MANAGEMENT OF ALPINE AND SUBALPINE MOUNTAINOUS AREAS FOR WATER YIELD

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The Southern Rocky Mountains are the major water-yielding areas of the southwestern portion of the United States. Above 5,000 feet in elevation, the proportion of precipitation appearing as streamflow each year steadily rises with an increase in elevation. This proportion ranges from less than 10 percent at the lower elevations to well over 50 percent at the higher.

The Continental Divide of the Southern Rocky Mountains is the headwaters of four major rivers; the Colorado, the Platte, the Arkansas, and the Rio Grande. Characteristically, snow accumulates over-winter in these headwaters and melts during the months of May and June. At this time, swollen mountain streams are common and water is plentiful. In contrast, summer and fall flows are low and water supplies become limited. This regional characteristic of over-winter snow storage provides the opportunity for manipulating the annual snowpack where it is influenced by vegetation, soils, and climate.

Vegetation

The three predominant vegetation types in the Southern Rocky Mountains are: (1) ponderosa pine-bunchgrass type (montane), occuring between the elevations of 5,000 and 8,500 feet; (2) Engelmann spruce-subalpine fir, lodgepole pine, aspen type (subalpine), found between the elevations of 8,500 and 11,500 feet; and (3) alpine grasslands (alpine), occupying lands above 11,500 feet elevation (fig. 1). At a particular elevation where these types meet, they grade into one another. South exposures will contain the type of the lower elevation and north exposures that of the next higher elevation.

Water Yield

Although a prime source of water, the Southern Rocky Mountains receive but moderate amounts of precipitation. On areas above 9,000 feet, annual precipitation does not average more than 30 to 40 inches and decreases rapidly with lower elevation. Of the 30 to 40 inches, 60 to 80 percent occurs as snow, which begins to persist on the ground during October and accumulates with little or no loss by melting until the spring thaw in April, May, and June.

Water yield from mountain lands follows elevational changes with highest yields coming from the higher elevations and lowest from the lower (fig. 2). Yields of 18 acre-inches per acre or more come from the alpine grasslands and from that area of dwarf trees at timberline. Dense forests of Engelmann spruce, subalpine fir, lodgepole pine, and aspen yield 6 to 18 acre-inches per acre from areas above 8,500 feet in elevation. The ponderosa pine type yields 3 to 6 acre-inches per acre between the elevations of 5,000 and 8,500 feet.

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Of the approximately 20 million acre-feet of water yielded annually from the Southern Rocky Mountains, it is estimated that 35 percent comes from alpine grasslands, 50 percent from Engelmann spruce-subalpine fir, lodgepole pine, aspen forests, and 15 percent from ponderosa pine-bunchgrass type.

Increasing Water Yields

Alpine Snowfields

A survey of selected alpine snowfields in the Southern Rocky Mountains during the summers of 1955-1958 confirmed the belief that such fields are important contributors to summer streamflow. This work showed that vertical ablation averaged 1.9 feet of snow per week during July and August. Specific gravity of the snow varied from 0.60 to 0.75. This means that about 1 1/4 feet of water were released per unit area of snow.

Vapor transfer studies carried out in late-lying alpine snowfields during the summers of 1957 and 1958 showed a net gain of moisture on the snow surface from condensation during a nine-day period of humid weather and a net loss of moisture from the snow due to evaporation during a period of dry, windy weather. Over a period of several months net exchange approaches zero. Even on a daily basis the net vapor transfer averaged only 2 to 3 percent of the daily melt. Never during the two test periods did it exceed 4.5 percent of daily melt. Hence, this net vapor transfer can be ignored for most practical purposes.

Winter observations of snow accumulation in the alpine for the past two years have furnished some quantitative data on local drift patterns. It has been observed that snow transport starts in the unprotected spots, with winds above 10 to 12 mph. provided the snow surface is not crusted. At some higher speed, perhaps 25 to 35 mph., all snow not in the immediate lee of vegetation or terrain irregularities is subject to wind erosion. Thus, snow drifts that develop in relatively exposed situations with light winds are carried away at higher velocities. Winds can move snow more effectively after surface irregularities are filled by snow and the terrain is smooth. Maximum accumulation of snow takes place in the natural catchment areas when strong winds follow or accompany moderate or heavy snow storms.

Experiments are under way to see if artificial barriers can be used in conjunction with natural terrain features to increase the amount of snow trapped in the natural alpine catchments. To date only standard, vertical slat and wire snow fencing has been used (fig. 3). Tests during the winter of 1956-57 showed no appreciable advantage in erecting this type of fence so that it leaned into or away from the prevailing wind nor in overlapping two sections to get greater density. A single thickness of fence on vertical poles was easier to put up and in these tests appeared to trap as much snow as the more elaborate fences.

Spruce-fir, Lodgepole Pine Type

At the Fraser Experimental Forest, the effects of harvesting timber from a mature stand of lodgepole pine on over-winter snow accumulation was an early study of increasing water yields. The stand averaged about 75 feet in height and 12,000 board feet per acre. Twenty plots, 8 acres in size, were used, four intensities of cutting applied, and comparisons made with uncut plots. The residual volumes per acre remaining under the four intensities were: 6,000, 4,000, 2,000, and

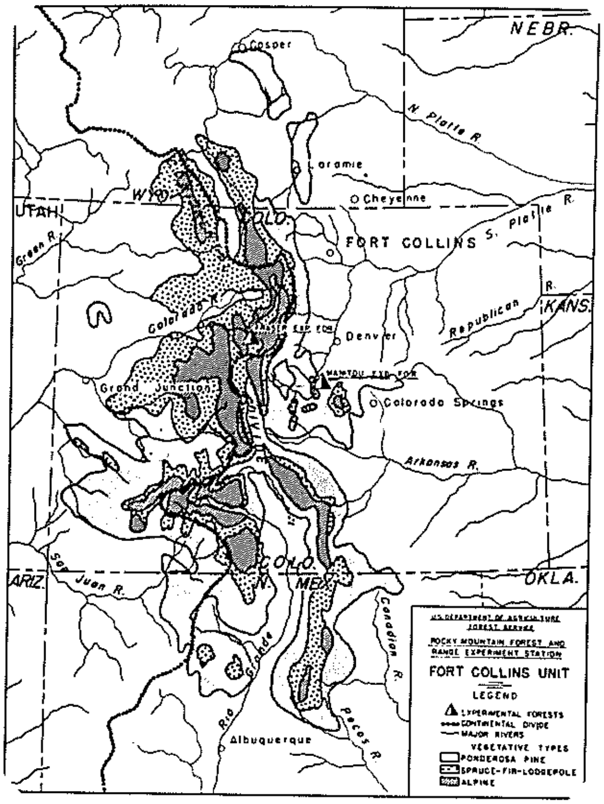

Figure 1. Predominate vegetation types, Southern Rocky Mountains.

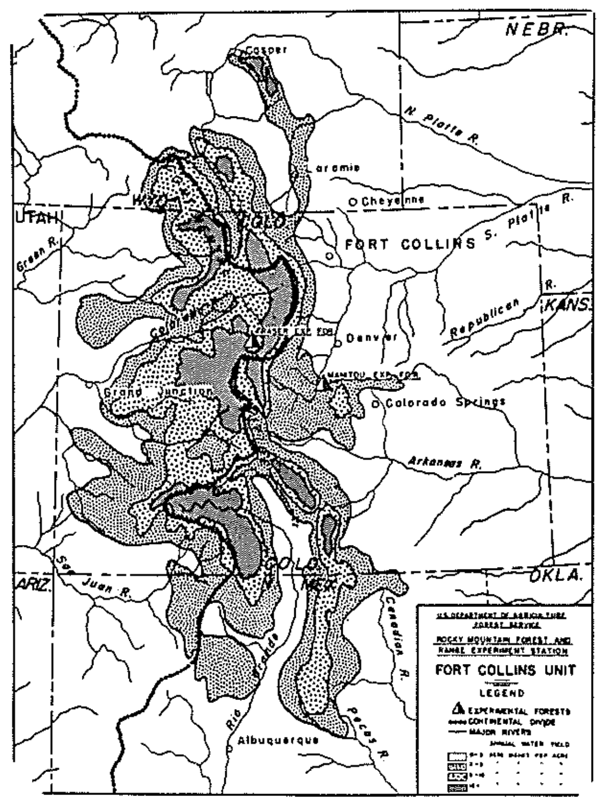

Figure 2. Annual water yield, Southern Rocky Mountains.

zero board feet in trees of sawlog size, 9.5 inches, d.b.h. or larger.

Measurements of winter snow accumulation, spring and summer precipitation, and summer losses of soil moisture over a 3-year period showed that the commercial clearcutting increased the water available for streamflow by 31 percent, or from 10.3 to 13.5 inches per year. The lesser intensities of cutting produced proportionately less increases in available water.

The effects of different patterns of timber harvesting were the subject of another plot study made in a mature stand of Engelmann spruce and subalpine fir averaging 18,000 board feet per acre and lying on a steep, north-facing slope. On each treated plot the harvesting left the same 40 percent of the original volume but the pattern differed from plot to plot. On one plot the harvesting left uncut strips 66 feet wide alternating with equal strips from which all trees 9.5 inches d.b.h. and larger had been removed. On another plot, harvesting was by group selection, whereby half of the plot area was cleared of mature timber by making openings 66 feet in diameter. From each of these plots, an additional 10 percent of the original volume was removed in a salvage cutting from the uncleared area. On a third plot, the cutting was by individual tree selection and the residual stand approximated a heavy shelterwood.

Snowpack comparisons among these plots and an untreated plot, over a 3-year period, indicated that the timber harvesting caused an average increase of 22 percent in the winter snowpack or an increase from 12.4 to 15.2 inches of water equivalent. There was no difference in the snowpack among the patterns of treatment, but the rate of spring snowmelt was slightly lower on the plot cut in a group-wise pattern, where shading from sunlight was more complete. The results indicated that on such a slope the snow accumulation was not related to the pattern of timber harvesting but only to the volume of timber removed.

The gaging of Fool and East St. Louis Creeks was begun in 1943 and continued without the logging of either watershed until 1954. The two watersheds are contiguous. That of East St. Louis Creek has an area of 1,984 acres. Fool Creek, the watershed finally treated, has an area of 714 acres of which 550 acres, or 77 percent, was in a dense mature stand of lodgepole pine, Engelmann spruce, and subalpine fir (fig. 4).

Following completion of a 12-mile road network, the logging of Fool Creek was started in 1954 and completed in 1956. The pattern of cutting was one of alternate clear-cut strips of different widths, 1, 2, 3, and 6 chains, running normal to the contours. From the clear-cut strips all live trees 4 inches d.b.h. and larger were removed. Fifty percent of the commercially timbered area of the watershed or 40 percent of the entire watershed was so cleared.

Although the final 20 percent of timber harvest was not completed until the summer and fall of 1956, that year has been classed as a post-treatment year for preliminary reporting. This gives four years of record to show the effect of the harvest. For each of these years, the excess of actual water yield over that predicted from the comparison with East St. Louis Creek is shown in table 1. Before the treatment of Fool Creek watershed, the annual water yield from this drainage averaged 13 inches; yield from East St. Louis Creek averaged 19.5 inches.

Table 1.--Actual versus predicted water yield from Fool Creek in post-treatment years.

Years	Predicted yield	Actual yield	Actual yield minus predicted yield
		Area inches	
1956	11.4	15.6	4.2
1957	19.6	23.0	3.4
1958	11.4	13.5	2.1
1959	10.5	13.6	3.1

Most of the increase in yield has occurred during the spring freshet period of May and June, but there has also been a small increase in the summer and early fall months. Each year the early rise of Fool Creek is more rapid than formerly, and in 3 years the spring peak has been higher than it would have been had the timber not been cut. However, in 1957, the timber removal combined with a particular weather pattern to cause a peak appreciably lower than predicted by comparison with the behavior of East St. Louis Creek.

Ponderosa Pine Type

Water yield from streams originating in the ponderosa pine type averages less than 6 inches annually. A surplus of water is built up during the winter to be released as snowmelt in the early spring, followed by a period of water deficit during the summer and early fall. Evapo-transpiration is largely responsible for this deficit and amounts to over 15 inches. For temporary periods the water deficit may be reduced and streamflow augmented during summer rainstorms that may be either of a general nature or localized thundershowers. The bulk of the annual water yield occurs in April and May, and becomes gradually less during the summer and fall.

North exposures of the ponderosa pine zone offer some possibilities of increasing water yield through the harvest of timber (fig. 5). These possibilities were pursued in a preliminary way by means of plot studies during 1957-58 and 1958-59, near the Manitou Experimental Forest.

In a mixed stand of ponderosa pine and Douglas-fir on a north exposure, two batteries of 3 one-acre plots each were established to measure the water content of over-winter snow accumulation under cut and uncut conditions.

Two plots were left uncut, on two others 60 percent of the merchantable volume was selectively cut, and on the remaining two, all merchantable timber was removed. The basal area was reduced from an average of 120 square feet per acre to 94 square feet per acre under selection cutting and to 43 square feet under commercial clearcutting. Comparison of maximum snowpacks, in inches water content, of individual commercially clearcut and uncut plots during both winters showed an average increase of 1.2 inches with a range of .24 to 2.6 inches.

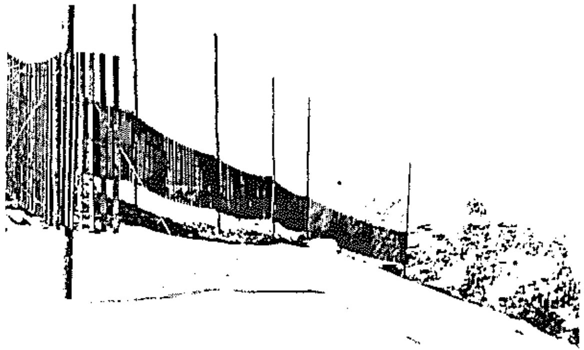

Figure 3. Vertical slat and wire snow fencing is used to trap additional snow in natural alpine catchment areas.

Figure 4. Strip cutting on Fool Creek watershed (left); East St. Louis Creek to the right. Fraser Experimental Forest.

Figure 5. Snow accumulates over-winter on north exposures (right), but disappears rapidly on south (left), ponderosa pine type.

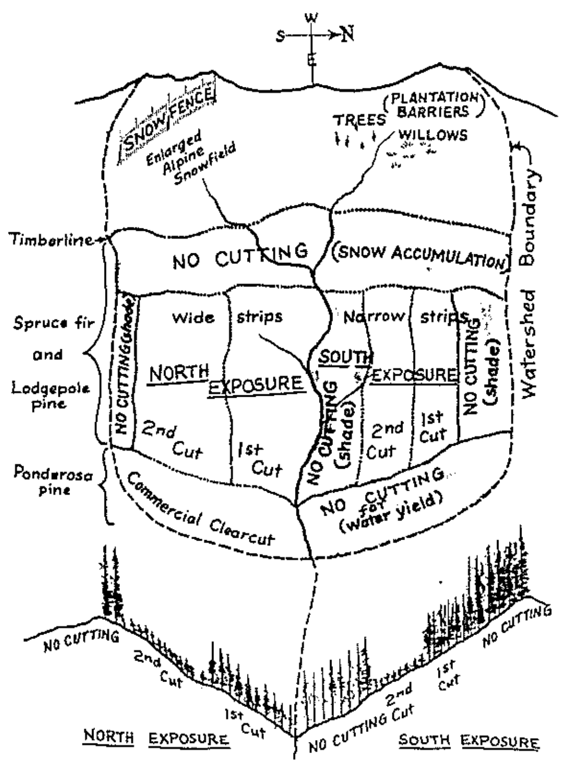

Figure 6. Sketch showing how a watershed might be managed for effective water yields.

Although snowfall during the two winters was different, the increase in water content of the maximum snowpack on the commercially clear-cut plots was significant when compared to the uncut plots. This was not true of the selectively cut plots. Snow disappeared from all plots at about the same time, indicating a speed-up in snowmelt on the commercially clear-cut plots.

Mountain Watersheds

Future management of the high elevation lands of the Southern Rocky Mountains will more and more be directed towards water as the primary product. The watershed thus becomes the basic unit of land area for resource management. In keeping with the subject of this discussion we might speculate on how a watershed might be managed for effective water yields by increasing water supplies and by altering the timing of streamflow (fig. 6). What we, and others, have learned from plot and watershed studies has been put together in a single sketch to accomplish two purposes; namely, (1) to deduce how a watershed might be managed and (2) to point up the watershed research needed before such a management program can be undertaken. All situations can't be covered nor can agreement be reached now on how to manage for effective water yield.

A watershed managed for effective water yield conceivably might include (1) snowfences or plantations to increase the size of alpine snowfields, (2) clearcut strips of varying width to increase snow accumulation in the spruce-fir lodgepole pine forests and (3) commercial clearcutting on north exposures only in the ponderosa pine, Douglas-fir forests. A considerable portion of the forests would remain uncut to allow for snow accumulation near timberline, to shade openings, to curtail windthrow, and to protect south exposures in the ponderosa pine from excessive erosion. Even with all of this manipulation there is no guarantee that increased water yield or change in the timing of streamflow would result because of variations in topography, climate, soils, vegetation density and composition.

If a watershed were to be managed for effective water yield, as described above, new problems would be created and considerably more research would be needed to warrant such intensive management measures. For example, it is yet to be proven that barriers will materially increase the size of alpine snowfields and that this increased size will result in additional late summer streamflow. What is the relation of these enlarged snowfields to either the increase or decrease of avalanche hazards?

In the spruce-fir forests little is known about the exact influence of solar radiation on snow accumulation and melt in dense forest stands, in alternating clearcut and uncut stands, and on different exposures and slopes. Likewise, information is sparse on transpiration changes from uncut to cut forest stands. Comparative studies are needed as to which individual species of trees, grasses, or shrubs are the superior watershed cover from the standpoint of water yield. The reaction of the different soils to vegetation manipulation for water yield is not thoroughly known. Nor are all the facets of silviculture and timber harvest explored in the spruce-fir lodgepole pine type. Although timber harvest has resulted in increased water yields, the reasons why the increase occurred are not readily apparent, nor have the possible changes in the timing of streamflow been investigated. Since these high elevation forests are the prime source of water in the Southern Rocky Mountains, information concerning their management for water yield is urgently needed.

Past timber harvesting in the ponderosa pine on south exposures has resulted in the deterioration of the site through accelerated erosion. Opportunities appear to exist on north exposures covered with ponderosa pine and Douglas-fir to increase water yield by commercial clearcutting. That such increases might occur is still to be proven and associated studies of silviculture, regeneration, and methods of harvest must precede such a test. As in the case of the spruce-fir lodgepole pine type, little is known concerning the influence of solar radiation on snow accumulation and melt, the transpiration of cut and uncut ponderosa pine stands, and the reaction of different soils to vegetation manipulation.

SUMMARY

Water yielded from the alpine and subalpine mountain areas of the Southern Rocky Mountains constitutes the most abundant and constant annual supply of four major rivers; the Rio Grande, the Colorado, the Plattes, and the Arkansas. These rivers provide the water needed for irrigation, industries, homes, and towns located for the most part, outside of the mountains. Water for these purposes is often used several hundreds of miles away from its source.

Present day watershed research indicates that water yields from mountainous areas may be increased through the use of barriers in alpine snow catchment basins and by the harvesting of timber in the spruce-fir lodgepole pine stands. Improving water yields from ponderosa pine stands is not so clearly indicated. Research results to date point to a possible increase in annual water yield of 20 to 25 percent but that this increase occurs at a time when water is plentiful and not at the peak of its highest demand.

Applying present-day watershed management knowledge to an entire watershed for effective water yields will result in many pitfalls. The most pressing of these is the lack of research results needed to more adequately understand the behavior of a watershed when its natural environment is altered for the purpose of increasing or changing the timing of annual water supplies. The speeding up of watershed management research in mountainous areas will provide the basis for future management measures sorely needed in the development of southwestern water supplies.