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INTERMOUNTAIN FOREST & RANGE EXPERIMENT STATION
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Throughout this study, all three scientists were stationed in Logan at the Forestry Sciences Laboratory, where they were assigned to the water yield improvement work unit.

INTRODUCTION

This paper summarizes recently completed studies on water use by several important plant communities in the Intermountain Region. These studies were designed to inventory water use and to evaluate the effects of several vegetation conversion and stand manipulation practices on potential water yield.

Data were collected from 219 moisture sampling locations representing 14 sites and 10 vegetation types. Soil moisture depletion and evapotranspiration data from some of these sites have been or are in the process of being published elsewhere (see list of references in table 1, page 7). However, data on six vegetation types from five of the sites probably will not be reported in other publications.

The format is designed to provide the administrator, the researcher, and the student with soil moisture depletion and estimated evapotranspiration data taken from a wide variety of vegetation types, soils, and elevations. Obviously, all sites and vegetation types have not been studied in this short period. A summary of these data in a single publication may prevent unnecessary duplication of this work by others and point up gaps in our knowledge of water consumption.

SITE DESCRIPTIONS

All study sites are within three general areas of Utah (fig. 1). Sites 1, 2, and 3 are in northern Utah within the Logan River drainage (upper right). Sites 4 through 8 are in north-central Utah on the Davis County Experimental Watershed northeast of Bountiful (lower right). Sites 9 through 14 are in central Utah on the Great Basin experimental area east of Ephraim (lower left).

Each study was planned and conducted independently; consequently, supplementary soil and vegetation descriptions are not uniform. Brief site descriptions are presented in table 1; more detailed considerations of the soils and vegetation for most sites are available in the literature citations (last column). Their location within the site is referenced by plot designations, such as 5a, 5b, 5c (tables 1 and 2, pages 7 and 10, respectively). Natural understory vegetation on all sites was maintained throughout each study; vegetation-type designations indicate only the overstory or dominant species.

METHODS AND RESULTS

Studies were to determine comparative water losses from two or more vegetation covers on paired or adjacent plots (e.g., mature versus clearcut aspen or aspen versus grass). Soil moisture on the study plots was measured several times each season with neutron moisture probes. All measurements on the Davis County Experimental Watershed (sites 4 through 8, tables 1 and 2) were made with a Nuclear Chicago probe; all others were made with a Troxler probe.¹ Measurements were taken in the top 6 inches and at 1-foot intervals thereafter to the bottom of each hole.

The number of holes drilled at each site and their depths are presented in table 2. Most were drilled by a hand-held pneumatic jackhammer, except those on sites 7 and 8, where a track-mounted pneumatic drill was used. The latter method results in more uniform soil moisture access holes and more accurate readings.²

¹Trade names are used for identification only; they do not imply endorsement by USDA Forest Service.

²Richardson, B. Z. Installation of soil moisture access tubes in rocky soils. J. Soil and Water Conserv. 21(4): 143-145. 1966.

Figure 1.--Map of Utah with three enlarged areas showing locations and elevations of study sites.

The average maximum and minimum water contents and evapotranspiration estimates for all sampling points are given in table 2. The maximum water content shown is the amount measured on the initial sampling date, which varied from year to year depending upon phenology and accessibility. Minimum water content is the amount measured on the final sampling date, usually the minimum reached during the growing season. The difference between maximum and minimum measurements represents soil moisture depletion. Because the amount and distribution of summer rainfall profoundly affected these final moisture measurements, precipitation was measured on or near each study area. Precipitation during the growing season was added to soil moisture depletion to obtain an estimate of evapotranspiration.

DISCUSSION

Treatment effects can be evaluated by considering the treatment area as a system in which various inflow and outflow parameters can be measured and balanced. The general and somewhat oversimplified water balance equation

$$Q = P - ET - I - \Delta GW - \Delta S \quad (1)$$

is used frequently in forest hydrology problems of this type. In the equation, Q is streamflow, P is precipitation, ET is evapotranspiration, I is interception, ΔGW is change in groundwater aquifer storage, and ΔS is change in soil moisture storage.

If treatments are confined to small plots, some estimate of effects can be obtained by modifying the water balance equation and making some necessary assumptions. On a small plot, streamflow and changes in the groundwater aquifer storage no longer are considered because they cannot be measured readily. Treatment benefits are restricted to measurable site parameters, and interception losses and reduced evapotranspiration become a measure of treatment effects. Interception losses are difficult to evaluate and are not characterized adequately for most vegetation types; therefore, interception usually is pooled with the evapotranspiration term. The water balance equation now can be written

$$ET = P - R - D - \Delta S. \quad (2)$$

In equation (1), deep seepage of soil moisture (D) and surface runoff (R) are not considered as separate terms. Deep seepage is assumed to be part of the soil moisture storage term (S), until such time as it is incorporated in the groundwater and reappears as streamflow (Q), or contributes to aquifer storage (GW). In plot studies, however, deep seepage is defined as the soil water that moves below the depth of rooting or below the depth of soil moisture measurements and, as such, must be considered a loss to the site. Because deep seepage is difficult to measure, it is assumed to be negligible or, when paired plots are compared, to be uniform; then, in either case, results are not unduly biased. Surface runoff also is a potential loss to the site and must be considered in equation (2). Surface runoff can be collected and measured, but usually is negligible on well-vegetated sites in the watersheds of the Intermountain Region. On the single bare plot (5c), precipitation has been corrected by estimated runoff (table 2). Precipitation and soil moisture measurements can be made with relative ease and accuracy on small study areas.

Slatyer³ suggests that the water balance equation be reduced to $ET = \Delta S$ during dry weather, because surface runoff and downward drainage are closely linked to soil water recharge. Throughout much of the West, including Utah, summer precipitation on well-vegetated land seldom exceeds the immediate storage capacity of the surface few inches of soil. Therefore, it is readily available to loss by evapotranspiration. For this reason, the water balance equation becomes $ET = \Delta S + P$ during the summer months.

Results presented in table 2 were taken from several independent studies and reflect water loss estimates from a large variety of vegetation covers and sites. Both soil moisture depletion and evapotranspiration are influenced by a large number of factors, including aspect, elevation, and several variables (e.g., climate, vegetation, and soil). Therefore, comparisons of water losses from dissimilar sites are suspect (table 2). However, this is not to say that all trends and observations are invalid. We simply want to caution against indiscriminate use of the data and to point out that comparisons of water withdrawal by various cover types are most valid when based on results obtained from paired plots.

For example, certain trends in water consumption associated with single variables were noted and reported in the independent studies mentioned above. These observations were perfectly valid within the context of a particular study. However, as the scope of available information broadens with increased sampling, these trends are confounded and masked by the influence of other variables. To cite an instance, when aspen sites 11 and 12 were considered separately, data indicated a definite trend in water use at two elevations. But, when evapotranspiration losses for all aspen sites during a single season are considered, no trends attributable to elevation are apparent as shown below.

<u>Elevation</u> (Ft.)	<u>Soil moisture depletion</u> (In.)	<u>Precipitation</u> (In.)	<u>Evapotranspiration</u> (In.)
6,100	8.31	4.29	12.60
7,000	11.55	4.30	15.85
7,640	9.29	1.01	10.30
7,800	9.51	1.01	10.52
7,900	5.67	4.80	10.47
8,400	17.39	1.13	18.52
9,200	7.62	5.55	13.17

Our estimated losses probably are conservative, because the moisture that moved laterally into the plots subsequently is lost by evaporation or transpiration. It should also be noted that depletion figures represent only the soil moisture changes within the depth of measurement (4 to 9 feet). This depth does not necessarily represent the maximum depth of root penetration on a given site. Because moisture withdrawal by roots below the depth of measurement is not included in the depletion figures, we may have underestimated depletion and evapotranspiration losses.

Maximum moisture contents are constant on a given site, rarely varying more than 1 or 2 inches for the entire measured profile. Seldom, if ever, in the mountain watersheds of this region does winter precipitation fail to fully recharge the soil profile. Hence, differences in maximum moisture contents merely reflect the difficulty in measuring field moisture capacity. Slight differences in moisture storage recorded for the particular day that initial measurements were made each year are due to gravitational water still present in the profile or to previous water withdrawal by evapotranspiration.

³Slatyer, R. D. Plant water relations. New York: Academic Press. 366 pp. 1967.

Minimum moisture contents and resulting soil moisture depletion values vary considerably both between sites supporting a given vegetation type and between years on any given site. These data reflect both moisture withdrawal and precipitation characteristics prior to final measurement. In some years, summer storms repeatedly replenish moisture deficiencies in the surface few feet of soil, but this water usually is lost through evapotranspiration within a few days. Most of the late-season rainfall contributes to the replenishment of soil moisture deficits.

Growing season rainfall fluctuated greatly between the study years of 1963 and 1967. For example, summer rainfall on site 5 averaged 4.61 inches, but ranged from 1.13 to 10.43 inches. This type of variation is advantageous because it provides a good estimate of the extremes that can be expected in soil moisture depletion and evapotranspiration values. Measurements from site 5a during 1963 and 1965 illustrate how rainfall can influence soil moisture measurements and contribute to interpretation problems. Maximum water content in the 9-foot profile was essentially the same (37.73 and 37.55 inches) during each year. Minimum moisture contents were 18.61 inches in 1963 and 25.72 inches in 1965. Rainfall in 1965 was nearly twice as great as in 1963. When precipitation was added to the soil moisture depletion figures, evapotranspiration was estimated to be 1.89 inches greater for the 1963 growing season.

To make the results more comparable, total evapotranspiration values cited in table 2 were converted to inches of evapotranspiration per foot of measured soil profile. Then the highest and lowest evapotranspiration value for each vegetation type for all years and sites were used to construct figure 2. The graph illustrates the wide range of evapotranspiration values that might be expected over several years on many mountain sites. These results should not be considered conclusive as data on several of the vegetation types were taken for a limited number of sites and years of measurement.

Tree and shrub types show a generally greater loss than sagebrush-grass, grass-herb, or bare types. Estimates for both sagebrush-grass (site 8) and bare types (site 5c) are based on but one site each and so are not reliable. Certainly, we would not expect the same minimum evapotranspiration value per foot of soil from both bare and well-vegetated sites, and--when legitimate comparisons are made--our expectations are substantiated. Comparative losses from adjacent grass-herb and bare plots (5b and 5c, table 2) show evapotranspiration losses nearly always 0.5 inch or greater per foot of soil on the vegetated plot.

In all instances, sprout vegetation has a narrower range than respective mature types; so sprout ranges are found on the lower side of the evapotranspiration scale, although there is considerable overlapping (fig. 2).

The range of evapotranspiration losses from Douglas-fir (*Pseudotsuga menziesii*) appears to be too small, but the information available is meager, representing data recorded for 2 years from site 16 and for a single year from site 3b.

Most of the information assembled is for aspen, Gambel oak, and grass-herb types, consequently, the range of evapotranspiration losses per foot of soil is widest for these types. The higher evapotranspiration losses from the grass-herb type overlap all the other tree and shrub types, especially in the 1.75- to 2.75-inch range. Maximum rates of evapotranspiration are 3.26 and 3.10 inches per foot of soil from the mature aspen and oak types, respectively.

Figure 2.--Range of evapotranspiration estimates for several vegetation types.

CONCLUSIONS

Results of all studies indicate that moisture depletion is greatest early in the growing season (May to July) and that late-season losses generally are confined to withdrawal from deeper parts of the soil profile. By the end of each summer, most of the available soil moisture throughout the rooting depth is depleted.

On paired plots, mature aspen stands utilized 0.48 to 4.50 inches more soil moisture from the upper 6 feet of profile than sprout stands. These differences diminish rapidly after the first year as sprout stands mature and evapotranspiration accelerates. Comparisons of evapotranspiration losses on Gambel oak plots show mature oak utilizes only 0.25 to 1.15 inches more moisture from the upper 6-foot soil profile than 1-year-old sprout stands. In two instances, 3-year-old oak sprouts had greater evapotranspiration losses than mature stands. Removal of oak and aspen can prolong water savings only if sprouting is prevented.

An indication of prospective water savings following conversion of aspen to grass can be obtained from moisture measurements on sites 1, 2, 5, and 6. Reduced evapotranspiration losses ranged from 1.08 to 5.18 inches from 6-foot sampling depths and 2.76 to 7.59 inches from a 9-foot soil profile. The average reduced water consumption on plot 5 was 5.75 inches for the 4-year period. Conversion of Gambel oak to grass (site 4) reduced evapotranspiration losses by 4.55 and 3.83 inches from an 8-foot-deep soil.

Shallow-rooted plants extract less water from depth than deep-rooted vegetation; this is the premise upon which all vegetation conversion practices for increased water yields are based. The difference in evapotranspiration losses before and after treatment is water saved. Eventually, such water will emerge as streamflow or will be stored in the groundwater aquifer. Obviously, treatments will be most beneficial on sites showing the greatest decrease in rooting depths.

Table 1. --Site locations and information on associated soils and vegetation

Site no.	Location	Soils	Vegetation	References
1, 2, 3	At three elevations in Logan Canyon drainage.	At least 6 ft. of relatively rock-free, clay-loam soil; calcareous parent material.	All located within three adjacent vegetative types -- Douglas-fir (<i>Pseudotsuga menziesii</i>), aspen (<i>Populus tremuloides</i>), and grass-forb; vigorous grass-forb vegetation, 3 to 5 ft. tall by late summer.	
4	Three adjacent plots in Stone Creek drainage, Davis County Experimental Watershed.	Coarse-textured soil; mica-schist parent material; solum, approximately 20 in. deep, underlain by fractured rock containing small amounts of silt and clay.	<p>Plot 4a. -- Gambel oak (<i>Quercus gambelii</i>), mature stand; trees, 8 to 14 ft. tall; basal area, 65 sq. ft./acre; luxurious herbaceous understory.</p> <p>Plot 4b. -- Mature oak cut, allowed to resprout; understory vegetation same as 4a.</p> <p>Plot 4c. -- Mature oak cut, sprouts killed by spraying in 1965; several grasses introduced.</p>	<p>Tew, R. K. 1966. Soil moisture depletion by Gambel oak in northern Utah. U.S. Forest Serv. Res. Note INT-54. 7 pp.</p>
5	Three adjacent 0.1-acre plots near headwaters of Parrish Canyon, Davis County Experimental Watershed.	Dark-brown, sandy-loam; gneiss-schist parent material; depth variable; large boulders and rocks prevalent.	<p>Plot 5a. -- Scrubby aspen overstory. Lush herbaceous understory; average tree height, 17 ft.; basal area, 100 sq. ft./acre; ground cover, 73% vegetation, 12% litter, and 15% bare.</p> <p>Plot 5b. -- Aspen overstory removed in 1947; original understory, grasses and herbaceous species, has deteriorated since treatment; in 1967, ground cover, 21% litter, 30% bare, and 49% vegetation, of which 11% was tar weed (<i>Madia glomerata</i>).</p> <p>Plot 5c. -- All vegetation removed in 1947; plot kept bare until 1968.</p>	<p>Johnston, Robert S. Evapotranspiration from bare, herbaceous, and aspen plots: a check on a former study. Water Resources Res. (In press.)</p>

8 Table 1. (con.)

Site no.	Location	Soils	Vegetation	References
6	Two plots on lower Chicken Creek watershed, Davis County Experimental Watershed.	Reddish-brown, loamy soil, well-drained, deep; parent material, shale and conglomerate rock.	<p>Plot 6a. -- Aspen overstory; lush grass-forb understory. Most abundant grass, mountain brome (<i>Bromus carinatus</i>); ground cover, 56% vegetation, 29% litter, and 15% bare.</p> <p>Plot 6b. -- Important grass species: mountain brome, cheatgrass (<i>Bromus tectorum</i>), tar weed, and catchweed (<i>Galium aparine</i>); ground cover, 48% vegetation, 11% litter, and 41% bare.</p>	
7	Six subplots on upper Chicken Creek watershed, Davis County Experimental Watershed.	Deep, loamy soil developed in colluvium; mixed sandstone, gneiss, and schist parent materials.	<p>Plot 7a. -- Mature, two-storied aspen on three subplots; average tree heights, 48 and 17 ft.; basal area, 90 sq. ft./acre; ground cover, 67% vegetation, 27% litter, and 6% rock. (See accompanying reference for information on other plots.)</p> <p>Plot 7b. -- Aspen removed in 1964 from three subplots, allowed to resprout; ground cover, 75% vegetation, 18% litter, and 7% bare; understory species similar on both sites. (See accompanying reference for information on other plots.)</p>	Johnston, R. S. 1969. Aspen sprout production and water use. USDA Forest Serv. Res. Note INT-89. 6 pp.
8	Near head of Halfway Creek watershed, Davis County Experimental Watershed.	Extremely immature, rocky, sandy loams, 4 to 5 ft. deep; gneiss-schist parent material, granitic intrusions.	Site, a single plot. Major species: big sagebrush (<i>Artemisia tridentata</i>), various grasses (<i>Poa</i> sp., <i>Agropyron</i> sp., <i>Festuca</i> sp.), and forbs (<i>Lupinus</i> sp., <i>Erigonium</i> sp., and <i>Aster</i> sp.); ground cover, 32% shrubs, 23% grass and forbs, 7% litter, and 38% bare and rock.	

Table 1. (con.)

Site no.	Location	Soils	Vegetation	References
9, 10	At various elevations in Ephraim Canyon drainage.	Clays and silty clays from either Flagstaff Limestone Formation or North Horn Formation; profiles at lower elevation oakbrush sites poorly developed, compared with those at higher elevation sites.	Gambel oak, 7 to 10 ft. tall at 6,600-ft. elevation, 10 to 14 ft. tall at 7,900-ft. elevation. In 1963, mature oak clearcut on selected plots; vigorous sprout stand followed cutting.	Tew, R. K. 1967. Soil moisture depletion by Gambel oak in central Utah. U.S. Forest Serv. Res. Note INT-74. 8 pp.
11, 12	do.	do.	Mature aspen, 120 to 272 stems/acre; basal area, 162 sq.ft./acre on lower elevation sites, 202 sq.ft./acre on higher elevation sites; clearcut in 1963; subsequent sprouting provided two age groups at each site for purpose of comparison.	Tew, R. K. 1967. Soil moisture depletion by aspen in central Utah. U.S. Forest Serv. Res. Note INT-73. 8 pp.
13	do.	do.	Mostly penstemon (<u>Penstemon rydbergii</u>); some native grass species.	do.
14	do.	do.	Snowberry (<u>Symphoricarpos oreophilus</u>); two age groups; mature plants, approximately 3 ft. tall, and young sprouts.	do.

Table 2.--Soil moisture depletion and evapotranspiration losses from 10 vegetation types in Utah

Site no.	Elevation	No. of holes	Depth	Year	Maximum	Minimum	Soil moisture depletion	Precipitation	Evapo-transpiration
	Ft.		Ft.				Inches of water		
ASPEN (Mature)									
1a	6,100	6	6	1965	22.56	17.48	5.08	--	--
				1966	23.07	14.76	8.31	4.29	12.60
				1967	22.70	14.30	8.40	5.00	13.40
2a	7,000	6	6	1965	23.20	19.90	3.30	--	--
				1966	25.47	13.92	11.55	4.30	15.85
				1967	28.44	13.83	14.61	5.00	19.61
3a	8,500	5	6	1966	26.21	12.51	13.70	3.90	17.60
5a	8,400	3	9	1963	37.73	18.61	19.12	5.06	24.18
				1964	36.02	18.77	17.25	1.83	19.08
				1965	37.55	25.72	11.83	10.43	22.26
				1966	34.54	17.15	17.39	1.13	18.52
				1967	38.62	18.24	20.38	--	--
6a	7,640	6	6	1966	21.46	12.17	9.29	1.01	10.30
				1967	24.01	14.52	9.49	2.47	11.96
7a	7,800	6	6	1965	20.92	15.67	5.25	5.87	11.12
				1966	20.72	11.21	9.51	1.01	10.52
				1967	21.52	10.86	10.66	2.47	13.13
11a	7,900	12	6	1964	29.65	21.57	8.08	3.98	12.06
				1965	28.96	23.62	5.34	10.65	15.99
				1966	30.00	24.33	5.67	4.80	10.47
12a	9,200	12	6	1964	23.74	15.33	8.41	3.78	12.19
				1965	24.07	18.69	5.38	9.28	14.66
				1966	23.86	16.24	7.62	5.55	13.17

Table 2. (con.)

Site no.	Elevation	No. of holes	Depth	Year	Maximum	Minimum	Soil moisture : depletion	Precipitation	Evapo- transpiration
	Ft.		Ft.				Inches of water		
					ASPEN (Sprout)				
7b	7,800	6	6	1965	21.63	19.60	2.03	5.87	7.90
				1966	20.61	14.65	5.96	1.01	6.97
				1967	21.55	13.91	7.64	2.47	10.11
11b	7,900	12	6	1964	30.24	23.36	6.88	3.98	10.86
				1965	29.74	25.63	4.11	10.65	14.76
				1966	30.32	25.13	5.19	4.80	9.99
12b	9,200	12	6	1964	22.94	17.59	5.35	3.78	9.13
				1965	22.97	22.09	0.88	9.28	10.16
				1966	23.28	18.07	5.21	5.55	10.76
					DOUGLAS-FIR				
1b	6,100	6	6	1965	22.69	17.47	5.22	--	--
				1966	22.61	14.89	7.72	4.29	12.01
				1967	22.71	14.39	8.32	5.00	13.32
3b	8,500	5	6	1966	16.93	7.13	9.80	3.90	13.70
					GAMBEL OAK (Mature)				
4a	7,130	9	8	1963	26.00	13.47	12.53	5.99	18.52
				1964	24.84	--	--	2.90	--
				1965	24.16	17.78	6.38	10.68	17.06
				1966	24.93	14.20	10.73	4.08	14.81
				1967	25.54	14.46	11.08	7.15	18.23
9a	6,600	12	6	1964	24.79	15.29	9.50	3.31	12.81
				1965	23.21	17.20	6.01	9.07	15.08
				1966	22.13	14.75	7.38	4.01	11.39
10a	7,900	12	6	1964	30.05	18.46	11.59	3.98	15.57
				1965	29.17	21.18	7.99	10.65	18.64
				1966	26.76	17.81	8.95	4.80	13.75

Headquarters for the Intermountain Forest and
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Johnston, Robert S., Ronald K. Tew, and Robert D. Doty.

1969. Soil moisture depletion and estimated evapotranspiration on Utah mountain watersheds. Intermountain Forest and Range Exp. Sta., Ogden, Utah 84401. 13 pp., illus. (USDA Forest Serv. Research Paper INT-67)

Soil moisture depletion was measured with a neutron moisture probe on 14 sites representing 10 vegetation types on mountain watersheds in Utah. A water balance equation was used to estimate evapotranspiration (ET). Both soil moisture depletion and ET varied considerably between sites and from year to year. Aspen (*Populus tremuloides*) sprouts utilized from 0.48 to 4.50 in. less water from 6 ft. of soil than mature aspen; Gambel oak (*Quercus gambelii*) sprouts utilized from 0.25 to 1.15 in. less water than mature oak. By converting aspen to grass, ET losses were reduced from 1.08 to 5.18 in. from the surface 6 ft. of soil and up to 7.59 in. from a 9-ft. soil depth.

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