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Department of
Agriculture

Forest Service

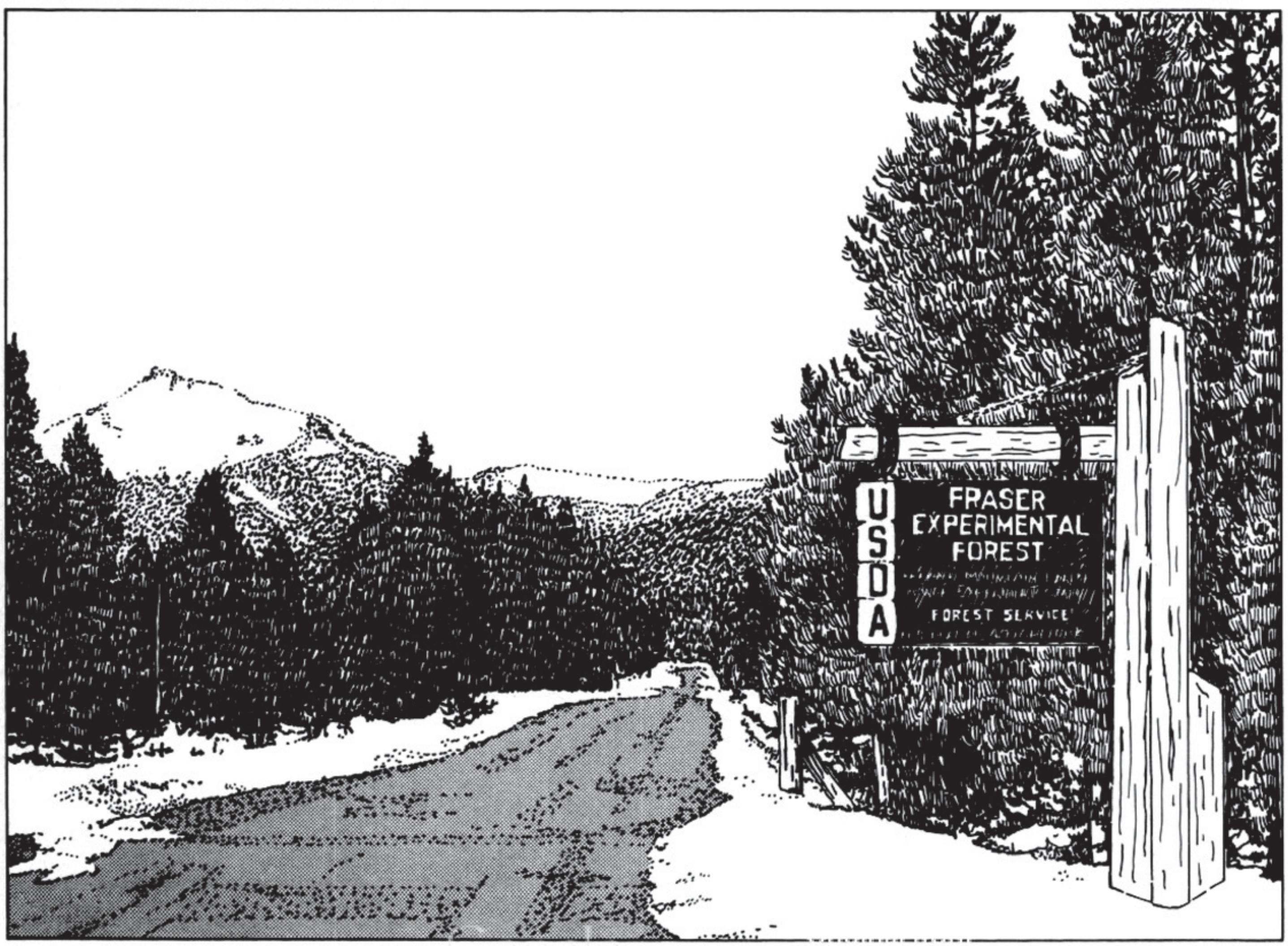
**Rocky Mountain
Forest and Range
Experiment Station**

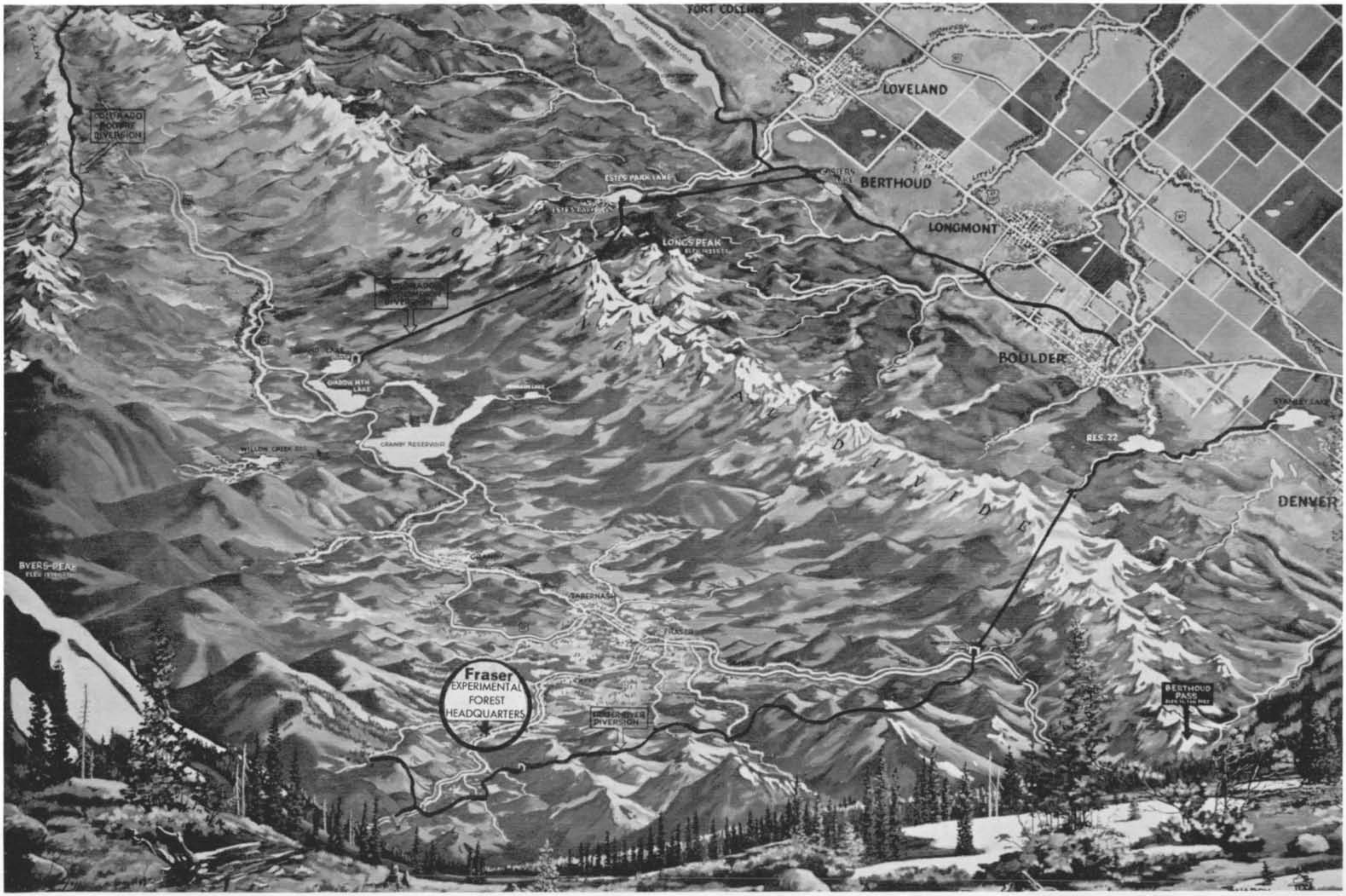
Fort Collins,
Colorado 80526

General Technical
Report RM-118

The Fraser Experimental Forest, Colorado: Research Program and Published Research 1937–1985

Robert R. Alexander, Charles A. Troendle, Merrill R. Kaufmann, Wayne D. Shepperd, Glenn L. Crouch, and Ross K. Watkins





FORT COLLINS
LOVELAND
BERTHOUD
LONGMONT
BOULDER
DENVER
ESTES PARK LAKE
LONGS PEAK
CONTINENTAL DIVIDE
RES. 22
STANLEY LAKE
SHADOW MTN LAKE
GRANBY RESERVOIR
WILLOW CREEK RES.
BYERS PEAK
GRANBY
TABERNASH
FRASER
Fraser
EXPERIMENTAL
FOREST
HEADQUARTERS
FRASER RIVER
DIVERSION
BERTHOUD
PASS

Abstract

This report provides an overview of the research done on the Fraser Experimental Forest. It replaces GTR's RM–40 and RM–40A by Robert R. Alexander and Ross K. Watkins, published in 1977 and 1978. Included are descriptions of physical features and resources, highlights of past and current research, and the publications derived from that research.

USDA Forest Service
General Technical Report RM-118

May 1985

The Fraser Experimental Forest, Colorado: Research Program and Published Research 1937–1985

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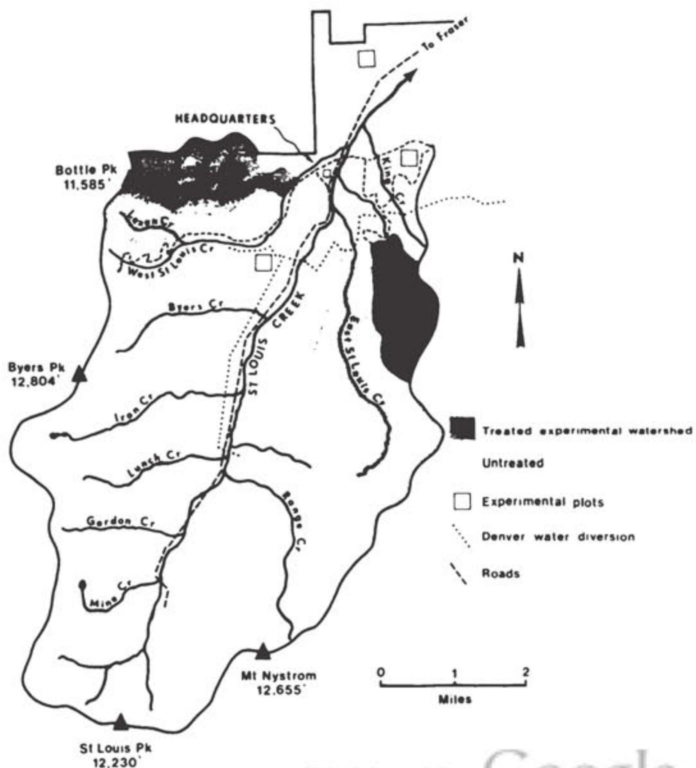
The Fraser Experimental Forest, Colorado: Research Program and Published Research 1937–1985

Robert R. Alexander, Charles A. Troendle, Merrill R. Kaufmann, Wayne D. Shepperd, Glenn L. Crouch, and Ross K. Watkins

The Fraser Experimental Forest was established in 1937 in the heart of the central Rocky Mountains. This 36-square-mile outdoor research laboratory maintained by the Rocky Mountain Forest and Range Experiment Station is located 50 air miles west of Denver, Colo. The location is well suited to the study of timber, water, and wildlife management, and their integration in high elevation subalpine coniferous forests.

In the West, water is vital to life and development. St. Louis Creek, the main drainage on the Fraser Experimental Forest, is typical of headwater streams that are the source of 85% of the annual yield of about 20 million acre-feet of water from the Colorado Rockies.



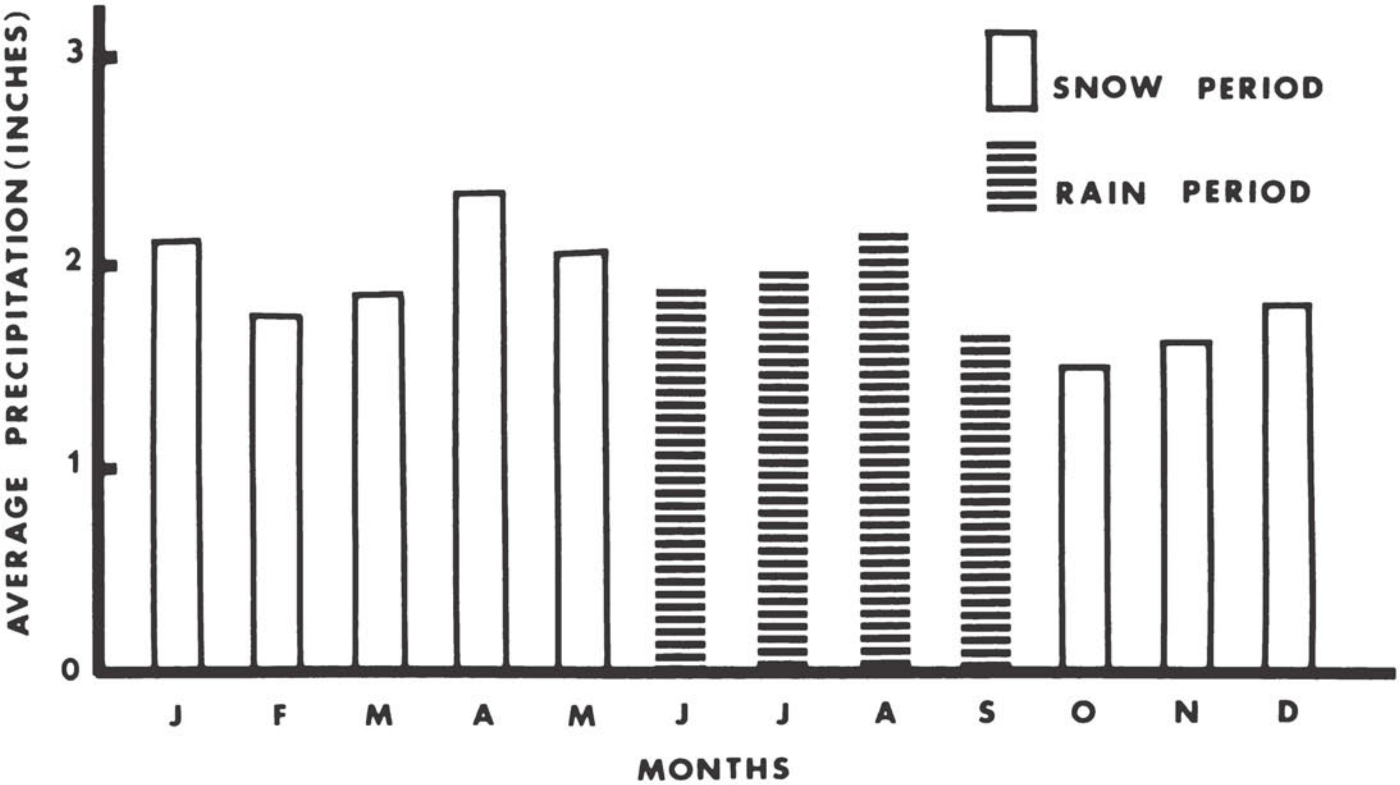
The relationship between water sources in high elevation forests, extensive transmountain diversion, and domestic, industrial, and agricultural users is shown in the schematic view of the Fraser Experimental Forest and its surrounding country on the inside front cover. The Colorado-Big Thompson transmountain diversion taps the headwaters of the Colorado River and brings water through the 13-mile-long Alva Adams Tunnel to users on the east side of the Continental Divide. The Fraser River transmountain diversion, constructed by the City of Denver to bring water from St. Louis and Vasquez Creeks, crosses the Continental Divide through the pioneer bore of the 6-mile-long Moffat Tunnel.

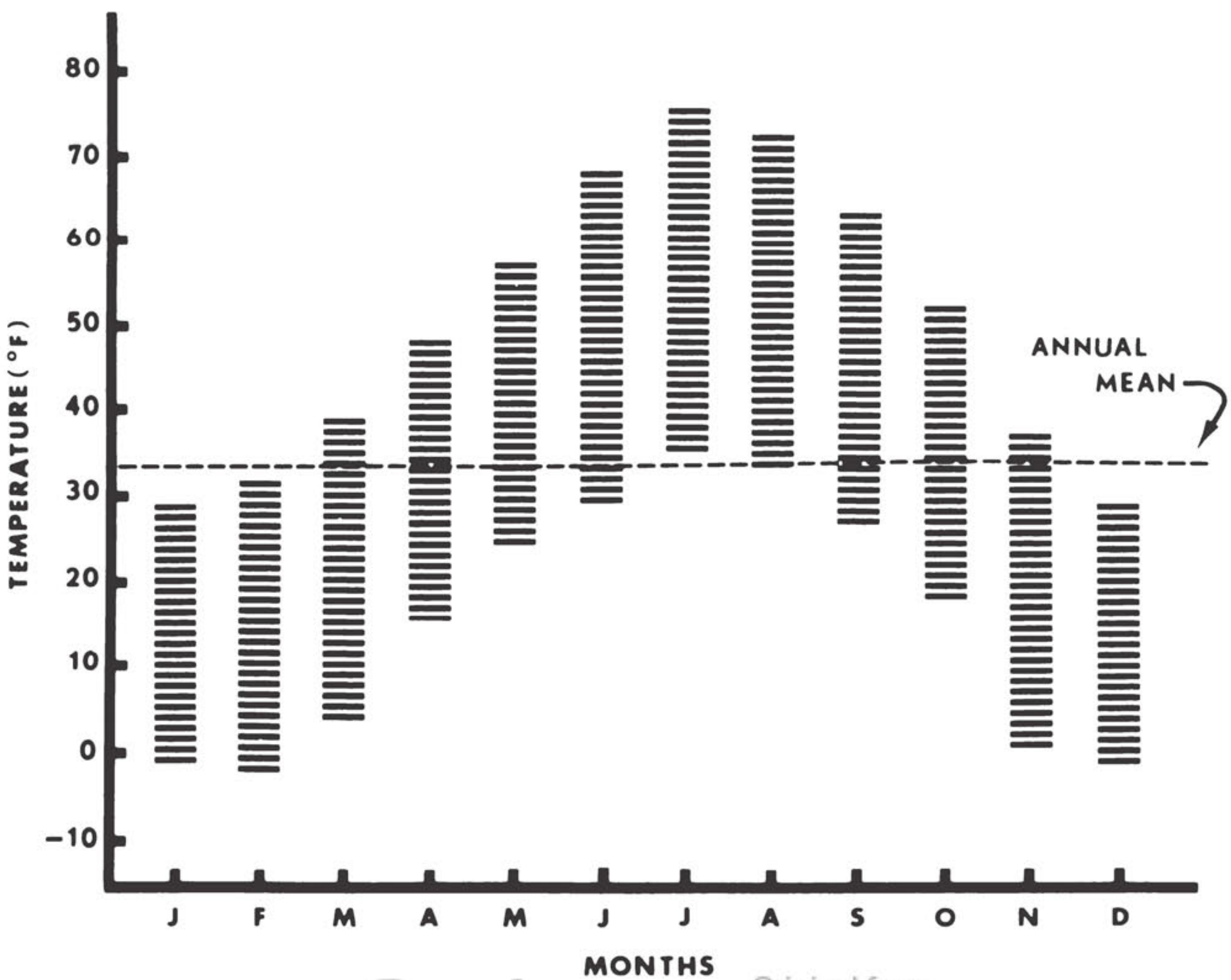
THE FOREST

Elevation of the Experimental Forest ranges from 8,800 feet at the main entrance along the road from the town of Fraser, to 12,804 feet at the summit of Byers Peak. About three-fourths of the Forest lies above 10,000 feet, and about one-third is above timberline.

Climate

Climate is cool and humid with long, cold winters and short, cool summers. Average yearly temperature at Forest headquarters (9,000 feet elevation) is 33° F, and frost can occur any month of the year. Mean monthly temperature for January is 14° F, for July 55° F, with an observed range of about –40 F° to 90° F. Annual precipitation measured at the headquarters area varies from about 17 to 28 inches, with an average of nearly 23 inches. Precipitation over the entire Experimental Forest averages about 28 to 30 inches, with nearly two-thirds falling as snow from October through May.


SNOW PERIOD
RAIN PERIOD
AVERAGE PRECIPITATION (INCHES)
0
1
2
3
J F M A M J J A S O N D
MONTHS

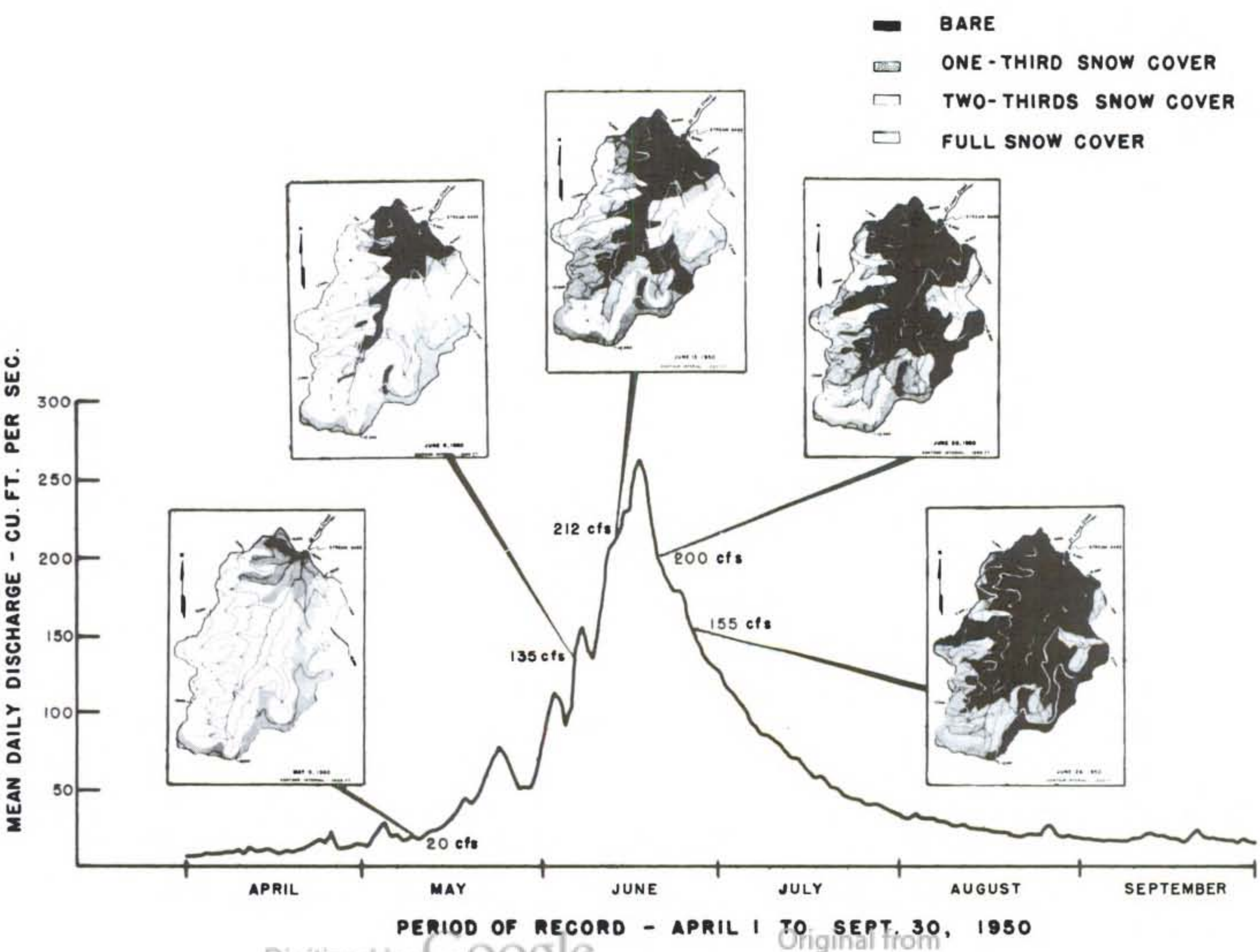

TEMPERATURE (°F)
-10
0
10
20
30
40
50
60
70
80
ANNUAL MEAN
J F M A M J J A S O N D
MONTHS

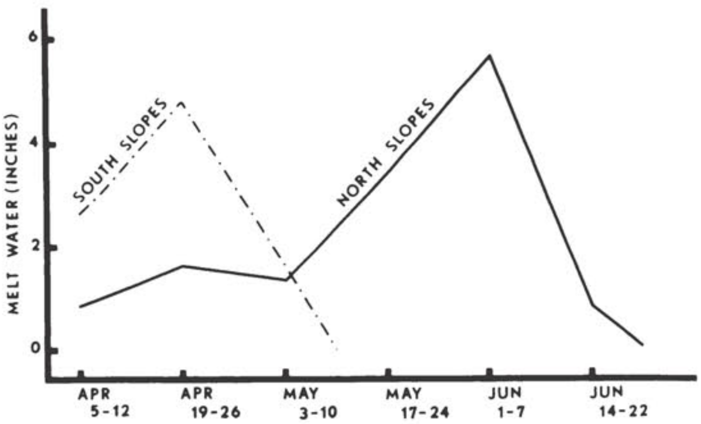
Water Yield

Snowfall is the key to water yield. On the Experimental Forest, the first snow is deposited in early fall, and the pack gradually accumulates to its peak water equivalent in early spring. Long, cold winters keep temperatures within the snowpack well below freezing until late March or April. Peak seasonal snow accumulation averages about 15 inches water equivalent, and during melt season, the depleting snowpack is augmented by 5 inches or more of additional precipitation. Rainfall during summer and early fall averages 8 to 10 inches. Of the total 28 to 30 inch input, about 12 to 15 inches becomes streamflow. Streams begin to rise from minimum flows in April, reaching peak levels in June. Streamflow then rapidly recedes, nearing baseline flows again in late summer.

Snow Cover Disappearance

The entire Forest is covered with snow by the end of winter. As spring advances, snow disappears progressively from lower to higher elevations. Snow melts and disappears from south slopes first. Maximum melt rate is about 0.75 inches per day on south slopes and 0.5 inches on north slopes. When 50% of the snow has disappeared, spring streamflow peaks on the main drainage; when 80% of the snow is gone, streamflow is declining. Temperature, humidity, and wind also influence the daily rate of snowmelt which, in turn, governs streamflow. Continuous records of these factors have been useful in calculating rates of streamflow on the St. Louis Creek drainage, and in forecasting daily streamflow.





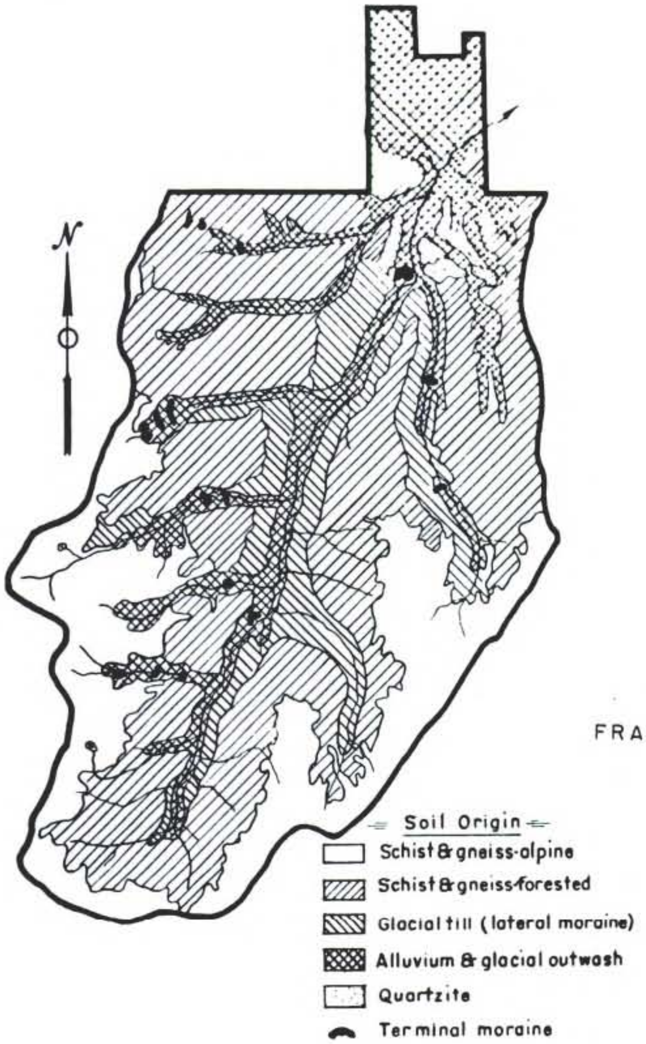
Geology, Landforms, and Soils

Topography of the Experimental Forest is typical of the Southern Rocky Mountain Province. The west side of the Forest is characterized by rugged mountains and narrow, steep-sided valleys filled with alluvium and glacial outwash. South and east sides of the Forest are remnants of an old peneplain, dissected by mountain glaciers and characterized by long, gentle, relatively uniform slopes. The north side is a nearly level, broad valley dissected by St. Louis Creek and surrounded by rolling hills.

Parent material of soils on the Forest generally is derived from gneiss and schist rocks. Occasionally, there are small outcroppings of granitic rock, which weathers more slowly than schists. Typical soils from schistic and granitic rock contain angular gravel and stone, with very little silt and clay. They are very permeable and capable of storing considerable amounts of water during snowmelt. At high elevations, especially on the west side of the Forest, soils have developed in material weathered from sandstones. These soils are shallow, have large amounts of stone, and have fine sand or sand textures. Alluvial soils occur along main streams, with parent material a mixture of glacial till, glacial outwash, and recent valley fill. Bogs originating from seeps or springs that emerge on slopes are scattered throughout the Forest.

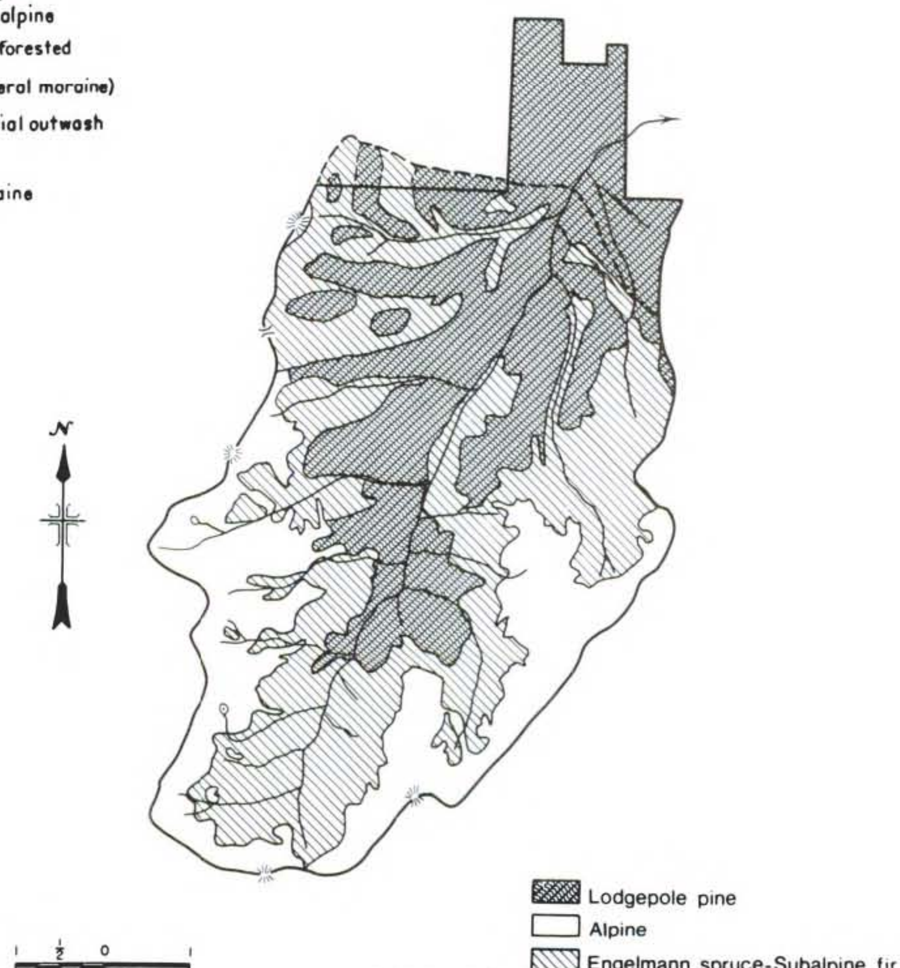
Vegetation

Native vegetation is typical of the subalpine forest zone of the central Rocky Mountains. Engelmann spruce and subalpine fir are predominant trees at higher elevations, on north slopes, and along streams; lodgepole pine is the predominant tree at lower elevations and on drier upper slopes. In virgin stands, trees range from 200 to 400 years old. Second-growth lodgepole pine on the north end of the Forest originated after fires, and is about 60 years old. Scattered patches of aspen occur in areas opened up by logging or fire. Occasionally, a large, old (450 to 500 years) Douglas-fir can be found. The forest floor generally is covered with a layer of duff and litter and often a dense mat of whortleberry. Herbaceous vegetation is generally sparse except along streams, and in openings resulting from disturbance. Barren rocks intermix with alpine tundra, meadows, and bogs above timberline.



FRASER EXPERIMENTAL FOREST – COLORADO

NATIVE VEGETATION



Wildlife

Many kinds of wildlife live on the Forest, but no one species is abundant. Trout occur in some streams, beaver ponds, and lakes. Elk, deer, black bear, and mountain lion are the Forest's big game animals. Moose have occasionally been sighted but are not considered part of the Forest's resident big game population. Elk are found in alpine grasslands and high cirque basins in summer, but do not winter in any part of the Forest. Mule deer are more common than elk. In summer, they graze in timbered areas and openings intermixed with timber. In winter, they move to lower areas off the Forest. Black bears are shy and rarely seen. Mountain lions are only occasional visitors. Small, fur-bearing mammals include marten, weasel, mink, badger, muskrat, red and gray foxes, coyote, bobcat, and beaver along some watercourses. Snowshoe hares, pine squirrels, porcupines, marmots, chipmunks, ground squirrels, mice, gophers, shrews, and voles also are present. Numerous game and nongame birds occur on the Forest. Some are residents, others are seasonal, and still others are migratory.

Recreation

The Forest provides a variety of recreational opportunities, with two developed campgrounds, 20 miles of specified roads, and many trails. In summer, users camp, hike, fish, backpack, and view and photograph scenery. In fall, hunters seek blue grouse, elk, and deer. Snowmobiling and ski-touring are popular in winter.

RESEARCH PROGRAM

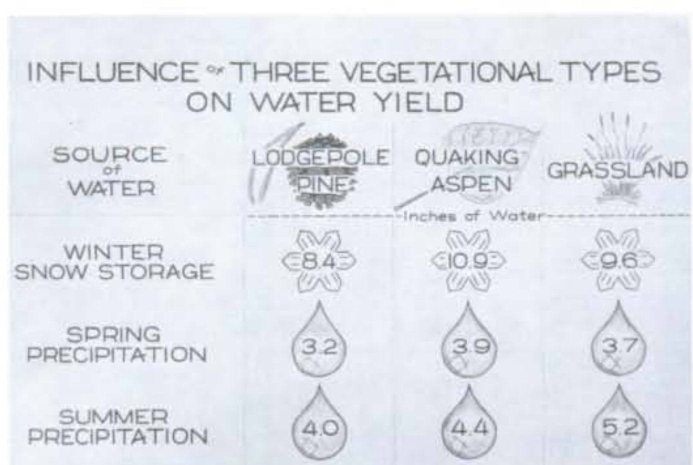
The research program at the Fraser Experimental Forest is concerned with regenerating new forest stands, increasing growth and yield of trees, increasing water supplies and maintaining water quality, determining water use and availability, improving wildlife habitat for game and nongame animals, and determining the integrated effects of timber harvesting on these resources. Specifically, research objectives are:

1. Understanding how trees grow, reproduce, and interact; how the hydrologic system operates on headwater streams, and what the food and cover requirements of wildlife are.
2. Learning how natural forest cover influences the tree, water, and wildlife systems.
3. Observing how harvesting timber changes the influence of the forest on these systems; and
4. Devising timber harvesting systems to achieve the desired changes in forest cover that will provide the best mix of timber, water and wildlife benefits.

Publications derived from research at the Fraser Experimental Forest are listed by subject matter categories at the end of the text

RESEARCH HIGHLIGHTS

Early studies included observations in natural plant communities or environments to determine their effects on snow accumulation. Results showed more precipitation reached the ground under aspen and in grasslands than under dense lodgepole pine stands. These studies provided clues to the effect on water yield when forest stands were harvested for timber or thinned to improve growth.



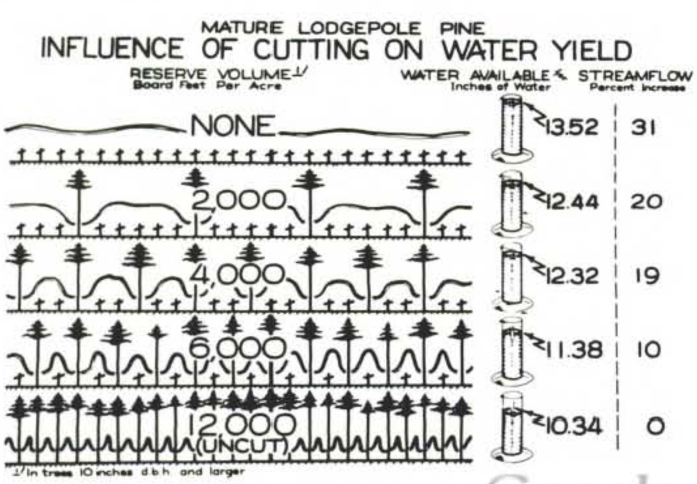
Plot studies of harvest cuttings and thinnings followed. Their purpose was to determine how different methods and intensities of tree removal affected the snowpack and tree reproduction, growth, and mortality. A third research phase applied a timber harvesting system to an entire watershed to measure its effects on (1) streamflow and snow accumulation and melt; (2) sedimentation; (3) tree regeneration, growth, and mortality; and (4) big game use, forage availability, and preference. This included basic hydrologic studies aimed at measuring water loss from both vegetation and the overwinter snowpack. The present phase involves pilot testing of timber, water, and wildlife systems and their interactions in relation to timber harvesting on other watersheds; and basic studies of water use by trees and stands and the movement of meltwater through the soil profile.

Harvest Cutting in Lodgepole Pine

Twenty 5-acre plots were established in 1938 on the King Creek drainage in mature lodgepole pine. After snowpack, regeneration, and stand inventory measurements had been recorded, plots were logged in 1940, with treatments ranging from clearcutting to no cutting. Residual volumes in trees 9.5 inches in diameter and larger on logged plots were 0, 2,000, 4,000, and 6,000 board feet (fbm) per acre. Uncut plots averaged about 12,000 fbm per acre.

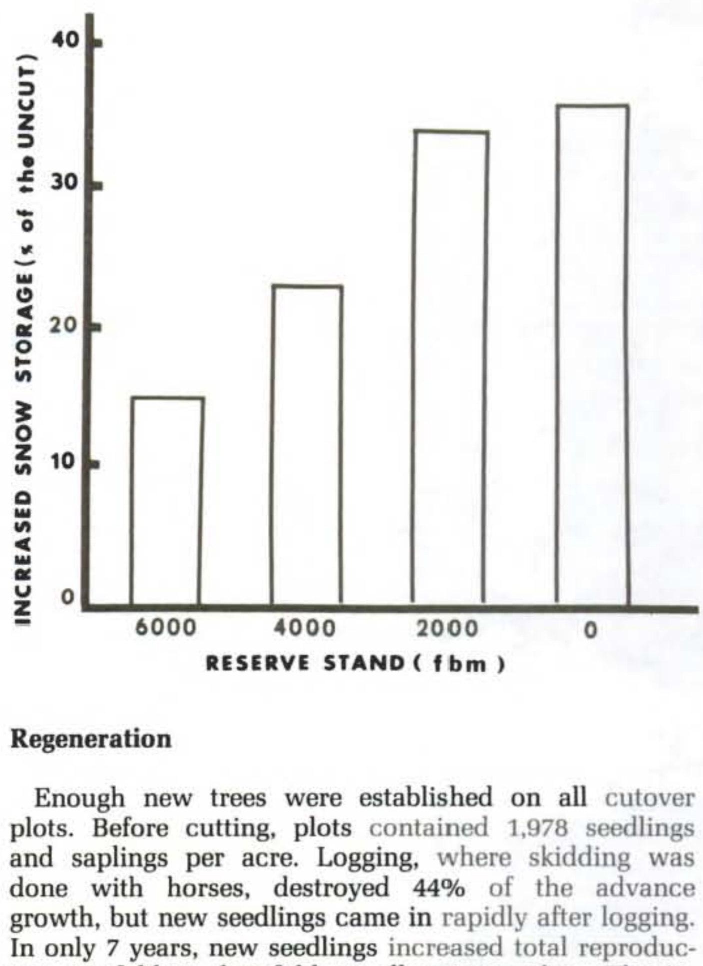
Water Available for Streamflow

After winter snowpack accumulation, net summer precipitation input, and growing season soil moisture depletion following timber harvest were monitored, an estimate was made of the effect that different cutting intensities have on water available for streamflow. The estimate was based largely on changes in net precipitation and only superficially addressed other E.T. changes known to have occurred. The largest increase was on clearcut plots; the smallest was on 6,000 fbm reserve plots.



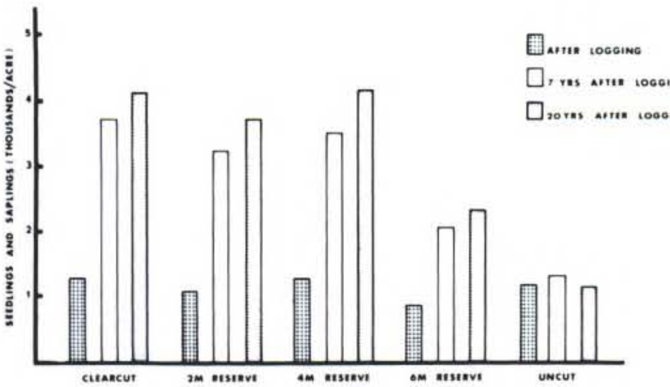
Snow Accumulation

Most of the increase in water available for streamflow came from increased snow storage on cutover plots. Although young trees developed rapidly on cutover plots, snow storage amounts have changed little in the years since cutting, especially on the clearcut plots. The increased snow on clearcut plots is primarily due to the aerodynamic effect of the openings on the snow deposition pattern rather than solely due to reduced interception loss. More snow is deposited in the openings and less in the downwind forest during the storm. The smaller increases observed under partial cutting were largely a reflection of interception saving rather than changes in the deposition pattern. This increased accumulation in the open will persist until new trees, established after logging, are tall enough to change the aerodynamic effect on snow accumulation. To increase snow accumulation, clearcutting of mature lodgepole pine in small patches is the most desirable method of harvesting.



Regeneration

Enough new trees were established on all cutover plots. Before cutting, plots contained 1,978 seedlings and saplings per acre. Logging, where skidding was done with horses, destroyed 44% of the advance growth, but new seedlings came in rapidly after logging. In only 7 years, new seedlings increased total reproduction twofold to threefold on all cutover plots. The increase was greatest on clearcut plots and least on 6,000 fbm reserve plots. Reproduction continued after 1947, but at a much slower rate, and the increase was not directly related to cutting method.

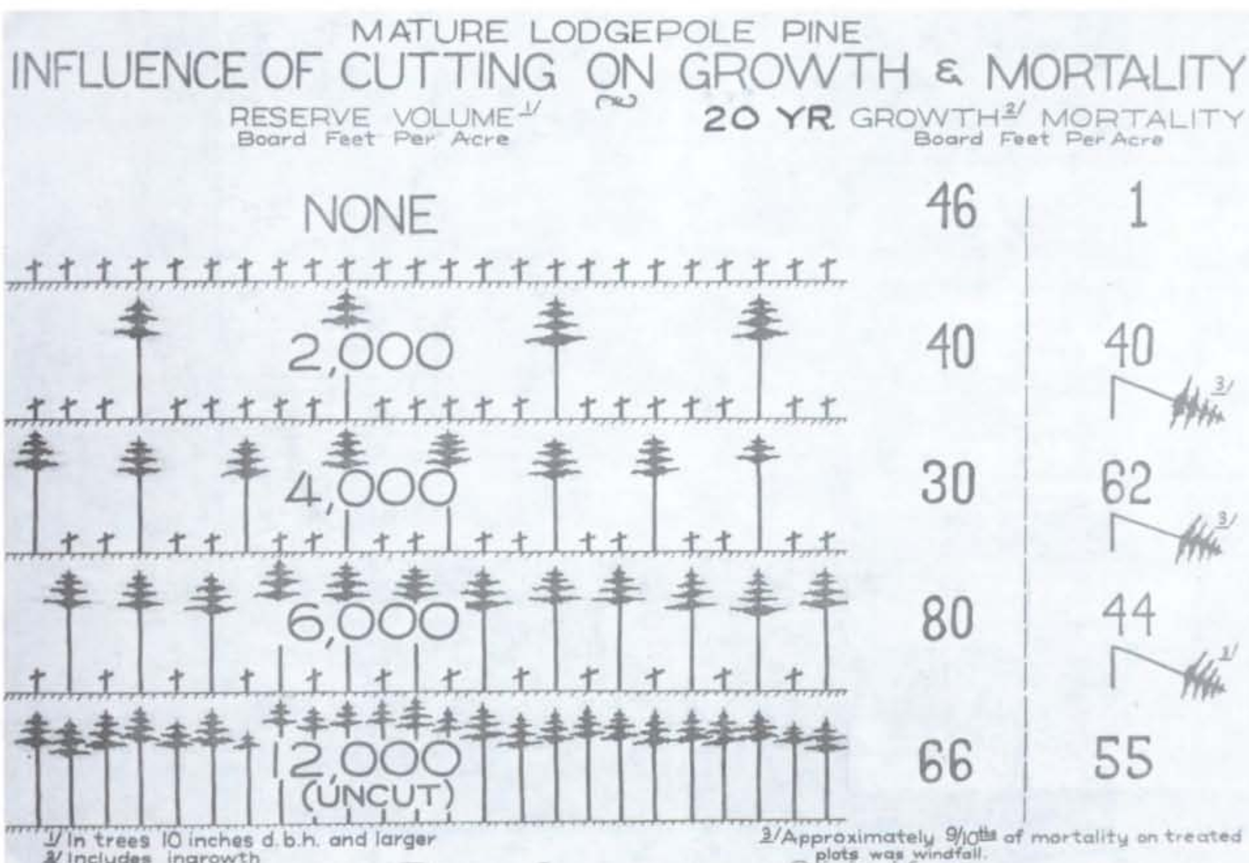


Growth and Mortality

Heavy mortality during the first 7 years after cutting resulted in little new growth on 6,000 fbm reserve and uncut plots, and an actual loss of volume on 2,000 and 4,000 fbm reserve plots. No measurable volume losses occurred on clearcut plots because no merchantable-sized trees were left. After 1947, mortality declined, and net growth increased on all plots. After 20 years, however, only the 6,000 fbm reserve plots grew more than uncut plots. Windfall was responsible for nearly all mortality on partially cut plots and about half the mortality on uncut plots. Because of heavy mortality, clearcutting and replacement of the old stand with a vigorous new one is recommended as the most desirable method for harvesting old-growth lodgepole pine. Partial cutting requires leaving large reserve volumes of low vigor trees, increasing the risk of future mortality.

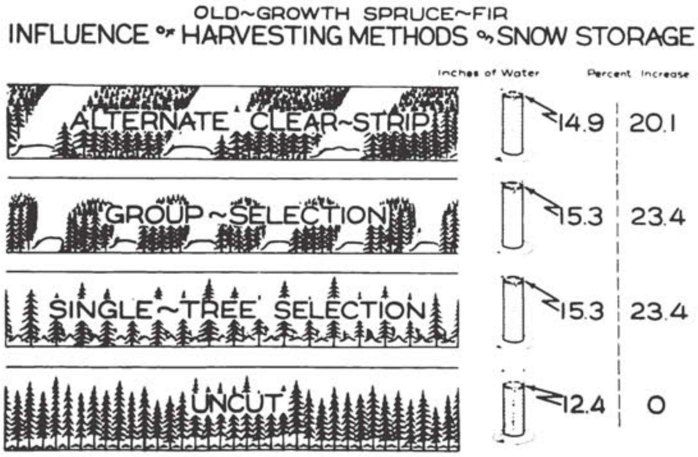
Harvest Cutting in Spruce-Fir

In 1944, four 8-acre plots were established on the West St. Louis Creek drainage to evaluate methods of cutting in old-growth spruce-fir forests. Treatments tested were alternate-strip clearcutting, group selection cutting, and individual tree selection cutting. Each treatment removed 60% of the volume in trees 9.5 inches diameter at breast height (d.b.h.) and larger. Alternate-strip clearcutting removed 50% of the volume in alternate strips 1 chain wide; an additional 10% was removed from the leave strips by cutting overmature trees. Group selection cutting was used to remove 50% of the volume in small circular openings about 1 chain in diameter; an additional 10% was removed by cutting trees in the between-groups stand. Individual tree selection cutting removed 60% of the volume uniformly over the entire plot. Residual volume on cutover plots averaged 6,460 fbm per acre. The original volume of 17,745 fbm per acre remained on the uncut plot.



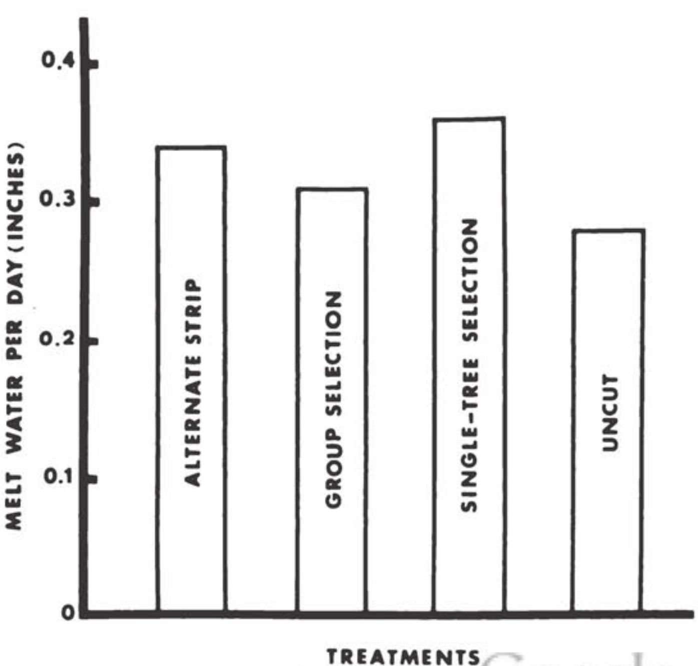
Snow Accumulation

Snowfall reaching the ground increased on all cutover plots after logging. Measurements in four of the years after logging showed an average accumulation of 22% more water equivalent on cutover plots than on the uncut plot, but there were no differences in snow storage between treatments.



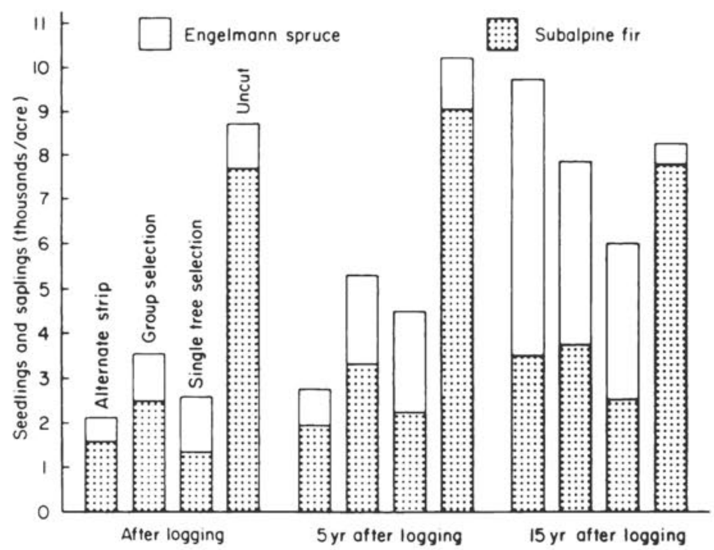
Snowmelt

Weekly measurements of rates of snowmelt during the spring showed only slight differences between treatments. Snow melted fastest (0.36 inch per day) after individual tree selection cutting and slowest (0.28 inch per day) in the uncut plot.



Regeneration

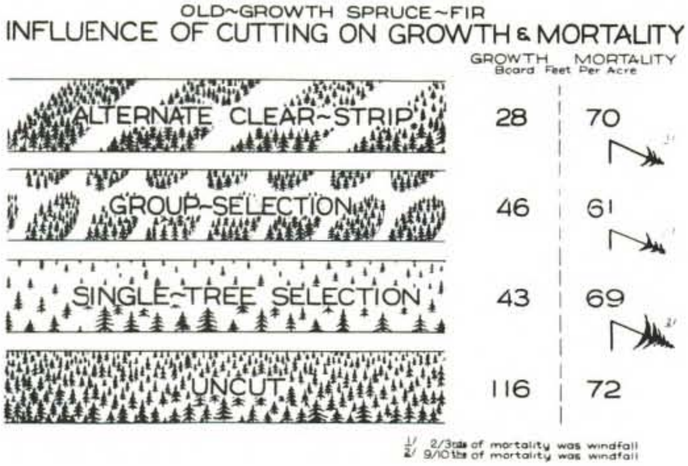
Reproduction was adequate under any cutting method tested. Before logging, plots averaged 6,344 seedlings and saplings per acre, with the ratio of fir to spruce ranging from 5 to 1 on the alternate strip clearcut plot to about 1 to 1 on the individual tree selection plot. Logging—where skidding was done with horses—destroyed 52% of the advanced reproduction. Damage among the three cut plots was heaviest on the individual tree selection plot where the entire area was disturbed, and was least on the group selection plot where about one-third of the area was disturbed. Subsequent reproduction established at only a moderate rate during the first 5 years after logging. Initial recovery was poorest on the alternate strip clearcut plot, where only about half as many trees established as on other cutover plots. The rate new reproduction established accelerated after 1949. The largest increase was on the alternate strip clearcut plot where new reproduction outnumbered the increase on group and individual tree selection cutting plots by three and four times, respectively. The number of new spruces was three to five times greater than new firs on all cutover plots.



Growth and Mortality

Growth of residual stands was not stimulated by the cutting methods tested. Furthermore, differences in board foot volume growth between cutting treatments were unimportant. Mean annual growth on all plots was proportional to reserve volume.

Mortality was not materially different between plots. Windfall caused at least two-thirds of the mortality on cutover plots, with the heaviest losses on the individual tree selection plot. Disease and insects were responsible for most of the mortality on the uncut plot. Because of more abundant and better distributed spruce reproduction, and less susceptibility of residual stands to windthrow, alternate strip clearcutting and group selection cutting were the most desirable harvesting method tested for old-growth spruce-fir stands.

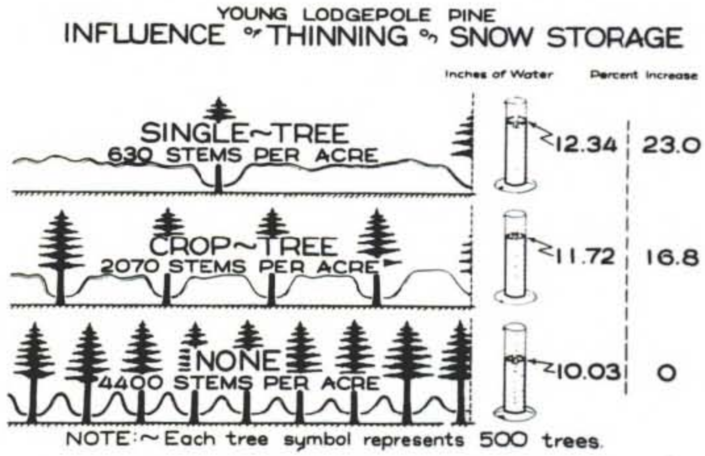


Thinning Young Lodgepole Pine

Eighteen 1/4-acre plots were established in 1944 in young (35-year-old) lodgepole pine stands in the main St. Louis Creek drainage to test thinning methods. Original stand density varied from 2,100 to 8,576 stems per acre. After snowpack and stand inventory measurements were made, six plots—designated single tree—were thinned uniformly from below in 1945, reserving 630 trees per acre. On six other plots—designated crop tree—all trees within a 16-foot-diameter circle around each of 100 crop trees per acre were cut. The remaining six plots were left unthinned as a control.

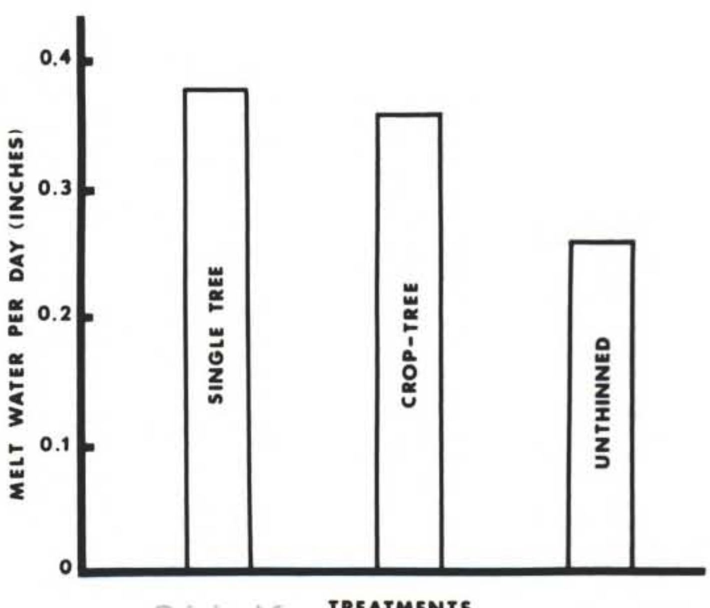
Snow Accumulation

Cutting resulted in more snow reaching the ground on thinned plots than in natural stands. The highest snow accumulation observed during a 3-year period was on single-tree plots where the largest number of trees had been removed.



Snowmelt

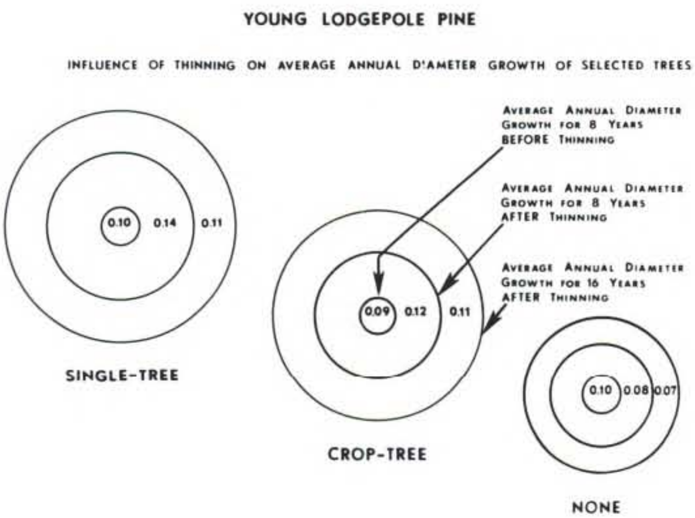
The rate of snowmelt during spring was greater on thinned than unthinned plots, but there was little difference in melt between single-tree and crop-tree thinning.



Growth

Diameter growth of the best 100 trees per acre was increased about 1–1/2 times by both thinning methods during the 16 years of observation, but diameter growth of all trees on plots was increased only by single-tree thinning. Basal area increment of the total stand was not affected by thinning. Cubic volume growth during the first 8 years of observation was greater in unthinned than thinned stands, but during the last 8 years of observation, there was no difference in cubic volume growth between thinned and unthinned plots.

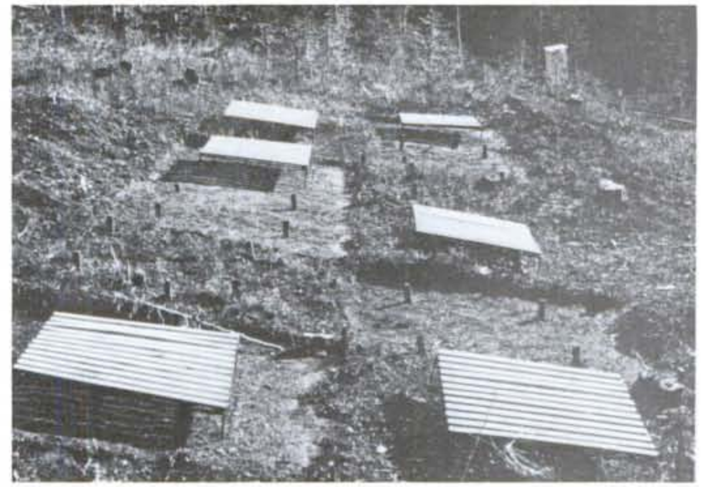
Because of larger increases in water available for streamflow and concentration of total stand growth on fewer stems, single-tree thinning was recommended, but not necessarily at the spacing tested.



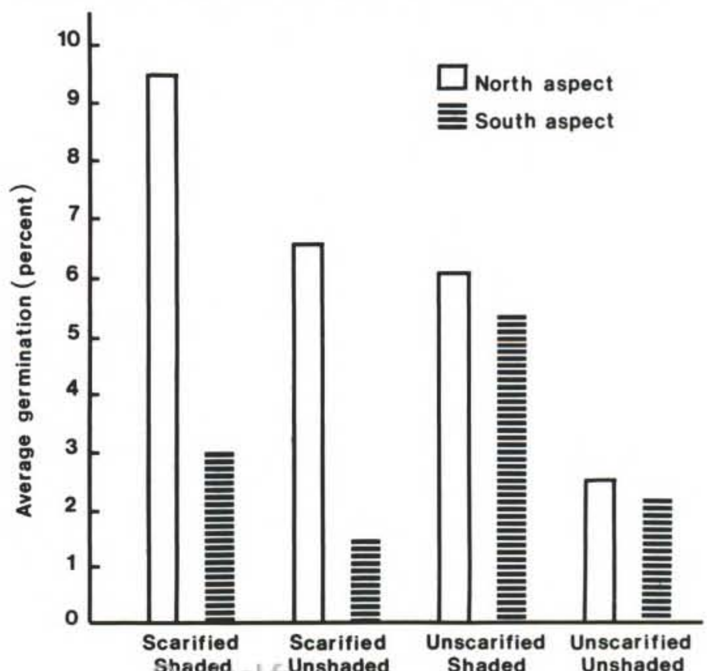
Environmental Factors Affecting Engelmann Spruce Regeneration

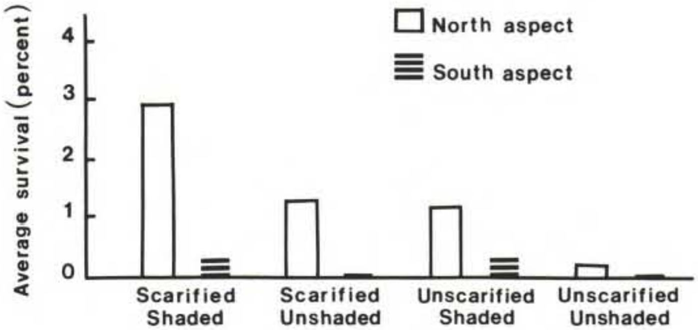
Two study areas were established in 1968 to identify factors limiting spruce regeneration success, and determine cultural practices needed to provide an environment suitable for spruce regeneration. Study plots were located in two 3.5-acre clearcut openings at 10,500 feet elevation, one on a north aspect of the Fool Creek drainage, the other on a south aspect of the West St. Louis Creek drainage.

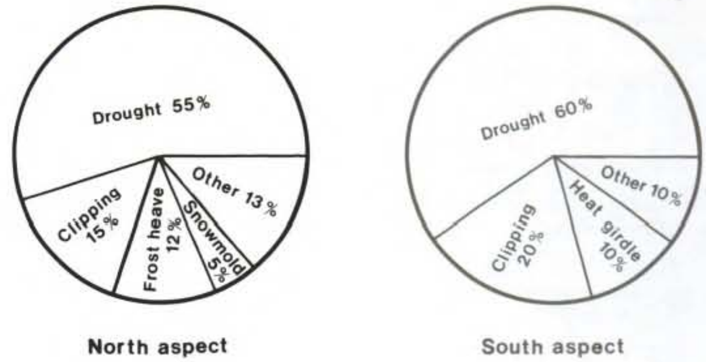
Each year for 10 years, twelve 1/4 milacre seedbeds were prepared at each study site. Each set was composed of four seedbed treatments—scarified-shaded, scarified-unshaded, unscarified-shaded, and unscarified-unshaded—replicated three times each. Seed from local sources was sown each fall on the current set of seedbeds to simulate natural seedfall.



Germination and survival observed from 1969 to 1982, was considerably better on the north aspect than the south aspect. However, total germination on the north aspect was only 6.1%, and only 2.9% of the seeds sown survived to the end of the study. Both germination and survival on the north aspect was best on scarified-shaded seedbeds and poorest on unscarified-unshaded seedbeds. Nearly 76% of the germinating seedlings died, with about 66% of the mortality occurring the first year. Nearly all the mortality was caused by drought, clipping by birds, frost heave and snowmold. Total germination of the south aspect was only 1.4%, and only 0.2% of the seeds sown survived to the end of the study. Germination was best on the unscarified-shaded seedbeds and poorest on the scarified-unshaded seedbeds. Survival was about the same on the scarified-shaded and unscarified-shaded seedbeds, but no seedlings survived on the scarified-unshaded and unscarified-unshaded seedbeds. About 95% of the germinating seedlings died on the south aspect, with 90% of the mortality occurring the first year. Most mortality was caused by drought, clipping by birds, and heat girdle.







Conditions favorable and unfavorable to Engelmann spruce regeneration are summarized below.

REGENERATION CONDITIONS

FAVORABLE		UNFAVORABLE
a >250,000 seed/acre	SEED CROP	<50,000 seed/acre
b North and East	ASPECT	South and West
c Ambient air >32° F night and <78° F day; maximum surface <90° F	TEMPERATURES	Ambient air <32° F night and >78° F day; maximum surface >90° F
d >0.50 in./week	PRECIPITATION	<0.40 in./week
e Light-textured, sandy-loam	SOIL	Heavy-textured, clay-loam
f >40% exposed mineral soil	SEEDBED	<20% exposed mineral soil
g 50–70% dead shade		<30% dead shade
h <2 in. duff and litter		>4 in. duff and litter
i Light vegetative cover <30% non sod-forming		Heavy vegetative cover >60% sod-forming
j Seedlings >12 weeks old by mid-Sept.	SURVIVAL	Seedlings <12 weeks old by mid-Sept.
k Low population of birds and small mammals that eat tree seed and young seedlings		High population of birds and small mammals that eat tree seed and young seedlings
l Protection from trampling		No protection from trampling
m Fall snow cover when frost heaving conditions exist		No fall snow cover when frost heaving conditions exist
n No late lying spring snowfields when conditions favorable to snowmold exist		Late lying spring snowfields when conditions favorable to snowmold exist

Watershed Studies: Fool Creek-East St. Louis Creek

Because more snow accumulated on experimental plots after timber harvest, it was assumed that more water was available for streamflow.[2] It was only an assumption, however, until similar cutting was done on a forested watershed where streamflow was measured and the assumption verified. Paired watersheds, one treated (Fool Creek) and one a control (East St. Louis Creek), were monitored as part of the experiment to determine the effect of timber harvest on streamflow.

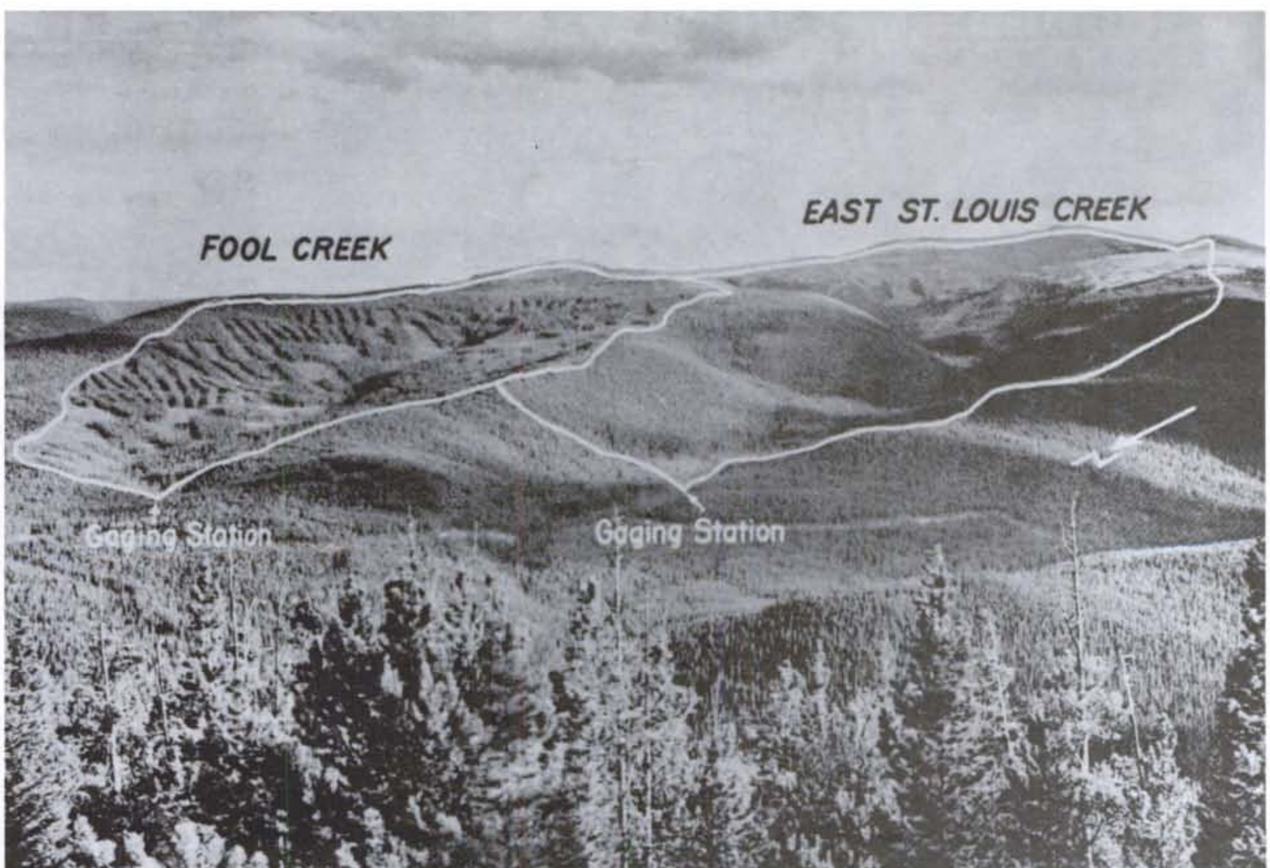
Fool Creek.—This is a 714-acre watershed at elevations ranging from 9,500 to 11,500 feet. Streamflow, precipitation, and snowpack accumulation have been measured since 1940. The original gaging station at Fool Creek, a combination San Dimas flume and two broad-crested weirs, was replaced with a 120° V-notch weir in 1980. The main channel flows north, with generally east and west aspects comprising 70% of the watershed area.

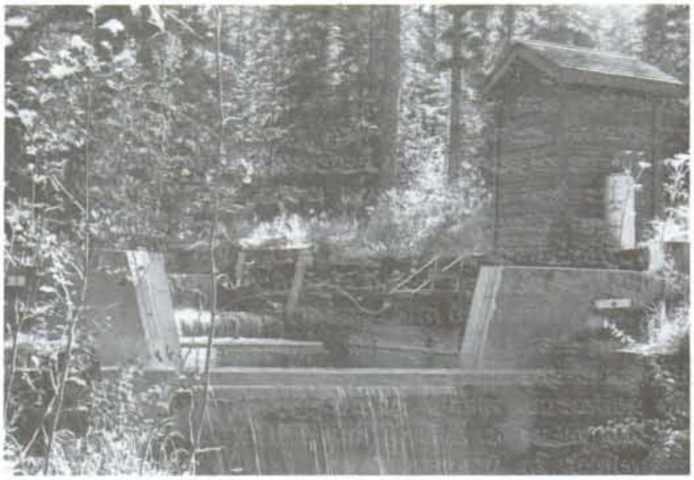
East St. Louis Creek.—This is a 1,984-acre watershed with elevation varying from 9,500 to 12,200 feet. It lies adjacent to Fool Creek, and is the untreated control. Major vegetation consists of lodgepole pine, Engelmann spruce and subalpine fir, with alpine tundra above timberline. Streamflow, precipitation, and snowpack accumulation have been measured since 1943. The original gaging station was a trapezoidal flume that was replaced in 1963 with a Cipolletti weir. Flow from the two watersheds correlated well during the pretreatment years, and changes in streamflow on Fool Creek resulting from timber harvest can be estimated using the flow of East St. Louis Creek.

[2]Streamflow is the quantity of surface water flowing past a given point in a stream channel. It is measured by flumes, weirs, or water control structures. Streamflow generally is expressed as a rate in cubic feet per second, or as an amount in acre-feet, or inches depth over a known area.

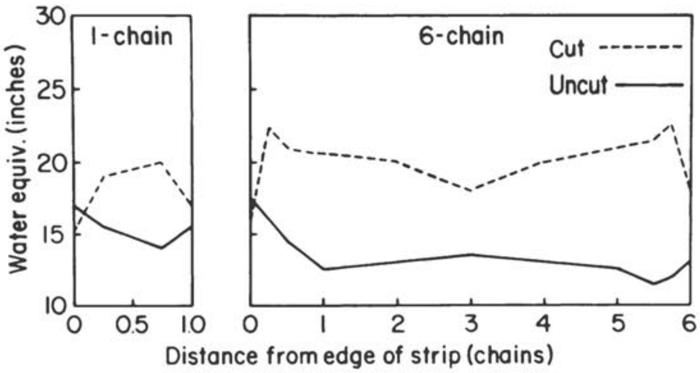
Alternate Strip Clearcutting

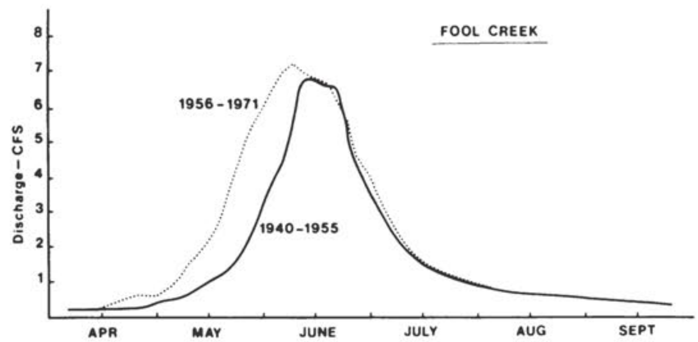
Fool Creek originally supported 6 million fbm of merchantable timber on 550 acres. About 55% was in the lodgepole pine type and 45% in the spruce-fir type.





These stands were overmature—250 to 350 years old. To harvest timber on Fool Creek, 3.3 miles of main access road and 8.8 miles of spur roads were constructed between 1950 and 1952. Spur roads were about 600 feet apart, located on the contour. Timber harvest, beginning in 1954 and ending in 1956, removed trees in alternate cleared strips at right angles to the contour. Four clearing widths—1, 2, 3, and 6 chains—were used. No timber was cut within 90 feet of the stream to minimize damage to the channel. On strips designated for cutting, all live trees 4 inches in diameter and larger were felled, and tops were lopped and scattered. In all, 278 acres of watershed were cleared, including 35 acres of roads. A total of 3.5 million fbm of timber was removed.





Snow Accumulation

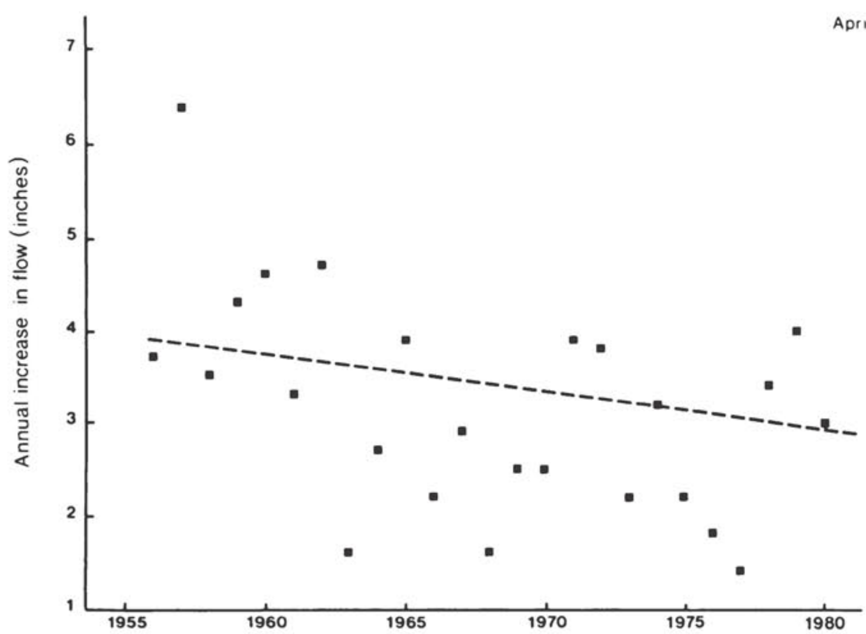
Comparisons of snowpack accumulation in alternate forested and clearcut strips indicate a large increase in water equivalent in open areas, with a small net increase in total snow accumulation on the watershed. There is a pronounced redistribution of snow as a result of cutting; more snow accumulates in cut strips than in the uncut forest. Before cutting, wind distributed snow rather evenly within the forest. Afterwards, the aerodynamics of the canopy were changed and the openings in the canopy efficiently trapped snow that formerly settled in adjacent forested strips. Thirty percent more water equivalent is deposited in the openings, largely the result of redistribution. However, the long-term record now available indicates that reduction in interception loss has resulted in a 10% increase in the peak snow water accumulation on Fool Creek.

Snowmelt and Water Yield

Removing timber from Fool Creek accelerated snowmelt rates and increased water yield by almost 40%. Most of the increase occurs as a substantially enlarged spring runoff. Peak flows, although increased, are not affected appreciably, and there is no detectable change in streamflow during midsummer and early fall. Twenty years passed before there was any strong indication that the effect of cutting timber on streamflow had diminished. Today, analyses indicate that the average effect of the timber harvesting treatment is being diminished by about 0.04 inches per year and that 70 to 80 years will be required for full return to pretreatment conditions.

Cutting trees and resultant redistribution of seasonal snowpack substantially increased runoff because some water formerly used during the melt period to replace soil moisture consumed by vegetation is now available for streamflow. Because more snow is deposited in openings where soil moisture deficits are lowest, and higher melt rates in openings make meltwater available earlier before evapotranspiration can deplete it, the efficiency of the treatment is enhanced.

After nearly 30 years the increase in streamflow is still 25% above pretreatment flow. This change is due largely to increased consumptive use by vegetative regrowth rather than any change in snowpack deposition pattern.



April to September runoff increase since harvest

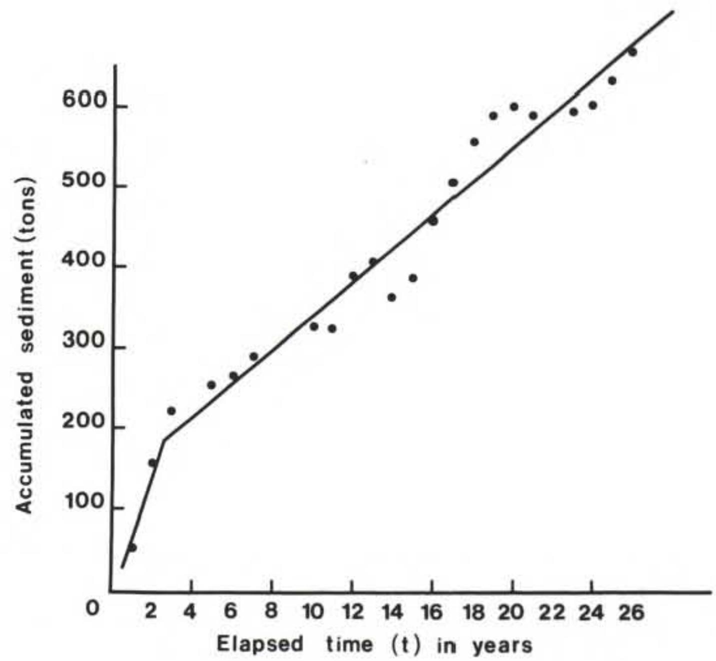
1956	3.7
57	6.4
58	3.5
59	4.3
60	4.6
61	3.3
62	4.7
63	1.6
64	2.7
65	3.9
66	2.2
67	2.9
68	1.6
69	2.5
70	2.5
71	3.9
72	3.8
73	2.2
74	3.2
75	2.2
76	1.8
77	1.4
78	3.4
79	4.0
80	3.0
81	1.7
82	4.5
83	4.0
$\bar{x}$	3.2 (inches)

Increase in annual flow from Fool Creek since harvest in 1955

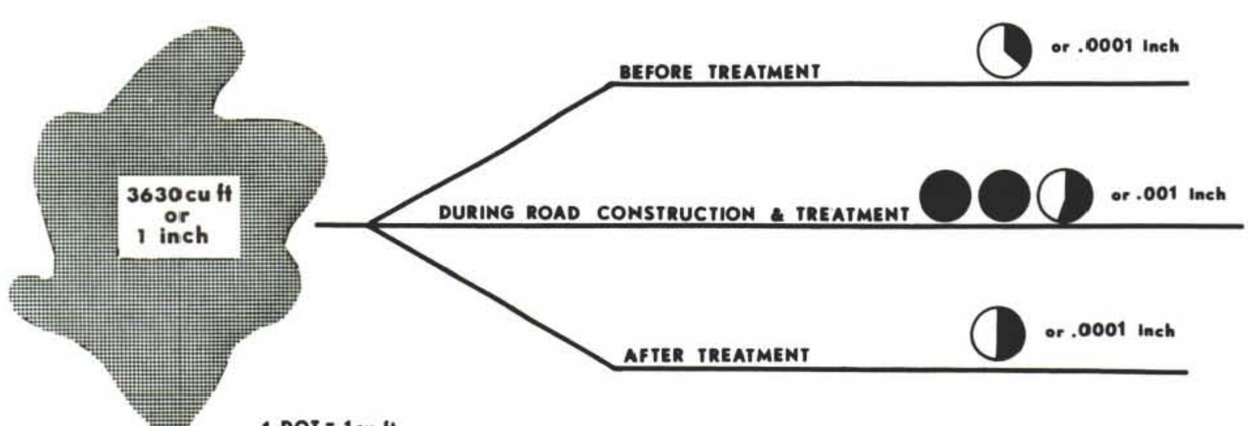
Sediment Yields

Construction of the road system on Fool Creek and associated timber harvesting caused little erosion, with no apparent reduction in water quality. The main access road was located to avoid damage to the stream channel, and spur roads were provided with surface drainage and culverts at stream crossings. After logging, spur roads were seeded to grass, and culverts were removed from alternate spur roads to reduce traffic. The main haul road is still routinely maintained.

Sediment yield during road construction and subsequent logging averaged about 200 pounds per acre, but decreased rapidly after logging despite continuing increase in runoff after timber harvest. Since logging, sediment yields have averaged 43 pounds per acre, compared with yields of 11 to 21 pounds per acre from undisturbed watersheds. The continuing increase in sediment yield may come from the 3.3 miles of main access road that are still being maintained. Suspended sediment was less than 5 parts per million during high flow periods in 1964 and 1965.

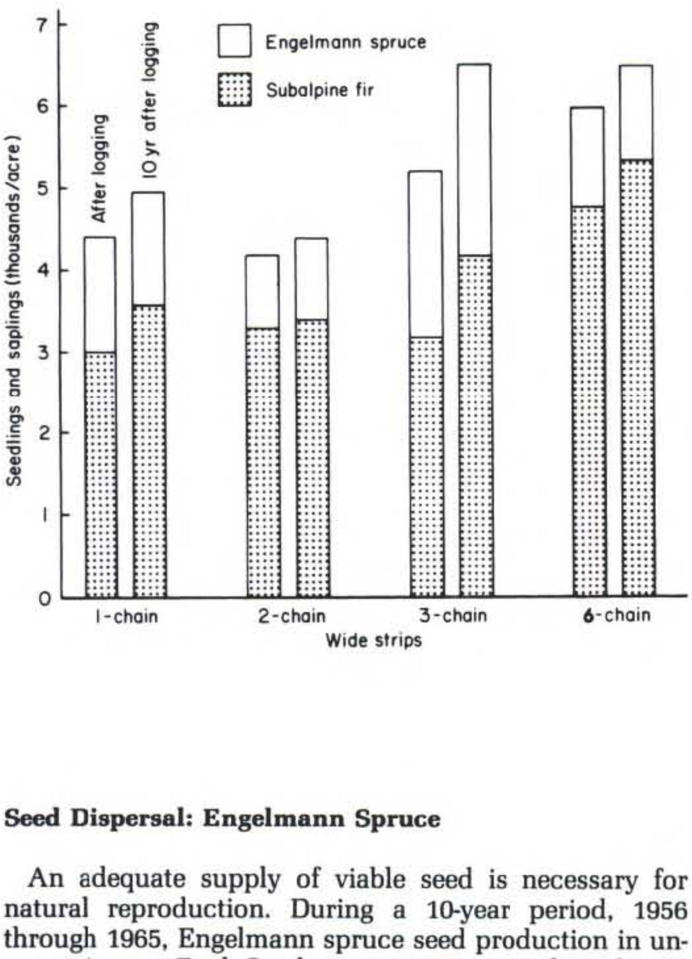


INCREASES IN SEDIMENT YIELD FROM FOOL CREEK WATERSHED
(714 ACRES)



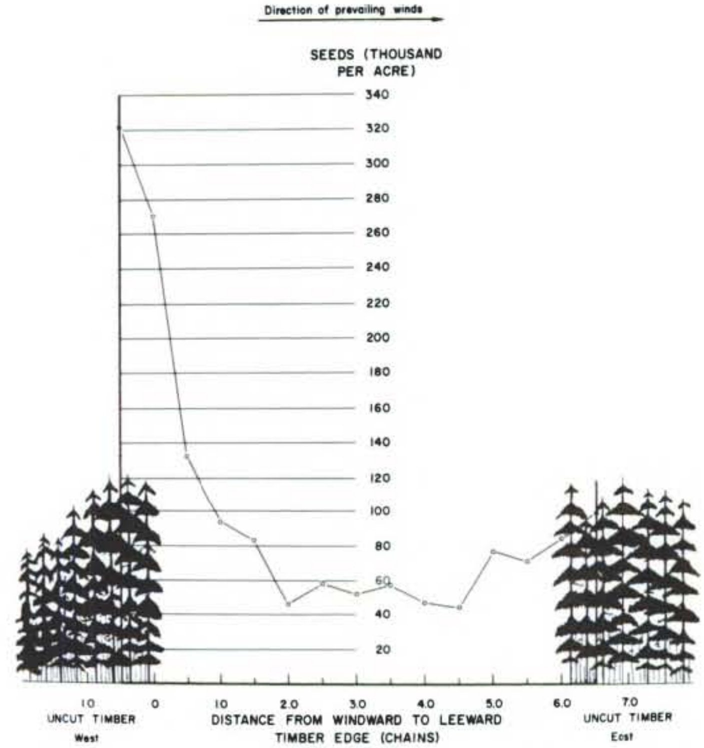
Regeneration: Spruce-Fir Type

In the spruce-fir type on Fool Creek where logs were skidded with horses, enough advanced reproduction survived logging to restock all cutover strips. The number of seedlings and saplings left after logging ranged from 4,183 per acre on 2-chain-wide strips to 5,957 per acre on 6-chain-wide strips. Firs outnumbered the more valuable spruces on all strip widths. Subsequent reproduction was not abundant on any strips 10 years after cutting. Recovery was best on 3-chain-wide strips, and poorest on 2-chain-wide strips. More new firs than spruces were established on all but 2-chain-wide strips.



Seed Dispersal: Engelmann Spruce

An adequate supply of viable seed is necessary for natural reproduction. During a 10-year period, 1956 through 1965, Engelmann spruce seed production in uncut strips on Fool Creek was 321,000 sound seeds per acre, but annual seedfall varied considerably. The 1961 crop contributed about 40% of the total seedfall. Moderate crops were produced in 1959 and 1963, but seed crops were rated poor to complete failure in the other seven years of observation. The number of seeds dispersed from standing trees into the cleared strips was greater in years of heaviest seed production, but seedfall was not uniformly distributed over the openings. In the 6-chain-wide strips, about half the seed dispersed fell within 1.5 chains of timber edge, with only about 10% falling near the center of the openings.



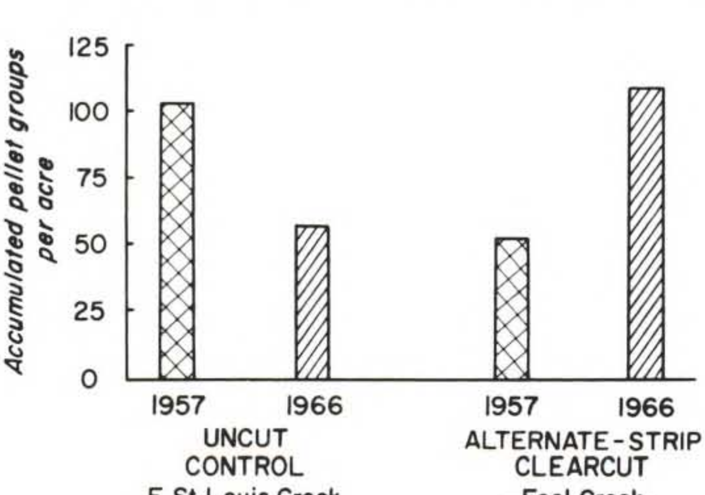
Windfall

Windfall after clearcutting on Fool Creek was observed for 10 years after cutting was completed. Blowdown was related to exposure to wind, cutting unit characteristics, and tree characteristics in the following ways:

1. Approximately 70% of 2,844 windthrown trees were felled by stormwinds from the west and the southwest.
2. About two-thirds of the trees blew down along the N, NE, E, and SE (leeward) cutting boundaries.
3. More trees were windthrown on downwind than on upwind aspects.
4. Cutting boundaries on ridgetops suffered heavy damage. Fewer, and about equal, numbers of trees blew down on upper, middle, and lower slopes.
5. Windfall was not directly related to width of opening.
6. Cutting boundaries oriented parallel to the direction of prevailing windstorms suffered more damage than those oriented at right angles to windstorms.
7. About two-thirds of the blowdown occurred within the first 2 years after logging.
8. Trees growing on soils where average depth of solum exceeded 12 inches were more windfirm than trees growing on shallower soils.
9. Trees growing in situations with rapid drainage were more windfirm than trees growing where drainage was slow.
10. All species and size classes were predisposed to windthrow in the same proportion in which they occurred in uncut stands.
11. Defect was associated with one-third or less of windthrow trees.

Mule Deer Use and Forage Values

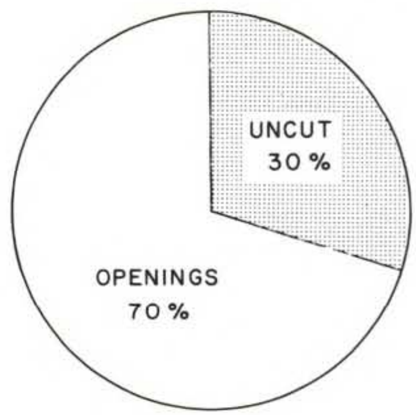
Immediately after logging, mule deer summer use on Fool Creek was less than on the adjacent unlogged watershed. Comparatively low use on Fool Creek may have been due to logging slash and to other disturbance associated with timber harvest. Ten years after logging, deer use was substantially higher on Fool Creek than on the control watershed, with most of the increase on cut



strips. Comparisons among cut strips indicated 3-chain-wide strips were used most heavily on both spruce-fir and lodgepole pine forests. The 1-chain-wide strips were used least in lodgepole pine, while 6-chain-wide strips were used least in spruce-fir.

Tame mule deer observed in food habit studies spent about 70% of their time and obtained about 70% of their food on cut strips. Since there were no differences between cut and uncut areas with respect to digestibility, crude protein content, or moisture content of forage species, deer preference for open areas was attributed to the increased amounts and variety of forage in cut strips. Although logging stimulated habitat changes beneficial to deer, enough forage was produced in unlogged areas to carry more deer than currently occupy the summer range. Deer populations in this area are limited by availability of winter range at elevations lower than on the Forest.

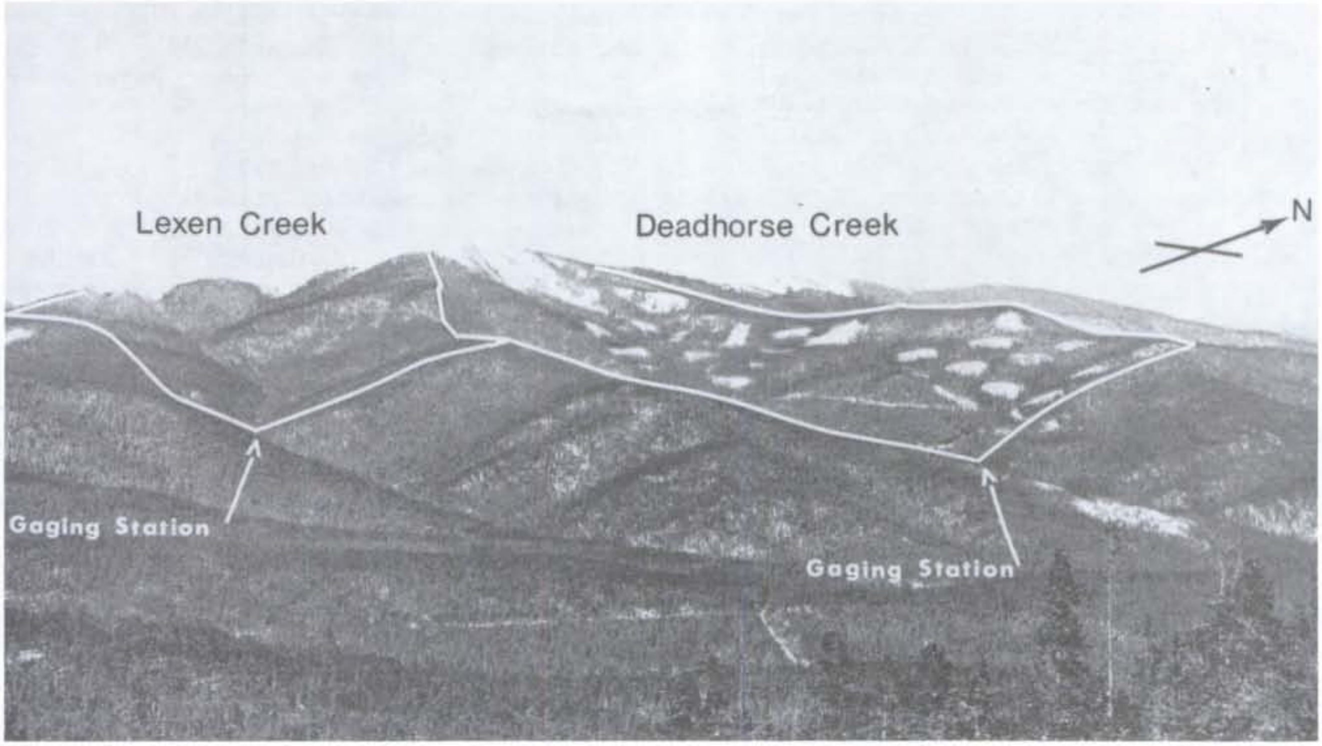
DEER USE OF OPENINGS AND UNCUT TIMBER



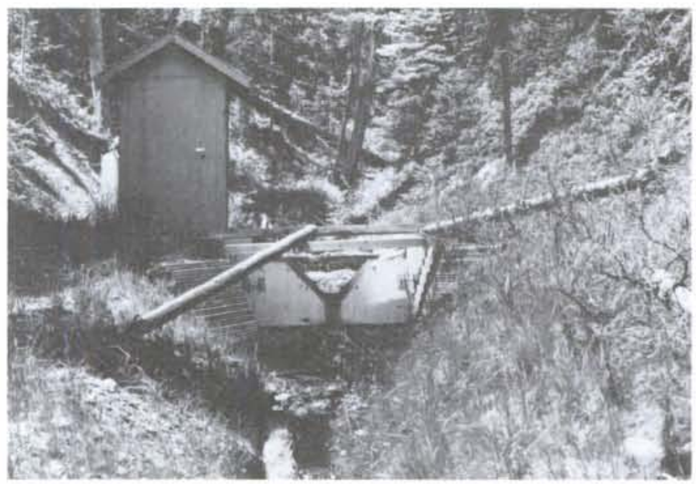
CURRENT RESEARCH

Watershed Studies: Deadhorse Creek—Lexen Creek

The hydrology of Deadhorse and Lexen Creeks has been studied since 1955. Long-term records of streamflow, snow accumulation and depletion, precipitation, sediment yield, and water quality are available. A comprehensive study of the snowmelt regime on these and other watersheds on the Fraser Experimental Forest resulted in development of the Subalpine Hydrologic Water Balance Model, a simulation model capable of predicting short- and long-term hydrologic impacts of a broad range of land-use alternatives. This model represents the state of the art after more than 30 years of watershed management research in subalpine coniferous forests. Any tool of this complexity and scope requires pilot testing before routine operational application. Pilot testing is being accomplished on Deadhorse Creek by (1) simulating several timber harvesting options on various subunits, (2) selecting and applying one of these alternatives on the ground in each subunit, and (3) comparing the runoff response predicted by the model with actual streamflow.



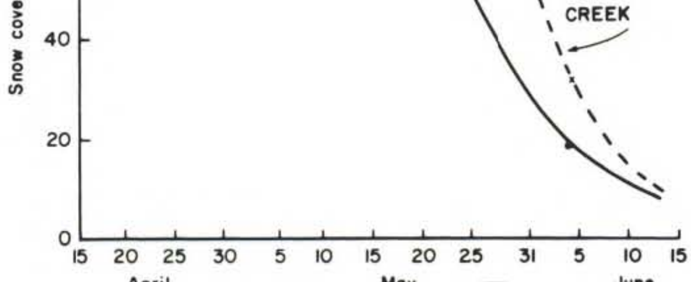
Deadhorse Creek.—This 667-acre watershed, which generally drains from west to east, was selected for treatment. Elevations vary from 9,450 feet at the main gaging station to 11,600 feet at the summit of Bottle Mountain. Major vegetation is spruce-fir along stream bottoms and all north and upper slopes, lodgepole pine on all lower and mid-south slopes, and alpine tundra above timberline. Deadhorse Creek is steeper than Fool Creek, with side slopes averaging almost 40%. The north and south exposures receive unequal amounts of energy in contrast to nearly equal radiant energy load on the east and west slopes of Fool Creek. There are three stream gaging stations on Deadhorse Creek. The main stream gage is a 120° V-notch weir, and gaging stations on the 100-acre North Fork and the 200-acre Upper Basin are 90° V-notch weirs. The main stream gage was constructed in 1955, the North Fork in 1970, and the Upper Basin in 1975.



Lexen Creek.—This is a 306-acre watershed at elevations ranging from 9,850 feet at the stream gaging station to 11,600 feet. It lies adjacent to Deadhorse Creek and is the untreated control. Vegetation, soils, and topography are similar to Deadhorse Creek. The stream gaging station is a 120° V-notch weir constructed in 1955. Flows from the two watersheds are well correlated, and Lexen Creek also can be used to estimate changes in streamflow on Deadhorse Creek caused by timber harvesting.

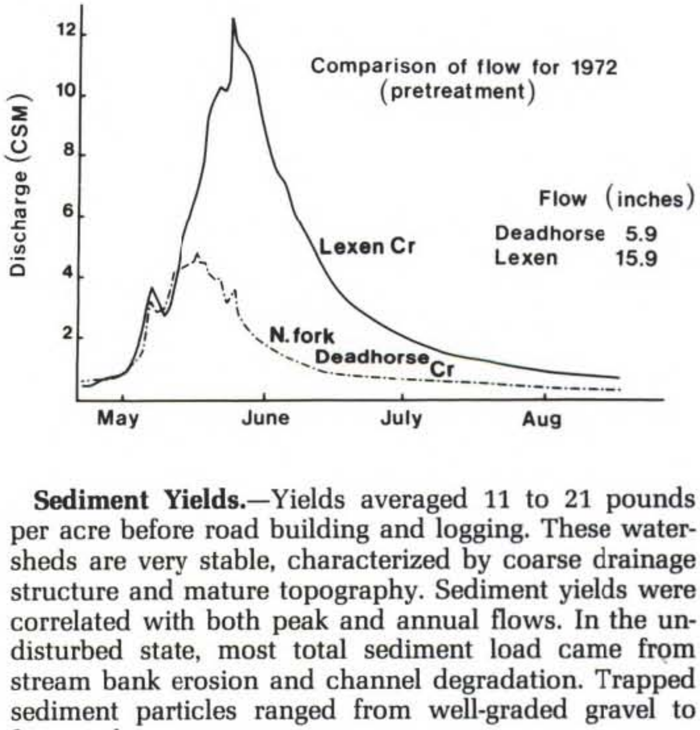
Pretreatment Hydrology

Snow Cover Depletion.—Depletion of the snowpack on Deadhorse Creek starts earlier than on Lexen Creek because of advanced snowmelt on the low-elevation south slopes. The rate of depletion on the Upper Basin of Deadhorse Creek was similar to Lexen Creek.



Snowmelt.—Snowpack melt rates differed considerably between low elevation north and south slopes on Deadhorse Creek. Time of maximum snowmelt on the Upper Basin of Deadhorse Creek and on Lexen Creek varied considerably less between north and south slopes. As a result, nearly 90% of seasonal runoff volume from the entire basin is generated before 60% of the area is bare of snow in either the Upper Basin of Deadhorse Creek or Lexen Creek. Also, more than 80% of these watersheds are still covered with snow when seasonal peak snowmelt runoff rates are reached.

Water Yields.—Streamflow from Deadhorse Creek varied from 60% of that of Lexen Creek in high runoff years to nearly 90% in low runoff years. The difference results from the variation in contribution to streamflow from the Upper Basin, North Fork, and lower Deadhorse Creek subdrainages. Streamflow from lower Deadhorse Creek averages less than 50% of that generated from the Upper Basin, even though precipitation at lower elevations is 80% of that at higher elevations. The North Fork, before treatment, yielded only about one-third as much streamflow as the Upper Basin.

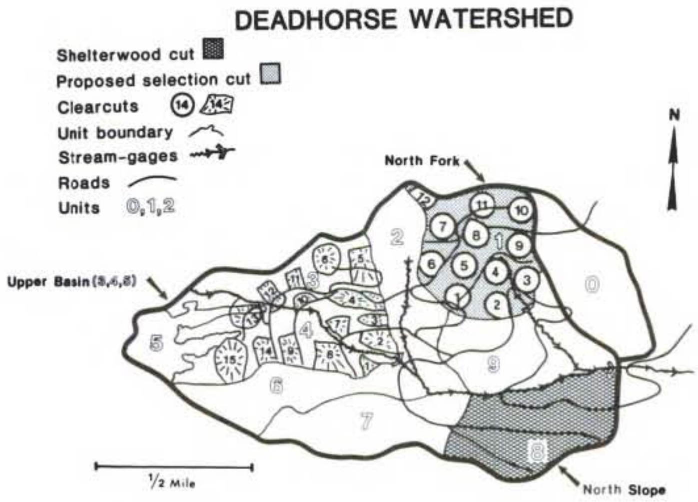


Sediment Yields.—Yields averaged 11 to 21 pounds per acre before road building and logging. These watersheds are very stable, characterized by coarse drainage structure and mature topography. Sediment yields were correlated with both peak and annual flows. In the undisturbed state, most total sediment load came from stream bank erosion and channel degradation. Trapped sediment particles ranged from well-graded gravel to fine sand.

Water Quality.—Natural flows from Deadhorse and Lexen Creeks were generally pure. Concentrations of all chemical components were low, pH values near neutral, and temperatures very cold (32° to 44° F).

Timber Harvest

In contrast to the roads in Fool Creek, which were constructed over a 2-year period, the approximately 9 miles of roads constructed in Deadhorse Creek have been constructed over a 26-year period. One mile of main access road was built in 1955 to harvest timber and construct stream gaging stations on Deadhorse Creek. Another 2.5 miles of main access road was constructed in 1970–1971. About 1 mile of main access road and about 0.75 mile of spur road were built in the North Fork unit in 1976. Approximately 1 mile of main access road and 0.5 mile of spur road were built in 1977–1978 in the North Slope unit, and about 2 miles of main access and spur roads were built in the Upper Basin unit in 1981.



North Fork (Response Unit 1).—Timber harvest on 11 subunits of this 100-acre unit was started and completed in 1977. The twelfth subunit was cut in 1978. Approximately one-third of the old-growth timber—principally lodgepole pine—was clearcut in 3-acre circular patches, spaced so that about equal areas of uncut timber were left between each opening. All live trees 4 inches d.b.h. and larger on the cut patches were felled. Logs were removed by skidding them downhill with wheeled skidders and small crawler tractors. Slash was lopped and scattered. Skid roads were water-barred, brushed in, and seeded. A total of 360,000 fbm of timber was removed. Water yields from this lower south slope have increased about 2 inches annually since cutting was completed, which is in agreement with

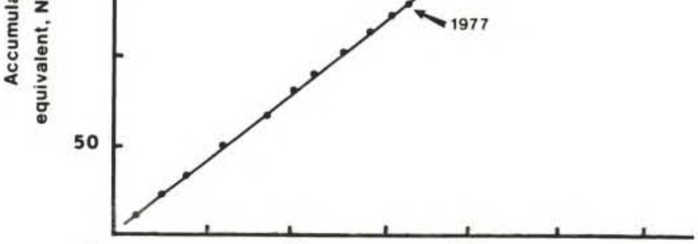
the long-term simulation of the hydrologic impact of this option. Present plans call for recutting the patches in about 30 years to maintain the increase in streamflow. A series of light partial cuts will be started in the between-patch stand with the ultimate goal of converting the old-growth stands to a managed broad-aged stand while maintaining the height of the present canopy.

North Slope (Response Unit 8).—Timber harvest on this 100-acre unit was started in 1980 and completed in 1981. Approximately 35% of the mixed spruce-fir—lodgepole pine timber in trees 7 inches d.b.h. and larger were removed on an individual tree basis over the entire area in the preparatory cut of a 3-cut shelterwood. Logging was by conventional downhill machine skidding. Slash was lopped and scattered. Skid roads were water-barred, brushed in, and seeded. A total of 600,000 fbm of timber was removed. Water yields from the North Slope have increased less than on the North Fork, which is in agreement with the long-term simulation of the hydrologic impact of this option. Present plans call for harvesting an additional 30% of the old-growth timber with the seed cut of a 3-cut shelterwood 20 years after the first cut, with the remainder of the timber removed 40 years after the first cut.

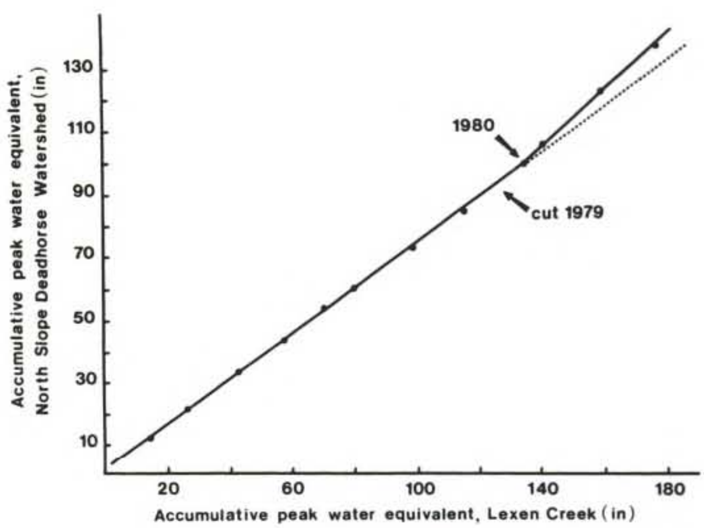
Upper Basin (Response Units 3 and 4).—Timber harvest on the 150 operable acres of this 200-acre unit was started in 1982 and completed in 1984. Approximately one-third of the old-growth mixed pine—spruce-fir was clearcut in 15 irregular-shaped patches that ranged in size from 1 to 5 acres. The openings were spaced so that about equal areas of uncut timber were left between each opening. All live trees 7 inches d.b.h. and larger on the cut patches were felled, and tops were lopped and scattered. Logging was by conventional downhill machine skidding. Skid roads were water-barred, brushed in, and seeded. A total of about 750,000 fbm of timber was removed. Long-term simulation of the hydrologic impacts of this option indicates an initial increase in streamflow of about 2+ inches. This option differs from the North Fork in that plans call for allowing the initial openings to regenerate and grow to maturity. An additional one-third of the area will be cut in new openings approximately 30 years after the first cut, with the last of the old-growth removed approximately 60 years after the initial cutting.

Posttreatment Hydrology

Snowpack Accumulation.—Unlike results on Fool Creek, clearcutting small openings on the North Fork (Response Unit 1) of Deadhorse Creek has not increased total snowfall accumulation. Although 22% more water occurs in the opening than in the surrounding forest, this accumulation pattern is primarily due to differences in snow deposition and redistribution rather than a reduction in interception loss. Because of its southerly exposure, any reductions in interception loss on the North Fork are assumed to be offset by increased ablation of the exposed snowpack in the openings where the snowpack melts earlier in the year.

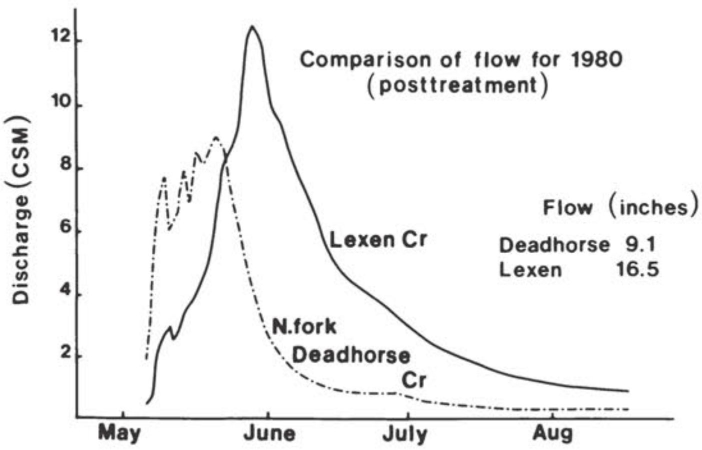


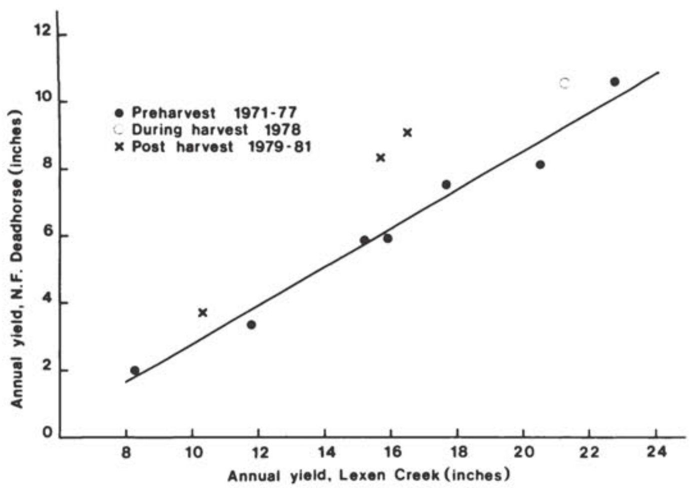
Harvesting timber by removing individual trees under a 3-cut shelterwood on the North Slope (Response Unit 8) significantly reduced evaporative loss of snow that otherwise would have been intercepted by the canopy. Long-term snow measurements on the North Slope and Lexen Creek show that the removal of about one-third of the basal area resulted in an increase in water in the snowpack by an average of 1.5 inches. This increase probably reflects a reduction in interception loss by the canopy that is not offset by increases in ablation loss from the snowpack below. The North Slope has a north exposure where shading of the snowpack is more effective in reducing evaporative loss than a south exposure. In normal water years, most of the increase in water in the snowpack can show up as increased streamflow.



Streamflow.—For the first 4 years after timber harvest, flow from the North Fork (Response Unit 1) increased 1.8 inches. Most of this increase came in May because of early melt and reduced recharge requirements, with no detectable effect from July to September. The magnitude of change is correlated with precipitation—the wetter the year, the larger the increase—as with Fool Creek. Peak discharges occur earlier than on Fool Creek but do not appear to be significantly increased. It is too soon to determine if the shelterwood cutting on the North Slope (Response Unit 8) has a significant effect, but an increase in streamflow is apparent. It is expected that the patch clearcutting in the Upper Basin (Response Units 3 and 4) will result in increases in streamflow comparable to the North Fork (Response Unit 1).

Water Quality.—Estimates of sediment production in weir ponds are the only observation of water quality made on Deadhorse and Lexen Creeks. Sediment export from the North Fork (Response Unit 1) of Deadhorse Creek more than doubled following road construction





and timber harvest, but recovery appears to have occurred in 4 to 6 years after harvest:

Year	Sediment Expected	Sediment Observed	Change
	lb/acre		
1978	19	52	33
1979	13	26	13
1980	16	23	7
1981	12	2	− 10

The significant increase in accumulated sediment was detected at the North Fork weir, but no impact was detected downstream at the main Deadhorse Creek weir.

Operational Watershed Management

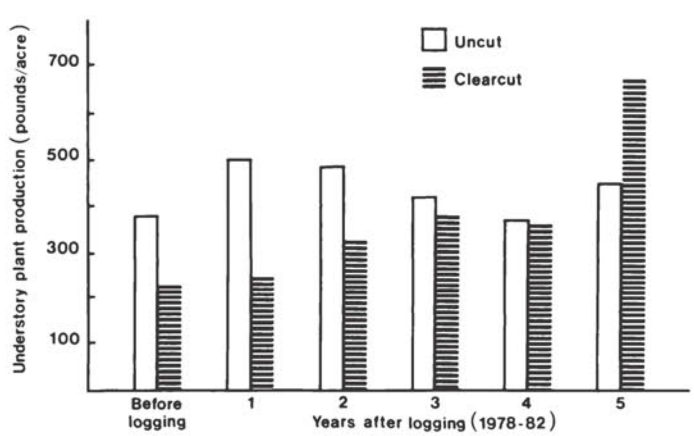
One of the objectives of the Deadhorse Creek study is to evaluate and verify the capability to simulate in advance the effect on streamflow of different timber harvesting options. Using the Subalpine Water Balance Model and a procedure using nomographic simplifications of the model (WRENSS), predictions were made before harvesting on the North Fork (Response Unit 1) of the average response expected after timber harvest:

Year	Observed increase	Simulated increase: Subalpine Hydrologic Model	Simulated increase: WRENSS
		inches	
1978	1.4	1.5	0.9
1979	2.3	1.8	1.8
1980	2.6	1.8	2.0
1981	0.8	1.8	1.6
$\bar{x}$	1.8	1.7	1.6

In general both simulators performed well. Technologies and models developed at the Fraser Experiment Forest are currently being studied in a large-scale pilot program on the East Fork Encampment River in Wyoming that will test water yield augmentation practices developed at Fraser under operational management conditions and evaluate the state-of-art hydrologic model.

Game Animal and Forage Response

Overall plant production was greater during the initial 5 years after clearcutting than before logging on the North Fork of Deadhorse Creek (Response Unit 1). Before harvest, most of the understory vegetation was *Vaccinium* spp. and a few woody plants, and this pattern continued after cutting. Graminoids (mostly sedges) and forbs, scarce in the uncut stand, increased somewhat after clearcutting but remained a lesser understory component. As indicated by percentages of crude protein and digestibility, the relative quality of understory as forage increased during the postlogging period. Pellet counts showed that big game use was low in the Deadhorse Creek watershed and continued so after logging, although a trend toward increased use by both elk and deer was evident on the clearcut areas of the North Fork.



Studies of understory vegetation and big game responses to the first entry shelterwood harvest on the North Slope (Response Unit 8) in 1979–1980 continue. Results will be summarized after the initial 5 years of postharvest observations have been completed.

Nongame Bird and Small Mammal Response

Compared with the uncut controls, clearcutting of small circular patches had little adverse effect on small mammal and songbird populations during the initial 2 years after cutting on the North Fork of Deadhorse Creek (Response Unit 1). Numbers of chipmunks increased, but changes in populations of other small mammals could not be attributed to clearcutting. After logging, bird species density increased in the North Fork, but bird numbers were slightly lower. Most of the decline was to species in picking and gleaning feeding and foliage nesting guilds.

There were about 18 Engelmann spruce, subalpine fir, and lodgepole pine snags 4 inches d.b.h. and larger per acre left on the North Fork after cutting, but less than one-half percent had cavity-nesting holes. Cavity-nesting birds used few of those available, selecting mainly trees larger than 8 inches d.b.h., with broken tops. No other characteristics examined seemed important in nest site selection.

Temperature and Humidity in Subalpine Watersheds

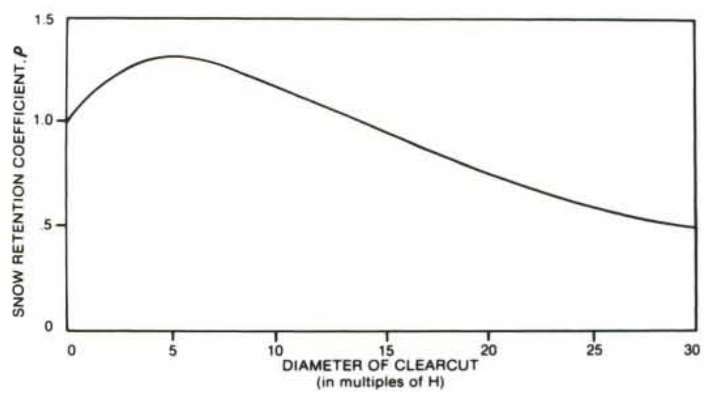
Studies were conducted to determine how air and canopy temperature and ambient absolute humidity could be predicted for subalpine watersheds, using weather data collected at a central weather station near the lower end of the watersheds. Direct beam irradiance had very little effect on air or canopy temperature, but temperatures within watersheds were influenced strongly by elevation. During most of the daylight hours, temperatures in watersheds could be estimated from central weather station temperatures adjusted with a standard adiabatic lapse rate effect of −5.4° F per 1,000-foot increase in elevation.

Cold air drainage reduced air temperatures at the central weather station by nearly 13° F during most of the night and early morning hours. Cold air drainage must be taken into account in estimating watershed temperatures from lower-elevation weather records. The cold air drainage provides a daily sample of upper-elevation air masses at the lower-elevation weather station. Thus humidity measurements made at lower elevations during cold air drainage can be used to estimate upper-level ambient absolute humidities or vapor pressures. However, localized thunderstorm activity causes variation in temperature and humidity during the storm period.

Water Transport and Use

Timber Harvesting Options and Snowpack Accumulation

Timber harvesting effects on snowpack accumulation have been a common objective of most watershed studies on the Experimental Forest. Clearcutting has had the most significant impact. Accumulated knowledge from numerous studies led to the development of a relationship between opening size, expressed in average tree heights, and the increase in snowpack accumulation. Openings trap more snow at the expense of the downwind forest because of changes in the aerodynamics of the forest canopy. Circular plots, 5 tree heights (5H) in diameter, were used on the North Fork of Deadhorse Creek because they are the optimal size for maximum snowpack accumulation. Irregular-shaped openings, 2H to 8H wide, are also considered practical, but large openings in excess of 15H in diameter have been considered detrimental to snowpack accumulation and water yield because wind scour reduces net precipitation. Partial cutting and/or thinning have not been considered as snowpack management alternatives because there is little or no opportunity for the redistribution of snow associated with clearcutting.



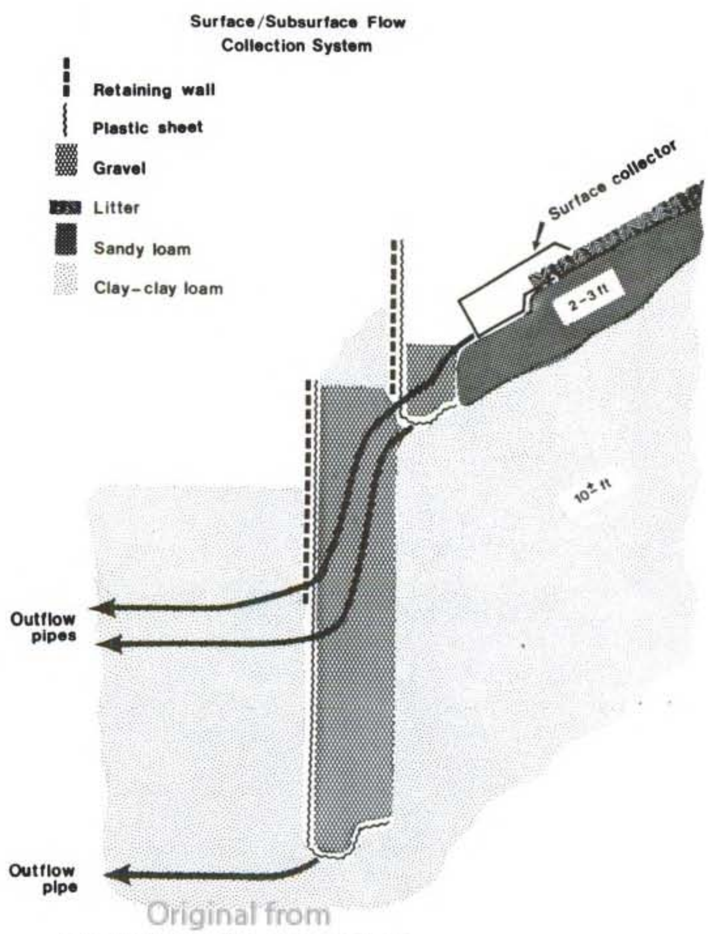
However, recent studies of thinning in young lodgepole pine and partial cutting in mature pine and spruce-fir indicate that these practices may result in a net increase in peak water equivalent. Preliminary results indicate that canopy reduction from removal of trees on an individual basis results in less interception of snow and subsequent evaporation from the canopy, resulting in a net increase in the snowpack on the ground. This increased snowpack will result in an increase in streamflow in all but the driest years.

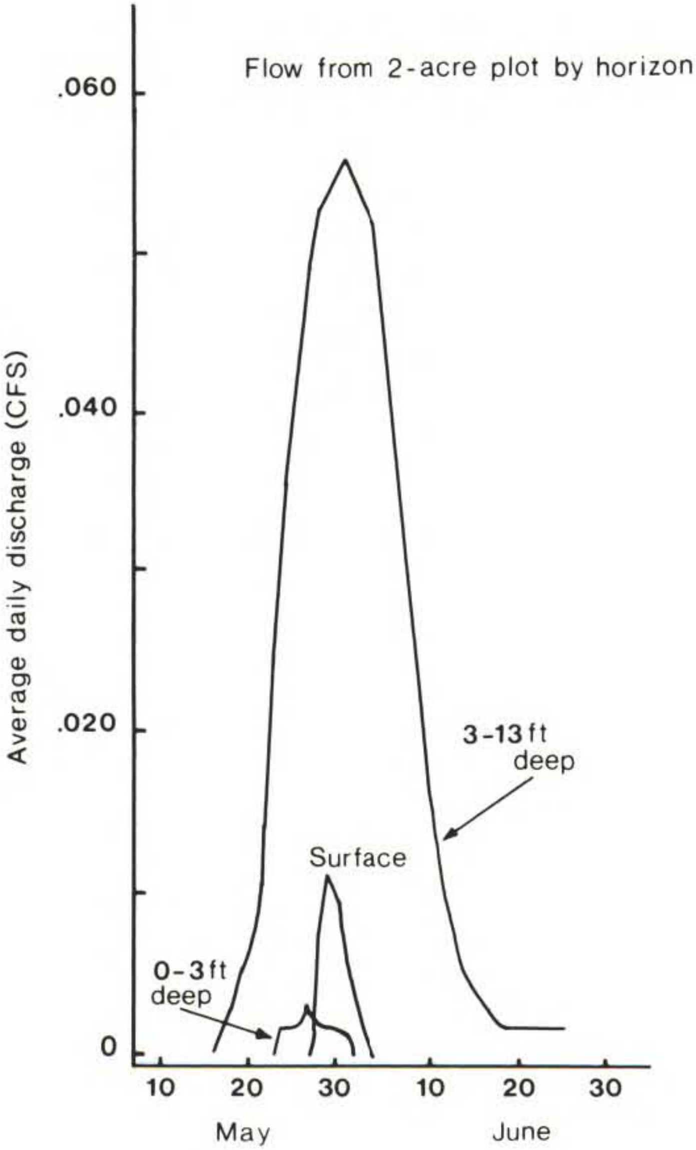
Research is also continuing on how large clearcuts—in excess of 15H—can be managed to minimize wind scour and maintain the snowpack on site. In a 22H opening where there were numerous residual stems and moderately heavy slash was left in place to provide roughness to retain snow, 20% to 30% more water accumulated in the snowpack than in the uncut forest. After the residual standing stems were removed, the remaining 18 to 24 inches of slash retained 10 inches of water in the snowpack, but wind scour removed about 60% to 80% of the additional snow after the slash was filled with snow. How long the slash will be effective is not known. Other alternatives, such as windrowing large material to maintain roughness until new regeneration can provide it naturally, need to be examined. Research will continue on how to describe the nature of the required surface roughness in large openings and on how to provide it.

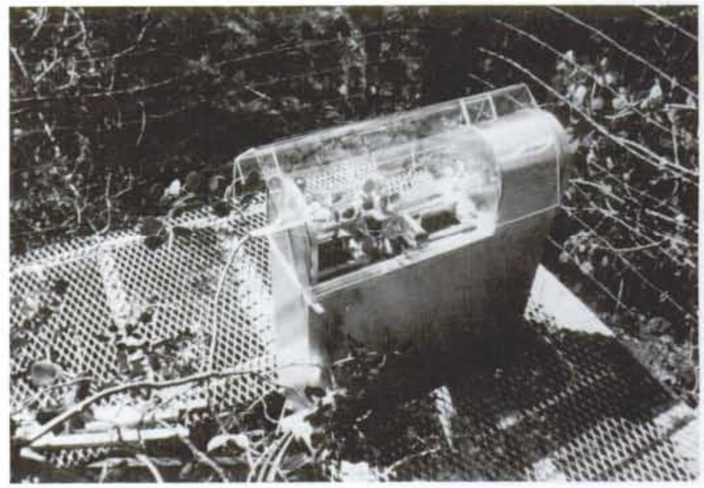
Mechanics of Meltwater Movement

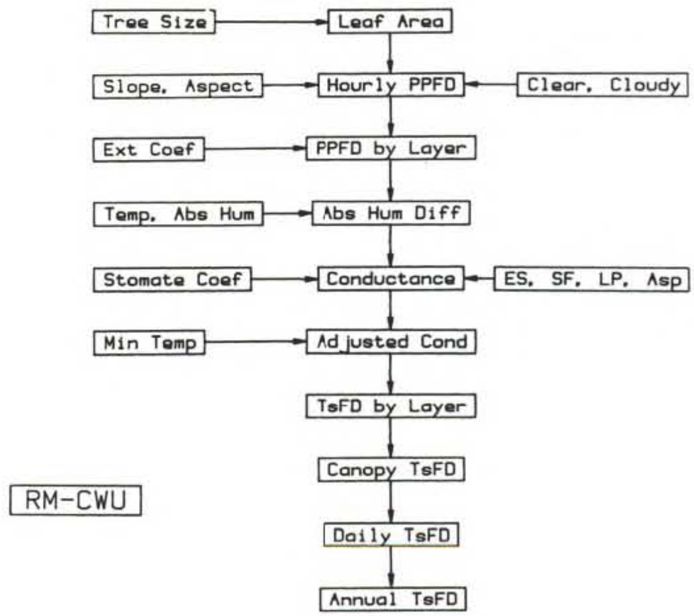
The pathway that meltwater takes as it moves through the soil to the stream channel greatly affects its ultimate disposition—whether the water is stored in place, lost to vapor through evapotranspiration, becomes streamflow, or enters the groundwater reserve. The significance of snow redistribution in the hydrologic cycle depends upon what happens to meltwater, as do increases in water following partial cutting because the increase in water equivalent must reach the stream channel to affect water yield. Timber harvest that reduces vegetation also reduces transpirational depletion of soil water, thereby making more on-site water available for streamflow. The mechanism by which water is routed through the soil controls the efficiency by which different timber harvesting practices and/or locations influence streamflow.

How water moves through the soil and the effects of timber harvesting on soil water content have been studied for several years. Study plots 50 to 100 feet wide and 600 feet long were installed to intercept and measure water moving laterally down forested hillsides on the surface and from two subsurface layers (0–3 feet and 3–13 feet below the surface). Observations from these plots indicate that meltwater generally infiltrates the soil mantle and percolates into less permeable layers; this results in a buildup of a temporary water table, causing the meltwater to move laterally downslope toward the stream. On the study sites, a restricting layer occurs 7 to 10 feet below the surface, and under continuous melt the soil mantle above this layer saturates and a perched water table develops resulting in significant lateral or downslope subsurface water movement. Most flow occurs in the deeper soil layers, with successively more occurring in shallower layers as the perched water table builds toward the surface. Little surface water flow has been observed. In most years, 6 to 8 inches of water equivalent has been lost from the snowpack before significant lateral subsurface flow occurred. For the study site, this represents an estimate of the recharge requirements under fully forested conditions. This information will assist in improving the Subalpine Hydrologic Model by providing a more site-specific simulation of impacts on water yield following timber harvest or other management activities that manipulate vegetation.









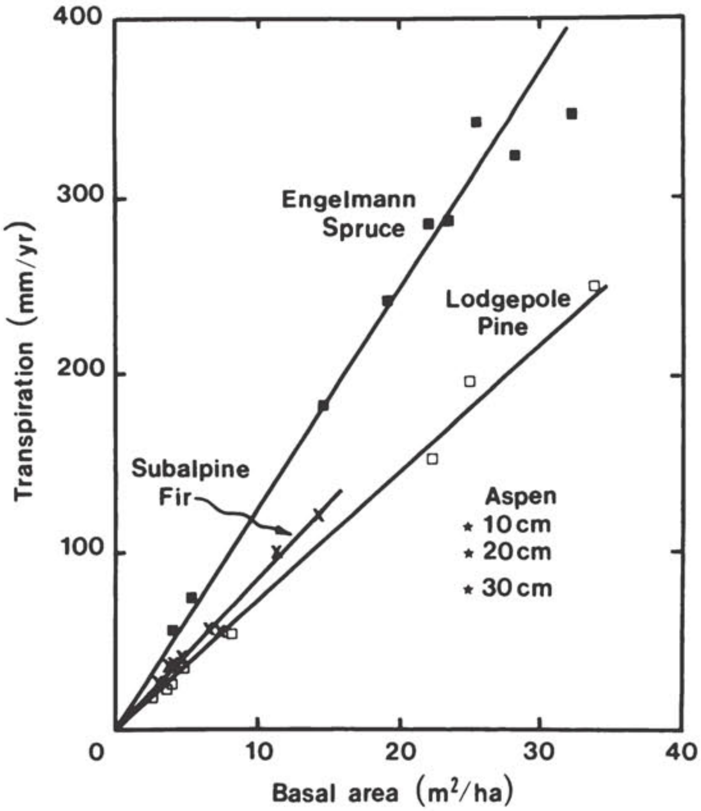
Tree Stomatal Behavior and Transpiration

About half of the precipitation falling on the Fraser Experimental Forest as either snow or rain is lost by evapotranspiration before it reaches the stream channel. Most of this loss is transpiration of water vapor from forest tree canopies. Stomatal regulation of gas exchange between air and plant is the key to transpiration. Using chambers to measure transpiration, it has been determined that the stomata of different tree species on the Fraser Experimental Forest respond primarily to visible irradiance and the humidity difference from leaf to air, with secondary responses to plant water stress and low temperature. Knowledge of stomatal behavior of forest trees has been used to develop a canopy layer model (RM–CWU) that estimates annual transpiration of subalpine forest canopies and stands for a wide range of stand and physiographic conditions.

Tree Species Differences in Transpiration and Water-Use Efficiency

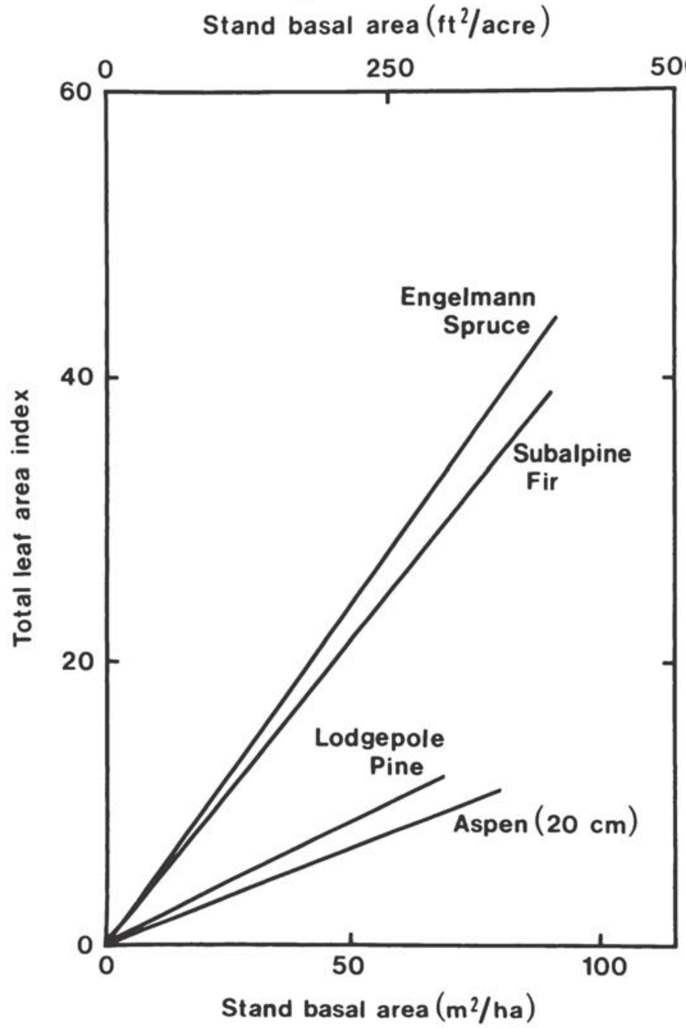
Differences in rates of transpiration among tree species in subalpine forests means that some species utilize less water and leave more available for streamflow. Data collected on the East St. Louis and Lexen Creek drainages show that in comparable stands, Engelmann spruce transpires 72% and subalpine fir 17% more water than lodgepole pine:

Rotation period	Timber volume	Transpiration	Water-use efficiency
	m^3/ha		m^3/m^3
Lodgepole pine			
120 years	505	205,000	0.0025
Engelmann spruce			
120 years	448	323,000	0.0014
180 years	762	602,000	0.0013



Foliage Area of Forest Tree Species

Surface area of tree foliage is an important factor in many forest processes and conditions such as transpiration, photosynthesis, interception of precipitation, environmental conditions on the forest floor, and wildlife habitat conditions within and beneath the forest canopy. Engelmann spruce, subalpine-fir, lodgepole pine, and aspen show a good relationship between leaf area and cross-section area of sapwood conducting tissue, and between leaf area index and basal area of each species in a stand. These relationships resulted in the development of predictive tools for estimating leaf area index from routine stand measurements that is a significant improvement over earlier estimates from crown closure and crown cover density.



While these watersheds do not contain aspen, estimates of the annual transpiration of aspen indicate less water used than by conifers. Under similar condition, sites where aspen stands occur are in part more moist because aspen uses less water. Large differences in transpiration between forest tree species suggests that total runoff from a watershed may be influenced by regulating species composition. Lodgepole pine has a much higher water-use efficiency because less water is used by pine to produce the same volume of wood as spruce-fir forests under the same site and stand conditions.

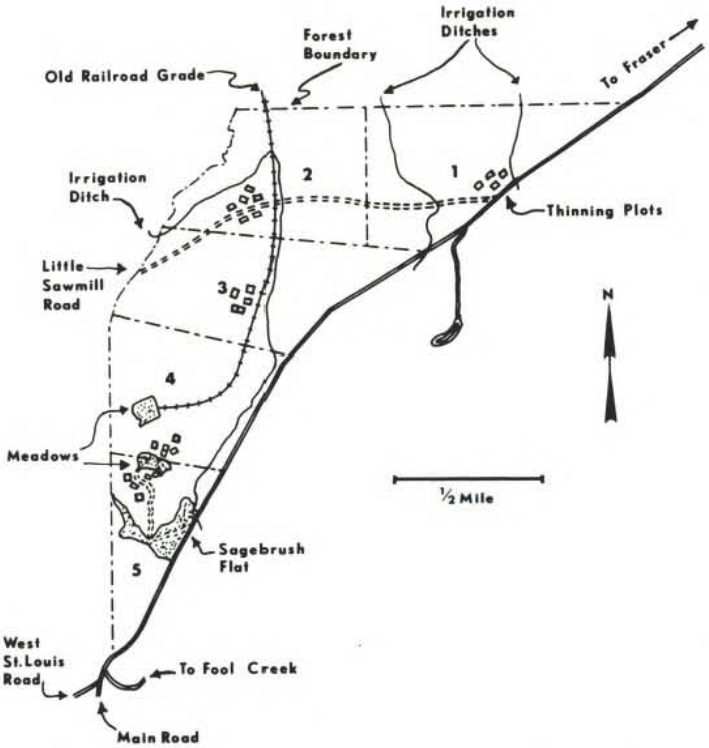
Factor	Engelmann spruce	Subalpine fir	Lodgepole pine	Aspen
Midday leaf conductance (cm/sec)				
Full sunlight	0.06	0.04	0.012	0.20
10% full sunlight	0.02	0.01	0.04	0.07
Leaf-air temperature difference (°C)	0	0	0	−1 to −5
Leaf area index (m²/m²)	15	5	6	5
Length of transpiration season (days)	210–245	210–245	210–245	105–115

Levels of Growing Stock—Young Lodgepole Pine

In 1975, a study was started in 60- to 70-year-old second-growth lodgepole pine stands on St. Louis Creek drainage to test different thinning levels. The study area was divided into five units, with one unit thinned each year for 5 years. Within each unit, four 0.4-acre plots were thinned from below, each to a different growing stock level (GSL's 40, 80, 100, 120). The first series of plots in Unit 1 were thinned in 1976, the last series of plots in Unit 5 were thinned in 1980. Additional plots thinned to a growing stock level of GSL 160 were added in 1981 in Units 2, 3, and 4. Suitable stands were not available in Units 1 and 5.

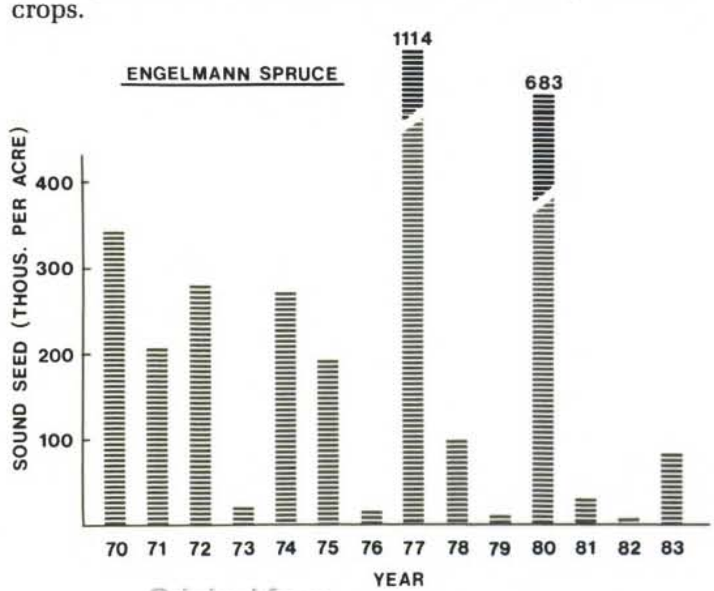
Periodic remeasurement will provide information on stand growth at different stocking levels, rate of spread and intensification of dwarf mistletoe infection, relative

herbage production in relation to basal area of residual overstory, soil moisture withdrawal in relation to overstory density and depth below the soil surface, and seasonal progress of soil moisture depletion. Present plans call for rethinning every 20 years to maintain stocking levels.



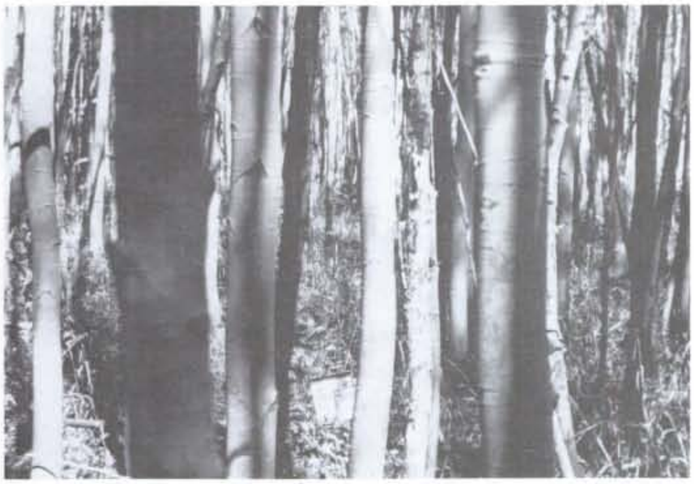
Engelmann Spruce Seed Production

A long-term study of Engelmann spruce seed production was started in 1968 on the Forest. By 1970, thirteen 0.4-acre plots had been established in stands with different age-classes and site characteristics. Good-to-heavy seed crops were produced during 7 of the first 14 years of observation, with some locations occasionally producing bumper crops. A higher proportion of sound seeds were produced in years with good-to-bumper crops than in years of poor-to-fair crops. Seed production was related to the number per acre and height of dominant and codominant spruces. This study will be continued to provide data needed to refine estimates of the frequency of good seed crops and the proportion of sound seeds produced in relation to total seedfall, and to identify the kinds of stands that produce good seed crops.



Aspen Thinning

An aspen thinning study was established in 1981 to determine the growth response of a 65-year-old aspen stand to treatments that remove 0%, 25%, 50%, 75%, and 100% of the original stand basal area. Half of each treatment area was fenced to exclude domestic livestock and big game. In addition to growth response, the effects of thinning on sucker response, production of understory vegetation, soil moisture, occurrence of disease, and use by large animals are monitored annually or throughout the growing season.



Expansion of Aspen in Conifer-Dominated Stands

Small patches of aspen, or widely spaced individual trees, grow in extensive conifer-dominated stands throughout the Rocky Mountains. Aspen provides prime habitat for many wildlife species, and its expansion into existing coniferous stands could improve habitat for current users and provide habitats for some species that conifers do not provide. Studies are currently underway in small circular openings with differing amounts of aspen and conifers, to determine how much residual aspen is required to insure that aspen is the dominant species after clearcutting. Concurrent studies are comparing species of nongame birds and mammals in small aspen patches growing as inclusions in extensive stands of 70-year-old lodgepole pine.

Initial Spacing of Lodgepole Pine

In 1984, a study was started to test the effects of initial spacing (500, 1,000, 1,500, and 2,000 stems per acre) on the diameter and height growth of lodgepole pine from the time of establishment until trees reach age 20 years.

Cutting Methods Demonstration Plots

Twelve cutting methods demonstration plots were installed on the Fraser Experimental Forest in 1983. Six cutting methods representing both even- and uneven-aged silviculture are duplicated in spruce-fir and lodgepole pine stands. Even-aged silviculture is represented by clearcutting and three shelterwood options. Clearcutting removed all growing stock regardless of size. Twoand three-step shelterwood removed trees from below, leaving the larger trees to provide a seed source and overstory shelter to new reproduction.

Simulated shelterwood removed the overstory from an established stand of advanced reproduction.

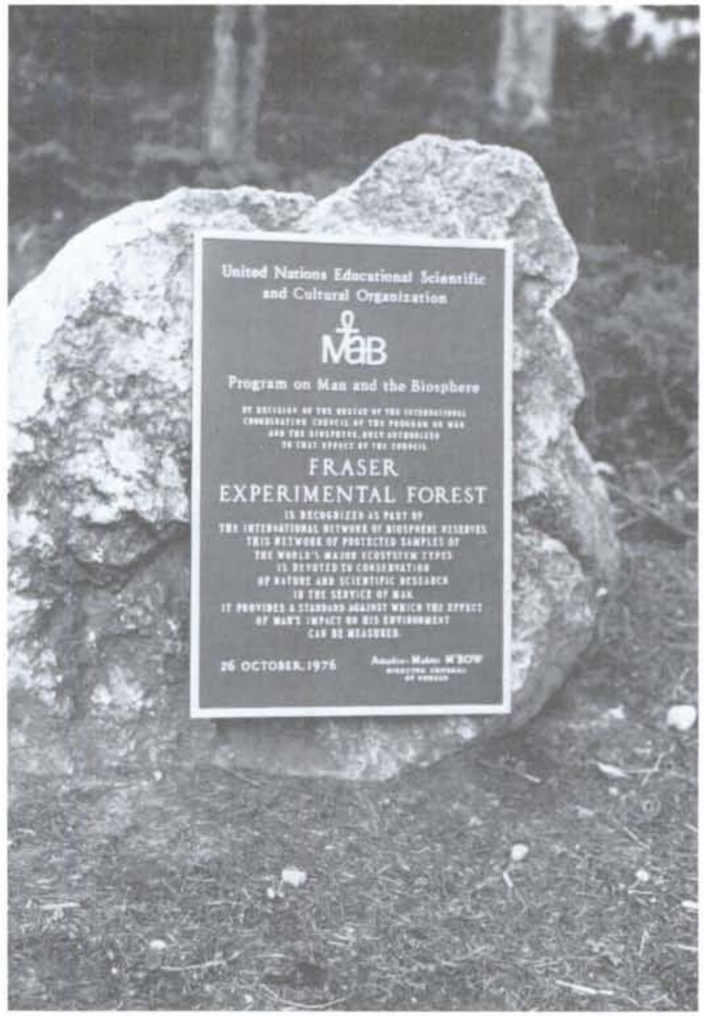
Uneven-aged silviculture is represented by individual tree and group selection cutting methods. Individual tree selection removed trees in all diameter classes from multistoried stands. Group selection in lodgepole pine removed trees in groups in a stand composed of several age classes. Group selection in spruce-fir stands removed groups of trees in a stand where trees were naturally clustered in groups separated by small openings.

SIDELIGHTS

Facilities of the Fraser Experimental Forest are used occasionally for graduate training, undergraduate field work, field meetings of forestry and conservation societies, and Foreign Agriculture Service programs in forestry. Excellent examples nearby serve as on-the-ground illustrations of both beneficial and harmful management practices in mountain ecosystems.

Opportunities for graduate students to undertake fundamental research in conservation and use of natural resources are excellent. Arrangements may be made on a cooperative basis with the USDA Forest Service through colleges, universities, foundations, or other interested groups.

The Fraser Experimental Forest is also a Biosphere Reserve (MAB–8) in the Man in Biosphere (MAB) program, which is designed with full recognition that cooperative interdisciplinary research at all levels is needed if pressing global environmental problems are to be solved. It is an intergovernmental effort to focus research, education, and technical training on filling this need.



Visitors are always welcome. To obtain more detailed published information about the experimental work, ask the resident scientists or send a request to Director, Rocky Mountain Forest and Range Experiment Station, 240 West Prospect, Fort Collins, Colo. 80526.

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APPENDIX 1

List of Ph.D. Dissertations and Masters' Theses

Timber Management

Noble, Daniel L. 1974. Natural regeneration of Engelmann spruce in clearcut openings in the Central Rockies as affected by weather, aspect, seedbed and biotic factors. Ph.D. dissertation, 187 p. Colorado State University, Fort Collins. [Diss. Abstr. 35(6):2530-B].

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APPENDIX 2

Species List of Birds

Common Name	Scientific Name
MIGRATORY BIRDS	
Mallard	*Anas platyrhynchos*
Teal	*Anas* spp.
Golden eagle	*Aquila chrysaetos*
American kestrel	*Falco sparverius*
Spotted sandpiper	*Actitis macularia*
Mourning dove	*Zenaida macroura*
Rufous hummingbird	*Selasphorus rufus*
Black-billed magpie	*Pica pica*
Clark's nutcracker	*Nucifraga columbiana*
Black-capped chickadee	*Parus atricapillus*
Mountain bluebird	*Sialia currucoides*
Red-winged blackbird	*Agelaius phoeniceus*
Western flycatcher	*Empidonax difficils*
Western wood pewee	*Contopus sordidulus*
Olive-sided flycatcher	*Nuttallornis borealis*
Horned lark	*Eremophilia alpestris*
Steller's jay	*Cyanocitta stelleri*
Common crow	*Corvus brachyrhynchos*
Dipper	*Cinclus mexicanus*
Red-breasted nuthatch	*Sitta canadensis*
White-breasted huthatch	*S. carolinesis*
Brown creeper	*Certhia familaris*
American robin	*Turdus migratorius*
Townsend's solitaire	*Myadestes townsendi*
Hermit thrush	*Catharus guttatus*
Gold-crowned kinglet	*Regulus satrapa*
Ruby-crowned kinglet	*R. calendula*
Yellow-rumped warbler	*Dendroica coronata*
Song sparrow	*Melospiza melodia*
Lincoln's sparrow	*M. lincolnii*
Wilson's warbler	*Wilsonia pusilla*

Common Name	Scientific Name
SEASONAL NESTING BIRDS	
Goshawk	*Accipiter gentilis*
Sharp-skinned hawk	*A. striatus*
Marsh hawk	*Circus cyaneus*
Red-tailed hawk	*Buteo jamaicensis*
Screech owl	*Otus asio*
Great horned owl	*Bubo virginianus*
Common nighthawk	*Chordeiles minor*
Broad-tailed hummingbird	*Selasphorus platycercus*
Northern flicker	*Colaptes auratus*
Yellow-bellied sapsucker	*Sphyrapicus varius*
Williamson's sapsucker	*S. thyroideus*
Hammond's flycatcher	*Empidonax hammondii*
House finch	*Carpodacus mexicanus*
Pine grosbeak	*Pinicola enucleator*
Pine siskin	*Carduelis pinus*
Red crossbill	*Loxia curvirostra*
Dark-eyed junco	*Junco hyemalis*
White-crowned sparrow	*Zonotrichia leucophrys*
YEARLY RESIDENT BIRDS	
Blue grouse	*Dendragapus obscurus*
White-tailed ptarmigan	*Lagopus leucurus*
Hairy woodpecker	*Picoides villosus*
Downy woodpecker	*P. pubescens*
Three-toed woodpecker	*P. tridactylus*
Gray jay	*Perisoreus canadensis*
Common raven	*Corvus corax*
Mountain chickadee	*Parus gambeli*

APPENDIX 3

Species List of Mammals

Common Name	Scientific Name
Vagrant shrew	*Sorex vagrans*
Northern watershrew	*S. monticolus*
Masked shrew	*S. cinereus*
Little brown myotis (bat)	*Myotis lucifugus*
Black bear	*Ursus americanus*
Marten	*Martes americana*
Longtail weasel	*Mustela frenata*
Shorttail weasel (rare)	*M. erminea*
Mink (rare)	*M. vison*
Striped skunk	*Mephitis mephitis*
Badger (occasional)	*Taxidea taxus*
Red fox	*Vulpes vulpes*
Gray fox	*Urocyon cenereoargenteus*
Coyote	*Canis latrans*
Mountain lion (rare)	*Felis concolor*
Bobcat	*Lynx rufus*
Yellowbelly marmot	*Marmota flaviventris*
Golden mantled squirrel	*Spermophilus lateralis*
Least chipmunk	*Eutamias minimus*
Colorado chipmunk (questionable)	E. quandrivittatus
Uinta chipmunk	*E. umbrinus*
Red squirrel	*Tamiasciurus hudsonicus*
Northern pocket gopher	*Thomomys talpoides*
Deer mouse	*Peromyscus maniculatus*
Bushytail woodrat	*Neotoma cinerea*
Mountain phenacomys (Heather vole)	*Phenacomys intermedius*
Boreal roadback vole	*Clethrionomys gapperi*
Montane vole	*Microtus montanus*
Long-tailed vole	*M. longicaudus*
Western jumping mouse	*Zapus princeps*
Muskrat	*Onadatra zibethica*
Beaver	*Castor canadensis*
Porcupine	*Erethizon dorsatum*
Pika	*Ochotona princeps*
Snowshoe hare	*Lepus americanus*
Elk	*Cervus elaphus*
Mule deer	*Odocoileus hemionus*
Moose	*Alces alces*

Alexander, Robert R., Charles A. Troendle, Merrill R. Kaufmann, Wayne D. Shepperd, Glenn L. Crouch, and Ross K. Watkins. 1985. The Fraser Experimental Forest, Colorado: Research program and published research 1937–1985. USDA Forest Service General Technical Report RM-118, 46 p. Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colo.

This report provides an overview of the research done on the Fraser Experimental Forest. It replaces GTR's no. 40 and 40A by Robert R. Alexander and Ross K. Watkins in 1977. Included are descriptions of physical features and resources, highlights of past and current research, and the publications derived from that research

Keywords: Cutting methods, forest regeneration, water yield, water-use, wildlife habitat

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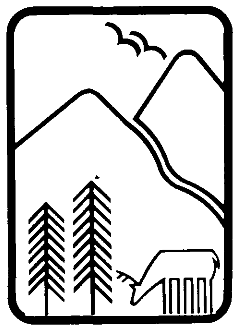
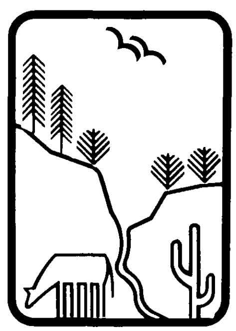


Rocky Mountains



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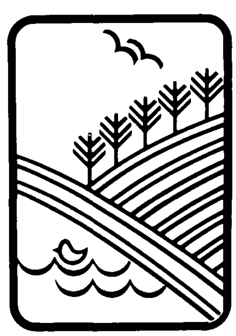

Great Plains

The Rocky Mountain Station is one of eight regional experiment stations, plus the Forest Products Laboratory and the Washington Office Staff, that make up the Forest Service research organization.

RESEARCH FOCUS

Research programs at the Rocky Mountain Station are coordinated with area universities and with other institutions. Many studies are conducted on a cooperative basis to accelerate solutions to problems involving range, water, wildlife and fish habitat, human and community development, timber, recreation, protection, and multiresource evaluation.

RESEARCH LOCATIONS

Research Work Units of the Rocky Mountain Station are operated in cooperation with universities in the following cities:

Albuquerque, New Mexico
Flagstaff, Arizona
Fort Collins, Colorado*
Laramie, Wyoming
Lincoln, Nebraska
Rapid City, South Dakota
Tempe, Arizona

*Station Headquarters: 240 W. Prospect Rd., Fort Collins, CO 80526