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Soil Moisture Recharge in Stands of Quaking Aspen and Gambel Oak in Central Utah

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SOIL MOISTURE RECHARGE IN STANDS OF QUAKING ASPEN AND GAMBEL OAK IN CENTRAL UTAH

by

James L. Boynton

A thesis submitted in partial fulfillment
of the requirements for the degree

of

MASTER OF SCIENCE

in

Forest Watershed Management

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To my wife Pat, I express appreciation and gratitude for her encouragement and assistance throughout this study.

James L. Boynton

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ABSTRACT

Soil Moisture Recharge in Stands of Quaking Aspen and Gambel Oak in Central Utah

by

James L. Boynton, Master of Science

Utah State Univeristy, 1968

Major Professor: John D. Schultz
Department: Forest Watershed Management

Soil moisture recharge was studied in quaking aspen and Gambel oak forest areas of central Utah. The rate, timing, and duration of the recharge period was observed. Soil moisture readings were taken periodically throughout the winter of 1966-1967.

Soil moisture recharge begins in October and continues until May. The period of most rapid increase in recharge is between February and May. This corresponds to a rapid decrease in the zenith angle of the sun at the surface of the area and also to a decrease in cloud cover over the area.

Deep soils and high infiltration capacities prevent surface runoff from the area. Both detention storage and retention storage capacity of the soils are high.

Soil freezing was not present during the winter months. Some patchy soil freezing is found in the spring but it is not extensive enough to influence the recharge phenomenon.

(49 pages)

INTRODUCTION

The demand for greater water supplies is growing, and particular emphasis is being placed on improving water yields from higher elevations. Greater yields have been obtained by reducing water use by plants during the growing season, by increasing the amount of snowfall reaching the ground surface, and by shading the snowpack to decrease melt rates. These changes all affect the timing, rate and duration of soil moisture recharge which, in turn, affects the water yields of watersheds. Thus, as the demands for greater water yields increase, it is necessary to examine more closely the recharge phenomena which occur on watersheds.

In central Utah, a project has been established to study increased water yields by manipulation of vegatation.[1] At higher elevations, precipitation falls mostly as snow and is much greater than it is in the lower valleys where people are concentrated. People obtain their water supplies from these higher areas. The timing, rate, and duration of water yield from such areas are determined by the soil moisture content during the recharge period. The subject of soil moisture recharge during

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[1] "Manipulation of Trembling Aspen and Gambel Oak for Increased Water Yields," Project No. 641, Utah Agricultural Experiment Station, in cooperation with Cooperative State Research Service, U. S. Department of Agriculture.

the winter recharge period has not been studied in the higher elevations of central Utah or in any other areas of which we know.

Soil temperatures, soil horizon development, parent material of soils, vegetative cover, and condition of the soil surface while recharge is occurring all influence soil moisture recharge. These factors may affect timing, duration, amount, or pattern of recharge. Knowing the amount and pattern of recharge at certain periods in the winter is important in evaluating and predicting changes in water yields, even if yields cannot be associated with a particular influencing factor such as soil development or vegetative cover. The trend, duration, and timing of recharge, by themselves, may be very useful tools in analyzing water yields.

OBJECTIVES

This study was established to evaluate the rate, timing, and duration of soil moisture recharge phenomena which occur in the higher elevations of central Utah. The rate of recharge, the length of time over which recharge occurs, and the onset and completion of recharge were observed. Not only was the manner in which recharge occurs studied, but some answers to the question of why recharge occurs were sought. Some of the factors which affect recharge were studied and measured, and their effects on soil moisture recharge are analyzed and discussed in this thesis.

REVIEW OF LITERATURE

Manipulation of vegetation

Manipulation of vegetative cover has been shown to be effective as a means of regulating soil moisture recharge. Regulation of the timing, duration, and amount of recharge has been accomplished successfully.

Studies by Bay (1958), Lull and Rushmore (1960), and Weitzman and Bay (1959) all substantiated the concept that snow accumulation is greater in hardwood forests than in conifer forests, but snowmelt is substantially slower in conifer forests. Horton (1945) explained the same fact in terms of forest cover density. He compared conifer forests and hardwood forests with regard to melt rate and found that the rate of melt decreased as the forest cover density increased. Lull and Rushmore (1960), in their study in the Adirondacks, stated that hardwood melt rates were about twice those of conifer stands and that melt in hardwood stands was complete about nine days earlier than in conifer stands.

Goodell and Wilm (1955), reporting on a study at Wagon Wheel Gap, Colorado, explained that aspen trees devoid of leaves in the winter offer very little obstruction to falling snow and allow more snow to accumulate on the ground. The size of trees in hardwood stands also affects the amount of snow accumulation and the length of recharge period. In a study in New Hampshire which compared the size of trees, Sartz and

Trimble (1956) found that snow accumulation was greater under sawtimber hardwood stands than under pole-sized hardwood stands. This study also showed that snow accumulation can be increased and the recharge period can be extended by cutting narrow strips in the east-west directions.

Another area of importance in soil moisture recharge is the control of timing of recharge and yields to meet the demands of moisture at certain times in the year. Eschner and Satterlund (1963) felt that the chance of rapid melt and consequently, rapid runoff from persisting snowpacks became greater as the cold winter proceeded to the warmer conditions of early spring. They pointed out that the chances of spring rains swelling snowmelt from the ripe snowpack were increased with manipulation of vegetation to prolong duration of the snowpack. However, they felt that forested areas would contribute less total runoff at a slower rate than would open areas. In the Wagon Wheel Gap study, Goodell and Wilm (1955) reported that the stream flow peak increased 50 percent and that it occurred about three days earlier than the average date of peak discharge before all standing trees had been removed. Berndt (1961) theorized that because of increased melt rates resulting from strip-cuttings to increase snow accumulation, stream flow from snow melt was not prolonged. He concluded that one could expect higher spring peaks from strip-cuttings.

Water yield improvement studies

Several researchers (Anderson, 1960; Anderson and Gleason, 1959; Christner, 1967; Croft, 1953; Croft and Hoover, 1959; Colman, 1953; Fletcher, 1952) have concluded that removing deep-rooted vegetation or converting from deep-rooted to shallow-rooted plants results in reduced evapotranspiration on deep, well-drained soils. They attributed this reduction to the fact that shallow-rooted vegetation depletes only the soil moisture in the upper part of the soil profile. This leaves more moisture at the lower depths of the profile.

Similar results were found by Thames, Stoeckeler, and Tobaski (1955) who pointed out that greater water yields can be expected to occur early in the spring because less moisture is required to recharge the soil. They emphasized that this early yield can be retained for use later in the season in areas where water yields contribute to the recharge of reservoirs for power or irrigation. Otherwise, the increased yield may occur when it cannot be utilized. Anderson (1960) and Anderson and Gleason (1959) found that the increase in soil moisture carry-over resulted in a greater water yield when heavy fall rains or winter melt occurred. Therefore, this soil moisture contributed to late fall floods or early spring runoff. They also agreed that some water may be gained when it is not wanted or needed.

Continuous or base flow

Groundmelt may be a source of winter stream flow and soil moisture recharge during the period in which a snowpack is present on the ground. Wisler and Brater (1959) suggested that stream flow of about 0.01 area-inch per day may arise from groundmelt, which they define as the melting of snow by heat transferred from the soil to the bottom surface of the snowpack. In Ontario, Gold (1957) measured soil heat flux which corresponded to a groundmelt of 0.03 inch per day under a 12-inch cover of snow during the months of February and March in 1955. Federer (1965) observed that soils were nearly always saturated by autumn rains in New England so that the groundmelt passed through the soil and reached the stream. He explained that areas where soils are not recharged by the time snow falls may be partially recharged during the winter months. In addition, he reported that increasing snow depth reduced the portion of heat lost to the air and increased that portion of heat available for snowmelt.

Effects of soil freezing on recharge

Soil freezing has been found to decrease water infiltration and rate of recharge. Different types of soil freezing cause various reductions of infiltration, and types of cover conditions affect the extent of soil freezing.

Stoeckeler and Weitzman (1960) found that infiltration into loamy sands of northern Minnesota was six times greater on the unfrozen soil plots than on the porous concrete frost plots. Infiltration was four times greater on the unfrozen soil than on the frozen soil. They added that significant differences in rates of reduction were found for different types of soils tested. Trimble, Sartz, and Pierce (1958) found concrete frost in the open and in the forest to be impermeable. They pointed out that the forested area was transversed in places by large, unfrozen areas that allowed water to enter the soil. They also found granular frost to be more permeable than unfrozen soil.

Pierce, Lull, and Storey (1958) felt that there was considerable difference between the common frost condtions of the open lands and the conditions commonly found in forested areas. They reported the frost of the open lands to be concrete and very impermeable, thus promoting surface runoff; but under the forested conditions, they found that infiltration occurred. Concrete frost was found to occur in hardwood stands at depths about one-half those found in coniferous stands.

DESCRIPTION OF STUDY AREA

Location and site layout

This study was conducted at four different sites, two in a pure stand of quaking aspen (populus tremuloides Michx.) and two in a pure stand of Gambel oak (Quercus gambelii Nutt.). The four sites are located in central Utah east of the town of Salina in Sevier County. All sites are on the Salina District of the Fishlake National Forest, U. S. Forest Service. Oak Site I and Aspen Site I are in Willow Creek Canyon about three and four miles, respectively, from the Forest Service boundary. Willow Creek Canyon is approximately eight miles northeast of Salina. Oak Site II is located five miles north on the Water Canyon road which leaves Utah Highway 4 about 12 miles east of Salina. Aspen Site II is two miles east of Gooseberry Ranger Station which is 19 miles southeast of Salina. The locations of the sites are marked on the map in Figure 1.

There are fourteen plots at each study site. Each plot is approximately 25 feet square. Two aluminum access tubes for the neutron soil moisture probe were installed two to three feet apart in the approximate center of each plot. A trench was dug around the perimeter of each study site and between the plots. The trenches were dug 30 to 36 inches deep, lined with plastic sheeting, and then refilled with the soil that previously had been removed. The purpose of the trenches was to sever root

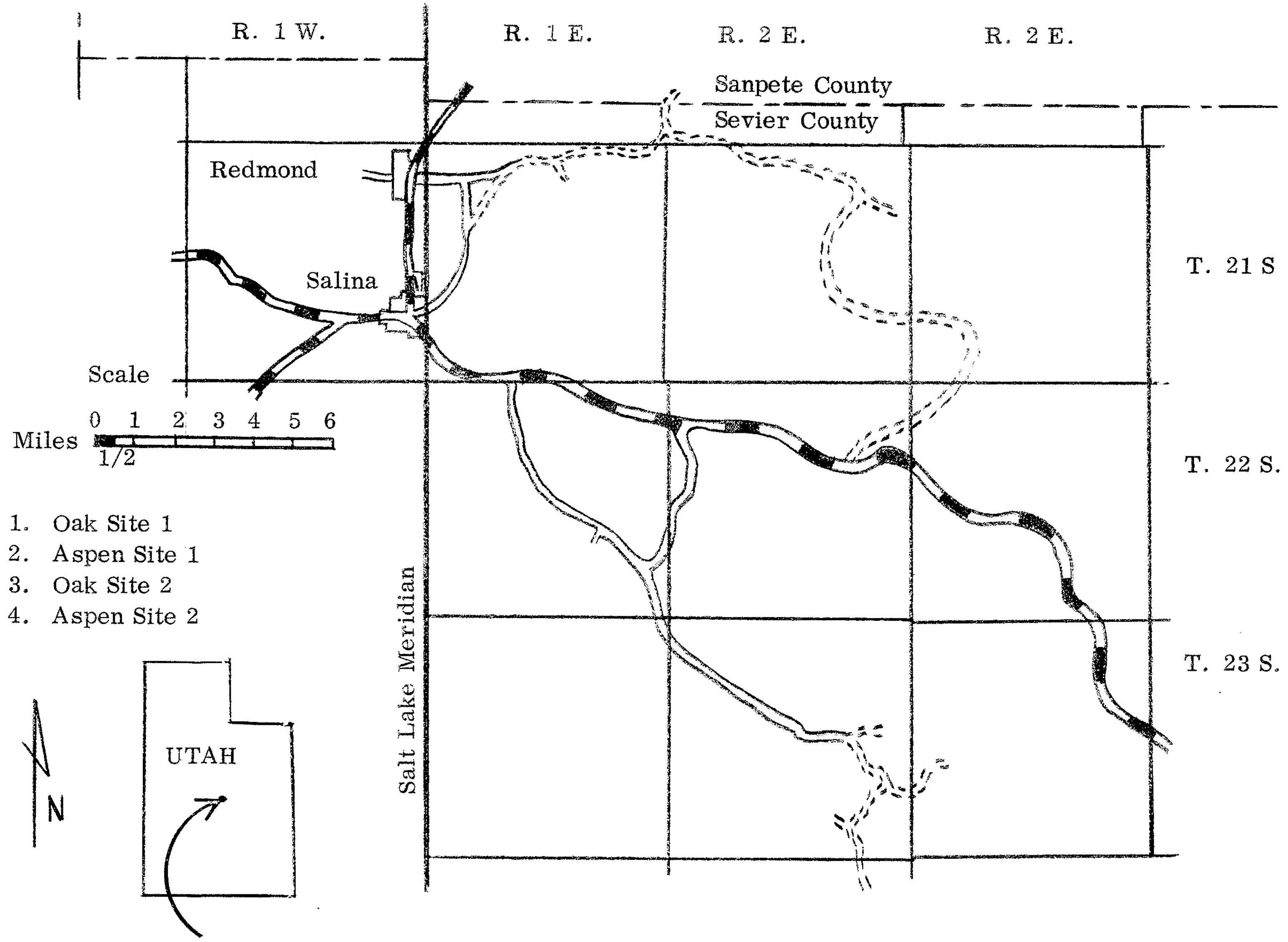

Figure 1. Location of study sites.

connections between plots. Plastic sheeting was used to minimize root penetration from one plot to another and to retard lateral movement of soil moisture. The trenches were completed for Oak Site I, Oak Site II, and Aspen Site I in the fall of 1964 and for Aspen Site II in the early summer of 1966. Diagrams of the plot layouts and their numerical identities are shown in Figure 2.

In the initial study for water yield improvement, seven treatments were applied at each site. Each treatment was used on two plots at each site. Treatments which were applied are: (1) 100 percent removal of basal area, (2) 75 percent removal of basal area, (3) 50 percent removal of basal area, (4) 25 percent removal of basal area, (5) injection of trees with sodium arsenite with a tree injector, (6) injection of sodium arsenite into the trees with the use of frustums, and (7) untreated control areas.

Elevation of all the plots is near 8,000 feet, but Oak Site I is the lowest of the four sites. Oak Site I lies on a 15- to 18-percent slope and has a southwest aspect. Aspen Site I has a slope of 8 to 10 percent and a northwest aspect. Oak Site II has a southern exposure and an 11- to 13-percent slope. Aspen Site II also has an 11- to 13-percent slope, but the aspect is west-southwest.

Geology and soils

The sites used in this study are located in the northwest portion of the High Plateaus of Utah, which are part of the Colorado Plateau province. The entire belt of the High Plateaus is subdivided by two

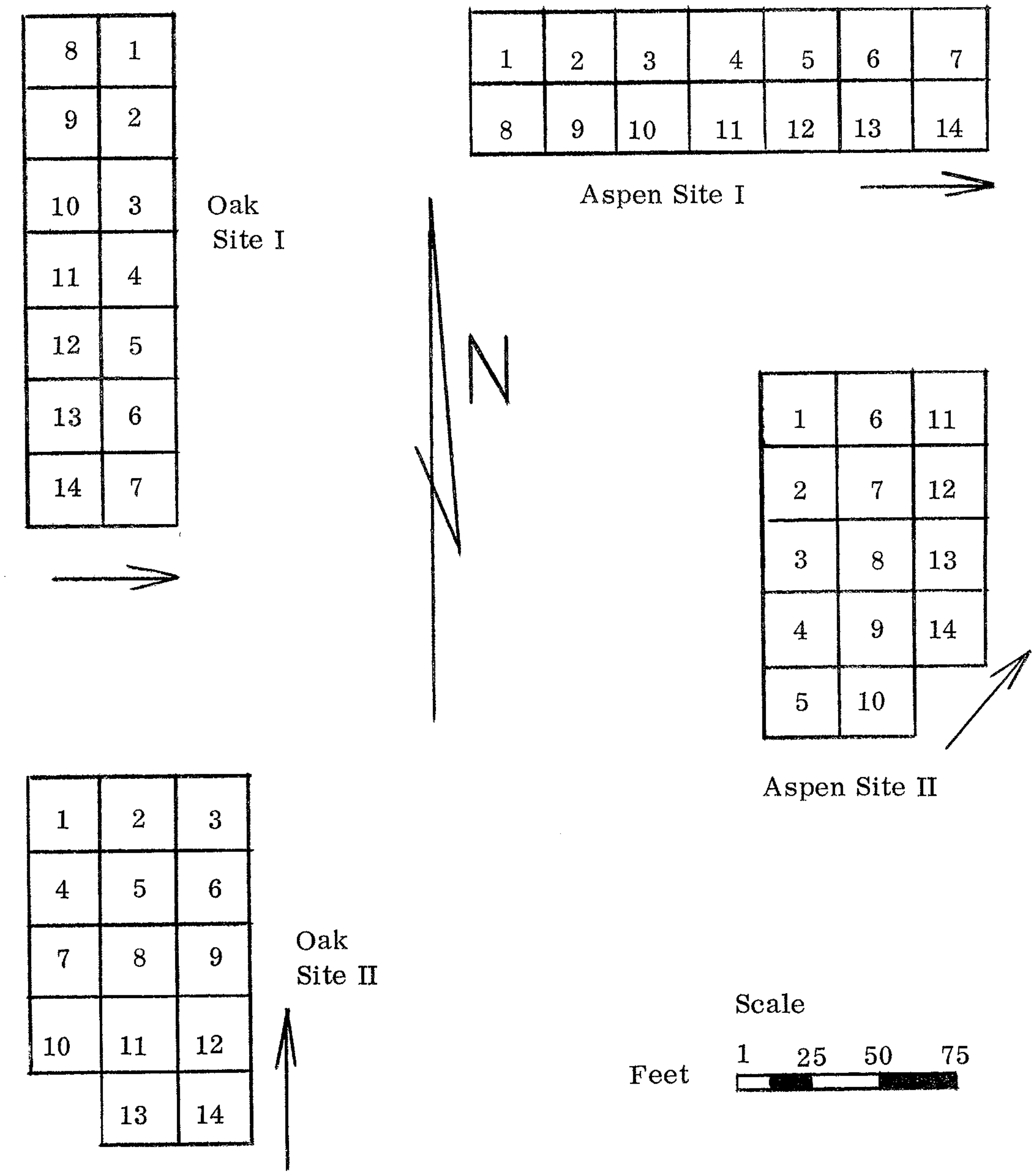

Figure 2. Plot layout and numbers of individual plots. Arrow beside each layout indicates the upslope direction.

trenches into three longitudinal strips. The plateaus of the eastern strip, named in order from north to south, are Wasatch, Fishlake, Awapa, and Aquarius (Fenneman, 1946). Fenneman points out that the north-and-south running fault-line scarps face west, and that the plateau surfaces slope eastward.

Oak Site I and Aspen Site I are located on the southwestern portion of the Wasatch Plateau. Oak Site II is located on the south edge of the Wasatch Plateau. The Fishlake Plateau is located to the south and is separated from the Wasatch Plateau by the narrow valley eroded by Salina Creek. Aspen Site II is located in the northern portion of the Fishlake Plateau.

No lava is found capping the Wasatch Plateau; but, on the Fishlake Plateau, lava flows reach far to the north near Aspen Site II (Hardy, 1952; Maurer, 1966). The four sites are on the North Horn formation which is late Cretaceous and early Tertiary (Maurer, 1966; Speiker, 1949). This formation is composed of red, grey, and green variegated shales, buff to red sandstones, conglomerates, and limestones. It is from 500 to 3,000 feet thick.

Oak Site I and Aspen Site I and II have soils which show signs of development from material other than the bedrock on which they sit. It appears that at these three sites, parent material moved in over the bedrock from upslope. At both aspen sites there is evidence of recent movement of material onto the site areas from outside the areas. Oak

Site II had some collovium deposited on it; however, the deposits were not as extensive at this site as at the other sites.

Oak Site I has a moderately well developed soil which gets deeper at the downslope edge of the site. Litter has accumulated to a depth of 0.25 inch and is underlaid by a layer of well mixed mineral soil and organic matter. The soil profile is divided into four hoirzons: 0 to 19 inches, which includes the litter and the mixture of organic matter and mineral soil; 19 to 29 inches; 29 to 39 inches; and 39 to 44+ inches. The 0- to 19-inch horizon has a texture of heavy clay loam and has a poorly developed structure. No rocks are present, and numerous roots descend to the boundary at 19 inches. This boundary is diffuse and smooth. The texture of the 19- to 29-inch depth is also heavy clay loam, and no structure is visible. Rock represents 15 to 25 percent of the volume in this horizon. The 29- to 39-inch horizon has a clay texture and an abundance of clay films. This horizon is 50 percent rock. The structure below 29 inches is strong, fine subangular blocky. Parent material which is highly calcareous is below 39 inches and has a 75 percent composition of rock. No bedrock is exposed at Oak Site I.

Aspen Site I has a soil with three distinct horizons: 0 to 12 inches, 12 to 24 inches, and 24 to 32+ inches. Within the 0- to 12-inch depth, litter has accumulated to a depth of 0.25 inch and it overlies a 1-inch layer of mixed organic matter and mineral soil. The 0- to 12-inch horizon has a texture of silty clay loam. No rocks are present, and there is no development of structure. Numerous roots penetrate down to the 12-inch depth where the boundary is gradual and very irregular. The 12- to 24-inch horizon shows signs of increasing clay content with a texture of silty clay and thick clay films on the ped surfaces. A strong, fine to medium subangular blocky structure is visible in this horizon. Root penetration is noticeably decreased from that in the 0- to 12-inch depth. Sandstone cobbles occupy 10 to 15 percent of the volume of the 12- to 24-inch horizon, and areas of decomposed sandstones are visible as colored mottles scattered through the profile. The boundary at 24 inches is abrupt and smooth. The texture in the 24- to 32+-inch horizon is silty clay, and there is no visible structure. Both sandstone and highly calcareous cobbles are found in this horizon and comprise 50 percent of the volume. The cobbles have the appearance of water-deposited materials.

Aspen Site II shows evidence of a new and shallow profile, 0 to 7 inches, which developed over an older and much deeper profile. The new profile appears to be an alluvial deposit which moved over the site and the older profile. It has two horizons, 0 to 3 inches and 3 to 7 inches, with a gradual and smooth boundary separating them. The upper profile has a silty clay loam texture and no visible structure. No rocks are present, and numerous roots penetrate the full depth. The boundary at the 7-inch depth between the two profiles is abrupt and smooth. The buried profile has two well-developed horizons, the upper one at the 7- to 21-inch depth and the lower one at the 21- to 36+-inch depth.

Textures at both horizons are silty clay; however, considerably more clay is present in the lower horizon than at the 7- to 21-inch depth. Heavy root penetration is evident in the 7- to 21-inch horizon. Percentage of rock increases considerably from 21 inches down to 36+-inches, ranging from 10 to 15 percent at the 21-inch boundary to 75 percent at the 36+-inch depth.

A soil pit was not dug at Oak Site II, but from records taken while access tubes were being installed, it was found that the soil at this site has a much sandier texture than soils at the other three sites. The soil is not deep, and it runs into sandstone parent material at shallow depths. Small outcrops of sandstone are evident in the area around the site.

Climate

The climate at the sites is distinguished by wet winters and relatively dry summers. The approximate annual precipitation falling for an average year and the inches of percipitation falling for the periods October-April and May-September are listed in Table 1.

Different storm patterns occur in the winter than in the summer. Winter storms generally drop a uniform amount of precipitation over all the sites with precipitation falling mostly as snow between October and April. By the end of November, a snowpack has begun to accumulate at these sites. Summer precipitation occurs mainly from afternoon convection storms which are very spotty and do not cover large areas. The intensities are generally very high, but the duration is short.

Table 1. Seasonal distribution of precipitation

Site	Inches of precipitation[a]		
	Normal Annual	October-April	May-September
Oak Site I	20-25	12-16	6
Aspen Site I	20-25	12-16	6
Oak Site II	25	16-20	6-8
Aspen Site II	25	16-20	8

[a] Taken from a map compiled by the Water Supply Forecast Unit and Office of State Climatologist, U. S. Weather Bureau, Salt Lake City, Utah, using adjusted climatological data (1921-50).

Air temperatures reach well below zero during the winter months. The lowest values are reached in December and January and range between 15 and 20 F below zero. Starting in February, the amount of cloud cover decreased and night temperatures went below freezing. Clearing during the day allows the days to warm up to as high as 45 F. In April and May, daytime highs of 50 to 55 F are not uncommon.

Vegetation

Both aspen sites have an open understory. Plants present at both sites are wild rose (*Rosa woodsii* Lindl.), yarrow (*Achillea lanulosa* Nutt.), blue grass (*Poa* sp.), and some June grass (*Koeleria cristata* L.). In addition, serviceberry (*Amelanchier utahensis* Koehne.) is present at Aspen Site I. There is some difference between the quaking aspen trees found on the two sites. The trees on Aspen Site I are 40 to 50 feet tall and the diameters range from 6 to 8 inches. On Aspen Site II the canopy is 45 to 50 feet above the ground, with a 4- to 9-inch range in diameter.

Composition of ground cover at Oak Site I and II is very much the same. Understory is comprised mostly of scarlet gillia (Gillia aggregata (Pursh) Spreng.), wild geranium (Geranium fremontii Torr.), serviceberry, yarrow, and some scattering of blue grass and June grass. Surrounding Oak Site II there is a big sagebrush (Artemesia tridentata Nutt.) which is not found near Oak Site I. The Gambel oak at Oak Site I grows in clumps, has a height of about 12 to 14 feet, and ranges in diameter from 1 to 3 inches. At Oak Site II, the tree heights are 15 to 25 feet. The stand is open with no close clumps of trees, the diameters range from 3 to 9 inches with the average of 5 inches.

PROCEDURE

Method of investigation

Six of the fourteen plots at each site were chosen to be used in this study. Two of the plots were those where 100 percent of the tree basal areas was removed, and two were control plots. The locations of the additional two plots were chosen to make it possible to obtain evenly distributed measurements of the soil moisture over the entire site. A list of plots studied, their treatments, and depths sampled is shown in Table 2.

The soil moisture content of the profile was measured in each of the two holes at each plot. Measurements were taken with a neutron-scattering depth moisture probe manufactured by Troxler Electronic Laboratories, Incorporated. The first reading in the profile was taken at the 6-inch depth, and subsequent readings were taken at one-foot intervals thereafter.

Access tubes were marked with stakes and flags so that they could be located under the snowpack without disturbing the site and snow cover too much. Small holes were dug in the snow cover to gain access to the tubes. Snowshoes were worn so that the snow around the access tube was not compacted unduly while the plots were metered.

Table 2. Plots studied, depths metered, and corresponding treatments

Site	Plot number	Depth (inches)	Treatment
Oak Site I	1	90	Control
	6	90	Injection of sodium arsenite with tree injector
	7	90	100 percent basal area removed
	9	90	Injection of sodium arsenite with tree injector
	11	90	100 percent basal area removed
	14	90	Control
Aspen Site I	1	78	100 percent basal area removed
	3	78	Injection of sodium arsenite with tree injector
	7	78	Control
	8	78	Control
	11	78	Injection of sodium arsenite with tree injector
	13	78	100 percent basal area removed
Oak Site II	1	102	Control
	2	102	100 percent basal area removed
	8	102	100 percent basal area removed
	9	102	Injection of sodium arsenite with tree injector
	13	102	Injector of sodium arsenite by frustum technique
	14	102	Control

Table 2. Continued

Site	Plot number	Depth (inches)	Treatment
Aspen Site II	1	66	Injection of sodium arsenite with tree injector
	3	66	Injection of sodium arsenite by frustum technique
	5	66	Control
	7	66	Control
	10	66	100 percent basal area removed
	13	66	100 percent basal area removed

Sample holes were dug through the snowpack down to the soil surface on plots not being used for this study and on areas adjacent to the sites so that occurrence and type of soil freezing could be observed.

Soil moisture readings were scheduled to be taken at one month intervals starting in November, 1966 and to continue until May, 1967.

Analysis of data

Percentage of recharge at the plots at various intervals was used for purposes of analysis. The total recharge capacity was determined by taking the difference between minimum and maximum inches of water measured in the soil profile during the year. This difference was considered to be the net amount of water recharge. The differences between the minimum reading at a hole and each of the other readings for the same hole were divided by the net amount of water recharge and multiplied by 100 to obtain the percentage of recharge for each date metered.

RESULTS AND DISCUSSION

The period from August, 1966, to May, 1967, was the first time that soil moisture readings were collected at these sites during the period of greatest soil moisture recharge. Readings from March, April, and May of 1967 were compared with readings of early spring for previous years. It was found that the total inches of water[1] in the profiles was greater in 1967 than in earlier years. The lowest total inches found in the profiles since the inception of the water yield study was begun were found in September and October of 1966. Tables 3, 4, 5, and 6 show the inches of water in the soil profile for each hole metered. The maximum and minimum inches of water present for the period studied are marked for each hole, and the amount of water recharge is given.

Percentage of recharge, as explained in the analysis of data, was calculated for each hole in a plot. The mean of these percentages was used to obtain the average percentage of recharge for the plot. In some cases, minimum recharge for the two holes on a plot did not occur on the same day for both holes. The average of the percentage of recharge for the two holes gives a value slightly greater than zero percent for the

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[1] "Inches of water" is a volumetric measure of amount of water in the profile. It is a layer of water one-inch deep covering a unit area. In a one-foot profile, two inches of water indicates that 10 inches of that profile is soil and air by volume and the rest is water.

Table 3. Inches of water present in the soil profile at Oak Site I

Date	Inches of water in the soil profile[a]					
	Plot 7		Plot 11		Plot 1	
	Hole A	Hole B	Hole A	Hole B	Hole A	Hole B
Aug. 9, 1966	33.3	32.9	35.6	36.2	32.4	33.4
Sept. 12, 1966	29.2[b]	28.2[b]	33.0[b]	34.9[b]	31.8	30.1[b]
Oct. 9, 1966	31.7	32.1	36.4	36.4	31.8	33.1
Nov. 3, 1966	32.0	32.6	36.2	37.6	32.1	35.0
Dec. 16, 1966	33.7	33.9	38.8	37.0	31.7[b]	36.6
March 25, 1967	40.0	40.6	44.7[c]	42.8	37.0	43.0[c]
April 15, 1967	41.9	43.6[c]	43.9	42.9[c]	39.4[c]	42.7
May 13, 1967	42.1[c]	43.3	43.3	42.8	39.0	42.5
Recharge amount[d]	12.9	15.4	11.7	8.0	7.7	12.9

Date	Inches of water in the soil profile[a]					
	Plot 14		Plot 6		Plot 9	
	Hole A	Hole B	Hole A	Hole B	Hole A	Hole B
Aug. 9, 1966	29.7	30.4	32.3	33.5	36.1	31.4
Sept. 12, 1966	25.8[b]	26.1[b]	29.4[b]	30.6[b]	34.1[b]	29.1[b]
Oct. 9, 1966	29.6	28.6	33.4	35.1	35.9	31.5
Nov. 3, 1966	29.4	30.7	33.7	35.2	37.5	31.8
Dec. 16, 1966	31.2	32.2	33.5	34.6	36.7	33.2
March 25, 1967	38.0	37.8	39.1	46.8[c]	40.3	42.8[c]
April 15, 1967	41.8[c]	40.3[c]	40.9	42.1	39.1	40.3
Recharge amount[d]	16.0	14.2	12.1	16.2	7.3	13.7

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[a] Totaled to a depth of 90 inches.

[b] Lowest total inches of water found in the soil profile for the period metered.

[c] Highest total inches of water found in the soil profile for the period metered.

[d] Difference between highest and lowest total inches of water.

Table 4. Inches of water present in the soil profile at Aspen Site I

Date	Inches of water in the soil profile[a]					
	Plot 1		Plot 13		Plot 7	
	Hole A	Hole B	Hole A	Hole B	Hole A	Hole B
Aug. 10, 1966	19.6[b]	23.2	23.1	23.4	17.4	17.8
Sept. 15. 1966	20.3	22.7[b]	22.9[b]	22.7[b]	16.4[b]	16.9[b]
Oct. 9, 1966	22.0	25.4	23.3	23.0	17.7	17.1
Nov. 1, 1966	22.2	26.7	25.6	25.5	18.7	18.6
Dec. 16, 1966	23.9	28.2	27.0	27.3	21.8	22.2
Feb. 11, 1967	23.7	26.8	26.6	27.9	21.0	22.3
March 25, 1967	30.5	22.5	28.7	28.9	26.6	17.3
April 15, 1967	35.1	37.0[c]	34.4[c]	34.6[c]	33.4[c]	32.4[c]
May 14, 1967	35.3[c]	36.1	32.0	33.1	32.5	32.2
Recharge amount[d]	15.7	14.3	11.5	11.9	17.0	15.5

Date	Inches of water in the soil profile[a]					
	Plot 8		Plot 3		Plot 11	
	Hole A	Hole B	Hole A	Hole B	Hole A	Hole B
Aug. 10, 1966	24.5	28.5	25.1	24.4	22.7	25.6[b]
Sept. 15, 1966	23.5	26.7	22.9	23.9	22.2	26.2
Oct. 9, 1966	22.8[b]	26.2[b]	25.9	24.6	22.2	26.7
Nov. 1, 1966	25.2	28.3	27.3	26.8	24.4	29.3
Dec. 16, 1966	26.7	32.1	29.6	28.9	26.2	30.8
Feb. 11, 1967	26.4	30.9	----[e]	----[e]	----[e]	----[e]
March 25, 1967	31.9	36.8	35.7[c]	36.3[c]	28.4	36.4
April 15, 1967	35.4[c]	41.0[c]	35.4	35.7	32.6[c]	36.8[c]
May 14, 1967	34.7	40.3	33.9	33.7	31.3	35.4
Recharge amount[d]	12.6	14.8	12.8	12.4	10.4	11.2

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[a] Totaled to a depth of 78 inches.

[b] Lowest total inches of water found in the soil profile for the period metered.

[c] Highest total inches of water found in the soil profile for the period metered.

[d] Difference between highest and lowest total inches of water.

[e] Data missing because plots could not be reached.

Table 5. Inches of water present in the soil profile at Oak Site II

Date	Inches of water in the soil profile[a]					
	Plot 1		Plot 14		Plot 8	
	Hole A	Hole B	Hole A	Hole B	Hole A	Hole B
Aug. 11, 1966	18.4	18.7	12.0	15.0	26.5	26.5
Sept. 15, 1966	17.5[b]	18.0[b]	10.9	10.5[b]	22.5[b]	24.1[b]
Oct. 8, 1966	18.8	20.7	10.8[b]	10.9	----[e]	----[e]
Oct. 29, 1966	18.4	19.7	11.4	13.4	24.5	26.2
March 25, 1967	26.7[c]	25.8	18.9	17.7	32.9	34.7
April 23, 1967	26.7	27.1[c]	19.0[c]	18.6[c]	36.3[c]	37.6[c]
May 14, 1967	26.7	25.9	18.2	18.4	35.2	36.9
Recharge amount[d]	9.2	9.1	8.2	8.1	13.8	13.5

Date	Inches of water in the soil profile[a]					
	Plot a		Plot 9		Plot 13	
	Hole A	Hole B	Hole A	Hole B	Hole A	Hole B
Aug. 11, 1966	39.6	35.4	18.9	17.6	10.2	13.8
Sept. 15, 1966	38.3	34.1	14.2[b]	14.6[b]	7.4[b]	11.7[b]
Oct. 8, 1966	39.0	38.3	18.1	17.0	10.2	13.3
Oct. 29, 1966	38.2[b]	36.2	17.7	17.1	10.2	13.5
March 25, 1967	46.1[c]	44.7[c]	29.7	27.2	18.2	20.8
April 23, 1967	45.9	41.3	29.2	27.7	18.8	20.8
May 14, 1967	43.8	42.4	30.0[c]	30.3[c]	21.0[c]	24.3[c]
Recharge amount[d]	7.9	10.7	15.8	15.7	13.6	12.6

[a] Totaled to a depth of 102 inches.

[b] Lowest total inches of water found in the soil profile for the period metered.

[c] Highest total inches of water found in the soil profile for the period metered.

[d] Difference between highest and lowest total inches of water.

[e] Data missing because plots could not be reached.

Table 6. Inches of water present in the soil profile at Aspen Site II

Date	Inches of water in the soil profile[a]					
	Plot 5		Plot 7		Plot 10	
	Hole A	Hole B	Hole A	Hole B	Hole A	Hole B
Aug. 12, 1966	20.5	20.5	24.7	21.0	25.5	24.5
Sept. 13, 1966	18.1[b]	19.1[b]	22.4[b]	20.1[b]	24.3[b]	24.0[b]
Oct. 9, 1966	19.4	20.4	----[e]	20.3	25.9	24.4
Nov. 4, 1966	20.9	21.1	23.6	21.5	25.8	24.9
Dec. 15, 1966	26.1	22.4	25.2	22.6	27.8	24.0
Feb. 12, 1967	24.7	22.0	25.4	23.1	27.8	27.8
March 25, 1967	31.8	29.3	31.8	33.1	32.2[c]	32.2[c]
April 23, 1967	31.8	32.7	34.1	32.4	----[e]	----[e]
May 21, 1967	33.5[c]	33.6[c]	35.1[c]	33.5[c]	----[e]	----[e]
Recharge amount[d]	15.4	14.5	12.7	13.4	7.9	8.2

Date	Inches of water in the soil profile[a]					
	Plot 13		Plot 1		Plot 3	
	Hole A	Hole B	Hole A	Hole B	Hole A	Hole B
Aug. 12, 1966	24.3	25.6	21.9	20.8	21.3	20.3
Sept. 13, 1966	23.0	24.1	20.9[b]	19.8[b]	19.8[b]	19.2[b]
Oct. 9, 1966	23.1	23.5[b]	21.9	20.5	21.0	21.3
Nov. 4, 1966	24.2	24.9	21.6	20.5	20.5	29.9
Dec. 15, 1966	24.7	24.7	22.1	----[e]	23.0	21.1
Feb. 12, 1967	20.7[b]	25.5	22.6	21.6	23.0	21.8
March 25, 1967	27.9	28.7	30.3	30.5	30.0	27.9
April 23, 1967	32.3[c]	32.4	28.9	33.1	34.5	35.0
May 21, 1967	32.3	33.9[c]	33.3[c]	34.8[c]	35.2[c]	35.3[c]
Recharge amount[d]	11.6	10.4	12.4	15.0	15.4	16.1

[a] Totaled to a depth of 66 inches.

[b] Lowest total inches of water found in the soil profile for the period metered.

[c] Highest total inches of water found in the soil profile for the period metered.

[d] Difference between highest and lowest total inches of water.

[e] Data missing because the plots could not be reached or water was in access tube.

average minimum percentage of recharge for the plot. When the maximum percentage of recharge is considered, values slightly lower than 100 percent are obtained for a plot average. This explains why the minimum averaged percentage of recharge at some plots was not zero and why the maximum values were less than 100 percent (Table 7).

Soil moisture content was at its lowest in September and October at all plots except Plot 13 at Aspen Site II. Plot 13 had its lowest soil moisture content in February (Table 7). It is believed that data from Plot 13 are not indicative of what generally occurs at these sites. Errors in taking soil moisture readings or extreme variability of the soil profile at this plot may have been responsible for the results obtained.

Curing of vegetation and timing of precipitation may be the reasons for the increase in percentage of recharge in late September and early October. The leaves start to drop from these deciduous trees in late September and early October in central Utah; therefore, transpirational drain from the soil is reduced because understory vegetation has already cured for the most part. When transpiration ceases from the soil, the addition of precipitation results in the beginning of soil moisture recharge. If evaporation is not excessive, the soil water reservoir begins to fill up in late September and October (Figures 3, 4, 5, and 6).

Precipitation generally comes as rain in early fall, but it turns to snow in October and November as the season proceeds. The early rains and some snowfall which melts immediately recharge the soil.

Table 7. Average percentage of recharge between August, 1966, and May, 1967

Date	Oak Site I					
	Plot 7	Plot 11	Plot 1	Plot 14	Plot 6	Plot 9
Aug. 9	31.2	18.0	21.3	27.4	21.0	22.1
Sept. 12	0.0	0.0	4.5	0.0	0.0	0.0
Oct. 9	22.4	24.0	16.2	20.7	30.5	21.0
Nov. 3	25.2	31.0	21.6	27.5	32.0	33.2
Dec. 16	36.0	38.0	25.2	38.4	29.3	32.8
March 25	82.1	99.4	84.4	79.4	90.1	92.5
April 15	99.2	96.6	98.9	91.2	93.9	92.4
May 13	99.1	93.4	95.5	100.0	83.0	75.2

Date	Aspen Site I					
	Plot 1	Plot 13	Plot 7	Plot 8	Plot 3	Plot 11
Aug. 10	2.1	3.8	6.9	14.5	10.6	2.4
Sept. 15	2.3	0.0	0.0	4.5	0.0	2.7
Oct. 9	17.1	3.0	44.5	0.0	14.5	4.4
Nov. 1	22.3	23.5	12.3	16.6	28.9	27.1
Dec. 16	33.0	37.2	33/0	35.5	46.3	42.5
Feb. 11	27.4	38.0	31.0	30.2	----[a]	----[a]
March 25	72.5	51.3	62.6	71.9	100.0	78.0
April 15	99.4	100.0	100.0	100.0	96.5	100.0
May 14	89.6	85.1	96.7	94.9	82.5	87.5

Date	Oak Site II					
	Plot 1	Plot 14	Plot 8	Plot 2	Plot 9	Plot 13
Aug. 11	8.8	35.1	23.4	15.0	24.4	18.7
Sept. 15	0.0	.6	0.0	.7	0.0	0.0
Oct. 8	21.9	2.4	----[a]	24.9	20.0	16.7
Oct. 29	14.3	21.6	15.1	9.9	19.1	11.5
March 25	92.9	93.5	76.9	100.0	89.2	75.8
April 23	100.0	100.0	100.0	82.5	89.2	78.0
May 14	93.4	93.8	93.4	74.6	100.0	100.0

Table 7. Continued

Date		Aspen Site II					
		Plot 5	Plot 7	Plot 10	Plot 13	Plot 1	Plot 3
Aug.	12	12.7	12.4	10.7	25.6	7.4	8.3
Sept.	13	0.0	0.0	0.0	12.8	0.0	0.0
Oct.	9	8.7	1.5	12.6	12.5	6.4	10.4
Nov.	4	16.0	9.9	15.0	21.9	5.2	4.4
Dec.	15	37.4	20.4	22.1	23.0	9.7	16.3
Feb.	12	31.5	23.0	43.3	9.6	12.5	18.5
March	25	75.1	85.5	100.0	56.0	73.6	60.1
April	23	91.4	92.0	100.0	92.8	76.6	96.8
May	21	100.0	100.0	100.0	100.0	100.0	100.0

[a] Data missing because plots could not be reached.

In late November and early December a snowpack begins to develop on the sites, and the rate of soil moisture recharge slows down.

If groundmelt is occurring at these sites, it is very slight. The increase between October and February at Aspen Sites I and II (Figures 4 and 6) may be caused by the groundmelt during this same period. This point cannot be illustrated for Oak Sites I and II because of missing data (Figures 3 and 5). Streamflow on the watershed was extremely low in late November and increased substantially in March at or near snowline elevation. The low streamflow throughout the winter may be an indication that groundmelt is low, although it may be sufficient to recharge the soil partially. Temperatures during the winter months at these sites must be low enough to minimize groundmelt of the snowpack. Soil temperatures before the snowpack begins to accumulate may be low

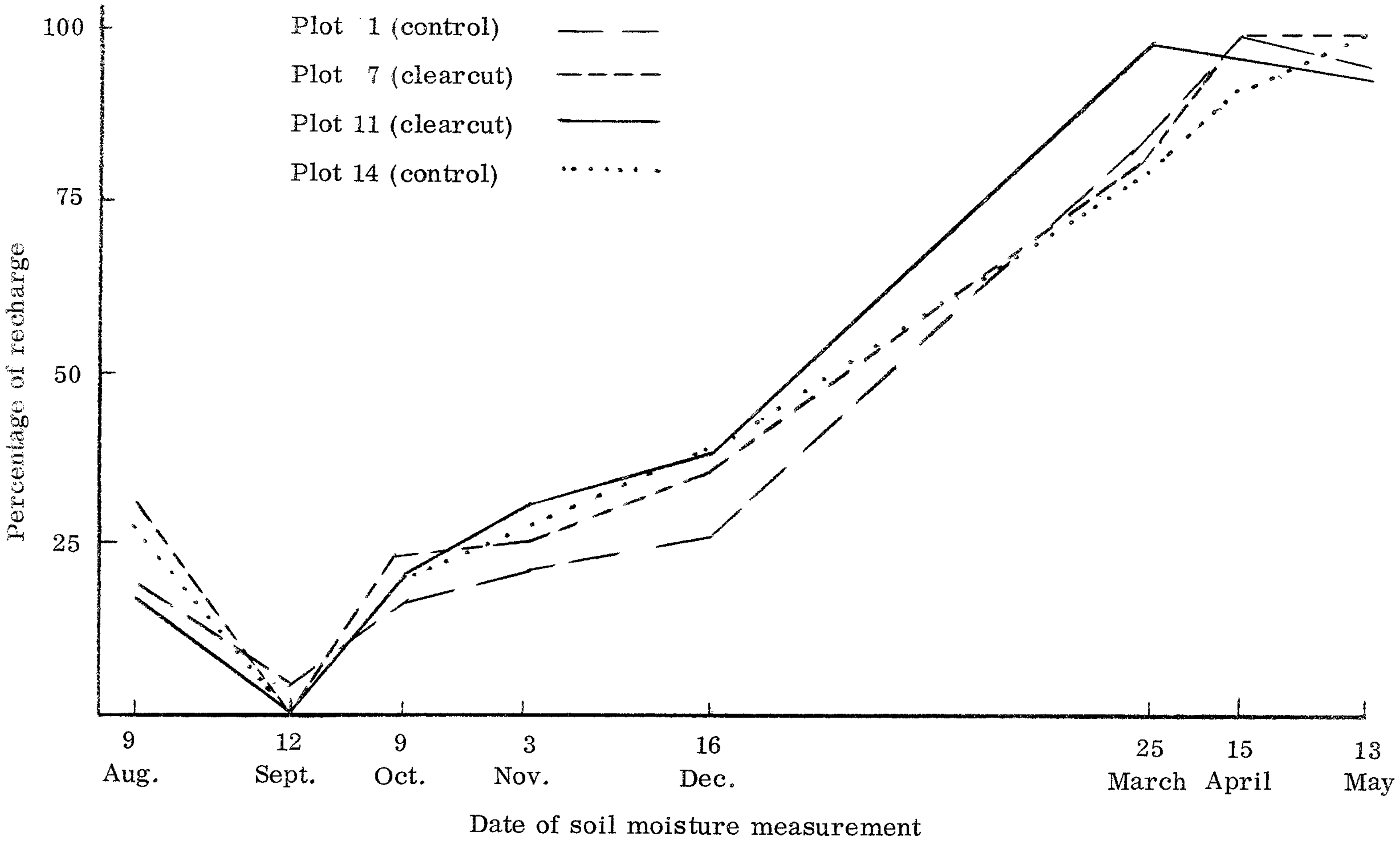

Figure 3. Average percentage of soil moisture recharge of profile for plots 1, 7, 11, and 14 at Oak Site I.

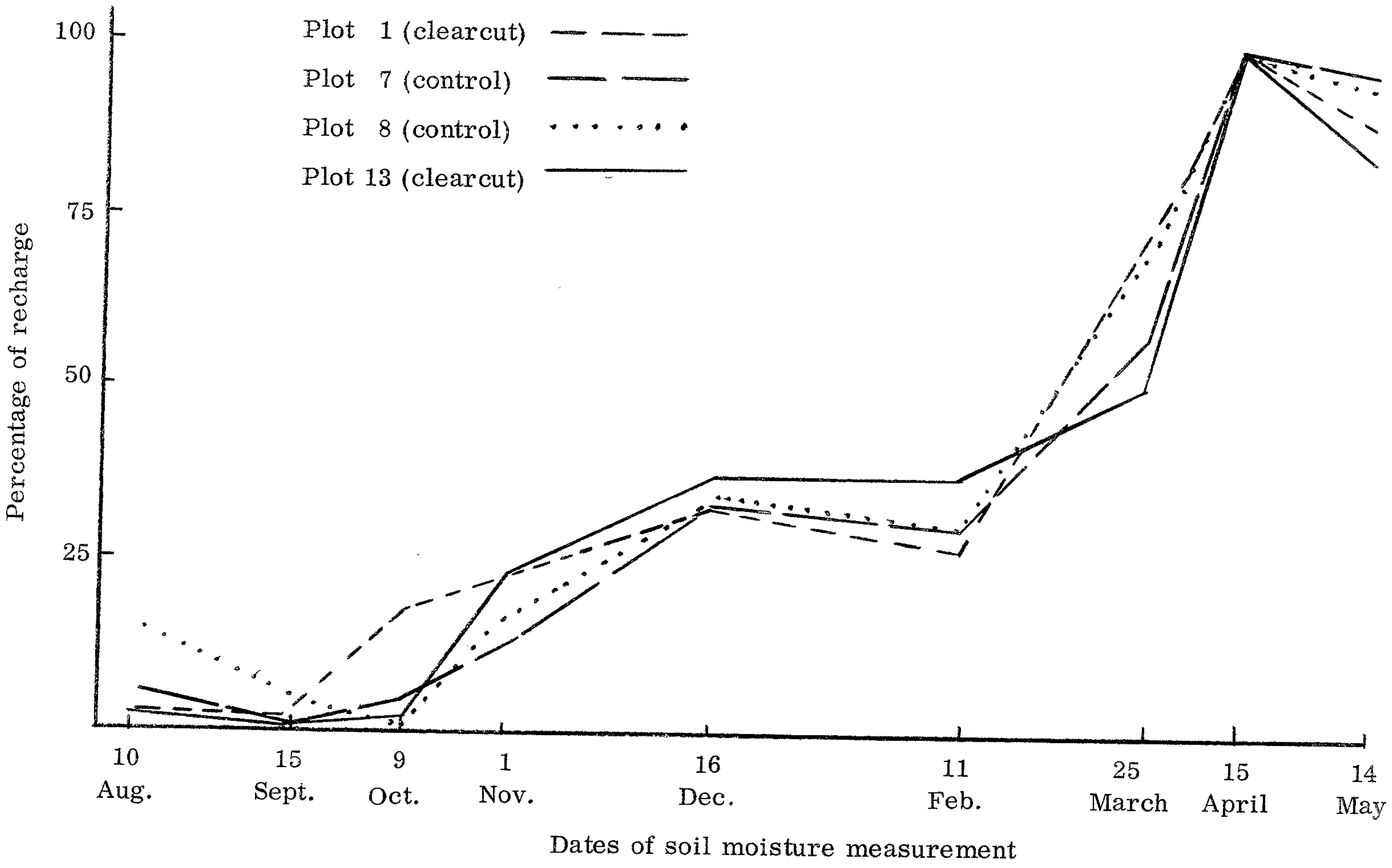

Figure 4. Average percentage of soil moisture recharge of profile for plots 1, 7, 8, and 13 at Aspen Site I.

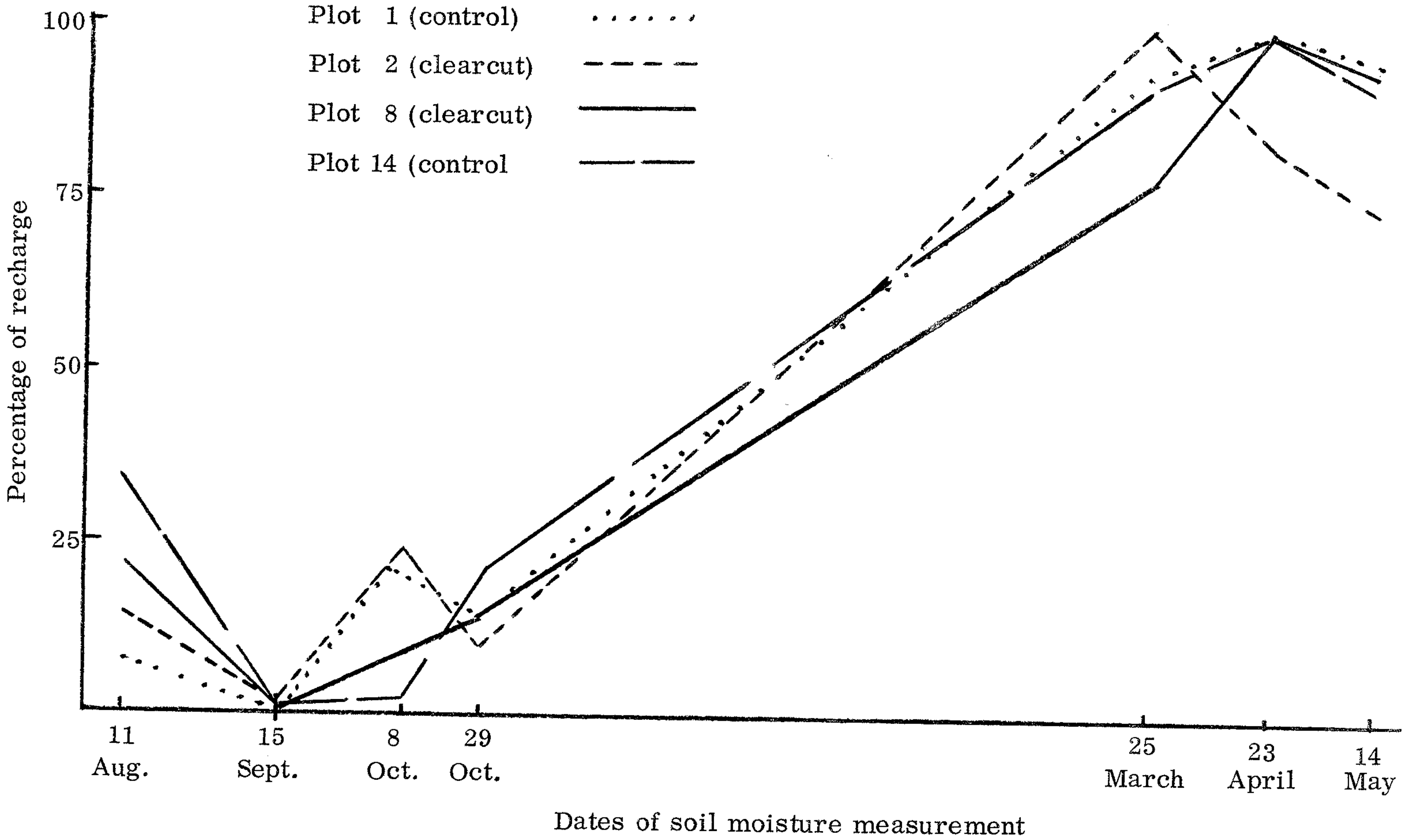

Figure 5. Average percentage of soil moisture recharge of profile for plots 1, 2, 8, and 14 at Oak Site II.

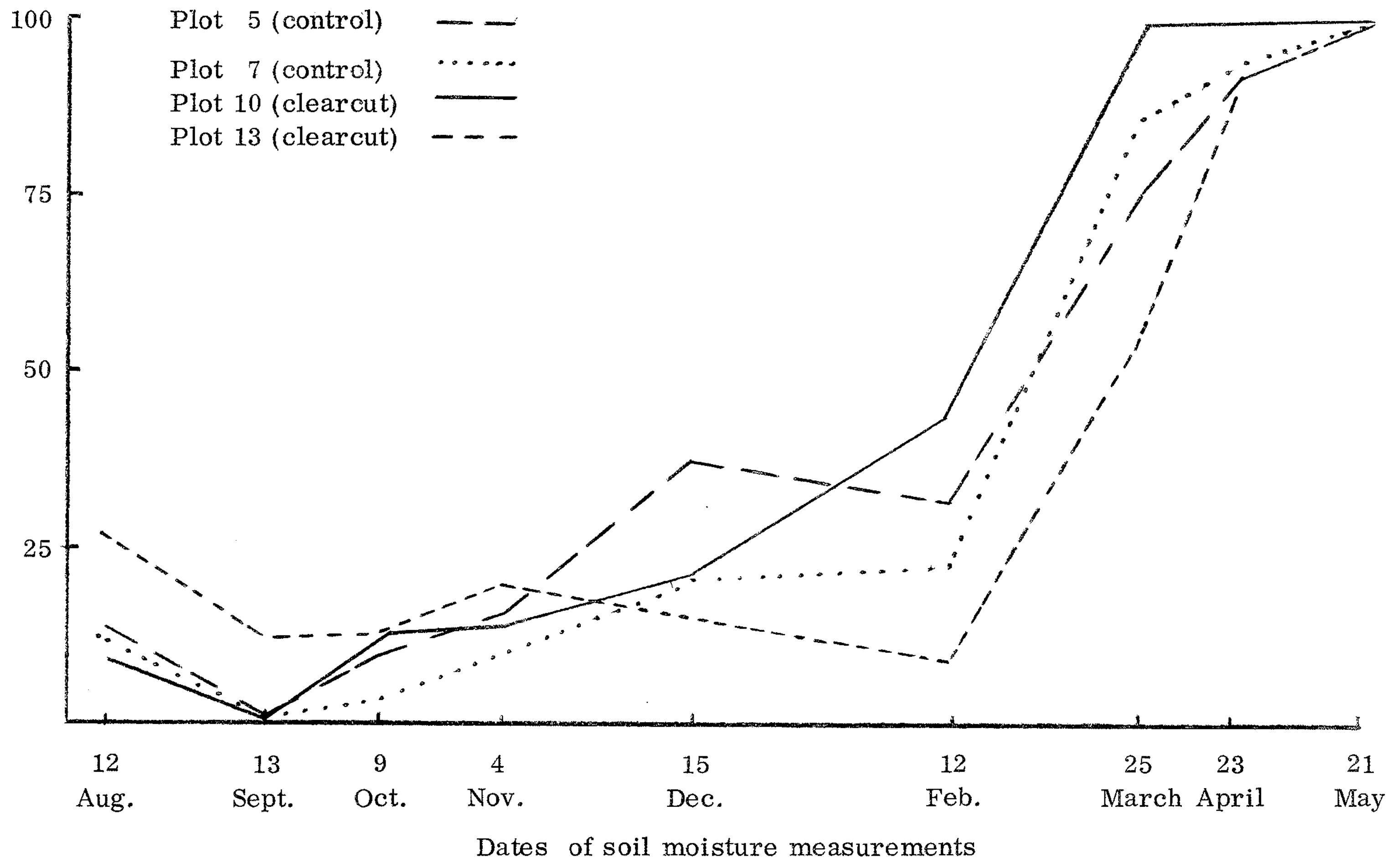

Figure 6. Average percentage of soil moisture recharge of profile for plots 5, 7, 10, and 13 at Aspen Site II.

enough to prevent melt at the ground and snowpack interface early in the winter.

The period between February and May showed signs of the greatest increase in percentage of recharge (Figures 4 and 6). At the onset of the most rapid increase in recharge 50 percent of total recharge had already occurred. Similar results were found by Eschner and Satterlund (1963). At all plots complete recharge occurred by early May (Figures 3, 4, 5, and 6). It had occurred at some plots as early as March. These plots showed a decrease in percentage of recharge after this until May. Most plots, however, completed recharge in April and May. The rapid change from cloudy, cold days and nights in February to the clearer and sunnier days in May explains why this rapid recharge occurs during this period. It was observed that cloud cover increased noticeably at the sites, and more solar radiation was able to reach the snowpack starting in February. The angle of incidence of the sun's rays at the study sites decreases from December 21 to June 21 or 22. The most rapid rate of decrease occurs during the period from February to April. The lower angle incidence allows less radiation to be reflected and more to be absorbed for melting the snow.

Type of vegetation cover at the sites has a considerable influence on the rate of snowmelt and consequently the rate of soil moisture recharge. The trees at the four sites are deciduous and do not begin to leaf out until late May. During the winter, very little protection from the sun is provided the snowpack from the bare limbs of the canopy and the boles of the trees. Protection from incoming radiation would be less under deciduous stands of oak and aspen than under a conifer stand (Bay, 1958; Lull and Rushmore, 1960). Even though the shade afforded by the trees at these sites is less than under a conifer stand, melt rates are slower in the hardwoods than in the open areas. This may be caused by the shade a hardwood stand casts on a snowpack, but it may be a result of more snow drifting into stands of hardwoods which act as wind breaks. The amount of snow present at the sites is not known because snow measurements were not taken during the period covered in this study.

Soil profile development and parent material influence the rate and amount of recharge which occur at a site. There was never any sign of surface runoff from the plots while snowmelt was occurring. It appears that melt occurs at a rate which allows the water to infiltrate the soil. The organic layer and the layer of highly mixed mineral soil and organic matter is well-developed at Aspen Site I and II and at Oak Site I. These well-developed organic layers promote fast and continuous infiltration into the soil profile. The higher amount of sand present at Oak Site II allows fast infiltration even with a poorly developed organic layer. Percolation of the soil water through the profile is assisted by well-developed structure at the lower depths at Aspen Sites I and II and at Oak Site I. Good infiltration rates and percolation rates of the soils at these sites makes it possible for these soils to accomodate high melt rates without surface runoff occurring.

These are fairly deep soils, and a large amount of water can be held in them. Much of the water at the end of the recharge period is held as detention storage. Because the soils have a large water holding capacity, they are able to retain the meltwater; and surface runoff is prevented. Water yields from the streams of the watershed tend to be smoother and less flashy than are yields from areas with shallower soils.

Soil freezing was never found at the study sites until the snow cover began to disappear. Soil moisture content is low enough to prevent soil freezing prior to the time of snow accumulation on the sites. In March, April, and May, when air temperatures are below 32 F in areas where snow cover has disappeared, soil freezes to a depth of 0.25 to 0.50 inch every night. This is not a permanent soil freezing condition, but it seems to be a result of the diurnal fluctuations in temperature. Frost heaving of the soil may make the surface somewhat more permeable for infiltration to take place.

SUMMARY AND CONCLUSIONS

Soil moisture recharge in the mountains of central Utah begins in late September and early October as a result of a cessation of transpiration from vegetation and an increase in amount of precipitation occurring at the same time. The recharge period lasts until April and May and has the fastest increase in percentage of recharge from February to April and May. During this period, approximately 50 percent of the total recharge occurs. The transition from cold, cloudy days to warmer days occurs between February and May and is mainly responsible for this rapid increase of recharge. The vegetation on these sites has no leaves while recharge occurs and high amounts of solar radiation are thus allowed to reach the snowpack surface. Even though the hardwoods provide little protection to the snowpack, snow disappeared sooner from the clearings than it did from the stands.

Infiltration rates at the soil surface and percolation rates within the soil allow the snowmelt to move into and through the soil profile at fast rates. Surface runoff is negligible. The depth of the soils and the high storage capacity allow large volumes of water to be held in the profile temporarily before discharge occurs as streamflow.

The only frost found at the sites was in early spring in areas where the snowpack had disappeared. No signs of soil freezing were observed under the snowpack during the winter. The frost which did occur in the spring disappeared each day by noon and was not a hindrance to infiltration.

Christner (1967) reports that the removal of deep-rooted vegetation increased the amount of soil moisture present at the end of the growing season on these sites. The removal of the trees will not affect the melt rate too much because these trees do not shade the snowpack much during the recharge period. In some cases earlier yields may occur. The moderately deep soils of these sites will hold the melt as they do now. With removal of trees from an area, less water will be needed to recharge the profile after the growing season. This should allow more water to be available for streamflow and it will show up as higher spring discharges from the streams. With the yields coming in the spring, the increase in yields due to removal of vegetation may come when it is not really too important.

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