WATER AND WATERSHED

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Quaking aspen dominates several million acres on mountainous watersheds in the West. The sites occupied receive enough precipitation to yield water to lower elevations. Most aspen areas receive 16 inches (40 cm) or more precipitation annually; many receive more than 39 inches (100 cm) (see the CLIMATES chapter), well in excess of on-site loss from evapotranspiration. The distribution of aspen in the West coincides well with areas that have deep winter snowpacks and that produce runoff (fig. 1) (see the DISTRIBUTION and CLIMATES chapters). The recharge of soil with snowmelt water during April and May is especially important to aspen and associated vegetation types (see the EFFECTS OF WATER AND TEMPERATURE chapter). Summer rains augment this stored water supply.

In the relatively arid western United States, water is a very important resource yielded from the aspen type. The importance of water increases as human populations grow and make greater demands on a limited, and mostly fixed water supply. The mountains of the interior West supply most of the water needed by arid and semiarid valleys. These water-yielding lands are covered with many vegetation types: mountain brush, spruce-fir, pine, sagebrush-grass, mountain meadows, and alpine tundra, as well as aspen. Aspen provides excellent protective cover on mountain sites that yield much high-quality water. For reasons discussed later, sites occupied by aspen provide more water than many other sites.

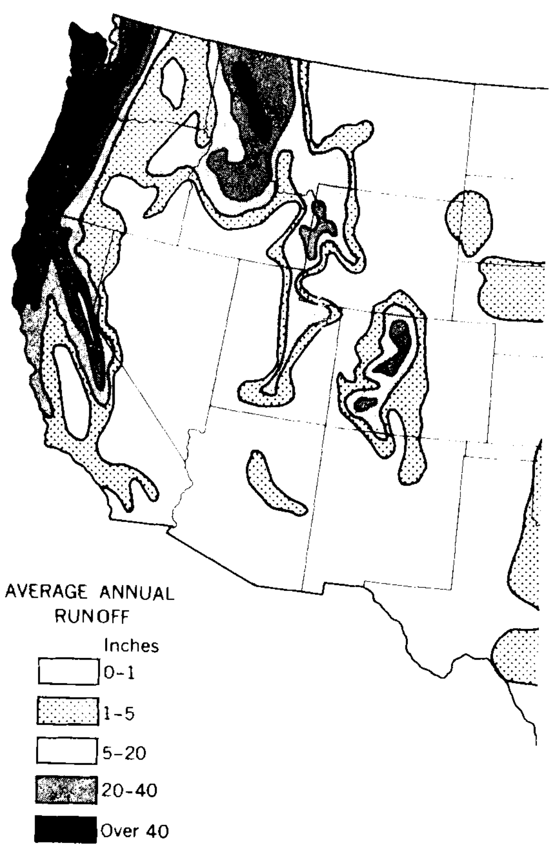

Figure 1.—Average annual runoff in the western United States.

Aspen Influences

Snow

During winter and early spring (typically for 4 to 6 months), most aspen sites in the West are snow-covered. The depth and ablation (snowmelt and evaporation) rates of the snowpack are affected by the aspen forest. In both Minnesota and New Mexico, for example, more snow accumulated under aspen; but it melted faster and disappeared earlier than from under conifers, primarily on southerly exposures (Gary and Coltharp 1967, Weitzman and Bay 1959). Swanson and Stevenson (1971) found that isolated leafless aspen and willow stands in Alberta retained a snowpack during chinook winds that melted all snow from large open areas. Small openings within these stands were effective snow traps, accumulating one-third more snow than elsewhere in the stand. They found that snow ablated 30% more slowly in these openings, extending the snowmelt runoff or groundwater recharge later into the spring.

Aspen forests intercept only minimal amounts of snow, especially compared to coniferous forests, where much of the snow may never reach the ground. In central Utah, Harper found 5% to 70% less water in the snowpack under mixed aspen-conifer stands than under pure aspen.[1] Dunford and Niederhof (1944) found 12% more snow under aspen than in the open. Nearby lodgepole pine contained 12% less snow than the open area, which was approximately 75% of the amount found under aspen. Intercepted snow may evaporate more readily than snow on the ground because of greater surface area exposure to radiation and wind. However, much of what is intercepted by tree crowns later may be transferred elsewhere within the forest (Miller 1962). Crown shape, crown closure, aspect and exposure, and climatic conditions during and after snowfall all affect the amount of snow intercepted and its later disposition.

In the Rocky Mountain West, the snow surface under a leafless aspen canopy is exposed to a high evaporation potential because of a relatively dry atmosphere, much direct solar radiation, and only partial shelter from wind. Some snow evaporates or sublimates. Doty and

[1] *Personal communication with Kimball Harper, Brigham Young University, Provo, Utah.*

Johnston (1969) measured losses from the snowpack under aspen, under conifers, and in the open, on a typical aspen site in Utah. They found twice as much evaporative loss from the snowpack in the open than they did under conifers. Losses under aspen were intermediate, averaging about 1 inch (2.5 cm) of water loss from the snowpack during a typical winter (fig. 2). However, these measurements were made when winds were less than 7 miles per hour (3 m/sec). When winds are greater, snow becomes airborne. Sublimation from these airborne snow particles is greater than from the snowpack surface because of more exposed surface area and the lack of a saturated air boundary layer. Thus, wind increases evaporative loss. In Doty and Johnston's (1969) study, air movement under the leafless aspen stand was only two-thirds that found in the open; snow drifting was less, and water loss from airborne snow, therefore, would be less than in the open. However, evaporative losses will vary with aspect and degree of protection provided by the vegetation.

Rain

The aspen canopy potentially intercepts much more rain in summer than snow in winter. For example, 10.3% of gross summer rainfall did not reach the ground in a dense Utah aspen stand (Johnston 1971). Because summer is the driest season in much of the West, this loss becomes much less important when converted to actual rainfall. In the Utah stand, the average summer rainfall was 4.5 inches (11 cm), of which only ½-inch (1.2 cm) was caught in and evaporated from the foliage. This corroborated earlier findings by Dunford and Niederhof (1944) in Colorado. They measured 15.7% interception of the 5 inches (13 cm) of summer rainfall—or an average summer season loss of 3/4 inch (2 cm).

Stemflow redistributes precipitation, and may be a significant influence in eastern aspen forests by funneling rain and nutrients to the feeding roots at the tree base (Clements 1971). However, both Johnston (1971) and Dunford and Niederhof (1944) found negligible stemflow in aspen stands in the West—only 1.4% and 1.1%, respectively, of the summer season rainfall. This small trickle down aspen boles is not likely to measurably influence the forest or its hydrology.

Wind

Wind during the growing season will increase evapotranspiration rates. Compared to an adjacent opening, air movement during summer was only one-sixth as much under a dense Utah aspen stand (Marston 1956), where the aspen cover reduced air velocities an average of 2.6 miles per hour (1.2 m/sec). This reduction, and the absorption of solar radiation by the overstory, reduces potential evapotranspiration under the canopy.

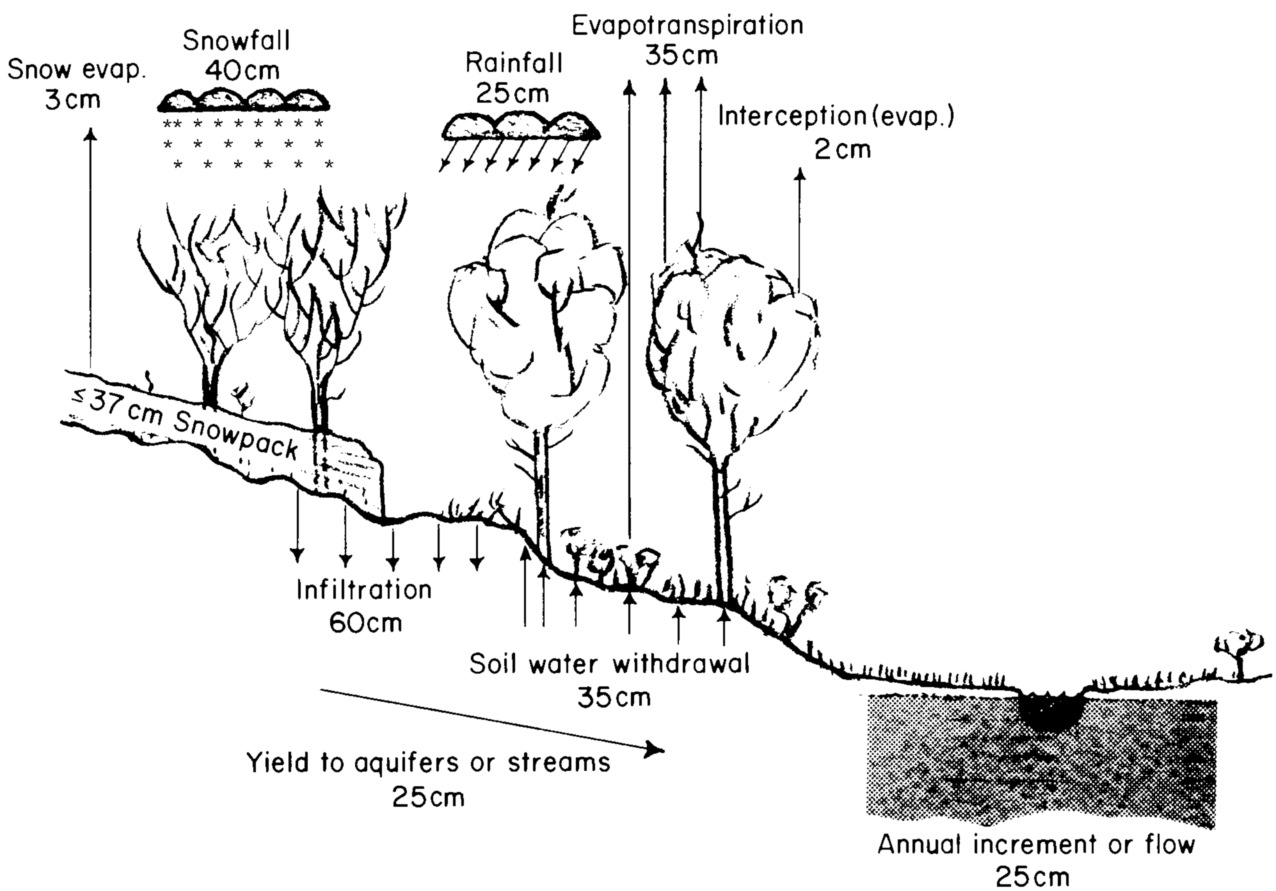

Figure 2.—Water balance in a typical western aspen catchment.

As noted previously, during winter, wind affects distribution and depth of snow, as well as its rate of evaporation. During this dormant season, air movement is greatest in large openings, less in aspen or other deciduous hardwood stands, and least in dense conifer stands.

Aspen-Soil-Water Relations

Sucoff (1982) provided a broad review of water relations in the aspens. Physiologically, aspen differs from its coniferous counterparts in the West. Transpiration from aspen, as from other deciduous hardwoods, is negligible during the dormant season. In contrast, evergreen coniferous trees in the same environment transpire in the spring, before aspen develops leaves, and continue to transpire in the autumn, after the aspen leaves drop. Because of this, conifers may use 3 to 7 inches (7 to 18 cm) more water per year than does aspen (Gifford et al. 1983, 1984; Jaynes 1978). While in leaf, however, aspen is a good wick, withdrawing water by the roots and transpiring it from the crowns. Aspen readily withdraws most available water from the soil to the depth of effective rooting, commonly 3–10 feet (1–3 m) (Berndt and Gibbons 1958, Gifford 1966).

Aspen forests transpire water throughout the growing season; but most is lost immediately after full leaf development in the spring and early summer (fig. 3) (Kramer and Kozlowski 1960, Tew 1967). Early in the growing season, the soil contains a full charge of available water. Daily periods of transpiration are longest on these long days. As the season progresses, decreasing soil water potentials, shorter days, and aging leaves all cause a decrease in water-use rates.

Summer rains wet the vegetation (interception), and, if more than 0.2 inch (5 mm) falls, enough reaches the ground to recharge the surface soil. The forest then transpires at or near its potential rate for a short period after each storm. However, within a few days, this added water supply is exhausted, and transpiration declines. These summer storms are frequent in the southern part of the aspen range (see the CLIMATES chapter).

The stems of aspen clones, in part, are interconnected on a common parent root system (DeByle 1964, Tew et al. 1969) (see the MORPHOLOGY and the VEGETATIVE REGENERATION chapters). Root-connected groups (2 to 43 stems) potentially can function as individual units for water transport, especially during times of moisture stress (fig. 4).

Soil water depletion during the growing season has been measured on a variety of aspen sites in Utah (Croft and Monninger 1953; Johnston 1969, 1970; Johnston et al. 1969; Tew 1967).[2] In all instances, the available water was extracted by aspen fully occupying the site from the upper 6–7 feet (2 m) of soil during the growing season (June through mid-September). Soil water potentials in these profiles at the end of summer often were near − 15 bars. In Arizona, New Mexico, and Colorado, where summer rain is much more frequent and abundant, soils may not dry out so thoroughly.

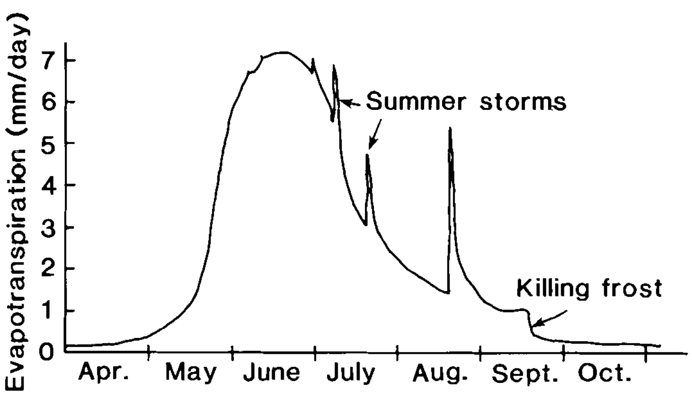

Figure 3.—Approximate evapotranspiration from the aspen forest during a typical growing season in the interior western United States.

Water begins to be extracted in significant quantities in the spring, when vegetative buds burst and new leaves emerge. It has not been possible to make valid soil water depletion measurements in the aspen forest in the spring until snowmelt ends and the soil profile ceases draining rapidly. By that time, many high-elevation aspen already are partially leafed out, and have transpired water. Therefore, the measurements in the cited Utah studies are conservative.

Precipitation during the growing season seldom recharges more than the surface 8 to 16 inches (20 to 40 cm) of soil under most aspen in the West. Because it, too, is lost to evapotranspiration, this precipitation increment is added to the measured soil water depletion to provide an estimate of evapotranspiration by the aspen community.

In Utah, estimated evapotranspiration using this method averaged 2.3 inches per foot (19 cm/m) of soil depth from mature aspen. It varied from 5.5–11 inches (14 to 28 cm), depending upon amounts of summer precipitation received and the soil physical properties that controlled the amount of available water held in the profile (Johnston et al. 1969). Based on an assumed average effective aspen rooting depth of 8 feet (2.5 m) and an average amount of summer precipitation of 4.7 inches (12 cm), a rough estimate of evapotranspiration from mature aspen in Utah is 17 inches (44 cm) per year. From similar work in southern Alberta, Singh estimated 16.5 inches (42 cm) of evapotranspiration from aspen during a 122-day growing season.[3] In contrast, Kaufmann more conservatively estimated evapotranspiration from aspen in Colorado to be less than 8 inches (20 cm) per year.[4]

[2] *DeByle, Norbert V., Robert S. Johnston, Ronald K. Tew, and Robert D. Doty. 1969. Soil moisture depleton and estimated evapotranspiration on Utah watersheds. 14 p. [Paper presented at International Conference on Arid Lands in a Changing World, June 3-13, 1969, Tucson, Ariz.] [Abstracts]*

[3] *Personal communication with Teja Singh, Canadian Forestry Service, Edmonton, Alberta.*

[4] *Personal communication from Merrill R. Kaufmann, USDA Forest Service, Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colo.*

Most soil water is withdrawn early in the growing season—when it is held under least tension and, therefore, is readily available to the rapidly transpiring trees. Tew (1967) found that more than 80% of the seasonal depletion took place in the first 49 days (40%) of the growing season. Later, water is withdrawn from deeper within the rooting zone. Because most roots are near the surface, available water is taken from the upper portion first. Once water is depleted from the upper zones, the roots near the bottom of the profile more slowly withdraw water and bring the trees through any late-summer drought. As noted previously, whenever summer rains recharge the surface soil, rapid uptake by surface roots resumes and transpiration temporarily increases.

Data from Utah indicate that most evapotranspirational demand is satisfied by water from the upper portion of the soil profile (Johnston 1970, Johnston et al. 1969). Unless the season is exceptionally dry, the lower portion will not lose all of its available water. Aspen roots typically do not fully occupy these lower depths, and water movement through the soil to the sparsely scattered root-absorbing surfaces is very slow at lower water potentials. Despite low water potentials within the tree, movement of the remaining water into the roots progresses slowly at the lower limits of the rooting zone.

Dense stands of aspen root suckers quickly replace aspen trees that are clearcut, burned, or otherwise quickly killed. These sucker stands use less water than the mature forest; in Utah they used from ½ to 5 inches (1 to 13 cm) less water from the surface 6–7 feet (2 m) of soil during the growing season (Johnston et al. 1969). Most of this savings is in the lower half of the soil profile; evapotranspiration from the upper half remains about the same as before. These differences diminish rapidly as sprout stands mature and transpiration accelerates. Within 10 or 20 years, the sprout stand probably will consume as much water as its parent trees did.

Water returned to the atmosphere by evapotranspiration is a loss to either streamflow or groundwater. The deficit in maximum soil water content at the end of each growing season, caused by evapotranspiration, first must be satisfied by autumn precipitation or by snowmelt before significant amounts of water will drain through the soil and be yielded from the watershed. Autumn rains usually do not recharge the mantle sufficiently to produce significant water yields. Instead, on most aspen watersheds in the West, spring snowmelt produces most of the streamflow or aquifer recharge. Water evaporated or transpired during the growing season from these sites is expressed as reduced water yields during the following spring and summer.

Overland Flow and Erosion

Aspen has a measurable influence on the underlying soil. Tew (1968) found the surface 6 inches (15 cm) of soil under Utah aspen stands had 4% more organic matter, higher water holding capacity, slightly higher pH, and more available phosphorus than adjacent stands of shrubs and herbaceous vegetation. Aspen produces

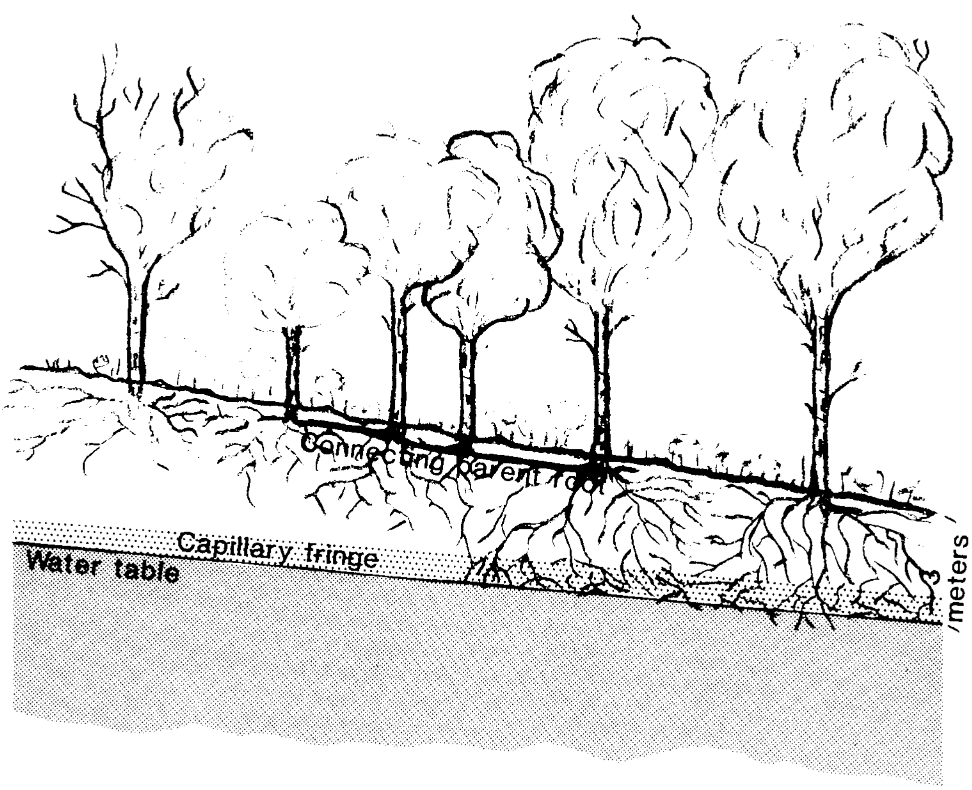

Figure 4.—Roots of an aspen clonal group, with four interconnected trees, tapping a water table.

nutrient-rich litter that decays rapidly (Bartos and DeByle 1981, Daubenmire 1953, Daubenmire and Prusso 1963). A thin surface organic soil horizon is typically underlain by thick A_1 horizon—high in organic matter content and available nutrients. Aspen are efficient nutrient pumps that enrich the surface soil horizons. (See the SOILS chapter.)

A well-stocked aspen stand provides excellent watershed protection. The trees, the understory of brush or herbaceous species, and the litter furnish virtually 100% soil cover. A mixture of herbaceous and woody root systems penetrate and anchor the soil. Erosion-producing overland flow is almost nonexistent under stands like these—even storms with 5-minute intensities approaching 6 inches (15 cm) per hour infiltrate the porous, humus-rich soil (Marston 1952). Snowmelt is never this rapid; large frontal systems usually provide gentle rains; only intense summer storms produce rainfall at rates approaching the infiltration capacity of aspen forested soils.

However, erosion in the form of mass movement or slumping takes place on many aspen-forested mountainsides in the West. This usually is the natural geologic rate of erosion on unstable landforms. Bailey[5] identified and described these landforms and associated hazards in northwest Wyoming; the principles apply elsewhere. Aspen is one of only a few tree species that colonize these unstable slopes. This erosion does not occur because of poor aspen cover; instead these landforms are covered with aspen, brush, and herbaceous species because of their instability. Under these conditions, aspen provides the best natural protection possible on soils that frequently have a high clay content, are plastic, and are often quite wet.

Erosion on otherwise stable aspen-covered slopes may occur if excessive use or abuse reduces the cover of vegetation and litter to 65% or less (Marston 1952). This usually results from excessive grazing and browsing by ungulates (Bailey et al. 1934, 1947).

In the aspen type of northern Utah, Marston (1952) found that less than 1% of any storm ran off the surface of well-vegetated plots. Erosion was negligible if less than 5% of the rainfall ran off as overland flow. The ground cover required to keep overland flow at 5% or less increased from 5% of the plot area at a rainfall intensity of 1.5 inches (4 cm) per hour to 65% at an intensity of nearly 3 inches (8 cm) per hour.

Meeuwig (1970) concluded that the proportion of the soil surface protected from raindrop impact by vegetation, litter, and stone was the most important factor in erosion control. Slope gradient and bulk density of the surface mineral soil varied directly with amount of erosion measured. Soil organic matter favored stability of fine textured soils but apparently increased erodibility of sandy soils.

[5] *Bailey, Robert G. 1971. Landslide hazards related to land use planning in Teton National Forest, northwest Wyoming. 131 p. USDA Forest Service, Intermountain Region. Ogden, Utah.*

Water Quality

Ungrazed aspen watersheds yield excellent quality water, within the limits imposed by geologic conditions. A pair of such watersheds in northern Utah, for example, yielded streamflow with less than 60 ppm suspended sediment, nitrate concentrations seldom exceeded 0.1 ppm; conductivity ranged from 70 to 342 μmhos (varying inversely with volume of streamflow); bicarbonate and calcium comprised the bulk of the dissolved chemical load; pH averaged 7.5; and there were very low but variable counts of bacteria (0 to 250 per 100 ml) (Johnston and Doty 1972). In Alberta, Singh (1976) found that dissolved solids concentration in streamflow from an aspen-grassland catchment averaged 270 ppm with a range of 148 to 331 ppm.

Bacterial counts, which include enteric bacteria, were high enough in streamwater to require treatment to meet potability standards, even counts from the virtually undisturbed Utah watersheds. Bacterial concentrations on these watersheds were highest during rising stages of streamflow—indicating a flushing action from the banks, from overland flow directly into the streams, and from beaver dams. Wildlife was the only known source of enteric bacteria in these Utah drainages (Johnston and Doty 1972).

Darling and Coltharp (1973) sampled stream water quality from three small watersheds in which aspen was a major vegetation component. Total coliform, fecal coliform, and fecal streptococci counts were higher in streams below the two grazed areas than the ungrazed area. Maximum counts were reached during snowmelt runoff and during the grazing period; minimum counts occurred in winter. There were no significant impacts from grazing on pH, temperature, turbidity, nitrate content, or phosphate content of the streamwater.

Clearcutting the aspen forest potentially could alter water quality, because this practice interrupts nutrient cycling, increases insolation at the forest floor, increases water yields, and even may cause some overland flow. Despite this potential, limited studies have not shown any appreciable change in water quality attributable to aspen harvest (Richardson and Lund 1976, Verry 1972). No major changes in water quality after clearcutting were evident in data from a Utah study, either (Johnston 1984).

Vegetation Type Comparisons

Aspen is not entirely unique; other vegetation types growing in the same environment also use water, protect the soil from erosion, and influence the hydrologic system.

The following comparison of vegetation types assumes all other factors are held constant—that elevation, soil type and depth, topography, climate, and geological conditions are identical across all vegetation types. Use by ungulates and by people are not considered. These conditions seldom, if ever, are present in the real world. Nevertheless, at least qualitative differences among aspen, conifers, mountain brush, and grass-forb communities are attempted in table 1. Comparisons can be made only horizontally across types, not vertically among parameters.

The amount of solar radiation that penetrates the vegetation and reaches the soil or snow surface is controlled by canopy density. Air movement within the stand or near the ground is similarly affected by the canopy. Conifers are dense throughout the year; aspen and mountain brush in winter generally provide only limited screening to wind or sunlight, although this can be greatly influenced by aspect and slope; and grass-forb cover has no effect when buried under snow.

The effect of vegetation on amounts of precipitation reaching the ground and its disposition (runoff, snowmelt, etc.) is hydrologically important. Perhaps the mountain brush, and definitely the grass-forb type intercepts less incoming precipitation than does aspen. Winter snowpacks likely are greatest under aspen, and their melt rates in the spring should be similar to those in the open grass-forb community.

The amount of water used by each of these vegetation types depends on the site. As a result, available data are more difficult to interpret than climatic data. Aspen, deciduous brush, and the grass-forb communities transpire significantly only in late spring and summer, whereas the conifers and evergreen brush species may transpire whenever water is available and leaf temperatures permit. Therefore, as noted previously, conifers most probably transpire more water per year (Gifford et al. 1983, 1984).

Table 1.—Comparative influences of four vegetation types in the western United States and southwestern Canada on several climatic and hydrologic parameters.[1]

Physical Parameter	Vegetation type			
	Aspen	Conifers	Mountain brush	Grasses and forbs
Climatic variables				
Solar radiation to ground				
Summer	----	----	---	--
Winter	--	----	-	0
Wind				
Summer	---	----	--	-
Winter	-	----	-	0
Interception				
Rain	+ +	+ + + +	+ +	+
Snow	+	+ + + +	+	0
Snowpack				
Water content	+ + +	----	+ +	+
Rate of melt	-	----	-	0
Water Use				
Transpiration season	Late spring and summer	Sp, Su, Au	*Deciduous* Late spring and summer *Evergreen* Sp, Su, Au	Late spring and summer
Amount	+ + +	+ + + +	+ + +	+ +
Rooting depth	+ + +	+ + +	+ + +	+ +
Soil water use				
Amount	+ + +	+ + + +	+ + +	+ +
Depth	+ + +	+ + +	+ + +	+ +
Water Yields				
Quantity	---	----	---	--
Timing	Intermediate	Latest	Intermediate	Earliest
Quality				
Chemical absence	+ + + +	+ + +	+ + + +	+ + + +
Sediment absence	+ + + +	+ + + +	+ + +	+ + +
Other				
Litter depth	+ +	+ + + +	+ +	+
Infiltration	+ + + +	+ + +	+ + +	+ +
Surface runoff	----	---	---	--
Erosion	----	---	---	--

[1] *– = relative decrease; + = relative increase; 0 = no likely change from that found in a hypothetical, large, open area without vegetation.*

Depth of rooting and amount and depth of soil water consumption during the monitored growing season are somewhat similar for the tree and brush species studied (Johnston et al. 1969). In contrast, the grass-forb type sends roots to less than one-half the depth and, consequently, uses much less water than its woody counterparts on deep, well-drained soils. All use more water than evaporates from bare soils (fig. 5).

Water yield is the residual after losses by evapotranspiration. Because the coniferous type has the potential of using the most water, yields from it presumably would be least. The converse is true for the grass-forb type. Although aspen and deciduous brush transpire during a shorter season and intercept less snow than the conifers, they withdraw water from just as great a depth as the conifers; therefore, yields from aspen and brushlands are estimated to be intermediate.

Snowmelt is earliest in the montane grass-forb community; therefore, peak spring streamflow is earliest, and it perhaps has the sharpest and highest peaks. Rate of snowmelt under conifers is slowest; but less snow is present on the ground under dense coniferous stands. As a result, the ground often is bare under these stands almost as early as in the aspen. To produce latest timing of peak spring flows and to sustain snowmelt flows well into summer (table 1), there would have to be many, relatively small, partially shaded openings to trap snow in the conifer forest.

If all other factors are held constant, quite similar quality water will be yielded from all four vegetation types. Streamflow from all types will be of markedly better quality than from any denuded area. The aspen type appears to have the potential of yielding the highest quality water because the soil that develops under it is porous, essentially neutral, high in incorporated organic matter, and biologically active. Conifers develop acid, nutrient-leached soils that have the potential of yielding dissolved materials to percolating water; some grass-forb types do not provide as good a protective cover from erosion as do forests; and water repellent materials are produced in both conifer and some brush types that can encourage overland flow.

Litter depths (surface organic soil horizons) are greatest under conifers and least under many grass-forb communities. This directly controls the amount of water that can be stored in or intercepted by this layer. In turn, infiltration, runoff rates, and other hydrologic variables are affected.

For reasons already stated, infiltration probably is best under aspen. It may be poorest under grass-forb cover, because this type often has shallow litter depths and high soil bulk densities. Therefore, the potential for surface runoff and erosion on the grass-forb type would be greater. The differences among vegetation types, however, are likely to be minor. Again, good data for undisturbed stands on like sites are not available.

All four types compared here seldom occur on truly similar sites. For example, conifers are able to occupy higher elevations than aspen; therefore, they often grow on sites that receive more precipitation. Thus, water yields from these conifer sites usually are greater, and, because of dilution, chemical water quality may be better than from nearby, but lower, aspen sites (Singh 1976).

Water Use and Yield

Irrigation has been the major consumptive use of water in the West. Domestic and industrial uses have grown, often at the expense of irrigation water where supplies already are fully allocated. Some water also is used to maintain fisheries and aquatic habitats. In addition, marshes and waterfowl refuges receive water in the form of irrigation flows and other "used" water, particularly in the Great Basin province.

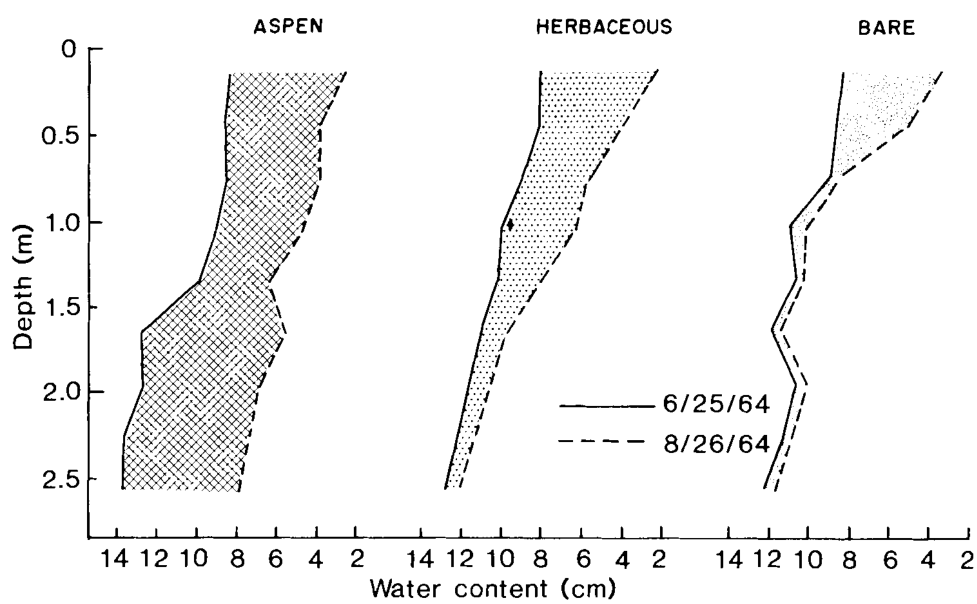

Figure 5.—Soil moisture profiles under three cover conditions on one site at beginning and end of growing season.

Water has long been an important commodity, vital to the growth and development of the West. However, the price paid for water usually does not reflect its value. What is paid for it in the marketplace usually reflects the costs to the processor (e.g., the municipality or irrigation company), not what the consumer would be willing to pay. The value of water varies with its use, as well as other factors. For example, water consumed by domestic and industrial users has a much higher value than that used for irrigation.

It may be useful to provide an estimate of the amount of water yielded by aspen lands in the mountainous West. Using averages from across the West, the aspen type receives about 24 inches (60 cm) of precipitation annually in the interior mountains. About 14 inches (35 cm) of this is lost by evapotranspiration (Johnston et al. 1969). The difference of 10 inches (25 cm) is potential water yield that could contribute to streamflow or groundwater aquifers. This is equivalent to a yield of approximately 4.8 million acre-feet of water per year from the aspen lands. (Options for improving water yield from aspen lands are discussed in the MANAGEMENT FOR ESTHETICS AND RECREATION, FORAGE, WATER, AND WILDLIFE chapter.)