PROFESSIONAL PAPER

WATERSHED MANAGEMENT CONCERNS IN GENERAL PLAN FORMULATION FOR REGIONAL GOVERNMENTS

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ABSTRACT OF PROFESSIONAL PAPER

WATERSHED MANAGEMENT CONCERNS IN GENERAL PLAN FORMULATION FOR REGIONAL GOVERNMENTS

Most city, county, and regional planners are more comfortable with discussing urban/suburban related issues than natural resource issues. The reason is due to the education planners receive. Eventually, counties and regions, and cities with large open areas, will have to plan for the managed production of all resources as they become scarcer. This paper addresses the watershed basin as an area that should be managed for its most important product: water. The paper attempts to show the planner the basics of watershed management, methods to include watershed management in general plans, and concepts of water law that affect ownership of watershed water. Discussion departs from the traditional approach of watershed management planning for regional economic development and soil erosion control to focus on the watershed as a resource producer.

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The inspiration of others not withstanding, I assume all responsibility for the content of this paper. I hope the planner who reads it does not let it suffer the fate of old planning documents by collecting dust on the shelf.

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CHAPTER 1

WATERSHED MANAGEMENT VERSUS PLANNING

Introduction

> Watershed: All land and water within the confines of a drainage divide (SCSA, 1982:186).
>
> Watershed Management: Use, regulation, and treatment of water and land resources of a watershed to accomplish stated objectives (SCSA, 1982:186).
>
> Watershed Planning: Formulation of a plan to use and treat water and land resources (SCSA, 1982:186).
>
> Planning: Planning is revelation (MacKaye, 1968:171).

Watershed management as a natural resource discipline has not been well understood by land use or regional planning officials. This is generally due to the fact that management of a watershed is dependent upon practices in other disciplines such as forestry or range management. Consequently, the goal of watershed management, which is the controlled production, catchment, and containment of water from a natural physiographic unit, is not stated in planning documents. Instead, most community general plans express an interest in watershed management for erosion control, floodplain protection, or hillside management to prevent slope failure. These are certainly desirable goals, but they are best categorized as hazard reduction or retention of land productivity goals rather than a watershed management consideration.

The objective of this paper is to alert the planner to the value of the watershed as a producer of water. Chapter 2 is devoted to the concepts of watershed management that the planner should understand to be able to communicate the value of this resource to decision-makers and the public. Chapter 3 examines some of the planning techniques that can be used to protect the watershed resource so management for increased water yield can occur. Emphasis is placed on recognition of the watershed as a resource in a general plan document since these planning documents are widely accepted in the United States. Many communities and states require general plans for the government jurisdiction before development laws and land use decisions can be made. Chapter 4 discusses some of the principles of water law that affect ownership and rights to access to the water resource. The planner must be familiar with the water rights available in his jurisdiction since any additional water that results from watershed management will be subject to ownership claims. The planner will want to know who will benefit from the increased water yield to determine the most desirable planning approach to take.

An additional problem in addressing watershed management concerns by regional and land use planners is that most planners typically have a background in urban studies and are more comfortable in addressing urban issues rather than natural resource issues. Housing and transportation are likely to have more policy statements in a community general plan than resource protection or production. Policy statements for urban related issues will generally include specific strategies for their implementation, such as percentages of housing units necessary to satisfy low-income housing needs. For natural resource issues, the implementation strategies are much less defined, generally indicating a desire to preserve future options for use of the resource. The net result is that communities are using resource areas to meet current building needs since the policy for development of urban facilities is better stated than a program for "preserving future options" to satisfy natural resource needs.

One typical example of such natural resource policy vagueness can be found in the City of Arcata, California, General Plan of 1975. This city's Conservation and Open Space Policy states:

> Land should be used for the purpose for which it is most suited by virtue of its inherent natural characteristics, as modified by its locational relationships, whether that use be urban development, natural resource preservation and utilization, or agricultural production (City of Arcata, 1975:II-1).

This statement was acceptable to the State of California which has one of the toughest and most comprehensive General Plan requirements in the Nation. Planners may applaud the statement's comprehensiveness, but it offers little direction to a decision-maker who must balance land use issues. Now, however, communities are starting to recognize the impact of urban sprawl, and are looking for new goals and policy statements to give resource areas equal footing with the community's urban needs (Kusler, 1980).

The Water Resource

One resource that is starting to have a profound impact on human development patterns is water. Water has historically been the determiner of location for many cities which have been sited on lakes, seashores, or along a navigable river, but the commodity itself has been essentially regarded as a free good. Payment for water is a relatively new phenomenon required primarily to cover the cost of storage and conveyance structures and treatment. Little value may be placed on the water itself if there is an abundant supply. Allocation becomes a problem only if supplies are not adequate for all users. Then, documented ownership may be required which is protected by water law. The first users to claim the available supply in arid areas simply took it and made no payment to anyone for the use of the water. It was a public resource but it was used without public control. If water is to be controlled as a public good, the value of the resource will have to be established. A complete statement of the public value of water would help in the equitable allocation and distribution of the resource.

Many regions of the world are now finding that their water resources are not adequate to meet all the competing needs. Contamination of fresh water from various pollution sources is also taking its toll. Inefficiency in storage and transportation, with capital shortages limiting repairs, subtracts from the available water supply. Finally, most of the suitable sites for water storage projects are already developed. Ecological concerns, capital shortages, and regional rivalries limit the development of project sites still available, making it difficult to avoid potential water shortages (Koelzer, 1982).

The Global 2000 Report to the President paints an even grimmer picture by stating:

> Regional water shortages will become more severe. In the 1970-2000 period, population growth alone will cause requirements for water to double in nearly half the world. Still greater increases would be needed to improve standards of living. In many Less Developed Countries, water supplies

> will become increasingly erratic by 2000 as a result of extensive deforestation. Development of new water supplies will become more costly virtually everywhere (Council on Environmental Quality, et al., 1982:2).
>
> As pressure on water resources increase, conflict among nations with shared water resources are likely to intensify. Interstate disputes between upstream and downstream users of multinational and national river basins are particularly apt to occur over questions of water rights and priorities. Longstanding quarrels could easily worsen as pressures become critical (Council on Environmental Policy and U.S. Department of State, 1982:159).

Certainly, a problem is beginning to emerge from our handling of water as a resource in the past, and how we plan for its availability and allocation in the future.

In order to plan for water for community use, a planner must have a clear understanding of the hydrologic cycle, which explains movement and location of water. The planner should also be familiar with the source of available water: the watershed. The planner must then be able to state the community's need for an adequate water supply and translate these needs into goals and policy statements in a general plan. Water policy makers have studied water supply problems but the emphasis has been on construction of structures to impound streams and rivers, and pipe systems to bring the water to the user. The result has been an increased reliance on diversions from remote watersheds (Kolezer, 1982). Now the planner must take the lead to establish policies that ensure that the local watershed will continue to produce water either naturally, or in an enhanced state, for community needs. In essence, the planner must learn the principles of watershed management in order to incorporate the watershed resource, and its product of water, into the goals and policy statements of general plans.

Importance of Watershed Land Use Control

Good watershed management should be able to protect a community from flood hazards as well as to provide an anticipated water supply to help satisfy community needs. Unfortunately, little land use control is exerted in the upper reaches of a watershed to meet these goals. Most community floodplain zoning is structured to keep buildings out of the lower elevations next to the stream channel. These same zoning ordinances do little to control second home and luxury or large tract development from creating impervious surfaces in the higher elevations (Corwin and Hefferman, 1975). Instead of retention reservoirs for storage, communities have to build flood control detention facilities to protect low lying property. Certainly, the distinction is a fine point, especially with multi-purpose water projects, but every dollar expended on flood control is capital diverted from municipal, industrial, residential, or irrigation water supply projects.

The issue of water supply is probably the most important reason why a community should want to encourage watershed management. In the western United States, the importance of storing water is well understood. Water supply is also becoming a critical concern in the eastern United States as well, both in terms of quantity and quality. Capital for construction of major water projects that divert water hundreds of miles is becoming more difficult to obtain. The environmental impacts of such projects are also becoming increasingly difficult to justify, as in the recent voter defeat of the Peripheral Canal Project in California (Howard, 1982:15). The immediate and long-term alternative to such large-scale projects would be for regional communities to protect, enhance, and develop their local supply of water. To control the source of the water supply requires watershed management. To manage a watershed requires land use controls of man-induced activities, and statements of goals, objectives and policies in a community or regional master plan to direct the watershed management strategy, and to provide legal and moral backing to the imposition of land use controls in the watershed (Smith, 1979).

Purpose

This paper is written to serve as a guideline for community and regional planners to understand and address the value of watershed managment in comprehensive planning documents. Application of watershed management goals, policies, and objectives to land use controls will also be stressed. With a clearer understanding of the benefits of a watershed, and application of controls to meet community standards for the appropriate uses of land within a watershed, a community or region can gain in water quantity and quality. The goal of increasing the regional freshwater supply is considered as the primary reason for addressing watershed management in planning documents. This is a change from "traditional" watershed planning that often stressed soil erosion control and regional growth from outdoor water recreation over local water supply (U.S. House of Representatives, 1970).

Many communities and regions are faced with the prospect of water shortages in the near and long-term future. Past efforts to supply and purify water have relied on engineering projects to build containment structures and treatment plants. This task has generally been funded with Federal, state, and local money for projects constructed on a community or regional scale. While region-wide agencies such as soil conservation districts or river basin commissions often exist which may have responsibilities for managing watersheds, there is, unfortunately, little interaction between such special-purpose districts and the communities. The community may pay a share of the project cost for facilities but may not have exerted control over the processes that cause a need for the facilities (Getzels and Thurow, 1979). Districts and commissions often lack the land use controls to implement their programs, although they recognize the impacts of the watershed on the downstream community. Since capital sources are scarcer for water-related projects, communities must share and use the land use control powers they have with the watershed agencies, or take the lead role in order to protect and enhance their water supply.

It is anticipated that the audience of this paper will be planners for community and regional governments. In order to relate the paper to the planner's experience, the county level of government will be used in the discussion. The county is an appropriate level for study since a county generally has the authority to prepare a comprehensive plan and to regulate land uses. Counties also typically have a sufficient area within their jurisdiction to encompass a watershed that provides water for the county residents. This approach should not preclude incorporated cities, or larger regional authorities from utilizing the content of the paper. The important factors are a recognition of the value of a watershed, authority to regulate land uses, and legal boundaires that include a significant portion of a watershed. Planners should remember that any land area is a potential water producer.

One of the purposes of the paper is to alert planners, and other interested readers, to the importance of the management of the watershed and to its significance as a community resource. Watershed concerns can be appropriate additions to comprehensive plans, even if urban related issues were only formerly addressed. The result can be complementary to both the urban land use concerns and natural resource concerns.

Since this paper is intended for use by planners, the discussion of technical issues in watershed management will be limited to areas where a planner has the necessary skills to interpret and use the information. The skills will generally be in terms of map interpretation for identifying the physical properties of a watershed and concepts that can be expressed without relying on additional extensive research. It should be understood that the planner is a generalist who can identify community goals and prepare a plan for their implementation. The planner must seek the skills of a specialist, such as a hydrologist, civil engineer, or watershed manager, to prepare detailed information on a specific watershed. From this, the planner interprets the specialist's report to prepare land use control ordinances while addressing the community goals. The planner will not become the watershed manager, but rather, the land use manager to allow watershed management to proceed.

As stated earlier, the practices of watershed management, and the resources involved, have overlapping boundaries with other natural resource disciplines. For clarity, this paper will define the concern of watershed management as the managed production of water from the land. Practices to manipulate water production are best described in more technical works. Land use controls and community goals will be focused on preservation of the land base for watershed management to be possible. Water production will be addressed in terms of surface and sub-surface water supply. Hopefully, this paper will be of use to community or county planners and interested citizens and will cause them to seek the assistance of the watershed management profession which has much to offer in meeting the water needs of a community.

CHAPTER 2

WATERSHED MANAGEMENT FOR THE PLANNER

Planner Involvement

A regional planner need not become a watershed manager to articulate the value of watershed management in comprehensive planning documents. A clear understanding of watershed management goals and policies as a resource is all that is required. Many times, information can be compiled from agencies that have a direct role in watershed management, hydrology, floodplain management, or water resources planning. The value of available information, however, comes only from interpretation of the data into goals and policies that focus the decision-making process for resource allocation. The planner must understand the basic concepts to translate the professional's document into lay terms. In other cases, no information may be available, and the planner will have to generate basic data to justify selected goals and policies. Neither interpretation nor data generation need be feared if the planner uses some skills basic to his trade: map interpretation, information gathering, and statistical analysis.

Since this paper is limited to the discussion of watershed management for the managed production of water, concepts discussed in this chapter will identify data necessary to support this goal. This ignores goal statements of a watershed as a provider of timber, rangeland, soil to replenish floodplain agriculture lands, wildlife habitat, and outdoor recreation areas. The value of these resources can and should be justified in regional general plans to help give natural resources equal footing with urban planning goals. These resource goals, however, can best be stated under general plan sections more closely related to their topic area. Though planning stresses a comprehensive view, the inclusion of these resource topics under watershed management detracts from the water production goal.

Excellent sources used to develop this chapter include: F. A. Branson, et al., 1981; T. Dunne and L. B. Leopold, 1978; G. B. Griggs and J. A. Gilchrist, 1977; L. B. Leopold, 1968; R. K. Linsley, M. A. Kohler and J. L. H. Paulhus, 1975; and R. K. Linsley and J. B. Franzini, 1964. Additional inspiration came from D. Doehring, 1981, and I. L. McHarg, 1969. The planner who wishes to get further background information, or wishes to expand on the basic information presented, should obtain one or more of these sources for his use.

The Hydrologic Cycle

The basis for watershed management and the starting point for an understanding of the resource product of water can be found in the concept of the hydrologic cycle. Simply stated, the hydrologic cycle is:

> The circuit of water movement from the atmosphere to the earth and return to the atmosphere through various stages or processes, as precipitation, interception, runoff, evaporation, and changes in ground and surface water storage (SCSA, 1982:77).

Water is always in transit through the cycle, changing between the three phases of solid (snow and ice), liquid, and gas (water vapor). To the watershed manager, every stage of the cycle is important for determining correct management techniques. For the planner, the most important point in the cycle is that which yields usable water for domestic, industrial, and agricultural purposes. In liquid form, this water comes from one of two sources: runoff into a storage facility, and percolation into a groundwater aquifer. Figure 1 is a simplified diagram of the hydrologic cycle.

Most planners understand the concepts of precipitation, evaporation, evapotranspiration, and runoff, though the rate at which each occurs is typically obscure knowledge. The rate at which water passes through the hydrologic system is extremely important if gains and losses in water levels are critical. The easiest example of the importance of rate change is where rapid runoff leads to flood conditions whereas slower runoff allows for containment in storage structures. A less dramatic but equally important example is the loss of water from an open reservoir due to surface evaporation. Such losses can total more than one-half inch a day under certain conditions (Linsley, et al., 1975:161). While one day's loss would not be visually detectable, the loss over a period of a month would be quite apparent and a matter of concern if it were to be the cause of severe rationing of water.

To consider the watershed area as a supplier of water, the planner must collect information on the precipitation of the area. The best source of information is the National Weather Service Annual Summaries, which list data by reporting station. Important precipitation data include:

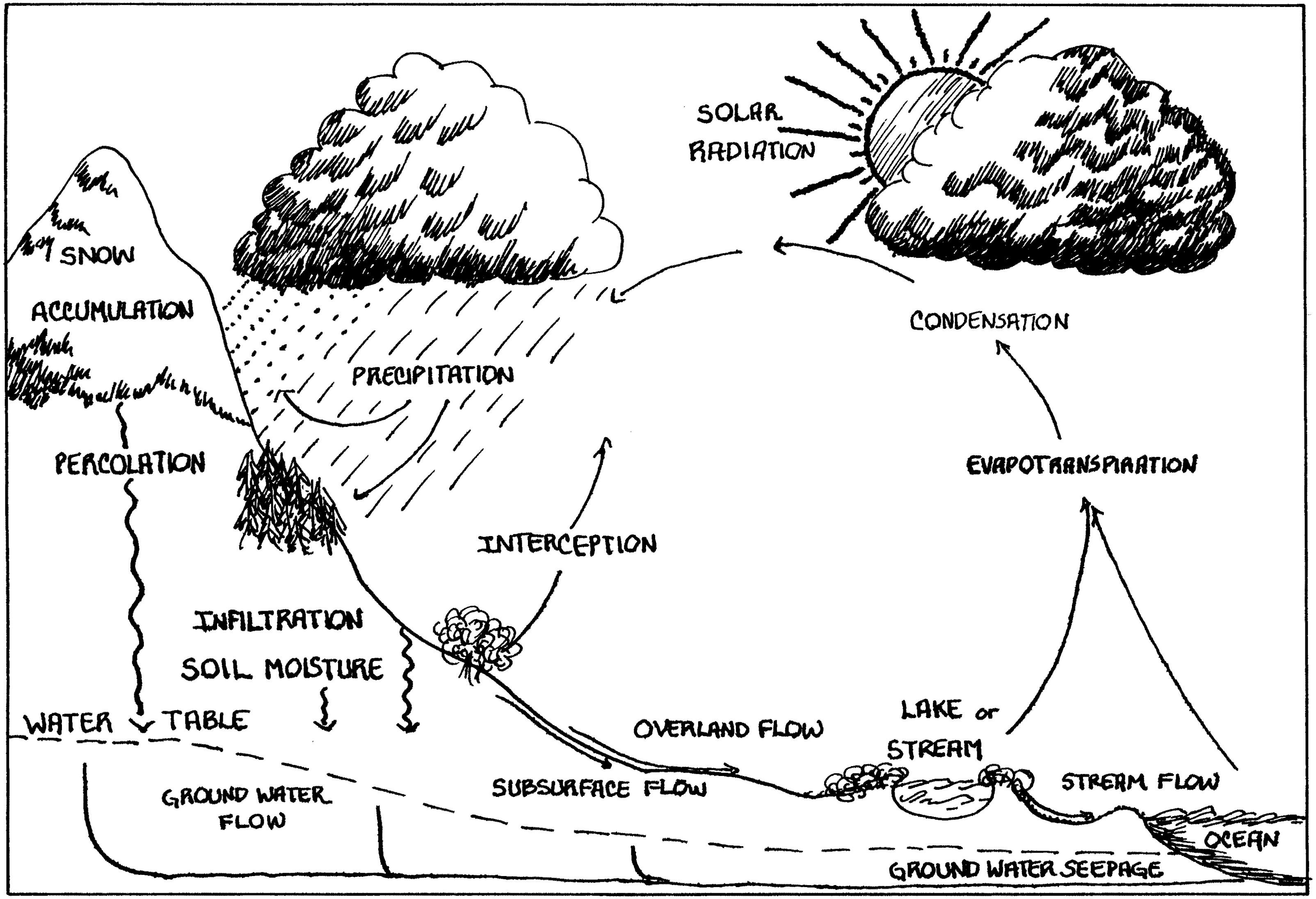

Figure 1. Conceptual hydrologic cycle.

(1) depth: the magnitude of the rainfall.
(2) area: the region over which the precipitation occurs.
(3) duration: the time period during which the precipitation occurs.
(4) intensity: the rate of precipitation in centimeters (inches) per hour (Griggs and Gilchrist, 1977:247).

Obviously, the planner can be quickly overwhelmed by the magnitude of data just related to precipitation. The planner needs to keep in mind that the purpose of precipitation data for the watershed section of a general plan document is to make an eventual quantitative statement of water yield expected from the regional watershed. It may be sufficient to state in the general plan the expected water yield on an annual basis, and leave the seasonal variances to the water agency authorities. Of course, planners do become involved in more specific planning or environmental documents than general plans, so it can be well worth the effort to establish a data base that includes precipitation and hydrologic data.

Variable Source Area Concept

To add further complexity to the precipitation input to watershed water yield, the planner should be aware of the variable source area concept. The concept stresses the fact that not all precipitation contributes equally to the water that flows out of the watershed. This can be easily seen where precipitation at higher elevations is in the form of snow and hail, which stores water for release at a warmer time compared to rain. The concept, however, also refers to water flow rates within the watershed by assuming:

> . . . that certain regions within a watershed contribute runoff to the storm hydrograph while other areas act as recharge or storage zones. Important factors to consider

> in determining whether an area contributes to runoff (or to the groundwater) include its physical position with respect to the channel, its soil properties, and the storm characteristics. Valley bottoms are generally considered to be the areas that contribute to streamflow while ridge tops constitute recharge areas. The area in between the valley bottoms and ridge tops, often referred to as the dynamic zone, may be either contributing or recharging, depending upon the storm size and temporal characteristics, antecedent soil water content, and soil properties (Branson, et al., 1981:77).

The importance of the variable source area concept to the planner is twofold. First, the concept means that there will not be an immediate one-to-one correspondence between precipitation and water yield, if ever at all. The planner needs to remember that the hydrologic cycle allows for the accounting of all water in the system. Water is never "lost"; it may return to the atmosphere through evapotranspiration, or travel through the watershed too slowly to be of any planning significance for water yield due to the variable source area concept. Second, the concept will have a direct impact on the planning for land uses within the watershed. Water table recharge areas should not be used for waste or effluent disposal, heavy fertilizer or biocide applications from farming or forestry operations, or urban uses that create impervious surfaces. Runoff areas must be protected from uses that cause excessive erosion to occur.

Water Balance

The hydrologic cycle is best expressed in watershed management by the concept of the water balance. The water balance idea was developed by C. Warren Thornthwaite in 1944 to describe the various locations to which precipitation was portioned after a storm event. The water balance is expressed in equation form as:

$$P = i + \Delta ET + OF + \Delta SM + \Delta GWS + GWR$$

where: P = total precipitation.

i = interception by vegetation or other surfaces of the water so that it evaporates and does not reach the ground surface.

AET = actual evapotranspiration of the water before it reaches the stream, lake, ocean, or becomes available for man's use.

OF = overland flow.

SM = the change in soil moisture from pre-storm conditions. This water is eventually returned to the atmosphere from direct evaporation, or from transpiration and use by plants.

GWS = the change in the groundwater storage. This is the increase in the groundwater depth which becomes available for man's use through pumping of the groundwater aquifer.

GWR = groundwater runoff, where the water flows from the groundwater aquifer to the surface at a stream, lake, or ocean (Dunne and Leopold, 1978:236-238).

To simplify the water balance concept, it is the planner's task to find out what percentage of the total precipitation actually adds to the water yield of a watershed. This percentage varies from watershed to watershed due to incoming precipitation levels, vegetation, climate, soils, slope, and watershed length and area. The water balance is the accounting statement of the various percentage that does not add to water yield.

Unfortunately for both the regional planner and the watershed manager, there is no single source of data for the components of the water balance. In fact, except for precipitation, there are no accurate methods for completely measuring the other parameters. Since this limitation exists, the planner should consult with the watershed manager or hydrologist for their best estimates to either complete the equation, or to determine a percentage range for the precipitation that becomes water yield. Caution should be employed in choosing the percentages since too low an estimate of water yield can lead to under design of storage and containment facilities. Too large an estimate can leade to a greater expenditure of funds on facilities, and possibly severe water shortages if urban development is stimulated by an overly optimistic water yield forecast. The planner may not be involved in the design of the storage system, but the initial water flow calculations will influence the level of action the county takes in the watershed.

Watershed Descriptors

Before more can be said about runoff and water yield, the planner ~~needs~~ to know some of the physical descriptor terms for a watershed. "Drainage basin characteristics include the topographic elements of relief, slope, stream channel system, and basin size and shape" (Branson, et al., 1981:257). The regional planner's first concern should be to identify the watershed's total size and shape, and to delineate those areas within the planning jurisdiction to be included in the general plan and subject to land use controls. The most desirable situation would be one in which the entire watershed or a major portion will be within the planning areas. Otherwise the planner will have to estimate the water yield for the included area, taking into account the variable source area concept, and arrange with adjacent jurisdictions for mutually beneficial land use controls within the watershed.

Watershed drainage area and shape is determined with use of United States Geological Survey topographic quadrangles. The regional planner working for a county will typically use a 1:62,500 scale map since a large area is within the map borders. A watershed boundary is delineated by ridgetops or any topographic rise that causes water to drain into separate watercourses. Stream courses eventually join other streams and smaller drainages become components of larger and larger watersheds until in the United States, this eventually leads to the two major watersheds, separated by the Continental Divide, with all water flowing either to the Atlantic Ocean or the Pacific Ocean. Obviously, the regional planner must scale the identification of watershed units to a reasonable number given the size of the planning area involved. Some principles that may be useful to follow in identifying distinct watersheds would be:

a. Group subdrainages that have similar vegetation;
b. Group subdrainages that have similar climatic or physiographic features;
c. Group subdrainages that have similar economic activities;
d. Group subdrainages that have similar existing or proposed land uses.

In all cases, the subdrainages must be adjacent to each other to compose a watershed. For planning purposes, it is appropriate to identify the delineated watershed with a commonly agreed upon name so the public can recognize the watershed areas involved in the general plan.

Once the appropriate watersheds have been identified on the topographic map, the area within can be measured. The three most commonly used methods are: (1) use of a polar planimeter; (2) use of a dot grid; and (3) use of geometric subdivisions. All three methods should provide sufficient accuracy for both planning work and water yield calculations. More accurate methods might be used if time, money, and equipment are available, involving the use of a computer mapping system analog to digital converter, or a survey crew, but the greater accuracy obtained is of doubtful necessity for planning work.

The shape of the delineated watershed planning unit is an important factor in understanding water yield, runoff rates, and choosing appropriate land uses in the region. Watershed shape is the result of subsurface geology that has influenced the resultant drainage patterns. Watershed shape can be either long and narrow, fairly round with drainage evenly distributed, or similar to a half moon, where the drainage pattern is much more pronounced on one side of the main channel than the other (Bloom, 1978). The bedrock of the region presents areas that are more easily eroded by flowing water than other areas, allowing stream channels to incise the landscape. If the bedrock erodes equally, a dendritic drainage pattern will emerge, with slope determining the flow of water. This type of watershed will be characteristically round, with drainage equally divided around the main channel. If the bedrock is not easily eroded, or is in seams of erosive and non-erosive rock, the resultant drainage will tend to be narrow and linear. If two separate bedrock units meet, with different erosive characteristics, then the third type of watershed shape will result (see Figure 2).

The importance of watershed shape for land use planning will be discussed in the next chapter. Shape is also an important descriptor of runoff rates and water yield since the longer distance water has to travel over land to a stream channel, and the longer a stream channel is to the mouth of the watershed, the greater is the transmission loss of water. Watershed shape cannot, unfortunately, be translated into a direct coefficient to state mathematically the transmission loss, but information on shape can be used to temper the estimates of water yield. Some have attempted to state mathematically the shape of a watershed including a concept of "circularity," where the ratio of the area of the basin to the area of a circle with an equally lengthened perimeter is calculated. Another concept is that of "elongation," where a ratio is calculated between the area of a circle with the same perimeter as the watershed, and the maximum basin length of the watershed (Branson, et al., 1981:262). These concepts, however, only allow for comparison between watersheds as to the relative shape, and do not correlate to water transmission losses from runoff and water yield.

Another widely used descriptor of a watershed is the concept of drainage density. The drainage density is calculated by dividing the summation of the lengths of stream channels in the watershed by the total basin area. In equation form, this is:

$$Dd = L/A$$

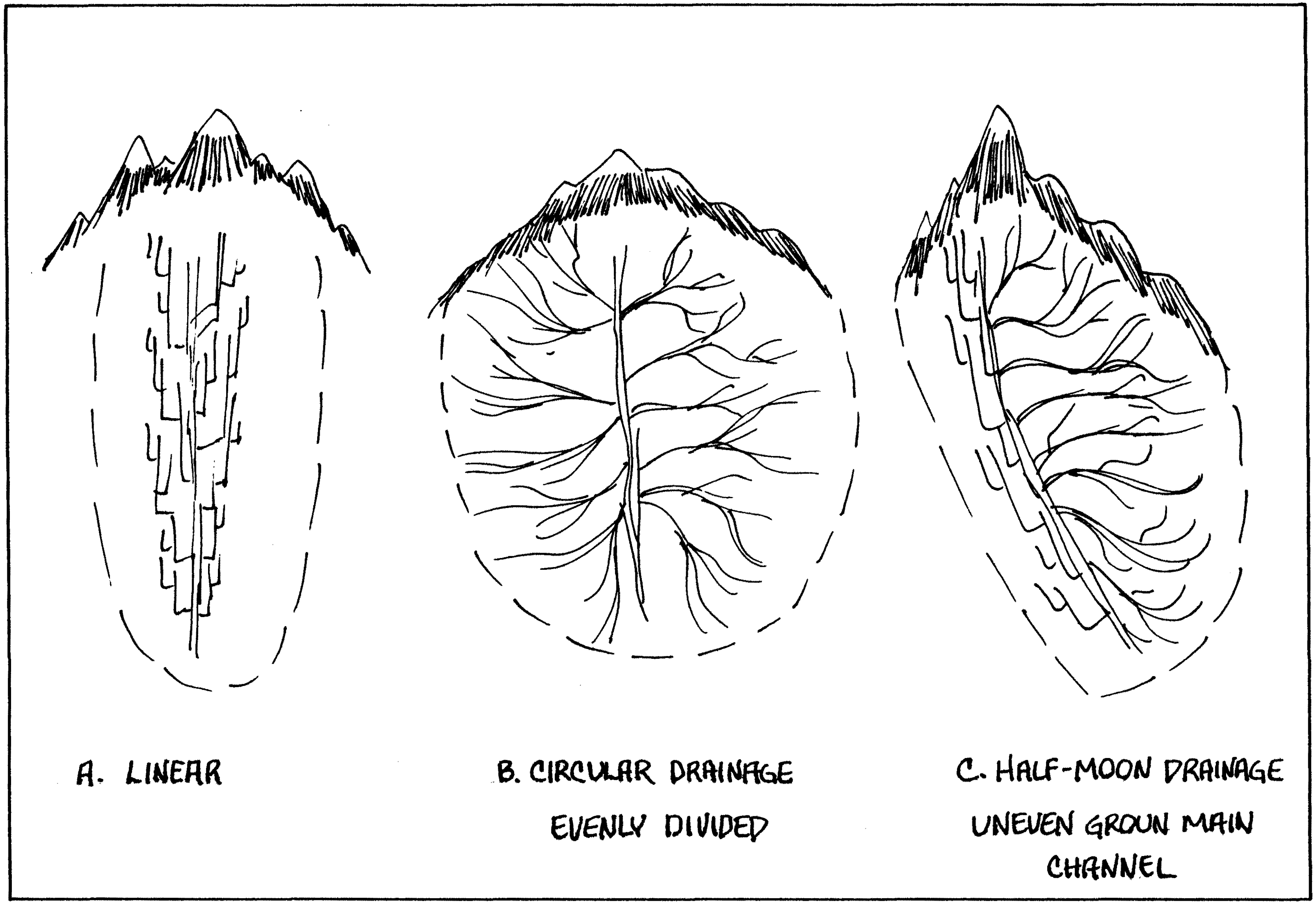

Figure 2. Characteristic watershed shapes.

Total channel length is determined by measuring streams depicted as perennial or intermittent on the U.S.G.S. quad sheets. This ignores ephemeral streams which carry flow only in direct response to precipitation, but some arbitrary cutoff must be chosen, otherwise the drainage density value could be logically carried out to a one-to-one correlation. If, because of the arid nature of the region, ephemeral stream channels are included, the calculated drainage density should include this modifying descriptor. The planner should also conduct a field check to make sure the existing stream channels are as represented on the topographic map. Current air photos can be very useful for this task.

Drainage density is a measure of dissection texture of the land surface by flowing water. High drainage density values are indicative of high flood peaks, high sediment load, high relief, and dry or well drained soils. As Linsley, et al. point out:

> A high drainage density reflects a highly dissected watershed, which should respond relatively rapidly to a rainfall input, while low drainage density reflects a poorly drained watershed with slow hydrologic responses. Observed values of drainage density range from as low as three in parts of the Appalachian area of the United States to 400 or more in Badlands National Monument, South Dakota. Low drainage densities are observed where soil materials are resistant to erosion or very permeable and where relief is small. High values may be expected where soils are easily eroded or relatively impermeable, slopes are steep, and vegetal cover is scanty (Linsley, et al., 1975:419).

The determination of what is a high versus a low drainage density value can only be made after calculating the average value for several watersheds in the region. A high drainage density value should suggest the inappropriateness of most land uses including agriculture, building construction, or public improvements such as roads and bridges. Suitable uses can include dispersed recreation and grazing. As with watershed shape, drainage density is not a mathematical determinant in runoff or water yield equations, but the concept is important in understanding the differences between the outputs of two watersheds and the land uses and management practices appropriate in each.

Planners who wish to verify their stream length or watershed area values may apply a relationship first identified by John T. Hack of the U.S. Geological Survey in 1957 (Dunne and Leopold, 1978:500). Hack determined that most drainage areas increase with distance downstream at a predictable rate. The relationship is expressed as:

$$A = 0.57\ L^{1.67}$$

where: A = drainage area in square miles.

L = the length of the main channel in miles.

Proof of the relationship comes from data for watersheds throughout the world, in various climatic areas. This concept is a variation of the watershed size calculations, but it is useful since one parameter can be used to find the other. The values in Hack's equation should be fairly close to those measured by the planner. If either the length or area values do not coincide with the watershed planning area, the planner may want to go back to the topographic map to make certain than an important section was not excluded from the watershed area, or that the entire main channel has been identified.

This final section of the chapter is devoted to the concepts of runoff, water yield, and water harvesting. The basic concepts already discussed should lead the planner to the conclusion that if water is put into the system, moved at various rates and controlled by physical characteristics of the watershed, the water will eventually emerge in the stream channel ready for man's use. In-depth discussion of the various processes involved has been ignored since the regional planner is mainly concerned with the availability of the water for man, and the protection of its source. Estimations of runoff and water yield can also be achieved using simple concepts rather than relying on extensive data and expensive measuring techniques. The simplest approach has been pioneered by the Soil Conservation Service using only precipitation data to determine runoff quantities. Chapters 9, 10 and 20, entitled "Hydrologic Soil-Cover Complexes," "Estimation of Direct Runoff from Storm Data," and "Watershed Yield," from Section four of the U.S. Soil Conservation Service National Engineering Handbook have been reproduced here as Appendix A. With this appendix a planner can follow, step by step, the development of the simple equation used to estimate runoff and water yield. The basic points will be addressed here.

Watershed Runoff

Watershed runoff is one component of the hydrologic cycle where precipitation minus basin recharge minus groundwater accretion equals runoff. Basin recharge is the addition of water to the surface soil layers to replace the water lost to direct evaporation, evapotranspiration, or consumptive use by plants (Brady, 1974). Groundwater accretion is the result of water percolating into the ground water aquifer. Runoff can be expressed as water traveling through the watershed by three different routes: overland flow, interflow, or groundwater flow. Overland flow is surface flow above the land to a stream channel. If the soil or land surface is relatively impervious, most precipitation will become overland flow, leading to "flashy," high peak flooding. Interflow is water that moves through the soil horizons, parallel to the land surface, until it eventually resurfaces in a stream channel, or is fed by gravity into a groundwater aquifer. Interflow water moves more slowly through the hydrologic system than surface flow, which is the reason why streams do not return to pre-precipitation levels immediately after the storm stops. Groundwater flow is precipitation that infiltrates the ground surface, percolates through the soil and groundwater table, and eventually reaches either a stream channel or the ocean. The rate of movement for the three types of flow cannot be expressed in simple terms, but a hierarchy can be seen from the fastest, overland flow, to interflow, to the slowest, groundwater flow. For the planner who is concerned with usable water, the quantities of water that can be harvested from surface runoff, that reach the mouth of the watershed, and that are moving slowly through an aquifer and are available for pumping are the values to be identified.

A coefficient can be used to express basin recharge and groundwater accretion so that runoff can be stated as a function of precipitation. The identification of the coefficient is central to the Soil Conservation Service runoff equation, and to a runoff equation presented by Linsley and Franzini. The equation by the latter two authors is useful for short term, single event storms, but it is also a basic statement of annual basin runoff. Their equation is:

$$R = kP$$

where: R = runoff.
P = precipitation.

Both R and P must be expressed in the same volume units, such as inches depth, for the equation to be valid. Expression k is the runoff coefficient with values shown in Table 1. Thus runoff is expressed as a percentage of precipitation as was stated earlier in the discussion of the hydrologic cycle. The coefficient values may be refined for a given area and change as new land use development patterns emerge, but these values will generally be correct. For the planner, it is simply a matter of tallying the land uses in the watershed to determine how much runoff will occur. If the watershed is fairly large, the planner will want to recognize that different depths of precipitation will occur in spatially

Table 1. Coefficient values for a simple runoff equation.

Land Use	Runoff Coefficient
Urban Residential	
Single Houses	0.30
Garden Apartments	0.50
Commercial and Industrial	0.90
Forested areas depending on soil	0.05 - 0.20
Parks, Farmland, Pasture	0.05 - 0.30
Asphalt or Concrete Pavement	0.85

Source: Linsley and Franzini, 1964:40-41.

different areas, so that a summation of the runoff equations might offer more accurate results.

The Soil Conservation Service method is an expanded version of the Linsley and Franzini coefficient concept offering greater accuracy of the runoff value without additional data measurement requirements. The S.C.S. equation is:

$$R = \frac{(P - 0.2S)^2}{(P + 0.8S)}$$

where: R = the direct storm runoff in inches.

P = the storm rainfall in inches.

S = watershed storage in inches.

The S value is transferred into an easily identified conceptual value called the Curve Number (CN), by the equation:

$$CN = \frac{1000}{S + 10}$$

so that

$$S = \frac{1000}{CN} - 10$$

The Curve Number is a dimensionless unit that ranges between 0 and 100, where zero is a completely pervious watershed with no surface runoff, and 100 is a completely impervious watershed, with no infiltration, so that runoff equals rainfall (Branson, et al., 1981:294).

Curve Number values are identified by the Soil Conservation Service and are based on the antecedent moisture condition of the ground. The antecedent moisture condition is "the amount of water stored in soil on the day of a storm; determined by the total rainfall accumulating during the preceding five days" (SCSA, 1982:8). The planner does not have to determine the Curve Number or antecedent moisture condition in the field since the Soil Conservation Service has already done so based on four considerations: (1) soil type, (2) vegetation type, (3) cover, and (4) soil moisture as expressed through antecedent precipitation. To determine the appropriate CN value, the planner will have to have a basic knowledge of the vegetation and soils in the watershed, while the Soil Conservation Service assumes the soil moisture based on average conditions. These values can be found in Appendix A. For very rapid calculations, the planner may wish to use the average Curve Number values for typical watershed uses found in Table 2.

The Linsley and Franzini and Soil Conservation Service runoff equations are designed to be used for single storm-runoff events. This, however, does not preclude their use to determine seasonal or annual runoff, which is the more important information to the planner for water yield purposes. As Linsley and Franzini state:

> Over the period of a year, variations in antecedent conditions tend to average out, and the refinements necessary in storm rainfall-runoff relationships become less important. Often a simple plotting of water-year precipitation against water-year runoff is sufficient (Linsley and Franzini, 1964:48).

Figure 3 is a graphic representation of the precipitation-runoff relationship for a river in California.

Thus, more and more confidence can be placed on precipitation data to determine runoff. If precipitation data are available for a long historical period, it will even be possible to show years of low water

Table 2. Average curve number values for watershed land uses.

Land Use		Curve Number
Pasture or Range	Good Plant Cover	63.5
	Fair Plant Cover	70.3
	Poor Plant Cover	80.5
Woods	Good Plant Cover	41.0
	Fair Plant Cover	62.0
	Poor Plant Cover	67.3
Farmsteads		75.3
Dirt Road and Right of Way		82.5
Hard Surface Road and Right of Way		85.0
Paved Parking Lot, Roofs, Driveways, etc.		98.0
Residential Urban		80.0
Commercial Urban		85.0
Industrial Urban		95.0

Source: Smith, 1982.

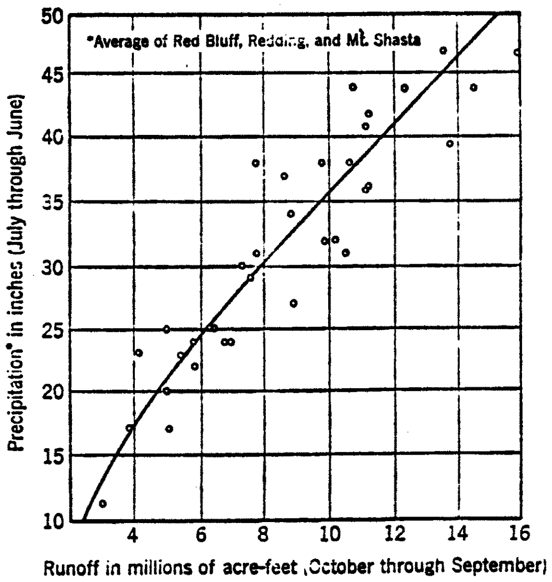

Figure 3. Relation between annual runoff and precipitation for the Sacramento River above Red Bluff, California (Linsley and Franzini, 1964:48).

yield compared to years of high water yield. This is important since water harvesting becomes more valuable in low precipitation-runoff years. If there is little annual precipitation in the region as a normal condition, water harvesting may soon become imperative.

Water Harvesting

In order for man to use the runoff from a watershed, methods must be used to store the water and transfer it to the point of use. If the usage or water demand is low, there may not be a need to store the water, but pumping, diversion, or gravity flow will still be necessary to get the water to the point of use. In all cases, the use of watershed runoff water can be viewed as being "harvested" by man. The actual quantity of water available to be put to some use is the water yield.

Water harvesting has traditionally been viewed in a much narrower context than all water diversions for man's use. The original definition of water harvesting was "the process of collecting and storing precipitation from land that has been treated [emphasis added] to increase the runoff of rainfall and snowmelt" (Branson, et al., 1981:101). Treatment to the watershed can include vegetation management, landscape alteration, chemical application, change in soil cover, or any modification that makes the surface more impervious to infiltration. Since men have been able to use water from all points in the watershed, and current practices allow for reuse of water as it travels through the drainage, the broader concept of water harvesting may be more appropriate. Ideal management of the watershed would allow for maximum conversion of runoff into harvested water.

The broad concept of water harvesting as the maximum use of runoff should allow the planner to consider structures to gain and store the runoff. In fact, water resource planning has always focused on the construction of large works such as dams and canals. For the county planner in an area without the financial resources to construct large facilities, other options are available to harness the watershed runoff. Small, 5,000 to 50,000 gallon storage tanks can be erected almost anywhere with a water collecting apron and debris filter to funnel the runoff into the tank, and a pipe and pump network to bring the water to a treatment plant for domestic distribution (see Figure 4). The collected water can also be used to offset water right allocations on the main stream channel for range or agriculture operations. By simply planning for appropriate land uses in the watershed, the planner can expect to maintain the maximum "natural" water harvest.

Watershed Yield

Watershed yield is the actual quantity of water that leaves the watershed basin after runoff and various losses have occurred. It can easily be viewed as a measure of the efficiency of the watershed in transmitting the precipitation to the stream. Chapter 20 of the Soil Conservation Society National Engineering Handbook, found in Appendix A, offers a method of calculating the watershed yield for an ungaged stream. If stream gage data are available from the U.S. Geological Survey, found in Water Resources Data by state and year, the planner can quickly determine the runoff that flows out the watershed. Using either method, the planner should be able to determine if some treatment should be considered

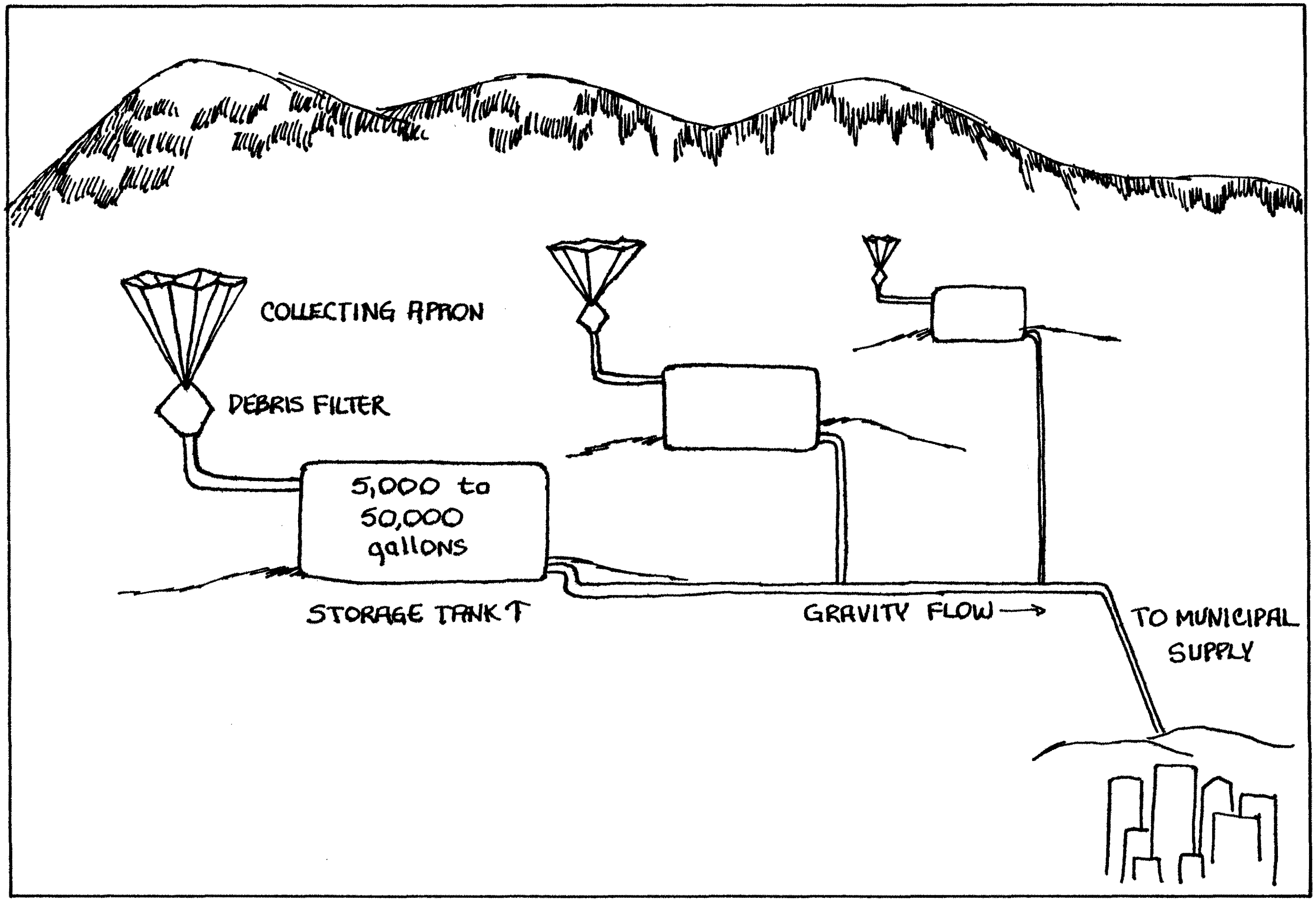

Figure 4. Conceptual water harvesting system.

to increase runoff, or if most precipitation already flows to the stream channel. Caution should be used in expecting every drop of water to flow out of the watershed; the hydrologic cycle is a natural force not easily tampered with. Watershed management can only refine the ground portion of the cycle to minimize water losses. Land use controls can allow for watershed management to proceed, and planners can articulate a statement of the values of this management.

While this chapter covers the basic principles of watershed management, many other important concepts have had to be excluded, such as flood hydrology, water quality, meteorology, and a host of land-based resource disciplines. An additional book could be included on the subject of groundwater supply, fluvial mechanics, and geomorphology. The purpose of this paper, however, is to introduce the county or regional planner to the importance of the watershed, a largely undeveloped and ignored section of a county or region, as a supplier of the local water supply, and the means by which to protect that supplier. If this serves to whet the appetite of the planner to gain more information and to work in closer cooperation with the resource specialist, then the purpose of this paper will be served. Since watershed management should now be familiar to the planner, it remains to be stated the planning techniques, including general plan recognition, that can benefit watershed management.

CHAPTER 3

WATERSHED PLANNING GOAL STATEMENTS AND LAND USE CONTROLS

"Traditional" Watershed Planning

Once the planner has assimilated the basics of watershed management and understands the value of the watershed basin as the source of local water, thoughts and ideas should begin to flow to incorporate this resource into the planning agenda. This chapter should help the planner identify some strategies to protect and promote this valuable resource. Many authors have helped form the impressions expressed here including: Corwin and Hefferman, 1975; Faludi, 1973; Getzels and Thurow, 1979; Healy and Rosenberg, 1979; Kusler, 1980; Marsh, 1978; Moss, 1977; Smith, H., 1979; Alden, 1974; Leopold, 1971 and 1968; and Mutter, et al., 1975. The county or regional planner, rich in his or her own experience, may feel ready to proceed with planning statements and land use strategies for watershed management, without investigating these references, or this chapter. It may be suggested, however, that a new perspective, or a restatement of familiar knowledge might lead to a beneficial outcome. Watershed management and concepts of water harvesting are not new, nor are most planning practices or theories, but their combination in the "urban" planning field is and the effect should be thoroughly stated.

The first problem the planner will face in trying to articulate watershed resource goals is that there will be some confusion or overlap with past Federal "watershed planning" programs and with floodplain management concerns. This is due to a host of Federal laws which, at various times and in different contexts, have mandated Federal agencies provide for watershed planning and have supplied money for counties, regional governments, and cities to do the same. Some of these statutes include the Watershed Protection and Flood Prevention Act of 1954, which addressed "erosion, floodwater, and sediment damages in the watersheds of the rivers and streams of the United States" (U.S. Congress, 1955:666). The Multiple-Use Sustained Yield Act of 1960 gives further recognition to watersheds by stating:

> It is the policy of the Congress that the national forests are established and shall be administered for outdoor recreation, range, timber, watershed [emphasis added] and wildlife and fish purposes (Hamilton, 1980:41).

More recently, many counties and regions have used section 208 of the Clean Water Acts and Amendments of 1972 and 1977 to plan for watershed land uses and practices that reduce non-point pollution into the local streams. Equally important, the Flood Disaster Protection Act of 1973, and the National Flood Insurance Program have stressed land use controls to limit unsuitable development in the expected flooding areas of the watershed (Moss, 1977).

The variety of Federal policies and programs related to the watershed and to its counterparts on the state level have done little to stress the value of the watershed as a producing resource. Instead, the emphasis has been on protecting the downstream citizens from the natural and man-induced processes that occur in the watershed. When the watershed has been identified as a resource, it is usually in terms of the land base necessary for economic development (Tolley and Riggs, 1961). The Tennessee Valley

Authority is best noted for this approach. Its large "watershed" projects are in fact large flood detention projects that originally provided construction jobs and now provide a source of electric power and water recreation areas for the tourism industry (Tennessee Valley Authority, 1982). The cost for this type of watershed planning is the displacement of valuable agriculture operations as exemplified in the Tellico Dam case (Rodgers, 1979:448-467). Certainly there are a number of positive results from the "traditional" approaches to watershed planning, but the underlying concept has been one of reaction to undesirable natural or economic conditions in the watershed. Now the planner should look to the watershed in anticipation of a desirable resource: water.

Planning Steps and the General Plan

Most planners are familiar with cyclical and linear planning models with the following steps: (1) identify goals and objectives; (2) gather data; (3) formulate alternatives; (4) refine data; (5) choose "best" alternatives; (6) implementation; and (7) evaluation. In current planning practices, the first five steps are carried out by preparing a general plan, step six is embodied in zoning, land use controls, and permit systems, while step seven depends on the initiative of the planner, or the controlling legislative body. The planner should complete the seven steps to determine the value and practicality of county involvement in the watershed. To do this, watershed management should be recognized in the general plan.

The general plan, and related titles of master plan, comprehensive plan, community plan, or plan elements, has meant many things to different groups. One of the best current definitions of a general plan is:

> A legal document often in the form of a map and accompanying text adopted by the local legislative body. The plan is a compendium of its general policies regarding the long-term development of its jurisdiction (Solnit, 1977:25).

Many states require the preparation of a general plan for all cities and counties, including Colorado, Oregon, Florida, and California. The composition of a general plan typically includes elements that describe the land resource or uses, housing, transportation and circulation, infrastructure, and local economy. Maps, figures and charts are used to portray the current and anticipated conditions. Goal and policy statements are included for each element to guide future legislation, land use proposals, and overall development of the community, county, or region. Alternatives are usually presented within each element that allow for immediate and later date actions to reach the stated goals and objectives of the general plan. An important requirement of all general plans is that goals, policies, and alternatives show internal consistency among elements so that no community conflicts occur. Watershed management concerns, to "fit" into the general plan document, will either need a separate resource element, or be included in an element that is related. Inclusion in a related element may be the best, comprehensive approach to integrating all natural resource concerns into the general plan, as long as a goal or policy statement is reserved for watershed management.

Natural Resources in General Plans

Without getting into a major discussion on the relative strengths and weaknesses of states' general plan laws, California's statutes show many avenues for including watershed management in the planning document. California is also the state from which the general plan statement used in the introduction came. That statement suggests that many communities may not be aware that the states allow them to recognize natural resource concerns. California has nine mandated elements, including: (1) land use, (2) circulation, (3) housing, (4) conservation, (5) open space, (6) seismic safety, (7) noise, (8) scenic highways, and (9) safety. A tenth element, parks and recreation, has almost equal footing with the mandated elements since construction of park facilities is dependent on an approved park and recreation plan. Two California elements, conservation and open space, offer the best platforms for watershed management goals, and the parks and recreation element can be a useful tool for establishing appropriate uses in critical portions of the watershed. The following excerpts from the State of California *Planning, Zoning, and Development Laws*, 1982, highlight the compatibility of these elements with watershed management:

> *Conservation* (65302.d)
> A conservation element for the conservation, development, and utilization of natural resources *including water* and its hydraulic force, forests, soils, *rivers* and *other waters*, harbors, fisheries, wildlife, minerals, and *other natural* resources. That portion of the conservation element including waters shall be developed in coordination with any countywide water agency and with all district and city agencies which have developed, served, controlled, or conserved water for any purpose for the county or city for which the plan is prepared. The conservation element may also cover any of the following:
>
> (1) The *reclamation* of land and *waters*.
> (2) *Flood control*.
> (3) Prevention and control of the pollution of streams and other waters.
> (4) *Regulation of the use of land in* stream channels and *other areas required for the accomplishment of the conservation plan*.
> (5) *Prevention, control*, and correction of the erosion of soils, beaches, and shores.
> (6) *Protection of watersheds*.
> (7) *The location, quantity,* and quality of the rock, sand, and gravel resources [emphasis added] (State of California, 1982:29-30).

> Open Space (65560.b).
> "Open-space land" is any parcel or area of land or water which is essentially unimproved and devoted to an open-space use as defined in this section, and which is designated on a local, regional or state open-space plan as any of the following:
>
> (1) Open space for the preservation of natural resources including, but not limited to, areas required for the preservation of plant and animal life, including habitat for fish and wildlife species; areas required for ecological and other scientific study purposes; rivers, streams, bays and estuaries; and coastal beaches, lakeshores, banks of rivers and streams, and watershed lands.
>
> (2) Open space used for the managed production of resources, including but not limited to, forest lands, rangelands, agricultural lands and areas of economic importance for the production of food or fiber; areas required for recharge of ground water basins. . . .
>
> (3) Open space for outdoor recreation, including but not limited to, . . . areas particularly suited for park and recreation purposes, including access to lakeshores, beaches, and rivers and streams; and areas which serve as links between major recreation and open space reservations, including utility easements, banks of rivers and streams, trails, and scenic highway corridors.
>
> (4) Open space for public health and safety, including but not limited to, . . . floodplains, watersheds, . . . areas required for the protection of water quality and water reservoirs [emphasis added] (State of California, 1982:54-55).

> Parks and Recreation (65303 A)
> A recreation element showing a comprehensive system of areas and public sites for recreation, including the following, and when practicable, their locations and proposed development:
>
> (1) Natural reservations.
> (2) Parks.
> (3) Parkways.
> (4) Beaches.
> (5) Playgrounds.
> (6) Recreation community gardens.
> (7) Other recreation areas [emphasis added] (State of California, 1982:37).

Other states may have similar wording in their general plans enabling acts or subsequent administration guidelines, so it is the planner's task to find the best route to spell out watershed management goals in the general plan.

Once the authority or ability to recognize specific natural resource concerns in a general plan is established, the planner begins the familiar process of getting the community or county to agree on the goal, policy, and alternative statements. The planner, having been introduced to the basic concepts of watershed management, proceeds to educate the decision-makers, and the general public, of the need to protect the resource for its most favorable management. Support is gathered from the resource managers, and data are collected to verify the need for community involvement and for inclusion in the general plan. The planner should have ready maps identifying the major watershed drainages within the jurisdiction and a preliminary water balance account showing the expected runoff yield from annual precipitation. Additionally, information should be compiled showing the current water usage, by category, for the community or county and a brief statement of the percentage increase water harvesting can make to the total supply, and where the harvested runoff could be most efficiently applied. The process can be long and involved, requiring coordination and support from the resource manager and the water supply staff, and data compilation by the planner. The result may be no more than one or two paragraphs in the general plan, but this type of community endorsement is essential if land use controls are to be imposed on the activities occurring in the watershed.

General Plan Statements

There is no single, ideal statement that every planner can insert into the county general plan to benefit watershed management. The "variable source area" concept and differences in regional precipitation and runoff discussed in the previous chapter limit any management scheme to the specific characteristics of a particular watershed. Water law, which will be discussed in the next chapter, has its own influences on how a watershed can be managed to produce water. There are, however, some common points that can be included in goal and policy statements. These would include:

(1) A policy statement to preserve and enhance the local and regional water supply through appropriate land management;

(2) A policy statement to endourage the managed production of water from the watershed resource area;

(3) A goal statement encouraging land uses and the implementation of techniques that increase the water yield of the watershed;

(4) A goal statement that guides legislative decisions on the appropriate uses to be approved within the watershed;

(5) A goal statement that encourages cooperation with all jurisdictions in the county to plan an adequate municipal water supply for all county residents. This goal may include consolidation of water supply agencies for management efficiency;

(6) An alternative statement that allows for strict "conservation" or "open space" zoned uses within critical portions of the watershed;

(7) An alternative statement that allows for construction of private party water harvesting structures as a means of reducing demand on municipal water supply;

(8) An alternative statement that allows for land uses compatible with watershed management on a zoning or permit basis;

(9) An alternative statement that sets up a mechanism for the county to purchase or collect easements, or if necessary, to purchase critical watershed areas, to meet the watershed goals. Easements may be deeded to the county to collect overland flow in return for subdivision or construction approval. The alternative statement would also allow for a county system of water harvesting structures to supplement municipal supplies;

(10) An alternative statement that encourages county cooperation with other regional and local jurisdictions, and Federal landholders to provide for non-conflicting land uses in watersheds separated by political boundaires; and

(11) An alternative statement that encourages a planning program to gather watershed data, work in cooperation with watershed managers, and identifies legislative action necessary on the state level to achieve the goals.

These points specifically address the watershed water resource, but the planner can easily expand the concepts to include water supply conservation, floodplain management, water quality concerns, erosion control, aquifer recharge area protection, and compatibility with other natural resource needs for forestry, range management, agriculture, and outdoor recreation.

Information Needs

In addition to data on water yield and the watershed, the planner should be prepared with facts on water consumption, impervious land area due to various uses, population projections, and any other information that could influence the need for enhancing the watershed resource, or that limit its usefulness.

Water supply and consumption is one of the most influential control factors in land development and economic growth for a region. Water usage can be divided into categories of consumptive versus non-consumptive use. Consumptive use of water means that after the water is diverted and applied to the use, it is either evaporated or incorporated into the product and cannot return to the stream. Non-consumptive water use is that water that is returned to the stream after diversion for the use. If a major portion of the water supply is consumed after use, then downstream reuse is limited along with economic growth. Table 3 summarizes the major users of water in the United States and the gross and consumptive use of each category. If data are available from the local or regional water supply agency, the planner should use the information to show where potential or actual shortages exist. The information in Table 3 can be useful to compare the region to national trends, or to generate regional data if none are available.

There have been a number of studies which show the relationship between impervious land area and high volume runoff for floodplain management. Luna B. Leopold's work, including Hydrology for Urban Land Planning - A Guidebook on the Hydrologic Effects of Urban Land Use, is a very useful source for describing the effect of urbanization on

Table 3. Major uses of water in the continental United States (from U.S. Geological Survey).

User	Gross Use (Millions of Gal/Day)	Consumptive Use (Millions of Gal/Day)	Notes
Navigation, recreation, maintenance of aquatic ecosystems, dilution and purification of wastes	Very large, but undefinable	Low?	
Generation of hydroelectric power	2,300,000	≥11,000	Main consumptive use is evaporation from reservoirs in arid West. Unpolluted.
Industry: self supplied	120,000	3,500	Almost all for cooling of power plants: 25% saline. Results in thermal pollution.
Industry: from public supplies	7,000	?	Process water heavily polluted.
Agriculture: irrigation	120,000	97,000	Polluted by fertilizers, pesticides, and high concentrations of dissolved salts.
Agriculture: rural domestic and livestock	4,000	3,000	Largely from local wells and springs. Heavily polluted with organic wastes.
Municipal	23,000	5,000	Heavily polluted.

Source: Dunn and Leopold, 1978:442.

hydrology. The planner can make use of such studies to determine the effect of existing and proposed land uses on the amount of impervious area, and the rate of watershed runoff. Table 4 shows the estimated

Table 4. Percentages of impervious land area within land-use categories with low, intermediate, and high estimate for each category.

	Impervious Land Area		
Land Use Category	Low (%)	Intermediate (%)	High (%)
Single-family residential	12	25	40
Multiple-family residential	60	70	80
Commercial	80	90	100
Industrial	40	70	90
Public and quasi-public	50	60	75
Conservational, recreational and open	0	0	1

Source: Branson, et al., 1981:242.

percentage of impervious area for various land use classes as a function of total area developed in the class. The percentage of impervious area based on a range of residential lot sizes was calculated by Leopold and is shown in Table 5. As stated previously, the planner is concerned with

Table 5. Impervious area for residential lots.

Lot Size of Residential Area (sq. ft.)	Impervious Surface Area (percent)
Less than 6,000	80
6,000 - 15,000	40
Greater than 15,000	25

Source: Leopold, 1968:2.

both the volume and rate of watershed runoff. Impervious surfaces maximize volume, but the runoff rate is almost instantaneous.

Instantaneous runoff, often called flash floods, requires flood protection measures including detention reservoirs that slowly release the accumulated water so as not to harm downstream property. Land in its natural state moves water over and through it more slowly than a completely sealed surface so water can be collected and retained in storage structures for future use. If our knowledge of precipitation patterns was perfect, and funding was unlimited, we could build dams that could store all possible flood waters from the watershed, so all the water could be put to beneficial use. Instead, we are uncertain as to the quantity and timing of future flows and our dams only have so much capacity between the normal storage pool level and the crest of the dam, so the water must be released from the dam to make room for more flood waters. If the rate of runoff into reservoirs is slow, release rates from the dam can be reduced. Watershed management addresses this issue by determining techniques to increase or decrease the percentage of impervious area to control the runoff rate. Land use planning is the mechanism by which watershed management techniques can be implemented.

Questions for a Land Use Control Program

In preparing the general plan statements on watershed management, the planner should be addressing methods of land use control that allow the goals to be reached. Primary concerns of the planner should be:

(1) Who owns the land, and in whose jurisdiction is it?

(2) What controls does the county have over the land from enabling legislation: zoning, land use permits, bulding permits, etc.?

(3) How much development is proposed for the county, and what percentage would be likely to occur in the upper watershed reaches?

(4) Who is likely to benefit from increased water yield. Should only private owners be encouraged to undertake a program to supplement municipal supplies?

(5) Can the county afford the capital to construct a watershed harvesting system?

(6) Can the county afford to purchase easements and the critical watershed areas either voluntarily, or as the result of a court decreed "taking" of the land value? and

(7) Is the goal of watershed management and water harvesting economically justified currently, or is the county addressing the issue to preserve future options?

Each of these questions can affect the type of land use control that is most effective for watershed management.

Land ownership patterns influence land use planning since the county government has few controls over certain lands. In a large portion of the western United States, the Federal government controls the upper reaches of the major watersheds. In some cases, this can work to the benefit of the region since many Federal agencies, such as the Forest Service, have watershed management as a primary concern. Because little development will occur, construction-related problems do not exist. However, other land uses such as forest cutting or mining can and do occur, without the direct control of the county. Most Federal agencies are required to consult with local jurisdictions before allowing any land use. Having a general plan that recognizes the value of the watershed can improve the quality of, and increase the influence of, the county input. If other counties control a portion of the watershed, or if municipalities are given complete control of land use issues within their jurisdictions, the county will have to secure their cooperation to affect land use issues. Again, having general plan goals can be helpful to influence adjacent decision-makers.

The types of powers which a state has given to its counties can have a direct influence on land use controls. Almost every county in the United States has the authority to zone land uses within their unincorporated jurisdiction. Some counties even have control of zoning in municipalities. Other powers include issuing conditional or special use permits which may be dependent upon, or independent of, zoning classifications. Building permits can be a land use control, though the county can only affect size, shape, or construction materials if the zoning allows for the use.

Many Federal and state programs call for the county to issue permits or to control funding for a variety of purposes including the control of air and water pollution, the construction of health facilities, schools, low-income housing, and the establishment of regional transportation routes. If coordinated, these controls and permits can be used to successfully meet the goals of the general plan. For example, a large portion of the watershed may be zoned for agriculture. If a housing development is proposed for single family use, in addition to the zone change which would be required, the county may specify the location of trunk sewer lines and county roads funded in part with state and Federal money. The county planner must be aware of all programs and controls available to make the watershed goal, along with compatible land uses, a reality.

If the county is not under development pressure, there may be plenty of time to implement a watershed management program to fulfill the general plan goals. If virtually every square inch of the county is urbanized, the planner may only be able to dream of natural resource concerns. Anywhere in between, the planner should assess what open watershed area is available and work on a program that protects the most critical areas to minimize the urban impact. When zoning is already in place to protect the upper watershed area, a general plan statement may serve to reinforce that designation and safeguard it from rezoning efforts. If zoning allows any use in the watershed, the general plan work can lead to a reassessment of the zoning for compatible uses only. Without development pressure, there may be little desire to protect the watershed resource, but the greatest benefits occur when management is possible. Property owners in the watershed and the public will probably benefit more from a county program that allows greater flexibility in the use of property than a program hastily put together that severely limits uses.

The benefits from watershed management are shared by both the public and private sectors. The county's management philosophy will determine how these benefits are shared. If the expected water yield is to augment municipal water supplies, the public gains the greatest benefit by controlling the water. If the water yield is captured by the private farmer to irrigate his land, the public still benefits since the farmer can reduce his draws from the irrigation water supply, or from the groundwater aquifer. The same would be true for commercial or industrial users. The county may not have control over the efficiency of the use, but the increased water yield still allows for economic growth, or offset of existing water shortages. Should the county opt to harvest runoff water for municipal supplies, land must be purchased to construct the storage structures, water rights must be filed on the stored water, and easements must be gained to have runoff flow over the land to the structures. Finally, rights-of-way must be gained for pipes to connect up with the municipal lines. The cost for the county to actively participate in water harvesting can be small to extravagant depending on the scale of the system. The decision to fund a water harvesting system does not occur during the general plan step, but the issue will eventually surface if the county reserves an option to collect water.

The questions of whether the county can afford to construct a water harvesting system, purchase land and easement, and purchase water rights if necessary are ones that should be continuously considered during the general plan process, and afterward. If water harvesting is never economically feasible, due to an overabundant clean water supply, then the county probably will not address the issue. If the water supply is adequate now, but shortages loom in the future, the county should preserve the watershed management option, but not fund any purchases until a complete economic comparison can be carried out between conventional water storage projects, water harvesting, or a combination of the two. Water harvesting may be uneconomical for 20 or more years, but can never succeed if the land resource is not available. If shortages currently exist, causing a moratorium on growth, there may be a good economic justification for the county to undertake water harvesting projects.

Since land values, labor and construction costs, and financing all have major roles in project costs, and each are constantly changing, what calculates out as uneconomical today may become favorable next year. A county may own land within the watershed which it has purchased for parks, maintenance yards, and other facilities, or donated by citizens. If it can put this land to dual use by building a water tank on the site, a portion of the water harvesting cost can be cut. Easements would still have to be gained to allow runoff to reach county collectors, especially if the county-owned land is in small, scattered parcels. The planner must consider creative techniques to gain these easements at a minimum cost to the county.

No quick statement can be made on the cost of a water harvesting system just as a price is hard to fix on large dam facilities. The variables listed above play havoc with the costs so that the final price is usually not known until after construction is complete. It is not unusual now to find costs of 100 million dollars and more for water projects to serve 100,000 new residents (Koelzer, 1982). Diversions over 200 miles can double this cost. Economies of scale make the cost of supplying water for the next 100,000 people cost less, but transmission costs remain about the same.

Population and Domestic Water Supply

The final piece of information the planner must collect to discuss water supply and need intelligently is the estimated population growth for the county. If the county population is declining, or will remain stable for the planning horizon, there may be little need to discuss water supply. This is especially true if there is more fresh water than the county can use, and exports to other regions would still have little effect on local economic growth. If growth projections show a need for additional water, the planner should start looking at all alternatives including watershed management. Table 6 and Table 7 are from a U.S.

Table 6. Anticipated daily domestic uses of water by a family of four.

Family Use of Water	Average Daily Use Liters Per Day Per Family	Liters Per Day Per Capita	Gallons Per Day Per Family	Gallons Per Day Per Capita
Drinking and water used in kitchen	30	7.6	8	2
Dishwasher (3 loads per day)	57	14	15	3.75
Toilet (16 flushes per day)	363	91	96	24
Bathing (4 baths or showers per day)	303	76	80	20
Laundering (6 loads per week)	129	32	34	8.5
Automobile washing (2 carwashes per month)	38	9.5	10	2.5
Lawn watering (180 hours per year)	379	95	100	25
Garbage disposal unit (1% of all other uses)	13	3	3	0.75
TOTAL	1,312	328	346	86.5

Source: U.S.G.S., 1977:6.

Table 7. Estimated daily per capita use of freshwater in the United States.

	Gallons Per Person Per Day	Liters Per Person Per Day
Water required for survival	Less than ½	Less than 2
Average personal consumption of water (liquids and water in foods)	About 1	About 4
	National Averages in 1970	
Domestic uses of all kinds (indoor and outdoor uses); home connected to public water-supply system	75	280
Public water systems, including public-supply water for domestic, industrial, commercial, and public (fire-fighting, parks, etc.) uses and water-system losses (population[1] served in 1970: 165,000,000).	166	628
Self-supplied industrial use (total population[1] in 1970: 205,900,000)	777	2,940
Combined public, rural, industrial, and irrigation uses (excluding hydro-electric power)	1,550 (If saline water use is added, per capita use is 1,800 gallons or 6,810 liters.)	5,870
Water for hydroelectric power	13,600	51,500

[1] Includes Puerto Rico and Virgin Islands (U.S.).

Source: U.S.G.S., 1977:6.

Geological Survey report that describes the uses domestic water is put to, and the estimated daily per capita use of fresh water in the United States. These, or similar data, will provide guidance for estimating future water demand for municipal water. Conservation could lower the value of 86.5 gallons per day per capita, but a hot, arid climate may cause the value to rise, especially where uncontrolled lawn watering is allowed. Population growth itself is dependent on a number of factors, but the planner should have fairly accurate estimates available from the preliminary work on the general plan. Domestic water demand is calculated as the population times the per capita consumption, plus reserve for fire suppression. Total municipal demand includes domestic use as well as commercial and industrial uses on the water system, plus a reserve for future population and economic growth.

Once the concepts of watershed management and planning are joined and the needs for water are articulated, it would seem there is little for the planner to do but see that they are carried out. Unfortunately, in the case of water resources, there is one more factor to be considered--water law. The next chapter will detail the common principles of water law in the United States and how the laws can affect watershed management. The understanding of watershed principles, planning techniques, and water law are all necessary if watershed water resouces are to be dealt with effectively in county planning.

CHAPTER 4

WATER LAW

Water Law Doctrines in the United States

Equally, if not more important than an understanding of basic watershed principles, the county or regional planner must know the principles of water law applicable in the state of their jurisdiction. The right to use water in various quantities and priority of use has been a legal issue debated in many United States courts since our Country's foundation. The planner can assume that any action taken to harvest or increase the water yield from the watershed will face a legal challenge which may call for judicial review to determine if existing water rights are being violated. With an understanding of water rights doctrine, the planner can tailor the county's approach to watershed management to avoid court action, or the planner can be better prepared to help document the county's case before the courts.

Water law in the United States has developed from two distinct influences based on hydrologic differences between eastern and western United States. Both doctrines are still followed today. The two water rights doctrines are riparian doctrine and appropriation doctrine. Riparian doctrine is found east of the Mississippi River and the appropriation doctrine is followed in the 17 western states. Alaska also follows the appropriation doctrine, but Hawaiian water rights are based on a combination of riparian doctrine and ancient Hawaiian custom that awards water rights with land grants (Hutchins, 1971). California and Texas are both appropriation states, but both have some rules found in riparian law due to their early Spanish-Mexican influences. Each state has legislation which establishes the rights of public and private parties to use the waters of the state based on one of these two doctrines. Typically, state water law will also address priorities of beneficial use, methods to record water rights with a state administrator, and a system of legal appeals, including court action, to resolve conflicts. Though state laws typically do not address water harvesting in the upper reaches of the watershed before the runoff reaches the stream, this water, too, is also subject to one or the other of the water rights doctrines.

The Riparian Doctrine

The riparian rights doctrine came to the United States with settlers from Europe and has judicial roots in English common law. The doctrine's main premise is that the water flowing in a stream is available for use by the adjacent, riparian land owner for his beneficial use, and that all land owners along the stream are entitled to an equal share of the stream regardless of who owned riparian land first, or location on the stream. In the precedent setting court case of Stratton vs. Mount Hermon Boy's School (216 Mass, 83, 103 N. E. 87), the Massachusetts Supreme Court stated:

> The governing principle of law . . . is this--A proprietor may make any reasonable use of the water of the stream in connection with his riparian estate and for lawful purposes within the

> watershed, provided he leave the current diminished by no more than is reasonable, having regard for the like right to enjoy the common property by other riparian owners. If he diverts out of the watershed or upon a disconnected estate the only question is whether there is actual injury to the lower estate for any present or future reasonable use (Rodgers, 1979:34).

Thus, the riparian rights water doctrine specifies that the natural flow of a stream cannot be materially lessened, or increased to cause flooding, by an upstream owner to the disadvantage of the downstream owner. Furthermore, diversion of stream waters must be for a beneficial or reasonable use (Lindsley and Franzini, 1964:135). The determination of a reasonable water usage, based on various court cases, is dependent upon the following factors:

(a) the purpose of the respective uses,
(b) the suitability of the uses to the water source or lake,
(c) the economic value of the uses,
(d) the social value of the uses,
(e) the extent and amount of harm caused,
(f) the practicality of avoiding the harm by adjusting the use or the method of use of one proprietor or the other,
(g) the practicality of adjusting the quantity of water used by each proprietor,
(h) the protection of existing values of land, investments, and enterprises, and
(i) the burden of requiring the user causing the harm to bear the loss (Rodgers, 1979:36).

Since all property owners along the stream share equally in water rights and priority in use, what is a beneficial use to one can be instituted by all.

Riparian water rights originate from land ownership adjacent to any natural body of water. The water rights are transferred with sale of the property, and if the land is divided into parcels, only the parcel adjacent to the water body receives the water rights. Thus, if two or more parcels are created, each with frontage along the stream, then two or more water rights are created with full rights to the stream. Water rights, however, can be separated from the land title and sold to any buyer. Any land division after water rights separation will not receive new rights to the stream. The holder of the water rights must still satisfy the rights of the downstream user, but can store his share of the flow and transport it within the basin for his beneficial use. The riparian doctrine does not allow for interbasin transfer of water if the use is considered greater than ordinary or natural, and not a beneficial use, since downstream users' rights are dependent upon return flow, or a natural quantity of flow past their property.

Government entities can use the power of eminent domain to appropriate more than their equal share of the stream flow, and are usually granted the special privilege of being able to make interbasin transfers of water for municipal purposes. Since the water rights result from ownership next to the water, lack of use of the water does not negate those rights. The planner should recognize that current usage patterns may have little bearing on future water demands if the water right owners start to put the water to beneficial use.

The riparian rights doctrine is a fair means of allocating access to and use of water in an environment where surface water is plentiful. This moist hydrologic condition is generally true of the eastern United States. With few exceptions, water demand in the East has not been equal to the available flow of the streams and rivers. Where demand has been greater, large diversion projects have been built using the special government status to bring water to the shortage areas. In the future, however, new diversions may be limited as stated earlier by financing, environmental requirements, and greater demand by local watershed users. Increased local watershed protection and water harvesting may provide some relief in the shortage areas.

The Appropriation Doctrine

The appropriation doctrine is based on the premise of "first in time, first in right" (Linsley and Franzini, 1964:137). Since water in the western states and territories was considered a public good available to all citizens, and development was encouraged, anyone could divert water to put it to a beneficial use. Diversion could be to any location in or outside the watershed. The right to use the water was then secured by filing a statement of water use with the county clerks, or with the water courts. Use of the water is not limited by providing for natural flow downstream unless a senior water right holder is downstream. Appropriative water rights are not based on geographic location, only the rank or order in which claims are filed. If the senior water right holder is downstream, he must receive his full appropriation of water even if that requires junior upstream water right holders to stop diverting for a period of time. Exceptions to the rule are provided in state statutes for low flow conditions, but they do not affect the planning of watershed management.

The appropriation doctrine was the result of mining camp logic in California, where water was diverted to run sluice boxes and hydraulic mining equipment. Water was critical to work the mining claims so the protection of access to an adequate water supply became a legal issue early in growth of the West. Since mining operations could be located in the hills of the watershed, rather than along the stream banks, it was necessary for the diversion take the water away from the stream. Thus, appropriation water rights are not tied to land ownership adjacent to the stream. In fact, most western lands are publicly owned, and most mining in the 1800s was on unpatented land, so ownership of water rights could easily occur without any land ownership.

Many of the land use conditions that existed with the start of the appropriation doctrine still exist today, but because most water in the western states is already held in right, little appropriation can occur. Water rights can be sold to any user, but the transfer must not impact the holder of senior or junior water rights. The senior right holder wants to be assured that his legal diversion is maintained. Junior holders with lessor diversions than the water right sale want to make sure that they too are not materially damaged. The key legal concept is that the priority or ranking of water rights holders can divert as much as they can put to use, and file their claim based on that use. The holder cannot then increase the diversion, or change the use that the water is put to since the next and next claimants are putting the available water to their respective uses. Thus, the "first in time, first in right" doctrine also holds the user to "first and only use."

Comparisons Between the Doctrines

There are many differences between the riparian and appropriation doctrines. Most important is the ability to divert any quantity of water to any location outside a watershed under the appropriation doctrine compared to the riparian rights. This is perfectly logical in the arid West, where water may be far away from the activities of man. Riparian-law states enjoy more surface water, enabling man to locate his activities in any desirable setting.

The concept of beneficial uses is another difference between the two doctrines. Riparian doctrine equates beneficial use to the quantity of water that can be shared by all adjacent land owners to the stream. Water for irrigation or industrial purposes can only be used in quantities that still allow for other property owners to exercise their rights. Under appropriation doctrine, any quantity diverted is considered beneficial as long as it is put to use by man. The only limit to the diversion is prior water rights that must be satisfied. This allows for mining, irrigation, power production, industrial processes, municipal, and domestic uses, whereas riparian rights rarely allow for more than domestic use, small plot irrigation, instream power production, and for municipal purposes under eminent domain. Another major difference is that riparian rights arise from land ownership, while appropriative rights can exist without any title to land. Finally, riparian water rights are not enhanced or diminished by date of purchase of the streamside property. Appropriation water rights, in terms of quantity of water available for diversion, are entirely dependent upon state recognition of filed water claims.

Diffuse Surface Water Rights

Water harvesting techniques and land use management to increase water yield will create additional water which can be subject to claims for use. If it is the county's goal to simply increase water yield regardless of who benefits from the additional water, then no government claims need be filed on the water. If the county's goal is to provide water for municipal or domestic use, then claims should be filed with the controlling water agency for any quantity of water created by enhancement techniques. If watershed runoff is to be stored in a system as shown in Figure 4, the county will definitely have to secure rights to the water. If the county does plan to use the water for municipal or domestic purposes, regardless if in a riparian or an appropriation state, it must show that the water quantities involved are not subject to existing claims. To do this, the planner must refer back to the hydrologic cycle concept to show where water that normally would be lost through interception and evapotranspiration and never reach the stream channel, has now been harvested for use.

The Federal government recognized the importance of securing off-stream surface water rights for watershed projects when in the Watershed Protection and Flood Prevention Act of 1954 (P.L. 83-566) it stated:

> Local organizations shall acquire, or privide assurances that landowners have acquired such water rights, pursuant to State law, as may be needed in the installation and operation of the work of (watershed) improvement (U.S. Congress, 1955:667).

The U.S. Government's concern is that by encouraging soil and water conservation practices, such as creating stock ponds, water that normally flows to stream channels would be impounded for use on property separate from the channel. If water right holders can legally claim that the detained water is in reality theirs, the government will have effected a taking without just compensation. If the upland property owner has the rights to the detained water, then other water right holders must forego the water, or wait for the unconsumed portion to reach them.

Various states, whether using riparian or appropriation doctrine rules, have addressed this situation by creating special conditions for "diffused surface water" and "salvaged" and "developed water." These are defined as:

> Diffused Surface Water is water that occurs, in its natural state, in places on the surface of the ground other than in a watercourse or lake or pond.
>
> Salvaged Water is that portion of water in a water supply which under natural conditions is lost, but which by means of artificial devices is recovered and made available for beneficial use.
>
> Developed Water is water which in its natural state does not augment a water supply, but which by means of artificial works is added to a water supply or is otherwise made available for beneficial use (Hutchins, 1971:22).

These are legal terms which are based on the concepts of surface runoff, water harvesting, and impounded water yield. Wells A. Hutchins eloquently states the concern for diffused surface water rights as thus:

> Is the landowner's right to withhold such naturally flowing diffused waters an absolute right? or is it qualified by the rights of others? or is it subordinate to the rights of appropriators on the stream to whose lands the waters would flow if not interfered with, and whose appropriative (or riparian) rights may be adversely affected by the upper landowner's operations? The growing importance of the problem arose from the fact that large-scale operations for controlling diffused surface waters throughout the upper portions of a watershed conceivable might materially alter the flow in the streams that naturally drained the watershed (Hutchins, 1974: 537).

Carried to an extreme argument, even the catchment of a rain barrel of water could be construed as depriving a low lying water right holder of his water.

Influence of Water Law on Planning

If a state recognizes the existence of diffuse surface water rights, then a county will have logical claim to water harvested in structures located in the watershed. If the state does not recognize this water right, then the water must be secured under the appropriate water law doctrine. The planner will have to check with appropriate state officials to find out if diffuse surface water rights are allowed. To secure appropriation doctrine water rights for offstream water harvesting structures, the county will have to file a claim based on unappropriated water still available in the drainage. If all available water is appropriated, as in the South Platte River of Colorado, the county may have to demonstrate to the water court that only salvaged water will be claimed and retained in the structures. Most state water courts accept this argument but will impose release requirements to simulate natural runoff.

Riparian doctrine states that do not recognize diffuse surface water rights present a problem in that water rights are then only recognized adjacent to a water body. Counties can use eminent domain proceedings to obtain the water rights, but compensation requirements can quickly make this infeasible. It is probably better for the planner not to consider water harvesting structures in this case and rely on instream impoundment structures to store water from improved land use practices. For both riparian and appropriation states that do not recognize diffuse surface water rights, the planner should ask the state legislators to look into the issue.

County or regional planning goals that stress watershed management and increased water yield for use by the private sector will not be directly influenced by water rights law. The assumption, as stated in the general plan, is that any increase in available water will benefit the public by meeting private needs. Still, water law is important to the planner since appropriation doctrine will allow water generated by the community's planning efforts to be diverted to another county or region. The county should be prepared to encourage the local citizens to file water claims to put the additional water to use. Also, what the county or region deems a desirable or beneficial use of water for allocation purposes may have little impact on the appropriation user if their water claim allows for a different use. For example, if the county has a goal of using all available water for domestic uses only, imposes land use controls so runoff is maximized, and allows private parties to file on the newly available water, there may be no state controls that stop the filer from applying the water to irrigation uses.

No quick statements can be made as to what water rights are available to a county or regional government. Planning goals must recognize the existing water doctrine and state statutes that control water claim filing procedures, diversions, quantities that can be used, and beneficial uses that the water can be put to. The planner may also recognize the possibilities for state legislative change and the use of favorable court decisions to secure water rights. Unfortunately, states that have not had a water supply problem in the past may not be very flexible in adapting their regulations to meet increased watershed yield goals. No absolute advantage is inherent in the riparian doctrine or the appropriation doctrine for a goal of increasing water yield, but a knowledge of the basic premises, and the reason for two doctrines in one country may help the planner adapt the county goal statements for the best results.

CHAPTER 5

SUMMARY AND CONCLUSIONS

Planning Education

In reviewing this paper, the professional planner and the planning advocate may develop a feeling that the material presented is all well and good, but the idea is not necessarily new. Many writers have stressed the need to integrate natural resources into community planning. Ian McHarg's masterpiece, Design With Nature, can be cited as the cookbook for the comprehensive planning approach. Earlier writers such as Benton MacKaye and Patrick Geddes deserve equal credit for integrating natural resource disciplines into land use planning. MacKaye's and Geddes' concept of "geotechnics: (geo earth, technics use) what ought to be on earth" (MacKaye, 1968:22), was probably the first attempt to look at all the uses man had for the earth in order to make the result of any future use a more habitable environment [emphasis added]. The importance of these writers' works is that they suggest a new way of looking at a familiar world. The author hopes this paper will do the same.

There are many definitions given to planning, most of which change with whatever emphasis society places on planning's results. MacKaye's definition of "planning is revelation" is useful for its simplicity and for its endurance through time. Revelation is achieved only after education is achieved, data are gathered, and results are analyzed.

The start of any planning endeavor is to learn about the system to be planned for. Without basic knowledge, the planner cannot establish the goals to be achieved, and cannot decide what data will be useful to reach the goal. If the education is incomplete or faulty, the results of planning will be less than desired. Thus, revelation comes from knowledge.

To say that planners do not know anything about natural resource disciplines would be insulting and unfair. To say that planners have been overwhelmed with urban related problems and have not had an opportunity to plan for resource related concerns would probably be more accurate. Since planning problems have been in the urban field, the purpose of most source handbooks and research studies has been to provide answers to urban questions. Now, planners are faced with increasing incidences of natural resource shortages and must plan to protect what supply is left for equitable and beneficial allocation. Unfortunately, there are few guidebooks and little research in this planning area. The planner has the benefit of comprehensive planning theory developed by MacKaye, Geddes, McHarg, and others but must educate himself or herself on the specifics of the resource to be planned for. This paper is a short course on one such resource: the watershed and its product of water.

The Basic Concepts

Some of the concepts discussed in this paper have been stripped to the bare essentials. Other concepts pertinent to watershed management, but not to planning, have been ignored entirely. Watershed management is an umbrella resource that covers a variety of topics including soil erosion, floodplain processes, slope stability, water quality, groundwater recharge, and a host of other concerns. These topics have been left to other authors. If a resource is viewed as a supplier of a vital product, then management of the resource should be to provide that product for beneficial use. In forest management, the product is timber; in range management, the product is forage for grazing; in watershed management, the product is water. This short course is designed to address the basic concepts of the watershed resource, and to show how this resource can be integrated into the planning process.

Water produced from a watershed is just in a transitory stage within the hydrologic cycle. The fact cannot be overstated, and is the basis for any planning effort to manage the resource. Processes within the watershed control how much precipitation appears as runoff, and how fast. Chapter 2 of this paper addresses how the planner can estimate the quantity of water available from the watershed. The planner may have resource specialists available to draw this information from, but the planner must understand the data, and the limitations in gathering it. The planner should be aware that this short course education does not instill the techniques to go out and physically measure the data, but only to collect results from available reports and summaries. Still, the planner has enough information available now to formulate general plan statements to manage the watershed resource.

Chapter 3 provides the planner with some techniques to give recognition to watershed management in general plans. California's statutes were used to show that many states have language in planning enabling laws to allow for natural resource values to be considered with traditional urban needs. Policy, goal, and alternative statement guidelines are included to give the planner suggestions on how to fit watershed management into local planning documents. Finally, specific philosophical problems are identified which the planner and the decision-makers must address in developing the general plan and land use controls to decide who will gain the greatest benefit from the resource. Again, most of the ideas are not new but are restatements of fairly common planning practices and theory. The purpose of chapter 3, however, is to take this common knowledge and apply it to a "new" problem: how to plan for watershed management for local or regional benefit.

As with any resource that has competition for its supply and allocation, ownership of the resource may determine who gains and who pays. Water is no exception but the concept of ownership is tempered by the fact that not all the water is "consumed" in its use. Return flow allows a portion of the water supply to be used over and over before it drains to the ocean or is evaporated away. Since the user only "owns" the water while applying it to whatever the use, laws have been established to settle disputes on who has first access to the water, what quantity can be used, and what the water can be used for. Chapter 4 is a discussion of the two major water law systems in the United States and some of the implications water law has on water gained from watershed management. The chapter is not designed to make the planner a legal expert on water law and water rights. Rather, it should give the planner some insight into the complexities of water or any resource allocation issue. The planner should research what the water laws are that affect the state, and determine how much water is still available to be claimed in the watershed planning unit. Next, the planner must estimate how much additional water could be generated from either an intensive watershed management program or from construction of a water harvesting system and decide if the local, county, or regional jurisdiction can file claims to that water. If the jurisdiction has to resort to eminent domain proceedings, an estimate of the cost, and the return for the water rights, should be made. Chapter 4 should make the planner consider the institutional barriers that must be overcome for the jurisdiction to benefit from the planning process, and the managed production of the resource.

Future Questions

There are many questions left to be answered before a planner can claim that the planning process will successfully deliver water from the watershed. Many of the answers must come from resource specialists, economists, and engineers, but the planner may become involved in coordinating all the responses so the legislative decision-makers have a complete study package. The questions involved include:

(1) What type of water harvesting system is feasible for the watershed? Are structures necessary, or can runoff from land treatment flow directly to a stream channel?

(2) What are the costs and benefits from investing in an active watershed management and water harvesting system?

(3) Would a passive system of undeveloped land be the best watershed management proposal? If a passive system is appropriate now, would an active management system become necessary later?

(4) What are the environmental impacts associated with an active or passive management system; and

(5) Who will be displaced by the planned management of the watershed? Would property rights be so diminished from the land use control program that a legal taking would occur?

Answers can only be developed at the watershed level. What is appropriate and feasible in one watershed may not be in another. The planner cannot make rash judgments and this paper cannot supply quick answers; only study of the local situation will provide results.

This paper can offer the planner insight for protecting large, undeveloped tracts of land in his or her jurisdiction. Even if a management program for the watershed is not available for the immediate future, the option to effectively use the watershed should be given recognition in planning documents. The results of watershed management may be needed now, or far into the planning horizon, but without a statement of its value in a general plan, the full benefits may never be seen.

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APPENDIX A

CHAPTERS 9, 10, AND 20 FROM SOIL CONSERVATION SERVICE NATIONAL ENGINEERING HANDBOOK

NATIONAL ENGINEERING HANDBOOK

SECTION 4

HYDROLOGY

CHAPTER 9. HYDROLOGIC SOIL-COVER COMPLEXES

by

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SCS NATIONAL ENGINEERING HANDBOOK

SECTION 4

HYDROLOGY

CHAPTER 9--HYDROLOGIC SOIL-COVER COMPLEXES

CONTENTS

CHAPTER 9. HYDROLOGIC SOIL-COVER COMPLEXES

A combination of a hydrologic soil group (soil) and a land use and treatment class (cOver) is a hydrologic soil-cover complex. This chapter gives tables and graphs of runoff curve numbers (CN) assigned to such complexes. Its CN indicates the runoff potential of a complex during periods when the soil is not frozen, the higher a CN the higher a potential, and specifies which runoff curve of figure 10.1 is to be used in estimating runoff for the complex (chap. 10). Applications and further discussions of CN are given in chapters 10, 11, and 12.

Determinations of Complexes and CN

AGRICULTURAL LAND

Complexes and assigned CN for combinations of soil groups of chapter 7 and land use and treatment classes of chapter 8 are given in table 9.1. Also given are some complexes that make applications of the table more direct. Impervious and water surfaces, which are not listed, are always assigned a CN of 100.

ASSIGNMENT OF CN TO COMPLEXES. Table 9.1 was developed as follows. The data literature was searched for watersheds in single complexes (one soil group and one cover); watersheds were found for most of the listed complexes. An average CN for each watershed was obtained by the method of example 5.4, using rainfall-runoff data for storms producing the annual floods (chap. 18). The watersheds were generally less than 1 square mile in size, the number of watersheds for a complex varied, and the storms were of 1 day or less duration. The CN of watersheds in the same complex were averaged, all CN for a cover were plotted as shown in figure 7.2, a curve for each cover was drawn with greater weight given to CN based on data from more than one watershed, and each curve was extended as far as necessary to provide CN for ungaged complexes. All but the last three lines of

Table 9.1.--Runoff curve numbers for hydrologic soil-cover complexes

(Antecedent moisture condition II, and $I_a = 0.2\,S$)

Land use	Cover		Hydrologic soil group			
	Treatment or practice	Hydrologic condition	A	B	C	D
Fallow	Straight row	----	77	86	91	94
Row crops	"	Poor	72	81	88	91
	"	Good	67	78	85	89
	Contoured	Poor	70	79	84	88
	"	Good	65	75	82	86
	"and terraced	Poor	66	74	80	82
	" " "	Good	62	71	78	81
Small grain	Straight row	Poor	65	76	84	88
		Good	63	75	83	87
	Contoured	Poor	63	74	82	85
		Good	61	73	81	84
	"and terraced	Poor	61	72	79	82
		Good	59	70	78	81
Close-seeded legumes 1/ or rotation meadow	Straight row	Poor	66	77	85	89
	" "	Good	58	72	81	85
	Contoured	Poor	64	75	83	85
	"	Good	55	69	78	83
	"and terraced	Poor	63	73	80	83
	"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
	"	Fair	25	59	75	83
	"	Good	6	35	70	79
Meadow		Good	30	58	71	78
Woods		Poor	45	66	77	83
		Fair	36	60	73	79
		Good	25	55	70	77
Farmsteads		----	59	74	82	86
Roads (dirt) 2/		----	72	82	87	89
(hard surface) 2/		---	74	84	90	92

1/ Close-drilled or broadcast.

2/ Including right-of-way.

Table 9.1B.--Runoff curve numbers for urban and suburban land use for antecedent moisture condition II. (From U.S. Soil Conservation Service, 1975).

Land Use		Hydrologic soil group			
		A	B	C	D
Open spaces, lawns, parks, golf courses, cemeteries, etc.					
Good condition:	grass cover on 75% or more of the area	39	61	74	80
Fair condition:	grass cover on 50% to 75% of the area	49	69	79	84
Commercial and business area (85% impervious)		89	92	94	95
Industrial districts (72% impervious)		81	88	91	93
Residential[1]					
Average lot size	Average % impervious[2]				
1/8 acre or less	65	77	85	90	92
1/4 acre	38	61	75	83	87
1/3 acre	30	57	72	81	86
1/2 acre	25	54	70	80	85
1 acre	20	51	68	79	84
Paved parking lots, roofs, driveways, etc.[3]		98	98	98	98
Streets and roads					
Paved with curbs and storm sewers[3]		98	98	98	98
Gravel		76	85	89	91
Dirt		72	82	87	89

---

[1] Curve numbers are computed assuming the runoff from the house and driveway is directed toward the street with a minimum of roof water directed to lawns where additional infiltration could occur.

[2] The remaining pervious areas (lawn) are considered to be in good pasture condition for these curve numbers.

[3] In some warmer climates of the country a curve number of 95 may be used.

CN entries in table 9.1 are taken from these curves. For the arbitrary complexes in the last three lines the proportions of different covers were estimated and CN computed from previously derived CN.

Table 9.1 has not been significantly changed since its construction in 1954 but supplementary tables for special regions have been developed. These tables are given later in this chapter.

USE OF TABLE 9.1. Chapters 7 and 8 describe how soils and cover of a watershed or other land area are classified in the field. After the classification is completed, CN are read from table 9.1 and applied as described in chapter 10. Because the principal use of CN is for estimating runoff from rainfall, the examples of applications are given in chapter 10.

NATIONAL AND COMMERCIAL FOREST: FOREST-RANGE

Chapter 4 of "Forest and Range Hydrology Handbook," U.S. Forest Service, Washington, D. C., 1959, describes how CN are determined for national and commercial forests in the eastern United States. Section 1 of "Handbook on Methods of Hydrologic Analysis," U.S. Forest Service, Washington, D. C., 1959, describes how CN are determined for forest-range regions in the western United States. Selections from these handbooks are given here to show the differences from SCS procedure; the handbooks should be consulted for details and examples.

Forest in Eastern United States

In the humid forest regions of the eastern United States, soil group, humus type, and humus depth are the principal factors used in the Forest Service method of determining CN. The undecomposed leaves or needles, twigs, bark, and other vegetative debris on the forest floor form the litter from which humus is derived. Litter protects humus from oxidation and therefore indirectly enters into the determination; if the depth of litter is less than 1/2 inch the humus is considered unprotected and the hydrologic condition class (fig. 9.1) is reduced by 0.5.

Humus is the organic layer immediately below the litter layer from which it is derived. It may consist of mull, which is an intimate mixture of organic matter and mineral soil, or of mor, which is practically pure organic matter unrecognizable as to origin from material lying on the forest floor. Humus depth increases with age of forest stand until an equilibrium is reached between the processes that build up humus and those that break it down. As much as 12 inches of humus may be produced under favorable conditions, but a depth of 5 or 6 inches is considered the maximum attainable under average conditions. Under good management practices (proper use, protection, and improvement), humus is porous and has high infiltration and storage capacities. Under poor management practices (burning, overcutting, or overgrazing), humus is compact enough to impede the absorption of water.

Humus is evaluated by means of degrees of compaction, which are:

1. Compact. Mulls are firm; mors are felty.

2. Moderately compact. A transition stage.

3. Loose or friable. Mulls are not firm; mors are not felty.

Frost in compact humus is the concrete form, which inhibits infiltration, and in loose humus it is the granular or stalactite form, which does not. Because of the correlation between humus type and frost, a separate determination of the effects of frost is unnecessary.

The hydrologic condition of a forest area is the runoff-producing potential. The condition class is indicated by a number ranging from 1 to 6, the lower the number the higher the potential. The relation between classes and humus type and depth is shown in figure 9.1.

DETERMINATION OF CN FOR PRESENT HYDROLOGIC CONDITION. The CN for the present hydrologic condition of a forest area is determined as follows: sample plots are located in the area; soil group, litter depth, humus type, and humus depth are determined by means of shallow soil wells dug in the plots; the nomograph, figure 9.1, gives the hydrologic condition class of the plot; the network chart, figure 9.2, gives the CN. An average or weighted CN is obtained as described in chapter 10.

DETERMINATION OF CN FOR FUTURE HYDROLOGIC CONDITION. The CN for the future hydrologic condition of a forest area is determined from the improvement potential of the area, which is estimated by means of table 9.2. Definitions of terms used in the table are:

Improvement potential. The potential for improvement of the hydrologic condition of a site by proper use and treatment in the future. Physiography of the site enters into the determination of potential. The symbols for classes of potential are H = high, M = moderate, and L = low. A high potential means the most rapid rate of improvement, a low potential the slowest.

Table 9.2.--Physiographic factors and forest hydrologic-condition-improvement potential indexes

Aspect	Soil class	Soil depth	Slope position											
			Lower slope (streambank to one-fourth distance up slope)			One-fourth to one-half distance up slope			One-half to three-fourths distance up slope			Upper slope (three-fourths distance to top of slope)		
			Slope percent 0-20	21-40	41+	Slope percent 0-20	21-40	41+	Slope percent 0-20	21-40	41+	Slope percent 0-20	21-40	41+
		(inches)												
North to east	Clay	13-24	H	H	M	H	M	M	M	M	L	M	L	L
		25+	H	H	H	H	H	H	H	H	M	H	M	M
	Loam	13-24	H	H	H	H	H	M	H	M	M	M	M	L
		25+	H	H	H	H	H	H	H	H	H	H	H	M
	Sand	13+	H	M	M	M	M	L	M	L	L	L	L	L
South to west	Clay	13-24	M	M	L	M	L	L	L	L	L	L	L	L
		25+	H	M	M	M	M	L	M	L	L	L	L	L
	Loam	13-24	H	M	M	M	M	L	M	L	L	L	L	L
		25+	H	H	H	H	H	M	M	M	M	M	M	L
	Sand	13+	M	L	L	L	L	L	L	L	L	L	L	L
Northwest and southwest	Clay	13-24	H	M	L	M	M	L	M	L	L	L	L	L
		25+	H	H	H	H	M	M	H	M	L	M	M	L
	Loam	13-24	H	H	M	H	M	M	M	M	L	M	L	L
		25+	H	H	H	H	H	H	H	H	M	H	M	M
	Sand	13+	M	L	L	M	L	L	L	L	L	L	L	L

This is table 4.1 in U.S. Forest Service "Forest and Range Hydrology Handbook."

Aspect. A compass reading to the nearest octant, taken from the center of the sample plot and looking downslope on a line at right angles to the contours.

Soil class. Texture of the mineral soil immediately below the humus layer if any. Note that these classes differ from the soil groups of chapter 7 because the classes are concerned with forest growth, the groups with runoff.

Soil depth. A determination made in the sample plot. Rock outcrops or soils less than 13 inches deep are put in the 13- to 24-inch class.

Slope. A percentage reading of land slope, taken at the center of the plot.

Slope position. A forest growth class based on the vertical position of the plot relative to a stream (fig. 9.3).

Once the improvement potential is known, the time period for achieving the potential is estimated on the basis of use and treatment to be given the area; consideration is given to measures for protection from fire, overgrazing, overcutting, damaging logging, and epidemics of insects or diseases, to tree planting in open fields or woods openings, and to stand improvement. The CN for the area is estimated using figure 9.4, as illustrated in the following example.

Example 9.1.--A forest area has a present hydrologic condition class of 1.3 and soils in the A group. The improvement potential is high and it is estimated that a 50-year period is necessary to bring the area to this level. Determine the future CN for the area.

1. Determine the present CN. Enter figure 9.2 with the hydrologic condition class of 1.3 and at the line for soil group A read a CN of 54.

2. Determine the future hydrologic condition class. Enter figure 9.4 with the present class of 1.3, go across to the curve for high potential, and read 6 years on the time scale. To this value add one-half the improvement period: 6 + (50/2) = 31 years, follow the "high" curve to its intersection with 31 years on the time scale, and read a future class of 3.4. This estimate is based on 100 percent accomplishment of recommended use and treatment; if less accomplishment is expected, the condition class is proportionately reduced.

3. Determine the future CN. Enter figure 9.2 with the future class of 3.4 and at the line for soil group A read a CN of 37.

Forest-Range in Western United States

In the forest-range regions of the western United States, soil group, cover type, and cover density are the principal factors used in estimating CN. Figures 9.5 and 9.6 show the relationships between these factors and CN for soil-cover complexes used to date. The figures are based on information in table 2.1, part 2, of the Forest Service "Handbook on Methods of Hydrologic Analysis." The covers are defined as follows:

Herbaceous.--Grass-weed-brush mixtures with brush the minor element.

Oak-Aspen.-- Mountain brush mixtures of oak, aspen, mountain mahogany, bitter brush, maple, and other brush.

Juniper-Grass.--Juniper or piñon with an understory of grass.

Sage-Grass.--Sage with an understory of grass.

The amount of litter is taken into account when estimating the density of cover.

Present hydrologic conditions are determined from existing surveys or by reconnaissance, and future conditions from the estimate of cover and density changes due to proper use and treatment.

SUPPLEMENTARY TABLES OF CN

Tables 9.3, 9.4, and 9.5 are supplements to table 9.1 and are used in the same way.

Table 9.3 gives CN for selected covers in Puerto Rico. The CN were obtained using a relation between storm and annual data and the annual rainfall-runoff data for experimental plots at Mayaguez.

Table 9.4 gives CN for complexes in a typical watershed in Contra Costa County, California. The CN were obtained by the Contra Costa County Flood Control District and SCS, using streamflow data from the watershed and a trial-and-error process. The range in CN for a particular cover and soil group indicates the variation for soil subgroups.

Table 9.5 gives CN for sugarcane complexes in Hawaii. The CN are tentative estimates now undergoing study. Degrees of cover in the table are defined as follows:

Table 9.3.--Runoff curve numbers for hydrologic soil-cover complexes in Puerto Rico (antecedent moisture condition II, and I_a = 0.2 S).

Cover and condition	Hydrologic soil group			
	A	B	C	D
Fallow	77	86	91	93
Grass (bunch grass, or poor stand of sod)	51	70	80	84
Coffee (no ground cover, no terraces)	48	68	79	83
Coffee (with ground cover and terraces)	22	52	68	75
Minor crops (garden or truck crops)	45	66	77	83
Tropical kudzu	19	50	67	74
Sugarcane (trash burned; straight-row)	43	65	77	82
Sugarcane (trash mulch; straight row)	45	66	77	83
Sugarcane (in holes; on contour)	24	53	69	76
Sugarcane (in furrows; on contour)	32	58	72	79

Table 9.4.--Runoff curve numbers for hydrologic soil-cover complexes of a typical watershed in Contra Costa County, California (antecedent moisture condition II, and I_a = 0.2 S).

Cover	Condition	Hydrologic soil group			
		A	B	C	D
Scrub (native brush)	----	25-30	41-46	57-63	66
Grass-oak (native oaks with understory of forbs and annual grasses)	Good	29-33	43-48	59-65	67
Irrigated pasture	Good	32-37	46-51	62-68	70
Orchard (winter period with understory of cover crop)	Good	37-41	50-55	64-69	71
Range (annual grass)	Fair	46-49	57-60	68-72	74
Small grain (contoured)	Good	61-64	69-71	76-80	81
Truck crops (straight-row)	Good	67-69	74-76	80-83	84
Urban areas:					
Low density (15 to 18 percent impervious surfaces)		69-71	75-78	82-84	86
Medium density (21 to 27 percent impervious surfaces)		71-73	77-80	84-86	88
High density (50 to 75 percent impervious surfaces)		73-75	79-82	86-88	90

Table 9.5.--Runoff curve numbers; tentative estimates for sugarcane hydrologic soil-cover complexes in Hawaii (antecedent moisture condition II, and $I_a = 0.2 S$).

Cover and treatment	Hydrologic soil group			
	A	B	C	D
Sugarcane:				
Limited cover, straight row	67	78	85	89
Partial cover, straight row	49	69	79	84
Complete cover, straight row	39	61	74	80
Limited cover, contoured	65	75	82	86
Partial cover, contoured	25	59	75	83
Complete cover, contoured	6	35	70	79

Limited cover.--Cane newly planted, or ratooned cane with a limited root system; canopy over less than 1/2 the field area.

Partial cover.--Cane in the transition period between limited and complete cover; canopy over 1/2 to nearly the entire field area.

Complete cover.--Cane from the stage of growth when full canopy is provided to the stage at harvest.

Straight-row planting is up and down hill or cross-slope on slopes greater than 2 percent. Contoured planting is the usual contouring or cross-slope planting on slopes less than 2 percent.

* * * *

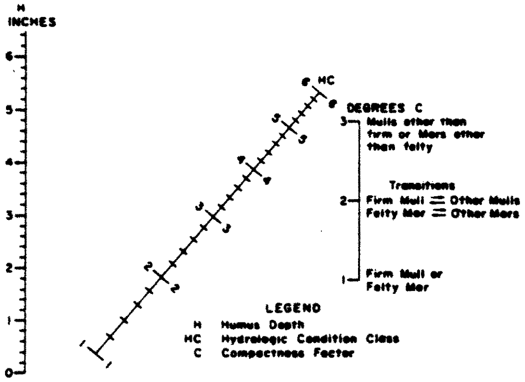


FIGURE 9.1 PRESENT HYDROLOGIC CONDITION OF FOREST AND WOODLAND

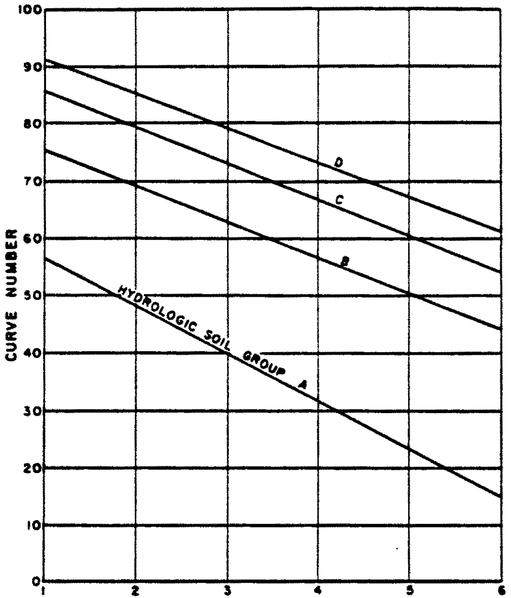
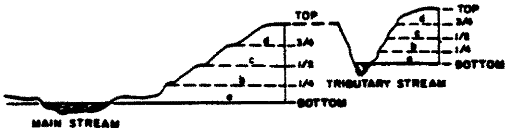


FIGURE 9.2 CURVE NUMBERS BY HYDROLOGIC SOIL GROUP AND FOREST HYDROLOGIC CONDITION CLASSES



A. - TRIBUTARY STREAM IN RELATION TO MAIN STREAM, MOUNTAINOUS

B. - PLATEAUS AND FOOTHILLS

C. - PRAIRIES, COASTAL PLAIN

a - LOWER SLOPE
b - 1/4 TO 1/2 DISTANCE UP SLOPE
c - 1/2 TO 3/4 DISTANCE UP SLOPE
d - UPPER SLOPE

FIGURE 9.3 - EXAMPLES OF SLOPE POSITION

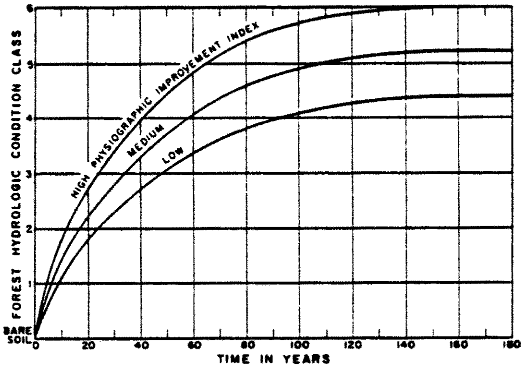


FIGURE 9.4 RATE OF IMPROVEMENT OF FOREST HYDROLOGIC CONDITION UNDER MANAGEMENT. STARTING CONDITION - BARE SOIL

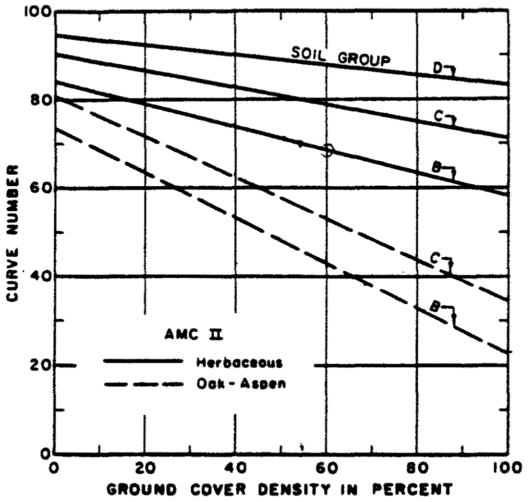


Figure 9.5.--Graph for estimating runoff curve numbers of forest-range complexes in western United States: herbaceous and oak-aspen complexes.

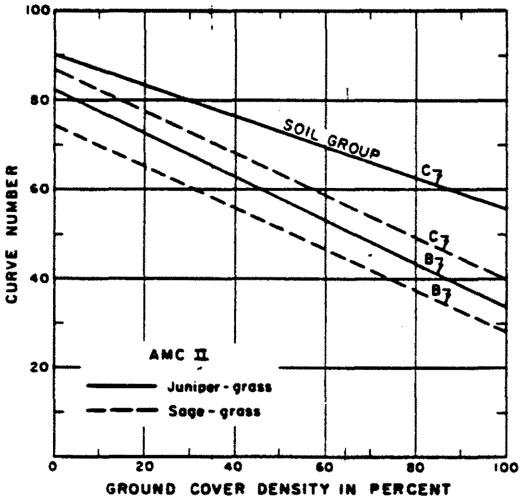


Figure 9.6.--Graph for estimating runoff curve numbers of forest-range complexes in western United States: juniper-grass and sage-grass complexes.

NATIONAL ENGINEERING HANDBOOK

SECTION 4

HYDROLOGY

CHAPTER 10. ESTIMATION OF DIRECT RUNOFF FROM STORM RAINFALL

by

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SECTION 4

HYDROLOGY

CHAPTER 10--ESTIMATION OF DIRECT RUNOFF FROM STORM RAINFALL

CONTENTS

Figures

Tables

CHAPTER 10. ESTIMATION OF DIRECT RUNOFF FROM STORM RAINFALL

The SCS method of estimating direct runoff from storm rainfall is described in this chapter. The rainfall-runoff relation of the method is developed, parameters in the relation are discussed, and applications of the method are illustrated by examples.

Introduction

The SCS method of estimating direct runoff from storm rainfall is based on methods developed by SCS hydrologists in the last three decades, and it is in effect a consolidation of these earlier methods. The hydrologic principles of the method are not new, but they are put to new uses. Because most SCS work is with ungaged watersheds (not gaged for runoff) the method was made to be usable with rainfall and watershed data that are ordinarily available or easily obtainable for such watersheds. If runoff data are also available the method is adaptable to their use as illustrated in chapter 5.

The principal application of the method is in estimating quantities of runoff in flood hydrographs or in relation to flood peak rates (chap. 16). These quantities consist of one or more types of runoff. An understanding of the types is necessary to apply the method properly in different climatic regions. The classification of types used in this handbook is based on the time from the beginning of a storm to the time of the appearance of a type in the hydrograph. Four types are distinguished:

Channel runoff occurs when rain falls on a flowing stream or on the impervious surfaces of a streamflow-measuring installation. It appears in the hydrograph at the start of the storm and continues throughout it, varying with the rainfall intensity. It is generally a negligible quantity in flood hydrographs, and no attention is given to it except in special studies (see the discussion concerning the relationship of I_a to S in figure 10.2).

Surface runoff occurs only when the rainfall rate is greater than the infiltration rate. The runoff flows on the watershed surface to the point of reference. This type appears in the hydrograph after the initial demands of interception, infiltration, and surface storage have been satisfied. It varies during the storm and ends during or soon after it. Surface runoff flowing down dry channels of watersheds in arid, semiarid, or subhumid climates is reduced by transmission losses (chap. 19), which may be large enough to eliminate the runoff entirely.

Subsurface flow occurs when infiltrated rainfall meets an underground zone of low transmission, travels above the zone to the soil surface downhill, and appears as a seep or spring. This type is often called "quick return flow" because it appears in the hydrograph during or soon after the storm.

Base flow occurs when there is a fairly steady flow from natural storage. The flow comes from lakes or swamps, or from an aquifer replenished by infiltrated rainfall or surface runoff, or from "bank storage", which is supplied by infiltration into channel banks as the stream water level rises and which drains back into the stream as the water level falls. This type seldom appears soon enough after a storm to have any influence on the rates of the hydrograph for that storm, but base flow from a previous storm will increase the rates. Base flow must be taken into account in the design of the principal spillway of a floodwater-retarding structure (chap. 21).

All types do not regularly appear on all watersheds. Climate is one indicator of the probability of the types. In arid regions the flow on smaller watersheds is nearly always surface runoff, but in humid regions it is generally more of the subsurface type. But a long succession of storms produces subsurface or base flow even in dry climates although the probability of this occurring is less in dry climates than in wet climates.

In flood hydrology it is customary to deal separately with base flow and to combine all other types into direct runoff, which consists of channel runoff, surface runoff, and subsurface flow in unknown proportions. The SCS method estimates direct runoff, but the proportions of surface runoff and subsurface flow (channel runoff is ignored) can be appraised by means of the runoff curve number (CN), which is another indicator of the probability of flow types: the larger the CN the more likely that the estimate is of surface runoff. This principle is also employed for estimating watershed lag as shown in figure 15.3. The rainfall-runoff relation of the SCS method can be made to operate with a particular type of flow; it was linked with direct runoff, as described in chapter 9, for the convenience of applications.

The Rainfall-Runoff Relation

The most generally available rainfall data in the United States are the amounts measured at nonrecording rain gages, and it was for the use of such data or their equivalent that the rainfall-runoff relation was developed. The data are totals for one or more storms occurring in a calendar day, and nothing is known about the time distributions. The relation therefore excludes time as an explicit variable; this means that rainfall intensity is ignored. If everything but storm duration or intensity is the same for two storms, the estimate of runoff is the same for both storms. Runoff amounts for specified time increments of a storm can be estimated as shown in example 10.6, but even in this process the rainfall intensity is ignored.

DEVELOPMENT

If records of natural rainfall and runoff for a large storm over a small area are used, a plotting of accumulated runoff versus accumulated rainfall will show that runoff starts after some rain accumulates (there is an "initial abstraction" of rainfall) and that the double-mass line curves, becoming asymptotic to a straight line. On arithmetic graph paper and with equal scales the straight line has a 45-degree slope. The relation between rainfall and runoff can be developed from this plotting, but a better understanding of the relation is had by first studying a storm in which rainfall and runoff begin simultaneously (the initial abstraction does not occur). For the simpler storm the relation between rainfall, runoff, and retention (the rain not converted to runoff) at any point on the mass curve can be expressed as:

$$\frac{F}{S'} = \frac{Q}{P} \qquad (10.1)$$

where

F = actual retention

S' = potential maximum retention $(S' \geq F)$

Q = actual runoff

P = potential maximum runoff $(P \geq Q)$

Equation 10.1 applies to on-site runoff; for large watersheds there is a lag in the appearance of the runoff at the stream gage, and the double-mass curve produces a different relation. But if storm totals for P and Q are used equation 10.1 does apply even for large watersheds because the effects of the lag are removed.

The parameter S' in equation 10.1 does not contain the initial abstraction and differs from the parameter S to be used later. The retention S' is a constant for a particular storm because it is the maximum that can occur under the existing conditions if the storm continues without limit. The retention F varies because it is the difference between P and Q at any point on the mass curve, or:

$$F = P - Q \tag{10.2}$$

Equation 10.1 can therefore be rewritten:

$$\frac{P - Q}{S'} = \frac{Q}{P} \tag{10.3}$$

Solving for Q produces the equation:

$$Q = \frac{P^2}{P + S'} \tag{10.4}$$

which is a rainfall-runoff relation in which the initial abstraction is ignored.

The initial abstraction is brought into the relation by subtracting it from the rainfall. The equivalent of equation 10.1 becomes:

$$\frac{F}{S} = \frac{Q}{P - I_a} \tag{10.5}$$

where I_a is the initial abstraction, $F \leq S$, and $Q \leq (P - I_a)$. The parameter S includes I_a; that is, $S = S' + I_a$.

Equation 10.2 becomes:

$$F = (P - I_a) - Q \tag{10.6}$$

equation 10.3 becomes:

$$\frac{(P - I_a) - Q}{S} = \frac{Q}{(P - I_a)} \tag{10.7}$$

and equation 10.4 becomes:

$$Q = \frac{(P - I_a)^2}{(P - I_a) + S} \tag{10.8}$$

which is the rainfall-runoff relation with the initial abstraction taken into account.

The initial abstraction consists mainly of interception, infiltration, and surface storage, all of which occur before runoff begins. The insert on figure 10.1 shows the position of I_a in a typical storm. To remove the necessity for estimating these variables in equation 10.8, the relation between I_a and S (which includes I_a) was developed by means of rainfall and runoff data from experimental small watersheds. The relation is discussed later in connection with figure 10.2. The empirical relationship is:

$$I_a = 0.2\,S \tag{10.9}$$

Substituting 10.9 in 10.8 gives:

$$Q = \frac{(P - 0.2\,S)^2}{P + 0.8\,S} \tag{10.10}$$

which is the rainfall-runoff relation used in the SCS method of estimating direct runoff from storm rainfall.

Retention Parameters

Equation 10.9 states that 20 percent (an average, as figure 10.2 shows) of the potential maximum retention S is the initial abstraction I_a, which is the interception, infiltration, and surface storage occurring before runoff begins. The remaining 80 percent is mainly the infiltration occurring after runoff begins. This later infiltration is controlled by the rate of infiltration at the soil surface or by the rate of transmission in the soil profile or by the water-storage capacity of the profile, whichever is the limiting factor. A succession of storms, such as one a day for a week, reduces the magnitude of S each day because the limiting factor does not have the opportunity to completely recover its rate or capacity through weathering, evapotranspiration, or drainage. But there is enough recovery, depending on the soil-cover complex, to limit the reduction. During such a storm period the magnitude of S remains virtually the same after the second or third day even if the rains are large so that there is, from a practical viewpoint, a lower limit to S for a given soil-cover complex. Similarly there is a practical upper limit to S, again depending on the soil-cover complex, beyond which the recovery cannot take S unless the complex is altered.

In the SCS method the change in S (actually in CN) is based on an antecedent moisture condition (AMC) determined by the total rainfall in the 5-day period preceding a storm. Three levels of AMC are used: AMC-I is the lower limit of moisture or the upper limit of S, AMC-II is the average for which the CN of table 9.1 apply, and AMC-III is the upper limit of moisture or the lower limit of S. The CN in table 9.1 were determined by means of rainfall-runoff plottings as described in chapter 9. The same plottings served for getting CN for AMC-I and AMC-III. That is, the curves of figure 10.1 when superimposed on a plotting also showed which curves best fit the highest (AMC-III) and lowest (AMC-I) thirds of the plotting. The CN for high and low moisture levels were empirically related to the CN of table 9.1; the results are shown in columns 1, 2, and 3 of table 10.1, which also gives values of S and I_a for the CN in column 1. The rainfall amounts on which the selection of AMC is based are given in table 4.2; the discussion in chapter 2 concerns the value of rainfall alone as a criterion for AMC. Use of tables 4.2 and 10.1 is demonstrated later in this chapter. In the section on comparisons of computed and actual runoffs an example shows that for certain problems the extreme AMC can be ignored and the average CN of table 9.1 alone applied.

RELATION OF I_a TO S. Equation 10.9 is based on the results shown in figure 10.2 which is a plotting of I_a versus S for individual storms. The data were derived from records of natural rainfall and runoff from watersheds less than 10 acres in size. The large amount of scatter in the plotting is due mainly to errors in the estimates of I_a. The magnitudes of S were estimated by plotting total storm rainfall and runoff on figure 10.1, determining the CN, and determining the S from table 10.1. The magnitudes of I_a were estimated by taking the accumulated rainfall from the beginning of a storm to the time when runoff started. Errors in S were due to determinations of average watershed rainfall totals; these errors were very small. Errors in I_a were due to one or more of the following: (i) difficulty of determining the time when rainfall began, because of storm travel and lack of instrumentation, (ii) difficulty of determining the time when runoff began, owing to the effects of rain on the measuring installations (channel runoff) and to the lag of runoff from the watersheds, and (iii) impossibility of determining how much interception prior to runoff later made its way to the soil surface and contributed to runoff; the signs and magnitudes of these errors are not known. Only enough points are plotted in figure 10.2 to show the variability of the data. The line of relationship cuts the plotting into two equal numbers of points, and the slope of the line is 1:1 because the data do not indicate otherwise. A significant statistical correlation (chap. 18) between I_a and S can be made by adding more points and increasing the "degrees of freedom", but the standard error of estimate will remain large owing to the deficiencies in the data.

Graphs and Tables for the Solution of Equation 10.10

Sheets 1 and 2 of figure 10.1 contain graphs for the rapid solution of equation 10.10. The parameter CN (runoff curve number or hydrologic soil-cover complex number) is a transformation of S, and it is used to make interpolating, averaging, and weighting operations more nearly linear. The transformation is:

$$CN = \frac{1000}{S + 10} \qquad (10.11)$$

or

$$S = \frac{1000}{CN} - 10 \qquad (10.12)$$

Tables for the solution of equation 10.10 are given in SCS Technical Release 16 for P from zero to 40.9 inches by steps of 0.1-inch and for all whole-numbered CN in the range from 55 through 98.

USE OF S AND CN. It is more convenient to use CN on figure 10.1, but it will generally be necessary to use S for other applications such as the analysis of runoff data or the development of supplementary runoff relationships. Example 5.5 and figure 5.6(b) illustrate a typical use of S. The relationship is developed using S, but a scale for CN is added later to the graph for ease of application.

Table 10.1. Curve numbers (CN) and constants for the case $I_a = 0.2 S$

1	2	3	4	5
CN for condition II	CN for conditions I	III	S values*	Curve* starts where P =
			(inches)	(inches)
100	100	100	0	0
99	97	100	.101	.02
98	94	99	.204	.04
97	91	99	.309	.06
96	89	99	.417	.08
95	87	98	.526	.11
94	85	98	.638	.13
93	83	98	.753	.15
92	81	97	.870	.17
91	80	97	.989	.20
90	78	96	1.11	.22
89	76	96	1.24	.25
88	75	95	1.36	.27
87	73	95	1.49	.30
86	72	94	1.63	.33
85	70	94	1.76	.35
84	68	93	1.90	.38
83	67	93	2.05	.41
82	66	92	2.20	.44
81	64	92	2.34	.47
80	63	91	2.50	.50
79	62	91	2.66	.53
78	60	90	2.82	.56
77	59	89	2.99	.60
76	58	89	3.16	.63
75	57	88	3.33	.67
74-	55	88	3.51	.70
73	54	87	3.70	.74
72	53	86	3.89	.78
71	52	86	4.08	.82
70	51	85	4.28	.86
69	50	84	4.49	.90
68	48	84	4.70	.94
67	47	83	4.92	.98
66	46	82	5.15	1.03
65	45	82	5.38	1.08
64	44	81	5.62	1.12
63	43	80	5.87	1.17
62	42	79	6.13	1.23
61	41	78	6.39	1.28
60	40	78	6.67	1.33
59	39	77	6.95	1.39
58	38	76	7.24	1.45
57	37	75	7.54	1.51
56	36	75	7.86	1.57
55	35	74	8.18	1.64
54	34	73	8.52	1.70
53	33	72	8.87	1.77
52	32	71	9.23	1.85
51	31	70	9.61	1.92
50	31	70	10.0	2.00
49	30	69	10.4	2.08
48	29	68	10.8	2.16
47	28	67	11.3	2.26
46	27	66	11.7	2.34
45	26	65	12.2	2.44
44	25	64	12.7	2.54
43	25	63	13.2	2.64
42	24	62	13.8	2.76
41	23	61	14.4	2.88
40	22	60	15.0	3.00
39	21	59	15.6	3.12
38	21	58	16.3	3.26
37	20	57	17.0	3.40
36	19	56	17.8	3.56
35	18	55	18.6	3.72
34	18	54	19.4	3.88
33	17	53	20.3	4.06
32	16	52	21.2	4.24
31	16	51	22.2	4.44
30	15	50	23.3	4.66
25	12	43	30.0	6.00
20	9	37	40.0	8.00
15	6	30	56.7	11.34
10	4	22	90.0	18.00
5	2	13	190.0	38.00
0	0	0	infinity	infinity

*For CN in column 1.

10.8

Applications

The examples in this part mainly illustrate the use of tables 4.2, 9.1, and 10.1 and figure 10.1. Records from gaged watersheds are used in some examples to compare computed with actual runoffs. The errors in a runoff estimate are due to one or more of the following: empiricisms of table 4.2 or figure 4.9, or table 9.1 and similar tables in chapter 9, of the relation between AMC (columns 1, 2, and 3 of table 10.1), and of equation 10.9; and errors in determinations of average watershed rainfall (chap. 4), soil groups, (chap. 7), land use and treatment (chap. 8), and related computations. Consequently it is impossible to state a standard error of estimate for equation 10.10; comparisons of computed and actual runoffs indicate only the algebraic sums of errors from various sources.

SINGLE STORMS. The first example is a typical routine application of the estimation method when there is no question regarding the accuracy of rainfall, land use and treatment, and soil group determinations.

> Example 10.1.- During a storm an average depth of 4.3 inches of rain fell over a watershed with a cover of good pasture, soils in the C group, and an AMC-II. Estimate the direct runoff.
>
> 1. Determine the CN. In table 9.1 at "Pasture, good" and under soil group C read a CN of 74, which is for AMC-II.
>
> 2. Estimate the runoff. Enter figure 10.1 with the rainfall of 4.3 inches and at CN = 74 (by interpolation) find Q = 1.83 inches.

In practice the estimate of Q is carried to two decimal places to avoid confusing different estimates. Except for such needs the estimate should generally be rounded to one decimal place; in example 10.1 the rounded estimate is 1.8 inches. If the storm rainfall amount is not accurately known the estimate is rounded even further or the range of the estimate is given as in the following example.

> Example 10.2.--During a thunderstorm a rain of 6.0 inches was measured at a rain gage 5.0 miles from the center of a watershed that had a flood from this storm. The drainage area of the watershed is 840 acres, cover is fair pasture, soils are in the D group, and AMC-II applies. Estimate the direct runoff.

1. Determine the average watershed rainfall. Enter figure 4.4 with the distance of 5.0 miles and at line for a rain of 6.0 inches read a plus-error of 2.8 inches. The minus-error is half this, or 1.4 inches. The watershed is small enough that no "areal correction" of rainfall is necessary (see figure 21.-- and related discussion in chapter 21), therefore the average watershed rainfall ranges from 8.8 to 4.6 inches.

2. Determine the CN. In table 9.1 the CN is 84 for fair pasture in the D soil group.

3. Estimate the direct runoff. Enter figure 10.1 with the rainfall of 8.8 inches and at CN = 84 (by interpolation) read an estimated runoff of 6.87 inches; also enter with the rainfall of 4.6 inches and read a runoff of 2.91 inches. After rounding, the estimate of direct runoff is given as being between 2.9 and 6.9 inches or, better yet, between 3 and 7 inches. The probability level of figure 4.4 can also be used with the runoff estimate.

Table 10.1 is used when it is necessary to estimate runoff for a watershed in a dry or wet condition before a storm:

Example 10.3.--For the watershed of example 10.1, estimate the direct runoff for AMC-I and AMC-III and compare with the estimate for AMC-II.

1. Determine the CN for AMC-II. This is done in step 1 of example 10.1; the CN is 74.

2. Determine CN for other AMC. Enter table 10.1 at CN = 74 in column 1 and in columns 2 and 3 read CN = 55 for AMC-I and CN = 88 for AMC-III.

3. Estimate the runoffs. Enter figure 10.1 with the rainfall of 4.3 inches (from ex. 10.1) and at CN = 55, 74, and 88 read (by interpolation as necessary) that Q = 0.65, 1.83, and 3.00 inches, respectively. The comparison in terms of AMC-II runoff is as follows:

AMC	CN	Direct runoff, Q		
		Inches	As percent of rainfall	As percent of Q for AMC-II
I	55	0.65	15.1	35.6
II	74	1.83	42.5	100
III	88	3.00	69.8	164

Note that the runoff in inches or percents is not simply proportional to the CN so that the procedure does not allow for a short cut.

10.10

ALTERNATE METHODS OF ESTIMATION FOR MULTIPLE COMPLEXES. The direct runoff for watersheds having more than one hydrologic soil-cover complex can be estimated in either of two ways: in example 10.4 the runoff is estimated for each complex and weighted to get the watershed estimate; in example 10.5 the CN are weighted to get a watershed CN and the runoff is estimated using it.

Example 10.4.--A watershed of 630 acres has 400 acres in "Row crop, contoured, good rotation" and 230 acres in "Rotation meadow, contoured, good rotation." All soils are in the B group. Find the direct runoff for a rain of 5.1 inches when the watershed is in AMC-II.

1. Determine the CN. Table 9.1 shows that the CN are 75 for the row crop and 69 for the meadow.

2. Estimate runoff for each complex. Enter figure 10.1 with the rain of 5.1 inches and at CN of 75 and 69 read Q's of 2.52 and 2.03 inches respectively.

3. Compute the weighted runoff. The following table shows the work.

Hydrologic soil-cover complex	Acres	Q(inches)	Acres X Q
Row crop etc.	400	2.52	1,008
Meadow etc.	230	2.03	467
Totals:	630		1,475

The weighted Q is 1475/630 = 2.34 inches.

Example 10.5.--Use the watershed and rain data of example 10.4 and make the runoff estimate using a weighted CN.

1. Determine the CN. Table 9.1 shows that the CN are 75 for the row crop and 69 for the meadow.

2. Compute the weighted CN. The following table shows the work.

Hydrologic soil-cover complex	Acres	CN	Acres X CN
Row crop etc.	400	75	30,000
Meadow etc.	230	69	15,870
Totals:	630		45,870

The weighted CN is 45,870/630 = 72.8. Use 73.

3. Estimate the runoff. Enter figure 10.1 with the rain of 5.1 inches and at CN = 73 (by interpolation) read Q = 2.36 inches. (Note: Q is 2.34 inches just as in example 10.4 if the unrounded CN is used.)

Without the rounding in step 2 of example 10.5, both methods of weighting give the same Q to three significant figures, and there appears to be no reason for choosing one method over the other. But each method has its advantages and disadvantages. The method of weighted-Q always gives the correct result (in terms of the given data) but it required more work than the weighted-CN method especially when a watershed has many complexes. The method of weighted-CN is easier to use with many complexes or with a series of storms, but when there are large differences in CN for a watershed this method will under- or over-estimate Q, depending on the size of the storm rainfall. For example an urban watershed with 20 acres of impervious area (CN = 100) and 175 acres of lawn classed as good pasture on a B soil (CN = 61) will have the following Q's by the two methods (all entries in inches):

Storm rainfall:	1	2	4	8	16	32
Q (weighted-Q method):	0.10	0.27	1.14	3.91	10.85	26.10
Q (weighted-CN method):	0	.13	1.03	3.89	10.97	26.34

This comparison shows that the method of weighted-Q is preferable when small rainfalls are used and there are two or more widely differing CN on a watershed. For conditions other than these the method of weighted-CN is less time-consuming and almost as accurate.

MULTIPLE-DAY STORMS AND STORM SERIES. Data from a gaged small watershed will be used in the following example to illustrate (i) an application of the method of estimation to a storm series such as used in evaluation of a floodwater-retarding project, (ii) treatment of multiple-day storms, which differs from that of design storms in chapter 21, and (iii) the amount of error generally to be expected from use of the method. The data to be used are taken from:

Reference 1. "The Agriculture, Soils, Geology, and Topography of the Blacklands Experimental Watershed, Waco, Texas," Hydrologic Bulletin 5, U.S. Soil Conservation Service, 1942.

Reference 2. "Summary of Rainfall and Runoff, 1940-1951, at Blacklands Experimental Watershed, Waco, Texas," U.S. Soil Conservation Service, 1952.

The watershed is W-1 with an area of 176 acres, average annual rainfall of 34.95 inches for the period 1940-1952 inclusive, and average storm rainfall depths determined from amounts at four gages on or very near the watershed. According to figure 4.6 (its scales must be extended for so small a watershed) the storm rainfall amounts will have a negligible error. With this exception the data to be used are equivalent to those ordinarily obtained for ungaged watersheds.

Example 10.6.--Estimate the runoff amounts from storms that produced the maximum annual peak rates of flow at watershed W-1, Waco, Texas, for the period 1940-1952 inclusive.

1. Determine the soil groups. Reference 1 shows that the soils are Houston Black Clay or equivalents. Table 7.1 in chapter 7 shows these soils are in the D group.

2. Determine the average land use and treatment for the period 1940-1952. Reference 2 gives information from which the average land use and treatment is determined to be:

Land use and treatment	Percent of area
Row crop, straight row, poor rotation	58
Small grain, straight row, poor rotation	25
Pasture (including hay), fair condition	15
Farmsteads and roads	2

3. Tabulate the storm dates, total rainfall for each date, and the 5-day antecedent rainfall. Reference 2 gives the information shown in columns 1 through 5 of table 10.2.

4. Determine the CN for AMC-I, -II, and -III. Table 9.1 gives the CN for each complex; the computation of the weighted CN for AMC-II is:

Hydrologic soil-cover complex	Percent/100	CN	Product
Row crop etc.	0.58	91	52.7
Small grain etc.	.25	88	22.0
Pasture etc.	.15	84	12.6
Farmsteads etc.	.02	94	1.9
Totals	1.00		89.2

No division of the product is necessary because "percent/100" is used. The CN is rounded to 89. CN for the other two AMC are obtained from table 10.1 and are:

AMC:	I	II	III
CN:	76	89	96

Table 10.2.--Working table for a storm series.

Year	Month	Day	Storm rainfall (in.)	Antecedent rainfall (in.)	AMC	CN	Estimated runoff		Actual runoff		Differences	
							By days (in.)	Storm totals (in.)	By days (in.)	Storm totals (in.)	By days (in.)	Storm totals (in.)
1940	Nov.	22	4.74	0.18	I	76	2.32		2.32		0	
		23	2.20		III	96	1.77		2.02		- .25	
		24	2.03		III	96	1.61		1.39		.22	
		25	.38		III	96	.13	5.83	.26	5.99	- .13	- 0.16
1941	June	10	2.39	1.38	III	96	1.96	1.96	2.05	2.05	- .09	- .09
1942	Sept.	7	3.89	.22	I	76	1.65		.35		1.30	
		8	3.36		III	96	2.91		2.02		.89	
		9	.78		III	96	.44	5.00	.46	2.83	- .02	2.17
1943	June	5	1.58	.09	I	76	.22	.22	.51	.51	- .29	- .29
1944	April	29	3.63	0	I	76	1.45		1.56		- .11	
		30	2.64		III	96	2.21		2.15		.06	
	May	1	6.37		III	96	5.90		6.92		- 1.02	
		2	1.10		III	96	.73	10.29	.13	10.76	.60	- .47
1945	March	2	.77	.41	I	76	0		.23		- .23	
		3	2.50		III	96	2.07	2.07	2.15	2.38	- .08	- .31
1946	May	12	2.90	1.08	III	96	2.46		2.11		.35	
		13	.95		III	96	.59	3.05	.84	2.95	- .25	.10
1947	March	18	1.74	0	I	76	.29	.29	.85	.85	- .56	- .56
1948	April	25	3.10	.05	I	76	1.08	1.08	1.17	1.17	- .09	- .09
1949	July	4	2.86	.03	I	76	.92	.92	1.07	1.07	- .15	- .15
1950	Feb.	12	1.94	1.08	III	96	1.52	1.52	1.09	1.09	.43	.43
1951	June	16	1.64	1.28	II	89	.74	.74	.19	.19	.55	.55

5. Determine which AMC applies for each rain in column 4, table 10.2. The AMC for the first day of a multiple-day storm is obtained by use of dates in columns 2 and 3 (to get the season), antecedent rainfall in column 5, and figure 4.9. The AMC for succeeding days in a multiple-day storm is similarly obtained but with the previous day's rain (from column 4) added to the antecedent rainfall. The results are shown in column 6. The CN for the AMC are shown in column 7.

6. Estimate the runoff for each day. Enter figure 10.1 with the rainfall in column 4 and the CN in column 7 and estimate the runoff. The results are tabulated in column 8.

7. Add the daily runoffs in a storm period to get the storm total. The totals are shown in column 9. This step completes the example.

Actual runoffs for W-1, taken from reference 2, are given in columns 10 and 11 for comparison with the estimates in columns 8 and 9. Differences between computed and actual runoffs are shown in columns 12 and 13. For some estimates the differences (or estimation errors) are fairly large; the errors may be due to one or more of several causes, of which the most obvious is applying an average land use and treatment to all years and all seasons in a year. The quality of land use and treatment varies (that is, the CN varies from the average) from year to year because of rainfall and temperature excesses or deficiencies and during the seasons of a year because of stages in crop growth as well. In practice the magnitudes of the variations are generally unknown so that the method of this example is usually followed; if they are known, the CN are increased or decreased on the basis of the hydrologic condition as described in the next section. A comparison made later in this chapter illustrates that errors of estimate, even when fairly large, do not adversely affect frequency lines constructed from the estimates as long as the errors are not all of one type.

SEASONAL OR ANNUAL VARIATIONS. The average CN in table 9.1 apply to average crop conditions for a growing season. If seasonal variations in the CN are desired, the stages of growth of the particular crop in the complex indicate how much and when to modify the average CN.

For cultivated crops in a normal growing season the CN at plowing or planting time is the same as the CN for fallow in the same soil group of table 9.1; midway between planting and harvest or cutting times the CN is the average in table 9.1; and at the time of normal peak growth or height (usually before harvest) the CN is:

$$CN_{\text{normal peak growth}} = 2\,(CN_{\text{average}}) - (CN_{\text{fallow}}) \qquad (10.13)$$

Thus, if the average CN is 85 and the fallow CN is 91, the normal peak growth CN is 79. After harvest the CN varies between those for fallow and normal peak growth, depending on the effectiveness of the plant residues as ground cover. In general, if 2/3 of the soil surface is exposed, the fallow CN applies; if 1/3 is exposed, the average CN applies; and if practically none is exposed the normal peak growth CN applies.

For pasture, range, and meadow, the seasonal variation of CN can be estimated by means of tables 8.1 and 8.2; for woods or forest, the Forest Service method in chapter 9 is applicable.

Changes in CN because of above- or below-normal rainfall or temperature occur not only from year to year but also within a year. They are more difficult to evaluate than changes from normal crop growth because detailed soil and crop histories are necessary but seldom available; climate records are a poor substitute even for estimating gross departures from normal. Runoff records from a nearby streamflow station are a better substitute because they provide a means of relating CN to a runoff parameter (for an example see figure 5.6(a)) and approximating the variations of CN.

The CN of table 9.1 do not apply for that portion of the year when snowmelt contributes to runoff. The methods of chapter 11 apply for melt periods. Chapter 12 contains a discussion of snow or freezing in relation to land use and treatment.

<u>VARIATION OF RUNOFF DURING A STORM</u>. The variation of runoff during the progress of a storm is found by the method of the following example. This method is also used for design storms in chapter 21.

> Example 10.7.--Estimate the hourly pattern of runoff for a watershed having a CN of 80 and condition AMC-II before a storm of 20 hours' duration, using rainfall amounts recorded at a rain gage.
>
> 1. Tabulate the accumulated rainfalls at the accumulated times. Accumulated times are shown in column 1, rainfalls in column 2, of table 10.3
>
> 2. Estimate the accumulated runoff at each accumulated time. Use the CN and the rainfalls of column 2 to estimate the runoffs by means of figure 10.1. The runoffs are given in column 3.
>
> 3. Compute the increments of runoff. The increments are the differences given in column 4. Plotting these increments shows the pattern of runoff (the plotting is not given).

10.16

Table 10.3.--Incremental runoffs for a storm of long duration

Time	Accumulated rainfall	Accumulated runoff	ΔQ
	(inches)	(inches)	(inches)
1:00 a.m.	0	0	
			0
2:00	.15	0	
			0
3:00	.30	0	
			0
4:00	.62	0	
			.08
5:00	1.01	.08	
			.10
6:00	1.27	.18	
			.04
7:00	1.36	.22	
			0
8:00	1.36	.22	
			.01
9:00	1.38	.23	
			0
10:00	1.38	.23	
			.09
11:00	1.55	.32	
			.16
12:00 noon	1.87	.48	
			.24
1:00 p.m.	2.25	.72	
			.25
2:00	2.61	.97	
			.03
3:00	2.66	1.00	
			.01
4:00	2.68	1.01	
			.41
5:00	3.22	1.42	
			.76
6:00	4.17	2.18	
			.56
7:00	4.82	2.74	
			.09
8:00	4.93	2.83	
			.06
9:00	5.00	2.89	

RUNOFF FROM URBAN AREAS. Whether a conversion of farmlands to urban area causes larger amounts of storm runoff than before depends on the soil-cover complexes existing before and after the conversion; determination of the "before" and "after" CN is sufficient for a decision. A comparison of runoffs, using real or assumed rainfalls, gives a quantitative answer. Impervious surfaces of an urban area cause runoff when the remainder of the area does not so that the method of example 10.4 is best used. But these surfaces may not contribute runoff in direct ratio to their proportion in the area as the following case illustrates.

Figure 10.3 shows storm rainfall amounts plotted versus runoff amounts for Red Run, a fully urbanized watershed of 36.5 square miles' drainage area, near Royal Oak, Michigan. The data are from "Some Aspects of the Effect of Urban and Suburban Development upon Runoff" by S. W. Wiitla; open-file report, U.S. Geological Survey, Lansing, Michigan; August 1961. This watershed has 25 percent of its area in impervious surfaces and presumably runoff amounts should never be less than those shown by the 25-percent line on the figure. But the data show that the surfaces are only about half effective in generating runoff. The report does not state why this deficiency occurs but does state that "Flood peaks on the urban basin were found to be about three times the magnitude of those for natural basins of comparable size." Determination of the effects of urbanization may therefore require as much use of the methods in chapters 16 and 17 as of those in this chapter.

APPLICATIONS TO RIVER BASINS OR OTHER LARGE AREA. The runoff-estimation method is not restricted to use for small watersheds. It applies equally well to river basins or other large areas providing the geographical variations of storm rainfall and soil-cover complex are taken into account; this is best accomplished by working with hydrologic units (chap. 6) of the basin. After runoff is estimated for each unit the average runoff at any river location is found by the area-runoff weighting method of example 10.4.

INDEXES FOR MULTIPLE REGRESSION ANALYSES. The parameter CN is not a desirable index of watershed characteristics in a multiple regression analysis (chap. 18) because there is generally insufficient variation in the CN to provide a statistically significant result. The parameter S is the preferred index. It is used without change if it is an independent variable in a regression equation with the final form of:

$$Y = a + b X_1 + c X_2 \ldots\ldots \qquad (10.14)$$

where Y is the dependent variable; a, b, c, etc. are constants; and the subscripted X's are the independent variables. But if the final form is

$$Y = a X_1^b X_2^c \ldots\ldots \qquad (10.15)$$

it is necessary to use (S + 1) instead of S to avoid the possibility of division or multiplication by zero. The equation for lag used to develop figure 15-3 uses (S + 1) for this reason; otherwise the graph would give a lag of zero time for an impervious surface (because S is zero when CN is 100) no matter how large an area it might be.

ACCURACY. Major sources of error in the runoff-estimation method are the determinations of rainfall and CN. Chapter 4 provides graphs for estimating the errors in rainfall. There is no comparable means of estimating the errors in CN of ungaged watersheds; only comparisons of estimated and actual runoffs indicate how well estimates of CN are being made. But comparisons for gaged watersheds, though not directly applicable to ungaged watersheds, are useful as guides to judgment in estimating CN and as sources of methodology for reducing estimation errors.

A comparison of storm totals in example 10.6 shows that estimated amounts are fairly close to recorded amounts in 7 out of 12 years, — despite the use of a CN for average land use and treatment. On the whole, this is acceptable estimation in view of the limitation on the CN. But the results are better if the storm totals are used as data in a frequency analysis (chap. 18). Figure 10.4(a) shows data from columns 9 and 11, table 10.2, arranged in order of magnitude in their respective groups, and plotted versus their sample percent-chance values. Solid or broken lines connecting the points identify the groups. It is evident from the plotting that one frequency line serves equally well for either group. Thus the estimation errors, though large for some estimates, do not preclude the construction of an adequate frequency relationship. The reason is that the errors are random, being neither all plus or all minus nor all confined to a particular range of magnitudes.

The example of W-1 at Waco demonstrates that estimation errors should be kept random. One way of accomplishing this is to apply the CN for AMC-II to all storms in a series. A second example illustrates this.

Storm runoffs and rainfalls for Amicalola creek, Georgia, are given in columns 5 and 6 of figure 5.5. The CN is 65 for AMC-II, as determined in example 5.4. This CN and the rainfalls give the following estimates of runoff (actual runoffs are shown for comparison):

Year	Runoff (in.) Estimated	Runoff (in.) Actual	Year	Runoff (in.) Estimated	Runoff (in.) Actual
1940	1.64	0.81	1947	1.06	1.59
1941	2.15	1.40	1948	2.13	1.36
1942	1.81	1.74	1949	2.06	1.85
1943	1.22	1.65	1950	.89	1.15
1944	.91	1.16	1951	1.46	1.33
1945	.12	.36	1952	.93	2.01
1946	1.92	2.33			

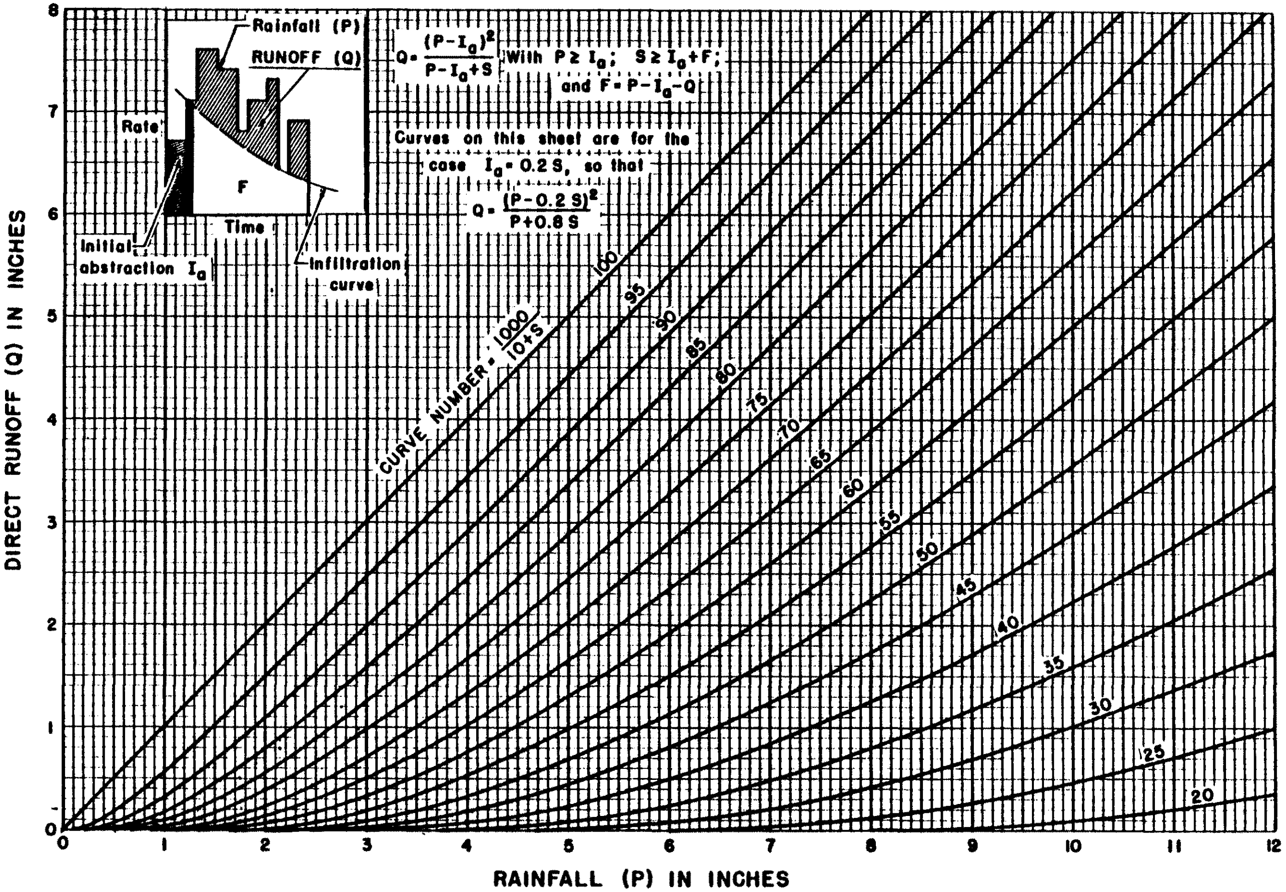
In a plotting of estimated versus actual runoff the scatter of points indicates a moderately low degree of correlation, but the scatter also indicates that the errors are randomly distributed, which means that a reasonably good result on probability paper can be expected. Figure 10.4(b) substantiates this: again a single frequency line will do for either group. The curvature of the plottings signifies only that 13 years of record on this watershed are insufficient for an adequate frequency line (chap. 18); discrepancies in the lower half of the plotting come from this insufficiency.

In practice the CN for an ungaged watershed cannot be estimated by means of runoff data, as the CN for Amicalola Creek was, but it can be estimated from watershed data at least as well as that for W-1 at Waco. It will take correct identification of soil-cover complexes, especially if there are few complexes in a watershed or they differ little from each other or one of them dominates the area. But if there are many complexes of about equal area and in a wide range of CN, it is likely that misjudgment of several will not adversely affect the estimate of the average CN. Using complexes that are properly identified and rainfall data that are adequate, runoff estimates are made accurately enough for practical purposes.

* * * *

HYDROLOGY: SOLUTION OF RUNOFF EQUATION $Q = \frac{(P-0.2S)^2}{P+0.8S}$

P = 0 to 12 inches
Q = 0 to 8 inches



REFERENCE

Mockus, Victor; Estimating direct runoff amounts from storm rainfall: Central Technical Unit, October 1955

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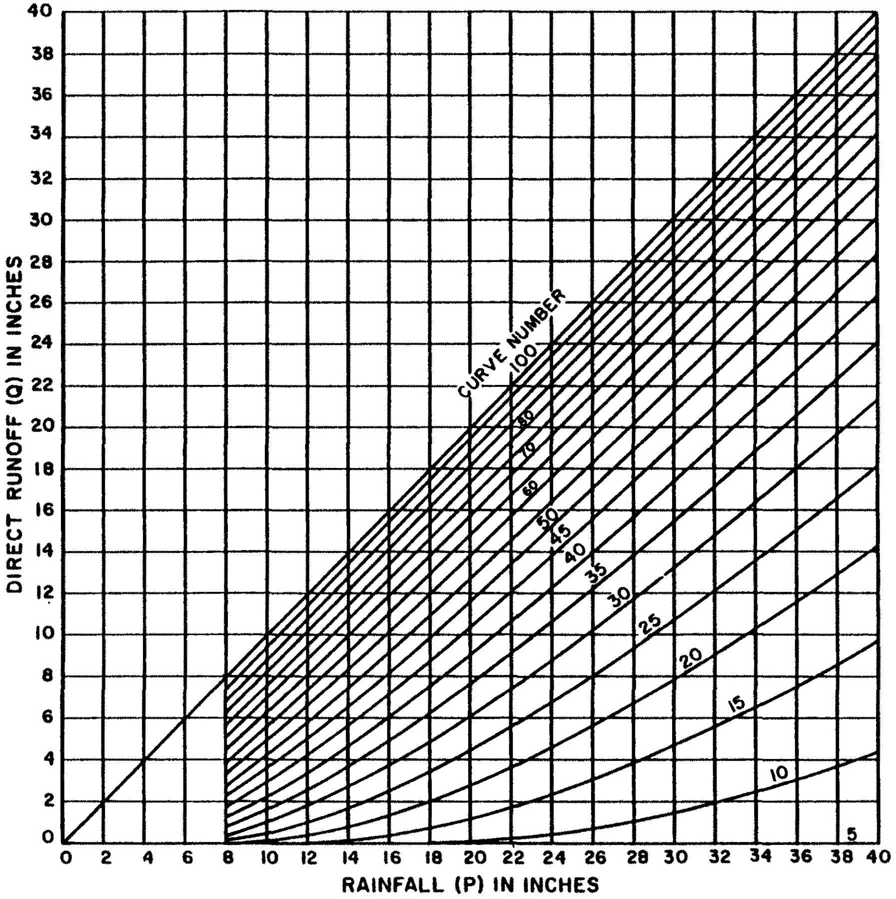
REVISED 10-1-64

Figure - 10.1 (1 of 2)

HYDROLOGY: SOLUTION OF RUNOFF EQUATION $Q=\frac{(P-0.2S)^2}{(P+0.8S)}$

P=8 to 40 inches
Q=0. to 40 inches



REFERENCE

Mockus, Victor; Estimating direct runoff amounts from storm rainfall:
Central Technical Unit, October 1955.

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DATE 6-27-56

Figure 10.1 (2 of 2)

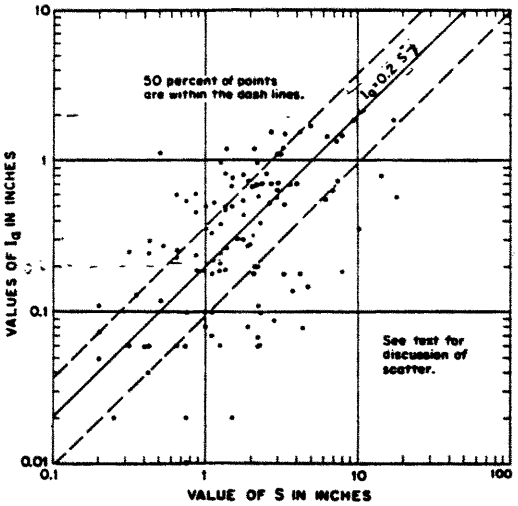

Figure 10.2.--Relationship of I_a and S. Plotted points are derived from experimental watershed data. < 10 acres

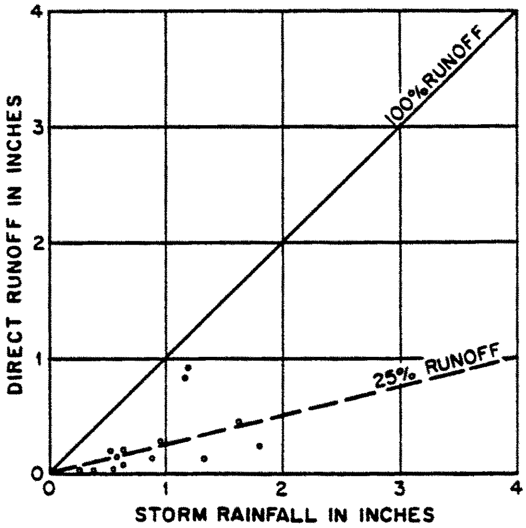

Figure 10.3.--Expected minimum runoff (dashed line) and actual runoff (plotted points) for an urbanized watershed.

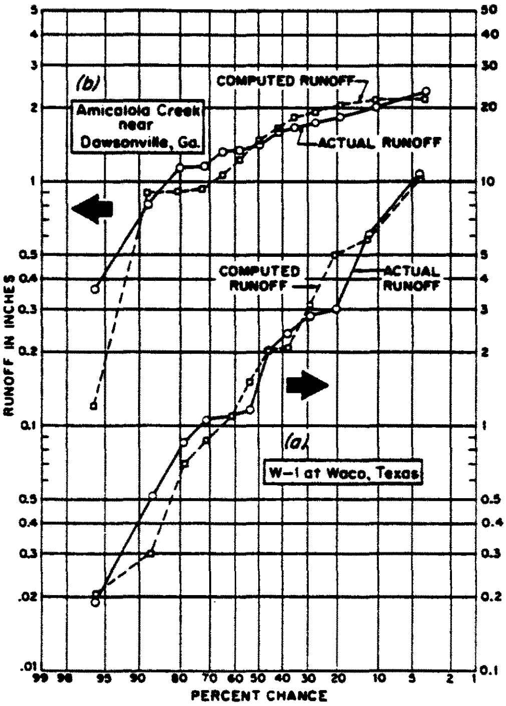

Figure 10.4.--Comparisons of computed with actual runoff on a frequency basis.

NATIONAL ENGINEERING HANDBOOK

SECTION 4

HYDROLOGY

CHAPTER 20. WATERSHED YIELD

by

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NATIONAL ENGINEERING HANDBOOK

SECTION 4

HYDROLOGY

CHAPTER 20. WATERSHED YIELD

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CHAPTER 20. WATERSHED YIELD

The water yield of a watershed, by years or seasons or months, is used in the planning and design of some watershed projects, especially those involving irrigation. The hydrologist supplies estimates of these yields, as required, or supplies methods adapted to specific local conditions by which others may make the estimates. This chapter contains general methods for estimating water yields on ungaged watersheds, with suggestions for such modifications as local conditions may justify.

Summary of Problems

Watershed yield is dependent on many physical factors, most of which usually cannot be quantitatively determined during ordinary field operations. Methods of estimating yield from ungaged watersheds may be classified as follows:

(a) Using only climatic factors. Examples are graphs or equations using precipitation and temperature, or only precipitation.

(b) Using only geographic location. Examples are maps having lines of equal runoff, or the practice of estimating yield by interpolation between gaged watersheds.

(c) Using watershed and climatic factors. Examples are (1) water accounting method, (2) regional analysis, and (3) use of figure 10-1 and daily rainfall.

The choice of method often rests on the type of runoff to be estimated, which may be classified as:

(a) Yield as a residual of precipitation after evapotranspiration. Examples are watersheds where base flow predominates. Water accounting methods are useful with this type.

(b) Yield as an excess of surface supply over watershed surface intake. Examples are watersheds where surface runoff predominates. Methods using rainfall and infiltration are needed, such as a method utilizing figure 10-1.

(c) Yield as a diverted flow. Examples are watersheds having irrigation projects that get their supply outside of the watershed and their return flows occur inside; or watersheds with surface runoff predominating, whose streams carry return or waste flows from irrigation projects or municipal and industrial plants that pump their supplies from deep wells or receive them from outside the watershed.

Instrumentation and watershed conditions may suggest or govern the choice of method. These conditions may vary with watershed size--that is, instrumentation or methods suitable for a small watershed having surface runoff may be unsuitable for a large watershed (into which the small one drains) that has a high percent of base flow. The conditions may similarly vary with geographic location, the presence of water tables, elevation, aspect, and latitude. Other factors that have influence can also be listed. However, evaluation of the listed and unlisted factors is still more properly a research activity. In practice, the primary factors that can ordinarily be considered for ungaged streams are: (1) streamflow on nearby watersheds, (2) precipitation, (3) hydrologic soil-cover complexes, (4) evapotranspiration, (5) temperature, (6) transmission losses, and (7) base flow accretions.

Determinations of water yield will usually have two types of error, (1) that due to insufficient recognition of the natural fluctuations of yield from year to year, and (2) that due to insufficient recognition of the most important influences on yield in a given watershed. The first type of error can be reduced by working with long records, the second by further studies of all possible major influences. However, increasing the time spent on yield estimates does not always assure greater accuracy in the estimates. Therefore, the methods given below should be considered as giving estimates so broad that the influence of specific factors have large margins of error.

Methods for Estimating Yields

A fuller account of such methods will be given in the National Engineering Handbook, Section 4, Hydrology.

Regional analysis

The general procedure is described in Section 2.8 of the Guide. For water yield, the method is used with annual, seasonal, or monthly flows of gaged watersheds. The slopes of the frequency lines will vary, being flattest for annual yields and becoming steeper (larger R on figure 18-3) as smaller divisions of a year are used.

This method is suitable for estimating the first two types of runoff mentioned above. It is readily adapted to watershed conditions, when data are available, since the watersheds can be selected for whatever factors can be used. However, the factors (and not the regional analysis method) may very strongly govern the accuracy of the results for watershed yield. For example, if one of the important factors on the problem watershed is aspect, and it is too vaguely represented by the gaged watersheds used in the analysis, then the accuracy of the results of the regional analysis will suffer. Transmission losses, for example, may be insufficiently detected by this method, and additional field studies may be required to determine those losses.

Water accounting

This method is suitable for estimating the first type of runoff mentioned above. As presented here, the method is A. L. Sharp's modification and enlargement of a method proposed by C. W. Thornthwaite in Trans. Amer. Geophys. Union, pp. 686-693, April 1944. The transmission loss is not estimated by this method and must be determined by other methods (Chapter 19).

The flow chart in Chapter 10 will assist in understanding the following steps.

1. Obtain soils and land treatment data for the watershed.

2. Obtain estimates of the water-holding capacity of each soil or soil group, expressed as inches depth of water between the amounts at field capacity and wilting point. The soil depth for which this capacity is needed is the depth of the intensive root zone, or 3 feet, whichever is lesser.

3. Compute the water-holding capacity of the watershed, weighting by areal extent of the soils or soil groups.

4. Obtain watershed cover data for the season or seasons for which yields are to be estimated. Data needed are (1) types of cover, and (2) areal extent.

5. Compute potential evapotranspiration (potential ET), or consumptive use by months for each major crop or land use. The Blaney-Criddle method of computing potential ET is generally used as given in "Determining Water Requirements in Irrigated Areas from Climatological and Irrigation Data," by Harry F. Blaney and Wayne D. Criddle, Soil Conservation Service, U.S.D.A., SCS-TP-96, Washington, D. C., revised 1952.

6. Compute monthly weighted potential ET for the watershed.

7. Obtain monthly rainfall data for the watershed, for a period of years estimated to be long enough to give adequate yield values (see Chapter 18 on length of record). The estimate of length should be made after previous use of figure 18-3 with other yield data in the vicinity.

8. Compute average rainfall over the watershed, by months, for each year of record.

9. Tabulate rainfall and ET data as shown on table 20-1, and compute runoff, by months, for each year of record.

    (a) In table 20-1, the computation starts with a month when available soil moisture is fully depleted. It could start equally well with a month when the soils are fully saturated.

    (b) If there is a break in the year, as in table 20-1, the first month after the break should have either of the moisture conditions given in (a) above.

    (c) When the precipitation is snowfall, convert to water equivalent (watershed average) before using in line 1 (see Chapter 11 for methods). Watersheds consistently having snowfall on one portion and rainfall on the other should be subdivided and the yields of the subdivisions computed separately, then combined for total watershed yield.

    (d) Work with subdivisions if the watershed soils differ in water-holding capacities by more than about 100% of the smallest capacity or by more than about 1 inch, whichever is greater.

    (e) Work with subdivisions if the watershed precipitation consistently varies widely in amount at different localities. This may be determined using average annual precipitation. The variation over a watershed (or subdivision) should not be greater than about 30% of the smallest value, or about 3 inches, whichever is greater.

10. After completion of the computations for the selected length of record, test the runoff estimates for adequacy of length of record, using the method of Chapter 18. The test should be made with values that will be used in planning or design. For example, if annual values are to be used, when they are tested; if monthly values are to be used, then all October values are tested separately, next all November, and so on. If the length of record is not adequate, additional years of precipitation are added and the yield computations extended.

Transmission losses are subtracted after Step 10. If these losses are proportionately large, it may be necessary to test the modified yields for adequacy of length of record.

Table 20-1. Sample computation by water accounting method.

Line	Item	October	November	December	January	February	March	April	May	Seasonal runoff
	All units in inches				1947 - 1948					
1	[1] Average rainfall	5.65	1.04	1.88	2.41	2.34	5.48	10.04	1.34	
2	[2] Initial soil moisture	0.00[3]	2.87	1.74	2.62	3.20	3.20	3.20	3.20	
3	Total available moisture	5.65	3.91	3.62	5.03	5.54	8.68	13.24	4.54	
4	[4] Potential evapotranspiration	2.78	2.17	1.00	0.90	1.00	2.69	3.18	3.89	
5	[5] Actual evapotranspiration	2.78	2.17	1.00	0.90	1.00	2.69	3.18	3.89	
6	Remaining available moisture	2.87	1.74	2.62	4.13	4.54	5.99	10.06	0.65	
7	[6] Final soil moisture	2.87	1.74	2.62	3.20	3.20	3.20	3.20	0.65	
8	Runoff	0.00	0.00	0.00	0.93	1.34	2.79	6.86	0.00	11.92
					1948 - 1949					
1	[1] Average rainfall	0.75	0.84	3.53	1.24	2.22	7.34	0.03	0.46	
2	[2] Initial soil moisture	0.00[3]	0.00	0.00	2.53	2.87	3.20	3.20	0.05	
3	Total available moisture	0.75	0.84	3.53	3.77	5.09	10.54	3.23	0.51	
4	[4] Potential evapotranspiration	2.78	2.17	1.00	0.90	1.00	2.69	3.18	3.89	
5	[5] Actual evapotranspiration	0.75	0.84	1.00	0.90	1.00	2.69	3.18	0.51	
6	Remaining available moisture	0.00	0.00	2.53	2.87	4.09	7.85	0.05	0.00	
7	[6] Final soil moisture	0.00	0.00	2.53	2.87	3.20	3.20	0.05	0.00	
8	Runoff	0.00	0.00	0.00	0.00	0.89	4.65	0.00	0.00	5.54

---

[1] Average over the watershed for each month of record.

[2] At start of month. Same as "Final soil moisture" for previous month.

[3] See text, Step 9, notes (a) and (b).

[4] Average annual values for the month.

[5] Total available moisture, or potential ET, whichever is smaller.

[6] At end of month. Same as "Initial soil moisture" for next month. This is never larger than the water-holding capacity determined in Step 3 of the text--in this case, 3.20 inches.

Note: Data are for a West Coast area of the United States, where the June-September precipitation is negligible.

Direct runoff method

Daily rainfall values and figure 10-1 can be used to estimate yields when these are of the second type described. Generally it may be assumed that direct runoff is being estimated. The procedure consists of using the method of Chapter 10 with all rainfalls. Snowmelt runoff is estimated separately using the methods of Chapter 11.

Table 9-1, which is used to determine curve numbers on figure 10-1, gives average values for the year. In using this table for yield estimates it is usually necessary to go into more detail about the cover, so that the weighted hydrologic soil-cover complex number varies not only for antecedent moisture conditions but also for the variation in cover throughout a given year and from year to year.

The direct runoff method is usually very tedious, since all daily precipitation in a long period of record must be accounted for, day by day, using soil-cover complex numbers that vary from month to month or even more often. The laboriousness of the procedure, however, does not guarantee close accuracy in the yield estimate.

Major errors with this method will generally be in the determinations of soil-cover complexes (which will vary through the year) and in antecedent moisture conditions (which will vary not only with precipitation and temperature, but also with soil-cover complexes). This method is more suitable for small watersheds than for large ones, since the large watersheds will have some base flow, which may be a significant proportion of total yield. Estimates by this method generally will have such a margin of error that the effects of individual factors should not be given much significance.

Climatic and geographic factors

In areas where there is no abrupt change in precipitation, hydrologic soil-cover complexes, or geology, yield may be readily estimated using maps with lines of equal runoff. Generalized national maps, such as Plate 1 of U.S.G.S. Circular 52, should be used with great caution. The text of the Circular, page 9, states that "Figure 2 and plate 1 should not be used to estimate runoff from ungaged areas." More localized maps, however, such as those prepared by John H. Dorroh, Jr. for the Southwestern States, will be very useful, especially where the advice of the map's originator may be sought.

K. M. Kent has used a form of the "direct runoff method" described above to prepare typical yield frequency lines for selected soil-cover complex numbers, which are used with a state map giving precipitation indices. Given the soil-cover complex number, the yield for a given frequency is quickly estimated for any locality in that state.

Graphs and equations of precipitation and temperature, or precipitation alone, have been used in the past much more than they are today. Figure 2 of U.S.G.S. Circular 52 is an example (but see remark about Plate 1). Such graphs and equations should be used with great caution since so many factors are ignored.

Discussion

Since so many factors enter into the estimating of yields, and since both the relative importance and quantitative influences of some factors are nearly always unknown, estimates of yield should be conservative, according to the use they will have. The planners and designers who will use the yield estimates will be best able to state the direction and degree of conservativeness required. The hydrologist can obtain the conservativeness by the use of the methods given above, and those in Chapter 18, Frequency Methods.

APPENDIX B

COMMON CONVERSIONS AND EQUIVALENTS

COMMON CONVERSIONS AND EQUIVALENTS

Length

1 mm = 0.1 cm
= 0.001 m
= 0.0394 in

1 cm = 0.01 m
= 0.394 in
= 0.0328 ft

1 m = 100 cm
= 3.281 ft
= 39.37 in

1 km = 100,000 cm
= 1,000 m
= 3,281 ft
= 0.6214 mi

1 in = 25.4 mm
= 2.54 cm

1 ft = 12 in
= 30.48 cm
= 0.3048 m

1 yd = 36 in
= 91.44 cm
= 0.9144 m

1 mi = 5,280 ft
= 1,609 m
= 1.609 km

Area

1 mm^2 = 0.01 cm^2
= 0.00155 in^2

1 cm^2 = 100 mm^2
= 0.1550 in^2

1 m^2 = 10,000 cm^2
= 1,550 in^2
= 10.76 ft^2

1 ha = 10,000 m^2
= 2.471 ac
= 0.00386 mi^2

1 km^2 = 247.1 ac
= 0.3861 mi^2

1 in^2 = 6.452 cm^2

1 ft^2 = 144 in^2
= 929.0 cm^2

1 yd^2 = 9 ft^2
= 8,361 cm^2

1 ac = 43,560 ft^2
= 4,840 yd^2
= 4,047 m^2
= 0.4047 m^2

1 mi^2 = 27,878,400 ft^2
= 640 ac
= 259 ha
= 2.590 km^2

Volume

1 cm^3 = 0.0610 in^3

1 m^3 = 35.31 ft^3
= 264.2 U.S. gal

1 ml = 0.0610 in^3

1 liter = 61.02 in^3
= 0.2642 U.S. gal

1 in^3 = 16.39 cm^3

1 ft^3 = 1,728 in^3
= 7.480 U.S. gal
= 28,317 cm^3
= 28.32 liters

1 ac-ft = 325,851 U.S. gal
= 43,560 ft^3

Velocity

1 m/sec = 3.6 km/hr
= 2.237 mi/hr

1 km/hr = 0.2278 m/sec
= 0.9133 ft/sec

1 ft/sec = 0.6818 mi/hr
= 1.097 km/hr

1 mi/hr = 1.4767 ft/sec
= 0.4470 m/sec

Discharge

1 m^3/sec = 35.32 cfs

1 cfs = 0.0283 m^3/sec
= 28.32 liters/sec
= 2447 m^3/day

1 cfs for 1 day = 1.98 ac-ft

1 in/hr runoff from 1 ac = 1 cfs

Temperature

°C = 5/9(°F - 32)

°F = 9/5(°C) + 32

°K = °C + 273