United States
Department of
Agriculture

**Natural
Resources
Conservation
Service**

National Range and Pasture Handbook

Chapter 7 Rangeland and Pastureland Hydrology and Erosion

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Chapter 7 will eventually consist of three sections. Section 1 has information about the hydrologic cycle and the effects of vegetation, grazing, and management on hydrology and erosion. Section 2 will have information about hydrology and erosion models and other decision support tools that relate to rangeland and pastureland hydrology and watershed management. Section 3 will have information about how to apply and interpret models and other decision support tools to rangeland and pastureland. Recently revised Part 630 of the USDA-NRCS National Engineering Handbook, Chapter 2, Procedures, has information about work plans, hydrologic computations, and the hydrologic evaluation process.

At this time, hydrology and erosion models that can be used as decision support tools for rangeland and pastureland planning and management are either in a state of technical development or development of user interfaces for managers, and are undergoing validation to evaluate actual measured infiltration, runoff, and erosion with model estimated values.

Chapter 7 Rangeland and Pastureland Hydrology and Erosion

Contents:

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Chapter 7 Rangeland and Pastureland Hydrology and Erosion

Section 1 Hydrologic Cycle and Effects of Vegetation, Grazing, and Management on Hydrology and Erosion

Chapter 7 — Rangeland and Pastureland Hydrology and Erosion

Section 1 — Hydrologic Cycle and Effects of Vegetation, Grazing, and Management on Hydrology and Erosion

Contents:

Figures

Section 1 Hydrologic Cycle and Effects of Vegetation, Grazing, and Management on Hydrology and Erosion

600.0700 Introduction

The increasing importance of water to society has added a new dimension to the value of rangeland and pastureland and has reinforced and expanded the concept of multiple use. Society is challenging traditional uses as destructive and is demanding improved water quality, reduced erosion, new management alternatives, restoration of degraded lands, and more accurate soil erosion and water supply prediction techniques. The result is a critical need to understand rangeland and pastureland watersheds with respect to soil erosion and water quality, water yield, evapotranspiration, and the effects of global climate change.

The Soil and Water Resources Conservation Act of 1977 identified reduction of erosion and improvement of water quality and quantity as two of our Nation's highest resource priorities. Since the need for clean water is critical and rangelands comprise vast watershed areas in the United States (899.08 million acres in the 17 Western States of which 401.6 million acres are non-Federal), policies and activities must be formulated and implemented to arrest present resource degradation. With increasing concern over quantity and quality of surface and ground water supplies, judicious management of this natural resource is essential to the future well being of the Nation.

600.0701 Watershed management

Watershed management on rangeland and pastureland is concerned with the protection and conservation of water resources, but also considers that vegetation resources are managed for the production of goods and services. Rangeland and pastureland hydrology, which is founded on basic biological and physical principles, is a specialized branch of science in which land use effects on infiltration, runoff, sedimentation, and nutrient cycling (hydrologic assessments) in natural and reconstructed ecosystems are studied.

Why become astute in understanding the fundamentals of hydrology and how they are related to planning and management of range and pasturelands? Understanding hydrologic principles and processes and how these processes are affected by vegetation, vegetation management practices, and structural practices (engineering activities), allows land managers to integrate their thinking about how all the various activities in a given area affect the hydrologic cycle. The outcome of management decisions on upland environments must be understood because they directly impact the health and welfare of people and other resources downstream.

Conservation strategies on rangeland and pastureland watersheds can be classified as preventive or restorative. Generally, most situations are a combination of the two. Preventive strategies and sound management plans are equally as important as the more dramatic and sometimes more politically visible restorative actions. Preventing losses of soil, desirable vegetation, wildlife habitat, and forage production are much less costly than achieving the same benefit from a degraded situation by restoration. Depending on the severity of resource and watershed degradation (which includes water, soil, plant, animal, air, and human resources), restoration may not be feasible from an ecological and/or economic perspective. The results of rangeland and pastureland watershed degradation can be serious and irreversible. For each watershed and site within the watershed, a critical degree of deterioration from surface erosion exists. Beyond this critical point, erosion continues at an accelerated rate that cannot be overcome by the natural vegetation and soil stabilizing forces until a new equilibrium is achieved. Areas that have deteriorated beyond this critical point continue to erode even when the disturbance is removed and/or diminished.

Common problems and issues regarding rangeland and pastureland watersheds can be categorized as: ecological, management oriented, water quality and quantity, erosion, and economic. Table 7–1 summarizes the most common problems and issues on rangeland and pastureland watersheds.

Table 7–1 Common problems and issues on rangeland and pastureland watersheds

Category	Situation
Ecological	Understanding interrelationships: plant/soil complexes, ecology, environmental, hydrology
	Climatic shifts, vegetation response, and the hydrologic cycle
Management oriented	Trampling impacts and effect of grazing treatments on watersheds
	Water quality
	Range improvement practices and their effect on hydrology
	Riparian management and hydrologic implications
Water quantity and quality, and erosion	Enhancement of surface water, ground water, and aquifer recharge in response to vegetation manipulation
	Deficient water supplies
	Flooding
	Polluted surface water, reduced aquatic, fish, and wildlife habitat,
	Erosion and sedimentation from rangeland and pastureland watersheds
	Sludge and animal waste applications on rangeland and pastureland
Economic	Economics of watershed restoration

(a) Complexity of factors in rangeland and pastureland watersheds

The most significant factor facing resource managers and conservation planners is that no uniform set of management guidelines fits all rangeland community types, pastures, or other units of grazing land. Plant communities and associated environmental factors are interrelated and multivariate in nature (table 7–2). Interactions among plants, soils, environment, and management are complex.

Resource managers are challenged with synthesizing an overwhelming amount of scientific information relative to ecology, soils, hydrology, plant science, and grazing management. Simulation models and decision support tools offer help in understanding the correlation among many of the factors in a landscape. In conservation planning, many of the factors in table 7–2 must be integrated and considered with respect to the soil, water, air, plants, and animal components. With respect to hydrology and erosion, the land manager must consider how management alternatives and decisions will affect the hydrologic cycle.

Table 7–2 Interacting factors that affect the hydrologic cycle in rangeland and pastureland watersheds

Soils	Plants	Environmental	Management
Soil morphology	Types of plants	Climate	Grazing intensity
Texture	Rooting morphology	Types of storms	Timing of grazing
Bulk density	Plant growth form (bunch, sod)	Precipitation type	Continuous vs. rotational systems
Compaction	Plant life form (grass, shrub, forb, tree)	Duration of storm	Pitting
Organic matter	Plant biomass, cover, density	Intensity of storm	Chiseling
Aggregate stability	Cryptogams (mosses, lichens, algal crusts)	Topography	Herbicides
Nutrient levels	Plant canopy layers	Geology	Seeding
Soil structure	Plant architecture	Aspect	Brush management
Infiltration rates	Successional dynamics	Slope	Fire
Percolation rates	Native vs. introduced plants	Microtopography	Prescribed burning
Saturated hydraulic conductivity	Plant competition		Past management history
Runoff characteristics	Physiological characteristic of plant species		Fencing
Rills and gullies	Physiological response to grazing		Hoof impact
Porosity	Biodiversity		Class of livestock
Erosion dynamics	Phenological stages		Type of livestock
Salinity			Disturbance
Alkalinity			Stockwater location
Biotic components			Past disturbance from farm implements
Parent material			Recreation
Pedogenic processes			Kinds and types of wildlife
Soil chemistry			

(b) Hydrologic cycle and its components

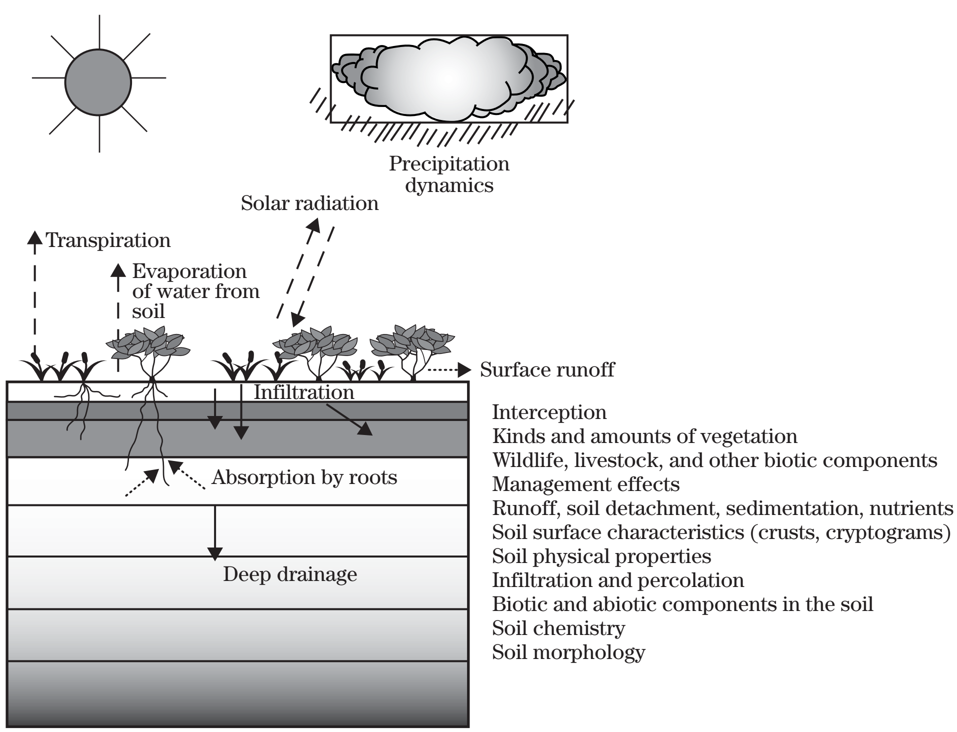
The hydrologic cycle is a continuous process by which water is transported from the oceans, to the atmosphere, to the land, through the environment, and back to the sea (fig. 7–1). Many subcycles exist, such as the evaporation of inland water, evaporation of water from the soil, transpiration of water from or by plants, and the eventual return of this water to the atmosphere. The sun provides the necessary energy required for evaporation that drives the global water transport system.

The complete hydrologic cycle is global in nature. On a worldwide basis, the amount of water is relatively constant. The problem of water supply lies with the uneven spatial and temporal distribution of this enormous quantity of water. Oceans cover 71 percent of the Earth's surface and contain 93 to 97 percent of the Earth's water. The fresh water supply available to people represents only 3 percent of the total global water supply, and 75 percent of it is frozen in glaciers and ice sheets. Only about 1 percent of the world's surface water is fresh water. Ground water accounts for about 25 percent of the fresh water supply. On a daily average basis, about 40 trillion gallons of water vapor exists in the atmosphere over the conterminous United States. Of this amount, about 4,200 billion gallons per day (bg/d) fall as precipitation. Approximately two-thirds of this amount returns to the atmosphere via evaporation and transpiration. The remainder, 1,380 bg/d of surface water is renewed daily to streams, lakes, oceans, or seeps underground.

During conservation planning, management alternatives and their effect on the hydrologic cycle should be considered and addressed. For example, a few questions with answers are given to demonstrate the process during planning.

Q1. What might be expected in terms of runoff if the plant community shifts from weedy annual species to more desirable perennial grasses?

Figure 7–1 The hydrologic cycle with factors that affect hydrologic processes



A. This depends on the species of weeds and perennial grasses (see section 600.0701(j), Vegetation effects on hydrologic processes).

What is the effect of juniper invasion (10, 25, 50 years) on understory vegetation, runoff and interill erosion?

Typically, over time, juniper increase in numbers and size, interrill erosion increases and gullies can develop because the understory vegetation decreases because of juniper competition for water, nutrients, space, and light.

What is the effect of heavy versus moderate stocking during a season where soils are typically wet?

This depends on the frequency and duration of wet soil conditions. Heavy stocking is detrimental to soil surface physical properties and consequently hydrologic condition, especially on heavier textured soils when soil conditions are wet. Research has shown that moderate season-long stocking generally maintains good hydrologic health. Other grazing systems involving rotations (of varying time and frequency of grazing) may also maintain good hydrologic condition and benefit key grazing species. Unfortunately, no set rule covers all rangeland plant communities and hydrologic response to grazing. Section 600.0702 has additional information on the effect of trampling and grazing on hydrology and erosion.

What are the benefits to a producer when forage grasses are managed to increase infiltration capacity twofold?

The response is significantly increased forage production, less runoff, and less soil loss.

What are the hydrologic effects of brush control in a particular rangeland plant community?

The influence of brush control on hydrology is dependent on the kind of brush, degree of brush in the stand, herbaceous cover, ecological site characteristics (soil, slope, vegetation composition), climate, weather before and after the treatment, kind of brush control treatment, and post-treatment practices. For example, the hydrologic effect of brush control in sagebrush, pinyon-juniper, mesquite, and chaparral are unique and cannot be generalized. For more specific information, refer to Hibbert 1979 and 1983, Branson et al. 1981, Blackburn 1983, Bedunah and Sosebee 1985, and Griffin and McCarl 1989.

What are the hydrologic effects of converting a sagebrush community to a grass dominated stand?

In one study where sagebrush cover was replaced with grass (via disk plowing the sagebrush), usable forage increased fourfold. Runoff from summer rainstorms was decreased by about 75 percent after the conversion. Another study compared chemical control of sagebrush with disk plowing. Infiltration was highest on the chemical treated sites, next highest in no treatment, and lowest on the disk plow sites for 3 years after the treatment. Sediment yield was also greatest on the disk plow sites after 3 years compared to the no treatment and chemically treated sagebrush sites. Sagebrush and grass use most of the onsite available water equally; therefore, little increase of water for offsite use can be expected following sagebrush control.

Do different shrubs and grasses affect infiltration and runoff differently?

Yes, certain grasses are associated with low infiltration and higher runoff. This phenomenon is described in section 600.0701(h and i). In an infiltration study in the Edward's Plateau, steady state infiltration rates among three vegetation types were as follows: sodgrass (1.8 in/hr); bunchgrass (6.3 in/hr); and oat mottes (7.8 in/hr). In question 6, it was shown that sagebrush converted to grass resulted in higher infiltration rates and less runoff. Making generalized statements about hydrologic response to vegetation is difficult. Specific knowledge about the site is recommended.

(c) Inputs to the watershed

(1) Precipitation

Precipitation, the source of all freshwater, is the single most important factor that controls the availability and variability of surface water resources. The average annual precipitation rate for the conterminous United States is about 30 inches per year. Some desert ecosystems receive less than 1 in per year, while the Olympic Mountains in Washington receive about 150 inches per year.

Departures from the mean may be extreme in any given year. When the overall supply of fresh surface water is considered without regard to distribution or quality, the resource far exceeds use. However, precipitation and subsequent streamflow are not constant, and there is no assurance that adequate supplies of surface water or quality will be available when it is needed.

Precipitation is the primary input of the hydrologic cycle. The three major categories of precipitation are convective, orographic, and cyclonic.

occurs in the form of light showers and heavy cloudbursts or thunderstorms of extremely high intensity. Precipitation intensity often varies throughout the storm. Most convective storms are random and last less than an hour. They generally contribute little to overall moisture storage in the soil.

results when moist air is lifted over mountains or other natural barriers. Important factors in the orographic process include elevation, slope, aspect or orientation of slope, and distance from the moisture source.

may be classified as frontal and nonfrontal and is related to the movement of air masses from high pressure to low pressure regions.

Water originating from other sources may affect a site. Deep-rooted shrubs, trees, and phreatophytes (riparian vegetation) may use shallow ground water or baseflow reserves.

Raindrop sizes vary with storm intensity, which affects soil surface stability and infiltrability. Average drop sizes for various storm intensities are:

- 1.25 mm diameter at 0.05 in/hr
- 1.80 mm diameter at 0.5 in/hr
- 2.80 mm diameter at 4.0 in/hr

Generally, a falling raindrop attains a terminal shape of a hemisphere or is oblate. An airborne raindrop over 1.5 mm in diameter travels at terminal velocity of 24.3 to 26 feet per second. Raindrops this size disrupt the soil surface on impact; whereas, drops smaller than 1 mm in diameter are less disruptive.

(d) Hydrologic factors in the watershed

(1) Interception

Vegetation intercepts raindrops, dissipating the kinetic energy of droplets. Interception is variable and is affected by plant height, leaf area, plant canopy cover, plant architecture, rainfall frequency, rainfall duration, amount of precipitation, type of precipitation, and time of precipitation. During small storms, water intercepted and evaporated without reaching the soil surface may be substantial, especially in shrub, tall grass, mixed grass, and bunchgrass communities. Some intercepted water runs down the stem or trunk of the plant and reaches the soil. This water is redistributed in a concentrated way and can either infiltrate depending on the volume of water and soil surface conditions, or it can run off. Interception loss during heavy storms is often a small proportion of the storm's total volume. Droplets, intercepted, and later falling from the canopy of shrubs and trees can form an erosive drip line under the plant.

On an annual basis, tree interception is greater than grass interception; however, at maximum growth some grasses have as much leaf area per unit area of ground as some trees. During the growing season, alfalfa can intercept as much rainfall as a forest. Water storage by grasses, shrubs, and trees is proportional to average heights and ground cover.

(2) Surface detention or storage capacity

Surface water excess tends to accumulate in depressions, forming puddles. The total volume per unit area is the surface storage capacity. Surface water storage or detention is a function of soil surface microtopography, slope, and soil physical properties, such as texture, bulk density, porosity, and soil structure. Vegetation structure and lifeform characteristics as well as surface litter affect soil surface microtopography. As slope increases, initial runoff usually occurs sooner and at an increased rate because of a decrease in the size of detention storage sites. Ponded water on the soil surface is lost through evaporation, or it infiltrates into the soil.

(e) Infiltration and analogous concepts

(1) Infiltration

Infiltration is the process by which water enters the soil surface and is affected by the combined forces of capillarity and gravity. Under dry conditions a higher initial infiltration rate is caused by the physical attraction of soil particles to water, which is called the matric potential gradient or matric suction gradient, but starts to decrease over time until a relatively constant rate is achieved (a curvilinear relationship). One or more of the following can cause decreased infiltration over time:

- gradual decreases in the matric suction gradient
- deterioration of soil structure
- the breakdown of soil aggregate stability
- consequential partial sealing of the profile by detachment and migration of pore-blocking particles
- a restricting layer in the soil profile

Typical "final" saturated steady state infiltration rates for sandy, loam, and clay soils that are void of vegetation are:

- sandy and silty soils—0.4 to 0.78 in/hr
- loams—0.2 to 0.4 in/hr
- clayey soils—0.04 to 0.2 in/hr

Note: These values give the order of magnitude. In actual situations infiltration rates can be considerable higher, particularly in the initial stages of the process where soils are well aggregated and surface mineral crusting is minimal.

Table 7–3 gives some approximate values for water storage and intake rates under irrigation.

(2) Infiltration capacity

When rainfall rates exceed infiltration capacity, surface runoff and/or ponding on the soil surface occurs. The infiltration capacity of the soil is dependent on soil texture, porosity of the soil, soil structure, soil surface conditions, the nature of the soil colloids, organic matter content, soil depth or the presence of impervious layers, the presence of macropores, soil water content, soil frost, and temperature of the soil.

(3) Infiltration rate

Infiltration rate is the volume flux of water moving into the soil profile per unit area of surface area.

(4) Infiltration curve

Figure 7–2 is an example of infiltration rates plotted against time (infiltration curves).

(5) Infiltrability

Infiltrability denotes the infiltration flux resulting when water at atmospheric pressure is freely available at the soil surface. Soil infiltrability depends upon the initial wetness, suction, texture, structure, soil layering and its uniformity, aggregate stability, and bulk density. Infiltrability may be high initially in some soils that have a high clay content and macropores and cracks in the soil surface; however, as these cracks swell, infiltrability decreases. Infiltrability may be impeded over time because clay particles expand, air pockets become entrapped, and the bulk compression of soil air is prevented from escaping as it is gradually displaced by water.

(6) Hydraulic conductivity

Hydraulic conductivity is the ratio of the volume of water passing through a cross-sectional unit area per unit time (flux) to the hydraulic gradient (the driving force acting on the liquid). Hydraulic conductivity

Table 7–3 Approximate relationships among soil texture, water storage, and water intake rates under irrigation conditions

Soil texture	Water stored (in/ft of soil)	Max rate of irrigation per hour (bare soil conditions)
Sand	0.5 – 0.7	0.75
Fine sand	0.7 – 0.9	0.60
Loamy sand	0.7 – 1.1	0.50
Loamy fine sand	0.8 – 1.2	0.45
Sandy loam	0.8 – 1.4	0.40
Loam	1.0 – 1.8	0.35
Silt loam	1.2 – 1.8	0.30
Clay loam	1.3 – 2.1	0.25
Silty clay	1.4 – 2.5	0.20
Clay	1.4 – 2.4	0.15

differs between unsaturated and saturated soil conditions. A saturated soil has a positive pressure potential. However, an unsaturated soil has a subatmospheric pressure, or suction, that is analogous to a negative pressure potential. The higher the saturated hydraulic conductivity of the soil, the higher its infiltrability.

(7) Percolation

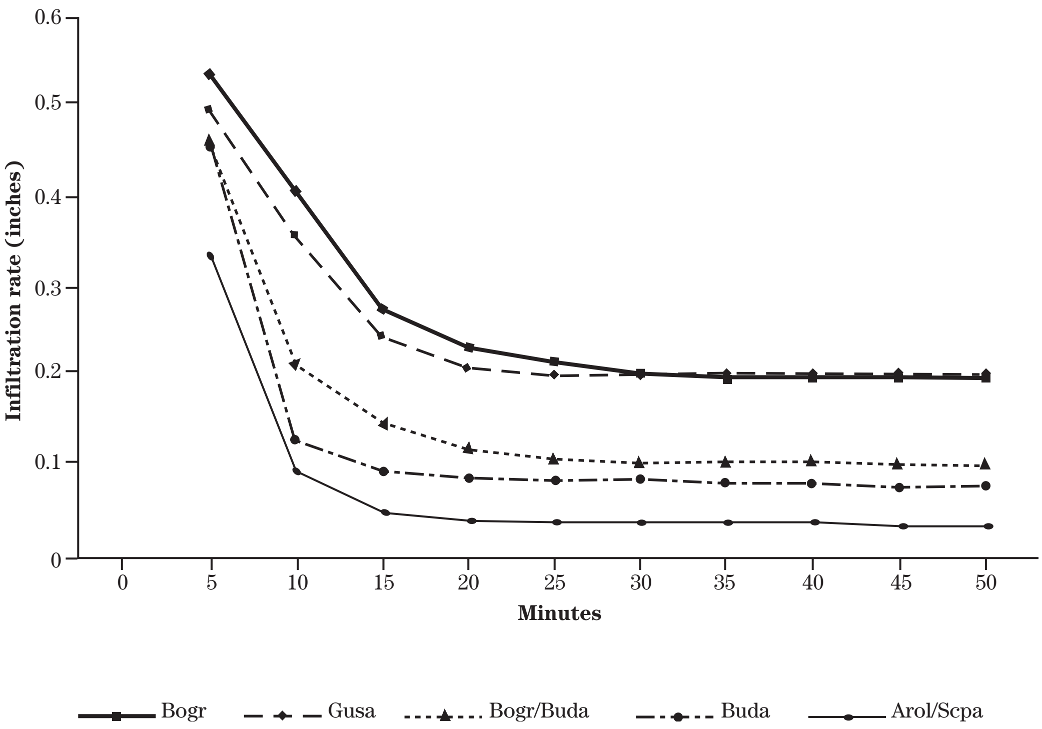
Infiltration is only as rapid as the rate at which water moves through the soil macropores and flows downward by the effect of gravity. This downward movement of water through the soil profile is percolation. Percolation of soil water past plant roots is deep drainage. The amount of water lost to deep drainage depends upon the infiltrability of the soil, the evapo-transpirational demand, and the substrate and geological conditions.

(8) Moisture profile

A moisture profile, comprised of the saturation and transition zone, transmission zone, wetting zone, and wetting front (fig. 7–3), is produced during infiltration. The saturation and transition zones are fully saturated. The transmission zone is the ever-lengthening unsaturated zone of uniform water content. The wetting zone is the area where the transmission zone joins the wetting front. The wetting front is the line of delineation where the soil changes from wet to dry.

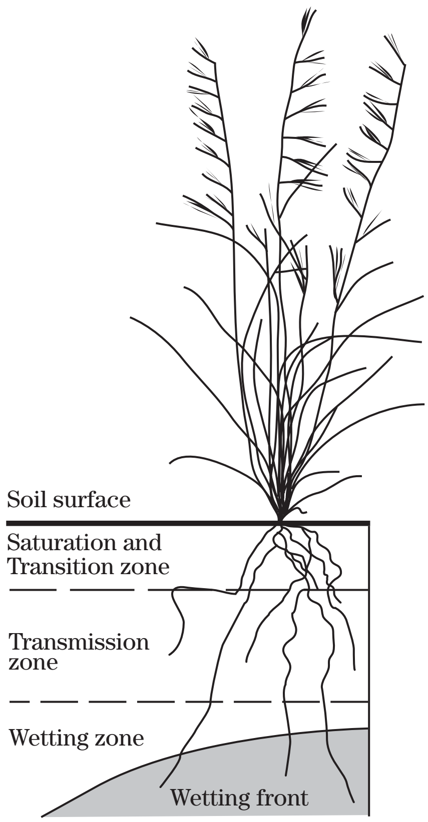
Depth to the wetting front is an important factor for sustained plant growth. Grasses that have laterally extending fibrous roots as well as a deep taproot are adapted to utilize precipitation from low precipitation events as well as subsurface water.

Figure 7–2 Average infiltration rates (50-minute simulated rainfall, 6.0 in/hr rate) on 5 plant community types associated with a loamy range site, Berda loam soil in west Texas [1/]



1/ Arol = perennial threeawn (*Aristida oligantha*)
Scpa = Texas tumblegrass (*Schedonnardus paniculatus*)
Buda = buffalograss (*Buchloe dactyloides*)
Bogr = blue grama (*Bouteloua gracilis*)
Gusa = perennial broomweed (*Gutierrezia sarothrae*)

Figure 7–3 Moisture profile during infiltration



(f) Watershed hydrograph

Various processes and pathways determine how excess water becomes streamflow. Hydrograph analysis is the most widely used method of analyzing surface runoff. A hydrograph is a continuous graph showing the properties of streamflow with respect to time. It has four component elements: channel precipitation, direct surface runoff, subsurface flow, and baseflow (fig. 7–4).

(1) Direct surface runoff

Surface runoff or overland flow occurs when rainfall rate exceeds infiltration capacity of the soil, the soil is impervious, or the soil is saturated. The rate and distribution of runoff from a watershed are determined by a combination of physiographic, land use, and climatic factors. These factors include:

- Form of precipitation (rain, snow, hail)
- Type of precipitation (convective, orographic, cyclonic)
- Seasonal distribution of precipitation
- Intensity, duration, and distribution of precipitation
- Plant community types and the character of vegetative cover
- Kind of vegetation as well as quantity of vegetation
- Watershed topography, geology, and soil types
- Evapotranspiration
- Antecedent soil moisture
- Degree of compaction; i.e., land use practices

Runoff is closely linked to nutrient cycling, erosion, and contaminant transport. It can be a sensitive indicator of ecosystem change.

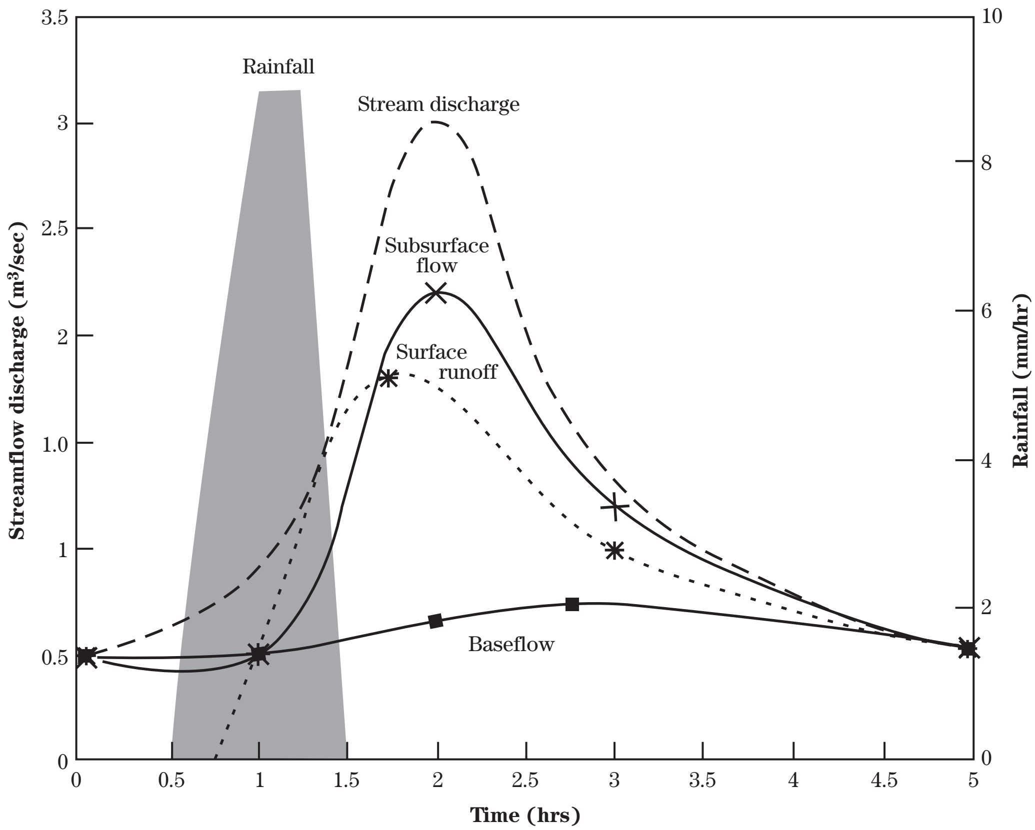
(2) Baseflow

Baseflow is the portion of precipitation that percolates into the soil profile and is released slowly and sustains streamflow between periods of rainfall and snowmelt. It does not respond quickly to rainfall.

(3) Subsurface flow

Subsurface flow is infiltrated water that is impeded by a restrictive layer in the soil (e.g., hardpan, caliche layer, bedrock). Subsurface water is diverted laterally and flows through the soil until it arrives at a stream channel over a short period where it is considered part of the storm hydrograph.

Figure 7–4 Example hydrograph of a watershed showing the relationship of water flow pathways



(g) Evapotranspiration

Evapotranspiration (ET) includes evaporation from soil, water, and plant surfaces and transpiration from plants. About 99 percent of water taken up by the plant is lost through transpiration. It is the major component of water loss in semiarid and arid rangelands. Table 7–4 gives ET rates for various vegetation types. Evapotranspiration affects water yield and largely determines what proportion of precipitation input to a watershed becomes streamflow. Changes in vegetation composition that reduce ET result in an increase in streamflow and/or groundwater recharge, whereas increases in ET have the opposite effect.

Vegetation cover, by shading and reduction of wind velocity, can reduce soil evaporation rates. The greater the vegetation cover, the greater the interception and transpiration loss, which generally offsets the benefits of reduced evaporation.

(h) Hydrologic water budgets

Water budgets can be developed for rangeland and pastureland to account for hydrologic components. The hydrologic budget can be written as an equation:

$$WS = P - R - G - ET$$

where:
WS = water storage
P = total precipitation
R = surface runoff
G = deep percolation and/or groundwater flow
ET = evapotranspiration

Water is generally regarded as the limiting factor in rangeland forage production. A hydrologic budget can effectively show landowners the benefits of various conservation practices. Water storage relates to what could be available for plant growth at any time scale (daily, monthly, yearly). For local situations, reliable

Table 7–4 Average evapotranspiration rates for various vegetation types

Vegetation	ET rate
Pinyon-juniper	63–97% of annual precipitation
Honey mesquite (Texas)	95% of annual precipitation
Chaparral, California, 23 in/yr ppt	80–83% of annual precipitation
Rio Grande Plains (S. Texas) honey mesquite shrub clusters (shrub cluster)	0.09 in/d
Low sagebrush community, springtime	0.05 to 0.12 in/d under differing soil moisture and sunlight conditions (6-day average)
Wyoming big sagebrush/bluebunch wheatgrass, spring, Idaho, 12 in/yr ppt	0.07 in/d
Wyoming big sagebrush/bluebunch wheatgrass, summer, Idaho, 12 in/yr ppt	0.04 in/d
Low sagebrush/Idaho fescue, spring, Idaho, 13 in/yr ppt	0.09 in/d
Low sagebrush/Idaho fescue, summer, Idaho, 13 in/yr ppt	0.06 in/d
Mountain big sagebrush/grass, spring, Idaho, 19 in/yr ppt	0.10 in/d
Mountain big sagebrush/grass, summer, Idaho, 19 in/yr ppt	0.02 in/d
Mountain big sagebrush/grass, summer, Idaho, 30 in/yr ppt	0.12 in/d
Mountain big sagebrush/grass, fall, Idaho, 30 in/yr ppt	0.03 in/d
Forest, summer	0.12 to 0.2 in/d
Open desert vegetation	0.001 to 0.02 in/d

estimates can be made to determine available water storage. Precipitation is measured by rain or snow gauges. Surface runoff can be measured onsite. Deep percolation generally is not a significant factor in the equation when calculating a water budget for an individual storm or for short-term events (the exception being in sandy areas). For short-term events, assign a zero value to G.

Various estimates are available for ET (table 7–4). The luxury of having exact measurements is generally not available. Annual precipitation can be easily obtained, but estimates of surface runoff and ET need to be made. Observations during storms can be made with small rain gauges. Measure the total storm precipitation in one gauge and precipitation until runoff in another gauge.

Table 7–5 is an example of a water budget for various stands of grass in Major Land Resource Area (MLRA 102 A).

Table 7–5 Water budget examples for MLRA 102 A, Nebraska and Kansas Loess-Drift Hills; loamy site 25-inch average annual precipitation (data represent species composition for and water budgets for stands I, II, and III)

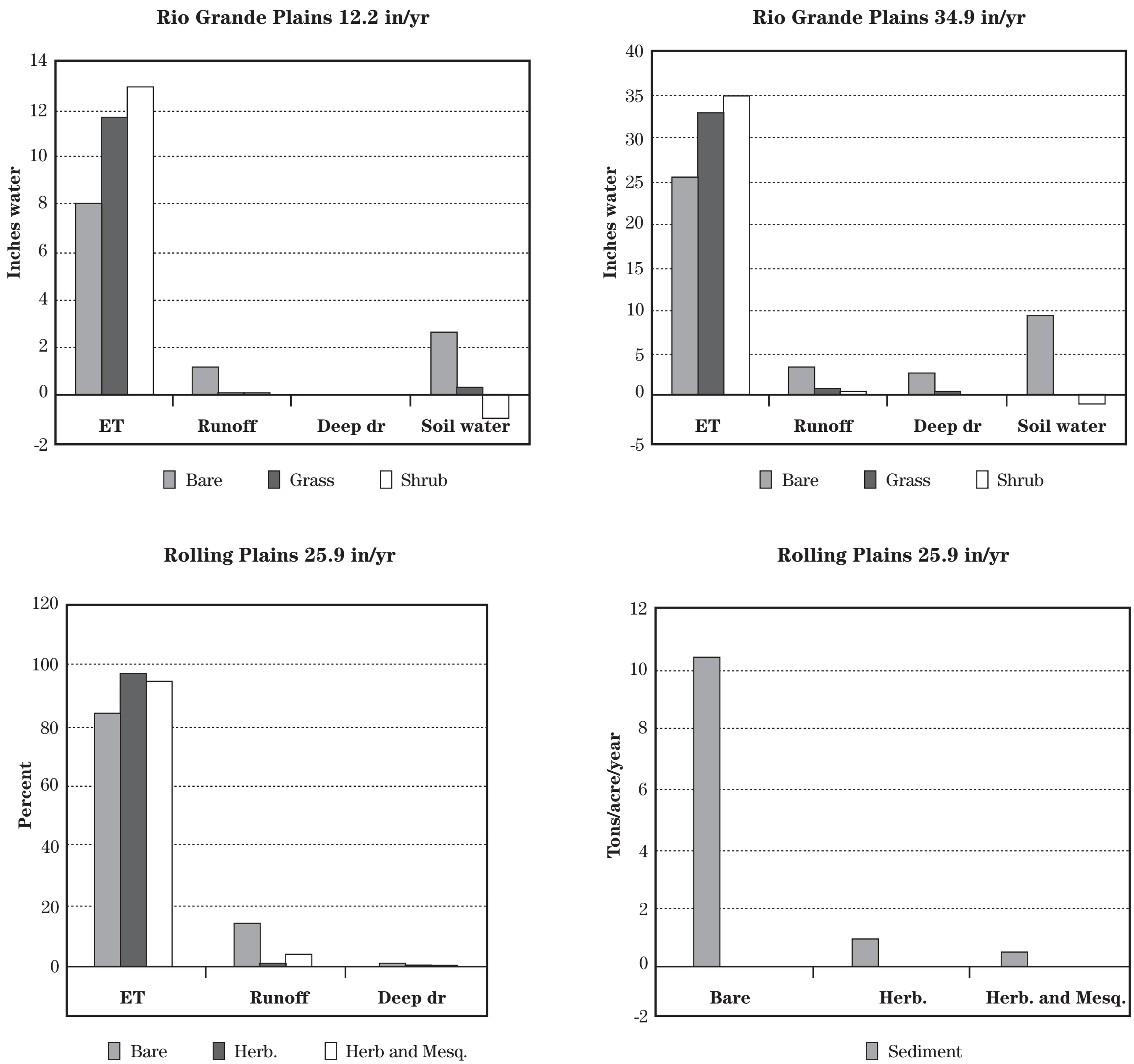
% composition	% composition		% composition
	stand I	**stand II**	**stand III**
Little bluestem	30-50	Kentucky bluegrass 75	25
Big bluestem	15-30	Smooth bromegrass 25	75
Prairie dropseed	10		
Porcupine grass	40		
Sideoats grama	5		
Grasses (subdominants)	5		
blue grama			
sedges			
prairie junegrass			
buffalograss			

	stand I		**stand II**		**stand III**	
Precipitation (in)	25		25		25	
	%	(inches)	%	(inches)	%	(inches)
Grass and litter interception	0.5	(0.13)	0.4	(0.10)	0.6	(0.15)
Surface runoff	20	(5.00)	45	(11.25)	30	(7.50)
Infiltration	77	(19.25)	52	(13.00)	68	(17.00)
Water loss after infiltation						
*Evaporation (ET)	94	(18.10)	95	(18.29)	95	(18.29)
Soil evaporation	60	(11.55)	60	(11.55)	60	(11.55)
Plant transpiration	34	(6.55)	35	(6.74)	35	(6.74)
Deep percolation	2.5	(0.63)	4	(1.00)	2	(0.50)
Change in soil water (affected by antecedent soil moisture)	0.0		–1.4		–0.6	

* Evapotranspiration (ET) is the sum of soil evaporation and transpiration.

Figure 7–5 shows water budgets for bare soil areas, grass interspaces, and shrub clusters for the Rio Grande Plains of Texas at two annual precipitation rates. It also shows a water budget for bare areas, herbaceous plants, and herbaceous and mesquite for the Rolling Plains of Texas and for sediment yield in that area.

Figure 7–5 Water budgets (in) for bare soil areas, grass interspaces, and shrub clusters for Rio Grande Plain of Texas at two annual precipitation rates and for Rolling Plains of Texas with sediment yield (ET = evapotranspiration, Deep dr = deep drainage, Herb. = herbaceous, Herb. and Mesq. = herbaceous and mesquite)



Sources: Rio Grande Plains data from Weltz, M.A., and W.H. Blackburn, 1995.
Rolling Plains data from Carlson, D.H., T.L. Thurow, R.W. Knight, and R.K. Heitschmidt, 1990.

(i) Water-use efficiency

The water requirement for a plant is the amount of water required to produce a given weight of above-ground dry matter (table 7–6). Water requirements for plants are affected by many factors, such as available water, physiologic characteristics of the plant, eco-typic variations of plants, environmental demands, phenology, plant rooting depth, length of growing season, temperature, and nutrient availability.

In some rangeland community types, comparing water-use efficiencies can show the benefits of converting shrublands to grass. Studies to determine water use efficiencies vary considerably; however, grasses tend to be more efficient in terms of water use compared to shrubs.

The water use efficiency of productivity is defined as

$$W_p = \frac{\text{Dry matter production (lb)}}{\text{Water consumption (gal)}}$$

Table 7–6 Water requirements

Plant species	Gallons water needed for 1 pound dry weight
Rangeland plant species in the pinyon/juniper type, for controlled field experiments at Cheyenne, Wyoming, and bermudagrass studies in Tifton, Georgia:	
Crested wheatgrass (*Agropyron cristatum*)	68 – 85
Western wheatgrass (*Pascopyrum smithii*)	52 – 84
Blue grama (*Bouteloua gracilis*)	72
Black grama (*Bouteloua eriopoda*)	69
Tobosa grass (*Pleuraphis mutica*)	110 – 136
Russian thistle (*Salsola australis*)	12 – 32
Fourwing saltbush (*Atriplex canescens*)	185 – 234
Broom snakeweed (*Gutierrezia sarothrae*)	310 – 716
Controlled field conditions at Cheyenne, Wyoming; water availability maintained at 0.3 to 0.8 bars at 12-inch depth; fine, sandy, clay loam, organic matter from 2-4%; data represents sixth harvest of the season (August 29):	
Blue grama	180
Slender wheat grass (*Agropyron trachycaulum*)	262
Western wheatgrass	191
Green needle (*Stipa viridula*)	293
Fawn tall fescue (*Festuca arundinacea*)	219
Garrison creeping foxtail (*Alopecurus arundinaceus*)	249
Latar orchardgrass (*Dactylis glomerata*)	253
Regar bromegrass (*Bromus bieebersteinii*)	267
Thickspike wheatgrass (*Agropyron dasystachyum*)	177
Alsike clover (*Trifolium hybridum*)	233
Dawson alfalfa (*Medicago sativa*)	385
Ladak alfalfa	332
Vernal alfalfa	332
Water use efficiencies at Tifton, Georgia:	
Coastal bermudagrass (*Cynodon dactylon*)	85
Common bermudagrass (*Cynodon dactylon*)	190

Studies at the Northern Great Plains Research Center in Mandan, North Dakota, showed that water use efficiencies of fertilized grasses generally increase. Comparisons among crested wheatgrass, smooth bromegrass, and native mixed grass prairie show that water use efficiency in response to nitrogen (N) fertilization was greatest for smooth bromegrass and least on mixed grass prairie. Under semiarid conditions, grass growth processes are controlled primarily by soil water availability and secondarily by N availability. Studies in the Eastern United States (Pennsylvania) with cool- and warm-season grasses have shown that during years of evenly distributed precipitation, N was the main factor controlling yields and water use efficiency accounted for 80 percent of the variation in yields of the species. When most precipitation occurred as large storm events or when precipitation was low or poorly distributed, soil water holding capacity was the major factor controlling yield and water use efficiency accounted for about 40 percent of the variation in yields.

(j) Vegetation effects on hydrologic processes

Infiltration and runoff are regulated by the kind and amount of vegetation, edaphic, climatic, and topographic influences. Vegetation is the primary factor that influences the spatial and temporal variability of soil surface processes, which affects infiltration, runoff, and interrill erosion rates on arid and semiarid rangelands. Each plant-soil complex exhibits a characteristic infiltration pattern.

The impact of vegetative cover to infiltration is not constant from one range-soil complex to another. In semiarid climates, vegetal cover has a minimal influence on infiltration: the erosion process is more complex and is a function of plants, soils, and storm dynamics.

Each plant community type must be evaluated in terms of what variables affect hydrology on the site. No one factor ever varies alone, especially with regard to hydrologic processes. Some variables are not consistently correlated in natural rangeland plant communities. The variables include:

- above- and below-ground plant morphology
- total production
- production of individual plant species
- total canopy cover
- canopy cover of individual plant species
- plant architecture
- sod forming growth form
- bunchgrass growth form
- interspace
- shrub coppice
- soil physical properties
- soil chemical properties

On rangeland, the amount of interrill erosion is highly dependent on the growth form of grasses (table 7–7). Interrill erosion is less, given equal cover, in bunchgrass vegetation compared to sodgrass types. The bunchgrass growth form and accumulated litter at the base of the plant help retard overland flow by slowing or diverting the flow of water. This results in decreased sediment transport capacity.

Table 7–7 Summary of canopy interception, interrill erosion, runoff, and erosion from oak, bunchgrass, sodgrass, and bare ground dominated areas, Edwards Plateau, Texas, based on 4-inch rainfall rate in 30 minutes (data from Blackburn et al., 1986)

	Oak motte	Bunchgrass	Sodgrass	Bare ground
% canopy interception	7	–	–	–
% grass and litter interception	–	0.5	0.4	0.0
% litter interception	12	–	–	–
Interill erosion (lb/ac)	0.0	179	1,250	5,358
% surface runoff	0.0	24	45	75
% infiltration	81	75.5	54.6	25

The similarity index to the historic climax plant community of a site may or may not be correlated to hydrologic health or watershed stability. Some stands of exotic annual species and undesirable invader shrubs are associated with high infiltration capacities. Presence of such species tends to lower the similarity index even though infiltration capacity is high and runoff potential low. Above- and below-ground structure (morphology) can be associated with enhanced or non-enhanced hydrology, irrespective of whether the plant is desirable, undesirable, a noxious weeds, increaser or decreaser designation, invader species, or native climax or introduced exotic.

(k) Vegetation effects on infiltration

Semiarid rangelands throughout the Western United States have significant spatial and temporal variations with regard to hydrologic and erosion processes. The spatial distribution of the amount and type of vegetation has been shown to be an important factor in modifying infiltration and interrill erosion rates on rangelands. On rangeland, shrub-coppice sites have a significantly higher infiltration rate under both frozen and unfrozen soil conditions than that in interspace areas.

Plant life forms, such as tall grasses, mid grasses, short grasses, forbs, shrubs, halfshrubs, and trees, and their compositional differences on a site, greatly influence infiltration and runoff dynamics. Infiltration is usually highest under trees and shrubs and decreases progressively in the following order: bunchgrass, sodgrass, and bare ground.

Plant growth form can dramatically affect infiltration. Studies of fibrous-rooted plants, such as bluebunch wheatgrass (*Pseudoroegneria spicata*), yarrow (*Achillea lanulosa*), cheatgrass (*Bromus tectorum*), and Sandberg's bluegrass (*Poa secunda*), are associated with increased infiltration (up to 25 percent) compared to taprooted species, such as Balsamroot (Balsamorhiza sagittata), prickly lettuce (Lactuca scariola), and lupine (Lupinus caudatus).

On pasturelands, several researchers found that 70 to 75 percent ground cover is a critical threshold with regard to runoff—cover exceeding 70 percent is slight. Runoff accelerates rapidly below 70 percent cover.

Examples from the literature on plant species effects and hydrology:

- **Tall grass sites—**Big bluestem (*Andropogon gerardii*), little bluestem (*Schizachyrium scoparium*), and indiangrass (*Sorghastrum nutans*) generally enhance infiltration capacity compared to sideoats grama and blue grama.

- **Short grass sites—**Several studies documented infiltration capacity with species composition. Water infiltrates three times faster under blue grama and silver bluestem (*Bothriochloa saccharoides*) than areas dominated by annual weeds, such as summer cypress (*Kochia scoparia*) and windmill grass (*Chloris verticillata*). Buffalograss stands are commonly associated with lower infiltration rates (up to 3 times) compared to blue grama stands, holding the soil type constant.

- **Weedy species—**Some weedy species, such as broom snakeweed (*Gutierrezia sarothrae*), are associated with similar infiltration rates as those in climax stands. On identical sites in west Texas, infiltration rates in broom snakeweed stands are equal to those climax blue grama stands. The implication of this is that similarity index of the site or successional stage is not always correlated with hydrologic condition because high infiltration rates can occur in early successional or on sites with less than 25 percent of the historic climax plant composition.

- **Comparative infiltration rates**—In trial plots on a Sharpsburg silty clay loam near Lincoln, Nebraska, infiltration rates were ranked as follows from lowest to highest: buffalograss, smooth bromegrass (*Bromus inermis*), blue grama, sideoats grama, crested wheatgrass (*Agropyron cristatum*), western wheatgrass, and big bluestem.

- **Infiltration rates, plant growth forms—**In rainfall simulation studies near Lincoln, Nebraska, infiltration rates on soils at antecedent moisture were 2.5 times lower on Kentucky bluegrass (*Poa pratensis*) dominated sites compared to those on big bluestem dominated sites.

- **Clubmoss versus midgrasses—**In rainfall simulation studies near Killdeer, North Dakota, runoff on soils at antecedent moisture with 17 to 25 percent composition, by weight, of clubmoss (*Lycopodium dendroideum*) had 0.28 inch per hour of runoff compared to near zero runoff on sites with native midgrasses.

(l) Runoff

Overland flow or runoff begins when infiltration capacity is surpassed and when storage capacity of surface depressions is filled. In general, runoff varies with scale, decreasing as the size of the contributing area increases and provides more opportunities for infiltration. Soil moisture content and/or soil frost conditions are major determinants of runoff amounts. Soil erodibility follows an annual cycle. It is highest at the end of a freeze-thaw period of late winter and lowest at the end of the summer rainy season when soils have been compacted by repeated rainfall.

The rate and areal distribution of runoff from a watershed are determined by a combination of physiographic, land use, and climatic factors, such as:

- Form of precipitation (rain, snow, hail)
- Type of precipitation (convective, orographic, cyclonic)
- Seasonal distribution of rainfall
- Intensity, duration, and distribution of precipitation
- Plant community types and the character of vegetative cover
- Kind of vegetation as well as the quantity of vegetation
- Watershed topography, geology, soil types, vegetation
- Evapotranspiration characteristics
- Antecedent soil moisture status
- Degree of compaction; i.e., land use practices

Runoff dynamics are poorly understood, and predictive capabilities in arid and semiarid landscapes are limited. In semiarid rangeland ecosystems, runoff is quite sporadic and generally comprises a small percentage of the water budget. Runoff is closely linked to chemical and nutrient cycling, erosion, and contaminant transport. It can also be a sensitive indicator of ecosystem change.

(m) Erosion

Soil erosion is the detachment of soil by wind and water. Variations in landscape, soil type, and available energy cause a continuum of detachment and deposition on rangeland resulting in most soil particles moving only a few feet. Sediment production is related to runoff, which is the principle means of soil detachment and transport. Climate, vegetation, soil, and topography are the major variables regulating soil erosion from rangelands. In the Western United States, rangeland watersheds yield most of the sediment load and forested watersheds produce the majority of streamflow.

The key to developing more effective management systems is in understanding that certain kinds of plants, vegetative growth forms, and vegetation clusters are more effective at stabilizing a site than others and provide early warning signals to rangeland degradation. In semiarid and arid environments, alterations of the natural plant community caused by either a natural event or human activity can cause the conversion of the original native plant species to exotic weedy species and deplete the already sparse vegetative cover in these areas. Reduction of vegetative cover causes increased surface runoff and often leads to accelerated erosion. Rills and gullies develop, followed by larger flow concentrations. Further dissection of the land surface results in a lower ground water table, decreased infiltration of snowmelt and rainfall, and lower streamflow. Perennial streams can become ephemeral because of depletion of ground water storage, which has a deleterious effect on riparian vegetation.

For every watershed and site within the watershed, there exists a critical point of deterioration resulting from surface erosion. Beyond this critical point, erosion continues at an accelerated rate that cannot be overcome by the natural vegetation and soil stabilizing forces. Areas that have deteriorated beyond this critical point continue to erode even when disturbance by human activity is removed.

Increases in erosion occur in watershed areas not protected by vegetation. Fine surface particles and organic matter are removed. Organic matter is rapidly decomposed on exposed soil, and raindrop impact further causes surface sealing, thus resulting in a more impermeable soil crust.

The first stage of erosion is interrill erosion. Interill erosion (sheet erosion) combines detachment of soil from raindrop splash and transport by a thin flow of water across the surface. Minute rills form concurrently with the detachment of soil particles. As runoff becomes more concentrated in rills and small channels, the velocity, mass of the suspended soil, and intensity of turbulence increases. As kinetic energy of the runoff event occurs, the ability of the waterflow to dislodge larger soil particles increases.

Sheet and rill erosion is common in more arid areas that have sparse vegetation cover and poor land use management. Rill erosion begins when water movement causing interrill erosion concentrates in discrete flow paths. This erosion produces the greatest amount of soil loss worldwide. Where soil is more resistant to sheet and splash erosion, erosion occurs mostly by rill and gullies. Sheet erosion is a more erosive process on sandy soil. Velocities of 6 inches per second are required to erode soil particles 0.3 mm in diameter. Velocities as low as 0.7 inch per second carry the particle in suspension.

Gully erosion occurs when runoff is concentrated at a nickpoint where elevation and slope gradient abruptly change and protective vegetation is lacking. Headcuts are caused as water falls over the nickpoint and undermines this point then migrates uphill.

Erosion on rangeland is often difficult to detect. Erosion can reduce productivity so slowly that the reduction may not be recognized until the site has reached a threshold level. Also, erosion can increase future runoff because of reduced infiltration. Increased runoff reduces available soil water, which affects plant growth. Less plant growth means less residue, and less vegetation and residue provide less cover, which increases erosion. Because water erosion strongly relates to runoff, increased runoff also leads to increased erosion. Thus, the process advances exponentially, and reversing it may become physically and economically impossible if it is not detected and controlled by proper management practices.

Water erosion on rangeland and pastureland can be determined in the field by a variety of indicators. (Some of these factors are accounted for in the rangeland health and pasture condition scoring models). The indicators include:

- Pedestalled plants and rocks
- Base of plants discolored by soil movement from raindrop splash or overland flow
- Exposed root crowns
- Formation of miniature debris dams and terraces
- Puddled spots on soil surface with fine clays forming a crust in minor depressions, which crack as the soil surface dries and the clay shrinks
- Rill and gully formation
- Accumulation of soil in small alluvial fans where minor changes in slope occur
- Surface litter, rock, or fragments exhibit some movement and accumulation of smaller fragments behind obstacles
- Eroded interspace areas between plants with unnatural gravel pavements
- Flow patterns contain silt and/or sand deposits and are well defined or numerous
- Differential charring of wood and stumps indicating how much soil has eroded after a fire

Soil surface characteristics impact runoff and erosion from rangeland and pastureland. Organic matter, bulk density, texture, structure, aggregate stability, porosity, and moisture conditions influence soil runoff and erosion by controlling the amount of infiltration and runoff from a site. Litter and vegetation reduce the soil's susceptibility to erosion by protecting the soil surface from raindrop impact, decreasing the velocity of runoff, encouraging soil aggregation, binding the soil with roots, and reducing soil compaction.

600.0702 Effect of trampling and grazing on hydrology and erosion

Rangeland and pastureland hydrology research has traditionally focused on the impacts of grazing on runoff and erosion. From a conservation-management perspective, the grazing management specialist should consider how the grazing practice or system is affecting the soil surface, plant species composition, and ultimately hydrology dynamics of the site, field, and watershed (fig. 7–6). The amount of disturbance to a site from hoof action by livestock depends on soil type, soil water content, seasonal climatic conditions, and vegetation type. The model in figure 7-6 shows that short-term reduction of infiltration occurs at the soil surface. Repetitive and continuous high intensity trampling increases bulk density (compaction) and breaks down soil aggregates. This results in lower infiltration, higher runoff, and a potential for erosion. If this action occurs on wet soil, soil aggregate stability is damaged even more, resulting in an impermeable surface layer. Modification of species composition over time can change hydrologic conditions on the site. Examples are given in section 630.0701(k) Vegetation effects on infiltration.

Figure 7–6 Model depicting effect of grazing practices on soil surface and subsequent results on plant communities, hydrology, energy and nutrient cycles, and erosion and sedimentation dynamics

Short- and Long-term Effect of Grazing Practices and Potential for Modification of

⇩

Soil Surface Properties

⇩

Plant Species Composition

⇩

Hydrology (Infiltration and Runoff)

⇩

Energy and Nutrient Cycles

⇩

Erosion and Sedimentation Dynamics

Grazing affects vegetation stature and composition and soil surface factors, which subsequently affect the hydrologic cycle (fig. 7–7). On a watershed scale, livestock grazing at intensified levels can initially decrease plant cover, cryptogamic crusts, soil aggregate stability, and soil organic matter and increase compaction and soil crusting. Improper grazing intensities, over longer periods, can and often do alter plant composition, which may seriously affect the hydrology of a watershed.

Trampling activity by grazing animal hooves reduce infiltration by altering soil surface physical factors: bulk density or compaction, breakdown of soil aggregates, and reduced porosity. Intense trampling as a result of doubled or tripled stock intensities in smaller paddocks for a short time (creating a herd effect) has been hypothesized as enhancing infiltration and reducing erosion. Research to date by rangeland hydrologists has not supported the idea that increasing the intensity of trampling enhances infiltration capacity.

Positive advantages to the environment, livestock, and hydrologic regime as a result of specialized grazing systems need to be documented in the plan and made available to others through the NRCS Grazing Land Technology Institute.

Hydrology studies on rangeland and pastureland summarize the following:

- Species composition changes can positively or negatively affect hydrology, depending on the individual species involved.
- Hydrology studies consistently show that ungrazed areas and study exclosures have the lowest runoff rates compared to the grazing systems in the respective study areas.
- The reaction to the impact of trampling varies with stocking rate, soil type, soil water content, time of grazing and seasonal climatic conditions, and vegetation type.
- On heavier textured soil, trampling impact on wet soil can break down soil aggregates and an impermeable surface layer can develop.

Figure 7–7 Diagrammatic representation of grazing and the relationship to soil surface modification, plant species compositional change, and the consequential effects on hydrology and erosion

Increase	Decrease
• plant cover	• runoff
• soil organic matter	• soil bulk density
• infiltration rate	• soil detachment and erosion
• soil water content	• sedimentation
• subsurface flow	• site entropy
• aquifer recharge potential	
• ET potential	
• litter	
• cryptogam response where present on ecol. site	
• rangeland health	
• plant community integrity	
• enhances soil structure	
• soil aggregate stability	
• balance nutrient and energy cycle	

Proper grazing management and expected plant community response

Excessive grazing and expected plant community response

Increase	Decrease
• runoff	• plant cover
• soil bulk density (compaction)	• soil organic matter
• soil detachment and erosion	• infiltration rate
• sedimentation	• soil water content
• site entropy	• litter
• risk of a nonrecoverable situation	• cryptogam response where present on ecol. site
	• rangeland health
	• plant community integrity
	• soil structure
	• soil aggregate stability
	• subsurface flow and aquifer recharge potential
	• soil surface stability
	• balanced nutrient and energy cycle
	• ET potential

- "Deferred rotation systems" with adequate rest periods generally maintain hydrologic parameters similar to those in ungrazed areas. Adequate rest periods vary with soil type and vegetation types. Monitoring soil surface conditions should be done on a site-specific basis.
- Watershed research data suggests that watershed conditions can be maintained and improved with light and moderate continuous grazing. There is little hydrologic response differences between light and moderate continuous grazing on rangeland hydrology.
- Heavy use by livestock may compact the soil, negatively impact soil structure, mechanically disrupt soil aggregates, reduce soil aggregate stability, and destroy cryptogamic crusts that may be essential to hydrologic stability. Infiltration capacity is generally reduced with increased grazing intensity mainly through vegetation removal, soil structure deterioration, and compaction.
- Short duration, high intensity grazing is associated with higher sediment production compared to moderate continuous grazing. The reduced standing vegetation and plant cover associated with this system appear to be the cause of the increased sediment production. A definite hydrologic advantage of increased stocking density via manipulation of pasture size and numbers has not been documented in the scientific literature.

  Caution needs to be exercised concerning short duration high intensity systems. Soil surface physical properties, mineral and cryptogamic crusts, and plant species composition must be monitored carefully. Rangeland plant communities are unique, and plant-soil interactions are complex and are not consistent from one vegetation-soil type to the next. This makes it difficult for the land manager, since consistency in hydrologic response is not well documented for many plant-soil complexes. Frequent onsite monitoring is essential.
- Studies have shown that on continuous heavily grazed pastures removal of grazing after a 3-year period reduced total runoff to within 10 percent of that on ungrazed pastures.
- In Midwestern pasturelands, the majority of soil loss occurs when the vegetation is dormant. Large runoff events (usually a small percentage of the total number of rainfall events) produce most of the runoff volume and erosion; however, these events cause the most concern in regards to soil erosion.
- Studies on pastureland in Ohio show that highest annual soil loss values (1.12 t/ac) occur on unimproved pastures grazed yearlong where cattle had direct access to riparian areas. Rotational summer grazing with more than 90 percent grass cover had trace amounts of soil loss.

Because grazing systems and hydrologic impacts vary, management specialists should consult references for particular grazing trials. (See Blackburn 1984; Blackburn et al. 1980 and 1981, Wood and Blackburn 1981, Warren et al. 1986, Weltz and Wood 1986, Warren 1987, and Holechek et al. 1989.)

(a) Sediment delivery

Sediment yield is the total sediment leaving a watershed as measured for a specific period of time and at a defined point in the channel. Most sediment is deposited at the base of hillslopes, on flood plains following high flows or floods, and in stream and river channels. Sediment yield predictions on Western rangelands are difficult and often subjective. Highly variable watershed characteristics make erosion prediction difficult.

On agricultural watersheds (cropland, pastureland), from 1 to 30 percent of the estimated erosion reaches and is delivered to rivers. About 8 percent of all erosion from cropland is deposited in estuaries and the ocean; however, cropland soil erosion is highly variable from site to site. Smaller watersheds generally have a higher sediment delivery ratio than that of larger watersheds.

Average sediment delivery ratios (SDR) for various sized watersheds are:

- 25 acre watershed—30–90
- 2,400 acre watershed—10–50
- 10,000 mi^2—5

Three examples of watershed and sedimentation case studies are given below:

Spomer et al. (1986)
- Dry creek basin in south-central Nebraska
- 20 square mile watershed area; 65 percent of land area is steep; 35 percent is relatively level
- 33 percent cropland, 66 percent rangeland
- High gully erosion rates
- About 60 percent of eroded soil reached the watershed outlet

Coote (1984)
- Prairie landscape in Manitoba and Saskatchewan, Canada
- Delivery of eroded soil to streams estimated to be about 5 percent

Lowrance et al. (1986)
- Forest, crop watershed in Turner County, Georgia
- 34 percent of watershed area was row crops
- 59 percent was forested
- About 1 percent of eroded soil was delivered to streams

Estimates of sediment delivery should be tempered by judgment and consideration of other influencing factors, such as soil texture, relief, type of erosion, sediment transport system, and deposition areas.

Models, such as the Systems Planning and Use on Rangelands [SPUR–2000 (SPUR with WEPP hydrology)], can be used to estimate sediment delivery (assuming proper calibration of model parameters for a specific site).

(b) Hydrology and erosion models

The following rangeland hydrology and erosion models are available to NRCS. These models can also be used on pastureland and other grazing land classes.
- Systems Planning and Use on Rangelands (SPUR–2000)
- Water Erosion Prediction Project (WEPP)
- Revised Hydrologic Curve Numbers (includes technology that recognizes the influence of plant species and spatial and temporal aspects of rangeland plant communities)

The Rangeland Health and Pasture Condition Scoring models can be used to obtain qualitative assessments of rangeland and pastureland. Both models are sensitive in detecting subtle changes that may indicate if a site is near or has passed a critical threshold. Once a resource manager is properly trained, a high degree of repeatability and reliability can be achieved.

The indicators of the Rangeland Health Model can be summarized into watershed function, site stability, and biotic integrity categories. All of these categories relate to watershed management and should be considered in planning and monitoring rangeland. A separate system for Pasture Condition Scoring exists for pastureland.

This section will be expanded as a separate section of the hydrology chapter when the WEPP and SPUR-2000 models have been validated and have user interfaces that facilitate use of the models. The applicability and appropriateness of available technologies will also be reviewed.

(c) Hydrologic effects of range improvement practices

Many researchers reported increases in infiltration following mechanical range improvement practices; i.e., root plowing, vibratilling, and pitting, by creating a macroporous surface that is able to store more water. On some mixed grass prairie sites, vibratilling and chiseling can break blue grama and buffalograss sod and allow the native midgrasses to reestablish (with proper grazing management). This procedure results in higher infiltration and lower runoff.

Brush control on rangeland can be accomplished by one or more means, such as prescribed burning, herbicides, and selecting the proper class of grazing animal. However, some managers are shifting more toward prescribed burning for managing rangelands. Generally, brush control on watersheds is done for two reasons:
- To increase available water to other usually more desirable forage plants, which can include seeding as part of the management action.
- To increase runoff water for offsite use by replacing deep-rooted shrubs with more shallow-rooted grasses and/or forbs, which consume less water.

Overall broad sweeping conclusions about the hydrologic impacts of brush control are difficult because of the interactions of climate, weather, vegetation composition before and after treatment, soil type, shrub control methods, density and type of shrubs, understory vegetation, timing of shrub control, and management after treatment. Brush control impacts vary over time and from one rangeland plant community type to another because of these natural variations. Improvements in hydrologic response following brush control are not automatic and depend upon the factors listed above.

(d) Fire dynamics on hydrology and erosion

Fire effects have a varied affect on the hydrology and erosion dynamics of a site. Variability depends on the intensity of the burn, fuel type, soil, climate, and topography. The effects of fire can be good and bad, depending on the objectives and where and how fire is used. Using wisdom, prescribed burning can be a beneficial and versatile management tool without damage to soil productivity and water quality.

Fire temperature affects humic acids in organic matter differently. Humic acids and organic compounds (long-chain aliphatic hydrocarbons) are lost at temperatures below 212 degrees Fahrenheit. At temperatures between 212 and 390 degrees Fahrenheit, nondestructive distillation of volatile organic substances occurs, and at temperatures between 390 and 570 degrees Fahrenheit, about 85 percent of the organic substances are destroyed by destructive distillation.

The duration and temperature of the fire can distill organic material and other substances downward into the soil and form a nonwettable hydrophobic layer. Fuels that burn quickly (e.g., grass) or very hot (brush piles) generally do not form a hydrophobic layer in the soil. Water repellent layers in the soil are most common in shrub communities where fires burn from 5 to 25 minutes. This situation is inherent in chaparral communities where 90 percent of the decomposed organic matter is usually lost as smoke and ash, and the remaining material is distilled downward and condensed in the soil. The thickness and depth of a hydrophobic layer depends on the intensity and duration of the fire, soil water content, and soil physical properties. Thicker hydrophobic layers form in dry soils than in wet soils; coarse-textured soils are more likely to become water repellent than fine-textured soils. Hydrophobic layers are also common in forest soils, particularly in ponderosa pine (*Pinus ponderosa*), lodgepole pine (*Pinus contorta*), and Douglas fir (*Pseudotsuga menziesii*) communities.

Grassland fires generally temporarily reduce infiltration and percolation rates. The extent of reduction is again dependent on the factors described above. In Chaparral, fire often reduces infiltration on moderate burns by forming the water-repellent layer. Cooler or very hot fires have either a lesser effect or no effect on infiltration. In forest communities, severe hot fires decrease infiltration; whereas, light burning has less effect and can increase infiltration.

Where increases in water yield are desired, brush-to-grass conversions should be done on sites where precipitation exceeds 16 inches per year and on slopes of less than 30 percent. This will minimize runoff and soil losses. Generally, conversion practices in pinyon-juniper communities with 14 to 20 inch per year precipitation rarely increase water yields. Successful grass cover establishment in 1 to 2 years on slight to moderate slopes and a cover of 60 to 70 percent is considered necessary for soil stability. In Arizona, shrub recovery after fire reduced runoff to similar levels of pre-fire conditions by the end of the fourth year.

(e) Riparian vegetation and grazing

Riparian zones occur along the interface between aquatic and terrestrial ecosystems. Riparian ecosystems generally make up a minor portion of the landscape in terms of land area, but are extremely important components in the planning and management of the rangeland or pastureland unit. Management and condition of the transitional zone (inactive flood plains, terraces, meadows) and upland sites are critical to the health of riparian ecosystems because they are areas of runoff and recharge. Excessive runoff and gully erosion on uplands ultimately impact the riparian zone and stream corridor.

A well-planned grazing system that provides periodic rest can alleviate many of the problems associated with livestock in riparian areas. Continuous season-long grazing is the most damaging grazing regime to riparian sites because livestock congregate and spend most of their time in these zones. Riparian zones compared to more rugged, steep upland sites in the Western United States provide available and easily assessable water, forage, and shade. Excessive live-stock impacts; i.e., heavy grazing and trampling, affect riparian-stream habitats by reducing or eliminating riparian vegetation, changing streambank and channel morphology, increasing stream sediment transport, and lowering of the surrounding water tables.

Livestock are perceived as a major cause of riparian degradation in the West. As a result, concerns from resource users have accelerated. In addition to forage for livestock, riparian areas often cover 1 to 2 percent of the summer rangeland area, but produce about 20 percent of the summer forage. Riparian areas have high value for fisheries habitat, wildlife habitat, recre-ation, transportation routes, precious metals, water quality, and timing of waterflows.

Rehabilitation of riparian zones can include rotation grazing schemes, complete exclusion of livestock, changes in type or class of animal, and techniques to improve livestock distribution (salt placement, development of watering areas away from the ripar-ian zone, fencing, herding, alternate turnout dates). Rest-rotation is one of the most practical means of restoring and maintaining riparian zones. Under moderate stocking, rest-rotation can improve ripar-ian vegetation and physical stability. Where live-stock grazing is compatible in a particular riparian area, grazing management practices must allow for regrowth of riparian plants and should leave suffi-cient vegetation cover for maintenance of plant vigor and streambank protection.

Streamside use of herbaceous forage in riparian areas in summer grazed pastures should be used judi-ciously (not more than 50 percent, by weight), and in the intermountain region, riparian plant communities have limited regrowth potential after midsummer. Rule of thumb stubble heights proposed by some grazing guides (4 inches) may or may not be ad-equate for certain species. State technical guides should be consulted for the dominant species on the site. Fall grazing should be monitored carefully because little or no regrowth potential remains. Utilization should be monitored on a per weight basis for native species or by height of stubble (as per state technical guides) for pasture or domestic species.