the base or to a low flow rate. Visually, the hydrograph appears to be truncated. Figure 6.23 contains a hydrograph of an effective detention system.

proposed detention technique has a variable storage capacity and unpredictable rate of release, it makes computation unreliable. On one hand, if a small yard sump (depression) has an inch diameter drain, the sump has known storage dimensions and the drain has a computable release rate. On the other hand, plant interception (storage) is an example of an unpredictable detention-release mechanism. The kind of rainstorm, type of plant, season, age, general health of the plant, and antecedent moisture conditions are among the variables which must be considered for accurate computation. Therefore, all of the techniques can again be placed along a continuum according to their respective control levels.

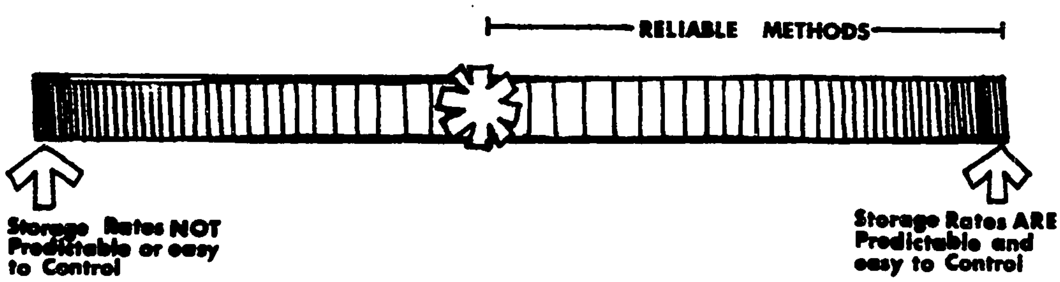
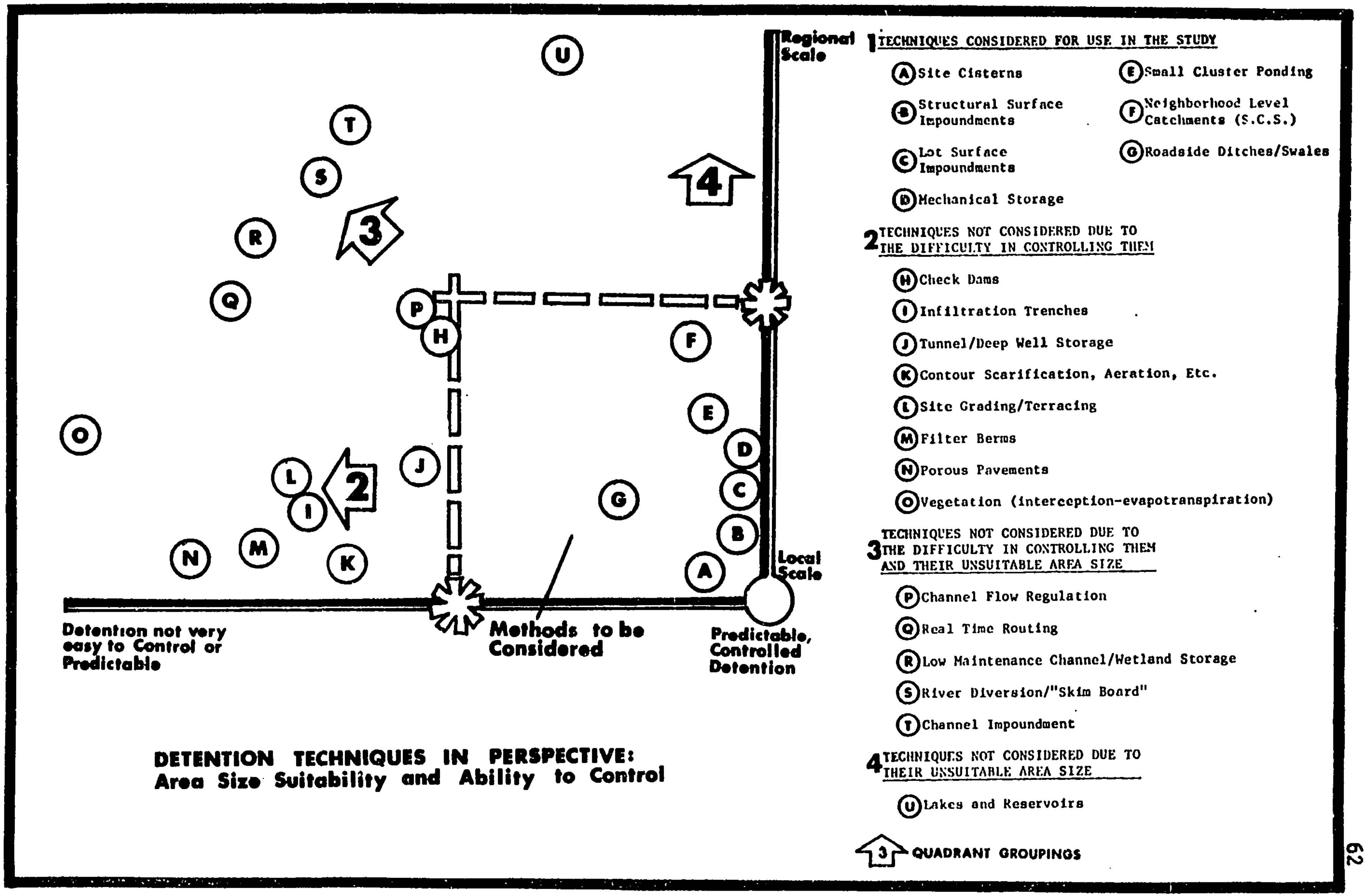


Fig. 4.2.--Detention Techniques Based on the Ability to Control

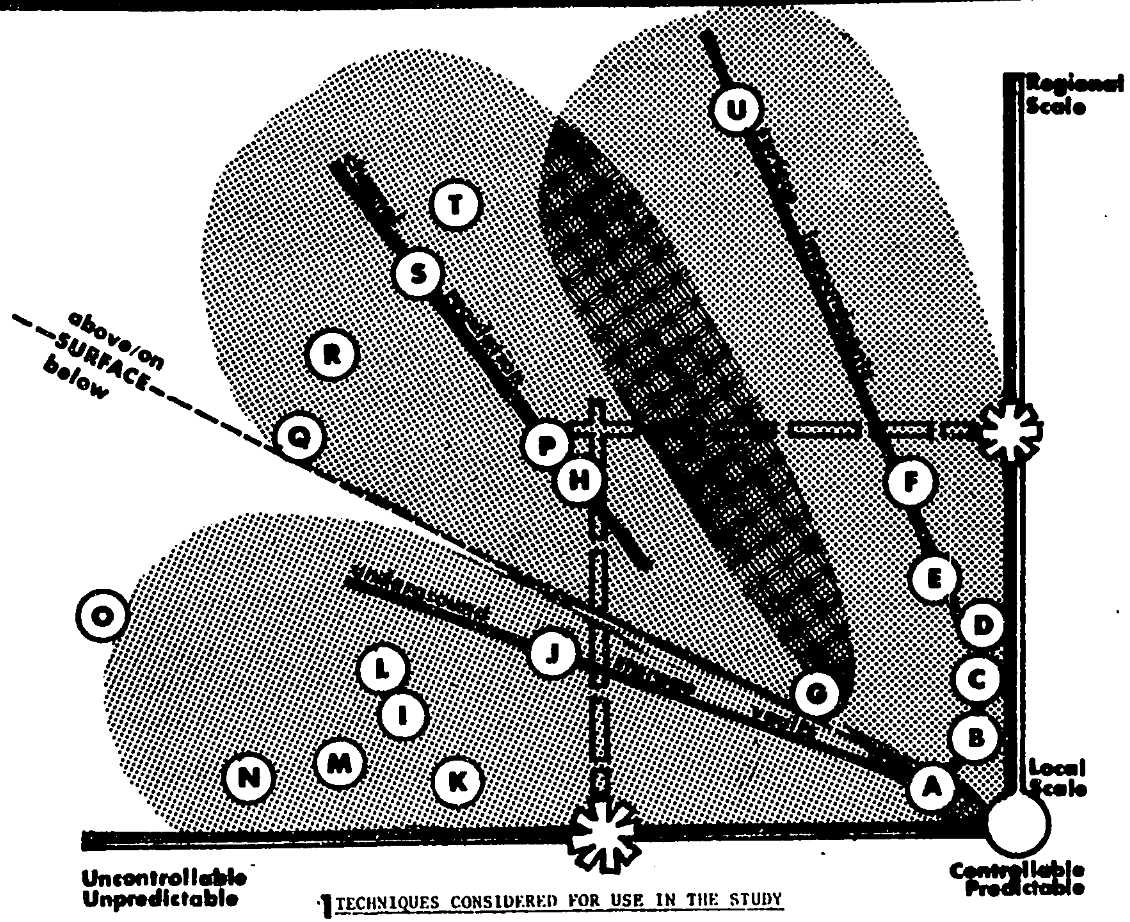
As in the runoff area suitability continuum, the asterisk represents the cutoff point where the controllability level becomes too unpredictable making the computation of a reliable hydrograph difficult.

If all techniques occupy a point along both the area size suitability and controllability continuums, their locations fall at a coordinate when the continua form the height and base of a two dimensional space. If a cutoff line is drawn perpendicularly from the asterisk on each continuum,



Regional Scale
Local Scale
Detention not very easy to Control or Predictable
Methods to be Considered
Predictable, Controlled Detention
DETENTION TECHNIQUES IN PERSPECTIVE: Area Size Suitability and Ability to Control
1 TECHNIQUES CONSIDERED FOR USE IN THE STUDY
A Site Cisterns
B Structural Surface Impoundments
C Lot Surface Impoundments
D Mechanical Storage
E Small Cluster Ponding
F Neighborhood Level Catchments (S.C.S.)
G Roadside Ditches/Swales
2 TECHNIQUES NOT CONSIDERED DUE TO THE DIFFICULTY IN CONTROLLING THEM
H Check Dams
I Infiltration Trenches
J Tunnel/Deep Well Storage
K Contour Scarification, Aeration, Etc.
L Site Grading/Terracing
M Filter Berms
N Porous Pavements
O Vegetation (interception-evapotranspiration)
3 TECHNIQUES NOT CONSIDERED DUE TO THE DIFFICULTY IN CONTROLLING THEM AND THEIR UNSUITABLE AREA SIZE
P Channel Flow Regulation
Q Real Time Routing
R Low Maintenance Channel/Wetland Storage
S River Diversion/"Skim Board"
T Channel Impoundment
4 TECHNIQUES NOT CONSIDERED DUE TO THEIR UNSUITABLE AREA SIZE
U Lakes and Reservoirs
3 QUADRANT GROUPINGS

Figure 4.3



1 TECHNIQUES CONSIDERED FOR USE IN THE STUDY

- (A) Site Cisterns
- (B) Structural Surface Impoundments
- (C) Lot Surface Impoundments
- (D) Mechanical Storage
- (E) Small Cluster Ponding
- (F) Neighborhood Level Catchments (S.C.S.)
- (G) Roadside Ditches/Swales

2 TECHNIQUES NOT CONSIDERED DUE TO THE DIFFICULTY IN CONTROLLING THEM

- (H) Check Dams
- (I) Infiltration Trenches
- (J) Tunnel/Deep Well Storage
- (K) Contour Scarification, Aeration, Etc.
- (L) Site Grading/Terracing
- (M) Filter Berms
- (N) Porous Pavements
- (O) Vegetation (interception-evapotranspiration)

3 TECHNIQUES NOT CONSIDERED DUE TO THE DIFFICULTY IN CONTROLLING THEM AND THEIR UNSUITABLE AREA SIZE

- (P) Channel Flow Regulation
- (Q) Real Time Routing
- (R) Low Maintenance Channel/Wetland Storage
- (S) River Diversion/"Skim Board"
- (T) Channel Impoundment

4 TECHNIQUES NOT CONSIDERED DUE TO THEIR UNSUITABLE AREA SIZE

- (U) Lakes and Reservoirs

DETENTION TECHNIQUES: GROUPS & TRENDS

Figure 4.4

a box within which the suitable techniques are located, is formed. Figure 4.3 is the result of this logic. Techniques which fall immediately outside of the cutoff lines are methods which can be considered for use under certain circumstances.

As each technique was placed in the position shown, additional patterns and groups became apparent.[9] Figure 4.4 shows the visually perceived trends and groupings or techniques. From the standpoint of groups, three wedge shaped sectors occur. The first includes methods related to impounded surface water. In that these impoundments of known dimensions rely on structures, a structured release from them is likely. Generally, methods in this group are predictable and span the full spectrum of area size suitability. The next group includes methods which control channels or routes of flow. These tend to be less capable of managing regional runoff due in large part to the increased difficulty in controlling the release of flow from the various restricting mechanisms.[10] The final group includes techniques which attempt detention through infiltration loss and subsurface storage. In general this group is suitable for small runoff areas and spans the entire controlment spectrum.[11]

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[9] It would be difficult to assign values of scale and controllability and statistically discriminate among these groups without a major research effort which would be ancillary to this study. There is little evidence even then that strong groupings would result. Simple visual discrimination is used here.

[10] An example of lessened release control is channel impoundment. This involves the constriction of points along the channel resulting in backwater storage. If the constricting devices become very predictable as would a weir, the channel impoundment becomes a small reservoir which is covered in the first group. Bridge openings, culverts, narrowing embankments are considered as impounding in this case.

[11] Vegetative techniques are considered the least predictable and they are suitable to small scale. In addition they involve some surface storage (interception) and losses from surfaces (evapotranspiration). They are shown as being on the outer fringes of the third group.

Three trend lines also show up as spines to each of the groups. The first involves the size of the surface impoundment. In other words, new detention techniques can be developed which utilized the impounment concept. These may fall along the line where size is the only variable, or off the continuum where some other factor such as release predictability is unique to it. The second trend line involves the scale of manipulation of flow. Channel flow restriction (P) and river diversion (S) are the only methods presently on the line. However, by extending the line toward the lower right hand corner of the diagram, a new technique of very regulated local channel flow (approaching the characteristics of impoundment) can be envisioned. The final continuum involves an increase in both scale and unpredictability, which is similar to the surface storage continuum. The reader can imagine a method which lies between a single residential cistern and deep tunnel and well storage. Sub-basement detention for large buildings and temporary inundation of subsurface parking structures are examples.

The Elimination of Certain Detention Techniques

This section introduces and discusses the detention techniques which will not be considered further in the study. Problems, such as area size suitability and reliability, which resulted in their elimination are given. Those eliminated fall into three groups representing each of the quadrants outside of the "cutoff lines." The first group includes techniques whose area size suitability is appropriate but whose controlment is considered inadequate (Fig. 4.3, Quadrant 2, H-Q). The second group includes methods considered inadequate in both area size suitability and controlment (Fig. 4.3, Quadrant 3, R-T). In the third group are those methods which are adequately controlled but more suitable to larger runoff areas (Fig. 4.3, Quadrant 4, U). The discussion begins in Quadrant 2.

Check Dams (H)

This method places a structure in the path of flow. This impediment is capable of allowing flow to pass through at a roughly predetermined rate. Flows in excess of that rate back up temporarily and sometimes build to a point where it passes over. The structure can be placed in a developed channel, gulley or on a slope and is generally viewed as a flow retarder and erosion and sediment control device.[12] As a structure with a very predictable impoundment and release mechanism it approaches being a surface catchment which will be covered under a separate heading. As a roughly developed flow retarder it resembles the effective but unpredictable terracing or contour scarification to be discussed later. Since this method can assume a number of forms and sizes, it is difficult to associate it with any particular land use pattern. It is inherently not suitable for developed areas where there is little surface space available for backwater. It will not be considered further due to its similarity to other methods which are going to be considered further or eliminated.

Infiltration Trenches and Wells (L)

This technique involves the development of a subsurface catchment filled with gravel or other porous material. The detaining qualities are threefold. First, the excavated volume serves as an immediate

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[12] Poertner, Practices in Detention of Urban Stormwater Runoff, Special Report No. 43, p. 154.

storage space. Second, given the various levels of porosity in soil horizons, the probability that a trench will intersect a horizon with better permeability (and one which is more distant from surface compaction) increases. Third, if the trench has the proportions of a cube, the amount of surface exposed to runoff for infiltration is increased 5 times over that of an ordinary surface. Figure 4.5 demonstrates the latter two aspects of infiltration trenches. An additional asset of the trench or well is that they can be installed without using large amounts of land or money. Infiltration trenches are commonly associated with the edges of large impermeable surfaces such as parking lots and densely developed commercial complexes.[13]

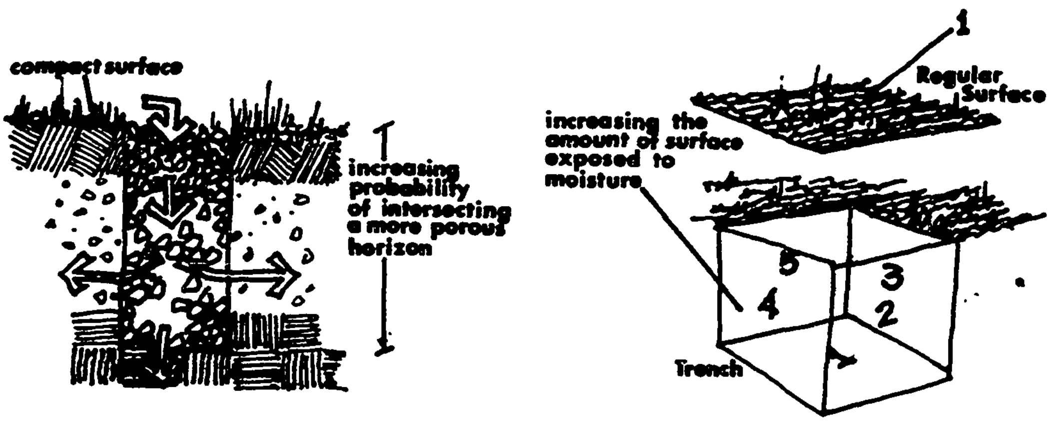

Fig. 4.5.--Infiltration Trenches

Drawbacks include unknowns in the area of groundwater and aquifer pollution and the tendency for the trench to clog with sediment (high maintenance). The condition of the trench, antecedent moisture levels, and the rate of interflow or re-release of the precipitation to overland flow make the method difficult to predict. Figure 4.6 demonstrates the

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[13] A video taping session involving the use of infiltration trenches in Montgomery County, Maryland, was observed by the author in April 1977 in Tulsa, Oklahoma. One of the three panelists was the S.C.S. District Agent from Montgomery County. The taping was for Channel 24, Tulsa.

technique. Titles followed by question marks are those aspects which render volume storage and releasė unpredictable.

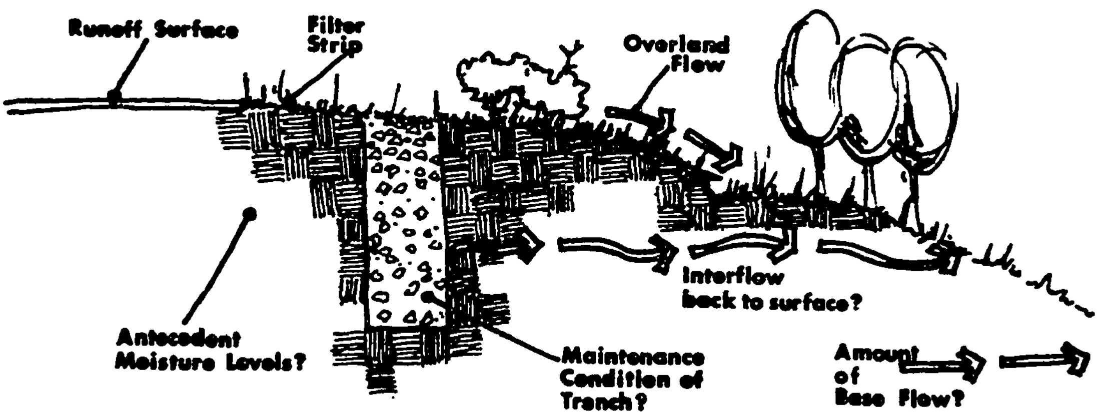

Fig. 4.6.--Flows in a Section of an Infiltration Trench

Tunnel-Deepwell Storage (J)

Techniques applying this concept include gravity flow or pumping of excess runoff into large subterranean chambers or wells. This method is particularly useful if the urban area is near existing underground chambers. If the chambers do not exist, the feasibility of developing them is forced only by extremely high surface land costs. Drawbacks are expense and environmental impact. The latter includes potential aquifer pollution and generation of geologic instability. The Chicago deep tunnel project is seen as a temporary holding tank for overlow from combined sewers during storms.[14] The runoff is later phased through treatment facilities by pumps. The occurrence of earthquakes near Denver was positively correlated with the Rocky Mountain Arsenal's deep well disposal of liquid industrial waste.[15] It is assumed that runoff storage could produce similar effects. The land use pattern associated with this technique is necessarily high intensity urban, due to the associated detention costs.

This technique is eliminated from further consideration for two reasons. First, the site specific investigation, which would be needed for engineering and environmental reasons, makes it difficult to use in case studies from which broader implications are to be drawn. Second, an urbanizing watershed or normal size and potential development would rarely justify the expense.

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[14]Further reference to the Chicago Deep Tunnel Project can be found in Poertner, Practices in Detention of Urban Stormwater Runoff, Special Report No. 43, p. 157. In addition the author seriously questions the use of combined sewers whose overflow required the tunnel project. Pollutants from the "first flush" of the surface are different from residential waste. Therefore efficient treatment system must target many more than one or two pollutants. The argument is often made that pollution control is most efficient when treated near the source of a unique pollutant; not later when a general system partially treats and dilutes a grab bag of wastes. In addition, the majority of the storm runoff after the first flush is good water which only mixes with combined sewer wastes to create unnecessary volume.

[15]Thomas R. Detweyler and Melvin G. Marcus, Urbanization and Environment (Belmont, California: Duxbury Press, 1972), p. 45.

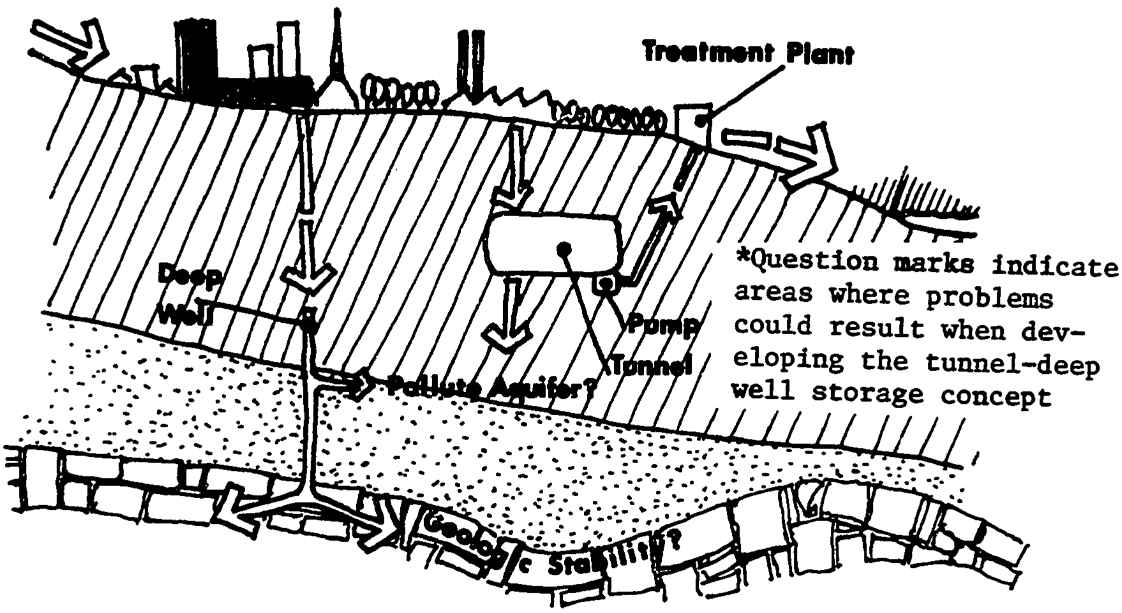

Fig. 4.7.--Tunnel-Deep Well Storage

Contour Scarification (K)[16]

Other than vegetation, this method is probably the least predictable in terms of runoff interception and release and is eliminated for this reason alone. This category of method includes attempts to reduce surface compaction to facilitate greater infiltration. When loose material is mixed with compact soils the method approaches that of the infiltration trench. Aeration, puncturing, and cross contour cultivation of hard packed surfaces produces variable infiltration capacities and with questionable life spans. Scarification (basin listing) or dragging a

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[16]Additional information on this technique can be found in Poertner, Practices in Detention of Urban Stormwater Runoff, Special Report No. 43, p. 154. Hewlett and Nutter have referred to a technique similar to this calling it basin listing. John D. Hewlett and Wade L. Nutter, An Outline of Forest Hydrology (Athens, Georgia: University of Georgia Press, 1969), p. 122.

ripping instrument across the runoff slope is subject to the same problems of predictability and life span. These are definitely all good conservation practices which should be added to the open areas of urban land as an inexpensive and added measure of detention. The section in Figure 4.8 summarizes some of the more common contour infiltration techniques.

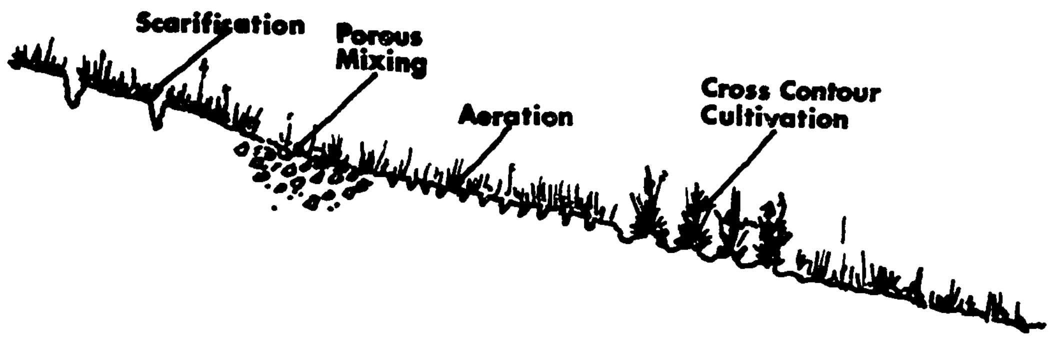

Fig. 4.8.--Contour Scarification and Other Infiltration Techniques

Site Grading and Terracing (L)[17]

These techniques are a more structured and effective form of the contour scarification techniques discussed above. They are eliminated for the same reasons, however. General site grading recognizes that steeper slopes generate greater amounts of runoff in shorter periods of time: Time of exposure to infiltration and time of accumulation is lessened. Therefore, if slopes are graded to lesser angles, runoff might be reduced and even trapped in surface depressions.[18]

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[17]Earl Jones, Jr., "Where is Urban Hydrology Practice Today?" Journal of the Hydrology Division, XCVII (February, 1971), 257-265.

[18]A counterproductive aspect is possible when contemplating the lowering of surface gradients by eliminating small hillocks, etc. When relief is lessened or eliminated, the amount of surface available for infiltration is lessened. The trade off is velocity and time for surface area.

Historically terracing is considered more effective and well established than contour scarification and site grading. Terracing, as a particular form of site grading, produces structures which predictably detain and release runoff and approach the characteristics of an impoundment which is addressed later. Considered here are the moisture traps set up on mountainsides by ancient civilizations and the moisture delays and erosion control devices set up in American agriculture.[19] These practices have proven to be excellent but site specific in quantification.[20] The two sketches show ancient mountain terracing and American cotton terracing practices. Terracing and site grading as above discussed has to date rarely (if ever) been used as an urban flood control measure.

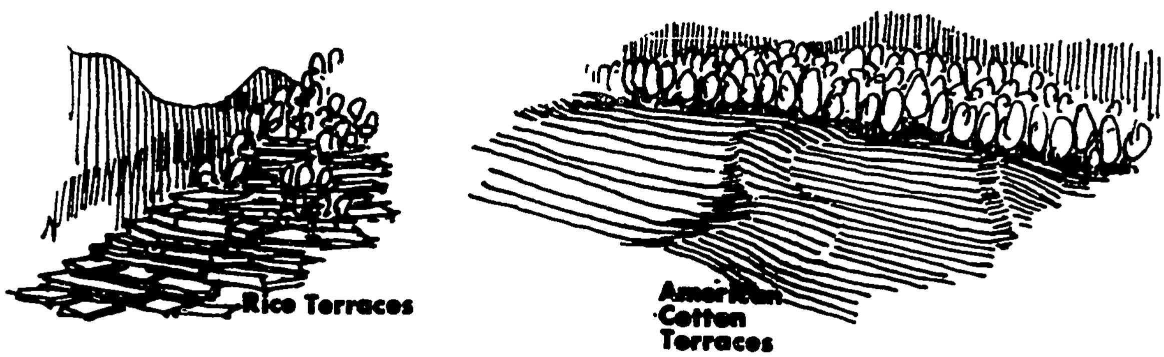

Fig. 4.9.--Terracing Techniques

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[19]H. C. Pereira, Land Use and Water Resources (Cambridge, U.K.: Cambridge University Press, 1973), p. 182.

[20]It should also be pointed out that techniques which are vague in terms of performance are difficult to legislate and legally defend when they are introduced as parts of runoff management ordinance. They are however easy to add to an existing detention system. The public works department of the urban area might develop these buffer measures on rights of way and public lands.

Filter Berms (M)[21]

The principle behind filter berms in runoff management is one of percolation time, delay of accumulation, and reduction of potentially damaging velocity. As presently applied, the technique is used to reduce velocity and settle out or trap sediment. Vegetative strips or gravel berms are placed across slopes and gulleys to impede the overland flow. The unpredictable nature of this technique and the reason for its elimination centers on the condition, season, type, and maturity of the vegetation or on the maintenance condition of the gravel berm.[22] Vegetation will later be eliminated again for similar reasons. The sketches below show the two basic types of filter berms.

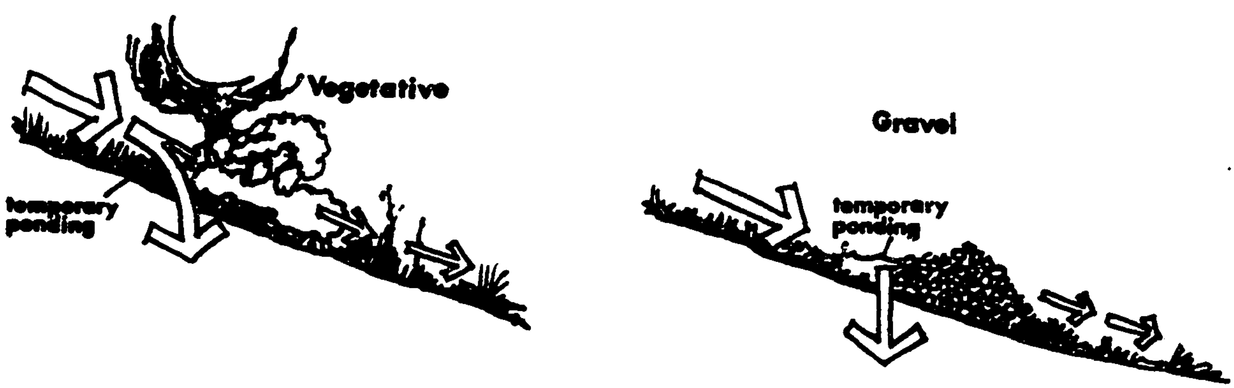

Fig. 4.10.--Vegetative and Gravel Filter Berms

Porous Pavement (N)

The major cause of man's creation of runoff increases is his urbanization, which covers and compacts soil and removes vegetation. It

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[21]Poertner, Practices in Detention of Urban Stormwater Runoff, Special Report No. 43, p. 154.

[22]Another drawback is that once the filter becomes saturated, equal amounts of runoff enter and leave (excepting small amounts of possible backwater). Gravel and vegetation should saturate early in a storm after which detention is ceased.

logically follows that if the amount of non-porous surfaces is reduced, the amount and rate of runoff should decrease. This is not a bad management concept and it is becoming more economically feasible each year. In that man's feet, functions, and machines continue to demand more paved surfaces; the compromise can be reached when the pavement is constructed with porous material. In urban design, the porous pavement technology is one of the most rapidly emerging approaches to surfacing. Porosities are known for certain materials but longer range percolation and detention capacities remain to be tested. Civil engineering literature has just begun to reflect some actual cost advantages of porous pavement over traditional forms in areas not subjected to heavy traffic.[23] As an added management possibility, porous pavement has an economic chance. The ability to legislate for it is more feasible when performance capacities are better known.

Fig. 4.11.--Porous Surfaces

Vegetation (0)

Man's alteration of the landscape usually increases both the volume and velocity of runoff. These alterations, whether urban or agricultural, commonly involve the removal of vegetation in conjunction with development.

[23] Thomas J. Jackson and Robert M. Ragan, "Hydrology of Porous Pavement Parking Lots," Journal of the Hydraulics Division, C (December, 1974), p. 1744.

An important consideration in this study of an alternative approach to runoff management is the reduction or elimination of changes on the land which tend to increase runoff. The removal of vegetation constitutes one of the major changes tied to runoff increases and should therefore be carefully considered. The use of plant materials can be one of the most effective methods for intercepting precipitation and for removing moisture from the soil (increasing the soil storage capacity by reducing antecedent moisture).[24] Robinette cites that an acre of turf will lose about 2,400 gallons (355 cu. ft.) through evapotranspiration on a summer day.[25] The question is how much and at what rate can specific vegetative masses reduce storm runoff? As noted in the section on the vegetative filter berm, too many variables come into play. Legislating the performance of something which relies on temperature, precipitation patterns, maturity, and antecedent moisture conditions is impractical. Likewise, the geographer attempting to compute runoff storage and discharge would suffer similar frustration. The following diagram illustrates the qualities of plants which tend to modify runoff by elimination (E) or detention (D).[26]

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[24] An obvious drawback to removing moisture through evapotranspiration occurs in areas where water deficits are common. The actual removal of vegetation to prevent those losses is common. Ultimately, one has to wonder whether or not certain areas became more arid as a result of the regional destruction of vegetation and sod. Storer in the Web of Life cites the moisture retention qualities of the thick black prairie sods which once covered large parts of the plains. John H. Storer, Web of Life (New York: New American Library, Inc., 1953), p. 68.

[25] Robinette, Plants/People/and Environmental Quality.

[26] Other vegetative unknowns which effect precipitation patterns (and thus runoff) include climatic change which results from large scale planting or removal of biomass. See Rudolph Geiger, The Climate Near the Ground (Cambridge, Mass.: Harvard University Press, 1950).

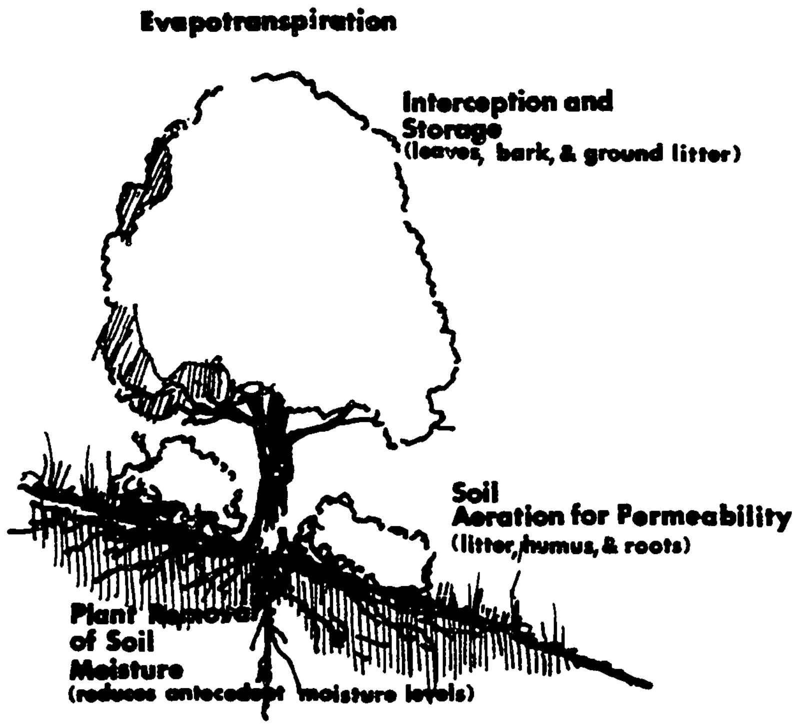

Fig. 4.12.--The Moisture Depletion Role of Vegetation

The use of vegetation is perhaps one of the most important potential runoff management techniques even though its performance varies or is unknown. Some form of vegetation cover is compatible with any land use. The key will be to provide good planting information to developers and provide an adequate encouragement or incentive for schemes which go beyond simple aesthetics.

Channel Flow Regulation (P)

The technique is the first of the group which were eliminated for being unpredictable for runoff areas larger than those being studied (Quadrant 3). Murphy and others include channel constriction as objects which impede flood flows and which must be eliminated from properly managed floodplains.[27] The problem cited is that streamflow is restricted with runoff inundating land behind the impediment. Yet if volume and speed went unimpeded, far greater damage is possible in some lower reach of the stream system. By intentionally causing flow restrictions in channels, the back up of runoff can be localized in areas which can withstand minor short term accumulations. The constriction can be such that the river channel below can cope with the maximum flow able to pass through. A common example of a constriction is a box culvert beneath a street. It is mistakenly viewed as an improperly sized aperture. As a detention technique, it is viewed as a release orifice.

This technique is not considered further because at the large scale, where box culverts and bridge constrictions are a factor, the watersheds are greater in area than the drainage basins being studied.[28] At a smaller and more appropriate scale, the technique is similar to check dams as well as small impoundments with controlled release devices which are discussed under other headings.

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[27] Murphy, Regulating Flood-Plain Development, p. 4.

[28] Intrusions into channels with fill or otherwise impeding the flow of streams and rivers also involves a complex, site specific series of changes in river morphology. This could in turn effect the flow capacities, a matter well beyond this study.

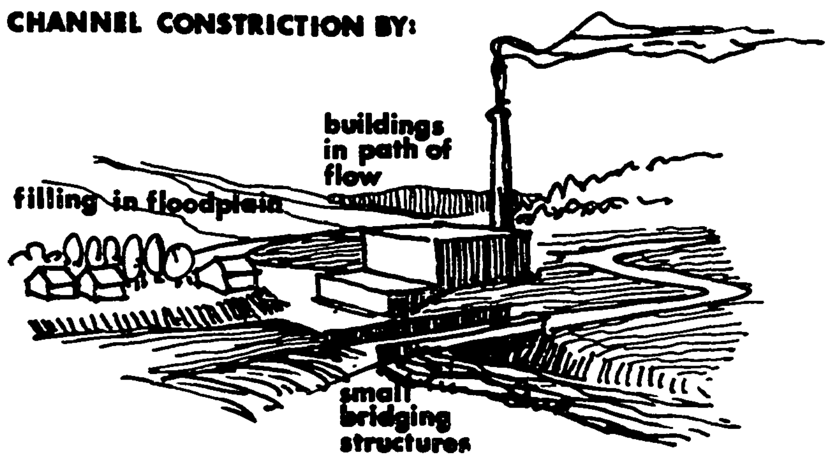

Fig. 4.13.--Regulating Channel Flow by Constriction

Real Time Routing (Q)

Techniques which can be considered as involving real time routing cover a broad spectrum. The common element to all of them is the time of accumulation. How much time does it take for runoff from various locations to flow together into significant amounts which could cause damage? Does this volume subsequently run into another causing even greater overbank flows? The principle is similar to rush hour traffic. Each factory or office lets out a handful of cars. It takes 50 cars ten minutes to get to the freeway from factory "X". Factory "Y" is ten minutes on the other side and lets out at the same time. The time of accumulation is ten minutes and the flood is the jammed freeway. If factory "X" builds a straight corridor to the freeway so that its "peak flow" accumulates in 5 minutes, the accumulations on the freeway are spread out so that a traffic jam is not created. This is real time routing. Channeling runoff straight to a stream from one side and delaying runoff by moving it along a maze of terraces on the other side can cause the two accumulations to enter the main channel at different times. This works fine when the storm passes over the short accumulation time side of the stream first. This neatly solved problem falls apart when the storm track comes from the delaying side. In a sense all dentention techniques rely on the real time routing approach to some extent. Impoundment is the delay of part of an accumulation.

If the probabilities of storm direction and intensity are correlated in give locations, real time routing policies can be made to work. Otherwise the system will have to have mechanical gates and computer controls to sensitize flows to specific storm situations. Presently there is no evidence of the existence of such a computerized real time routing system, even as a pilot research project. In addition, many of the controlling techniques included in this study are more simple, less expensive, and probably equally effective.

Low Maintenance Channel and Wetland Storage (R)[29]

This technique appears to go directly counter to the concrete lined channel which is the traditional urban runoff management approach.[30] When a stream in an urban area is left alone, four desirable things can

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[29]Low maintenance in the context of this technique refers to the idea that the alignment and vegetation of the channel is left in its natural state.

[30]The concrete lined channel appears to be the product of a number of urban attitudes. First, it was more efficient in speeding runoff away from the development. Second, it was easier to maintain in that the flow removed debris and the liner remained in place. Third, a strengthened and backfilled channel provided additional development acreage. Fourth, the brushy meandering alternative was viewed as a place where tires collected and mosquitoes and other vectors bred. Fifth, the frontier philosophy of the earlier American city dictated that vestiges of non-civilization be removed from civilized areas. The desire to reshape the land coupled with the public works and Bauhaus mentality earlier this century firmly established the articulated ditch as an unalterable fact. The "no frills", efficient public works attitude in the U.S. seems to have developed out of three sources. First, it may have been a backlash to the expensive and ineffective city beautiful movement which emerged from Chicago's Columbian exposition in 1893. (See Blake McKelvey, The Urbanization of America: 1860-1915 (New Brunswick, New Jersey: Rutgers Univer-

happen. First the valley cross section discourages development from encroaching on a potential floodpath. Concrete channels allow the surrounding lands to be raised slightly, encouraging a sense of development security. Second, an "improved" channel reduces the time of accumulation by increasing stream gradient and velocity and reducing distance. This is likely to be counterproductive to real time routing even though it is

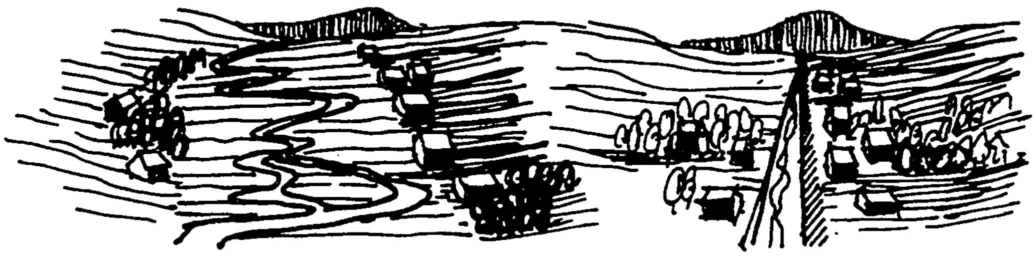

Fig. 4.14.--Natural Stream Channels and Encroachment

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sity Press, 1963), p. 115. In addition, the municipal reform movement at the turn of the century and the attraction of engineers and lawyers to the planning profession in the 1920's changed the boulevard and park priorities of the architects to the budgeted efficiency of streets, utilities, and housing. The second city efficient stimulus was World War I which necessitated the quick, basically functional, construction of urban housing for war labor. Utilities and drainage were designed to meet certain needs using the most efficient methods immediately apparent and available. See Arthur B. Gallion and Simon Eisner, The Urban Pattern (New York City:Third edition, D. Van Nostrand Company, 1975), p. 132. The third stimulus was probably provided by the depression jobs programs of the 1930's. Labor intensive public works projects developed streets, sidewalks, lined drainage ditches, and other urban utility systems.

The Bauhaus movement developed out of a German art and design school founded by Walter Gropius in 1919. Its basic premise, which was commonly misinterpreted, was that "form follows function." "Functionalism" was the American architects Adler and Sullivan's interpretation. The simplicity and technological streamlining advocated by the Bauhaus group made it easier for engineers to propose the efficient straightening and lining of drainage channels in the U.S. during the 1920's. See L. Moholy-Nagy, Vision in Motion (Chicago: Hillison & Etten Company, 1965), p. 42.

not being considered by the study. Third, the natural channel tends to be more resistive to flow due to increased resistance to flow. In effect, there are the same characteristics as those discussed under channel flow regulation (P). Fourth, if the channel cross sections were the same, the channel traveling the longer distance has the greater storage capacity. Although channels and wetlands have a high coefficient (C) of runoff, their ability to store large amounts of water with only a few inches rise in elevation is significant.

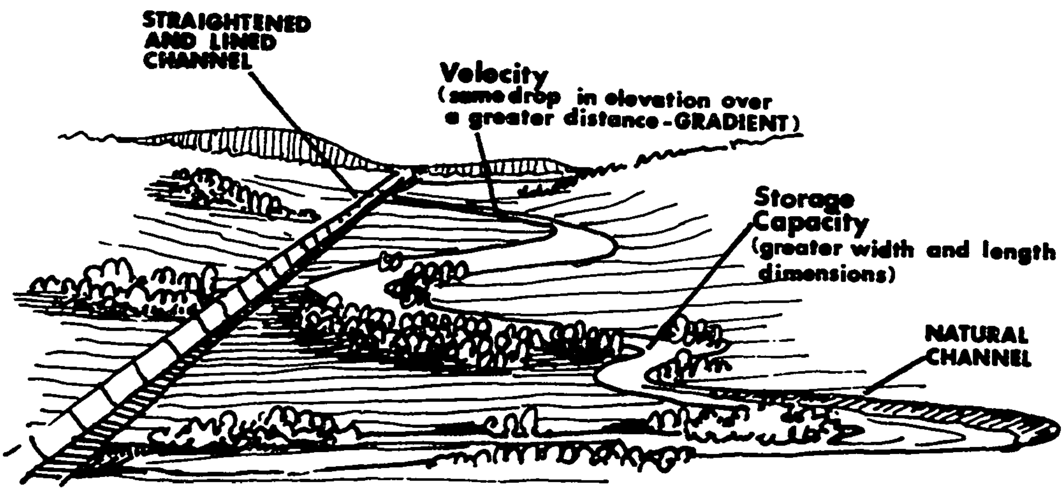

Fig. 4.15.--Real Time Routing and Channel Alteration

The detention proposals which are advocated and tested in this study do not promote the channel improvements (straightening and lining) discussed above. The specific detention performance of an unimproved channel, however, can only be determined by actual gauging and observing over a period of time. Basin gaugings and hydrologic histories are few and simply not available in the study area. The effect of an unimproved channel on surrounding land use is one of discouragement of encroachment and a potential encouragement of clustering in the developable space due to the loss of land to the channel and wetland use.

River Diversion (S)

Diversion of all or part of a flow recognizes that a damaging level of accumulation can be avoided by sending some of the contributing flows to other watersheds. Diversion implies the cutting through of a drainage divide. Historical precedent for diversion by cutting or tunneling includes a 6,000 foot tunnel to drain the surplus waters of the Lake Albano near Rome in 397 B.C.[31], Emperor Claudius' tunnel which lowered the surface of what is now Lake Fucino, 50 miles east of Rome, was restored in the late nineteenth century to a length of 21,000 feet.[32] In a sense, the accumulation of water pumped out of the Dutch polders constitute a diversion approach to runoff management.[33] A present day proposal has been made for the Chicago Metropolitan area: Flow levels in streams which exceed an acceptable stage strike an angled "skimboard" which diverts

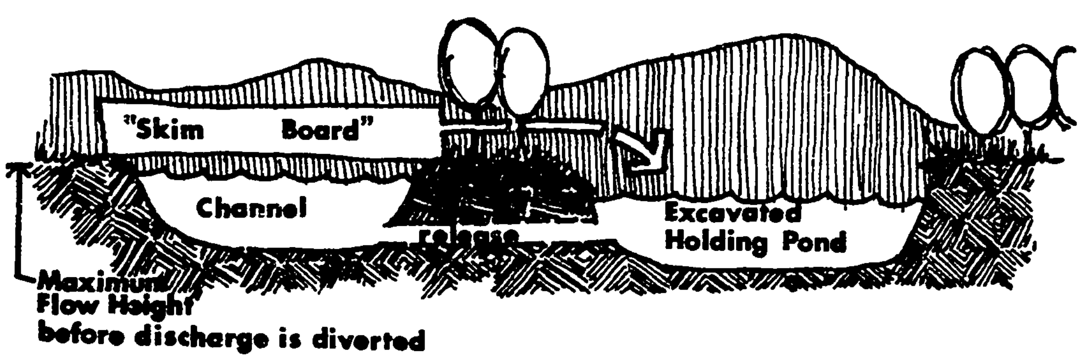

Fig. 4.16.--Flow Diversion and Storage Technique

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[31]George Perkins Marsh, Man and Nature (Cambridge, Mass.: The Belknap Press of the Harvard University Press, 1965), p. 300.

[32]Ibid, p. 301.

[33]Ibid, p. 294.

all of the excess runoff into an excavated holding pond.[34]. For purposes of this study the skimboard resembles a channel regulator or release control device which is covered under other methods. Land use associated with a channel diverter such as this would seem to be very intensive. The measure is an expensive alternative implying high land costs, although no particular pattern is necessarily required.

Channel Impoundment (T)

This technique is similar to the diversion, constriction, and reservoir methods discussed elsewhere. It is treated separately because, unlike reservoirs, the method can allow normal stream flow until a dangerous amount of runoff is imminent. A dam, often the size of one built for a full sized reservoir, is closed. An area behind the dam, for which flowage easement or title has been acquired, is inundated by the storage impoundment. An excellent example of a large scale channel impoundment is the Thomaston Dam Constructed on the Naugatuck River in Connecticut after the flood of 1955. A channel impoundment used for transportation is the Kerr-McClellan Navigation System on the Arkansas River. On the scale noted above the technique is applicable for very large watersheds. At the smaller scale the method approaches that of a temporary impoundment of the 3 to 5 acre displacement.

Lakes and Reservoirs (U)

In the last group are the presently common, large scale, multipurpose impoundments constructed by the Army Corps of Engineers, Regional Utility

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[34] The "skimboard" diversion proposal was presented by author and consulting engineer Herbert Poertner at a Floodplain Conference at the University of Tulsa (Oklahoma). The conference was co-sponsored by the Tulsa District Corps of Army Engineers and the University of Tulsa (Oct., 1976).

Authorities and the Bureau of Reclamation. When scaled down they become the blue-green impoundments to be introduced below. The flood pool of the typical reservoir represents the added elevation used during flood period. Lakes in the 20 to 40 thousand surface acre range which add 10 to 20 feet to their conservation pools can store 200,000 to 800,000 acre feet of excess flow. Reservoirs and lakes generally preclude any development inside of the acquired area.[35] Outside of the public ownership lines, scattered residential and tourist commercial land uses are attracted by the water based amenities.

Detention Techniques to be Considered

This subsection will introduce and briefly discuss the detention techniques which were surveyed and considered to be appropriate for use in small urbanizing watersheds. The format includes the introduction of the technique, potential assets and liabilities associated with it, and the types of land use which may tend to occur if the technique is applied. If a detention technique is desirable, land uses which naturally tend to work with it should be allowed. If an undesirable land pattern tends to occur with a particular detention technique, the use of the technique should be put to serious question. In effect, the planner should be selecting techniques which are effective and which encourage builders in the private sector to elect to develop in a manner that is good for the public and personal profit.

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[35] To increase the potential for land protection around the more recent reservoir projects, more land (excess condemnation) is being acquired.

Site Cisterns (A)

Historically, the source of water for home use has been a local water body or well, the aquaduct, and commonly the cistern which stored the water from rains for use during interim periods.[36] The cistern was used as a water source, but there is no reason why it could not be reintroduced as a runoff interceptor.[37]

The principle is based on the recognition that the urban surface is made up of many individual sites. If each site (residential, commercial or industrial) could be designed to manage its own runoff, the sum total of controlled sites is a well managed urban surface. Carried to an extreme, all water reaching the surface is arrested in place. Flooding cannot exist on a surface where water is not allowed to accumulate. If the full watershed is so controlled, the extent of areas subject to overbank flow is significantly reduced.[38] In this study cisterns, structural surface and lot impoundments are the most local form of runoff control.

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[36] The rain barrel or cistern in the historical context can be found in H.C. Pereira, Land Use and Water Resources (Cambridge, U.K.: Cambridge University Press, 1973), p. 6 and in Susan Jellicoe and Geoffrey Jellicoe, The Use of Water in Landscape Architecture (London: Adam and Charles Black Limited, 1971), p. 18. A general history of the house and its relationship to required resources such as water can be found in Stephen Gardiner, Evolution of the House (New York City: Macmillan Publishing Company, Inc., 1974).

[37] Many of the ideas used in this section should be credited to Professor George Reid (College of Engineering) of the University of Oklahoma whose unfunded research proposal promoted the concept of residential cisterns as a means of depleting local runoff.

[38] It can be argued that the physical floodplain will continue to exist. However, its formation is the result of periodic overbank flows. If periodic overbank flows cease other erosional forces may ultimately eliminate it since it is never reinforced.

Present building codes and subdivision regulations often require the drainage of a site into planned storm drains and streets before crossing other sites. The cistern concept is the exact opposite. The site should keep its own runoff before letting a slow flow work its way overland in grass swales to other detention devices.

As an example of the impact of an ideal residential cistern system, a 100 year storm is passed over a hypothetical test area.[39] With 6 inches of rainfall and 59% of it generating runoff a total of 1770 cubic feet of water would have to be detained on a 6000 square foot residential lot. A cistern having the dimensions of 15 feet by 20 feet by 6 feet of depth (the size of a large patio) would completely accommodate the maximum runoff possibility.

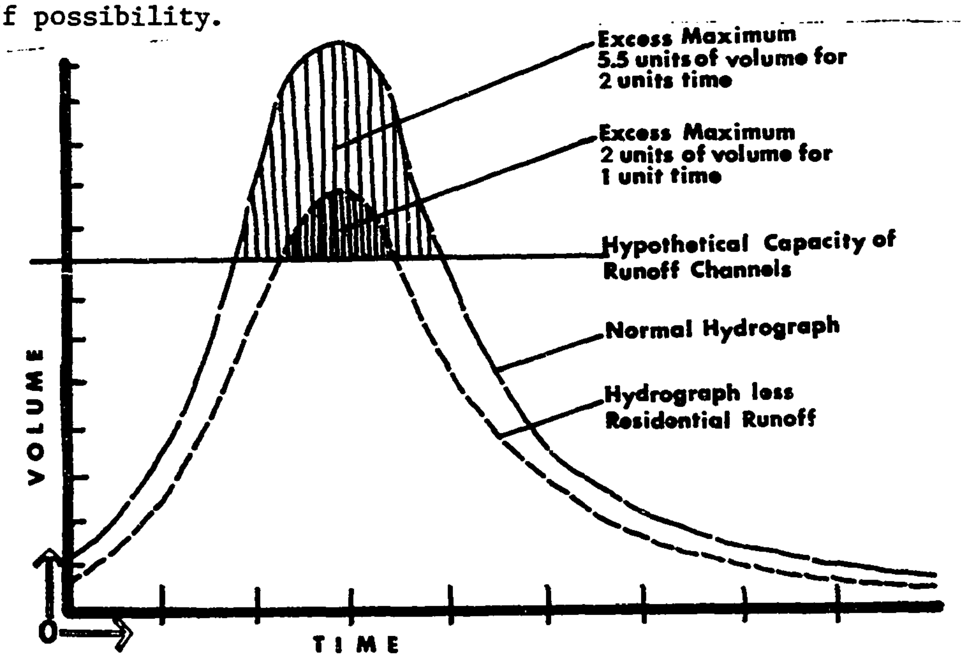

Fig. 4.17.--General Effect of Eliminating Residential Runoff From the Urban Runoff Hydrograph

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[39]The 100 year design storm used is a 6 hour, 6.2 inch storm for central Oklahaoma(see Figure A.1). The coefficient (C) of runoff is taken from Appendix B and is .59 (single family suburban). As an ideal situation the example is designed for 100% runoff detention.

If residential land constitutes 18% to 20% of the urban surface and each lot detained all of its runoff, the peak flow resulting from a storm could be reduced by up to 20%.[40] Figure 4.17 illustrates the depletion effect on an urban runoff hydrograph by elimination of residential discharge.[41] The costs of the cistern could be partly amortized over a long period in expenses recouped for lawn irrigation,etc. The expected increases in water cost in the future make the amortization more feasible.

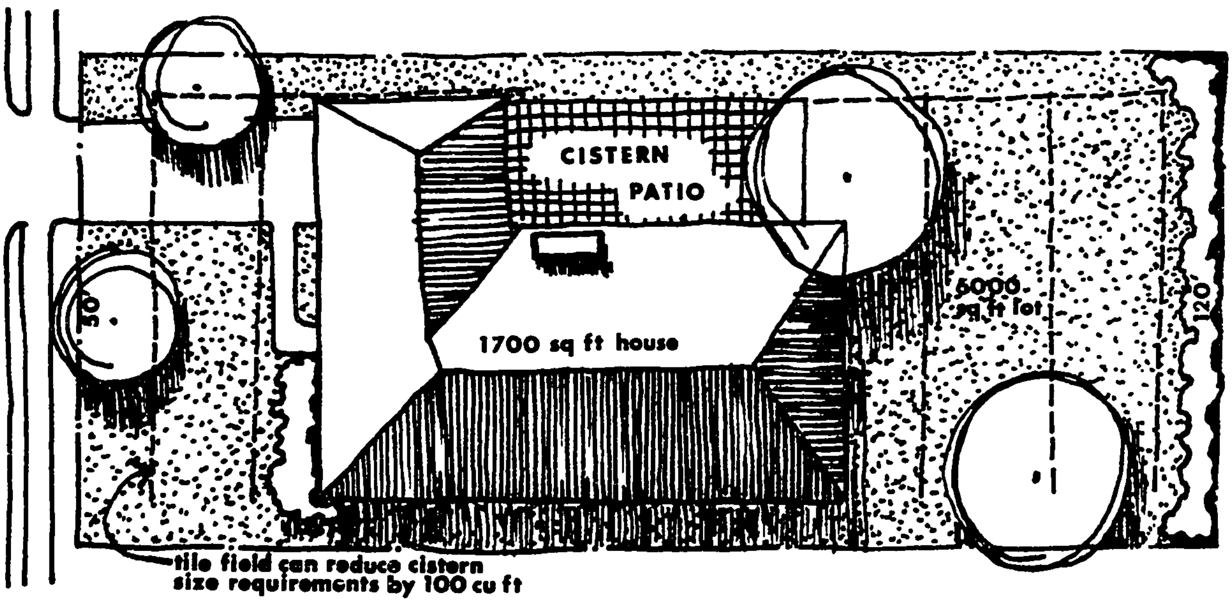

Fig. 4.18.--A Typical 6,000 Square Feet Residential Lot with a Stormwater Cistern

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[40]The 18% to 20% figure cited is taken from Marion Clawson, Suburban Land Conversion in the U.S. (Baltimore, Md.: The Johns Hopkins Press, 1971), p. 49. Note that this percentage drastically increases when discussing urbanizing watersheds which tend to be all streets and residences with some open space and commercial. The hydrograph (Fig. 4.17) also assumes that most of the precipitation from other land uses runs off. The unit of time measurement is taken from the base width of the curve at the capacity line. The unit of volume reading is a result of the total area under each curve.

[41]The Reid proposal (Demonstration and Evaluation of Stormwater Depletion Measures Applicable for Use on Residential Sites, an undated

There are a number of approaches to the subgrade vault (cistern). As a structure's basement there is a potential for reduced construction costs and a moderating influence in home heating and cooling loads. More common are the sand and gravel bottomed vaults and tile fields located at the low point in the lot.

Drawbacks include possible maintenance costs associated with the filling in of the vault with sediment. A well planted residential lot however should have little trouble with debris and silt. Another problem centers on the drainage of the vault. A detention system is ineffective if a storm passes over it before it has drained from the previous one. Infiltration may not be a reasonably rapid form of detention release. Tile fields and a drain to a lower area might make the drainage more predictable.

Land use implications are few. As shown in Figure 4.18 the cistern can be installed without effecting the size, layout, or use of the lot. There are however, some interesting implications when attempting to increase the feasibility of cistern use in residential land use.

The same residential lot is split into two 3000 square foot lots (Figure 4.19). Each has a house with the same interior space. The land use configuration is now multi-units detached (duplex) with a runoff coefficient of .73 (Appendix B). The resultant runoff for each residence

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research grant proposal, University of Oklahoma, Norman), used a lot similar to that shown in Figure 4.18. The design storm was a 24 hour six inch rainfall. Reid noted that the lot was 36.8% impervious and required 1442 cubic feet of storage. The shorter more intensive rainfall cited in the study would produce more runoff allowing the 1770 cubic feet figure to remain as a conservative figure for design purposes.

[42] If the back 30 feet of the lot were removed to common open space which is standard for multi-units, the resultant runoff might be computed as 750 square feet at .48 (open space) and 2250 sq.ft. at .73 or 1001 cu. ft.

is 1095 cubic feet.[42] This requires a cistern with the approximate dimensions of 12 feet by 15 feet by 6 feet (depth). Compared with the single family detached configuration, there is a per capita reduction in runoff of 38% even though the actual intensity of land use increases and develops higher runoff rates. Ultimately there exists the possibility of a 200 unit high rise condominium of a 2 acre lot with a parking garage. Using the "downtown" coefficient of .97 (Appendix B), the design storm runoff is 42,253 cubic feet. Regardless of the obvious increase in residential intensity, the per capita (unit) runoff

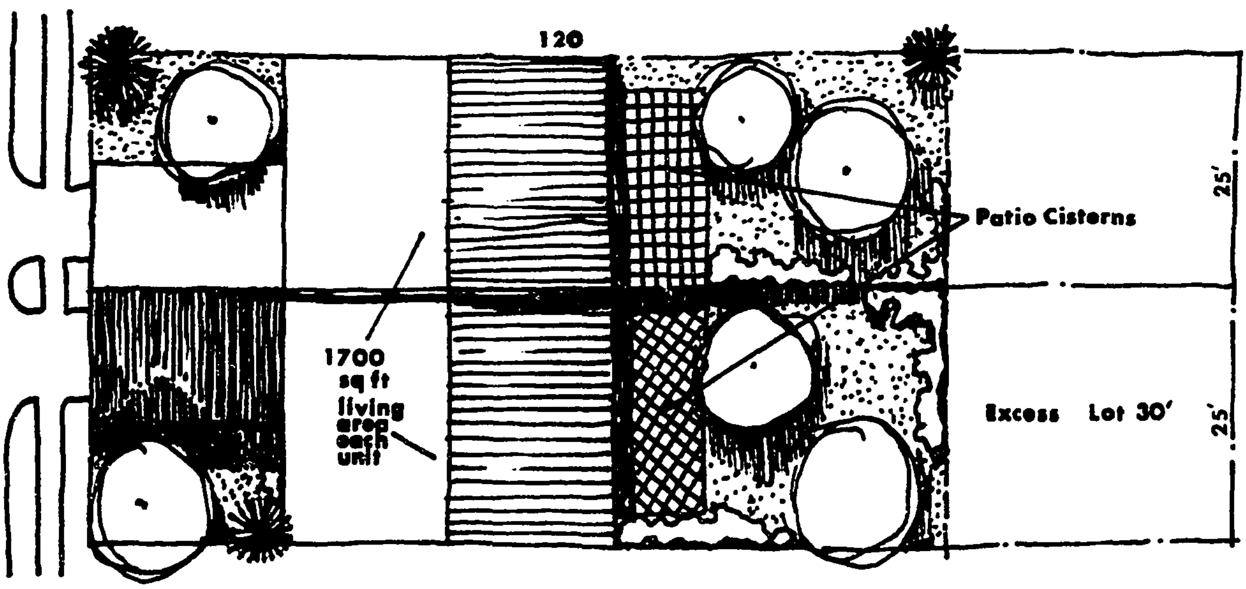

Fig. 4.19.--Rowhouse-Townhouse Lots with Stormwater Cisterns

[42] If the back 30 feet of the lot were removed to common open space which is standard for multi-units, the resultant runoffs might be computed as 750 square feet at .49 (open space) and 2250 sq. ft. at .73 or 1001 cu. ft.

rate is 211 cubic feet, a reduction of 88% compared to the single family unit.[43] Figure 4.20 illustrates the general relationships of residential configurations, detention costs and per capita (unit) runoff rates.

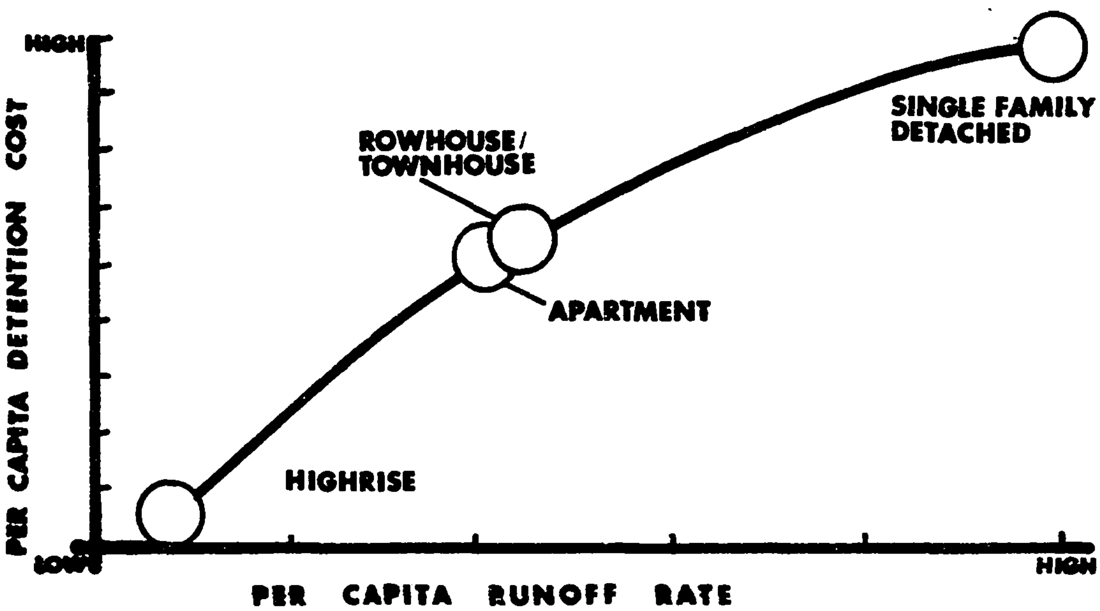

Fig. 4.20.—General Relationships: Residential Density, Detention Costs, and Per Capita Runoff Rates

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[43]As the required capacities of storage are reduced, the cost of the detention system per unit is reduced. The cost curve however will be more complex. Note also that this system of intensifying clusters and achieving detention efficiency breaks down when the spaces opened up by the clustering are developed with other clusters. The relationship is based on a fixed number of land use units in different configurations.

The result is that although higher density configurations generate higher percentages of runoff than low density ones, the net effect of a fixed number in a fixed space is a significant reduction of discharge. The clustered land use makes the installation of full detention cisterns more feasible. In effect, the cistern does not have direct land use impacts in terms of spatial displacement. It is the cost and effectiveness curve which tends to encourage the consolidation of land use into clusters and nodes.

Structural Surface Impoundments (B)

This detention technique recognizes that structures are inherently the most impermeable covers on the urban surface. Pavement can be made porous but structures must remain waterproof. The structure with its runoff rate approaching 100% is a major cause of the increased peak flows associated with urbanization. If the roofs are flattened (as is the case with most non-residential buildings) and their edges are extended upward to form small dams, precipitation is trapped rather than quickly drained. A 6 inch parapet could hold back the full 100 year, 6 hour storm.[44]

In fully developed suburban areas where residential land use makes up 75% to 85% of the land use, approximately 25% of the runoff

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[44]Unlike other forms of detention where runoff from adjacent areas can be channeled into a cistern or impoundment, the structural surface (rooftop) is realistically only appropriate for direct rainfall detention. Thus if the design storm precipitates 6 inches, the detention capacity of the roof needs to be 6 inches. The rate of release from the roof can either be computed as a percentage of the flow allowed to leave a certain area or no release at all until the end of the storm. If a 2 acre area is allowed to release 2 cu. ft. of flow per second (cusec) and the structure covers one of the acres, its share of the release rate is ½ or .1 cusec; this is discussed in more detail in the following chapter.

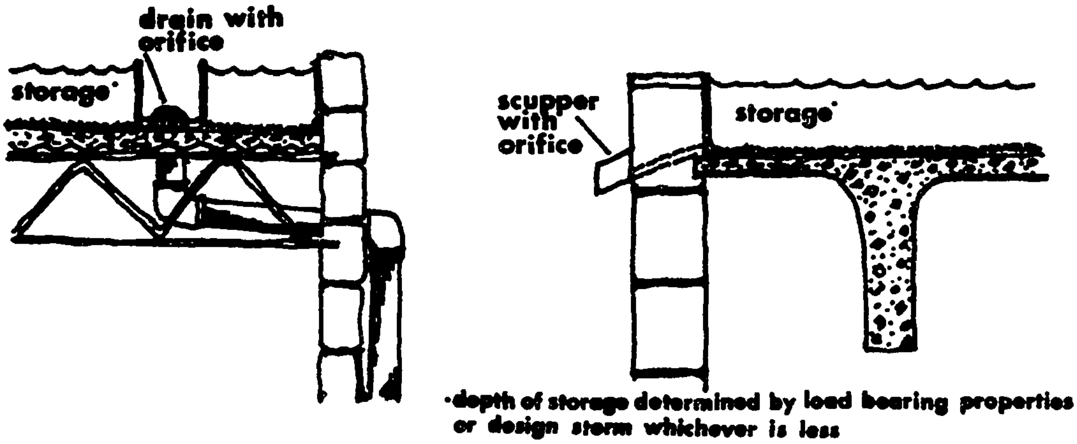

Fig. 4.21.--Structural Surface-Rooftop Detention

could be intercepted by rooftop impoundments.[45] The technique is much more applicable in central business districts such as the Denver Skyline Urban Renewal Project where structures cover 50% to 60% of the land.[46] Thus 50% to 60% of the runoff can be intercepted as well as 10% to 15% more in temporary plaza surface impoundments.

Roof top storage drawbacks include a revolutionizing of residential rooflines (from the peak and hip roof to flat) and plugged drains. Generally, building codes require adequate loadbearing for roof impoundments in most nonresidential structures.

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[45]This interception figure was computed by the author based on a 1700 square foot house on a 6000 square foot lot. An additional 1500 square feet (½ of the public right of way fronting the lot) is also included.

[46]Rooftop detention and some plaza impoundments are required in the Denver Skyline Project by the Urban Renewal Authority. Poertner, Practices in Detention of Urban Stormwater Runoff, Special Report No. 43, p. 91.

A unique asset of this technique is that non-residential rooftops are commonly flat and already equipped with facias or parapets which can be altered slightly to form dams. Most flat roofed structures also have roof drains and scuppers which can be modified to serve as release orifices.

The land use implications of structural surface impoundments are similar to those of the cistern. If the structure is the detaining mechanism, the higher the percentage of structural coverage the greater the potential detaining ability.[47] Another land use pattern is implied (not forced) when considering roof top storage efficiency. The runoff generator dealt with by this technique is the structural surface. The urbanization of a watershed involves the introduction of people and their structures. The amount of structural coverage per person becomes a critical factor to the generation of increased runoff.

An example takes a single family residential density of 11,500 people per square mile.[48] As a result roughly 23% of the area is under a roof.[49] By literally stacking the houses three high (maissonettes) the same number of people can live in the same space with only 8% structural coverage.

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[47]This holds true if the ancillary activities around the structures such as streets, parking, and sidewalks are not forced to increase as a result of increasing structural coverage. Note that rooftop storage efficiency does not force or strongly encourage a sprawling full coverage configuration. Reduction in coverage might make some other detention technique such as a catchment more feasible.

[48]Six units per acre x 3 people per unit x 640 acres = 11,520 people.

[49]3840 units per mile at 1700 square feet each covers 149.86 acres (23%).

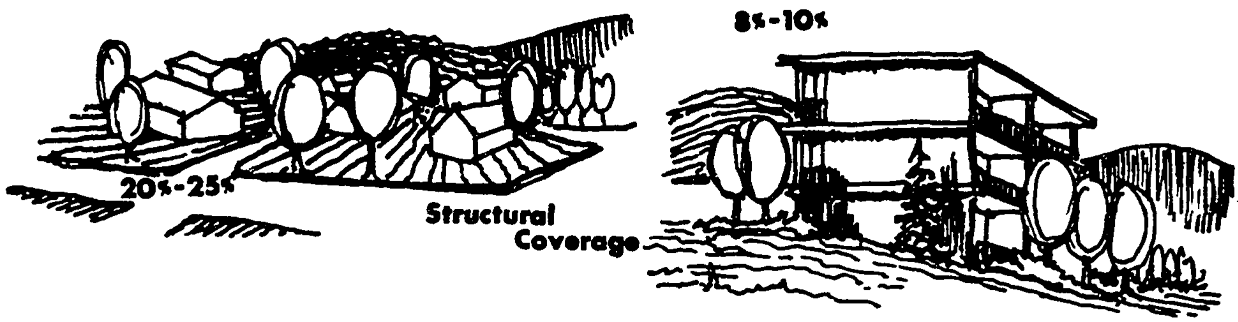

Fig. 4.22.--The Layering of Land Use and Subsequent Surface Coverage by Structure

In actual development situations such "stacking" and opening up of space is followed by pressure to fill up those spaces with more "stacks." An effective compromise in such a case is the allowance of a new three level "stack" for each existing three level "stack", the result is a doubling of population with an overall structural coverage reduction of 30% (to 70% of the one story single family detached coverage.)

Corbusier's megastructure and Soleri's archaeology are extreme futurist examples of "per capita roof" coverage efficiency.[50]

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[50]Additional information on the concept of archology can be gained in Paolo Soleri, Archology: The City in the Image of Man (Cambridge, Mass.: M.I.T. Press, 1964). Information on megastructure can be located in Robert Furneaux Jordan, LeCorbusier (New York: Lawrence Hill and Co., 1972).

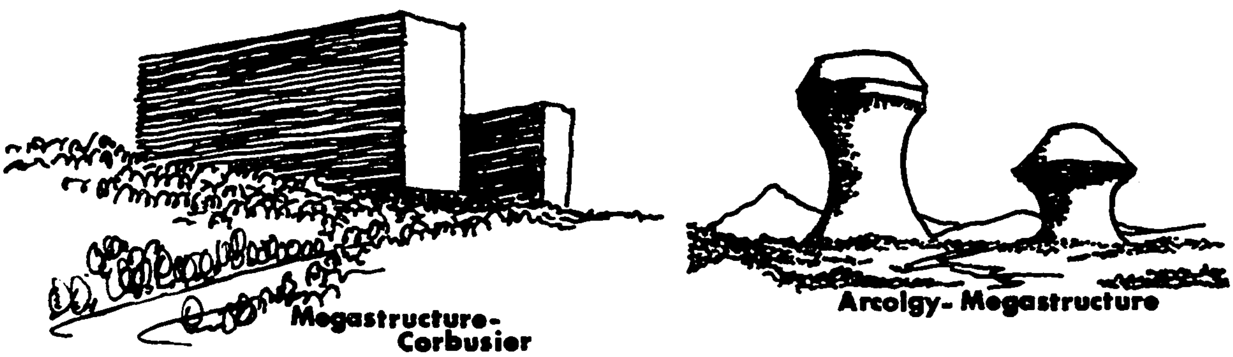

Fig. 4.23.--The Megastructure as a Per Capita Structural Coverage Efficiency

Lot Surface Impoundments (C)

This concept proposes that each site is responsible for the runoff generated by its surfaces and structures. Prior to leaving the site (lowest point), an impoundment is constructed to detain all runoff expected to result from the design storm. Larger and more complex sites

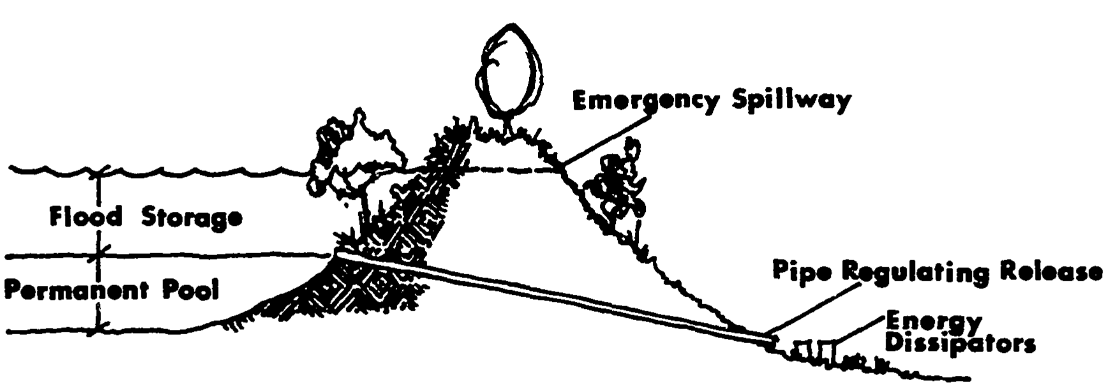

Fig. 4.24.--Wet Basin Detention

might utilize a series of impoundments on parking lots, plazas, and in open areas. The basic approach which applies to all flood control impoundments is to have an adequate storage capacity either on top of an existing water surface (wet basin) or in an otherwise dry basin. These approaches are often referred to as the blue-green concept.[51] Areas ordinarily open space (green) are temporarily inundated (blue) during storm periods and for a short period afterwards.

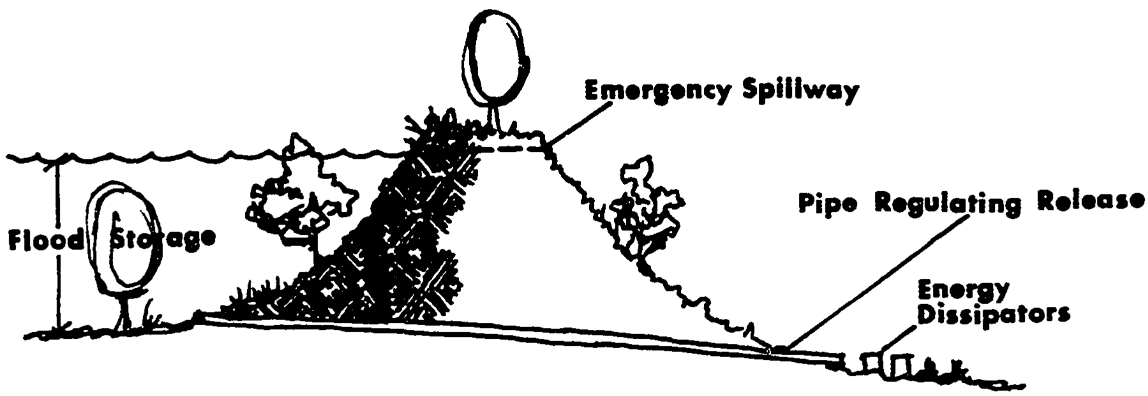

Fig. 4.25.--Dry Basin Detention

Examples of the detention capacities of various forms of site impoundments include:

1. A front yard impoundment on a 6000 square feet single family lot with a 50 feet frontage built to the simple specifications of Figure 4.26 will handle 100% runoff resulting from a 6 hour, 6 inch rainstorm.[52]

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[51] Jones, "Where is Urban Hydrology Practice Today?", p. 262.

[52] The design storm is based on Appendix A. The coefficient (C) of runoff for single family urban is .66 (Appendix B). The result and runoff is 1980 cubic feet. The yard storage volume (35 ft. x 25 ft. x 2.5 ft.) is 2187.5 cubic feet, less some capacity losses due to the containing edge.

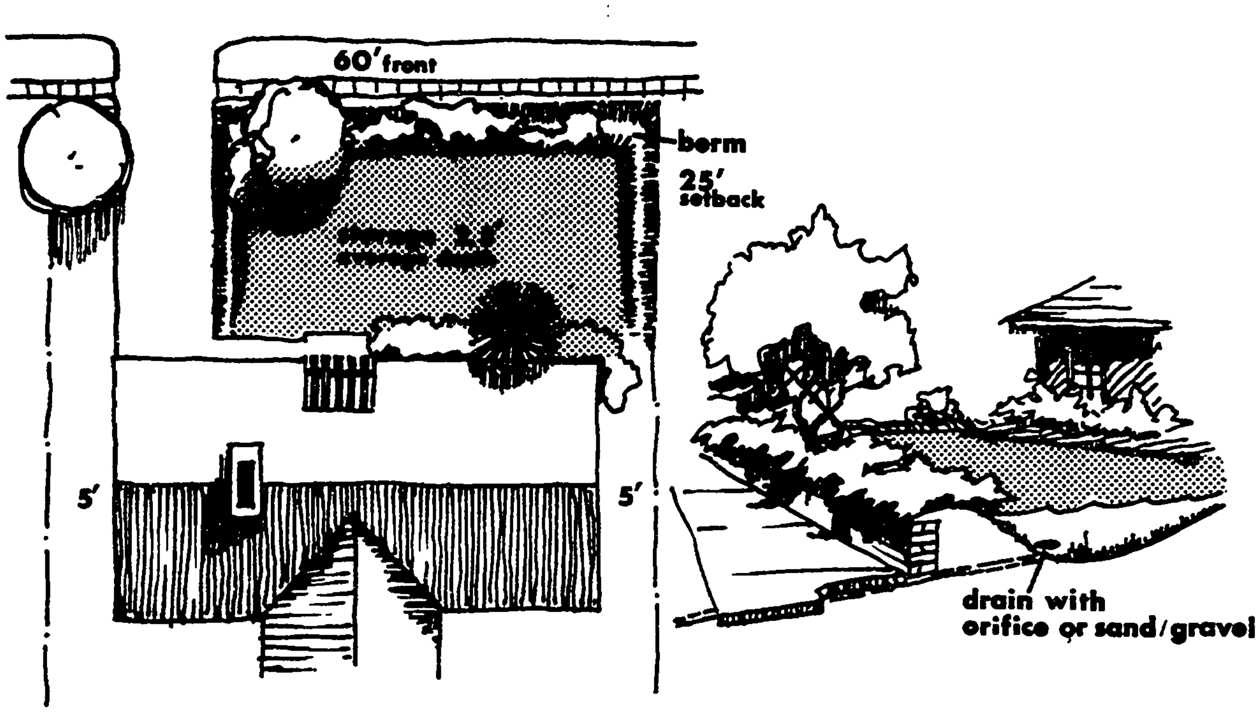

Fig. 4.26.--Lot Surface Impoundment-Residential Front yard

2. A sunken plaza (18 inches or sitting height below grade) can detain 100% of the runoff from an area three times its size for a 6 hour 100 year design storm (Appendix A). Places such as these are easily incorporated into site designs in large commercial centers and central business districts.

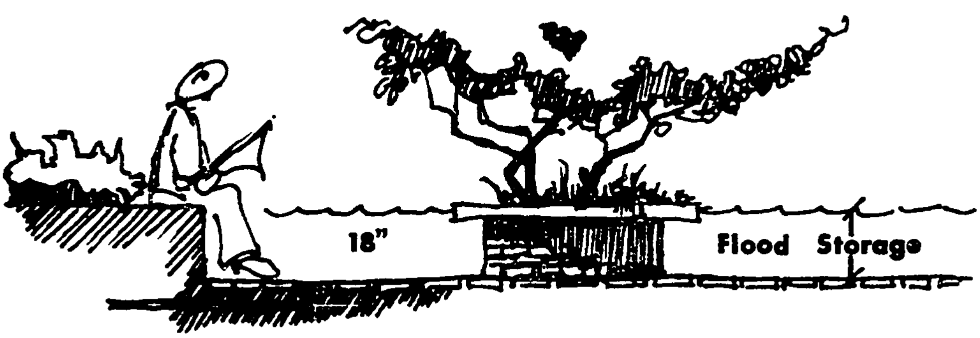

Fig. 4.27.--Public Plaza Impoundment

3. Two sunken tennis courts surrounded by 4 feet seating berms can detain 6 inch storm runoff from an apartment complex of 2.1 acres and housing 88 people.[53]

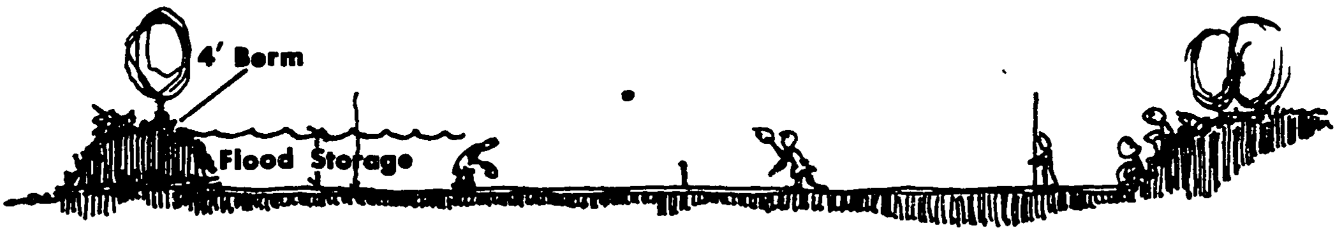

Fig. 4.28.--Multipurpose: Recreation-Temporary Impoundment

4. A sunken baseball field (8 feet) with bleachers built into the containing berms detains runoff from a 6 inch storm for a high density townhouse/condominium neighborhood of 60.6 acres housing 3270 people.[54]

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[53]A berm is a linear mound of earth which can serve as a dam. A dike is a very large scale berm while a cotton terrace is a smaller berm. The volume capacity of the two courts is based on standard measurements taken from Joseph DeChiara and Lee Koppelman, Planning Design Criteria (New York: Van Nostrand Reinhold Company, 1969), p. 215. 92 ft. x 98 ft. x 4 ft. = 36,064 cu. ft. storage. The coefficient of runoff (Appendix B) is .79 for apartments. Population is estimated at 14 units per acre and 3 people per unit.

[54]The baseball diamond dimensions (400 ft. x 400 ft.) are based on recreation standards in John Hancock Callender, ed., Time-Saver Standards (New York: McGraw-Hill Book Company, 1966), p. 1266. The highrise's downtown runoff coefficient of .97 (Appendix B) is used. The density is 18 units per acre and 3 persons per unit. The first known presentation of the concept was made in an article by John Rowley in the Chicago-Sun Times Sunday, February 27, 1966, p. 46 entitled "Park the Water - It's New Plan for Flood Control."

Drawbacks in the application of this technique include plugged release mechanisms, safety hazards for small children if not properly fenced and having steep sides, and stagnation if it is an unaerated wet basin with insufficient flow. In addition, the necessity of locating it at the site's lowpoint may reduce the potential flexibility of the site plan.

Assets include multipurpose economics, aesthetics, and a generally inexpensive way to manage runoff effectively. A related asset associated with any technique which attempts to localize control is that certain pollution problems can be abated. As sediment traps, suspended solids drop out closer to their point of origin. As a localized effort, types of pollution can be treated by effectively tailored methods before many different pollutants from different points consolidate necessitating general and perhaps less effective treatment.

The land use implication of lot surface impoundments depends on the type of impoundment. Catchments such as those in a residential yard presume an adequate amount of surface. Thus lawn ponding such as parking lots and plazas require changes only in the site engineering of existing patterns. Larger scale catchments such as the multipurpose tennis and baseball fields presume some consolidation of open space with the likelihood that the uses displaced cluster elsewhere on the tract. Without mechanical assistance or major landscape grading, the location of lot surface impoundments is fixed.

Mechanical Storage (D)

Despite the fact that this technique is suitable in scale and controllability for this study, it will not be used in any of the case studies or system examples for reasons of cost. The literature mentions skim plates, intake sluices, deep tunnels, and other obviously mechanical devices, but no specific discussion is made of mechanically removing and storing excess precipitation for runoff control purposes. Basically the runoff is redirected to a storage container where it can be released or used. Thus "unnatural" approach is likely to be prohibitively expensive. In addition, Tourbier and Westmacott note that if a subsequent flood occurs before the water in storage is released the device is useless in managing the second storm event.[55] The reuse storage risk increases with

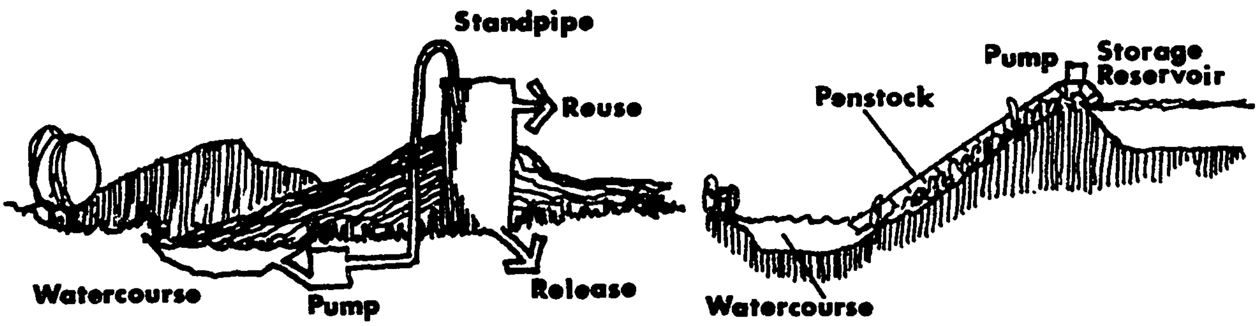

Fig. 4.29.--Mechanical Storage

the time of storage. In support of mechanical storage is the fact that its capacity and rates of release are the most controllable of the detention methods. Land use implications revolve around the method's cost. Either land costs are so high that the loss of any space for runoff management costs more than mechanical storage or that the runoff is a valuable enough resource to merit the assured collection. A probable reason for its use is the need to go into an intensively urbanized area

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[55]The failure to empty catchments quickly enough to manage subsequent runoff can also be used as a criticism of residential cisterns if they are not designed with the tile fields and drains. Joachim Tourbier and Richard Westmacott, Lakes and Ponds (Washington, D.C., The Urban Land Institute, 1976), p. 44.

where acquisition and demolition costs are prohibitive. As a result the technique will most likely be associated with high density development.

Small Cluster Ponding (E)

This technique is precisely the same as lot surface impoundments (C) discussed above with the exception of scale. The author treated this separately due to the nature of ownership patterns in developing watersheds. As the city expands, land ownership along the leading edge fragments due to speculation. As the parcels become smaller, impoundments which are constructed and controlled by a single developer become smaller. Small cluster impoundments require cooperative effort (perhaps guided by police power) of a group of land owners. The impoundments detain water from a larger runoff area and are necessarily larger. In this study runoff areas generally between 20 and 160 acres will be considered to fall into the cluster ponding scale.[56]

The land use indications are similar to those of site impoundments only at a larger scale where more clustering possibilities are feasible, assuming cooperation among owners. The only drawback is that the maintenance of such a facility would probably have to be a municipal responsibility because of the multiplicity of potential homeowner's associations. Damages resulting from the failure of these and larger impoundments become significant.

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[56]Cluster ponding refers to the clustering of tracts of different owners. There are two reasons for the 20 acre runoff area breaking point. First, a 15 to 20 acre tract is about the minimum size for designing any land use configuration which can apply clustering concepts which free up the space required for ponds. Second, in order to avoid stagnation without mechanical aeration some seepage or base flow is needed between storms. The U.S. Department of Agriculture states (in a isohyet map on page 47 of Lakes and Ponds published by the Urban Land Institute, 1976) that central Oklahoma requires a minimum of 20 acres to support 1 acre foot of storage in a man-made pond.

Neighborhood Level Catchments (F)

This technique constitutes the scale level just discussed. The neighborhood unit is a common planning module large enough to support an elementary school and generally small enough to facilitate walking.[57]

This level encompasses wet basins with permanent pools between 50 and 500 acre feet having additional flood storage capacities.[58] The ponds are similar in size and design to the larger rural catchments developed by the Soil Conservation Service. It is likely that runoff from outside a given neighborhood area will be involved. Ownership and operation by a public agency will probably be necessary. The potential change in flood pool elevation at this scale will also necessitate at least public flowage easements on the surrounding land.

This water based amenity along with the probable occurrence of a public park will encourage higher densities of residential land use or a more exclusive form of low density homes. If the park and impoundment fall near the outside edge of the neighborhood where transportation access increase value and visability, office parks and planned unit developments are likely. The central commercial-office-residence area of the Reston, Virginia newtown is an example.

Road Ditches or Swales (a)

In an effort to drain residential lots and to efficiently direct runoff to the nearest combined sewer or stream, street curbs became popular. As a result the old swales or roadside ditches which often

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[57]The neighborhood unit module in the U.S. west of Ohio is generally a square mile or section of land. The common definition can be found in Charles Abrams, The Language of Cities (New York: The Viking Press, 1971), p. 203.

[58]An impoundment of 50 acre feet averaging a 6 foot depth will displace 8.3 acres. A 500 acre feet catchment averaging 20 feet in depth will displace approximately 25 acres.

ponded during storms were eliminated. If a 50 foot lot (less than 10 foot driveway) were to front on a 2 foot deep and 6 foot wide grass swale, the detention capacity would be 480 cubic feet.[59] The driveway and an appropriately sized drain serve as the detention and release mechanism. Jones further states that minor streets do not require curbs for surface edge strength.[60] Curb costs are approximately $17,500 per mile (both sides of street). The money might be better spent acquiring 1 to 3 acres of impoundable recreation space.

As liabilities road swales are often criticized for being unsightly, difficult to maintain, and regularly stopped up nuisances. Swales might also make it more difficult to develop sidewalks and could require additional right of way.[61]

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[59] This would be 24% of the runoff based on 480 of 1980 cubic feet running off of a 6000 square feet lot (C of .66) during a 6 inch storm.

[60] Jones, "Where is Urban Hydrology Practice Today?", p. 260. The author was cautioned by J. Lee Rogers, a civil engineer (interview at the University of Oklahoma, Norman, July 12, 1977). Rogers took a dim view of the use of swales for the following reasons. First, the curb serves as a border which keeps traffic from running along the road shoulder and otherwise breaking off the paving edge. In addition, the curb provides surface structure support. Secondly, the swale has a history of clogging and requiring recurring cleaning costs. Third, swale reshaping and grass cutting is alleged to be costly. Fourth, turning off of the street and on to a driveway which is raised above a swale can be hazardous. Fifth, water allowed to flow off of the street and into ditches along it can cause moisture to accumulate in the street's sub base resulting in the heaving and cracking of the surface. Jones, (cited above) on the other hand, states that there is a definite minor street-residential area role for swales. The latter opinion can be expanded to include the reshaping of residential front yards so that impoundments are above grade (Fig. 4.26) or below grade by extending the swale into the yard. Most of the problems associated with present swales are attributable to their poor location and design.

[61] The Urban Land Institute, The American Society of Civil Engineers, and the National Association of Home Builders, Residential Stormwater Management (Washington, D.C. and New York: ULI, ASCE, NAHB, 1975) p. 37.

In its favor is the low cost ability to delay runoff by permeable grass lined channels. The capacity is also adequate enough to store the 100 year storm runoff from the streets and right of ways. This land use covers 16% to 20% of a city's surface.[62] Therefore the detention of runoff from right of ways can flatten the discharge hydrograph nearly as much as 100% detention from residential land use.

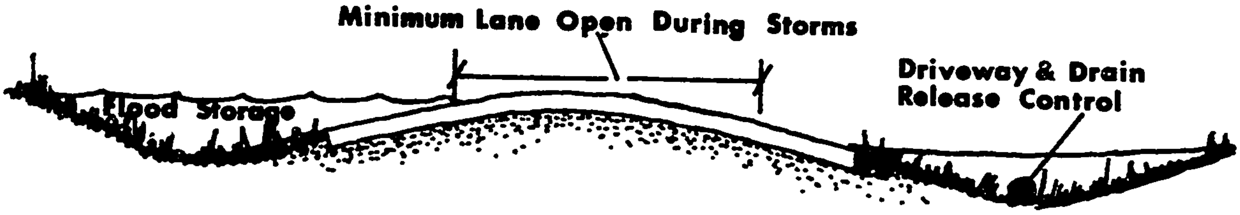

Fig. 4.30.--Minor Street Section With Stormwater Storage Swales

The street can also be inundated during peak storm periods to the extent that only a single emergency lane remains open. This would add a significant amount of detention volume to the swales.

The only land use implication of road ditches is the apparent requirement that the curbless road itself be subject to lower volumes of traffic. This can be associated with low density residential open space areas, and in some cases, institutional.[63]

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[62] The street runoff volume is based on a downtown C of .97, a section of 24 feet pavement on a 50 foot right of way. The swale measures 2 feet by 6 feet. The length of the street is 10 feet. The design storm is 6 inches in 6 hours. (Storage volume 240 cu.ft., runoff volume 242.5 cu.ft.)

[63] The author seriously questions the commonly cited attitude that curbless streets need to be reserved for low volume traffic loads. Interstate as well as state highways rarely have curbs with the exception of intersections and access ramps. If the point of volume can be argues, swale storage is limited only by topographical features (the inability to pond when the street goes up and down hills.)

Table 4.1

SUMMARY OF GENERAL LAND USE IMPLICATIONS OF DETENTION TECHNIQUES

	GENERAL LAND USE PATTERNS SUITABLE WHEN APPLYING THE TECHNIQUE TO EXISTING DEVELOPMENT	WHEN THE TECHNIQUE IS APPLIED PRIOR TO DEVELOPMENT		GENERAL COMPATIBILITIES	GENERAL INCOMPATIBILITIES
		ARE ANY SUBSEQUENT PATTERNS FORCED?	STRONGLY ENCOURAGED?		
SITE CISTERNS	None	No	No	Smaller single lots such residential	Becomes less feasible as tracts become larger and runoff coefficients increase
STRUCTURAL SURFACE IMPOUNDMENTS	Land uses associated with structures having flat roofs and proper loadbearing capacities - such as industrial, commercial, and institutional	No	Greater efficiency is achieved in land use patterns which involve maximum surface coverage by structure if structures detain 100% of the design storm - large commercial and office complexes - CBDs	-High intensity multi-family -CBD -Large commercial complexes - offices -Intensive institutional	-Open space -Agricultural -Low density-rural residential
LOT SURFACE IMPOUNDMENT	Low density patterns where uncovered lot surfaces are available - low density residential, campuses	Total coverage land uses are prohibited	Patterns must consolidate open surfaces to facilitate more efficient and effective impoundments	-Single family detached -Schools, churches, and hospitals with accompanying open spaces -Lower density forms of multifamily residential -PUDs	-CBDs -High density residential -Intensive commercial
MECHANICAL STORAGE	No, assumes existing high density land use or a severe water shortage	No	No	No	No
SMALL CLUSTER PONDING	Available open space	No	Tends to encourage clustering due to the loss of development space to impoundment	-Residential Subdivisions -Commercial and Office parks -Industrial parks	-Total lot/tract coverage land uses
NEIGHBORHOOD LEVEL CATCHMENTS	Generally assumes that there exists a large vacant lowland area	No	Clustering due to the loss of development space to impoundment and a tendency to intensify land usage in the cluster as a result of probable amenity associated with the open space	-Large PUDs -Public open space -Institutional	-Highly fragmented land ownership patterns -Total coverage development
ROADSIDE DITCHES OR SWALES	Curbless streets and sufficient right-of-way	No	Moderate to low intensity development	-Low density residential -Public open space -Small commercial/Office parks	-CBDs -High density/high traffic uses such as regional shopping centers

Figure 4.31 summarizes the detention techniques to be used and the author's estimate of land use patterns which might tend to associate with each.

Techniques for Releasing Flow from Detention

The purpose in runoff management is to keep the rate at which surface water accumulates and flows within predetermined and tolerable limits (volume and velocity). Therefore the accumulations are detained for calculated periods or what the Urban Land Institute calls "degrees of storage."[64] Permanent or long range storage has its risks.[65] This necessitates the release of detained runoff at rates great enough to achieve drainage in a reasonable amount of time and small enough not to exceed the volume velocity limits of the natural drainage network. The release can be mechanical, manual, or continuous.

Mechanical automatic merely implies that a system is designed to sense volumes, velocities, and times of flow and can automatically respond by closing off, opening up, or pumping out for tolerable release rates. The system is designed to make the management decision itself. A thermostat is the automatic equivalent in heating and cooling. The float in the watercloset is a more closely related example and is simpler.

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[64]The Urban Land Institute, The American Society of Civil Engineers, and the National Association of Homebuilders, <u>Residential Stormwater Management</u>, p. 32.

[65]If a detention device fails to drain before the next storm, the system may not be able to take on an adequate amount of new runoff. As a result, the system can overflow and cause flooding.

The manual release approach indicates that the opening up, adjusting, or shutting off is done by human decision and effort. A gate on a reservoir dam is raised slightly after the downstream reaches of a river subsides.[66] A homeowner removes the plug from the drain in his yard impoundment before going to work the morning after a big storm.

The set continuous release approaches are the principle methods used in this study. Stored volumes are released through medium whose design determines the maximum rate of flow. The minute discharge backs up in a detention facility it begins to pass out of it through percolation, an orifice, or a vertical opening (weir). Any combination or all of these techniques may be used.

Release through percolation (Fig. 4.32) means that the impounded runoff works its way into the watertable, shallow subsurface (interflow) or seeps through the impounding structure (filter berm). A cistern with a sand and gravel bottom and tile field is an example of release through percolation.

Drawbacks include a less than reliable rate of release because of the condition of the porous materials and antecedent moisture conditions. Acquifer recharging also induces a runoff quality and site specific investigation. Tile irrigation fields may require maintenance and certain soil conditions. Interflow might result in a re-release of water into

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[66] An excellent example of an instance of manual release decision-making took place at Lake Lugert in southwest, Oklahoma, after a series of heavy May rainstorms in 1977. The river below the dam was flooding and the lake level indicators showed that flows from above the dam were backing up to critical levels. The decision was made to open more of the gates and, in effect, increase the downstream flooding for fear of being faced with more severe alternatives later.

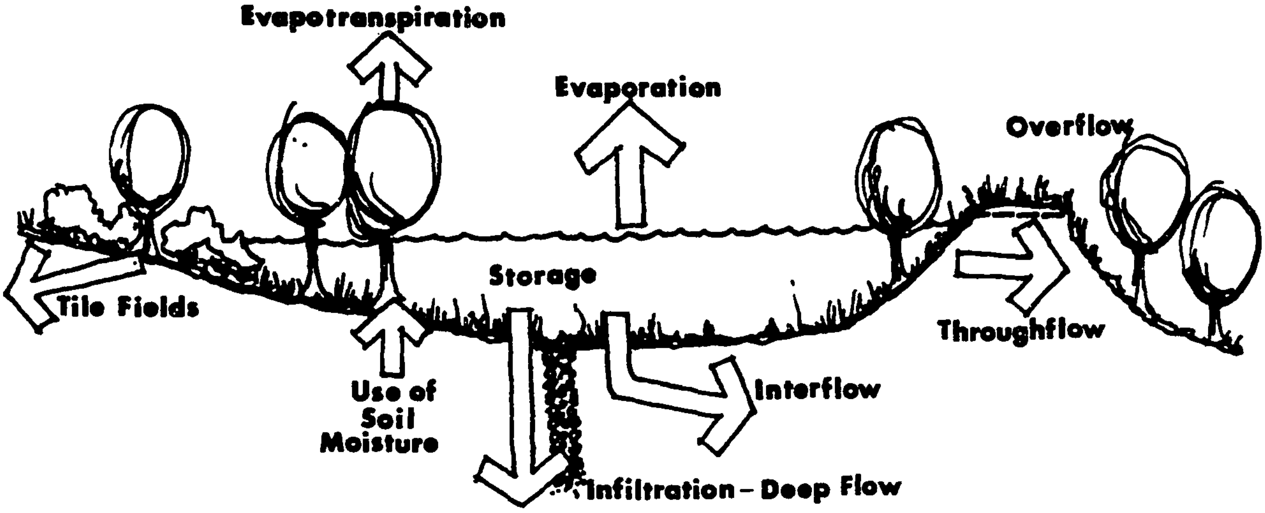

Fig. 4.31.--Detention Release Through Percolation-Infiltration

the inventory too quickly causing floods in lower stream reaches. Generally percolation will be found to be most effective when coupled with the orifice and vertical opening methods.

The orifice (opening) release technique is perhaps the most quantifiable and viable of the continuous release approaches. The designer simply determines the maximum rate of flow acceptable below the detention area and constructs an opening which allows that amount of water (or less) to pass through. The size of a roof drain, highway culvert, inlet pipe, or street storm drain determines the maximim rate of flow which can pass by their location. The orifice is an opening with a full perimeter.[67] The problem associated with them is that they are con-

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[67]The general equation for the discharge through an orifice or nozzle is $Q = C_d A \sqrt{2gh}$, where C_d is a discharge coefficient (which varies with relative size, shape of opening and Reynolds number), A is the cross sectional area at the smallest section, and H is the head, or vertical distance from the center of the orifice to the upstream freewater surface (Piezo-metric head), provided the height of the orifice is small compared to the head." Maurice L. Albertson and Daryl B. Simons, "Fluid Mechanics," in <u>Handbook of Applied Hydrology</u>, ed. by

sidered ideally sized when they allow all flows to pass through (maximum drain syndrome). "Inadequately" sized bridge culverts are called constrictions and are considered by engineers as being poorly designed.

Variable flows through an orifice do exist. For example, low flows may not even fill the cross section while higher elevations of backed up water build up a head which forces water through the maximum cross section at a high velocity. Engineers can calculate this maximum rate and consider it when selecting an orifice size. The vertical opening or weir technique is an orifice with the top section of its

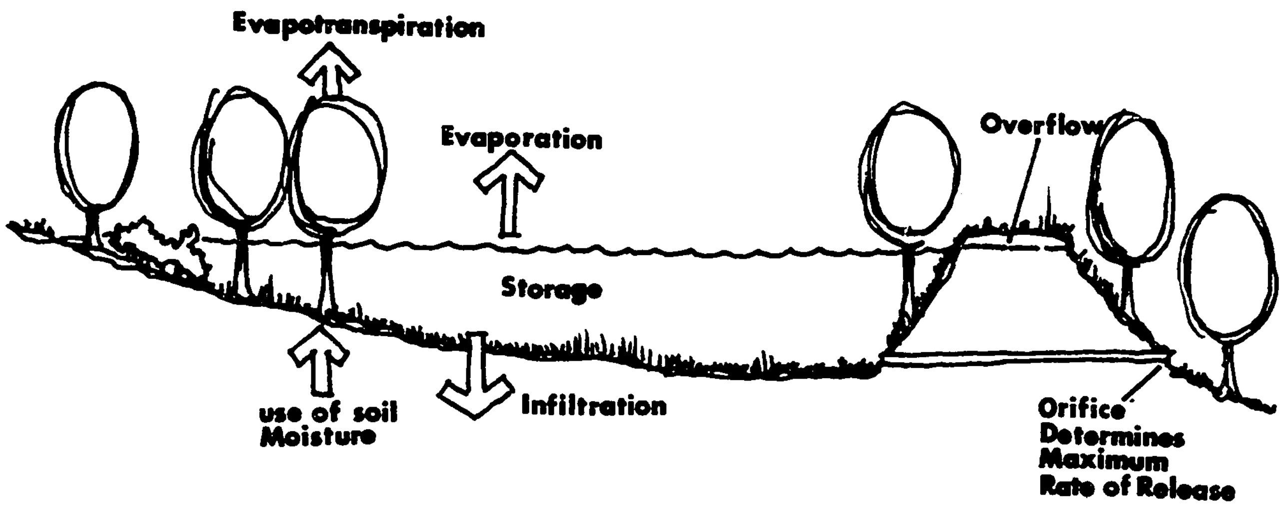


Fig. 4.32.--Detention Release Through an Orifice

perimeter removed: flow can continue to increase with the increase in elevation of the backed up flow. This increase is far greater than orifice flows associated with heads. The only release control is the width of the opening. The height is indefinite.[68]

Ven T. Chow (New York: McGraw-Hill Book Co., 1964), p. 7-45. The gravitational acceleration is 32 ft/sec.^{2} (g).

[68]The formulas for determining discharge through a vertical opening or weir are dependent upon the specific shape and other design properties of the structure. Further information can be found in Albertson and Simons, "Fluid Mechanics," p. 7-45.

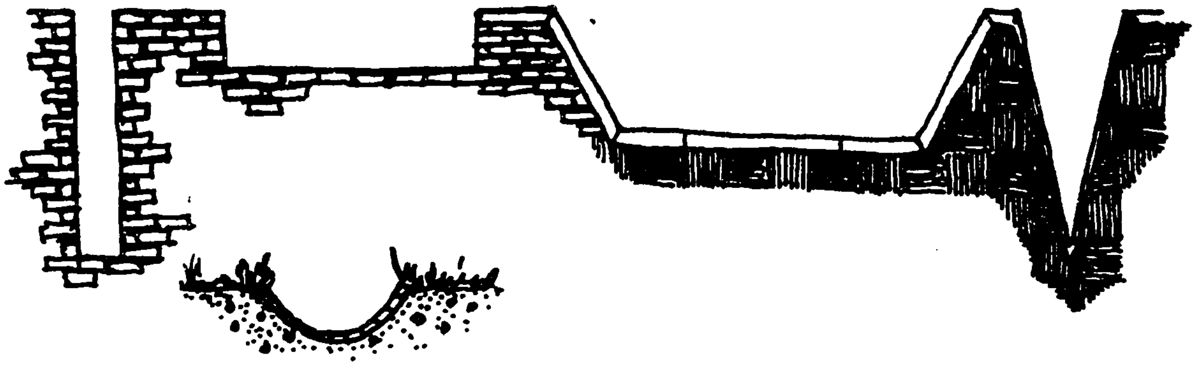


Fig. 4.33.--Example Forms of Vertical Openings

Computing the pattern of discharge accumulating in a detention facility and knowing the shape, depth and capacity of the impoundment can lead to a reasonably accurate knowledge of the pattern of outflow through the gap and into the downstream channel. As a result a gap

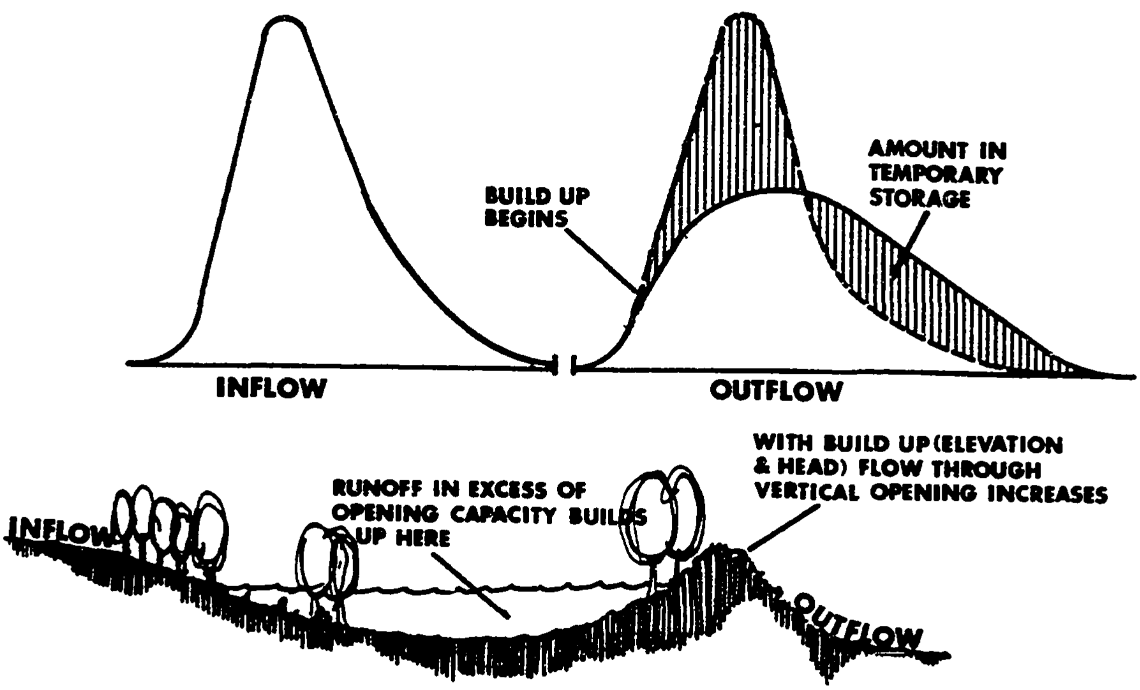


Fig. 4.34.--The Hydrograph as Modified by an Impoundment — With a Vertical Opening

or weir can be designed with a reasonable amount of accuracy. Generally a spillway or other form of vertical opening will appear as an emergency back up for a orifice in the event of overflow. The gap is more flexible than the orifice in coping with greater fluctuations in discharge and generally serves to flatten an incoming hydrograph by storage and modified outflow. Assuming that runoff has been successfully detained, the table below summarizes the methods for release and their performance characters. Note that any combination or groups of release techniques can be applied.

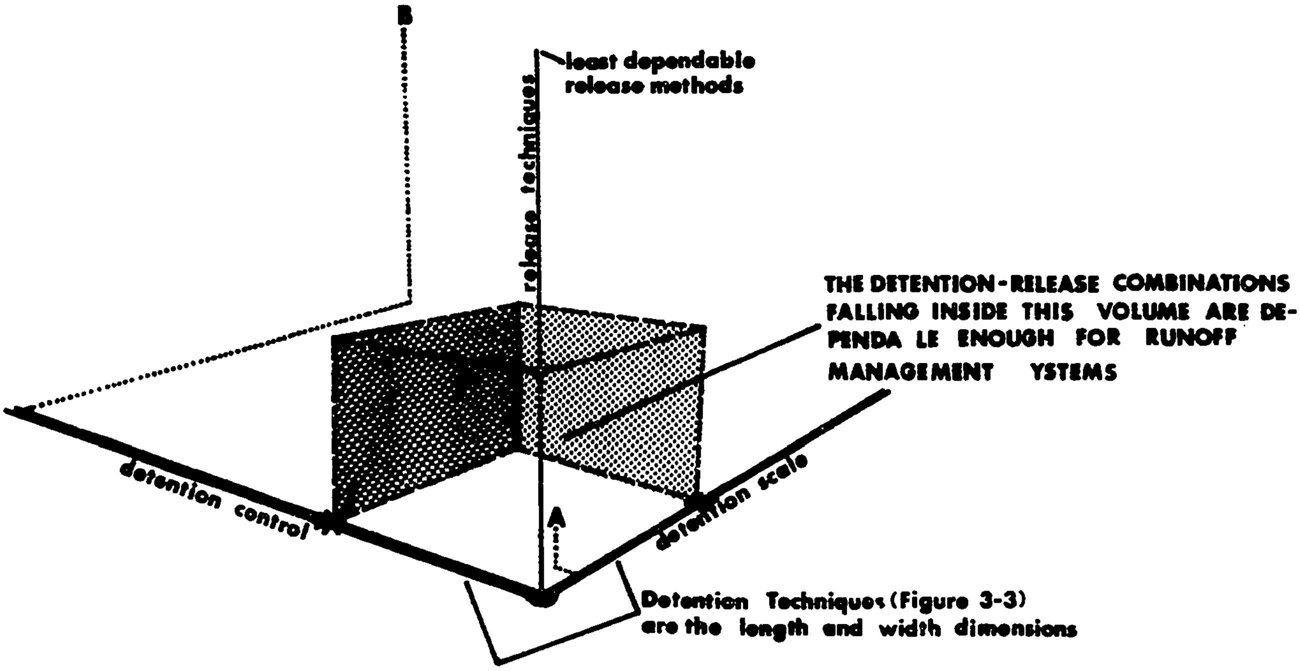
Table 4.2

Summary of Release Techniques

Detention Techniques	Release Techniques							
	evaporation	transpiration	use	mechanical	manual	continuous: infiltration	continuous: orifice	continuous: vertical opening
cisterns			●	○	●	●	●	
structural surfaces	●		●	○	●		●	○
lot surfaces	○	○	●		●	○	●	
mechanical			●	●	●		○	
small cluster ponding	○	○	●	○	○	○	●	○
neighborhood catchment	○	○	●	○	○	○	●	○
roadside ditches swales	○	○			●	○	●	

KEY: Good ● Fair ○ Poor (empty)

Before going on to the grouping of various detention techniques into runoff management systems, a matrix summarizing the compatibility of the release techniques with detention methods is developed (Fig. 4.37).



Source: The degrees (good, fair, poor) to which each detaining technique is capable of working with each release technique is based on a synthesis of the comments in the engineering and public works literatures.

Fig. 4.35 — Summary of Compatibilities Between Detention and Release Methods.

As in the previous continuums (area-size suitability and controlment), each release technique can be rated along a line of controlment. To place all detention release combinations in a summary perspecitve, the detention methods (Fig. 4.3) are used as the base of a three dimensional space. The release method continuum comprises the height (with the less controllable methods of release being furthermost from the base plane). The result is a layering of planes where most of the release techniques intersect with the detention techniques. (Fig. 4.35) At point A a very small scale highly predictable detention technique, such as mechanical storage, intersects with a very controllable release technique, such as a small orifice. At point B a very indefinite and large scale technique such as a channel and wetland storage is intersected by the unpredictable release technique transpiration. The shaded cube enclosed those combinations of acceptable detention scale and control (determined in Fig. 4.3) and acceptable release predictability (height limit).[69]

In runoff management systems, the idea is to group these acceptable combinations based on the capacity of the site and its use patterns. Release techniques from this point on are generally listed as a desirable rate of discharge rather than a specific method with dimensions. The release configuration most commonly assumed is a fixed orifice (continuous) and a backup emergency spillway.

Table 4.3

General Relationships Between Detention Techniques and Release Methods

TECHNIQUE	PREDICTABILITY OF RELEASE RATE	ABILITY TO MANAGE RUNOFF FROM STORMS WHICH FOLLOW SHORTLY THEREAFTER (3-7 DAYS)
1. EVAPORATION	Poor	Poor
2. TRANSPIRATION	Very Poor	Poor
3. STORAGE AND USE DEPLETION	Good (if rate of use is known)	Fair to Poor
4. MECHANICAL - AUTOMATIC	Excellent	Excellent
5. MANUAL	Excellent	Excellent
6. CONTINUOUS-SET		
A. PERCOLATION	Fair to Poor	Poor
B. ORIFICE	Excellent	Excellent
C. VERTICAL OPENING	Fair to Good	Excellent

Source: Author

[69] Extensive research on the shape of the three dimensional space within which the acceptable combinations fall can be done.

Hunch and gut reaction are apparent in these observations. These are appropriate benchmarks in a field where scrutiny of entrails for propitious omens frequently is more effective than the most careful search in academic publications.[1] Richard F. Babcock

CHAPTER FIVE

DETENTION SYSTEMS

Introduction

The preceding chapter introduced and discussed the possible land use implications of individual detention techniques. It is unlikely that a 10 square mile drainage area can effectively be managed either by a single detention facility or a single type of detention. Three good reasons are presented. First, to prevent damage due to poorly managed runoff throughout a watershed, detention must be localized. This implies that more than one device should be used since the watershed has more than one reach. One might call the second reason management ecology. If a system used many different techniques, failures which may occur as a result of a particular weakness of one technique will have less of a chance to cause the entire system to fail. Thirdly and perhaps most pragmatic, is the realization that many landowners, developers, and time frames are involved in urbanizing a watershed. Getting all of the people involved to cooperate on one device or even to agree on one technique is improbable. As a result of any of the above reasons there will tend to occur many different approaches to detention.

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[1] Richard F. Babcock, The Zoning Game (Madison, Wisconsin: University of Wisconsin Press, 1966), p. xiii.

What inherently causes these independent measures to tie together into a continuous system is the fact that water runs down hill - the natural drainage network.

Therefore, techniques previously introduced are placed in groups, series, or series of groups. This chapter will address the compatibility of various techniques, examine the ways in which certain groupings might require particular land use patterns, and demonstrate how example detention systems might work.

Technique Groups and Series

There are hundreds of possible combinations of even the limited number of techniques to be considered. Given the specifics of each site and the particular land use to be applied, certain methods will be significantly better suited. The question here is: are there any basic trends or rules of thumb for putting techniques together as systems?

Rules of thumb can logically be developed once the basic components of the detention system are understood. Figure 5.1 illustrates the detention process in a small drainage network. The system is similar to stream ordering with drainage of the first order (level) being the swales at the most local sites. Runoff accumulating at the first level is detained by a single technique or technique group (such as roof top storage and cisterns). These detention devices may not have the capacity to store all of the runoff or may not be situated so as to intercept all of the flow from the site. These excess flows and the flows resulting from designed release accumulate. It may be necessary to use a detention technique (or techniques) at the next level (II) to store these accumulations and prevent any overbank flow. The decision can also be made not to detain at level II and allow the various

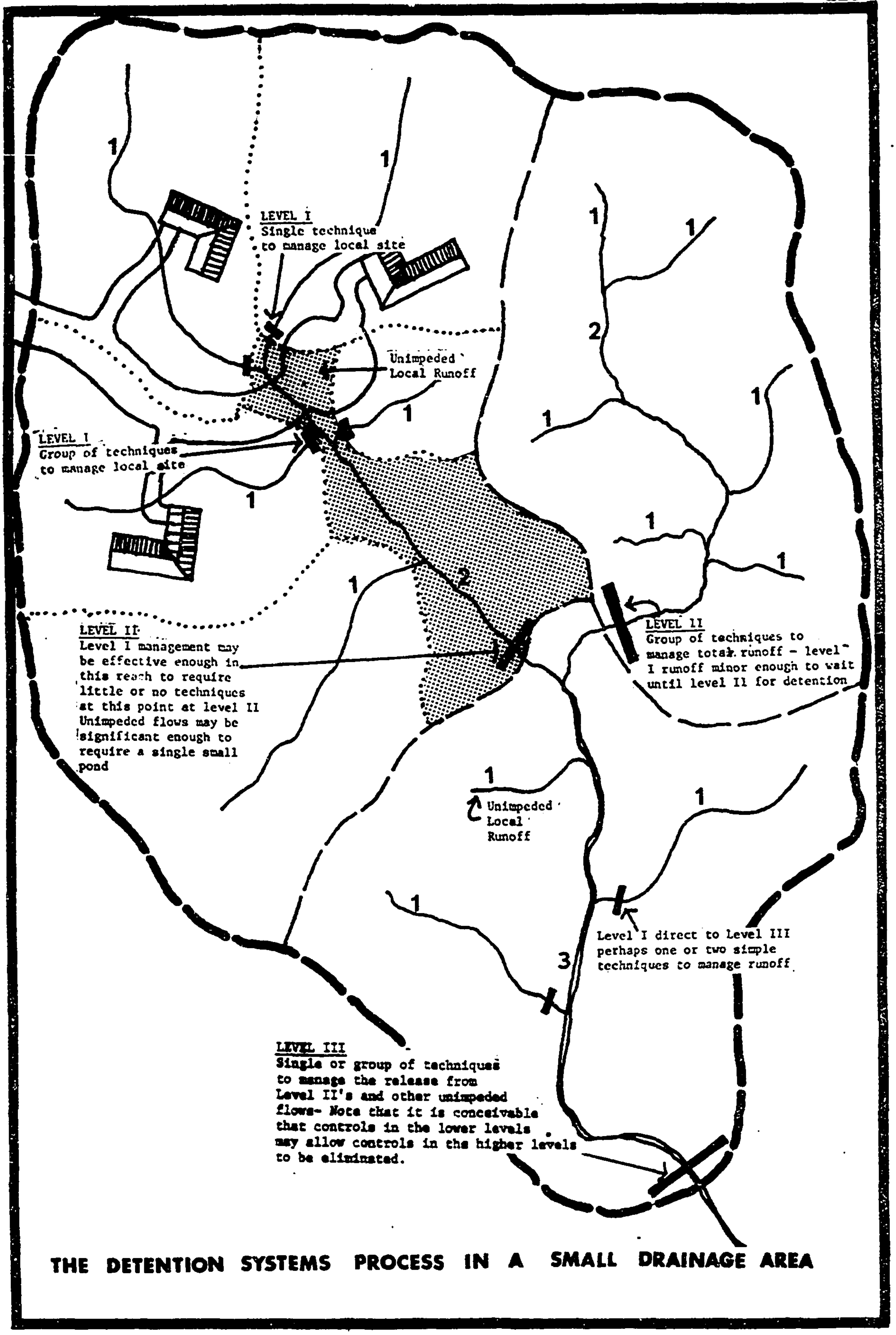
LEVEL I
Single technique to manage local site
Unimpeded Local Runoff
LEVEL I
Group of techniques to manage local site
LEVEL II
Level I management may be effective enough in this reach to require little or no techniques at this point at level II Unimpeded flows may be significant enough to require a single small pond
LEVEL II
Group of techniques to manage total runoff - level I runoff minor enough to wait until level II for detention
Unimpeded Local Runoff
Level I direct to Level III perhaps one or two simple techniques to manage runoff
LEVEL III
Single or group of techniques to manage the release from Level II's and other unimpeded flows- Note that it is conceivable that controls in the lower levels may allow controls in the higher levels to be eliminated.
THE DETENTION SYSTEMS PROCESS IN A SMALL DRAINAGE AREA

Figure 5.1

unimpeded flows and released flows to continue to level III where a larger storage facility or group of facilities is located and so on. It is quite conceivable that management at the most local level is so effective that detention at any of the higher levels will not be necessary. On the other hand local flows may be considered insignificant and allowed to run unimpeded to detention structures at level II or III.

Two things become evident in these management schemes. First, at any one level a single technique or group of techniques can be applied. Secondly, as runoff passes through the various levels (controlled or unimpeded) there results a series of technique applications. The series can be one of single techniques, technique groups, or a mixture of the two. The rules of thumb which were developed are contingent on this groups and series concept.

At the group level the study attempts to place all of the techniques to be considered along two sides of a matrix (Figure 5.2). At the point where two techniques intersect, the question is posed: can these two methods work together? Mutually reinforcing or compatible pairs are

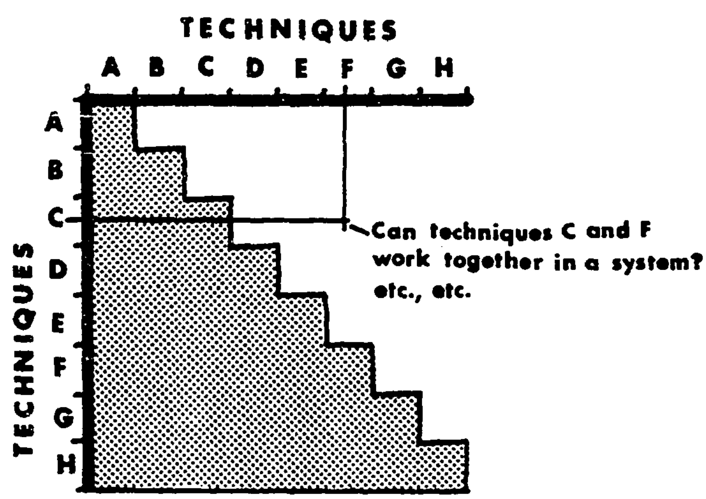

Fig. 5.2.--Compatible Pairs of Techniques Matrix

then placed in a similar matrix to determine the compatibility of pairs and so on. Pairs are considered to be compatible if under generalized detention circumstances they are not seen to come into conflict with one another.[2] It is found that none of the techniques necessarily conflicted with any of the other techniques when paired. Conceivably a major catchment and a small cistern could be paired and considered to be mutually reinforcing as detention devices. It is further assumed that if no techniques necessarily clashed, when properly applied, pairs of techniques would fit equally as well with other pairs. The resultant rule of thumb with regard to groups is that any combination of detention techniques may be applied at a given level.

The only potential area of conflict or inefficiency involves the consideration of techniques in series. Techniques in any combination can be applied to a given level. Does the next higher level make its technique selection as a response to certain constraints or commitments made by the grouping of detention methods in the preceding the level? Although it cannot be mathematically proven, there does appear to be a distinct effect of lower level selections on higher level groups. For example, if the most local level decided to manage its runoff by detention behind one large dam, the next level would be committed to managing the runoff released from the upper impoundment as well as that from other contributing upper impoundments and unimpeded flows. Logically this would require detention methods which could handle larger amounts of water from a greater runoff area.

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[2]Improper design such as oversizing can cause unnecessary overlapping with any set or group of techniques. Conflicts are noted only when properly designed results overlap or cause a competitive or mutually exclusive situation.

1 TECHNIQUES CONSIDERED FOR USE IN THE STUDY

- (A) Site Cisterna
- (B) Structural Surface Impoundments
- (C) Lot Surface Impoundments
- (D) Mechanical Storage
- (E) Small Cluster Ponding
- (F) Neighborhood Level Catchments (S.C.S.)
- (G) Roadside Ditches/Swales

2 TECHNIQUES NOT CONSIDERED DUE TO THE DIFFICULTY IN CONTROLLING THEM

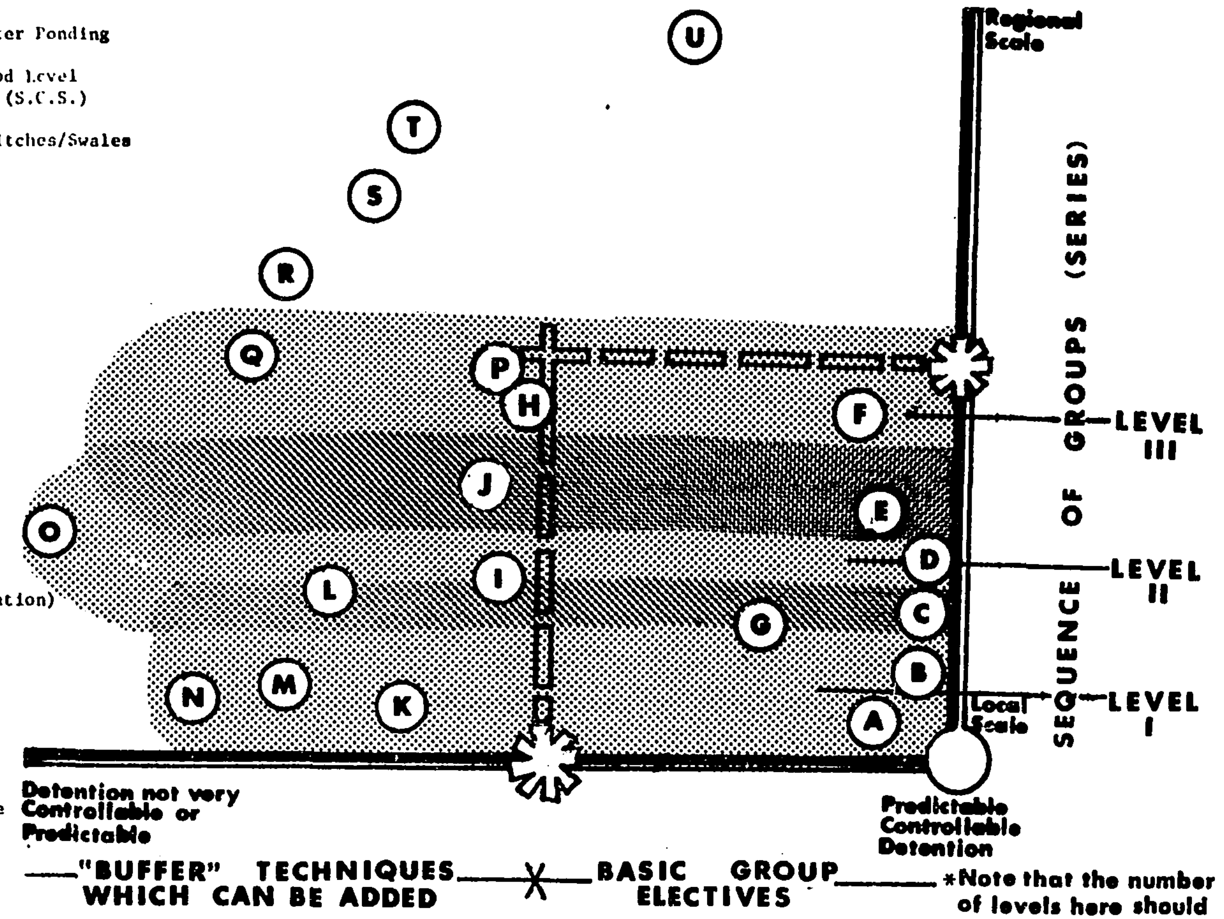
- (H) Check Dams
- (I) Infiltration Trenches
- (J) Tunnel/Deep Well Storage
- (K) Contour Scarification, Aeration, Etc.
- (L) Site Grading/Terracing
- (M) Filter Berms
- (N) Porous Pavements
- (O) Vegetation (interception-evapotranspiration)

3 TECHNIQUES NOT CONSIDERED DUE TO THE DIFFICULTY IN CONTROLLING THEM AND THEIR UNSUITABLE AREA SIZE

- (P) Channel Flow Regulation
- (Q) Real Time Routing
- (R) Low Maintenance Channel/Wetland Storage
- (S) River Diversion/"Skim Board"
- (T) Channel Impoundment

4 TECHNIQUES NOT CONSIDERED DUE TO THEIR UNSUITABLE AREA SIZE

- (U) Lakes and Reservoirs



DETENTION TECHNIQUES: GROUPS & SERIES

Figure 5.3

Small site impoundments and cisterns would be impractical even though the system could be made to work if there were enough of them. Even though there appears to be no limiting factors on grouping methods, the series or sequence of methods concept tend to limit selection. The resultant rule of thumb for a detention series is that techniques suitable for larger runoff areas should be used below (downstream) from techniques already applied. This coincides with the scale suitability continuum shown in Figure 4.3 of the preceeding chapter.[3] If the sequence of techniques is effected by this series consideration, the groups of techniques to be applied are limited. Figure 4.3 is shown modified again to illustrate the relationship between detention groups and series.

As an example, the third order drainage basin sketched in Figure 5.1 is utilized. The techniques which are available for first level usage fall in the lowest area of the figure. Normally, given the grouping rule of thumb, any method in the figure could be used or combined for use. However, since the series or sequence of levels must be considered, some larger scale methods need to be reserved for application in the next two levels. Therefore the direction to go when seeking methods is in the horizontal or left toward techniques suitable to the same scale but varying in controllability. The next level

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[3] Sequences moving toward larger facilities are not, however, the same as runoff area size suitability. Elements at higher levels (further down in the sequence) can actually involve smaller runoff area sizes if the methods in the lower levels are effectively managing their respective runoffs. The higher level devices may be detaining minimal amounts of release and a few areas of unimpeded flows. Larger scale detention methods are more appropriate at higher levels in the system because larger release rates are naturally associated with larger catchments.

applies methods from the next area (upward) and combines those methods with others to the left or right of them. The overlap in the example illustrates that techniques can be used in consecutive levels of management.

To carry the situation a step further, the developer can select cisterns, roof top storage, site impoundments and roadside swales to meet the runoff management criteria for his area along the uppermost reaches of the watershed (level I). The margin of safety can be expanded (through incentives perhaps) by incorporating less predictable techniques such as contour scarification, filter berms, and porous pavement. Management along channels which drain a level II area can use large site impoundments, mechanical storage (rarely), roadside swales, and small ponds. Terracing and vegetation can be added for extra measure. At the third level large ponds can be used as the basic method with check dams and channel flow regulators serving as a buffer. An acceptable level of management at all three levels needs to be accomplished using the predictable techniques.

Associated Land Use Patterns

The land use pattern, if effected at all, will depend upon the configuration of each arrangement system which is designed. On the other hand the management system is going to be designed in part as a result of the discharges associated with land use patterns.

Take a small urbanizing watershed and plan an effective detention system which releases runoff at a rate not to exceed the downstream channel capacity for all rainfall events up to and including the 100 year storm. Although the desire is to guide all development toward a comprehensive whole, it must be assumed that private enterprise is going to respond to the opportunity as it has done before. It will attempt to maximize profit on its investment and it will probably rely strongly on past patterns and proven experience. This time, however, it is setting itself up around a required detention system rather than simply engineering itself to drain. What will be some of the major influences on development decisions?[4] One of the problems in doing research in the detention systems area is that there are no existing urban watershed networks to examine in order to determine what land uses are in fact associated with which techniques. The developing detention facilities (not systems) of Chicago and Denver were either isolated structures in new development parcels or were added after development had established itself.[5] The amenity and detention systems in places such as Reston, Virginia; Earth City, Missouri; and other new towns were designed in conjunction with a comprehensively controlled de-

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[4]Richard T. Ely and George S. Wehrwein, Land Economics (Madison, Wisconsin: University of Wisconsin Press, 1964), p. 112. They note that economic pressure or profit is not the only guiding factor helping the land owner to decide what to do with his land. Institutional factors, customs, and sentiment can be just as influential. This study assumes that customs (past patterns) and economics (costs and returns) are the prime movers. The subbasin detention performance requirement should also serve as a principal institutional factor while sentiment (or idiosyncrasy) will always be an unknown variable predictable only by probability. Land Economics also points toward taxation policy, police power, and eminent domain as institutional motivators. This paper proposes to plan and design a system which encourages the desired decisions. This leaves the institution as a last ditch measure to nudge their responsive developer into his niche.

[5]Chicago and Denver were discussed during a presentation by Herbert G. Poertner, engineering consultant for the City of Chicago, during a Flood Plain Symposium at the University of Tulsa. The conference was cosponsored by the Tulsa District Corps of Engineers and the University of Tulsa (October, 1976).

velopment pattern.[6] Addressed here is the more common sequence of development. The land in watersheds on the leading edge of urban development is bought, subdivided, and sold by many different entrepreneurs. The general plan, if there is one, is most likely outdated and easily changed or ignored by the developers, financial institutions, and ultimately the public decision makers. The forces which provide the guidance are economic and physiographic.

Economic Influences

Although very complex and subject to debate, economics is a major factor in determining what a parcel of land will be used for. Only a couple of economic factors are seen to uniquely effect an area where a detention network is proposed, however. First Ely and Wehrwein and others note that as land rents or values increase the intensity of the land use also tends to increase.[7] If the detention system

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[6] Information on Earth City, Missouri can be found in Poertner, Practices in Detention of Urban Stormwater Runoff, p. 74. General new town plans are found in The American Institute of Architects, New Towns in America (New York: John Wiley and Sons, 1970). It should be noted that in the case of the comprehensively planned new towns the use of impounded water and greenway networks which follow the drainage patterns is universally employed. Drainage and flowage easements are commonly mentioned. Detention (dry impoundments, and cisterns) are rarely mentioned as being included along the greenways. Note also that Earth City is being developed on the 100 year floodplain of the Missouri River. Therefore, location is subject to legal question.

[7] Ely and Wehrein, Land Economics , p. 128-129. See also Marion Clawson, Suburban Land Conversion in the U.S. (Baltimore: Johns Hopkins Press, 1971). Particularly pertinent is the chapter entitled "Externalities and Interdependencies in Urban Land Uses and Values," p. 166-190. Note also that intensity of land use may refer to an increase in the density of a particular use or the change to a more intense form of use. An example of an intensity change within one use is to go from single family detached to multifamily residential. Intensity change by change of use is demonstrated by going from agricultural to commercial.

utilizes surface space such as for catchment and open channels, such space is eliminated from further development. The subsurface storm drains and narrow concrete ditches commonly used absorb less space.[8]

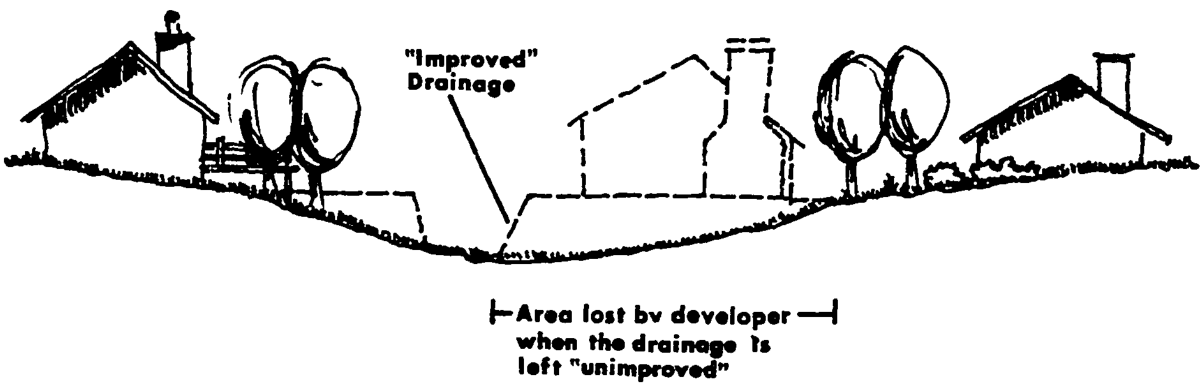

Fig. 5.4.--Loss of Development Space in Unaltered Drainage Channels

To demonstrate this, a developer purchases 20 acres of land for a housing complex for $100,000. He finds that 5 of the acres will have to be set aside for temporary stormwater impoundments. The cost of his developable land increases by 25% to $6,667 per acre. That increase in cost may be sufficient to cause him to decide in favor of townhouse condominiums at 14 units per acre over duplexes at 8 units per acre.

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[8]Argument can be made, however, that the detention space is not lost. Instead it is localized in multiple use open space. The value of lost land might also be recovered by the amount saved in surface detention costs when compared to channel improvements and storm drains. The concept of allowing a certain number of development units per acre which facilitates compact clusters outside of the "lost" detention space (density zoning, transfer of development rights, and cluster zoning) is another offsetting argument to be posed later.

The land use has changed to a more intensive form of residential with a gross density increase from 8 to 10.5 units per acre. There are many other effecting economic phenomena such as economic rent and amenity which cause land value to increase but displacement (reduction in supply) is potentially more attributable to the surface detention and runoff systems advocated in this paper.

At the most local sites in the upper reaches of the drainage area residential units might manage most of their runoff by yard catchments and cisterns. The loss of developable space here is minimal. Further down the drainage system where accumulations are potentially greater, more land may be lost to natural channel cross section and impoundments.

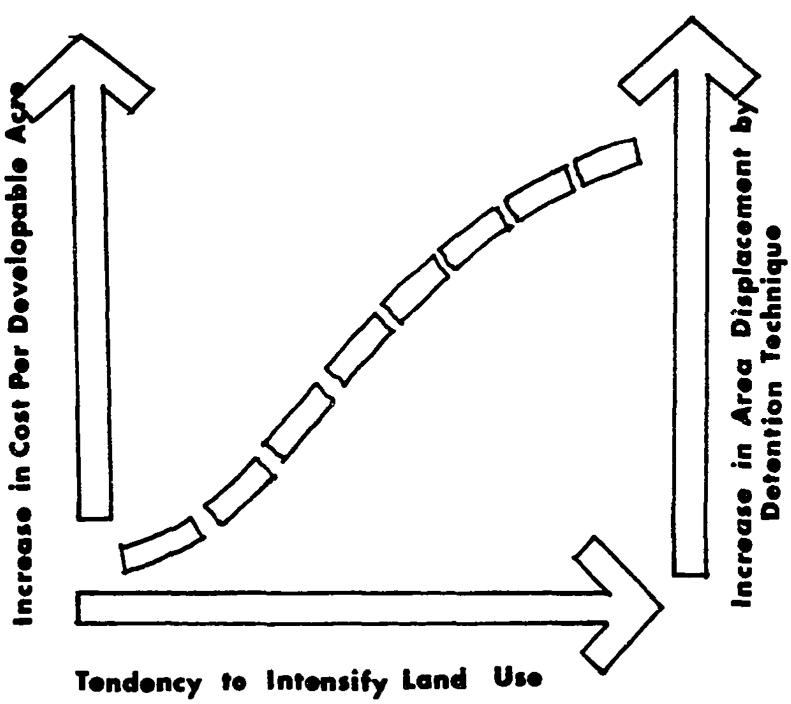

Fig. 5.5.--General Relationship: Loss of Land to Detention Techniques and Tendency to Increase Land Use Intensity

This can cause an increase in land use intensity. The general relationship derived from the above observations is shown in Figure 5.5.[9]

The second economic factor is related to the production cost of preparing the land for a certain development.[10] As detention construction costs go up, the pressure to intensify land use increases. This may take place even though the more intensive land uses produce more runoff and subsequently require larger detention systems.[11]

At the local residential scale, a system of site cisterns ($800 to $1000 per unit) backed up by a subdivision detention pond ($50 to $100 per unit) will cause a price increase of less than 2.5% per home.[12]

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[9]The actual computed relationship would merit an extensive research project in itself. It would also involve researching a phenomenon which exists only in a few isolated situations (not anywhere as a system).

[10]Ely and Wehrwein in Land Economics, p. 43, refer to production costs in light of agricultural land use. The capital and labor a farmer puts into his land should be less than what is anticipated as being paid for his crops if profit is to be made. The same principle applies to the developer (excluding intentional tax shelter losses). The cost of constructing a runoff management system constitutes a production cost.

[11]During storms of greater magnitudes (such as the 100 year event which is the study's design storm) the differences in runoff coefficients for different land uses tends to diminish while the potential difference for economic returns remains constant. This is why intensity increases in land use can take place despite runoff increases.

[12]The 1977 unit cistern prices are based on estimates used in Professor George Reid's unpublished undated research proposal "Demonstration and Evaluation of Stormwater Depletion Measures Applicable for Use on Residential Sites" (College of Engineering, University of Oklahoma) and his related notes and sketches. Prices were also obtained by the author in conversations with construction contractors in central Oklahoma. Small earthen dam impoundments with concrete spillways are estimated by the S.C.S. agents in Cleveland County, Oklahoma, with a rule of thumb relationship of $1.75 per cubic yard of earth moved for the dam (telephone interview). The 2.5% cost increase is based on a $1100 added to the price of a $40,000 to $45,000 home.

Such an increase can easily be built into the mortgage schedule of the home when purchased.

There is an interesting production cost pattern associated with various land uses when considering detention. As land use patterns become more intensive, larger and more expensive detention measures are required. As assumed before, however, the expensive rooftop catchments and large underground cisterns associated with a regional shopping center are surpassed by the increased potential for profit associated with the full coverage of the location. As land becomes so valuable that the feasible intensity facilitates multilevel parking and highrise construction, something unique happens to runoff detention costs. The stacking up of land use (as opposed to the spreading out and filling in) becomes the reflection of intensity change. In such instances the per capita land use unit cost for detention is reduced because vertical intensity does not increase runoff which is a horizontal coverage function. The general relationship of detention systems cost associated with land use is shown in Figure 5.6.[13]

Physiographic Influences

The use of land by man assumes that he has access to it. Therefore all land use is tied together by the access network - principally the street. Although the more sensitive land planners aligned their streets with the "lay of the land" there is little obligation to do so. Box culverts, storm drains, and combined sewers which could cut through

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[13] The central business (highrise) district land use which comprises the most intensive development in the figure is not represented in this study of the urbanizing watershed since such a level of intensity will not occur. In that the per unit cost of detention decreases for such land uses, the feasibility of their being made to comply with the detention system principles being developed is real.

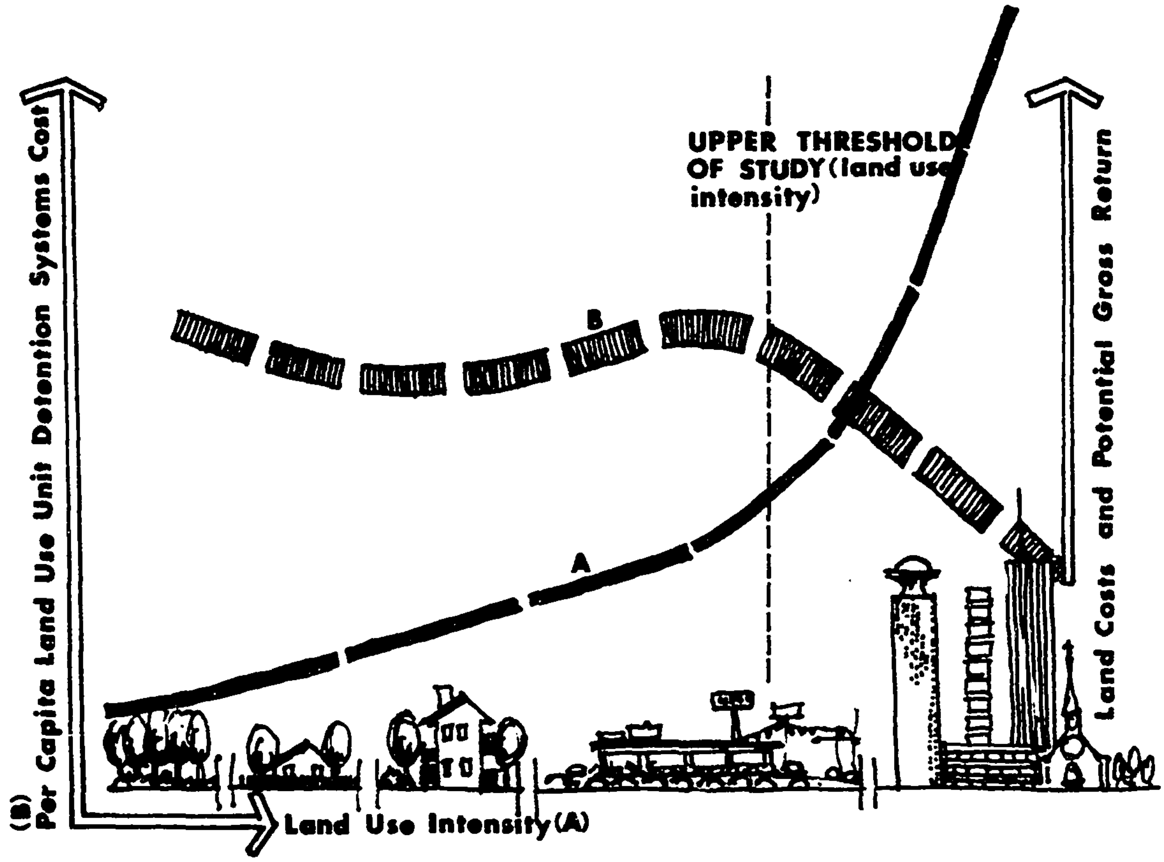
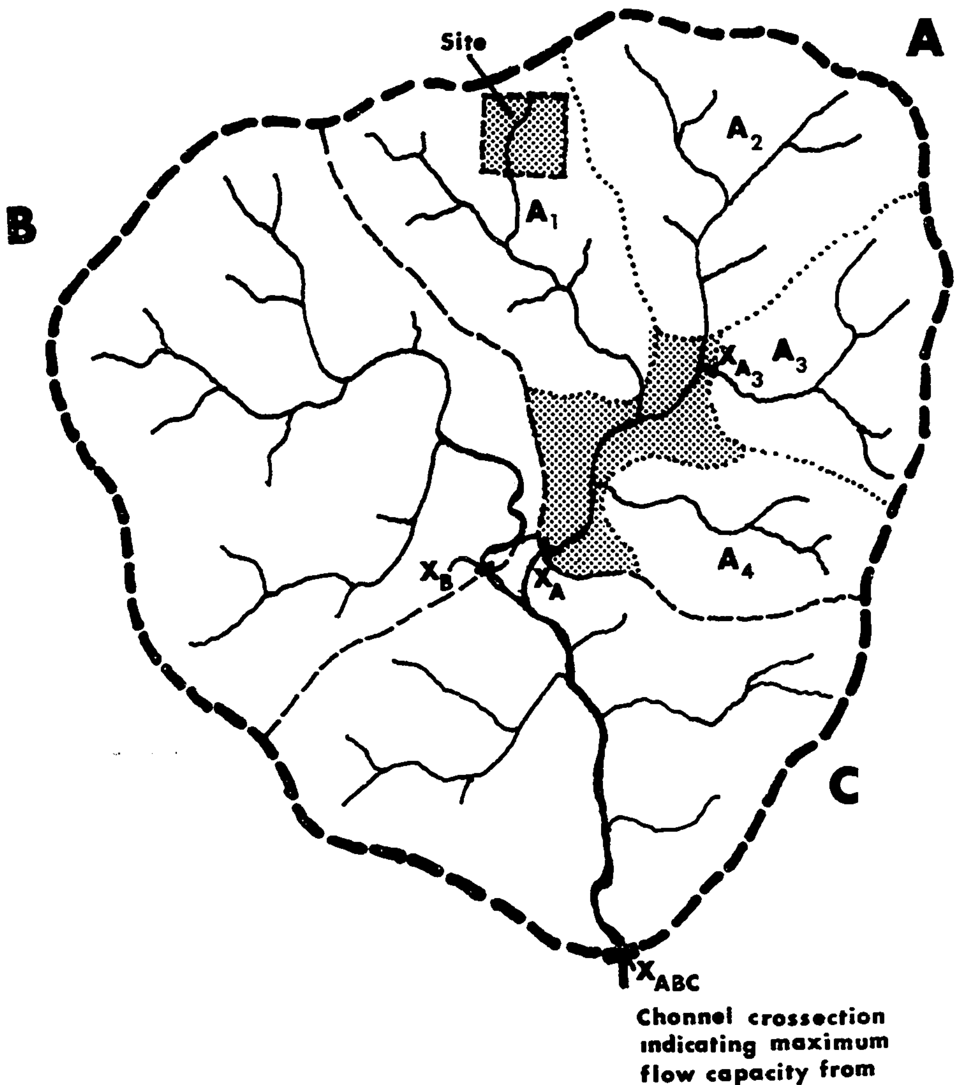


Fig. 5.6.--General Relationships: Detention Systems Costs and Land Use

ridgelines and beneath yards allowed the land use patterns to ignore the often subtle nuances of the drainage network. As a result, land use had only to adhere itself along the efficiently aligned street networks. With a system of interconnected cisterns, surface swales, impoundments, well and storage areas, there is the likelihood that land use will organize around drainage. Later streets which are not bound to gravitational flow are designed to provide access to the already situated uses. In effect this forces the land planner to be sensitive to land form simply because it now has a definite function. Land use is then served by two mutually reinforcing networks, the flow ways and the streets. The detention system, as previously noted, has a natural hierarchy beginning



No Scale

SUB BASIN AREAS AS DETERMINANTS OF MAXIMUM ALLOWABLE FLOW FROM DETENTION

Figure 5.7

with small local structures. The potential runoff accumulations, channel capacities, and detention facilities tend to increase through the higher levels. As a result a larger amount of space is used. Land use in the physical detention system should tend to organize as the leaves and branches of a tree. All are attached to branches of increasing size until the trunk is reached. The land use tree begins with its feathery top and outside edges and becomes more dense until it reaches the solid base.

Demonstrating How the Proposed Detention System Works

To present an example of how the proposed drainage basin detention system can work and how land use can be effected by it, a hypothetical watershed is presented in Figure 5.7. The palmate drainage basin has two major subbasins (A and B). The area designated as C constitutes the remainder of the watershed. Subbasin A is subsequently divided into four drainage areas.[14] These basins in turn, can be further subdivided.

The hypothetical basin contains a total of 1596 square units of land area.[15] For the sake of round numbers the discharge capacity of the stream channel cross section at the base of the watershed (point X_{ABC}) is 100 cubic feet per second (cusecs). Flow in excess of that rate will cause overbank flow. This is a matter which the detention system approach proposes to avoid.

---

[14] For each subdivision a portion of the area will not drain into the subbasins and will be computed independently. A shaded area as in Basin A will occur in subbasin A, when it is divided.

[15] The area figure was gained by a Keuffel and Esser Compensating Polar Planimeter (610000 Series) and actually represents 15.96 square inches on the scaleless figure.

The area of subbasin A_1 is 673 square units or 42% of the total shed area. Therefore the amount of flow leaving subbasin A should not exceed 42% of the capacity of the channel at X_{ABC} (42 cusecs) or the channel capacity at its own base (point X_A).[16]

The same principles can be made to apply at all subbasin levels. Subbasin A, within basin A has an area of 184 square units (18% of A and 8% of the total). The runoff released at its base should not exceed 8 cusecs or the channel capacity at point X_A[17]

For example, a developer purchases a tract of land in the A_1 area of subbasin A (shown as the stippled "site" in Figure 5.7). His tract contains 32 units of area which allows him to release runoff from it at a rate not to exceed 2 cusecs. What he plats and the way it is

---

[16]Obviously if the capacity at X_A were to be exceeded, flooding would again occur. The concept also precludes altering stream channel capacities and configurations at upstream locations. The changes potentially alter downstream capacities upon which the entire detention system is based. Generally, it is assumed that the downstream reach is capable of handling the sum of the capacities of the upstream capacities under normal rainfall patterns.

[17]It is possible to increase the amount of allowable flow leaving certain subbasins when considering the time of accumulation. When a storm passes over a watershed it takes different amounts of time for runoff to accumulate at various critical points. The distance the runoff travels, the slope, and the amount of roughness or resistance to flow met along the route (channels or overland) effects its timing. Such a consideration might allows the 27 cusecs of flow from area C in Figure 5.7 to complete its passage by point X_{ABC} before the 73 cusecs from subbasins A and B reach the same point. In effect the channel is never filled to capacity. The unused capacity could be redistributed on an area percentage basis thus increasing the allowable flows. Time of accumulation will not play a significant role in this study for three reasons. First, a storm of duration greater than most of the times of accumulation ends up sending runoff from all points in the watershed through the base at the same time. Second, if the basin is large enough the storm track can aggravate as well as alleviate flows based on times of accumulation. Third, this study does not assume that comprehensive and detailed plans are drawn up on a watershed before it urbanizes. Slopes, distances, roughness, and coefficients of runoff will therefore change as the basin develops. To compute future times of accumulation can result in disastrous guesswork.

platted is left up to him with the runoff rate being the only constraint. The cost of the land and its location gives the developer the market perception that anything from single family residential to multifamily residential and neighborhood commercial is feasible as a land use there. What are some of his potential responses based on the runoff detention and release approach?

Figure 5.8 is an enlargement of the site. The 32 square units will equal 16 acres. The design storm is a 6 hour 6.2 inch rainfall. The runoff rates and intensity distribution patterns are taken from Appendices A and B.

To begin with, the developer has an obligation to accept the appropriate share of drainage from the land above his tract (shown as the shaded area in the enlarged site figure). The natural surface drainage patterns shows .25, .3, and .2 cusecs entering the tract at A, B, and C respectively. As a result the acceptable rate of flow leaving the base of the tract is 2 cusecs plus the incoming .75 cusecs (2.75 cusecs).

<u>Development Scheme A</u> - Single Family Detached Residential on a Grid Street Layout.

The developer ignores the local topography and plats a typical grid street single family detached residential area (Figure 5.9). The residential use coefficient of runoff (C) is .66. An approximated discharge hydrograph is shown in Figure 5.10.[18]

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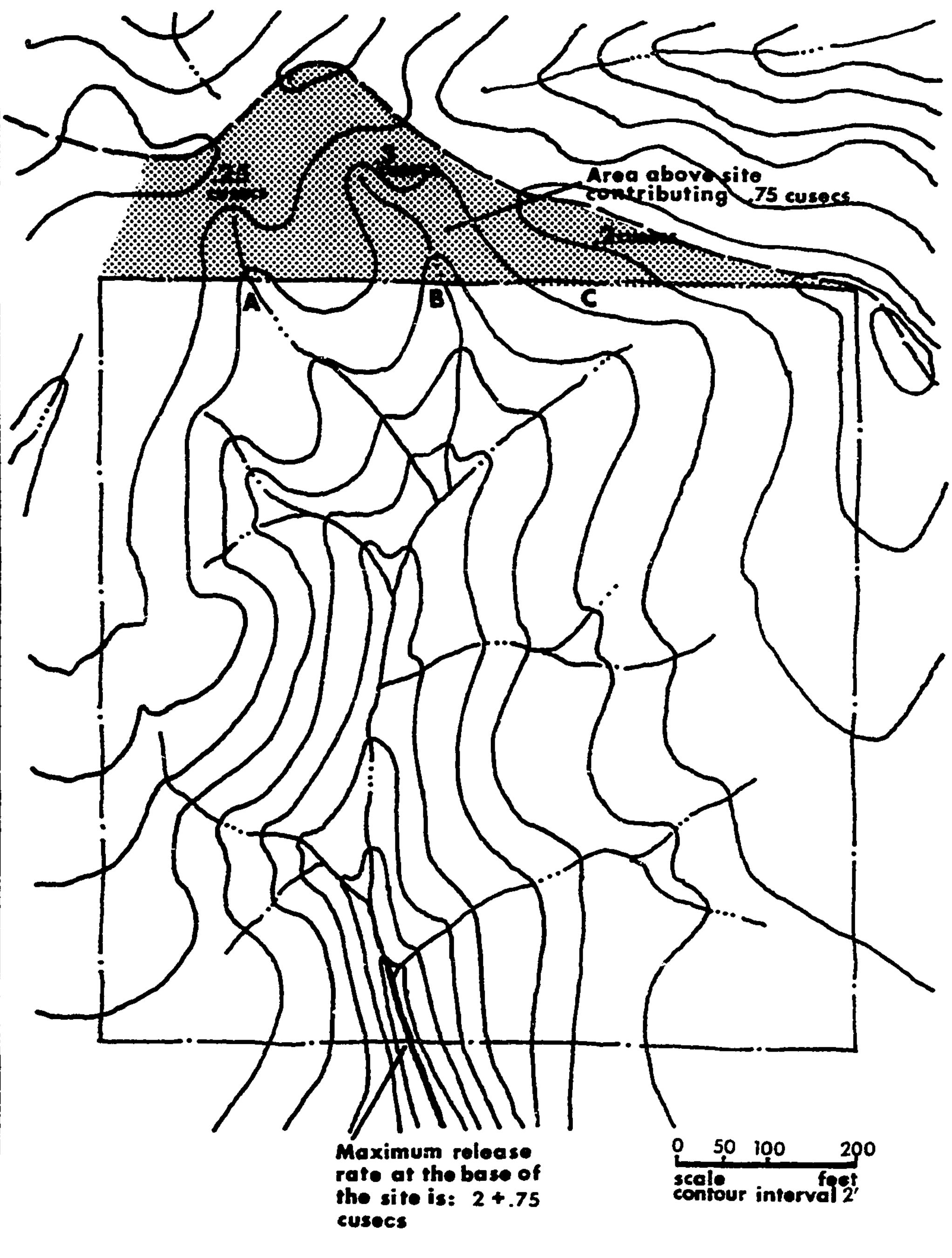
[18]The rough discharge hydrograph is based on area, rate of runoff and amount of rainfall. Time of accumulation which might have a slight effect on the shape of the curve is not considered. The baseflow, which could add to the runoff, is assumed to be zero. The coefficient of .66 assumes a higher urban density of single family detached.



EXAMPLE SITE FOR ALTERNATIVE DEVELOPMENTS

Figure 5.8

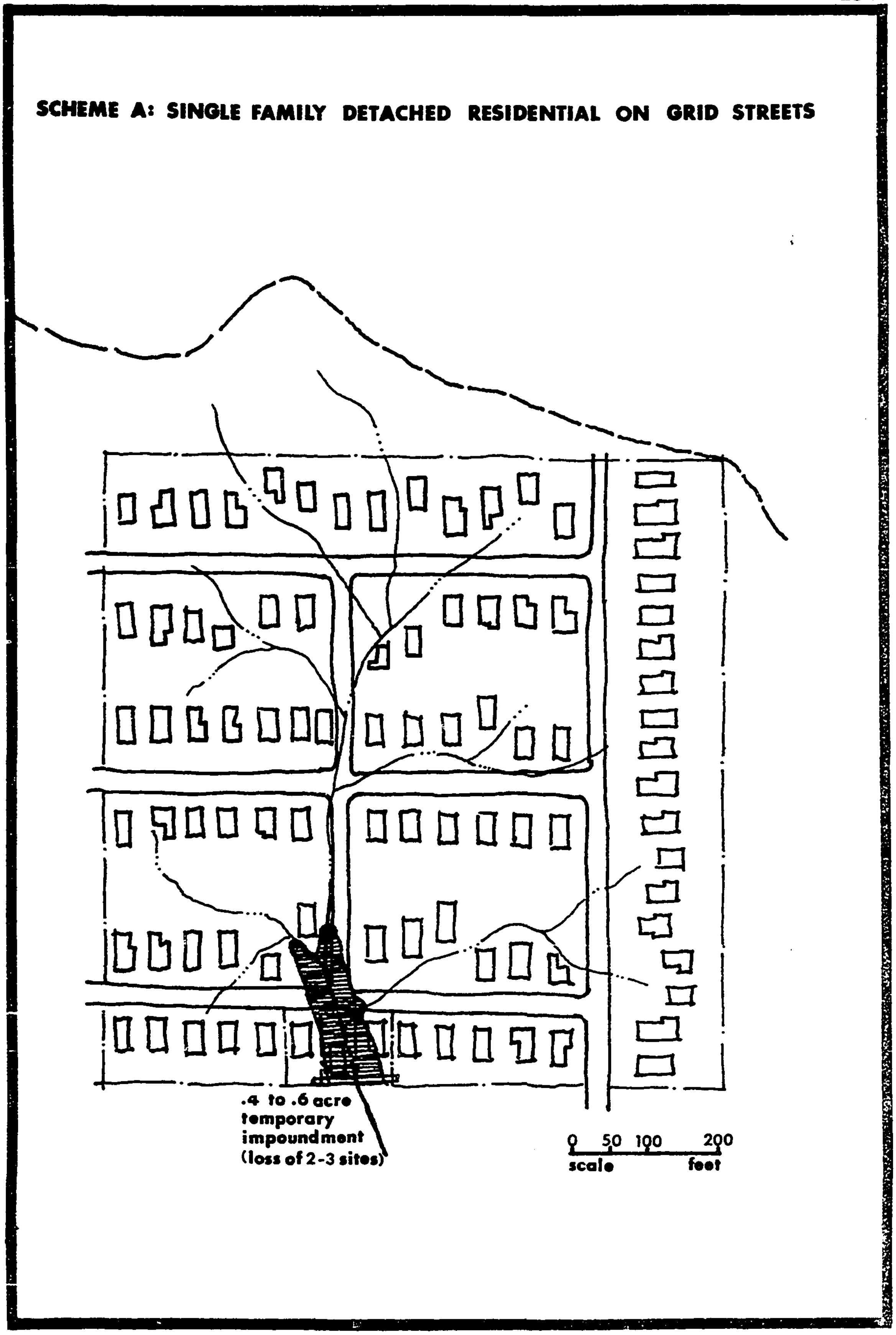

SCHEME A: SINGLE FAMILY DETACHED RESIDENTIAL ON GRID STREETS
.4 to .6 acre
temporary
impoundment
(loss of 2-3 sites)
0 50 100 200
scale feet

Figure 5.9

The acceptable rate of release (2 cusecs) allows 7,200 cubic feet of runoff to leave the tract per hour causing a detention buildup of 101,828 cubic feet during the design storm. The release rate then drains the backlog in 28 hours.

Where can the developer detain this necessary buildup? The 16 acre tract of single family density (approximately 6 units per acre) contains 95 houses. If each house had a cistern with a 2,135 foot capacity all detention requirements could be met. The 43,200 cubic feet released during the storm can account for runoff from up to 21% of the tract's surface which might not be subject to cistern control. A small release orifice could be installed at the base of the tract to regulate the otherwise uncontrolled flow. Backup at the orifice would be minimal since

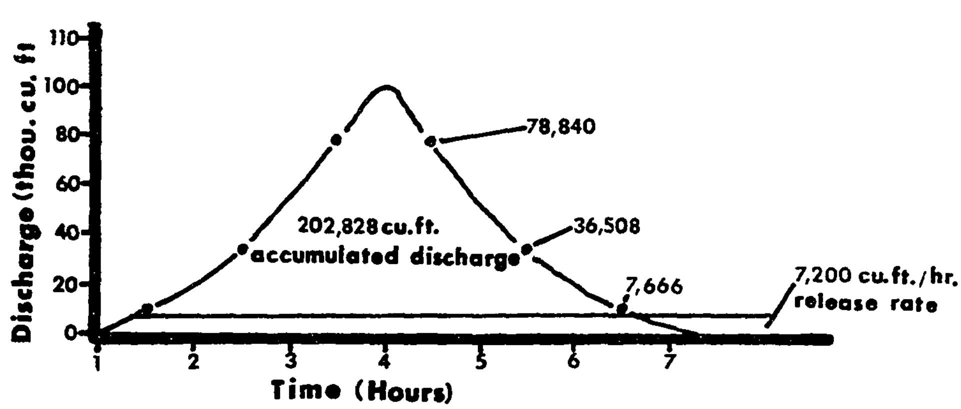


Fig. 5.10.--Discharge Hydrograph: Design Storm on Example Tract of Single Family Detached Residential.

the 43,200 cubic feet is less than one acre foot and is accumulated and released over a 6 hour period.

A cistern and tile field with a 2,135 cubic feet storage (20' x 15' x 7') is likely to be prohibitive in cost. Extending estimates of costs cited by Reid for smaller units, the cisterns could add from $3,000 to $3,500 to the price of a new home.[19] In addition, to rely on infiltration to handle 80% of a storm's runoff accumulation and to fully release it in a predictably short period of time is risky.[20]

More likely is the use of 1,000 cubic feet capacity cisterns in each of the 95 homes (95,000 cu.ft.).[21] The balance of accumulated runoff (107,828) can be handled by a temporary impoundment at the base of the tract. If the impoundment averaged 6 feet in depth, only .4 of an acre would be inundated for a short period of time during the 100 year storm. Costwise, the reduction in cistern size can save up to $19,000 for the subdivision. The added cost of the impoundment is $3,000 to $4,000 plus the loss of 2 to 3 residential lots.[22] The net decrease in production costs is $170,000 to $180,000.

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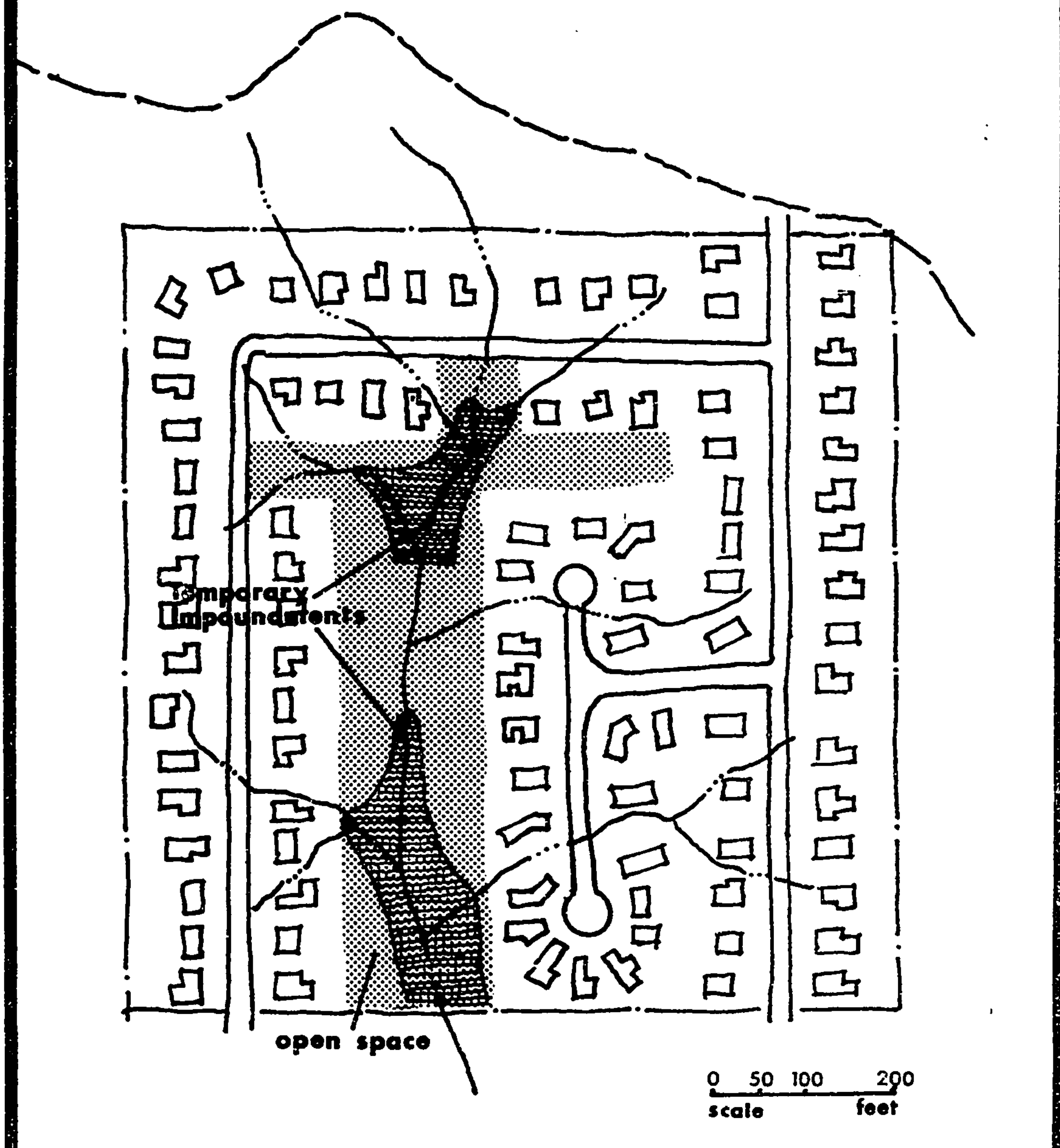
[19] Reid, "Demonstration and Evaluation of Stormwater Depletion Measures Applicable for Use on Residential Sites," Unpublished research proposal, University of Oklahoma, College of Engineering, undated, and related notes and sketches.

[20] The risk factor applies to the fact that if a detention device fails to drain itself in a reasonable amount of time a new storm can occur causing a potentially dangerous overflow.

[21] The 1,000 cubic feet cistern (15' x 15' x 4'6") is estimated to add between $1000 and $1500 to the cost of a new home. Prices are based on 1977 residential septic tank costs for central Oklahoma.

[22] Impoundment cost estimates are based on the rates used by the Soil Conservation Service in Cleveland County, Oklahoma. Clearance and land costs excluded, a small detention structure with an earthen dam and reinforced concrete spillway costs approximately $1.75 per cubic yard of earth (in the dam). See also footnote 12 of this chapter.



SCHEME A: ALTERNATIVE SINGLE FAMILY DETACHED RESIDENTIAL PATTERN

Figure 5.11

Before going on to another land use scheme, Figure 5.11 is shown to demonstrate a variation on the first pattern. As a result the developer has new and less expensive detention possibilities. First, as much as 5 acres of land might be opened up to the lower runoff coefficient of parks (.48) without significantly increasing the coefficient for the remaining area of 95 single family homes (.66). The net effect on accumulated discharge for the design storm is -28,548 cubic feet (a reduction of 14%).[23]

If 47 of the 95 houses were situated so that their cisterns could be replaced by front yard surface impoundments with a 2000 cubic feet capacity, the net reduction of flow to the larger impoundments is 70,500 cubic feet.[24] By temporarily inundating a few fronts yards, the maximum surface area of the larger catchments can be reduced by 11,750 square feet (.27 acres). A further modification assumes that there is the same amount of runoff in the cluster 95 home scheme as in the 95 home grid street scheme. Each of the homes is equipped with a 500 cubic feet cistern at $750 each (47,500 cubic feet). The balance (165,328 cu.ft.) flows into two temporary impoundments. The upper one drains 38% of the tract and should release .76 cusecs as well as the .75 cusecs it

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[23]Note that as the number and size of surface impoundments increase there can result a significant increase in runoff. This is due to the fact that the runoff coefficient of precipitation falling on water bodies is 100%. When compared to the residential C of .66 a major impoundment surface or two will begin to show up on hydrographs. The actual computation is difficult in that the size of the temporary impoundment's surface changes during the storm period. The factor is not considered significant in areas where impoundments at their maximum levels of detention cover less than 5% of the surface.

[24]Yard surface impoundment figure is based on typical front yard size with a 30 foot setback, 5 foot sideyards, 50 to 60 feet frontage less the 10 foot driveway. Average maximum depth is 2 feet.

receives from the tract above (1.51 cusecs). The lower pond releases the full allotment of 2.75 cusecs. Each pond will be responsible for its area percentage share of the balance of runoff since the homes are distributed fairly equally throughout the tract (77,075 cu.ft. upper and 125,753 cu.ft. lower). Resultant maximum pond sizes at a 6 feet average depth during the design storm are 13,000 square feet upper ($2500) and 21,000 sq. ft. lower ($3,000). The more effective and predictable detention system cost $75,000 to $80,000, a 50% + 55% reduction in cost when compared to the grid street system. The scheme using the front yard impoundment will save approximately the same amount. In addition the developer gains a 5 to 6 acre park amenity, reduces the lineal foot of street by 33%, and reduces utility lengths by approximately the same percentage.

Development Scheme B - Multi-Units Detached Residential[25]

In this instance the developer elects to maintain the interior size of each residence but reduces the lot size. As a result the cluster concept includes rowhouses/townhouses, and various other multiplex units. The initial B scheme maintains the same gross residential density (Fig. 5.12). The multiple units have a runoff coefficient of .73 and cover 9.3 acres. The balance of the tract (6.7 acres) has a park runoff coefficient of .48. The 7200 cubic feet per house (2 cusec) remains the same. The detention buildup for the design storm is 182, 718 cubic feet.[26]

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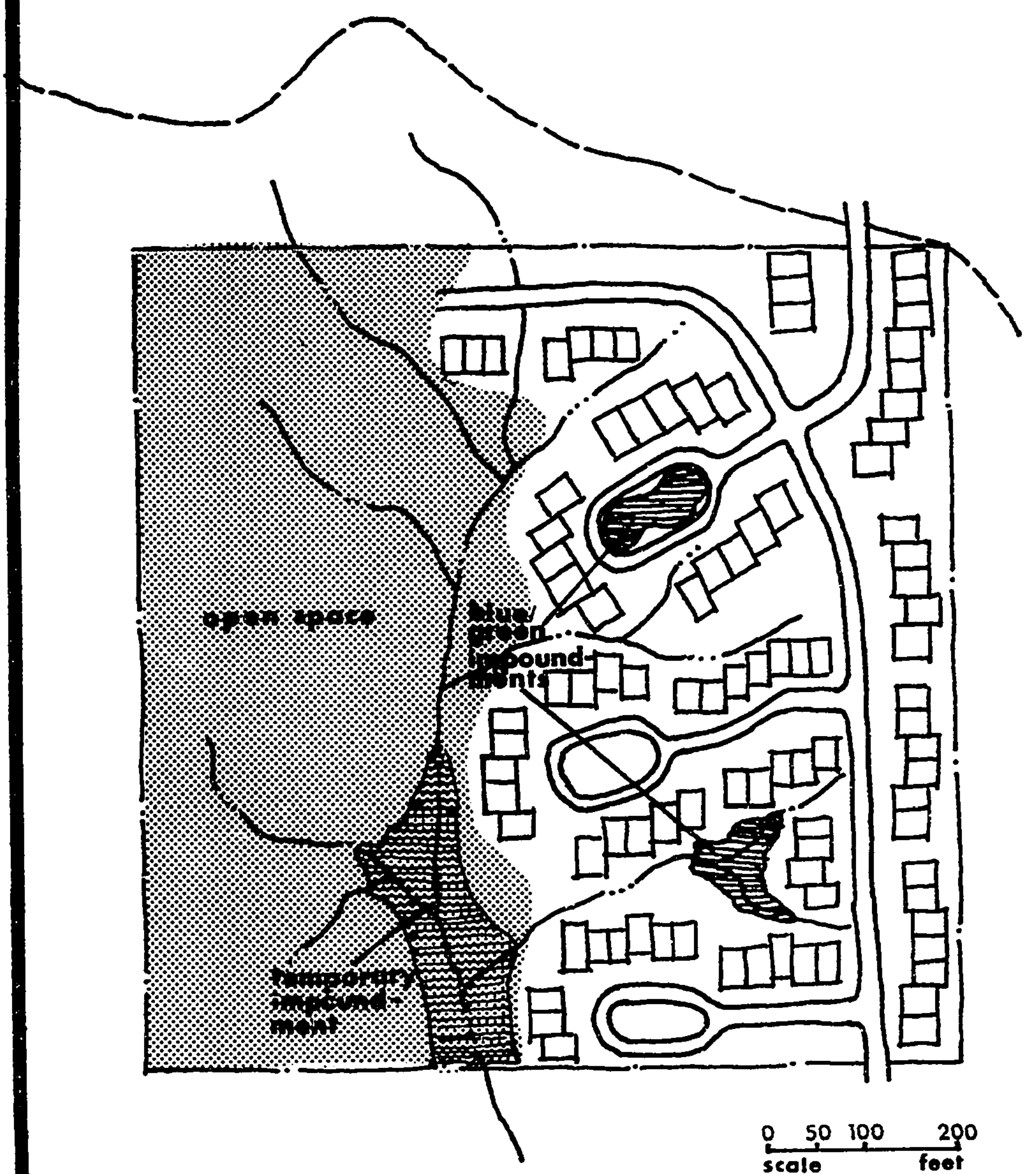
[25]Multi-units detached refer to dwelling units such as the duplex, triplex, and quadruplex. Short rows of townhouses (rowhouses), 4 to 8, are also included.

[26]The storm buildup is equal to the total runoff from the multi-unit detached (154,954 cu.ft.) plus the total from the open area (70,964 cu.ft.).



SCHEME B: MULTI-UNITS DETACHED RESIDENTIAL

Figure 5.12

The developer elects to detain 500 cubic feet per unit with $750 cisterns (47,500 cu.ft.). The balance is detained in roadside swales (18,600 cu. ft.) and impoundments (116,618 cu. ft.).[27] Using the blue-green concept (allowing flood runoff to add to the surface elevation of existing ponds) the developer constructs a catchment in the center of one housing cluster and another in the center of a roadway loop. The added storage capacity of the two is 40,000 cubic feet. This leaves 76,618 cubic feet to be impounded at the base of the tract.[28] Detention costs for the two blue-green catchments are minimized since they were principally constructed for amenity. The added capacity costs should be small. A rough estimate of the cost of this detention system is $80,000 ($850 per unit).[29] The cost per home for the detention system in this case is approximately $105.

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[27] Roadside swale storage is based on 4,100 feet of street (less driveways) by 1.5 feet average depth, by 4 feet average width. The rate of release from the swales is equal to or less than its share determined by the area drained.

[28] A matter which must be guarded against in designing a detention system is "underdetain" one area while "overdetaining" another. In this case 154,954 cubic feet of runoff resulted from the developed area. Had the various detention methods applied totalled an amount greater than the runoff from that area, there would be a danger of designing a structure for the "balance"that would be too small. The total amount of runoff detention might be adequate, but the locations for the facilities which make up the total may be inadequate.

[29] The least expensive way for a developer to meet his detention obligations is to build a single pond with a capacity of 225,918 cubic feet (9.9 acreas at 6 ft.). He should then have to determine whether or not there are any areas large enough within his tract to cause a local flooding problem if runoff is left alone until it reaches the pond. As the size of the development parcel increases the likelihood of local flooding also increases. This same idea allows places like Bird Creek in Tulsa, Oklahoma, to suffer severe flood discharge problems even though the Arkansas and Verdigris Rivers are two of the most structurally regulated rivers in the country.

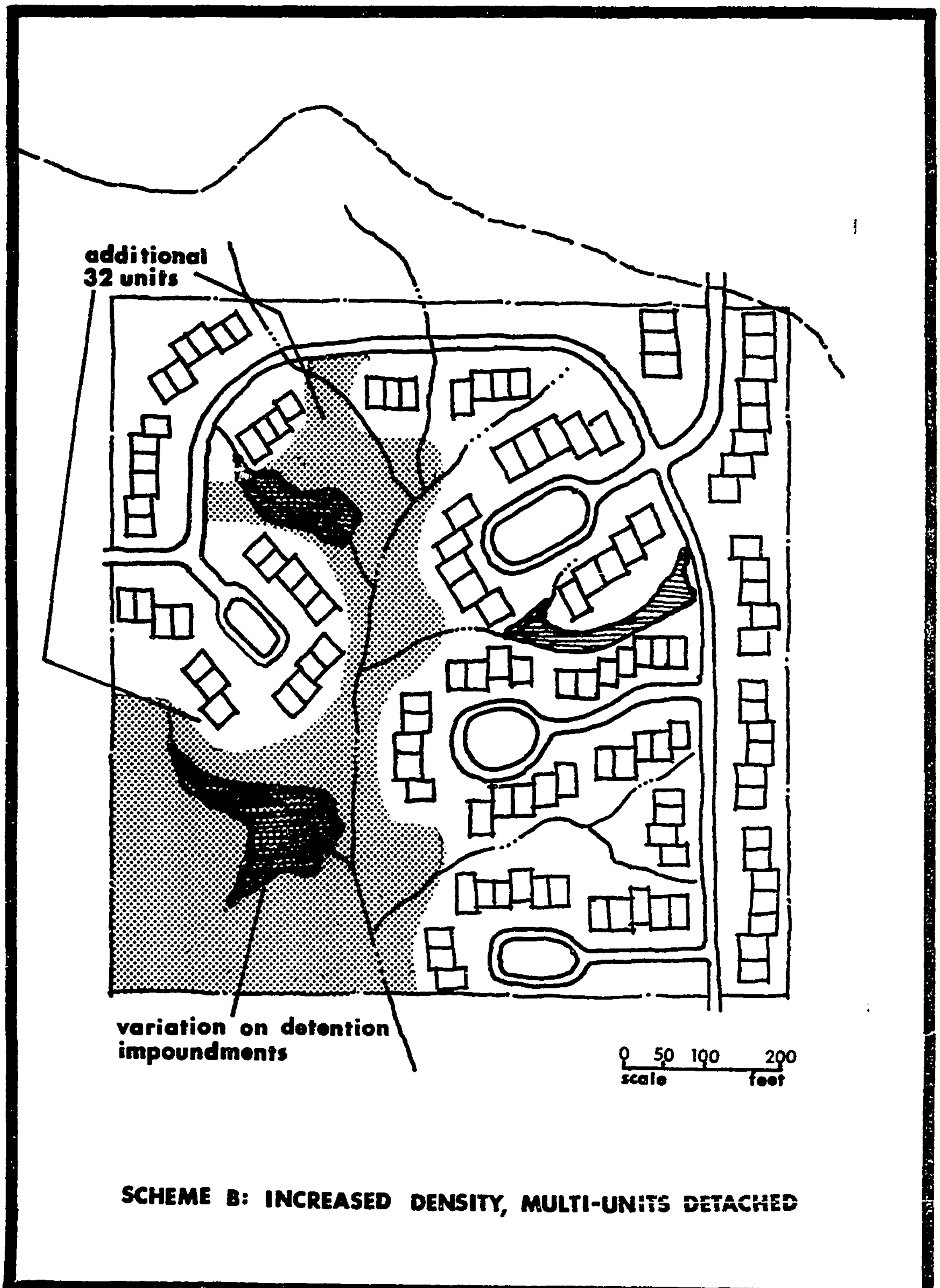
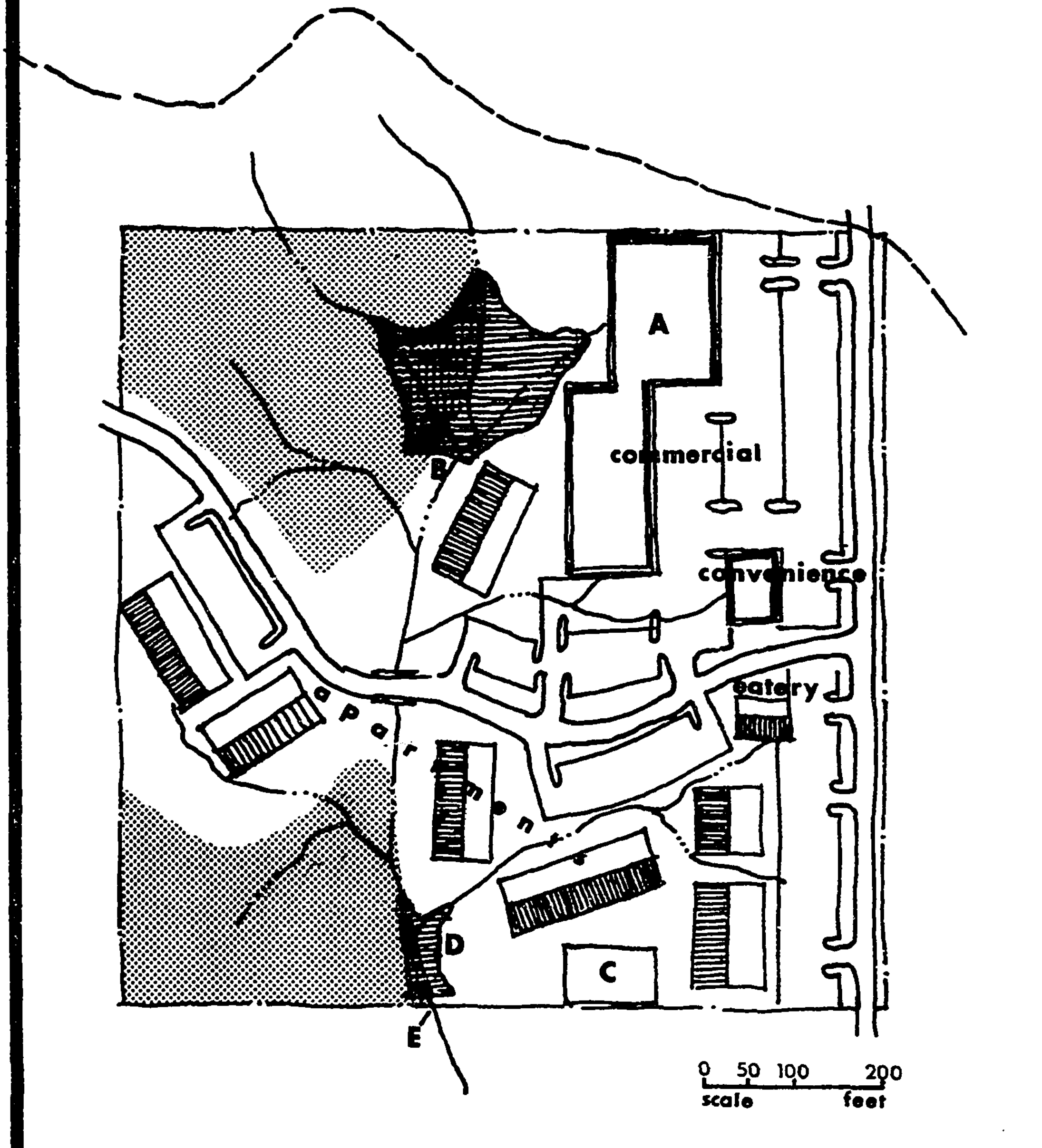

additional
32 units
variation on detention
impoundments
0 50 100 200
scale feet
SCHEME B: INCREASED DENSITY, MULTI-UNITS DETACHED

Figure 5.13



SCHEME C: RESIDENTIAL-COMMERCIAL MIXED LAND USE

Figure 5.14

Another notable effect which detention considerations may have on land use patterns is demonstrated in Figure 5.13 which is a variation on the multi-unit detached pattern shown in Figure 5.12. A discharge hydrograph for this pattern is almost identical to the one resulting from the single family detached on the grid street scheme of Figure 5.9 (240,364 cu. ft. and 246,828 cu. ft., respectively). The factor which would affect a decision of the land use pattern selected is that the multi-unit approach has 127 houses compared to 95 for the single family (33% increase). In addition, the multi-unit spacing offers a greater flexibility in the selection of detention techniques.

Development Scheme C - Mixed Use (Apartments and Neighborhood Commercial)

In this case the developer builds 95 apartment units and takes advantage of the tract's frontage to build a neighborhood commercial center. A 42,000 square foot building houses a chain supermarket, dry cleaners, drug store, and a couple of real estate offices. A convenience food store and hamburger eatery straddle the intersection (Fig. 5.14).[30]

The runoff discharged is 257,684 cubic feet.[31] The detention system includes rooftop storage (A) on the commercial buildings (21,563 cu. ft.)[32] Runoff from the open space, upper end of the shop-

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[30]The areas depicted in the figure are generally to scale. The parking area displacements are computed at 1 space per 150 square feet of gross floor area (commercial and 1.5 spaces per dwelling unit).

[31]Runoff coefficients (C) are 46% apartment coverage at .79, 30% commercial coverage at .79, and 24% open space coverage at .48.

[32]Note that the rooftop is limited to storing the precipitation which falls directly on it. For purposes of the study, the rate of release from the roof is that which is the share computed for the ground

ping center, and the incoming .75 cusecs is temporarily impounded behind a dam at B. The 135,000 cubic feet behind the structure at B is released at a rate based on the percent of land drained within the tract. The additional .75 cusecs is fully impounded. As a result, a lower impoundment will be able to release a larger amount without receiving the additional input. This concept works well when impoundment space is easier to find in the higher areas of a parcel. An additional 40,000 cubic feet of detention is gained by a sunken tennis court (C). During the storm the tract is allowed to release 59,400 cubic feet (43,200 for itself and 16,200 for the tract above it which is stored in the B impoundment). This leaves a requirement for a small pond (34,121 cu. ft.) at D and a regulating device (2.75 cusecs release) at E.

If the land was valuable enough to stimulate the development of a small commercial area and apartments, there is a good chance that the developer would want to fill more of the open space with apartments. This would increase the runoff (284,476 cu. ft.) by 10% and reduce the amount of surface space available for ponding. To achieve adequate detention the developer can construct many sunken multiple use recreation areas, underground cisterns, and channel storage. The costs of these more sophisticated devices quickly approaches that of the land. A number of land use detention system options take place. First, the present form of development can continue to intensify until the added costs of detention and land achieve equilibrium. Second, the costs might make it feasible for the developer to select a series of 5 to 10 story buildings, thereby reducing the amount of high runoff surface

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area covered by the building (7.2 cubic feet per minute). The roof, precluding evaporation, will drain in the 49 hours following the design storm.

resulting from each dwelling unit. In addition, more space having lower runoff rates is opened up for detention. The added expense here is multistory construction costs. The added incentives are the possibility of more units taking up less space, the production of less runoff, and open spaces for less expensive forms of detention. Third, the developer could acquire an additional tract of less expensive land along the drainage route and construct a detention pond to cope with the runoff he was unable to manage on the site. Fourth, he could purchase some storage space from developers of land above and below him. Fifth, the city could develop large open space areas with detention structures at critical points in the basin and sell detention storage rights to developers to meet release performance requirements. In the last three options, however, the developer would have to demonstrate that the unimpeded runoff from his tract would not produce potentially damaging local velocities or volumes anywhere between his project and the detention device he uses. Any excess flows might be abated sufficiently by one or two small devices with the balance of the flow being allowed to travel to the purchased detention space. The purchase of storage rights in multi-purpose public spaces could offset the advance acquisition and construction costs.[33] The use of such space between design storms and the use of most of the space during lesser storms is the advantage gained by the public.[34]

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[33]The public financing of detention facilities which are projected to produce income can be achieved with the use of revenue bonds.

[34]For the purposes of the summary comparisons at the end of this chapter, computations for runoff resulting from the construction of only 95 apartments were made. The commercial uses were removed and turned into parklands. Discharges in cubic feet from the whole tract during each of the 6 hours in the design storm were: (1) 7,323, (2) 34,352,

Development Scheme D - Interim Management of Undeveloped Lands Above Urbanizing Tracts.

In this case a land owner elects to develop on the tract below the site being used in this example. The example site is vacant land as is the 6 acres above it (under different ownership). What can be done to protect the developer from unimpeded vacant land runoff during the design storm (184,694 cu. ft. from example site and 69,260 cu. ft. from upper tract)?[35] The allowed runoff which the developer would be obliged to handle (2.75 cusec or 59,400 cu. ft. during design storm) is released leaving a balance of 194,554 cubic feet to be managed. There are three alternatives. First, the owners of the vacant land could be asked to develop detention devices knowing that they will eventually develop their respective tracts and need them anyway (Figure 5.15 "FIRST Second, the city can condemn parts of the upper tracts and develop detention devices (Figure 5.15 "SECOND"). Later, storage rights can be sold and some or all of the public expense is recouped. Third, the developer can develop a much larger detention system to handle the incoming runoff and then either hope to recoup some of his expenses by selling detention rights to the upper developers in the future or turning the structures over to the city for some consideration and let the city recoup the expenses (Figure 5.15 "THIRD").

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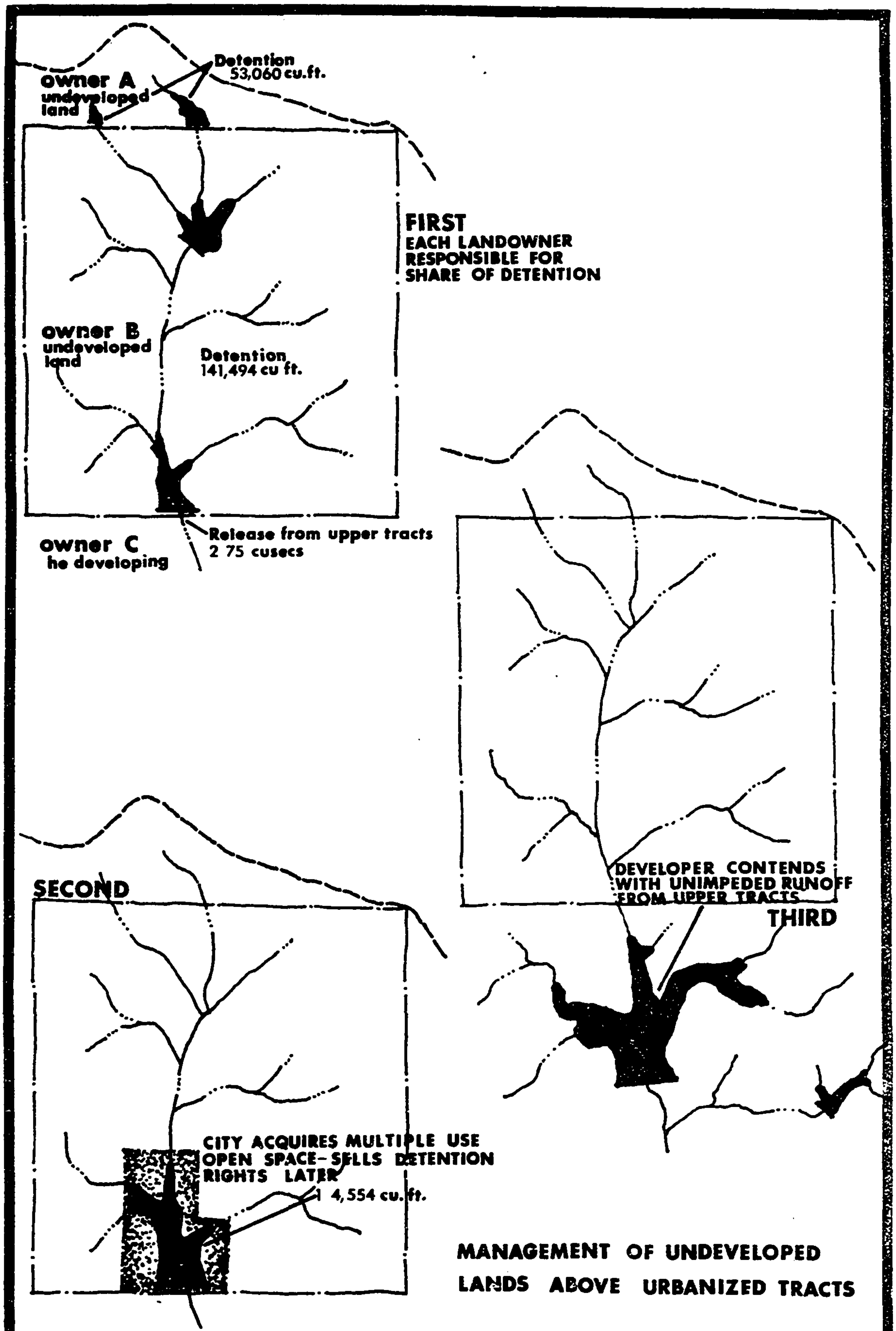
(3) 70,513, (4) 70,513, (5) 34,352, and (6) 7,232. The total discharge was 224,194 cubic feet.

[35]Runoff figure is based on the vacant land runoff coefficient (C) of .53 (Appendix B) applied to 22 acres for the design storm. Note that a lower coefficient could be used if the condition and use of the upper lands (forests, etc.) warranted. If the owners of the upper lands later changed the use, they would be required to manage any additional runoff produced by such changes.



Detention
53,060 cu.ft.
owner A
undeveloped
land
FIRST
EACH LANDOWNER
RESPONSIBLE FOR
SHARE OF DETENTION
owner B
undeveloped
land
Detention
141,494 cu ft.
owner C
he developing
Release from upper tracts
2 75 cusecs
DEVELOPER CONTENDS
WITH UNIMPEDED RUNOFF
FROM UPPER TRACTS
THIRD
SECOND
CITY ACQUIRES MULTIPLE USE
OPEN SPACE-SELLS DETENTION
RIGHTS LATER
4,554 cu. ft.
MANAGEMENT OF UNDEVELOPED
LANDS ABOVE URBANIZED TRACTS

Figure 5.15

Summary of Detention Systems

The example tract was used to demonstrate some of the logically simple ways a detention system can be designed to contend with a given storm. The impact of the system on land use patterns as well as the impact of land use on the design of the system were introduced. The systems and patterns were only a few of the possibilities. For every physical, economic, social, and political site situation there will be a number of detention systems - land use schemes which will be particularly suited to it. Yet the systems and the land use patterns are inextricable.

There appears to be some general relationship between the systems and associated land use patterns which are going to impact significantly on the planning of both:

1. The detention system is governed more strongly by gravity and interconnectedness than land use is by access.[36] Therefore, development should be situated so as to complement the detention system. The effect is that land use is designed to be situated along and around the drainage network. Presently, the drainage system is brought to the land use.

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[36]The detention system could be designed in a discontinuous fashion if the impounded water was reused. The system would also be discontinuous on the surface if storm drains cut beneath buildings or through ridgelines. Reuse is not considered by this study due to its complexity and variances in the speed and patterns of reuse. To be effective a detention device must be emptied in a reasonable amount of time. Although storm drains and excavated concrete channels probably have some role in the downstream reaches of a detention system, the major thrust of collection and detention relies on surface flow in grasslined and natural channels. Storm drains increase the velocity, gradient, and reduce time of accumulation. Pipes, concrete lining, and channel straightening also reduce the channel storage capacity. These are counter-productive to the delaying-detaining theme of what the study advocates.

2. An increase in the extent and intensity of land use both increases the loading on the detention system while tending to absorb the space required to cope with the additional runoff produced. Once the surface space is absorbed, on site subsurface methods provide more costly alternatives. Added detention costs ultimately exceed the high land costs which stimulates increased development. Thus land use patterns and detention systems reach a point of economic equilibrium.

3. The basic economics (runoff volume and resultant costs) of a detention system in an urbanizing watershed encourages the clustering of land use. Two reasons are evident in the case of the hypothetical tract. First, by consolidating open space the more efficient and economic methods of detention (such as channel and pond storage) are provided with the necessary space. Second, although clustering of a particular land use increases the coefficient of runoff, it does so in a smaller space. The space released from development and used as open areas experiences a reduced coefficient. The net result is less runoff for the same number of units of land use. This is particularly evident in the hydrographs for different configurations of the same number of housing units (95) taken from the example tract and design storm (Fig. 5.16). The single family configuration discharged the greatest amount of runoff (246,038 cu. ft.) followed by detached multi-units (225,918 cu. ft.), apartments (224,194 cu. ft.) and highrise (195,784 cu. ft.).[37] The runoff differences between various forms of multi-units and apart-

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[37] For the purpose of comparison only a 95 unit highrise building with a 2 floor parking garage was put on the tract and tested. The estimated area of development was 2.3 acres (13%). The coefficient used was .97 ("downtown business").

COMPARATIVE RUNOFF HYDROGRAPHS: EXAMPLE DEVELOPMENTS

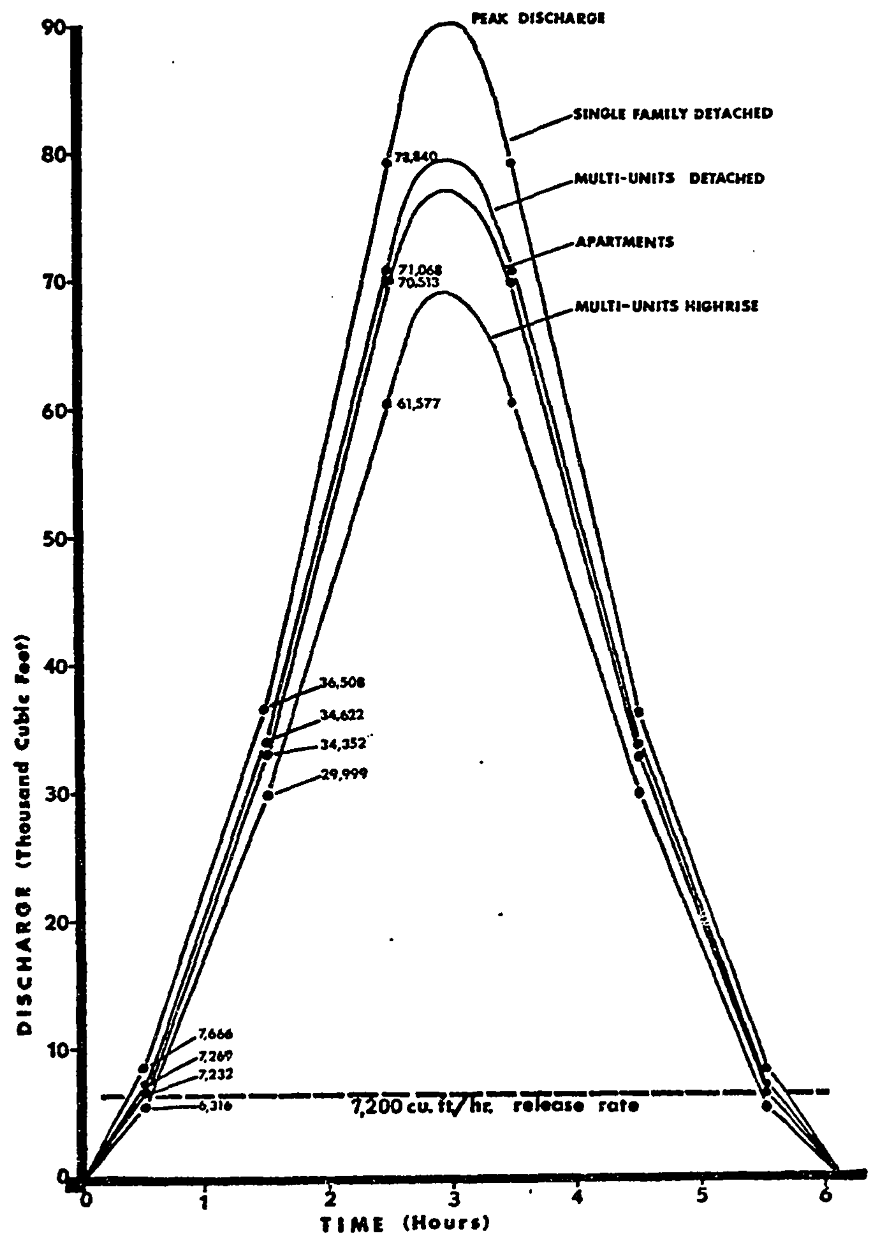

Figure 5.16

ments were minimal. The greatest differences occurred between free standing and stacked units. The point where the greatest differences occur is most likely to be during the peak period of the storm when unimpeded discharge is most critical. In terms of residential land use and runoff, the single family detached configuration is per capita the most expensive and inefficient. Logically, the same principle of intensified clustering holds true for commercial and industrial land uses.

4. In terms of systems of methods, the per capita land use unit costs of detention decrease when methods suitable for larger areas are used. The more localized the detention method (rooftops, cisterns, lot surface catchments) the more expensive the overall system becomes. On the other hand, the farther runoff is allowed to flow and consolidate with other runoff, the greater the risk of erosion and local flood damage. The optimum system is one localized enough to be cost and maintenance efficient. The precise design is subject to the specific site and design storm situation.

5. In a system where land ownership is fragmented to the point that detention methods are necessarily localized and therefore more costly, off site consolidated detention structures might be built publicly. The sale of detention rights could then be used to bear much of the cost of the multipurpose detention/open space public area.

The purpose of the next section of this study is to apply these detention techniques and systems of techniques to an actual watershed which lies on the urbanizing fringe of a city. The principles and relationships demonstrated in the hypothetical tract will now be tested against an actual physical space using its current ownership and land use patterns. The case study will attempt to achieve an adequate detention system without undue amounts of regulation and unreasonable cost demands on developers.

CHAPTER SIX

A CASE STUDY OF ROCK CREEK: MODELING THE PROPOSED DETENTION SYSTEM

Introduction

The purpose of this chapter is to apply the detention systems concept to an existing watershed and to test the application under the conditions of a design storm. Much of the potential value of this study depends on whether or not actual conditions allow the proposed approach to be feasible. In addition, the place and storm must not be so unique to the case study that the tested feasibility is questionable elsewhere.

The chapter sequence begins with the introduction and description of the case study watershed and the design storm to be used in the test. Next, the wider implications of the basin storm case are discussed. Following the introduction and justification of the case study, runoff hydrographs are calculated for various development (or non-development) alternatives in the watershed. The computed hydrographs are analyzed and compared. Finally a small section of the watershed (320 acres) is selected for a more detailed examination to determine whether or not the computed detention requirements on it are reasonable. This example section is also designed to demonstrate the interface between physiography of the watershed and the ownership patterns on it and how the two can be integrated. Particular strategies for implementation are recognized as varying temporally and spatially. The feasibility of implementation is the matter which remains relatively constant in different places and probably will increase with time.

The Case Study Watershed: Rock Creek

Rock Creek drains an 11.6 square mile watershed on the eastern edge of the urbanized portion of Norman in central Oklahoma (Fig. 6.1).

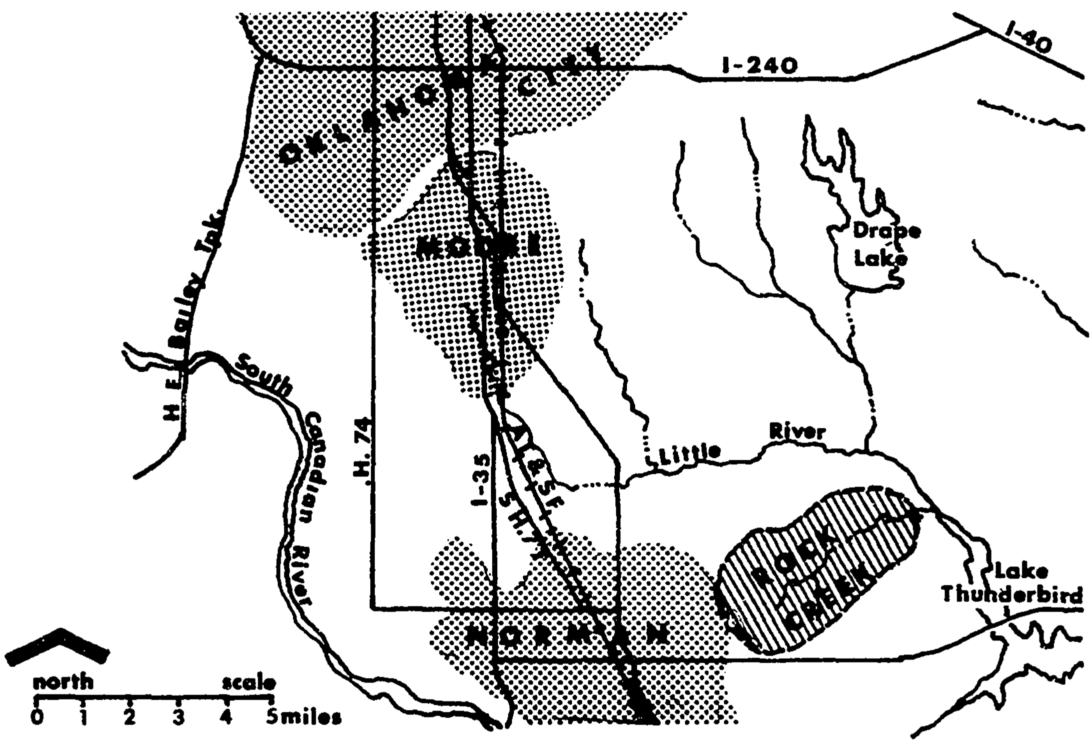

Fig. 6.1.--General Location of the Rock Creek Watershed

The creek flows into Little River which flows into the northwestern arm (Little River Arm) of Lake Thunderbird.[1] There are a number of controversies surrounding the potential (and perhaps inevitable) development of the watershed. A major conflict is between the expansion of the

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[1]Lake Thunderbird was constructed by the Bureau of Reclamation during the 1960's principally as a water supply for Norman, Del City, and Midwest City in central Oklahoma.

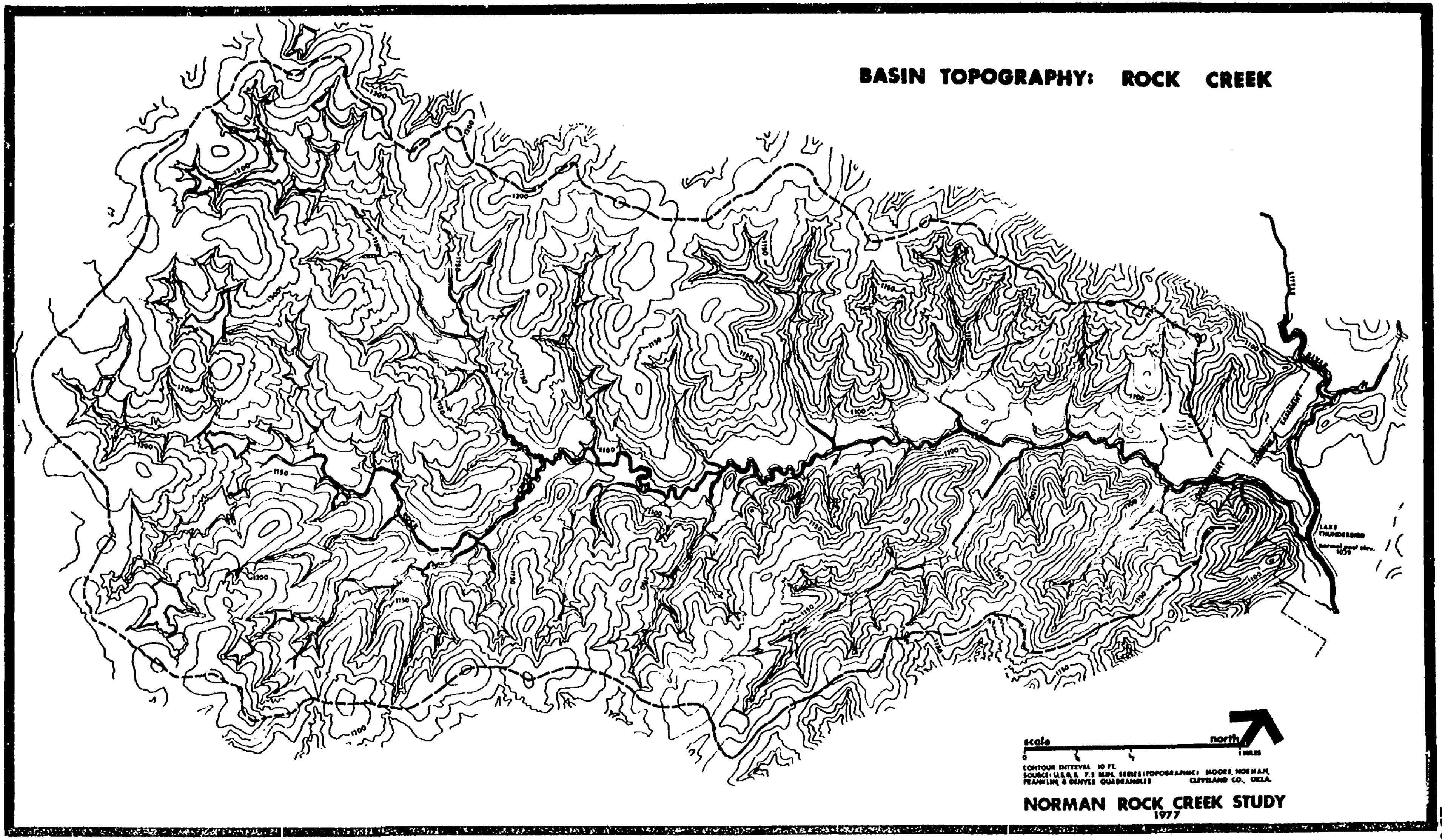
BASIN TOPOGRAPHY: ROCK CREEK
scale
north
0
1 MILES
CONTOUR INTERVAL 10 FT.
CLEVELAND CO., OKLA.
NORMAN ROCK CREEK STUDY
1977
LAKE THUNDERBIRD

Figure 6.2

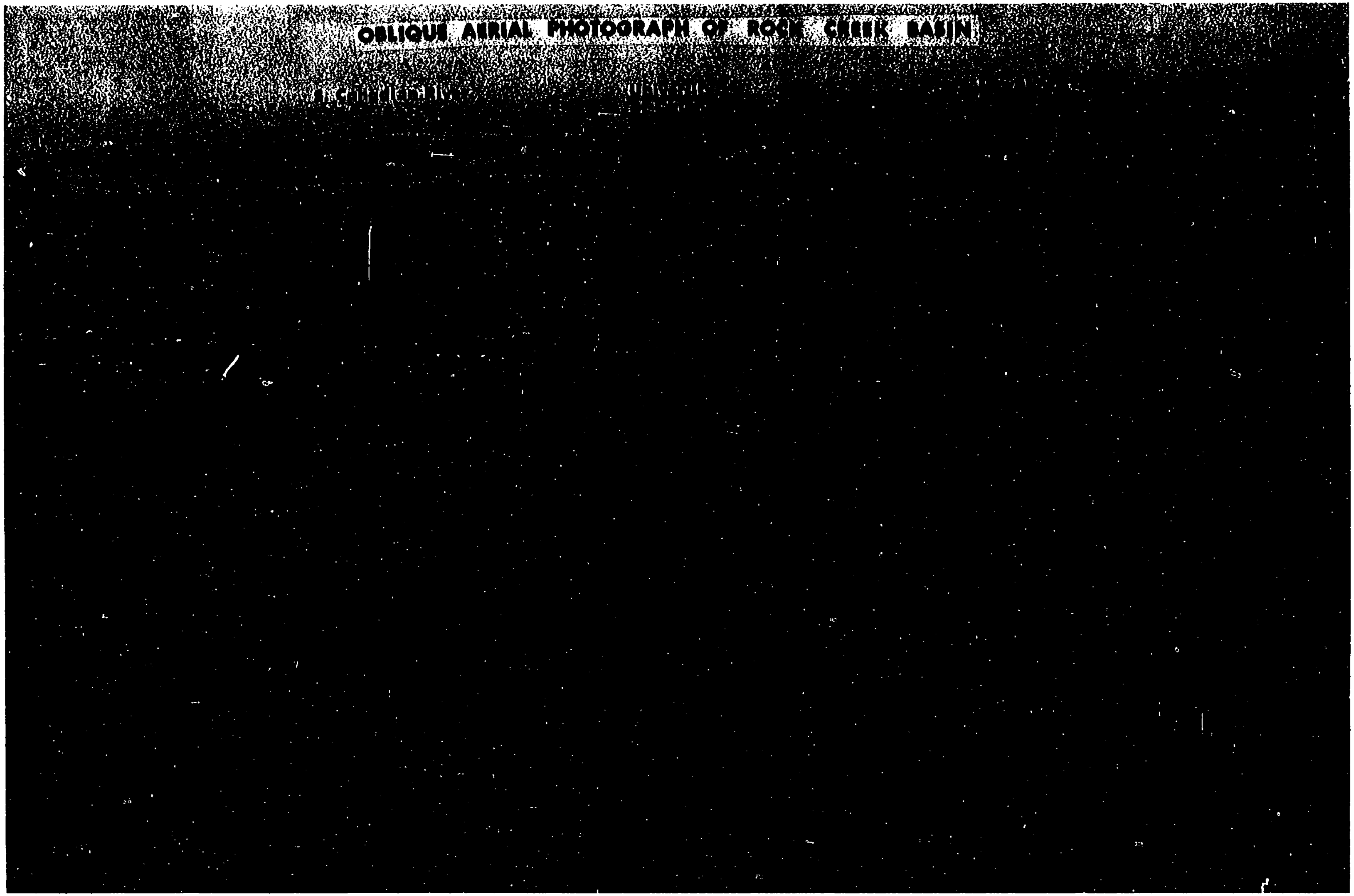

Figure 6.3

urban fringe with its potential water supply pollution and the urbanization of underutilized and vacant lands within the presently built up areas. This case study, however, will contend with the issue of managing the quantities of runoff associated with urbanization and storm events. Figure 6.2 shows the size, general form, and topography of the Rock Creek watershed. Figure 6.3 is an oblique aerial photo looking west-southwest up Rock Creek from its confluence with Little River.

The Case Study Design Storm

The 6 hour, 100 year storm for central Oklahoma is used as the design storm. The intensity distribution is in accordance with Figure 1 of Appendix A.[2] Aspects of the design storm are discussed below in the section dealing with wider implications of the case study.

The Wider Implications of the Case Study

This thesis uses a case study to determine whether or not the runoff management alternative being studied can be made to work under actual conditions. The value of both the case study and concept increases with the range of places and situations where they can be made to apply. In this study the general approach has been to assume the more severe rainfall and runoff conditions so as to create a

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[2] The reasoning behind the selection of the 100 year frequency storm is discussed in Appendix A. The 6 hour duration coupled with the resultant 6.2 inches of precipitation is selected because it is the most severe intensity duration combination which can be used in a detention-release system. The 7.5 inches and 8.6 inches which fall during the 12 hour and 24 hour storms respectively have significantly longer release times while experiencing little in additional precipitation. Specifically, the 12 hour storm has a 17% increase in precipitation over a 100% increase in release time. The 24 hour storm has 28% more precipitation than the 6 hour storm and a 400% increase in the time to release the detained runoff.

synthetic situation which probably exceeds actual or potentially observable circumstances. If the proposed detention system is put under a high level of computed stress, the wider implications are that under actual conditions the system is even more likely to work. In cases where the literature presents different opinions on what happens under given circumstances, the conservative threshold of opinion is assumed. Therefore, if the percentage of runoff from a residential land use is cited as being between 45 and 65, the latter is used in the study. This conservative approach results in a maximum test of feasibility. Other broadening implications in the storm and case study are found in the following discussions of U.S. storm intensity-distribution, basin size, ownership pattern, basin shape and slope, and the detention factor itself.

Design Storm

If the case study utilizes a 100 year storm, which is more severe than the 100 year storms in most other areas of the country, then the achievement of adequate detention is more feasible in those areas subjected to less precipitation. Figures 6.4 and 6.5 show storm intensity, frequency, and distribution patterns for the U.S. The shaded areas are those regions whose 100 year storms are equal to or more severe than the design storm. Therefore, the approach demonstrated in the case study is likely to be more feasible in watersheds in the unshaded areas if the local variable is the storm event.

Basin Size

Another variable is basin size. The runoff elements generally effected by basin size are time of accumulation and total discharge. However, all basins are subunits of larger watersheds. It can be argued

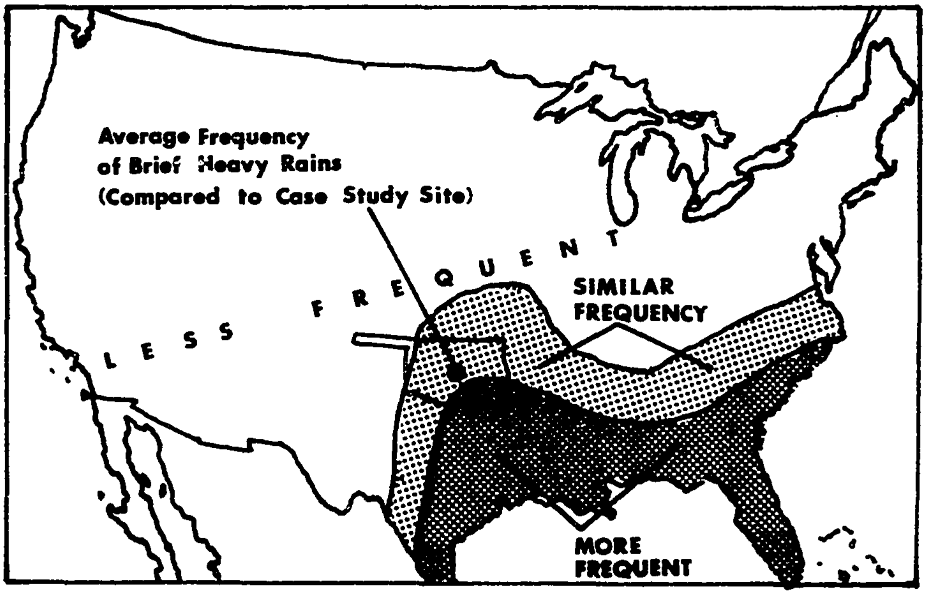

Fig. 6.4.--Frequency of Brief Heavy Rains in the U.S. Relative to the Case Study Site
(Adapted from map #626, p.244)

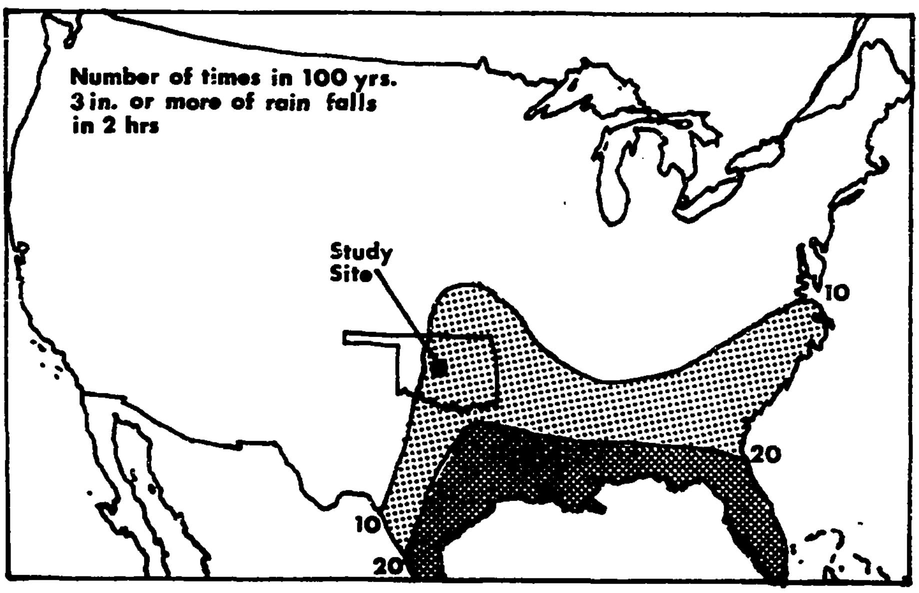

Fig. 6.5--Occurrence of the 3 Inch,-2 Hour Storn During a 100 Year Period Relative to the Case Study Site
(Adapted from map #635, p. 247)

Source of Figures 6.4 and 6.5: Stephen Sargent Visher, Climatic Atlas of the United States (Cambridge: Harvard University Press, 1954), Maps and pages as above cited.

that subsequent applications of the concept can limit their sizes to the combination of stream reaches which cover drainage areas of 11.6 square miles or less. While there is no proof that the application of the principles of detention-release will work in basins with larger drainage areas, there is no known reason why such principles would not work. Dalrymple's defining the small watershed as being less than 10 square miles in area provides a basis for the selection of a basin of the size of Rock Creek.[3] The smaller drainage basins are also more likely to receive uniform coverage by precipitation during a design storm. Chow defines the small watershed as one more sensitive to high intensity and short duration storms and land use.[4] Chow's maximum area criterion is approximately 50 square miles.

Ownership Patterns

Because the location, size, and shape of the parcels of ownership on the land often impact on the way that land is developed, variance in ownership patterns might effect the detention requirements in different basins differently. It is assumed that lands on the leading edge of most cities tend to break down into smaller ownerships with speculation and that ownership consolidation is more of an exception. Therefore the size of individual tracts is going to be similar in most small urbanizing basins. The shape of the parcels is another possible variable. The

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[3]Tate Dalrymple, "Hydrology of Flow Control," in Handbook of Applied Hydrology, ed. by Ven T. Chow (New York: McGraw-Hill Book Company, 1964), p. 25-2.

[4]Ven T. Chow and others, "Report of the Committee on Runoff, 1955-1956," Transactions of the American Geophysical Union, XXXVIII (June, 1957), p. 40. Dalrymple in "Hydrology of Flow Control" goes on to further confuse the definition of small watersheds by noting that the Corps of Army Engineering considers 1000 square miles or less as being small (p. 25-27).

division of land in most range and township systems has a natural tendency to become subdivided in square and rectangles which are fractions of one square mile sections of land.[5] The range and township framework within which these property shapes tend to occur is generally common to the western half of the U.S.

Basin Shape and Slope

Basin shape and slope are other variables which can effect both the volume of runoff and the time of its accumulation. If the case study had slopes and subbasin shapes which were consistent throughout, the character of its runoff hydrograph could have had implications for other basins having similar shape and slope characteristics. The actual basin, however, is not consistent throughout in terms of slopes and sub basin shapes. The topographic lines in Figure 6.2 show that the western end (upper reaches) of the Rock Creek watershed can be characterized as having wider and more gently sloping valleys than the eastern end (lower reaches). The steeper sloped valleys near the mouth of Rock Creek also tend to be longer and more narrow. These variations in landform make it more difficult to compare the Rock Creek basin with watersheds of similar size elsewhere. When presenting the wider implications of this case study, basin shape and slope is potentially the most limiting factor.[6]

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[5]In the southwest, undeveloped land beginning with the quarter section homesteading divisions community breaks down into fragments which are easily described in legal terms as being the Northwest one half of the Northeast one quarter of Section 27 Township 9 North and Range 2 West (NW2, NE4, Sec. 27, T9N, R2W), etc. The actual act of platting (a final step in the urbanization of the land) is often the first time more sophisticated surveys on irregularly shaped properties takes place.

[6]Note also that the presettlement (original) vegetation map which is discussed in Appendix D (Fig. D.1), shows the western edge of the post oak-blackjack forest as forming a rough north-south line near the

The Detention Release Factor

The factor which tends to negate all of the above areas of potential variance is the detention release system itself. If the sizes, shapes, slopes, and uses of different basins cause varying hydrologic responses, then the implications of case studies can be made to apply only to basins with similar features. The critical elements of hydrologic response here are the time of accumulation and the volume of discharge. If runoff is detained locally and released at a predetermined rate, the volume and time of discharge can be set by design regardless of the physiographic variations in different watersheds. As an extreme example, total detention of all precipitation at the most local level results in an identical hydrologic response in all basins. The broader implication of this case study which uses the detention release system is that use of the same concept in physiographically different basins tends to have similar results. As a result the concepts applied in the case study are generally applicable to most small urbanizing watersheds.

Comparative Discharge Hydrographs

The purpose of this section is to compare the hydrologic responses of alternative land use patterns in the Rock Creek watershed under identical design storm conditions. The first three patterns (presettlement, present, and standard urban grid) will use the drainage or unimpeded flow approach to runoff management. The fourth pattern will apply the proposed detention release concept.

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midpoint of the watershed. This edge roughly coincides with the transition between the wide, gently sloping subbasins of the western half and the steeper, longer, and more narrow subbasins of the eastern half.

If runoff is managed properly overbank flow should be prevented. Chapter Two discusses reasons why increasing channel capacity (section and velocity) is not desireable. Therefore the management effort needs to reduce discharge to a rate which can flow within the natural channel. By measuring the existing channel sections and gradients along Rock Creek and applying the fluid mechanics formulas for determining the capacity of flow in open, natural channels maximum rates of acceptable discharge can be determined. Figure 6.6 reflects the sample locations of natural channel flow capacities along Rock Creek.[7] The comparative merits of each land use scheme are determined by their respective degrees of overbank flow during the design storm. The presettlement discharge hydrograph is developed to determine the point of beginning for historic runoff rate.

Presettlement Runoff (Discharge)

To calculate what discharges may have occurred in the Rock Creek Watershed prior to settlement and alteration, a general vegetation map was reconstructed using the soil surveys.[8] It is assumed that the soil

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[7]Appendix C includes the methods for determining channel sections, gradients, and capacities.

[8]The cited soil survey was published by the Soil Conservation Service of the U.S. Department of Agriculture in cooperation with the Oklahoma Agricultural Experiment Station and entitled Soil Survey, Cleveland County, Oklahoma (publication date is October 1954). The native vegetation association with soil types is located in the survey in an unnumbered table entitled "Cleveland County, Oklahoma Soils: Summary of Important Characteristics." The assignment of each soil to a hydrologic soil group is done by tables in the U.S. Soil Conservation Service, Report of the Service, "Hydrology," in S.C.S. National Engineering Handbook (Washington, D.C.: U.S. Government Printing Office), Section 4, 1972.

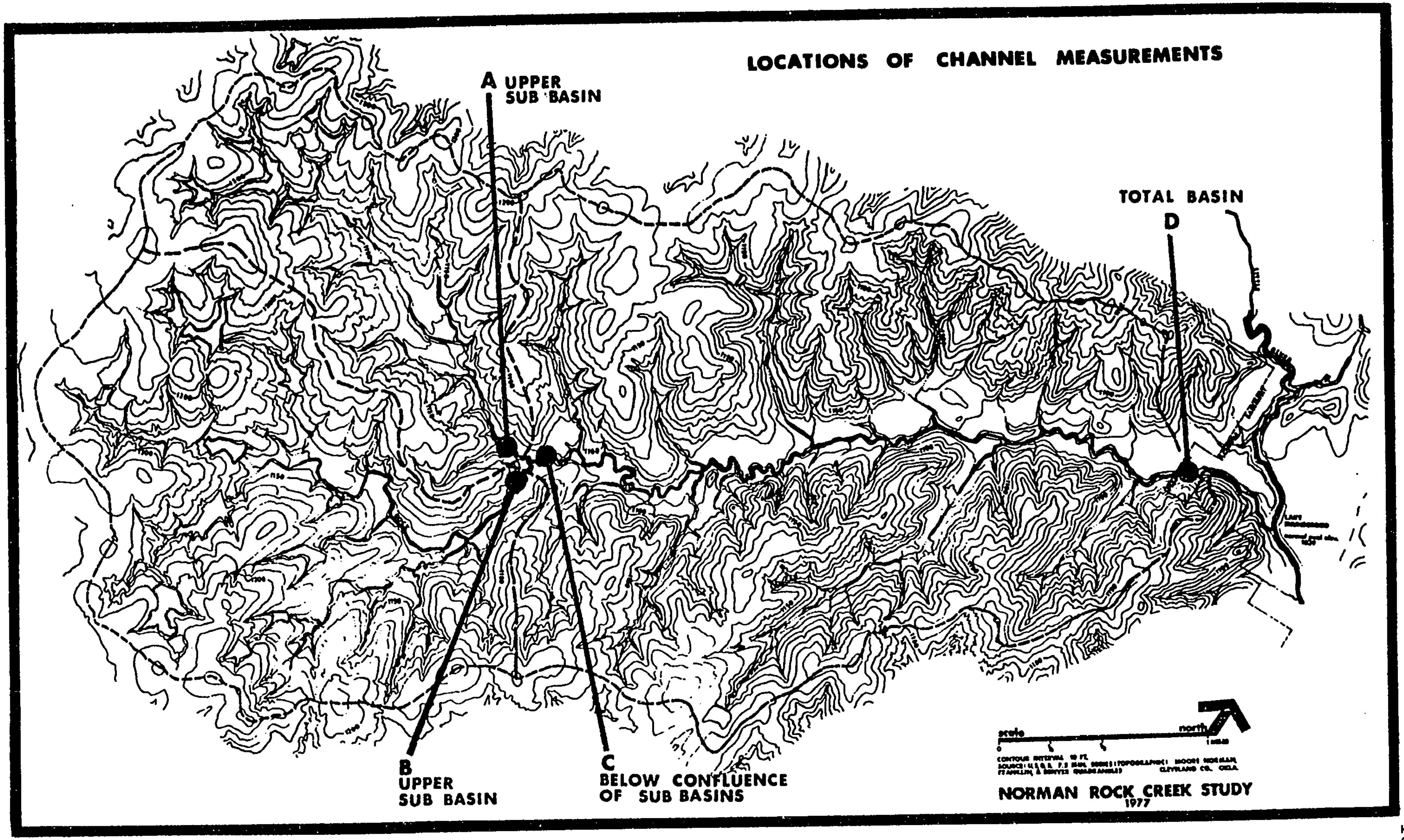
LOCATIONS OF CHANNEL MEASUREMENTS
A UPPER SUB BASIN
TOTAL BASIN
D
B
UPPER
SUB BASIN
C
BELOW CONFLUENCE
OF SUB BASINS
scale
north
NORMAN ROCK CREEK STUDY
1977

Figure 6.6

types have not significantly changed during the past 200 years. The vegetation which is naturally associated with each soil type is therefore assumed to be the community which occurred on a given site under pristine conditions. Figure 6.7 shows the reconstructed native vegetation and hydrologic soil groups and Table B.3 (Appendix B) provides the runoff curve numbers. The condition of the pristine soil cover complex is assumed to be "best". The resultant discharge hydrographs for the design storm under presettlement conditions are shown by sub basin areas in Figures 6.9 through 6.12 which follow these discussions.[9]

Present Land Use Runoff (Discharge)

Figure 6.8 shows the existing land use patterns in the Rock Creek Watershed.[10] Figures 6.9 through 6.12 illustrate the resultant discharge hydrographs for the design storm.

Standard Urban Development Runoff (Discharge)

If the watershed were to be completely opened to the typical urban development patterns what would the runoff hydrograph look like if the runoff management techniques (storm drains and improved channels) were also typical? To hypothetically develop the watershed with a typical urban pattern, a system of weighted coefficients of runoff is used. Clawson's table of "Land Use in Sample of Largest Cities in the United States, Circa 1966" is adapted to produce a percentage of various forms

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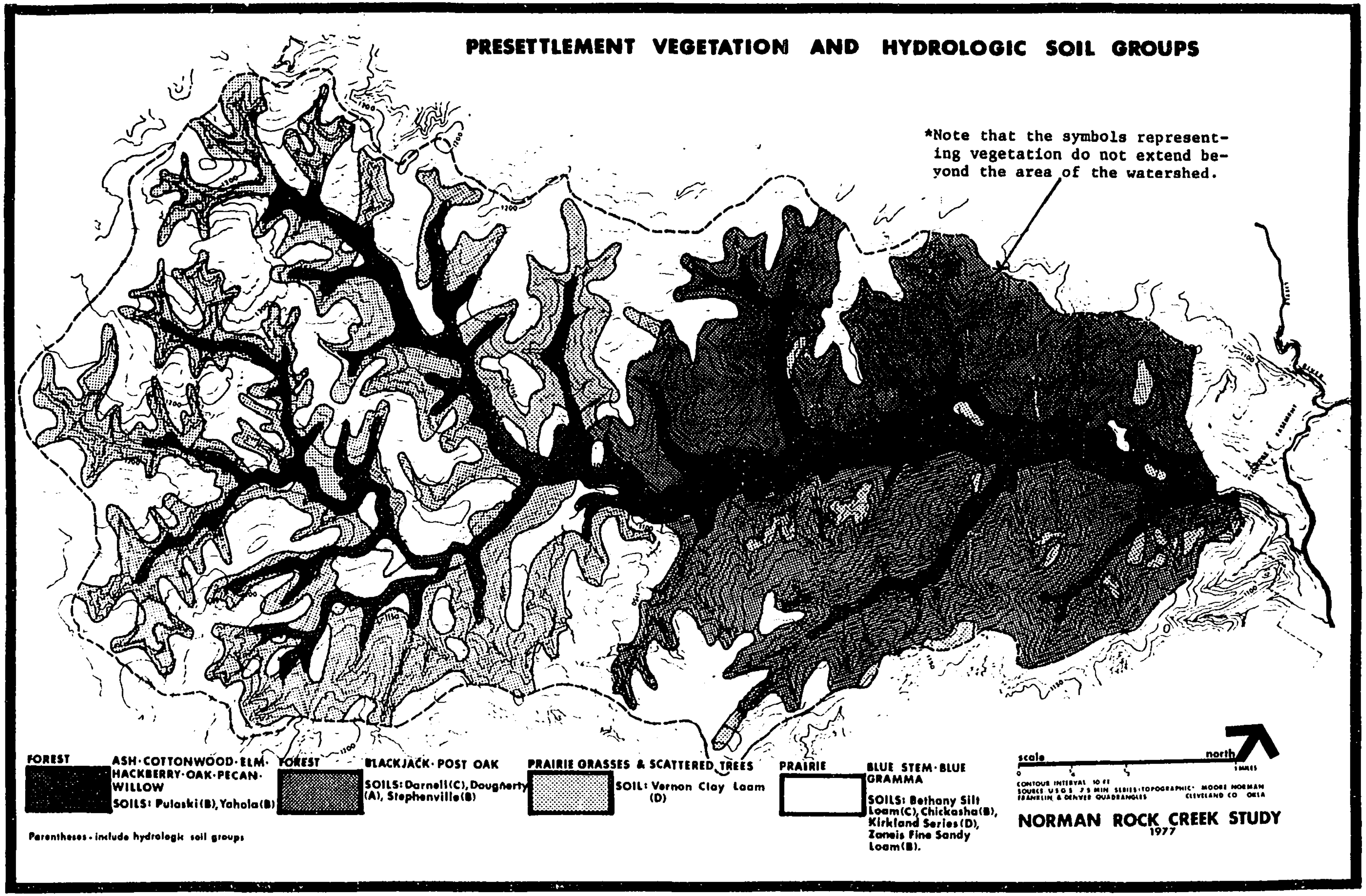
[9]Equations and computation methods for determining the discharge hydrographs for all of the alternative land use patterns and runoff management approaches can be found in Appendix D.

[10]Present land use patterns were determined by the use of four Oklahoma Department of Transportation 1"=600' Aerial Photos (April 1, 1976 flight date), Line 12, sheets 3 and 4, Line 13, sheets 3 and 4. The use pattern was checked by a field survey by automobile and July 1966 ownership records of Cleveland County Registrar of Deeds.



PRESETTLEMENT VEGETATION AND HYDROLOGIC SOIL GROUPS
*Note that the symbols representing vegetation do not extend beyond the area of the watershed.
FOREST
ASH·COTTONWOOD·ELM·HACKBERRY·OAK·PECAN·WILLOW
SOILS: Pulaski(B), Yahola(B)
FOREST
BLACKJACK·POST OAK
SOILS: Darnell(C), Dougherty (A), Stephenville(B)
PRAIRIE GRASSES & SCATTERED TREES
SOIL: Vernon Clay Loam (D)
PRAIRIE
BLUE STEM·BLUE GRAMMA
SOILS: Bethany Silt Loam(C), Chickasha(B), Kirkland Series(D), Zaneis Fine Sandy Loam(B).
Parentheses - include hydrologic soil groups
scale
north
CONTOUR INTERVAL 10 FT
NORMAN ROCK CREEK STUDY
1977

Figure 6.7

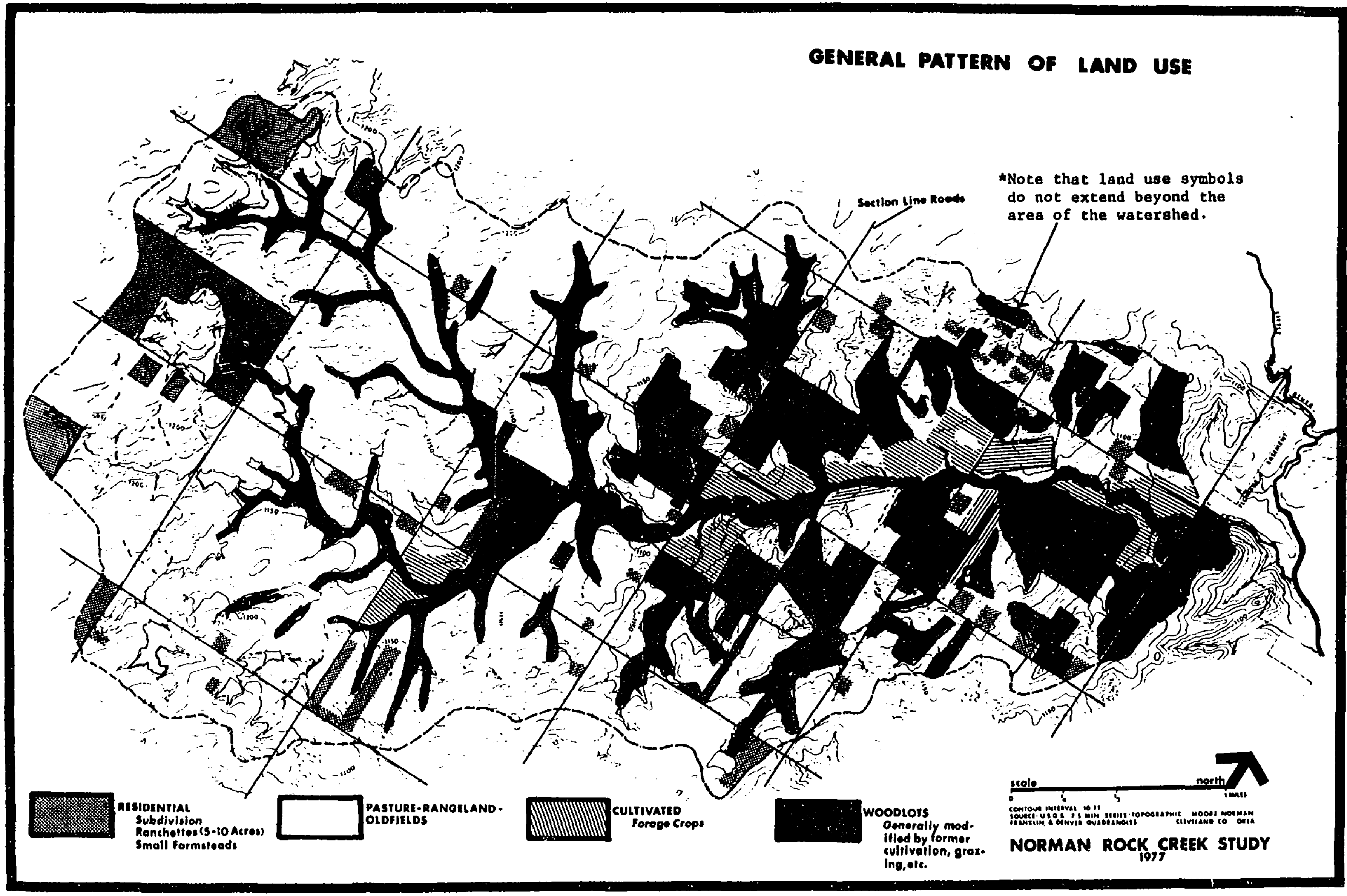

GENERAL PATTERN OF LAND USE
*Note that land use symbols do not extend beyond the area of the watershed.
Section Line Roads
RESIDENTIAL
Subdivision
Ranchettes (5-10 Acres)
Small Farmsteads
PASTURE-RANGELAND-OLDFIELDS
CULTIVATED
Forage Crops
WOODLOTS
Generally modified by former cultivation, grazing, etc.
scale
north
NORMAN ROCK CREEK STUDY
1977

Figure 6.8

of land use.[11] The coefficients of runoff are weighted according to the percentages. Figures 6.9 through 6.12 illustrate the resultant runoff hydrographs.

Full Development Runoff Hydrographs Under Detention Release Conditions

If the entire watershed were allowed to develop under a detention release runoff management network what could the discharge hydrographs be expected to look like? As in the case of the standard urban development pattern, the watershed is hypothetically urbanized. Clawson's land use percentages are reapplied with the residential lands being increased by the spaces allocated to uses which will not tend to occur in the basin (industrial, railroads, airports, and other).[12] The only pattern change from the standard format which is assumed to result due to the use of the detention release approach is the tendency for residential land use to cluster. The clustering tendency is a result of the economies gained in efficient and less expensive detention structures and the per capita runoff function discussed in Chapter Five. As a result, the adjustment of the land use percentage table will reflect an increase in multifamily residential uses, and increase in open space, a reduction in single family residential coverage, and a

[11]Clawson, Suburban Land Conversion in the United States, p. 48. The changes included the elimination of the industrial railroads, airports, and other percentages and the increases in residential. The residential pattern is assumed to include single family 38% (of total) and apartments 3% (of total). These changes are made based on the author's judgement on the location and character of the watershed and the realistic probability of its development under typical conditions. Adjustment is also necessitated due to the fact that Clawson's table does not total out to 100% as stated.

[12]Ibid.

Table 6.1

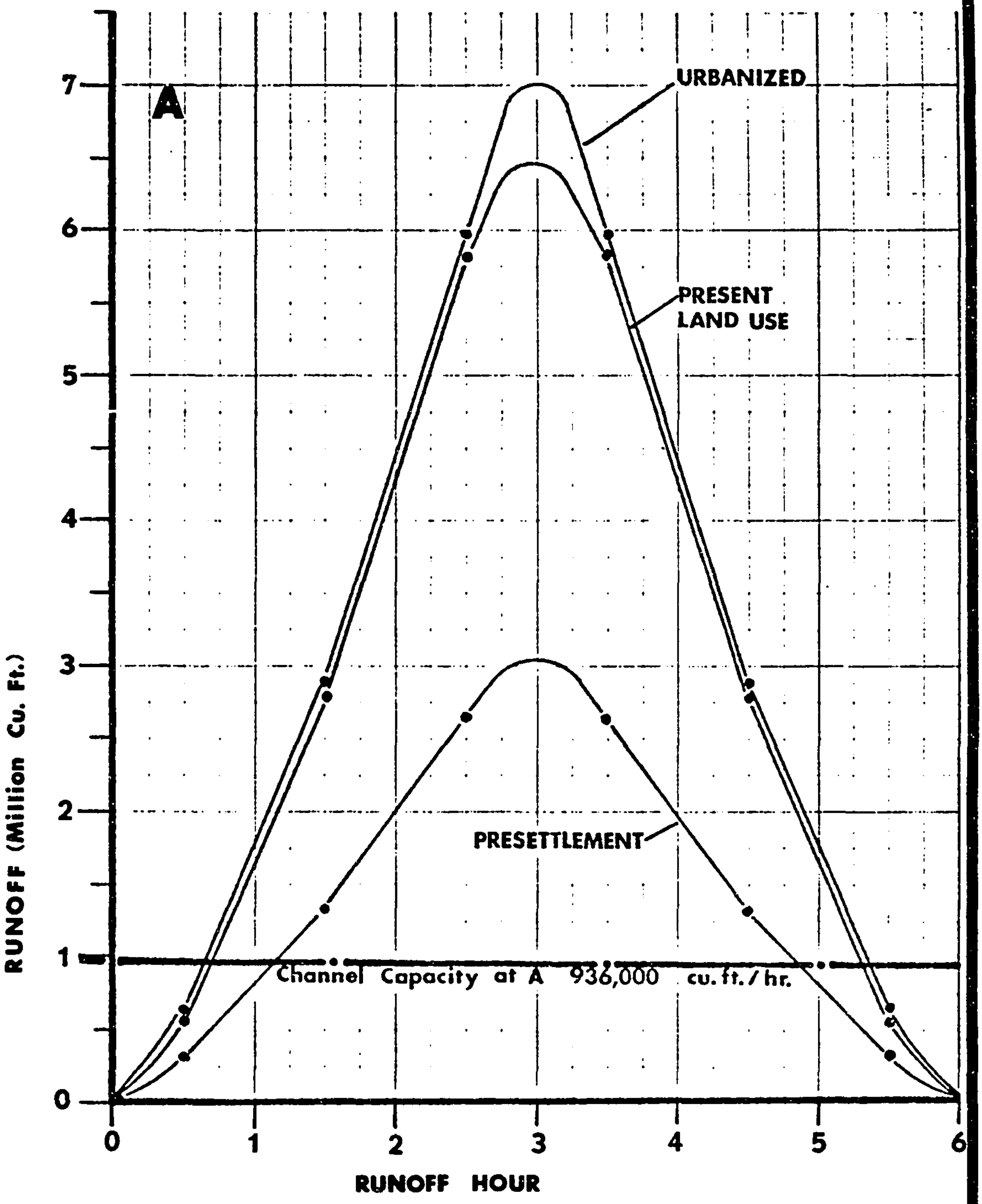
Land Use Percentages to be Applied in the Urbanization of Rock Creek Basin: Traditional Pattern

Type of Land Use	Percent of Land Area*	Adjusted Percentages**
Total	100	100
Public Streets	17.5	19.5
Total Excluding Public Streets	82.5	80.5
Privately Owned, Total	67.4	72.0
Residential (Apartments)	0	3.0
(Single Family)	31.6	40.6
Commercial	4.1	4.1
Industrial	4.7	0
Railroads	1.7	0
Undeveloped	22.3	24.3
Public and Semipublic Excluding Streets - Total	13.7	8.5
Recreation Areas	4.9	4.9
Schools and Colleges	2.3	2.1
Airports	2.0	0
Cemeteries	1.0	1.0
Public Housing	0.5	0.5
Other (by Subtraction)	3.0	0

* The source's figures do not add up to 100%

** Percentages adjusted by elimination or reduction of land uses such as railroads which were not likely to occur in the Rock Creek basin and increasing land uses such as residential which are more likely to occur.

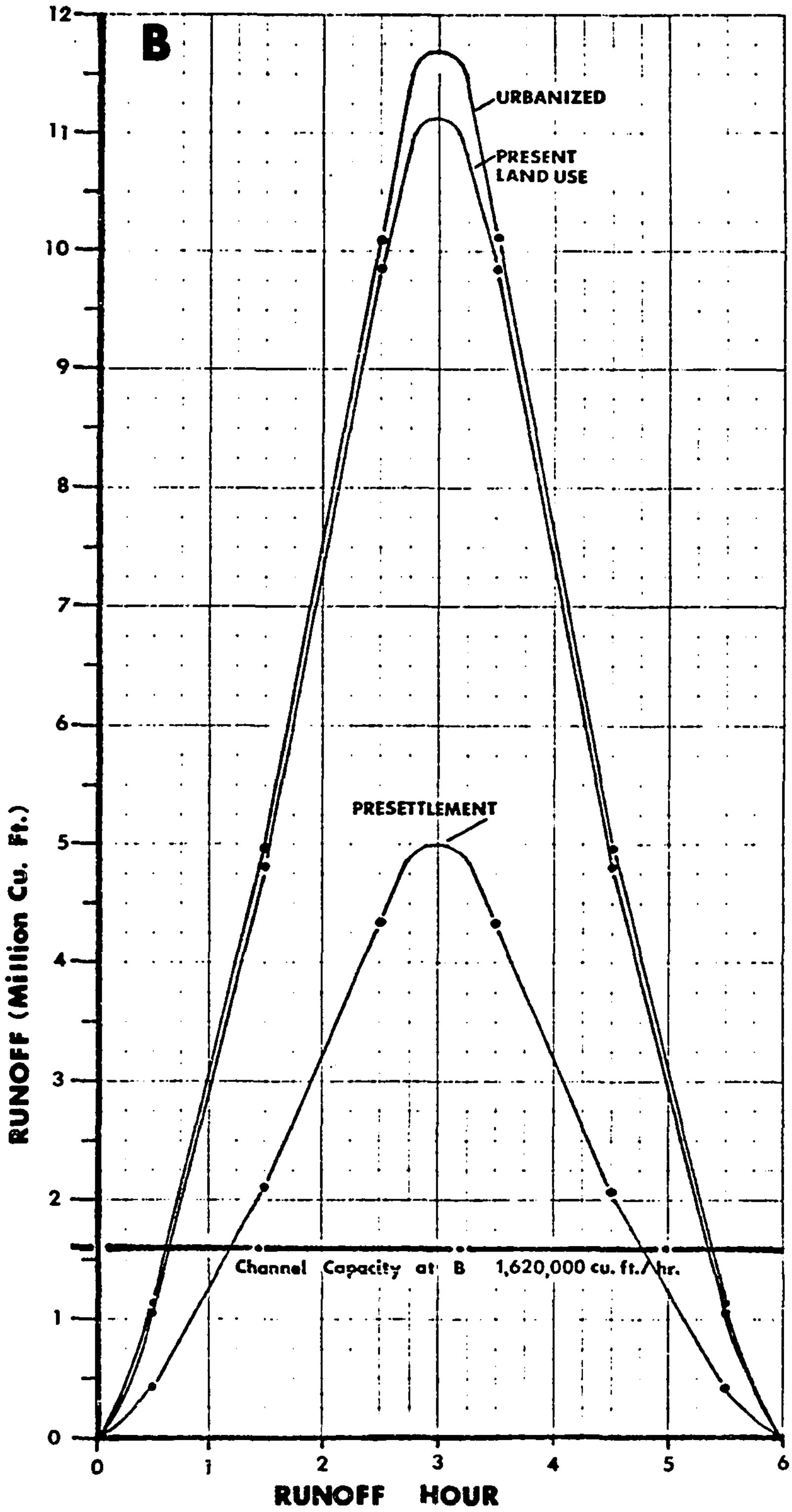
Source: Adapted from Marion Clawson, "Land Use in Sample of Largest Cities in the United States, Circa 1966", in Suburban Land Conversion in the United States (Baltimore: Johns Hopkins Press, 1971), p.49.



*The channel capacity line is based on the capacity in cusecs (Table C.1) multiplied by 3600 seconds per hour. The portion of the hydrograph above the capacity line represents overbank flow.

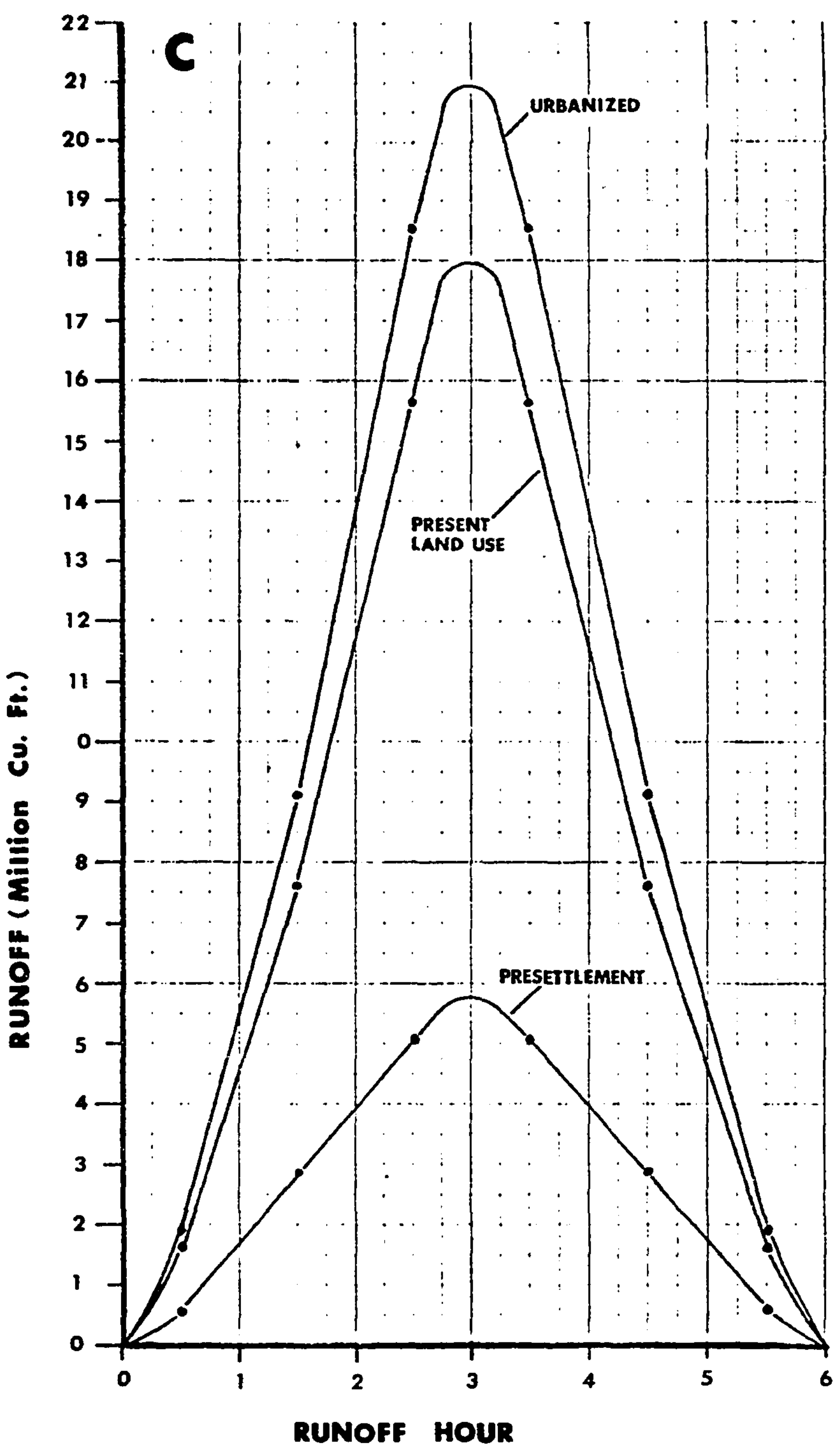
RUNOFF HYDROGRAPHS: SUB BASIN A

Figure 6.9



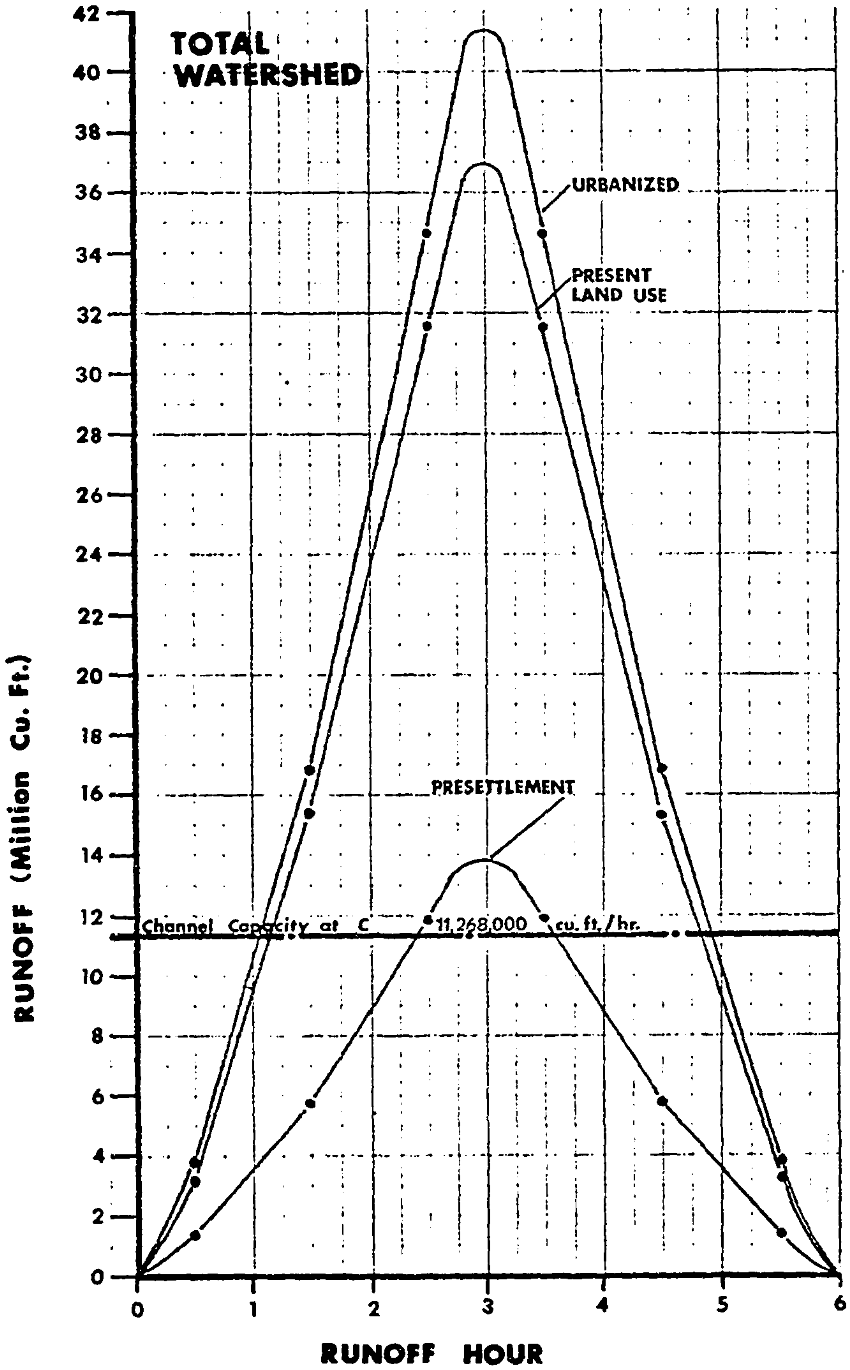
RUNOFF HYDROGRAPHS: SUB-BASIN B

Figure 6.10



RUNOFF HYDROGRAPHS: AREA C

Figure 6.11



RUNOFF HYDROGRAPHS: TOTAL BASIN

Figure 6.12

slight reduction in public streets.[13] Table 6.2 lists the adjusted percentage coverage by land use type. Because the difference in runoff resulting from the modification of urbanization was less then .5% (Appendix D), the same hydrograph as the one produced by typical urban development will be used. When placed in a detention release system, however, the runoff is accumulated and released at a rate designed not to exceed channel capacity. The capacity line is shown in the hydrograph figures. The discharge hydrograph as modified by the detention release concept rises to the capacity line and follows it until all of the water which has been temporarily stored in the system is released.

Analysis of the Runoff Hydrographs

Each of the four hydrograph figures displays the runoff in its respective basin area while comparing the runoff volumes of different land use alternatives in those areas. Two major comparative elements appear in the hydrographs. The first involves channel capacities and the second centers on the effects of different land uses.

With the exception of Area C which contributes flow at various points along the main channel of Rock Creek, each of the other areas and the basins as a whole flow through a measure point where a channel capacity has been determined. In the case of the design storm, flooding will be more severe in the upper reaches (Areas A and B) than at the

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[13]Public street coverage is generally lessened due to design efficiencies gained in clustering. The reduction estimate is conservative. When keeping residential density relatively constant, the development of multifamily structures frees space normally covered by single family detached structure. Even when increasing residential density as a bonus to planned unit or cluster developers the amount of open space will still tend to increase significantly.

Table 6.2

Land Use Percentages to be Applied in the Urbanization of Rock Creek Basin: Pattern Associated with Detention Systems [13]

Type of Land Use	Percent of Land Area*	Adjusted Percentages
Total	100.0	100.0
Public Streets	17.5	17.0
Total Excluding Public Streets	82.5	83.0
Privately Owned, Total	67.4	62.4
Residential (Single Family Detached)	31.6	16.0
(Multi-Units Detached)	0	9.0
(Multi-Units Attached)	0	6.0
(Apartments)	0	3.0
Commercial	4.1	4.1
Industrial and Railroads	6.4	0
Undeveloped	22.3	24.3
Public and Semipublic Excluding Streets	13.7	20.6
Recreation Areas	4.9	4.9
Open Space	0	12.1
Schools and Colleges	2.3	2.1
Airports	2.0	0
Cemeteries	1.0	1.0
Public Housing	0.5	0.5
Other (by Subtraction)	3.0	0

* The source's figures do not add up to 100%

Source: Adapted from Marion Clawson, "Land Use in Sample of Largest Cities in the United States, Circa 1966", in Suburban Land Conversion in the United States (Baltimore: Johns Hopkins Press, 1971), p.49.

[13]The residential adjustment was attained by assuming that the apartment market remained constant as 3% and the remaining 40.6% divided between single family (16%), multi-units detached (12%), and multi-units attached (12%). At 9 units per acre the multi-units detached achieve the same number of residences as single family (6 units per acre) on 25% less land. At 12 units per acre multi-units attached use 50% less land to equal the same number of residences as single family. The 3% and 6% land areas not used as a result were placed in a semipublic open land category.

base of the watershed. Release rates will therefore be computed based on the more limited capacities of the channels in the higher areas of Rock Creek. As a result the channel at the base of the watershed will not reach capacity under a detention release system. Using channel capacity limitations, Table 6.3 gives the times of release from detention by land use for Areas A and B. Streams in Area C and the lower basin will be at lesser capacities which will drain in approximately the same time.

Table 6.3

Times of Detention Release from Sub Basins A and B

	Total Runoff (Cubic Feet)	Rate of Release (Cubic Feet)		Drainage Completed (Hours After Storm)
		Per Hour	*During Storm	
AREA A				
Presettlement	8,293,498	936,000	5,616,000	2.9
Present Land Use	18,629,276	"	"	13.9
Urbanized	18,813,224	"	"	14.1
AREA B				
Presettlement	13,699,358	1,620,000	9,720,000	2.4
Present Land Use	31,302,962	"	"	13.3
Urbanized	32,204,684	"	"	13.9

*The duration of the design storm is 6 hours.

The hydrographs produced by the presettlement land use are considerably less than present land use and urbanization in all areas. In fact the 100 year storm produced only a minor flood problem at the base of the watershed under presettlement conditions. The difference between hydrographs of present land use and urbanization is minimal. The greatest difference occurs during the critical peak flow period. The conclusion is that Rock Creek is already experiencing runoff during

100 year storms which is nearly as severe as can be expected even when the basin is urbanized (in a suburban residential pattern).[15] Presently however, the flows are running through uninhabited lowlands and undeveloped flood plains.

Applying the Detention Requirements to an Example Tract of Land

A half section of undeveloped land in Sub basin B was selected by the author for the purpose of demonstrating the detention requirements at the ownership level. Figure 6.13 shows the location of the tract. The area was selected because it was located where ownership did not control an entire drainage unit. Other ownerships were above flowing in to it, and below receiving flows from it. Figure 6.14 shows the ownership patterns and the local drainage. Three owners are involved as possible developers while two others on very small tracts simply continue to use their lands as before.[16]

Area B has 2,174 acres and a channel with the capacity of 450 cubic feet per second at the mouth. If all of the land had an equal share of

---

[15]The similarity between the present land use and the urbanization hydrographs can be traced to three general causes. First, residential tracts, after construction, are not necessarily the major cause of increased runoff associated with urbanization. Large commercial, industrial, multifamily residential, streets, and construction sites increase runoff more significantly. Second, the hydrologic soil groups in the Rock Creek basin are, in their natural state, conducive to generating runoff. Therefore, even in an undeveloped condition, runoff is significant. Third, the primary difference in the runoff hydrographs of the present land use and the presettlement uses may be attributed to the condition of the vegetative cover. Presently, much of the land in the basin is divided into small farmsteads, ranchettes, and lands which are grazed and which are beginning to grow a shrub and (eventually) forest cover. The determinations of hydrologic soil groups and runoff curve numbers and coefficients are made in Appendix B. The computations of measured areal characteristics and weightings, which resulted in the runoff hydrographs are made in Appendix D.

[16]The 36 acre tract in the northwest corner belongs to the city of Norman which, for purposes of example, will be viewed as a developer.

the channel capacity each acre would be allowed to discharge .2 cubic feet of runoff every second (120 cubic feet per hour). Runoff in excess of .2 cusecs per acre must be retained somewhere in the detention system near that acre.[17] The developer is required to come up with a detention release plan which is no more complicated than the drainage plan he is presently required to submit under most subdivision ordinances. The

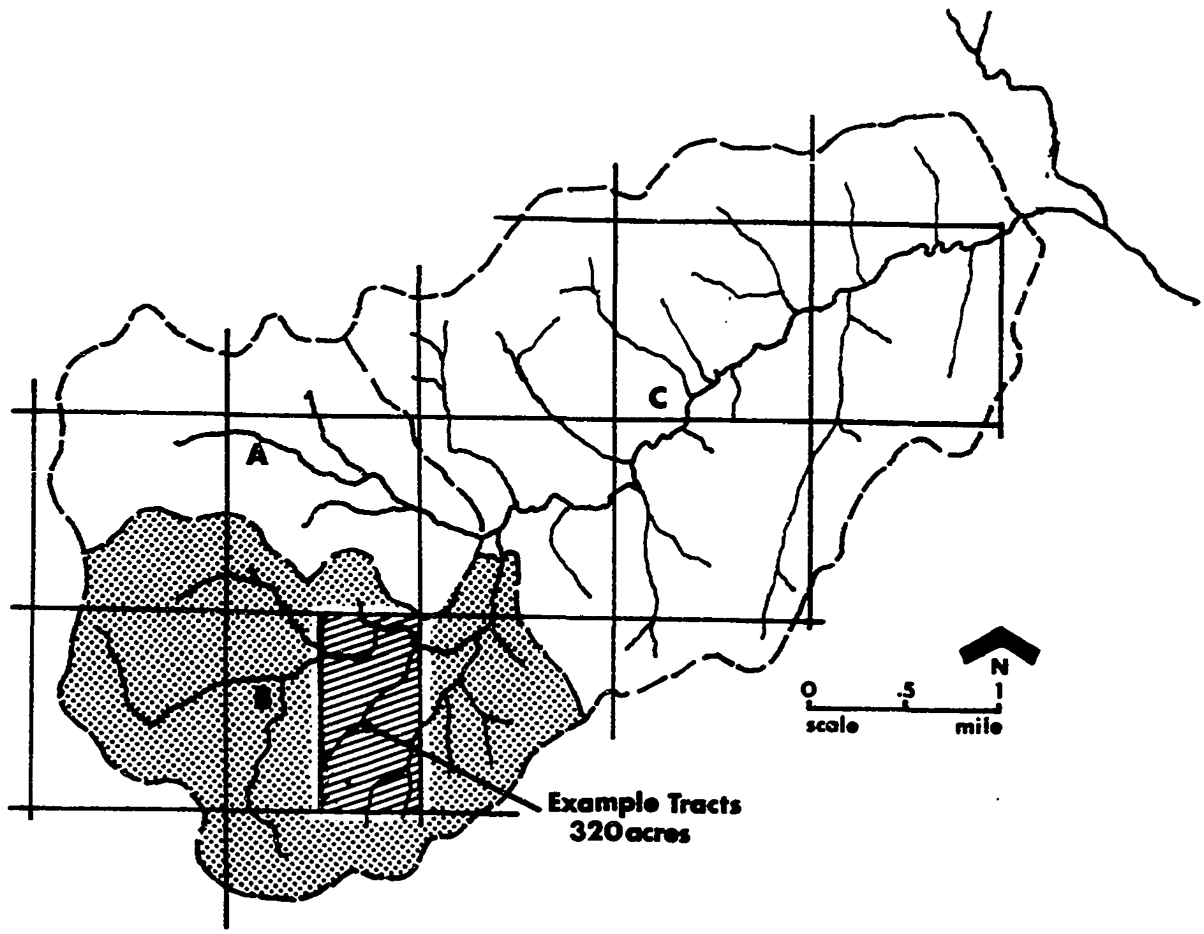

Fig. 6.13--Location of Example Tracts

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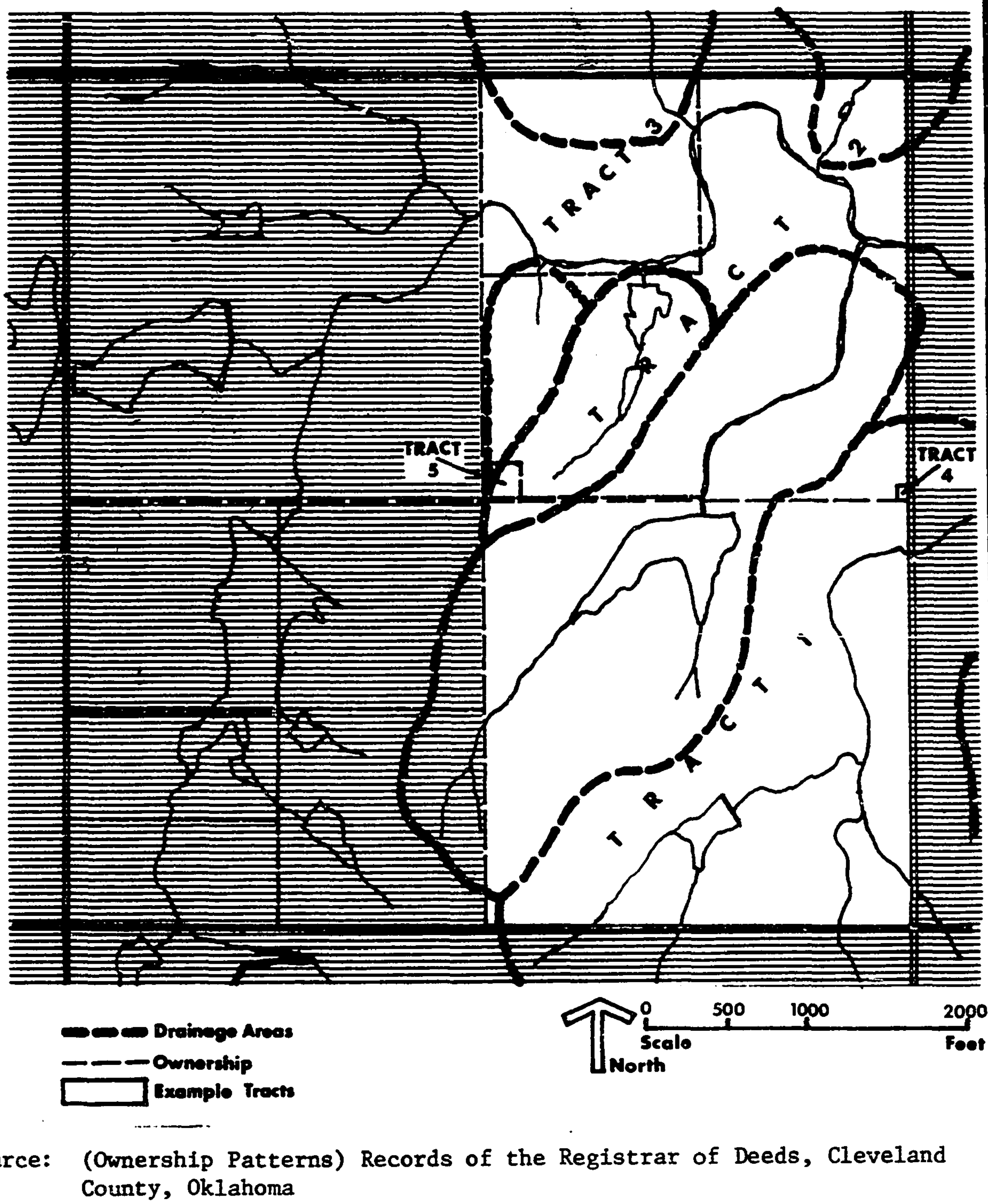
[17]The concept of detention "near that acre" acknowledges that damaging accumulations become more probable as the distance between the area which generates the runoff, and the place where the runoff is detained increases.

EXAMPLE TRACTS: DRAINAGE AND OWNERSHIP



Source: (Ownership Patterns) Records of the Registrar of Deeds, Cleveland County, Oklahoma

Figure 6.14

plan calculates the allowed runoff coming into the acreage (.2 cusecs per upstream acre), determines the amount to be released by the developed acreage, and subtracts that from the amount of runoff his development will produce under design storm conditions. The balance is kept in temporary storage structures which constitutes part of the detention plan.

Figure 6.15 lists the acreage by drainage area and by ownership parcel. The figure also shows the acreages lost to other drainage areas from the example ownership tracts and the acreages contributing to the tracts from the outside. Finally Figure 6.16 shows an input-output allowable flows diagram. Arrows designate the direction and amount of allowable flow (in cusecs).

Two Alternative Land Use Patterns and Detention Solution Scenarios

Given the allowable flows plan (Figure 6.16) the detention plan is simply what the developer is going to do with the runoff that is in excess of that which is shown in the allowable flows diagram. The amount of excess depends upon the pattern and intensity of land use and the resultant coefficients of different land use.

Scenario 1 - Single Family Detached Residential[18]

All three developers elect to go with the traditionally safe suburban single family market. The lots are slightly larger than usual

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[18]The example tract of land is located within the incorporated limits of the City of Norman, Oklahoma. Because the tract is situated outside (to the east) of the municipally sewered basin, land uses which produce effluent are limited to densities which can be served by individual septic tanks and tile fields. This is particularly critical since the Rock Creek watershed drains into Lake Thunderbird which is Norman's primary water supply. Norman presently permits one home per each 2 to 5 acres (residential estates) which would not allow the residential densities introduced in the following scenario. It is assumed, however, that if it can be demonstrated that the quality of

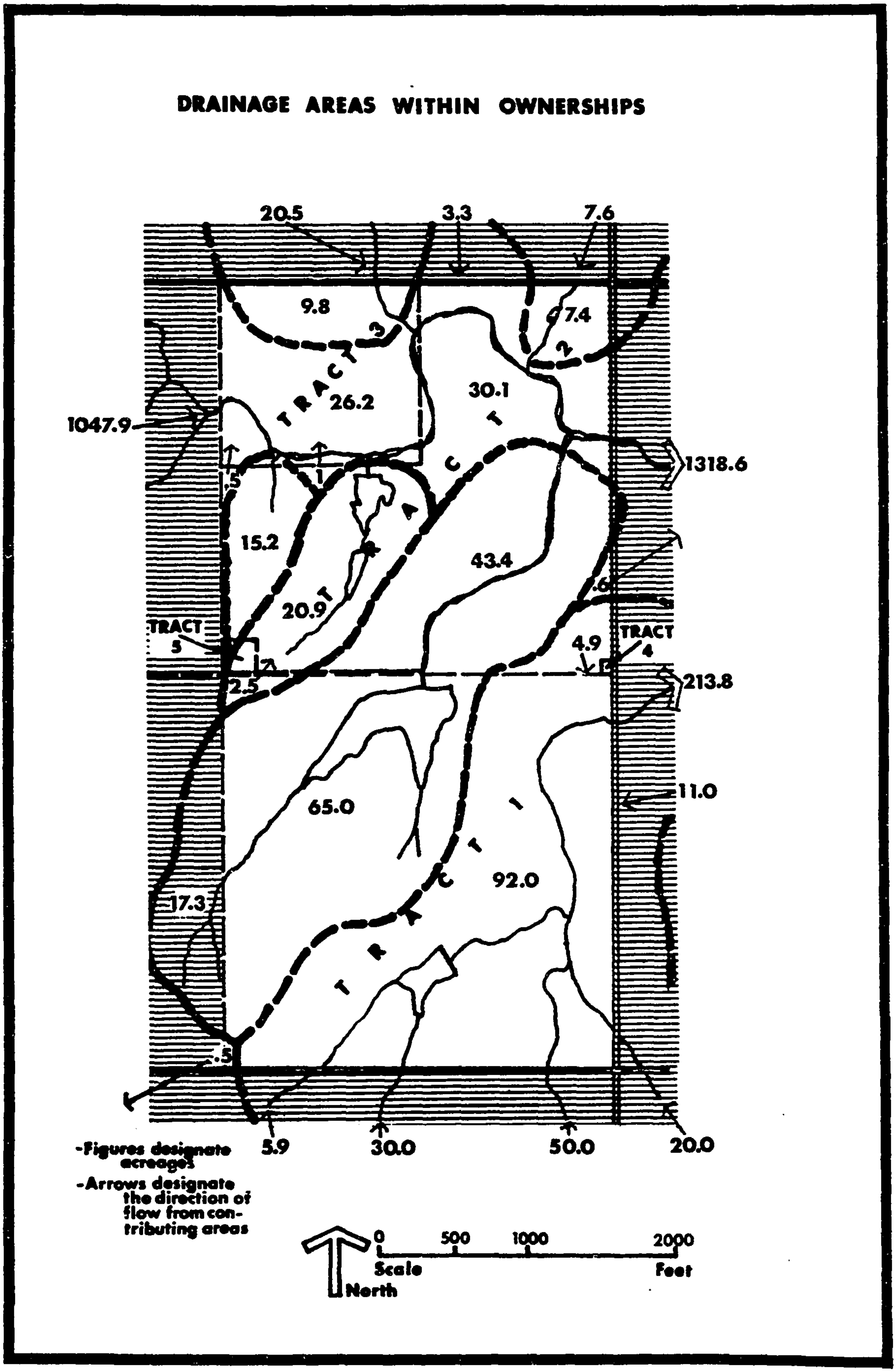
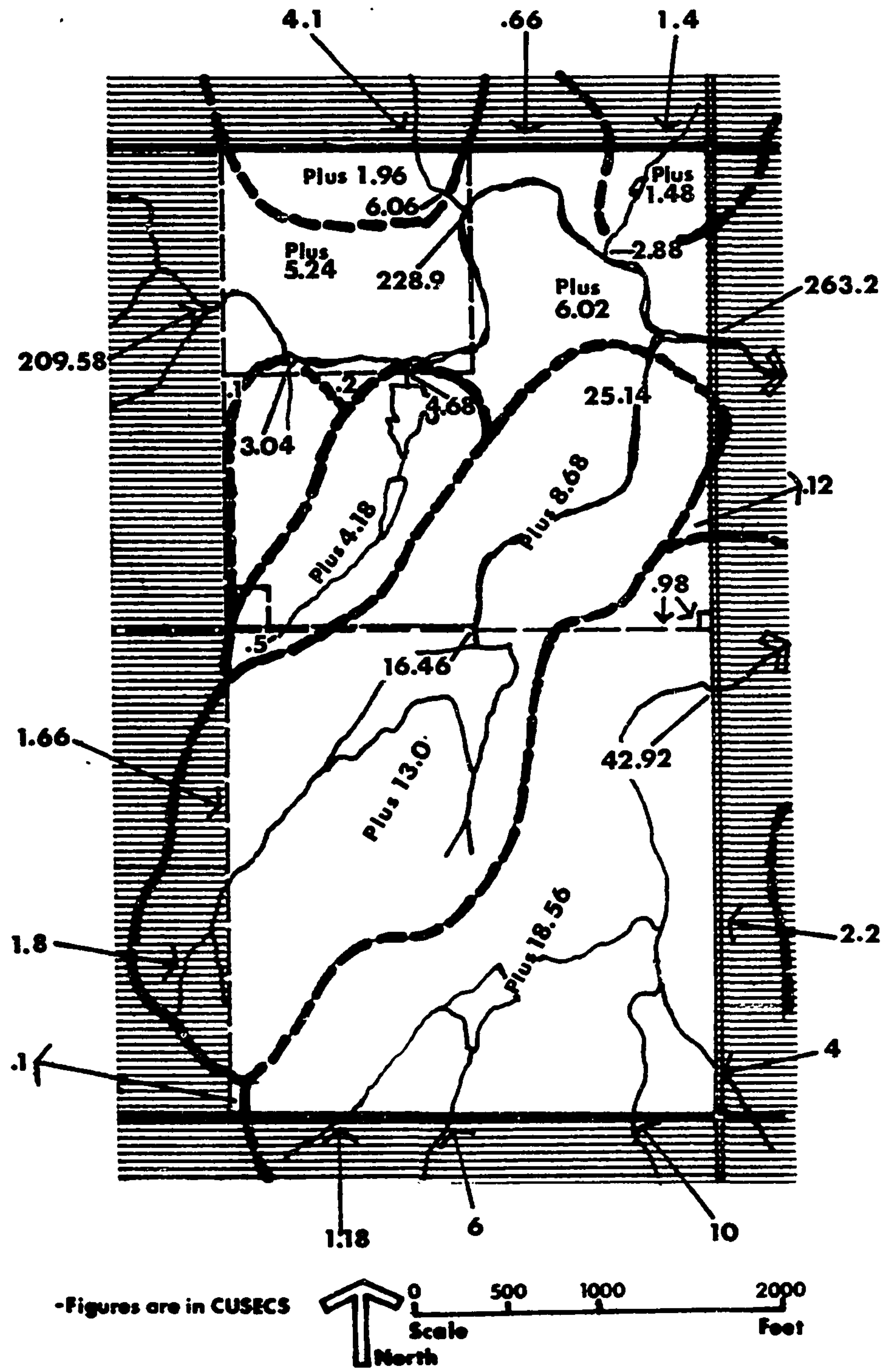

DRAINAGE AREAS WITHIN OWNERSHIPS
20.5
3.3
7.6
9.8
7.4
TRACT 3
TRACT 2
26.2
30.1
1047.9
1318.6
.5
1
15.2
43.4
20.9
.6
TRACT 5
TRACT 4
4.9
2.5
213.8
65.0
11.0
TRACT 1
92.0
17.3
.5
5.9
30.0
50.0
20.0
-Figures designate acreages
-Arrows designate the direction of flow from contributing areas
0
500
1000
2000
Scale
Feet
North

Figure 6.15



ALLOWABLE RATES OF FLOW PLAN

Figure 6.16

(5 homes per acre) since the homes will be built for sales in the $70,000 to $90,000 range. The coefficient of runoff is .59.[19] Figure 6.17 shows the detention requirements for the design storm by tract and drainage area for the tracts.[20] Figures 6.18 and 6.19 demonstrate the detention solution options and methods for Tracts 2 and 3. The individual site solutions presented in the figure-scenario attempt to illustrate both the wide range of options in meeting the detention performance standards as well as the simplicity of solving runoff problems heretofore met by a channel capacity improvement mentality.

---

water in the basin or lake is not compromised by more intensive development, the present low density zoning can be changed. One of the conclusions made in this study is that the proposed detention system's approach is likely to be compatible with water quality management efforts. Localized detention tends to contain pollutants near their sources, tends to reduce sediment load potentials and erosion, and as a basin wide system is identical with the water quality management area modules designated in recent federal legislation.

[19]A coefficient of runoff of .59 will cause 3.658 inches of runoff during a 6.2 inch rainfall. One cubic foot of runoff requires 3.28 square feet of land (or 13,280.5 cubic feet per acre during the 6 hour storm). The formula for the detention requirement for each drainage area within the tract is: 13,280.5 X (the number of acres) - (the allowable flow over the 6 hour period). Note that the flows allowed to come into the tract from upper reaches are allowed to pass through the example area at the same rate and do not effect the detention requirement. It will effect the rate of release allowed from the detention structure if it lies along the path of the upper area flows.

[20]The detention requirement is the cubic feet of detention storage needed to store the total amount of runoff for a 6 hour storm less that which is allowed to be released during the same 6 hour period. The release calculation is cusecs X 60 seconds X 60 minutes X 6 hours. The release orifaces in the detention structure are designed to continuously release the allowable cusecs based on the number of acres draining into the device.

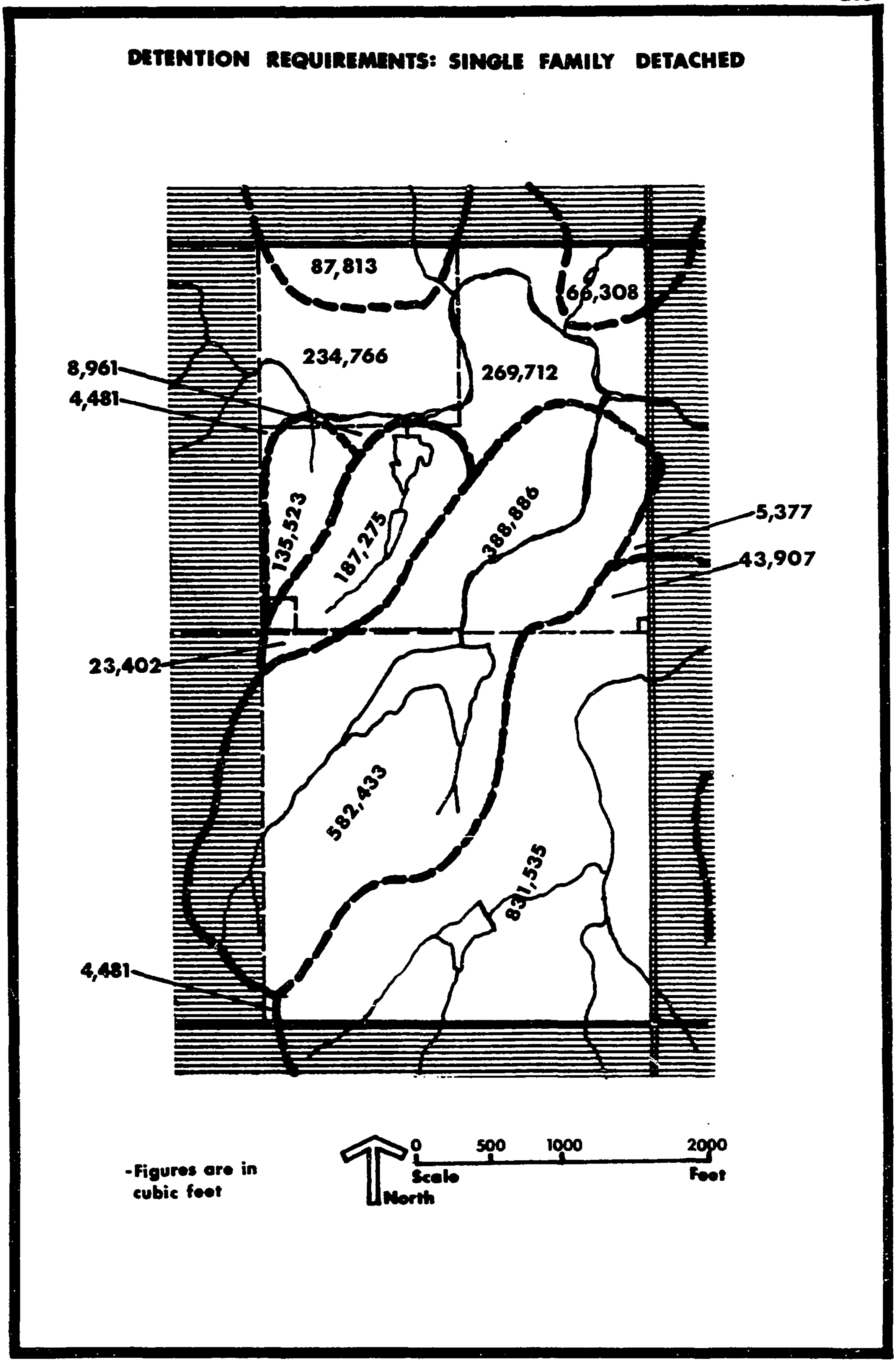

DETENTION REQUIREMENTS: SINGLE FAMILY DETACHED
87,813
234,766
269,712
8,961
4,481
135,523
187,275
388,886
5,377
43,907
23,402
582,433
831,535
4,481
-Figures are in cubic feet
0
500
1000
2000
Scale
Feet
North

Figure 6.17

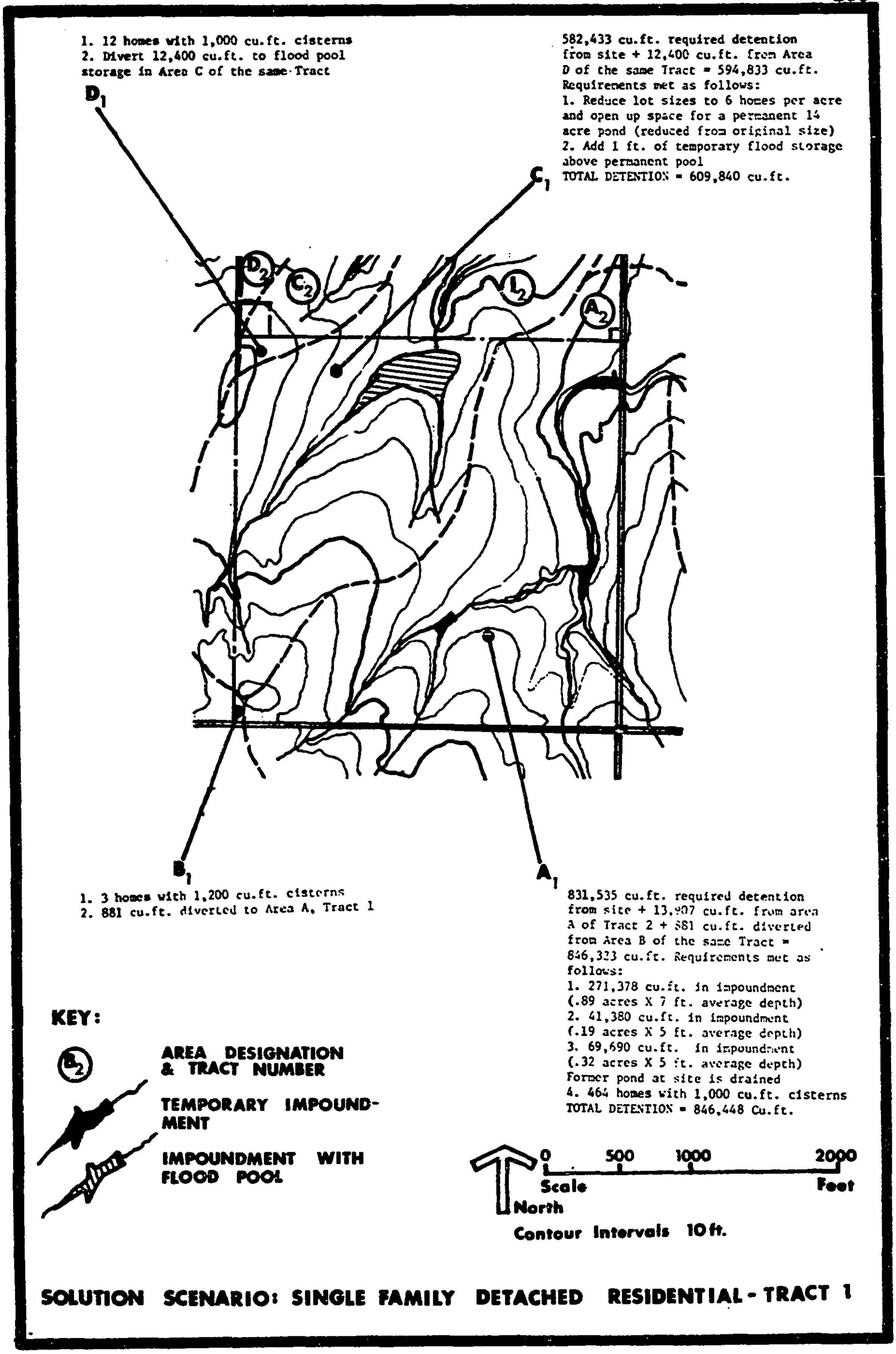

1. 12 homes with 1,000 cu.ft. cisterns
2. Divert 12,400 cu.ft. to flood pool storage in Area C of the same Tract
D1
582,433 cu.ft. required detention from site + 12,400 cu.ft. from Area D of the same Tract = 594,833 cu.ft. Requirements met as follows:
1. Reduce lot sizes to 6 homes per acre and open up space for a permanent 14 acre pond (reduced from original size)
2. Add 1 ft. of temporary flood storage above permanent pool
TOTAL DETENTION = 609,840 cu.ft.
C1
D2
C2
B2
A2
B1
1. 3 homes with 1,200 cu.ft. cisterns
2. 881 cu.ft. diverted to Area A, Tract 1
A1
831,535 cu.ft. required detention from site + 13,907 cu.ft. from area A of Tract 2 + 881 cu.ft. diverted from Area B of the same Tract = 846,323 cu.ft. Requirements met as follows:
1. 271,378 cu.ft. in impoundment (.89 acres X 7 ft. average depth)
2. 41,380 cu.ft. in impoundment (.19 acres X 5 ft. average depth)
3. 69,690 cu.ft. in impoundment (.32 acres X 5 ft. average depth)
Former pond at site is drained
4. 464 homes with 1,000 cu.ft. cisterns
TOTAL DETENTION = 846,448 Cu.ft.
KEY:
B2
AREA DESIGNATION & TRACT NUMBER
TEMPORARY IMPOUNDMENT
IMPOUNDMENT WITH FLOOD POOL
0
500
1000
2000
Scale
Feet
North
Contour Intervals 10 ft.
SOLUTION SCENARIO: SINGLE FAMILY DETACHED RESIDENTIAL - TRACT 1

Figure 6.18

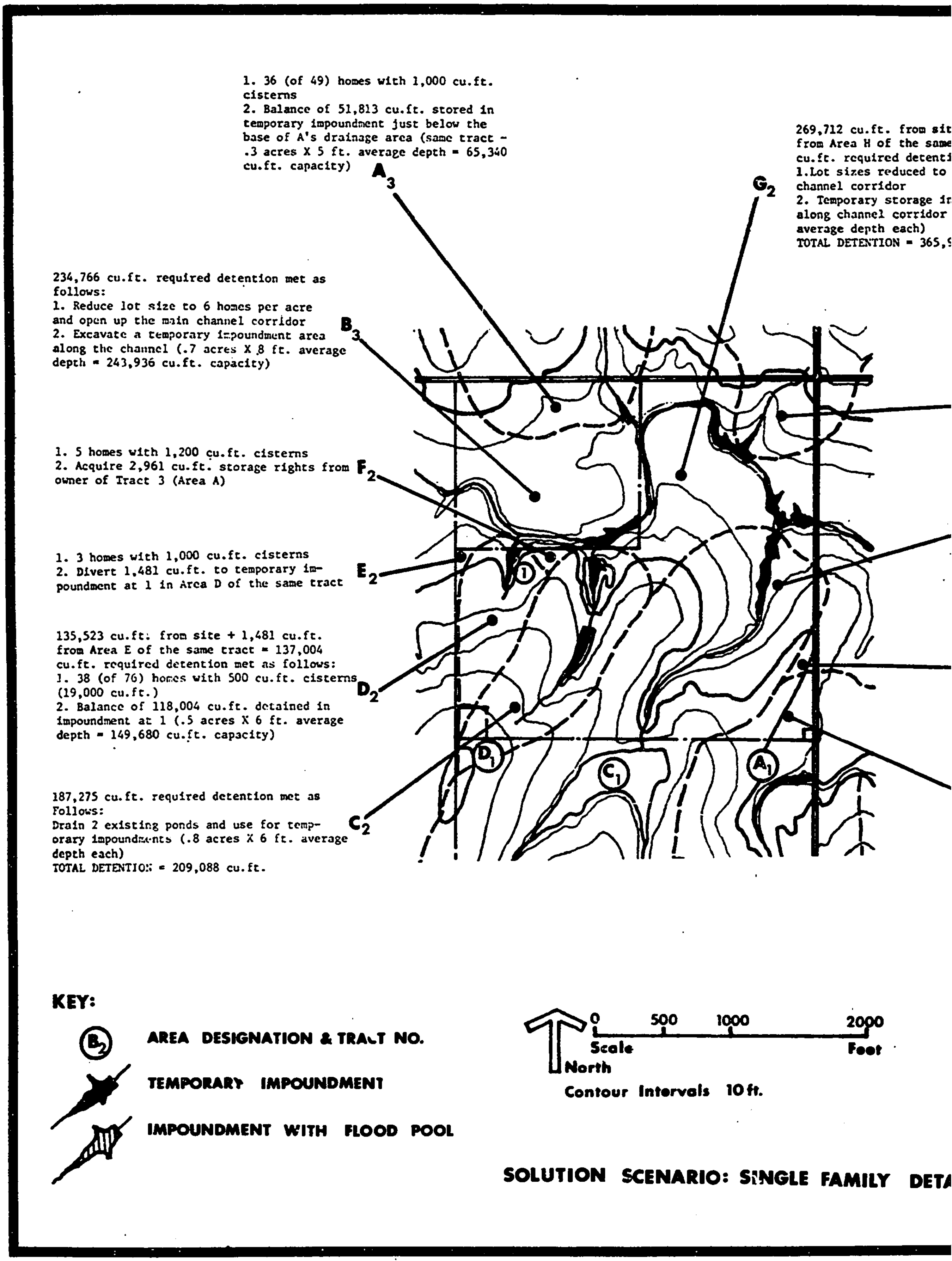

1. 36 (of 49) homes with 1,000 cu.ft. cisterns
2. Balance of 51,813 cu.ft. stored in temporary impoundment just below the base of A's drainage area (same tract - .3 acres X 5 ft. average depth = 65,340 cu.ft. capacity)
A_3
269,712 cu.ft. from sit
from Area H of the same
cu.ft. required detenti
1.Lot sizes reduced to
channel corridor
2. Temporary storage in
along channel corridor
average depth each)
TOTAL DETENTION = 365,9
G_2
234,766 cu.ft. required detention met as follows:
1. Reduce lot size to 6 homes per acre and open up the main channel corridor
2. Excavate a temporary impoundment area along the channel (.7 acres X 8 ft. average depth = 243,936 cu.ft. capacity)
B_3
1. 5 homes with 1,200 cu.ft. cisterns
2. Acquire 2,961 cu.ft. storage rights from owner of Tract 3 (Area A)
F_2
1. 3 homes with 1,000 cu.ft. cisterns
2. Divert 1,481 cu.ft. to temporary impoundment at 1 in Area D of the same tract
E_2
135,523 cu.ft. from site + 1,481 cu.ft. from Area E of the same tract = 137,004 cu.ft. required detention met as follows:
1. 38 (of 76) homes with 500 cu.ft. cisterns (19,000 cu.ft.)
2. Balance of 118,004 cu.ft. detained in impoundment at 1 (.5 acres X 6 ft. average depth = 149,680 cu.ft. capacity)
D_2
187,275 cu.ft. required detention met as Follows:
Drain 2 existing ponds and use for temporary impoundments (.8 acres X 6 ft. average depth each)
TOTAL DETENTION = 209,088 cu.ft.
C_2
1
D_1
C_1
A_1
KEY:
B_2 AREA DESIGNATION & TRACT NO.
TEMPORARY IMPOUNDMENT
IMPOUNDMENT WITH FLOOD POOL
0 500 1000 2000
Scale Feet
North
Contour Intervals 10 ft.
SOLUTION SCENARIO: SINGLE FAMILY DETA

Figure 6.19

from site + 47,808 cu.ft.
the same tract = 317,520
detention met as follows:
uced to 6 per acre to open
r
orage in 2 impoundments
orridor (1.4 acres X 6 ft.
ach)
= 365,904 cu.ft.

H_2

1. 37 homes with 500 cu.ft. cisterns
2. Divert balance of 47,808 cu.ft. to Area G of the same tract

I_2

388,886 cu.ft. required detention met as follows: an impoundment at the base of the drainage area (1.2 acres X 8 ft. average depth = 418,176 cu.ft. capacity)

B_2

1. 3 homes with 1,000 cu.ft. cisterns
2. Acquire storage rights for 2,377 cu.ft. balance from owner of tract to the east

A_2

1. 25 homes with 1,200 cu.ft. cisterns
2. Divert 13,907 cu.ft. to impoundment 1 in Area A of Tract 1 (acquired storage)

DETACHED RESIDENTIAL- TRACTS 2 & 3

Scenario 2 - Multifamily Detached Residential

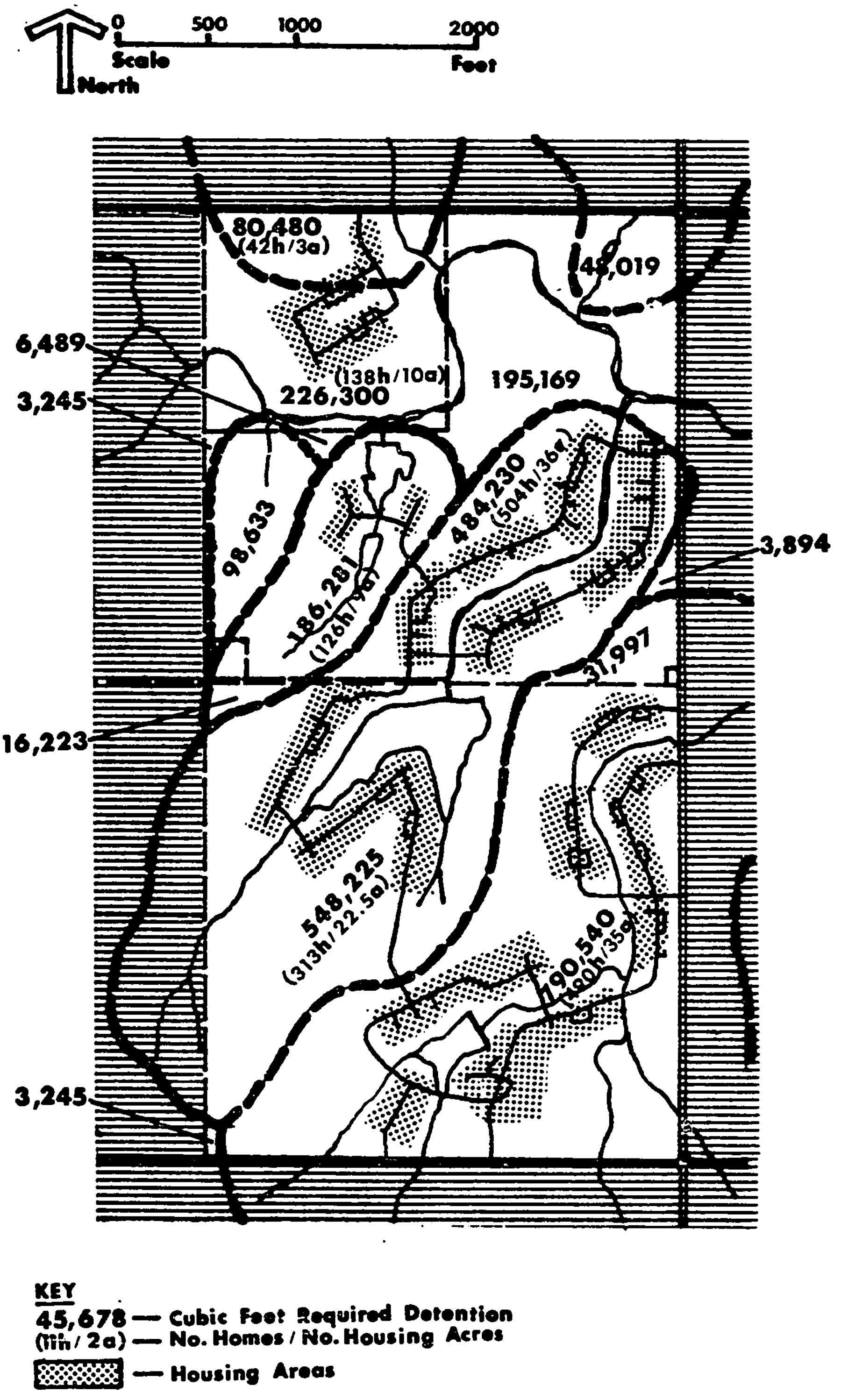
To provide a significantly different pattern of land use, a highly clustered, intensive form of residential land use is provided. In this instance all of the developers elect to construct groups of townhouse condominiums along the drainage ways where the only existing large trees are situated. The housing has the same amount of floor space as the single family detached structures in Scenario 1. The gross residential density remains the same also. The structural density in the clusters along the drainage ways and edges of existing ponds is 14 units per acre. (The coefficient of runoff is .73). The open slopes and ridge-lines are terraced and planted in oak groves and grass as open space-parklands (the coefficient of runoff is .48). Figure 6.20 shows the resultant detention requirements by drainage areas in each tract.[21] Figures 6.21 and 6.22 demonstrate the options for meeting the listed detention requirements.

Figure 6.23 illustrates both the traditional drainage and detention system hydrographs for subbasin B. The solutions expressed in the scenarios have the effect of truncating the hydrograph at the bankfall discharge line. The result is the required storage of a backlog of water and a drainage time of slightly more than three times the length of the design storm.

Detention requirements for a design storm of the 100 year magnitude were easily met in both scenarios. The example tracts were selected for

---

[21]Runoff computations are based on the number of acres of housing where C=.73 (16,437.8 cu. ft. per acre for a 6.2 inch rain), plus the number of acres of open space where C=.48 (10809 cu. ft. per acre for a 6.2 inch rain), less the allowable release rate of flow (cusecs) times 6 hours.

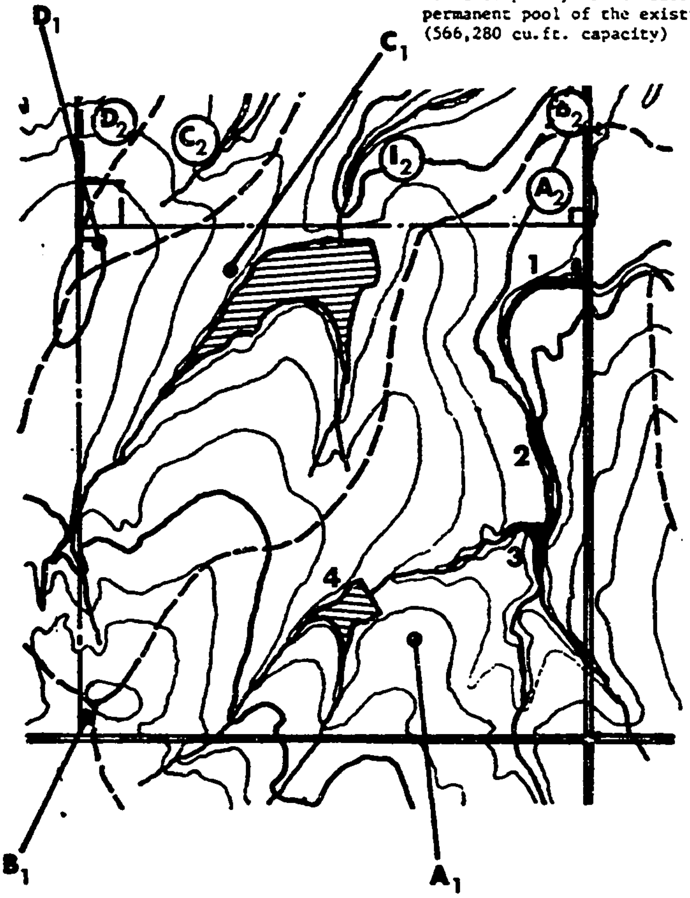


DETENTION REQUIREMENTS: MULTI-FAMILY DETACHED

Figure 6.20

1. Divert 10,000 cu.ft. to Area C of the same tract (use terracing and filter berms on open slopes above Area C's impoundment)
2. Acquire 6,223 cu.ft. of storage rights from the owner of Tract 3 (Area B)

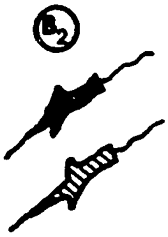
548,225 cu.ft. from site + 10,000 cu.ft. diverted from Area D of the same tract = 558,225 cu.ft. required detention met as follows:
Add a temporary .5 ft. flood pool above the permanent pool of the existing 26 acre pond (566,280 cu.ft. capacity)



. Divert 3,245 cu.ft. to Area A of the same tract (runoff should pass over terraced lands with vegetative filter strips and infiltration trenches)

790,540 cu.ft. from site + 3,245 cu.ft. diverted from Area B of the same tract + 11,997 cu.ft. diverted from Area A of Tract 2 = 805,782 cu.ft. required detention met as follows:
1. 209,088 cu.ft. in temporary impoundment at 1 (.8 acres X 6 ft. average depth)
2. 87,100 cu.ft. in temporary impoundment at 2 (.4 acres X 5 ft. average depth)
3. 196,020 cu.ft. in temporary impoundment at 3 (.75 acres X 6 ft. average depth)
4. 313,600 cu.ft. stored in a 4 ft. temporary flood pool above the permanent pool of the 1.8 acre pond at 4
TOTAL DETENTION = 805,808 cu.ft.

KEY:



B_2 **AREA DESIGNATION &TRACT NUMBER**

TEMPORARY IMPOUNDMENT

IMPOUNDMENT WITH FLOOD POOL

North

Scale 0 500 1000 2000 **Feet**

Contour Intervals 10 ft.

SOLUTION SCENARIO: MULTIFAMILY DETACHED RESIDENTIAL - TRACT 1

Figure 6.21

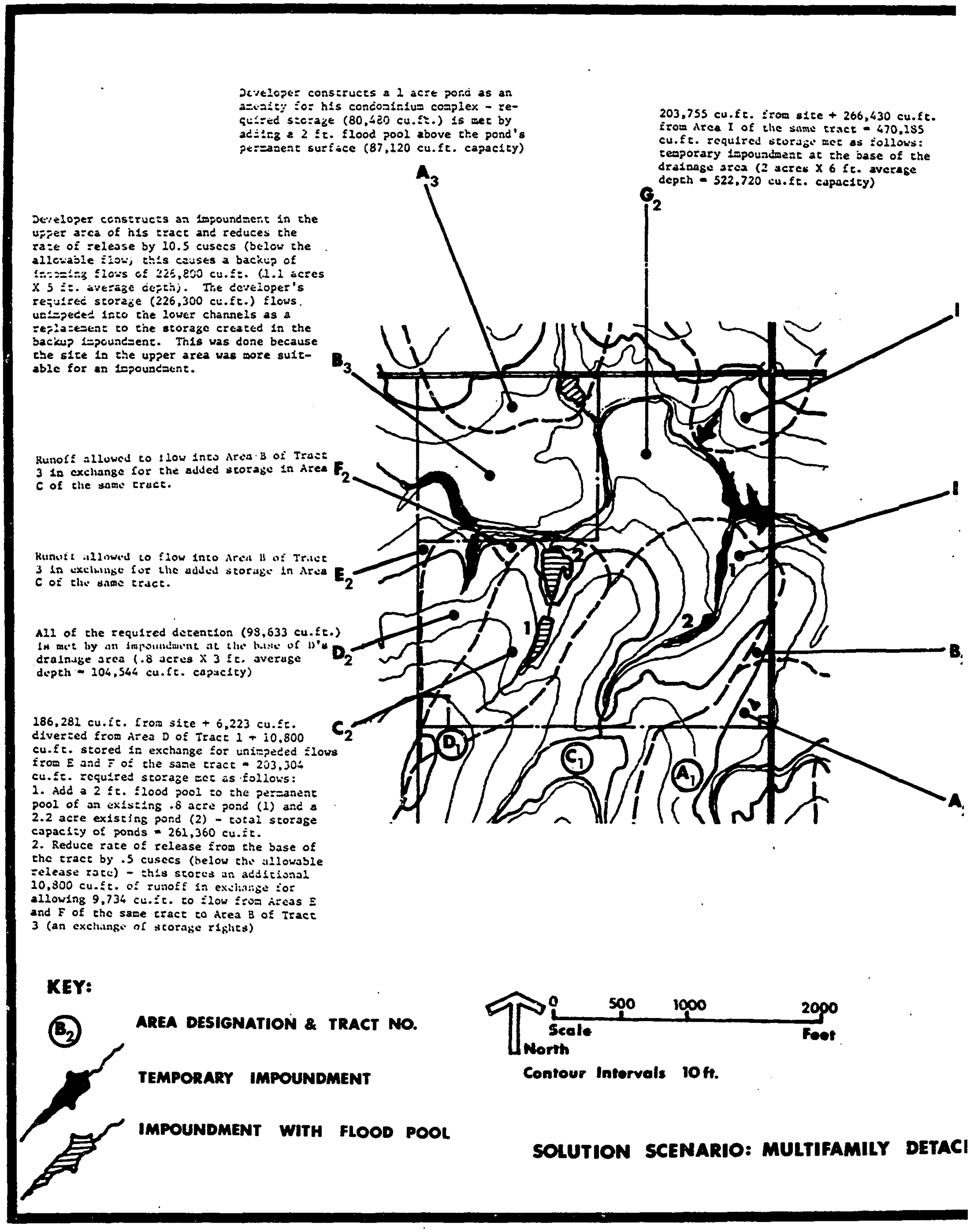

Developer constructs a 1 acre pond as an amenity for his condominium complex - required storage (80,480 cu.ft.) is met by adding a 2 ft. flood pool above the pond's permanent surface (87,120 cu.ft. capacity)
203,755 cu.ft. from site + 266,430 cu.ft. from Area I of the same tract = 470,185 cu.ft. required storage met as follows: temporary impoundment at the base of the drainage area (2 acres X 6 ft. average depth = 522,720 cu.ft. capacity)
A_3
G_2
Developer constructs an impoundment in the upper area of his tract and reduces the rate of release by 10.5 cusecs (below the allowable flow; this causes a backup of incoming flows of 226,800 cu.ft. (1.1 acres X 5 ft. average depth). The developer's required storage (226,300 cu.ft.) flows unimpeded into the lower channels as a replacement to the storage created in the backup impoundment. This was done because the site in the upper area was more suitable for an impoundment.
B_3
Runoff allowed to flow into Area B of Tract 3 in exchange for the added storage in Area C of the same tract.
F_2
Runoff allowed to flow into Area B of Tract 3 in exchange for the added storage in Area C of the same tract.
E_2
All of the required detention (98,633 cu.ft.) is met by an impoundment at the base of D's drainage area (.8 acres X 3 ft. average depth = 104,544 cu.ft. capacity)
D_2
186,281 cu.ft. from site + 6,223 cu.ft. diverted from Area D of Tract 1 + 10,800 cu.ft. stored in exchange for unimpeded flows from E and F of the same tract = 203,304 cu.ft. required storage met as follows:
1. Add a 2 ft. flood pool to the permanent pool of an existing .8 acre pond (1) and a 2.2 acre existing pond (2) - total storage capacity of ponds = 261,360 cu.ft.
2. Reduce rate of release from the base of the tract by .5 cusecs (below the allowable release rate) - this stores an additional 10,800 cu.ft. of runoff in exchange for allowing 9,734 cu.ft. to flow from Areas E and F of the same tract to Area B of Tract 3 (an exchange of storage rights)
C_2
I
I
B
A
1
2
2
1
D_1
C_1
A_1
KEY:
B_2
AREA DESIGNATION & TRACT NO.
TEMPORARY IMPOUNDMENT
IMPOUNDMENT WITH FLOOD POOL
0
500
1000
2000
Scale
Feet
North
Contour Intervals 10 ft.
SOLUTION SCENARIO: MULTIFAMILY DETAC

Figure 6.22

5 cu.ft. from site + 266,430 cu.ft.
rea I of the same tract = 470,185
required storage met as follows:
ary impoundment at the base of the
ge area (2 acres X 6 ft. average
= 522,720 cu.ft. capacity)

H_2 Required detention (48,019 cu.ft.) met by an impoundment at the base of the tract (.4 acres X 3 ft. average depth = 52,272 cu.ft. capacity)

I_2 Required detention (484,230 cu.ft.) met as follows:
1. 108,900 cu.ft. in an impoundment at 1 (.5 acres X 5 ft. average depth)
2. 108,900 cu.ft. in a similar impoundment at 2
3. Balance of 266,430 cu.ft. allowed to flow to Area G of the same tract

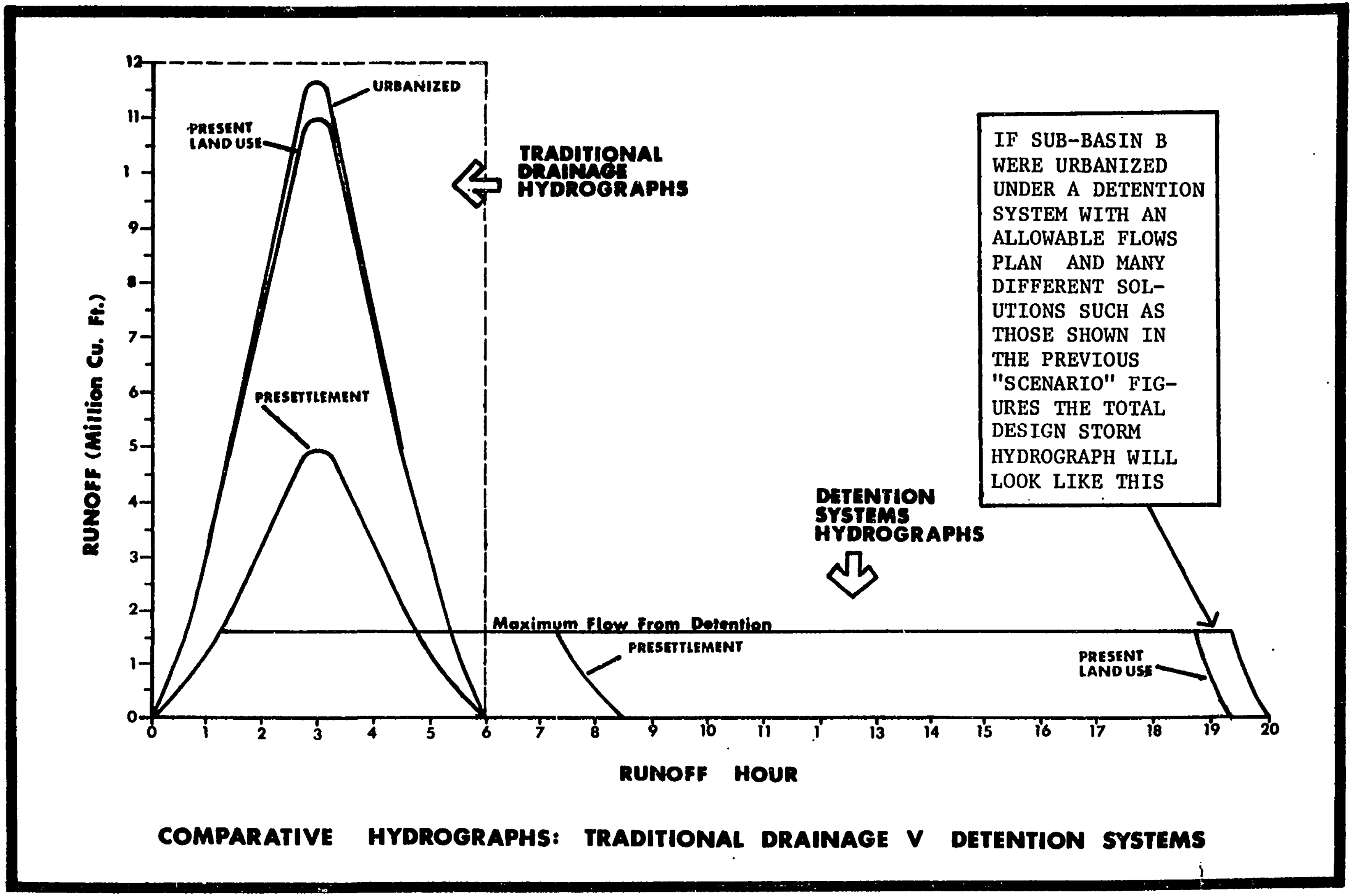
B_2
1. Terrace and plant filter berms on slope, store 2,000 cu.ft. in a cistern with tile field
2. Allow 1,894 cu.ft. to flow onto the tract to the east (acquired storage rights)

A_2
1. 11,997 cu.ft. diverted to impoundment in Area A of Tract 1 (acquired storage rights)
2. Balance of 20,000 cu.ft. collected on terraced and planted slope and directed to an impoundment (.2 acres X 3 ft. average depth = 26,136 cu.ft. capacity)

2000
Feet

ft.

RIO: MULTIFAMILY DETACHED RESIDENTIAL - TRACTS 2 & 3



URBANIZED
PRESENT LAND USE
TRADITIONAL DRAINAGE HYDROGRAPHS
PRESETTLEMENT
IF SUB-BASIN B WERE URBANIZED UNDER A DETENTION SYSTEM WITH AN ALLOWABLE FLOWS PLAN AND MANY DIFFERENT SOLUTIONS SUCH AS THOSE SHOWN IN THE PREVIOUS "SCENARIO" FIGURES THE TOTAL DESIGN STORM HYDROGRAPH WILL LOOK LIKE THIS
DETENTION SYSTEMS HYDROGRAPHS
Maximum Flow From Detention
PRESETTLEMENT
PRESENT LAND USE
RUNOFF (Million Cu. Ft.)
RUNOFF HOUR
COMPARATIVE HYDROGRAPHS: TRADITIONAL DRAINAGE V DETENTION SYSTEMS

Figure 6.23

their complexity. The many other tracts throughout the watershed are at least as easy to design for detention. The demonstration also showed that the municipality need only to determine an allowable flows plan, list a series of acceptable coefficients of runoff per land use, and a design storm. The developer's part of the detention plan is his designs to temporarily detain the runoff from his tract that is in excess of the allowable flow. This performance standard does not require cooperation among different owners. The acquisition or exchange or storage rights may be a totally private enterprise negotiation based on the local perception of the market for such. The scattered small parcels of already developed lands may be assessed by local government for the cost of detention required to properly detain their runoff or simply allowed to continue in a "grandfather clause" manner. Most of the detention structures and channel capacities are computed with a 5% to 10% margin of safety which can accept uncontrolled runoff from small areas such as the two tracts near the middle in the example scenarios. In addition, land treatment and vegetation which is not included as a runoff detention measure should widen the safety margin even more than conservative computation.

What remains is to provide a summary of the detention-release concept. The final chapter provides some conclusions, some potential areas of resistance against actual implementation of detention systems, and remarks on areas where the proposed concept needs to be further researched and developed.

The cycle of life is inextricably tied up with the cycle of water ... the water system has to remain alive if we are to remain alive on earth.[1]

Jacques Cousteau

CHAPTER SEVEN

SUMMARY AND CONCLUSIONS

Introduction

The study has sought to determine if the detention release systems approach to runoff management in small urbanizing watersheds can be effective by examining the methods and then testing them in an example watershed under a severe design storm condition. The case study in Chapter Six showed that even under extra stressful conditions a watershed based detention system can cope with runoff resulting from a major storm. The research initiated by this study can be continued into the drainage versus detention comparative costs area to assure what the preliminary costs seem to indicate. Other areas of continued research are shown in Figure 7.1. The costs of developing this detention system presently appear to be reasonable and should in fact become even more so once detention practices become common. This concluding chapter summarizes how a city can set up a simple detention systems framework for land developments, relates water quantity management to water

[1]Congressional testimony by Jacques Cousteau cited by Christopher Stone, Should Trees Have Standing? (New York: Avon Books, 1974), p. 96.

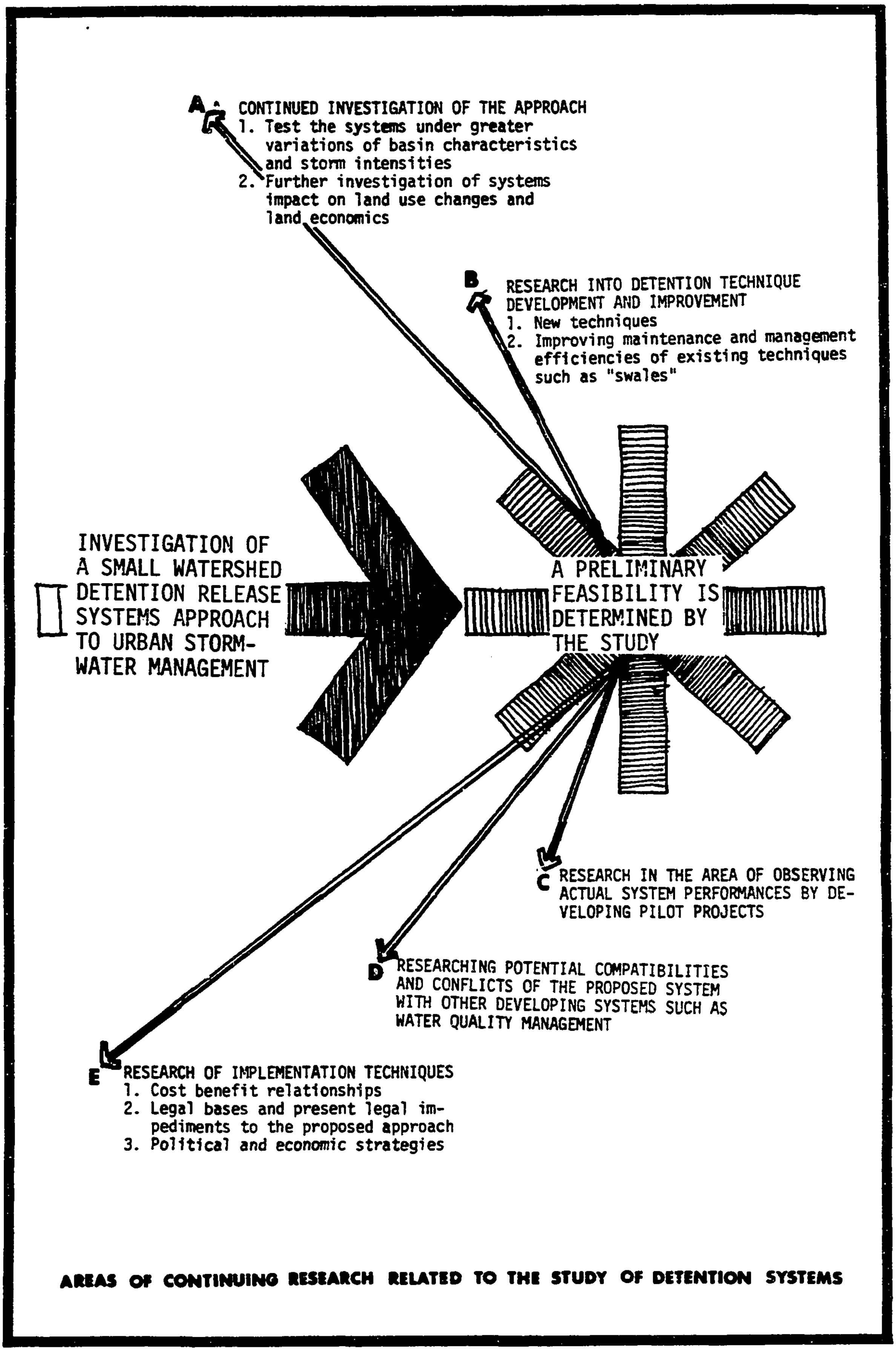

A. CONTINUED INVESTIGATION OF THE APPROACH
1. Test the systems under greater variations of basin characteristics and storm intensities
2. Further investigation of systems impact on land use changes and land economics
B RESEARCH INTO DETENTION TECHNIQUE DEVELOPMENT AND IMPROVEMENT
1. New techniques
2. Improving maintenance and management efficiencies of existing techniques such as "swales"
INVESTIGATION OF A SMALL WATERSHED DETENTION RELEASE SYSTEMS APPROACH TO URBAN STORM-WATER MANAGEMENT
A PRELIMINARY FEASIBILITY IS DETERMINED BY THE STUDY
C RESEARCH IN THE AREA OF OBSERVING ACTUAL SYSTEM PERFORMANCES BY DEVELOPING PILOT PROJECTS
D RESEARCHING POTENTIAL COMPATIBILITIES AND CONFLICTS OF THE PROPOSED SYSTEM WITH OTHER DEVELOPING SYSTEMS SUCH AS WATER QUALITY MANAGEMENT
E RESEARCH OF IMPLEMENTATION TECHNIQUES
1. Cost benefit relationships
2. Legal bases and present legal impediments to the proposed approach
3. Political and economic strategies
AREAS OF CONTINUING RESEARCH RELATED TO THE STUDY OF DETENTION SYSTEMS

Figure 7.1

quality management, and discusses potential areas of resistance to proposed needed change from drainage to the detention approach to management.

Setting Up a City's Framework for Runoff Detention Management

To dispel the fears of having to retain highly paid consulting engineers and purchasing sophisticated equipment to set up and regulate a detention ordinance, it should be noted that most subdivision regulations already require drainage plans. These are handled by building/ zoning inspectors and public works departments. The only difference between a drainage plan and a detention plan is that the former asks how the developer proposes to get rid of runoff while the latter asks how the developer intends to keep and then release it. Both plans require the computation of runoff.

Initially, a city would be divided into drainage areas. The flow capacities of the natural channels would be measured in each. The amount of water which would be allowed to run off of any parcel of land is determined by the acreage of that parcel relative to the acreage of the drainage area. If the parcel is one acre and the drainage area is 100 acres, the allowed runoff is 1% of the capacity of the channel which drains the 100 acres.

The result is a simple map of the city with delineated drainage areas with allowed rates of release indicated for each. The design storm is selected, adopted by ordinance, and thereafter becomes a constant. The coefficients of runoff for each type of land use can also be adopted and fixed as a city wide given. The public works department would also have a list of both the acceptable techniques for detention and the orifice shapes and dimensions with their resultant rates of release. The only matter that remains to be settled is the determination by the developer of the land use which will go on a given tract, what his plan for detaining and releasing the runoff will be. This equal distribution of drainage rights is similar to the principle of equal development rights which is becoming popular in urban planning literature.[2] As new detention-release techniques are developed, they can be added to the city's list of acceptable methods.

The Water Quantity - Quality Relationship

A critical question that can be asked of the detention release approach is: does it work against the present efforts to protect and improve water quality? In effect, the detention systems approach and water quality management are mutually reinforcing efforts. Three supportive areas are listed.

First, detention basins were actually developed to reduce erosion and to allow transported sediments to settle out by reducing flow volumes and velocity. The Soil Conservation Service used them extensively in agricultural areas and recently as required sediment traps

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[2]Development rights imply that all land use has equal amounts of development potential assigned to it. When a developer wants to put more on one parcel of land than that which has been assigned to it, he must gain the required amount of rights elsewhere. As a result the developer rights sold or given away from one parcel to another causes the selling parcel to lose those same rights by choice and thereby have to remain as open or partially open land. For further references on this concept see John Reps, "Public Land, Urban Development Policy," in Modernizing Urban Land Policy, ed. by Marion Clawson (Baltimore: The Johns Hopkins University Press, 1973), p. 15-48.

for urban construction sites.[3] Other transported pollutants are also allowed to settle in temporary holding structures. Detention techniques such as filter berms and infiltration trenches have filtering as well as settling potential.

Second, detention has the potential for localizing a pollutant. Point source pollution may be more effectively treated by a tailored method near the source rather than general all purpose treatments for the many forms of pollution at the outlet of a watershed.

Third, water quality management, like the proposed detention systems, requires a basin wide approach (area wide 208 planning).[4] Both contend with the same physiographic module and therefore can actually be mutually supportive.[5] Environmental planning in general

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[3]County sediment control regulations, with particular emphasis on construction sites, can be found in Montgomery and Prince George's Counties in Maryland and Fairfax County in Virginia. For further references see Joachim Tourbier and Richard Westmacott, Water Resources Protection Measures in Land Development - A Handbook (Newark, Delaware: New Castle County Planning Department, 1974). Chapter 5, "Legal Aspects of Water Resource Concerns in New Castle County, Delaware," surveys some of the present examples on water quantity and quality management legislation from local to federal government levels.

[4]Federal Water Pollution Control Act Amendments of 1972, 86 Stat. 816 (1972). Specifically, references to a basin or areawide approach to planning for the management of water resources can be found in the following locations in the Act: Section 102, in the reference to "basin" (C), (3), the references to the Great Lakes and river basin studies in Section 104, the Lake Tahoe basin study in Section 114, Areawide waste treatment management in Section 208, and basin planning in Section 209.

[5]An indication of the compatibility of quantity and quality management techniques is evident in Tourbier and Westmacott, Water Resource Protection Measures in Land Development - A Handbook. The authors briefly survey all of the water resource protection methods available to the urban design professions (planning and engineering) and categorize them into six groups (Chapter 3, "Resources Protection Measures.") They are: Group 1 - Measures to Control Increases in Runoff and Decreases in Infiltration Due to Urban Development, Group 2 - Measures to Control Soil Erosion, Group 3 - Measures to Minimize Flood Damage to Installations on the Floodplain, Group 4 - Measures to Minimize

must become more sensitive to the physical setting, and the watershed is perhaps the most appropriate way of subdividing physical settings.[6]

The Stumbling Blocks to Change

A fundamental change is proposed in this study and it can be expected that there will be a significant resistance to it. Only a few cities are using detention and then only as piecemeal, remedial treatments. Therefore, the system is unproven, allowing for a number of major stumbling blocks between the research which leads to the conclusion that detention systems can be effective and the actual construction of the systems in the urban landscape.

First, there is the problem of perception and mind set. Hazard perception research points to the likelihood that there is difficulty in simply realizing that there are problems and that the traditional approaches may not be solving them.[7] To carry the point a step further,

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Runoff Pollution from Urban Areas, Group 5 - Measures to Minimize Pollution from Sewage Effluent, and Group 6 - Measures to Minimize Problems Caused by Special Land Uses. Most of the techniques were variations of those cited by Poertner in Practices in Detention of Urban Stormwater Runoff and none, regardless of their respective categories, could be considered as being in conflict with any of the other techniques. In fact, many of Tourbier's and Westmacott's suggested sediment control methods were identical to those applied in this study for purposes of stormwater detention. However, as stated in the preface, an additional area of research related to this study should address the specific compatibilities between flood abatement measures and the techniques for achieving the goals and objectives of the Federal Water Pollution Control Act Amendments of 1972.

[6]R. J. Chorley, "The Drainage Basin as the Fundamental Geomorphic Unit," Introduction to Physical Hydrology, ed. by R. J. Chorley, (London: Methuen & Company LTD, 1969).

[7]Kates notes that a basic limitation to the human response to improved flood hazard information is a result of a lacking in a recent experience by individuals of an extreme event. The lack of motivation to make any adjustments and thereby avoid losses and to passively rely on existing structures to reduce the probability of such an event is

there is reason to doubt that many people even know what the traditional methods are. If directly effected by the problem, the individual mind set restricts the perception of the solution to the way things have always been done.

Second, existing law, usually in the form of subdivision regulations and municipal ordinances, prohibits detention or at least strongly discourages it. For example, in a proposed drainage ordinance for Norman, Oklahoma, the following appears:

> "Site grading shall be carried out in such a manner that surface water from each lot shall flow directly into a storm sewer, improved channel or paved street without crossing more than two adjacent lots" (underlining by author)[8].

This as well as many other terms, phrases and sentences preclude or discourage on site detention and encourage maximum drainage in improved channels and closed sewers. They are common to ordinances in most urban areas.

Third, the term drainage itself is seen as both a desirable effect to be achieved and as being closely associated with manipulating the land and its waterways so as to eliminate sumps and other "undesirable" areas of detained precipitation. The detention release system is a form of drainage, but is generally not perceived as such by many.

The fourth stumbling block is related to the resistance to flow in a channel. Manning's n, as an expression of the resistance to flow in

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entitled "prison of experience." Motivation is even lower according to Kates when the hazard has yet to be experienced by an individual. See Robert W. Kates, "Experiencing the Environment as Hazard," in Environmental Psychology, ed. by Harold M. Proshansky, William H. Ittelson, and Leanne G. Rivlin (New York: Holt, Rinehart and Winston, 1976), p. 415.

[8]Policies and Design Standards for Storm Drainage and Flood Hazard Areas, an unpublished proposed ordinance for Norman, Oklahoma, p. 13 Paragraph C (1977).

a channel, is incorporated in the expression

$$V = \frac{1.49}{n} R^{2/3} S^{1/2}$$

where V is the mean flow velocity, R is the hydraulic radius of the channel in feet, S is the slope of the channel, and n is the coefficient of roughness.[9] The consideration of resistance to flow in a channel constitutes a stumbling block because it encourages the improvement of channels and allows local runoff problems to be solved easily by efficiently accelerating greater volumes of runoff to other locations. To demonstrate this effect, Figure 7.2 shows a nomographic solution to the Manning Formula. The example channel is compared in its natural and altered (concrete lined) conditions alike. The slope and hydraulic radius areas (S and R) remain constant.[10] The n value for a naturally winding channel is .04 and the value for a concrete lined channel is .013[11]. The change in V is from 2.65 feet per second for the natural channel to 8.5 feet per second for the concrete channel. This is an increase in capacity of 320%. The impact of the change in n on the channel at the base of the case study watershed is to accomodate 36,057,600 cubic feet of the peak flow of approximately 41,250,000

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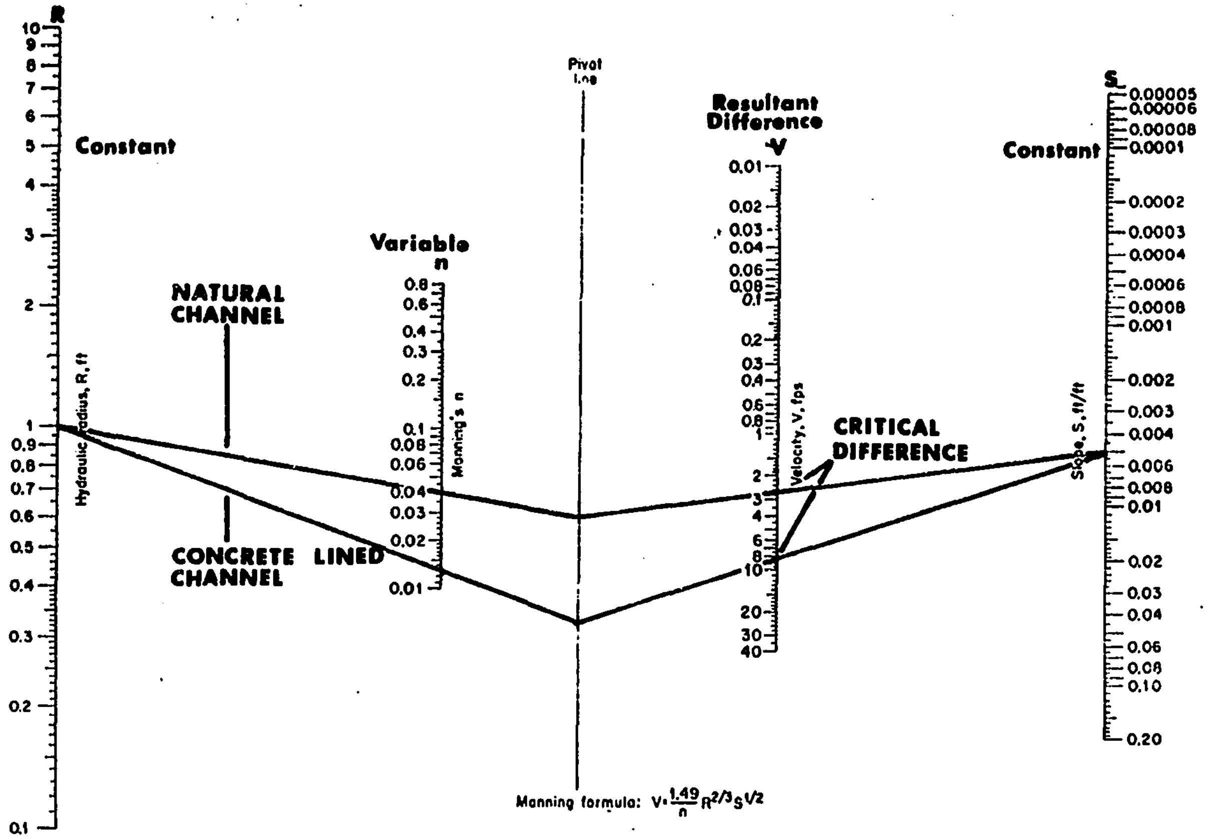
[9]For more discussion of the Manning Formula see Appendix C.

[10]Actually "S" will tend to increase in that it is assumed that an improved channel is straightened, thus increasing its gradient.

[11]Ven T. Chow, "Table 5.6 Values of the Roughness Coefficient N," Open Channel Hydraulics (New York: McGraw-Hill Book Company, 1959), p. 111-112.

IMPACT OF MANNING'S n ON VELOCITY OF FLOW



Source: Adapted from Ven T. Chow, "Appendix C. Nomographic Solution of the Manning Formula," Open-Channel Hydraulics (New York; McGraw-Hill Book Company, 1959) p.640.

Figure 7.2

cubic feet.[12] The result would be minor flooding for less than one hour of a 6 hour 100 year return frequency storm (rather than 4 hours of severe flooding).

It is also contended that the system is logical and is already feasible but the actual initiation of the practice will inherently make it more feasible. Once an approach is decided upon and initiated, the act of repeatedly using it makes it easier to institute each subsequent time due to methods improvement and trained personnel.[13] In addition, criticisms against techniques such as roadside swales can be silenced. For example, once there are enough swales constructed, it becomes feasible to develop a better material for road surfacing as well as a better swale maintenance technology. The institution of this approach will precipitate the improvement of the related technology. The entire field or site design, changing from one centered on drainage to one centered on coping with temporary detention will require a large amount of research and experimentation.

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[12] The flow rate used is taken from the fully urbanized hydrograph, Figure 6.12 in Chapter 6.

[13] The actual initiation of basin-wide urban stormwater detention systems will probably be in one of these areas. First, it is likely that a fiscally sound suburban community with severe flooding problems may construct a network of detention ponds throughout the developed areas of its drainage area and subsequently legislate that the detention approach be mandatory in the development of any remaining areas. Secondly, detention systems are likely to be constructed in a small basin which is about to be developed by one or a limited consortium of owners as a large planned unit development in conjunction with the popular greenbelt-open space amenities. Both of the above potential users of the detention systems approach probably involve upper middle income communities. Third, a water quantity management system is most likely to initially occur as a by product of the basin/wide water quality planning which is required by Section 208 of the Federal Water Pollution Control Act Amendments of 1972 (Public Law 92-500). Specifically, a local area may be encouraged to develop a water quality management system

The highly localized care of water (such as in a detention system) serves to recharge ground water supply and reinstitute interflows and low flows which are basic characteristics in the well managed natural watershed. These small scale networks of local management should become a basic building block in the future of both the quantity and quality of water.

The management of water as a resource of growing scarcity is about to become an issue which will make the issue of modern energy seem like a preparatory exercise. Modern energy is developed to maintain or improve upon an accepted quality of life. Water is a basic requirement for maintaining life itself.

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which also serves to manage water quantity (sediment control facilities as detention structures, etc.). Such encouragement may result from the 1972 Act through the following sections: as "experiments, demonstration and research" (Section 104), associated with research and development grants" (Section 105), and in conjunction with treatment and related facilities under Title II of the Act ("Grants for Construction of Treatment Works"). More funding is also likely under federal public works and jobs programs. Particularly compatible with the detention systems approach is the local recycling of water resources (closed cycle processes) supported by the Carter administration as proposed 1977-78 Amendments to the Water Pollution Control Act. As related to 208 planning, such an amendment can be interpreted as reflecting a growing federal government attitude that not only should water quality be upgraded, but that it should also be detained, reprocessed, and reused at the local level. President Carter's recommendations to Congress on the above amendment is discussed briefly in Ronald H. Rosenberg, "Administration Supports Water Act Amendments," Practicing Planner (Washington, D.C.: American Institute of Planners, 1977), VII, No. 3, September, 1977, pp. 17-18.

A P E N D I C E S

A - THE DESIGN STORM

B - RUNOFF COEFFICIENTS/RUNOFF CURVES

C - THE DETERMINATION OF CHANNEL CAPACITIES IN THE ROCK CREEK BASIN

D - COMPUTATION OF THE RUNOFF HYDROGRAPHS FOR THE ALTERNATIVE LAND USE PATTERNS IN ROCK CREEK BASIN

APPENDIX A

THE DESIGN STORM

The storm event which will be used for testing and for illustrative purposes in this study will be that of a 100 year return frequency for central Oklahoma. Although most hydrologists are beginning to contend that runoff management systems are best designed to contend with storms of the 2 to 5 year return frequency, the larger storm was selected due to the nature of recent federal floodplain legislation.[1] The 100 year storm has been used to determine the extent of the floodplain associated with watercourses for purposes of insurance and associated floodplain/land use regulations. If a detention system is feasible in controlling runoff from the 100 year storm, systems designed to contend with the more frequent events are logically more feasible.

The storm patterns occurring in central Oklahoma were selected because of the location of the case study watershed (Rock Creek in Norman). The broader implications of the regional storm patterns are significant however. In examining the precipitation isohyets for the U.S. east of the Rocky Mountains for different storm frequencies and durations, the precipitation falling in central Oklahoma generally exceeds all other areas with the exception of regions on the South Atlantic and Gulf coasts.[2] Tables 1 and 2 reflect the rainfall quantity-frequency and intensity-frequency patterns, respectively, for central Oklahoma.

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[1]Darryl W. Davis, "Optimal Sizing of Urban Flood Control Systems," Journal of the Hydraulics Division, CI, No. HY8, (1975), p. 1079.

[2]American Society of Civil Engineers and The Water Pollution Control Federation, Design and Construction of Sanitary and Storm Sewers, ASCE Manuals of Engineering Practice No. 37 (New York: American Society of Civil Engineers, 1960), pp. 36-42.

Table A.1

RAINFALL QUANTITY-FREQUENCY TABLE

Quantity of rainfall, in inches, to be expected once in the number of years, indicated for period of time from 5 minutes to 24 hours in central Oklahoma.

Duration	1 - Year	2 - Year	5 - Year	10 - Year	25 - Year	50-Year	100-Year
5 minute	.43	.54	.68	.81	.96	1.07	1.18
10 minute	.66	.83	1.05	1.25	1.48	1.65	1.82
15 minute	.83	1.04	1.33	1.58	1.87	2.09	2.30
30 minute	1.15	1.45	1.85	2.20	2.60	2.90	3.20
1 hour	1.45	1.80	2.35	2.75	3.25	3.60	4.10
2 hour	1.70	2.10	2.70	3.25	3.80	4.40	5.00
3 hour	1.85	2.24	3.10	3.60	4.20	4.75	5.40
6 hour	2.20	2.70	3.60	4.25	5.00	5.60	6.20
12 hour	2.60	3.20	4.30	5.10	5.90	5.70	7.50
24 hour	3.00	3.75	5.00	5.80	6.80	7.70	8.60

Source: REA Engineering and Associates, Inc., Norman, Oklahoma 1973-74 Drainage Study (Oklahoma City: REA Engineering and Associates, Inc.) 1974, Exhibit A-1, p. 42. Intensity frequency patterns for other locations in the U.S. can be found in the Rainfall Frequency Atlas of the U.S. published by the U.S. Department of Commercine in May, 1961.

Table A.2

RAINFALL INTENSITY-FREQUENCY TABLE

This table is the same as A.1 except that the intensity is expressed as inches per hour instead of the total inches expected in the period. (Central Oklahoma).

Duration	1 - Year	2 - Year	5 - Year	10 - Year	25 - Year	50 - Year	100-Year
5 minute	5.16	6.48	8.16	9.72	11.52	12.84	14.16
10 minute	3.96	4.98	6.30	7.50	8.88	9.90	10.92
15 minute	3.32	4.16	5.32	6.32	7.48	8.36	9.20
30 minute	2.30	2.90	3.70	4.40	5.20	5.80	6.40
1 hour	1.45	1.80	2.35	2.75	3.25	3.60	4.10
2 hour	.85	1.05	1.35	1.63	1.90	2.20	2.50
3 hour	.62	.75	1.03	1.20	1.40	1.58	1.80
6 hour	.37	.45	.60	.71	.83	.93	1.03
12 hour	.22	.27	.36	.42	.49	.56	.62
24 hour	.13	.16	.21	.24	.28	.32	.36

Source: REA Engineering and Associates, Inc., Norman, Oklahoma 1973-74 Drainage Study (Oklahoma City: REA Engineering and Associates, Inc.) 1974, Exhibit A-1, p. 42. Intensity frequency patterns for other locations in the U.S. can be found in the Rainfall Frequency Atlas of the U.S. published by the U.S. Department of Commerce in May, 1961.

Distributions not shown on graph

I. 1 HOUR STORM 4.1"/ 30 Min. Increments

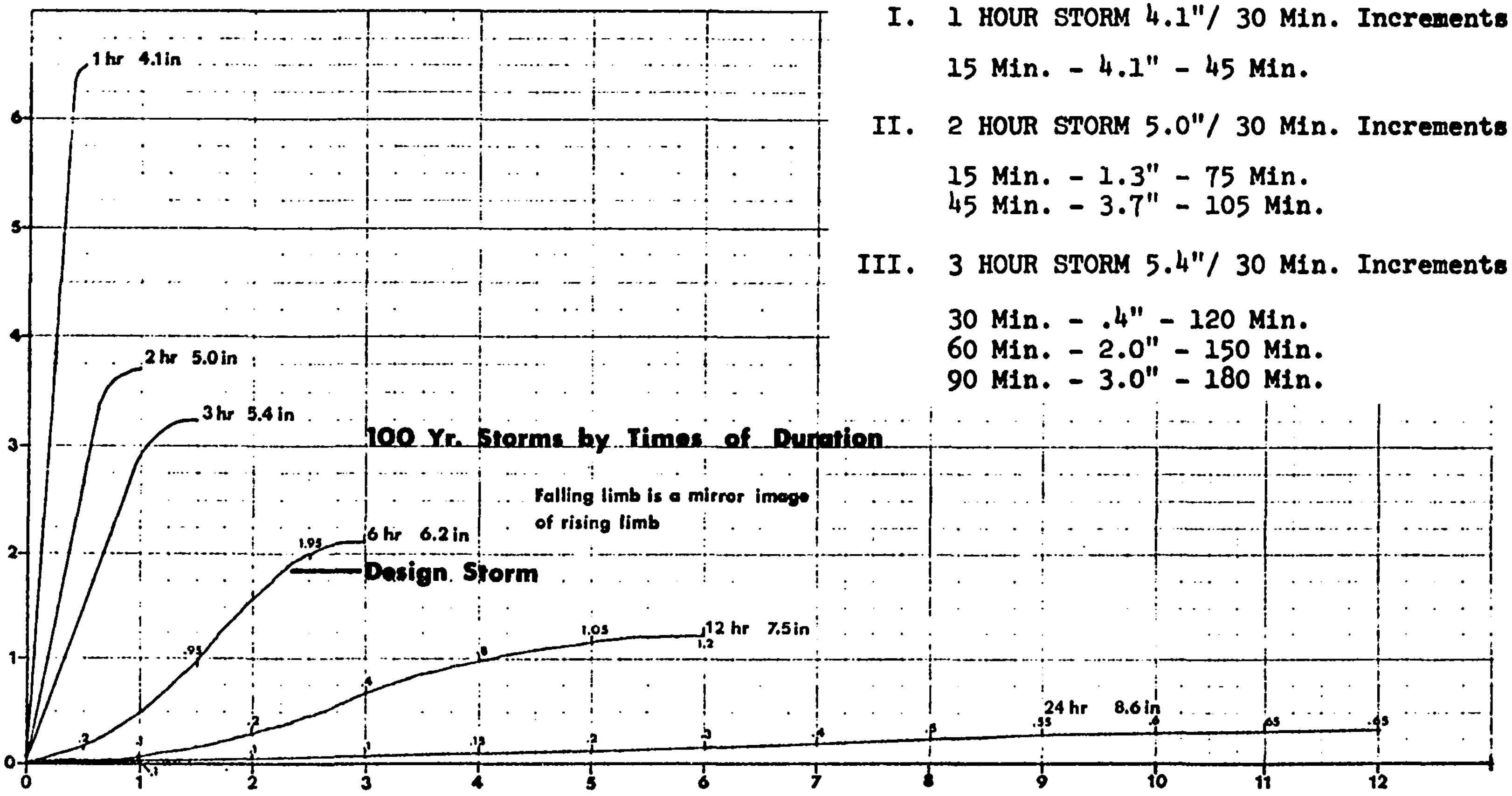
15 Min. - 4.1" - 45 Min.

II. 2 HOUR STORM 5.0"/ 30 Min. Increments

15 Min. - 1.3" - 75 Min.
45 Min. - 3.7" - 105 Min.

III. 3 HOUR STORM 5.4"/ 30 Min. Increments

30 Min. - .4" - 120 Min.
60 Min. - 2.0" - 150 Min.
90 Min. - 3.0" - 180 Min.



RAINFALL DISTRIBUTION FOR THE DESIGN STORM

Figure A.1

The next matter to be clarified for the purpose of the study is the intensity patterns of the 100 year storm for various durations. The intensity of rainfall during a given storm changes significantly. There is a potential for error when assuming equal distribution of rainfall intensity throughout. The histogram normally resembles a normal distribution with the intensities increasing toward the center and then decreasing. The Chicago Hydrograph Analysis assumes this pattern in its Design Storm Pattern.[3] The patterns used in this study were obtained by distributing the total accumulation under a hydrograph whose base is determined by the duration associated with each accumulation in Table A.1. The shape and height of each hydrograph is generally based on the intensity duration curves shown in Exhibit A-2 and A-3 of the previously cited Norman Drainage Study.[3] Precipitation occurring at the 100 year storm intensity for durations of less than one hour is considered as producing an instantaneous rainfall. For example, the 1.82 inches which falls during a 10 minute storm is not distributed at varying levels within the duration. Figure A.1. shows the assumed rainfall intensity patterns used for computation purposes.

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[3]Ibid., p. 57.

APPENDIX B

RUNOFF COEFFICIENTS/RUNOFF CURVES

Introduction

Appendix A considers the patterns of rainfall utilized in the body of the text. The critical issue in this study is the resultant runoff. Abstractions or losses between rainfall and runoff are represented by the coefficient of runoff. Vegetative interception, evaporation, infiltration, and surface depression storage are the principal causes in the natural reduction of runoff resulting from a given storm. Yet precisely what percentage of rainfall is eliminated by various land uses and conditions is subject to speculation and judgement. Although most hydrologists generally agree on the runoff relationships of land uses, the coefficients (C) assigned to them vary greatly. The American Society of Civil Engineers in a 1960 publication stated that the runoff coefficient was the "variable of the rational method least susceptible to precise determination and calls for the greatest exercise of judgement on the part of the designers."[1]

Since the study will rely on a synthetic, not observed, runoff hydrograph, the coefficients of runoff are selected by the author from the literature. The estimates selected are conservative so that the runoff management systems which rely on them will be more severely tested.[2] Computed runoff therefore tends to be slightly greater that what might actually be observed.

[1]American Society of Civil Engineers and The Water Pollution Control Federation, Design and Construction of Sanitary and Storm Sewers, p. 47.

[2]Runoff coefficients are presented as the percentage of rainfall which runs off. Conservative estimates therefore assume that larger percentages of rainfall runs off.

Urban Runoff Coefficients

The runoff coefficients presented in the literature are estimated for design storms up to the 10 year frequency of occurrence. The design storm for the study is of the 100 year magnitude. It is assumed (and supported) that "nearly all of the rainfall in excess of that expected from the ten year recurrence interval rainfall will become runoff and should be accomodated by an increased runoff coefficient."[3] The ten year storm coefficients will be computed to apply to the 100 year storm as follows:

$$C_{100} = Q_{100}/P_{100} \text{ where } Q_{100} = C_{10}P_{10} + (P_{100} - P_{10})$$

C = Coefficient of runoff

Q = Inches of runoff

P = Inches of Precipitation

Subscripts refer to the return frequency of the storm.

The tables below reflect the adjusted coefficients as computed for urban land use. The citations refer to the sources of the 10 year storm coefficients upon which the computations were based. The variables P_{100} and P_{10} are derived from the 100-year and 10-year columns of the Rainfall Quantity-Frequency Table in Appendix A and are based on the 6-hour duration storm.

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[3]Urban Land Institute, The American Society of Civil Engineers, and The National Association of Home Builders, Report Jointly Published by the Author Organizations, Residential Stormwater Management: Objectives, Principles, and Design Considerations, p. 31.

Table B.1

Urban Runoff Coefficients

Description of Areas	Runoff Coefficients (C)
Commercial	
Downtown	.97
Neighborhood	.79
Residential	
Single Family (Urban)	.66
Multi-units detached	.73
Multi-units attached	.83
Apartments	.79
Single Family (Suburban)	.59
Industrial	
Light	.86
Heavy	.93
Parks, Cemeteries	.48
Railroad Yard	.55
Unimproved/Vacant	.52
Pavement	
Asphalt/Concrete	.96
Brick	.90
Roofs	.96
Lawns (Sandy Soil)	
Flat (2%)	.38
Average (2-7%)	.42
Steep (8% +)	.45
Lawns (Heavy Soil)	
Flat (2%)	.43
Average (2-7%)	.46
Steep (8% +)	.55

Basic Source: American Socity of Civil Engineers and Water Pollution Control Federation, Design and Construction of Sanitary and Storm Sewers; A.S.C.E. Manuals of Engineering Practice No. 37 (New York: American Society of Civil Engineers, 1960), p. 48. (computations by author) the point of intersection parallel to the base to a direct runoff reading. The coefficient of runoff can be computed by dividing the direct runoff reading by the rainfall reading.

Table B.2

Runoff Curve Numbers for Hydrologic Soil-Cover Complexes

(1) Land use or cover	(2) Treatment or practice	(3) Hydrologic condition	(4) Hydrologic soil group A	B	C	D
Fallow	Straight row	Poor	77	86	91	94
Row crops	Straight row	Poor	72	81	88	91
	Straight row	Good	67	78	85	89
	Contoured	Poor	70	79	84	88
	Contoured	Good	65	75	82	86
	Contoured and terraced	Poor	66	74	80	82
	Contoured and terraced	Good	62	71	78	81
Small grain	Straight row	Poor	65	76	84	88
	Straight row	Good	63	75	83	87
	Contoured	Poor	63	74	82	85
	Contoured	Good	61	73	81	84
	Contoured and terraced	Poor	61	72	79	82
	Contoured and terraced	Good	59	70	78	81
Close-seeded legumes† or rotation meadow	Straight row	Poor	66	77	85	89
	Straight row	Good	58	72	81	85
	Contoured	Poor	64	75	83	85
	Contoured	Good	55	69	78	83
	Contoured and terraced	Poor	63	73	80	83
	Contoured and terraced	Good	51	67	76	80
Pasture or range	....	Poor	68	79	86	89
		Fair	49	69	79	84
		Good	39	61	74	80
	Contoured	Poor	47	67	81	88
	Contoured	Fair	25	59	75	83
	Contoured	Good	6	35	70	79
Meadow (permanent)	....	Good	30	58	71	78
Woodlands (farm woodlots)	....	Poor	45	66	77	83
		Fair	36	60	73	79
		Good	25	55	70	77
Farmsteads	....	.....	59	74	82	86
Roads, dirt‡	....	.....	72	82	87	89
Roads, hard-surface‡	....	.....	74	84	90	92

* From U.S. Soil Conservation Service [19].
† Close-drilled or broadcast.
‡ Including right-of-way.

Source: Harold O. Ogrosky and Victor Mockus, "Hydrology of Agricultural Land," in Handbook of Applied Hydrology, ed. by Ven T. Chow (New York: McGraw-Hill Book Company, 1964), p. 21-27.

Runoff Curve Numbers: Agricultural Land Use

For agricultural and other non-urban lands where man has altered the soil and vegetative cover, runoff will be determined by Runoff Curve Numbers (CN) as cited by Ogrosky and Mockus.[4] The two principal agents in estimating runoff are the soils and their vegetative cover (soil-cover complex).

Soils and their hydrologic properties are classified into four groups. Group A consists of sands and gravels, etc., well drained and having a high rate of infiltration (low runoff potential). Group B has soils of a moderate infiltrating capacity. Group C soils have a slow infiltration capacity while soils in Group D have the greatest runoff potential. The U.S. Soil and Conservation Service has developed a "Classification of Soils by Hydrologic Soil Groups."[5] The hydrologic condition of the vegetative cover is then observed in conjunction with the practices for planting those covers. The resultant numerical ratings of the soil cover complex are shown in Table B.2. Once the runoff curve number has been determined for an agricultural land use, direct runoff can be estimated from the chart in Figure B.1. The figures along the base of the chart are gained in the selection of the design storm. The reading of direct runoff is gained by a perpendicular line from the design storm precipitation along the base to an intersection with the appropriate CN number. A line is then drawn right from a point of intersection to a reading of direct runoff.

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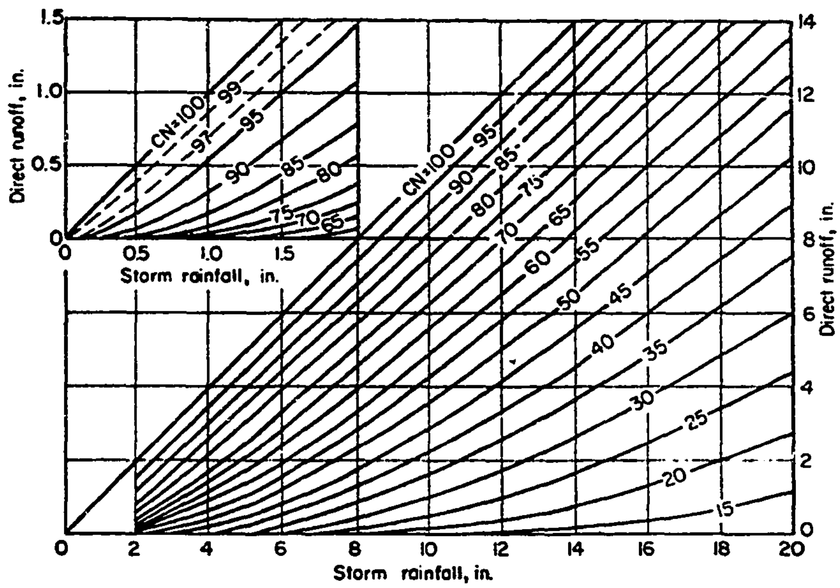
[4] Harold O. Ogrosky and Victor Mockus, "Hydrology of Agricultural Lands," in Handbook of Applied Hydrology, ed. by Ven T. Chow (New York: McGraw-Hill Book Company, 1964), p. 21-27.

[5] U.S. Soil Conservation Service, Report of the Service, "Hydrology," in National Engineering Handbook (Washington, D.C.: U.S. Government Printing Office), Section 4.

Figure B.1

Chart for Estimating Direct Runoff From Runoff Curve Numbers



Source: Harold O. Ogrosky and Victor Mockus, "Hydrology of Agricultural Lands," in Handbook of Applied Hydrology, ed. by Ven T. Chow (New York: McGraw-Hill Book Company, 1964), p. 21-27.

Runoff Curve Numbers: Forest and Rangelands

Runoff curve numbers (CN) were also developed by the U.S. Soil Conservation Service for forest and rangelands. They are given in Table B.3. Direct runoff and coefficients of runoff are determined using the same formulas and conversion charts as those for agricultural land use. In developing the synthetic unit hydrograph for the study, the presettlement forest and rangeland (pristine) condition was assumed as having a hydrologic condition class of "5.Best."

Table B.3

Runoff Curve Numbers for Hydrologic Soil-Cover Complexes: Forest and Rangelands

Hydrologic Condition Class	Hydrologic Soil Groups			
	A	B	C	D
1. Poorest	56	75	86	91
2. Poor	46	68	78	84
3. Medium	36	60	70	76
4. Good	26	52	62	69
5. Best	15	44	54	61

Source: Herbert C. Storey, Robert L. Hobba, J. Marvin Rose, "Hydrology of Forest Lands and Rangelands," in Handbook of Applied Hydrology, ed. by Ven T. Chow (New York: McGraw Hill Book Company, 1960), p. 22-47.

Runoff Rate Changes During the Design Storm

Runoff rates tend to increase during a storm as a result of soil, and vegetative saturation, and the filling of depression storage. Therefore, the coefficient of runoff which is given as total or average might be broken down into coefficients for increments of time during the storm. The result is coefficients which increase with time. The study, however, will assume a constant coefficient for a number of reasons. First, to speculatively introduce a rate of increase for each land use under each storm condition invites an unknown error factor; the literature vaguely suggests site specific judgement. Secondly, in detention systems total runoff is the critical issue since the fluctuations of runoff due to a change in coefficients are locally modified by accumulation and controlled release. Finally, it appears that the runoff curve numbers given for non-urban land uses already take some coefficient variance into consideration in their conversion charts.

APPENDIX C

THE DETERMINATION OF CHANNEL CAPACITIES IN THE ROCK CREEK BASIN

The principle thrust of the Rock Creek Case Study is to demonstrate that it is feasible to urbanize a watershed within the framework of a runoff detention system without causing any overbank flows under conditions of the design storm (100-year return frequency). Further, the thesis also investigates some of the problems which can result with the alteration or "improvement" of the natural drainage network. As a result, it is necessary to determine the natural channel capacities and methods for determining natural channel flow capacities for the case study.

Channel section measurements were made at four critical points in the watershed.[1] The first two sections are located at the base of the two major subbasins (points A and B in Fig. C.1). A third measurement was taken 50 meters below the confluence of the streams passing through A and B (point C in Fig. C.1).

The last section is located at the mouth of the Rock Creek Watershed (point D). Figure C.2 shows sections A through D and their dimensions and areas. The natural channel gradient of the streams in the confluence area of sections A, B, and C are calculated to be .005 foot per foot. The natural channel gradient at section D is .003 foot per foot.

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[1]Measurements were made by the author with the assistance of Dr. William C. Johnson on July 21, 1977.

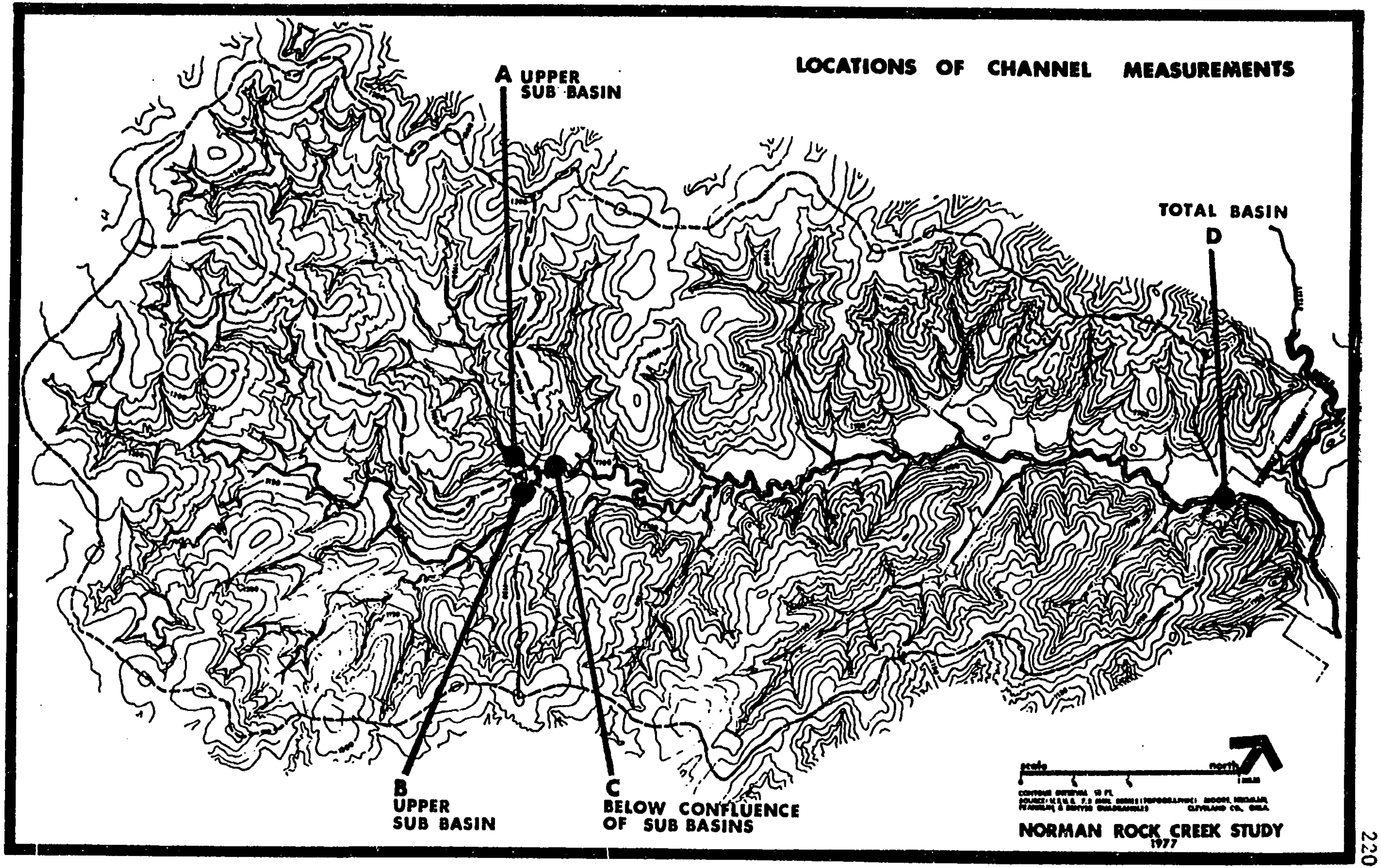
LOCATIONS OF CHANNEL MEASUREMENTS
A UPPER SUB BASIN
B UPPER SUB BASIN
C BELOW CONFLUENCE OF SUB BASINS
TOTAL BASIN D
scale
north
NORMAN ROCK CREEK STUDY
1977

Figure C.1

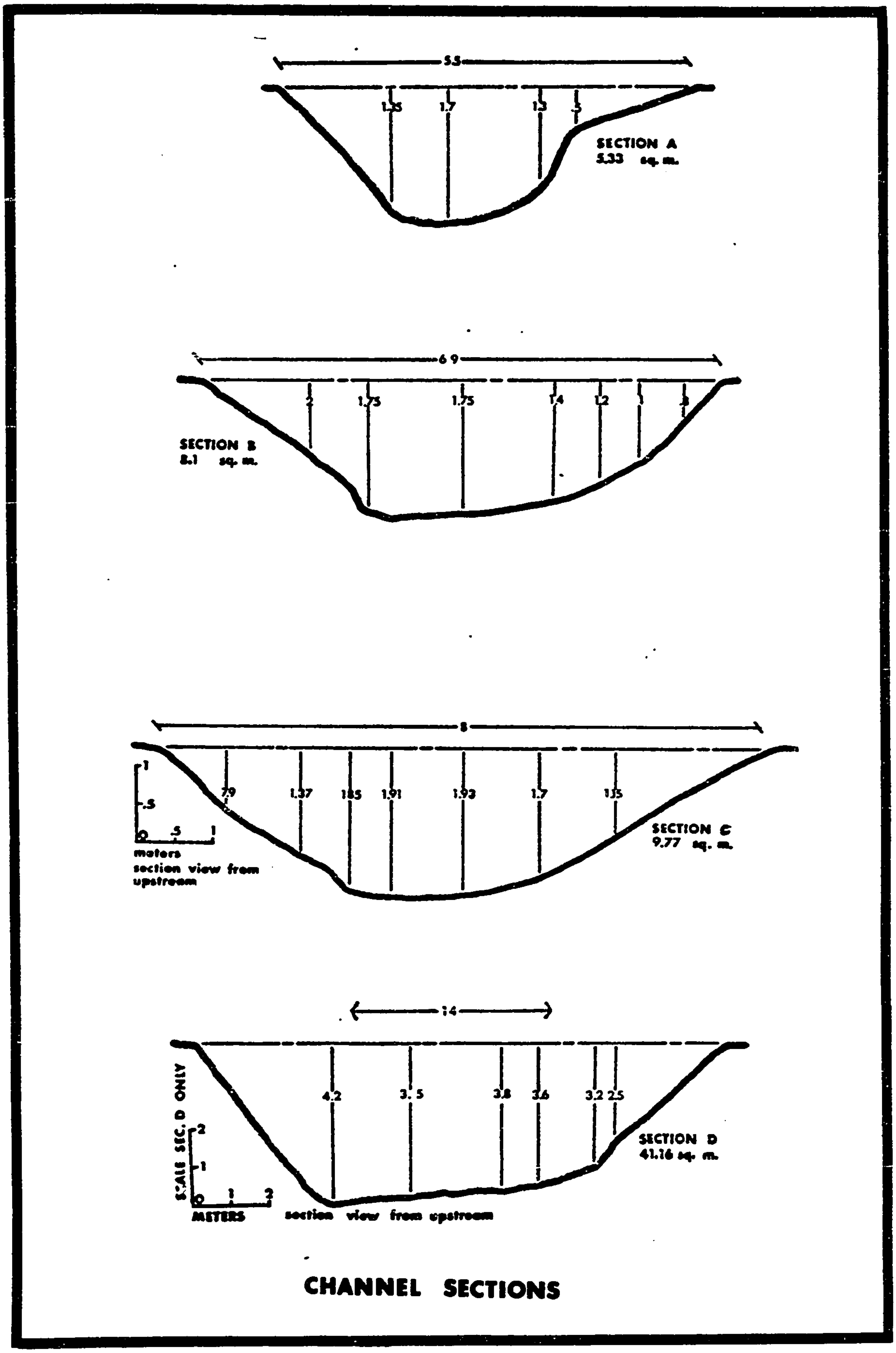
5.5
1.35
1.7
1.3
.5
SECTION A
5.33 sq. m.
6.9
.2
1.75
1.75
1.4
1.2
1
.8
SECTION B
8.1 sq. m.
8
.79
1.37
1.85
1.91
1.93
1.7
1.35
1
.5
0 .5 1
meters
section view from upstream
SECTION C
9.77 sq. m.
14
4.2
3.5
3.8
3.6
3.2
2.5
SCALE SEC. D ONLY
2
1
0 1 2
METERS
section view from upstream
SECTION D
41.16 sq. m.
CHANNEL SECTIONS

Figure C.2

The flow capacity of the channel in cubic feet per second (cusecs) is a function of the rate of flow and the crossectional area. The rate of flow is determined by the Manning Equation:

$$V = \frac{1.49}{n} R^{2/3} S^{1/2}$$

Where n is the Manning coefficient of roughness, R is the hydraulic radius in feet, and S is the slope of flow (gradient).[2] The Manning n values are taken from the table describing channel conditions in Chow.[3] The hydraulic radius (R) is determined by associating the section dimensions with the charts provided by Chow.[4] Chow also provides the nomograph for the solution to Manning's equation once the above noted variables are determined.[5] Subsequently, the capacity of flow in cubic feet per second (Q) is determined by $Q = AV$, where A equals the sectional area in square feet and V equals the velocity in feet per second (the solution to the Manning equation). The following table (C.1) summarizes the values and capacities of the Rock Creek at points where the section measurements were taken.

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[2] Ven T. Chow, Open Channel Hydraulics (New York: McGraw Hill Book Company, 1959), p. 99.

[3] Ibid., Table 5-6 "Values of the Roughness Coefficient," pp. 110-113.

[4] Ibid., Appendix B - "Geometric Elements for Trapezoidal, Triangular and Parabolic Channel Sections," pp. 629-639.

[5] Ibid., Appendix C - "Nomographic Solution of the Manning Formula," p. 640.

Table C. 1

Summary of Variables and Flow Capacities
of Measured Natural Channel Sections

Variables	Channel Section			
	A	B	C	D
(A) Area of Section (Sq. Ft.)	173.1	263.1	317.3	1336.9
Manning's n	0.04	0.04	0.04	0.04
(S) Slope (Ft./Ft.)	0.003	0.003	0.003	0.002
(R) Hydraulic Radius (Ft.)	4.40	5.30	5.80	12.75
(V) Rate of Flow (Ft./Sec.)	1.70	1.90	2.10	2.60
(Q) Capacity (Cusecs)	249.27	499.89	666.33	3475.94
(Q) Capcity Used in Case Study[6]	260.00	450.00	600.00	3130.00

[6]Although the channels presently have no low flow between storms, the probability of such flow will increase with a detention release system. As a margin of safety and to allow for low flows, 90% of the computed channel capacities are used in the case study.

APPENDIX D

COMPUTATION OF THE RUNOFF HYDROGRAPHS FOR THE ALTERNATIVE LAND USE PATTERNS IN ROCK CREEK BASIN

Introduction

The text of the case study relies on the synthetic hydrographs which are the end product of this appendix. The methods and computations will be based upon the design storm rainfall patterns and intensities of Appendix A and the rate of runoff functions in Appendix B.

The Presettlement Runoff

It is assumed that the natural vegetation is composed of those plant communities which associate with existing soils in the watershed. The hydrologic soil groups prior to settlement are assumed to be the same as they are now. Therefore, presettlement vegetation is determined through the use of existing soil characteristics. The condition of the soil cover complex prior to significant alteration by man is assumed to be "best." Figure D.1 shows the reconstructed vegetation patterns and the hydrologic soil groups.[1] Because there were a number of soil groups within a given plant community the hydrologic group values are included in Figure D.1. As a result each area of natural vegetation is assigned a weighted curve number (CN) based on the under-

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[1]The soil survey used for general vegetation reconstruction was published by the Soil Conservation Service of the U.S. Department of Agriculture in cooperation with the Oklahoma Agricultural Experiment Station entitled Soil Survey Cleveland County, Oklahoma (October, 1954). The native vegetation associated with each soil type can be found in the soil survey in an unnumbered table entitled "Cleveland County, Oklahoma Soils: Summary of Important Characteristics." The assignment of each soil to a hydrologic soil group is in accordance with Table 7.1 (Soil Names and Hydrologic Classifications) in the U.S. Soil Conservation Service, "Hydrology", in <u>S.C.S. National Engineering Handbook</u>, (Washington, D.C.: U.S. Government Printing Office, 1972), Section 4, pp. 7.1-7.26.

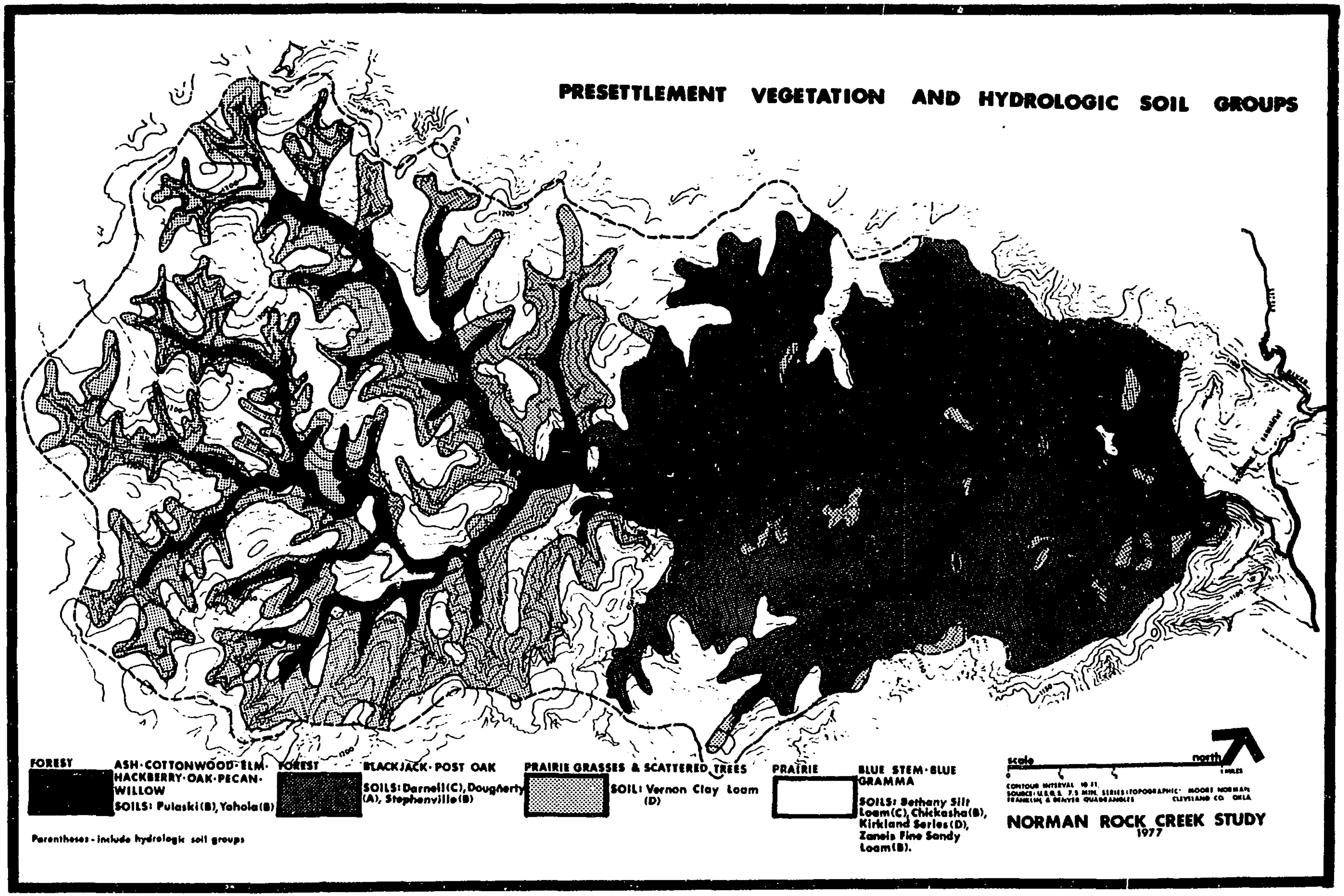

PRESETTLEMENT VEGETATION AND HYDROLOGIC SOIL GROUPS
FOREST
ASH·COTTONWOOD·ELM·HACKBERRY·OAK·PECAN·WILLOW
SOILS: Pulaski(B), Yahola(B)
FOREST
BLACKJACK·POST OAK
SOILS: Darnell(C), Dougherty(A), Stephenville(B)
PRAIRIE GRASSES & SCATTERED TREES
SOIL: Vernon Clay Loam (D)
PRAIRIE
BLUE STEM·BLUE GRAMMA
SOILS: Bethany Silt Loam(C), Chickasha(B), Kirkland Series(D), Zaneis Fine Sandy Loam(B).
Parentheses - include hydrologic soil groups
scale
north
NORMAN ROCK CREEK STUDY
1977

Figure D.1

lying soils and the "best" soil-cover complex condition. The weighted curve numbers according to vegetative areas are: lowland mixed hardwood forest (44), upland post oak-blackjack forest (44), prairie grasses with scattered trees (61), and blue stem blue gramma prairie (59).

The total runoff from each of the subbasins (Fig. D.2) is obtained from the weighted curve number based on the percent coverage by vegetative type. The Table D.1 summarizes the percent coverage by vegetative group type and the resultant weighted runoff curve number by sub basin areas.

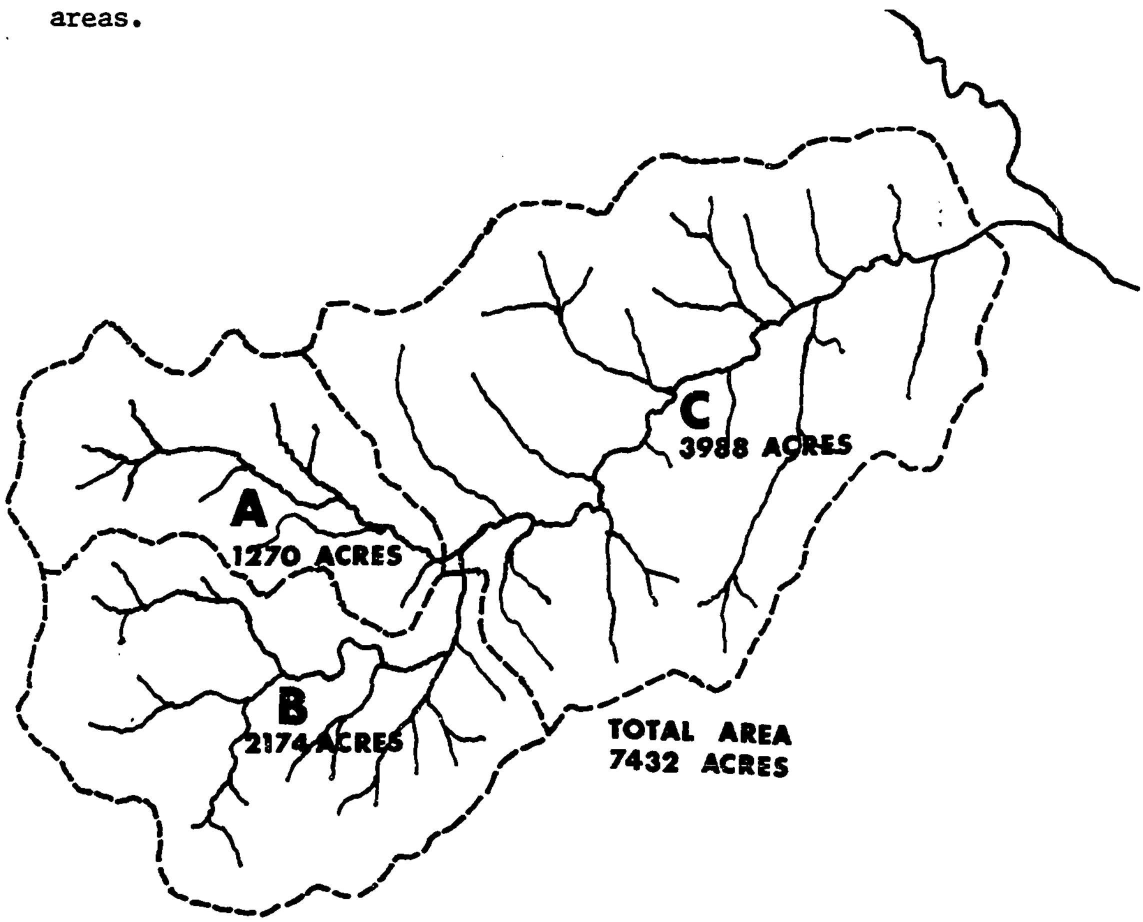


Fig. D.2. Rock Creek Subbasins and Their Areas

Table D.1

Summary of Curve Number Determination by Subbasin Areas (Presettlement)

	AREA			
	A	B	C	Total
Forest (lowland-mixed) CN = 44	18%	20%	28%	24%
Forest (upland oak) CN = 44	0%	0%	41%	22%
Prairie (scattered trees) CN = 61	38%	40%	11%	24%
Prairie CN = 59	44%	40%	20%	30%
Weighted CN	57.1%	56.8%	48.9%	52.6%

The weighted curve numbers are then applied to the rainfall intensity distribution curves for the 6 hour, 100 year design storm (Appendix A). The runoff figues are multiplied by the area involved to determine the discharge hydrograph produced under presettlement conditions. Table D.2 lists the computed discharge figures by the hour and area. The hydrograph display of these figures is found in Chapter 6 of the text.

Runoff for Present Land Use

By analyzing ownership patterns, air photos, and flying over the Rock Creek watershed, the present land use pattern can be characterized as former agricultural lands in transition toward urban-suburban conversion and some woodlands. The extreme western ridgeline area has been residentially developed. A small municipality (Hall Park) has its own sewage lagoons and is the only subdivision or urban character in the watershed and outside of the range of Norman's sewage system. The balance of the residential development is typically scattered ranchettes and farmsteads. The heavily sloped lands in the eastern end remain in oak forest cover. Bottom lands in the lower reaches are generally planted for hay and forage. The major land area of the basin can be classified as fair to poor upland pastures and old fields.[2] Figure D.3 is a graphic summary of existing land use.

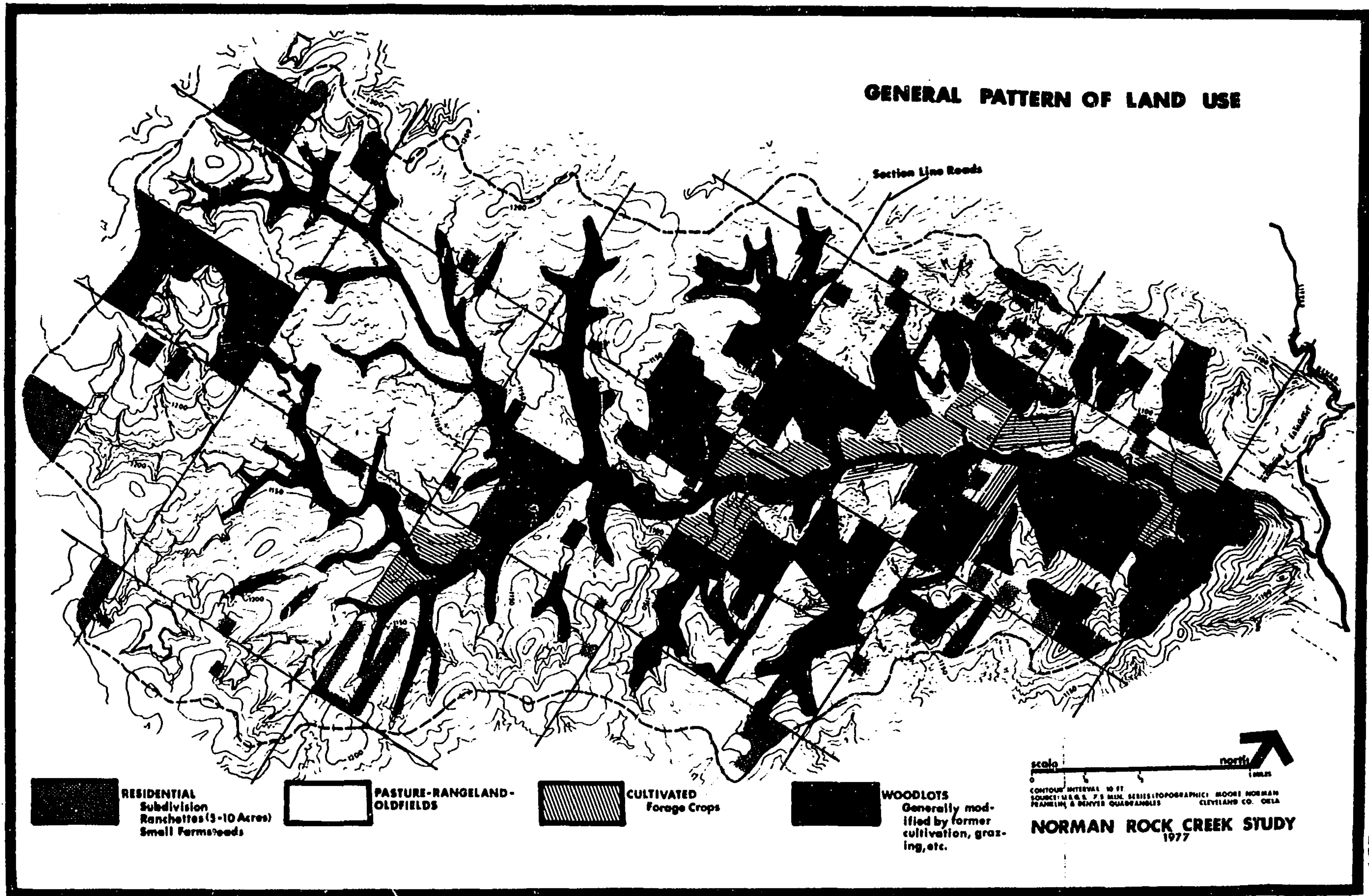
Table D.2

Time and Area Discharges: Presettlement*

Hour	Area A	Area B	Area C	Total Basin
1	267,381	441,942	521,157	1,230,480
2	1,272,337	2,099,300	2,475,310	5,846,947
3	2,607,031	4,308,938	4,080,938	11,996,406
4	2,607,031	4,308,437	5,080,938	11,996,406
5	1,272,337	2,099,300	2,475,310	5,846,947
6	267,381	441,942	521,157	1,230,480
Total Discharge	8,293,498	13,699,358	16,154,810	38,147,666

*Discharges listed in cubic feet.

[2]Observation of the watershed from the air, the examination of aerial photographs, and field surveys were made by the author. Many of the former grazing lands were not being used and were growing over with shrubs, vines and small trees. Other pastures, which were still being grazed, had not been recently cultivated and replanted and in some cases had rills, gulleys, and exposed soil.



GENERAL PATTERN OF LAND USE
Section Line Roads
RESIDENTIAL
Subdivision
Ranchettes (5-10 Acres)
Small Farmsteads
PASTURE-RANGELAND-OLDFIELDS
CULTIVATED
Forage Crops
WOODLOTS
Generally modified by former cultivation, grazing, etc.
scale
north
CONTOUR INTERVAL 10 FT.
NORMAN ROCK CREEK STUDY
1977

Figure D.3

The computation of runoff from the design storm is based on Table B.2 which lists curve numbers for hydrologic-soil cover complexes for agricultural land use.[3] The computed runoff from each area in the basin is a product of weighted Hydrologic Soil Groups and land use based on the percentage of coverage by each. Table D.3 summarizes the land use coverages and soil groups which lead to the cumulative weighting of the runoff curve numbers. Table D.4 lists the computed discharge

Runoff for Complete Urbanization: Typical Pattern

In this case it is assumed that the entire watershed is developed in a common suburban pattern. Table 6.1 in the case study chapter provides the percentages of land use coverage for a typical suburban development. These percentages are distributed equally throughout the watershed. As a result the weighted coefficient of runoff based on land use percentages (65.8) is applicable throughout the watershed. Table D.5 lists the computed discharges.

Runoff for Complete Urbanization: Modified To Fit With a Detention System

In this case it is assumed that the entire watershed is developed in a generally suburban pattern. However, due to the significant modification of the runoff management system, the common percentages of land uses are slightly changed. Chapters 4 and 5 discuss the tendency for greater detention efficiencies when land use is clustered (principally residential). Table 6.2 lists the land uses by percent. The changes are increases in multi-family residential configurations and

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[3]The only land use outside of the agricultural table is taken from Table D.1 of this appendix (Single Family Suburban).

Table D.3

Computation of the Runoff Curve Numbers for Present Land Use in Rock Creek

	Hydrologic Soil Groups A	B	C	D	Weighted CN	% Area
Area A Land Use (%)						
*Suburban Residential (Single Family)	-	-	-	100	79	5
Farmstead/rural residential	-	-	-	100	86	5
Pasture-Range (Fair)	-	-	15	85	83	75
Woodlands (Fair)	-	80	-	20	64	15
Weighted (CN Area A)					80	17%
Area B Land Use (%)						
*Suburban Residential (Single Family)	-	-	-	100	79	9
Farmstead/rural residential	-	-	-	100	86	5
Pasture-Range (Fair)	-	15	-	85	82	64
Small Grain (Good-Contoured)	-	10	-	90	83	4
Woodlands (Fair)	-	80	-	20	64	18
Weighted (CN Area B)					79	29%
Area C Land Use (%)						
Farmstead/Rural Residential	-	85	-	15	76	5
Pasture-Range (Fair)	-	60	-	40	75	35
Small Grain (Good-Contoured)	-	95	-	5	74	20
Woodlands (Fair)	-	90	-	10	62	40
Weighted (CN Area C)					70	54%
Total Basin Area CN					74	100%

*Suburban Residential value is a CN number converted from the coefficient

Source: author

Table D.4

Time and Area Discharges: Present Land Use*

Hour	Area A	Area B	Area C	Total Basin
1	595,363	1,010,127	1,621,404	3,226,894
2	2,858,978	4,797,337	7,700,234	15,356,549
3	5,860,297	9,844,017	15,778,136	31,482,450
4	5,860,297	9,844,017	15,779,136	31,482,450
5	2,858,978	4,797,337	7,700,234	15,356,549
6	595,363	1,010,962	1,621,404	3,226,894
Total Discharge	18,629,276	31,302,962	50,199,548	100,131,786

*Discharge listed in cubic feet.

Table D.5

Time and Area Discharges: Complete Urbanization - Typical Pattern*

Hour	Area A	Area B	Area C	Total Basin
1	608,594	1,041,798	1,911,081	3,561,473
2	2,881,312	4,932,262	9,047,775	16,861,349
3	5,916,706	10,128,282	18,579,388	34,624,376
4	5,916,706	10,128,282	18,579,388	34,624,376
5	2,881,312	4,932,262	9,047,775	16,861,349
6	608,594	1,041,798	1,911,081	3,561,473
Total	18,813,224	32,204,684	59,076,488	40,094,396

*Discharge listed in cubic feet.

open space which is gained by the clustering. Public streets are conservatively reduced assuming that clustering generally allows for more efficient street designs by reducing the frontage per dwelling. The overall population density is assumed to be the same as the typical suburban pattern. Methods of computation are also the same. The weighted runoff coefficient for the watershed under the modified urbanization pattern is 66.2. The difference in runoff between the two urbanization patterns from the entire watershed for the design storm is less than 0.5%. Therefore the hydrograph for the two is considered to be the same.

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Personal papers, documents and studies of Professor George Reid of the College of Engineering, University of Oklahoma.