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FOREST FLOOR CHARACTERISTICS OF MARMOT AND STREETER EXPERIMENTAL WATERSHEDS, ALBERTA

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ABSTRACT

Hydrologic and other physical properties of the forest floor under different forest cover types were investigated on Marmot Creek and Streeter Creek basins, two experimental watersheds in western Alberta, to determine their water-holding capacities. On the Marmot Creek mountain watershed, forest floor characteristics were compared for spruce-fir, partially cut spruce-fir, and young lodgepole pine forest covers on north, east, and south aspects. The Streeter Creek basin foothills watershed was characterized by aspen and balsam poplar. Measurements were taken of ground cover; forest floor weight, thickness, and bulk density; and depth of water held after draining, water held per centimetre of forest floor thickness, and weight of water per unit dry weight of forest floor.

On both Marmot and Streeter basins, water storage was correlated significantly with forest floor thickness and dry weight. On Marmot basin more water was held under cut and uncut spruce-fir than under pine and on north and east aspects than on south aspects, reflecting the greater forest floor depths and weights. The forest floor under poplar on Streeter basin held less water than the spruce-fir but more than the pine forest floors on Marmot basin. The greater the percentage by weight of decomposed organic matter, the greater the capacity of the forest floor to retain water.

RESUME

Les propriétés hydrologiques ainsi que d'autres propriété physiques de la litière sous différents types de couvert forestier ont fait l'objet de recherches à Marmot Creek et Streeter Creek dans l'ouest de l'Aberta, à l'effet de déterminer les capacités de rétention d'eau de ces deux bassins-versants expérimentaux. Sur le bassin du mont Marmot Creek les caractéristiques de la litière ont été comparées pour les peuplements forestiers d'épinettes-sapins, ceux d'épinettes-sapins partiellement coupés et les jeunes peuplements de pin tordu latifolié exposés au nord, à l'est et au sud. Le bassin des collines de Streeter Creek était caractérisé par un couvert de tremble et de peuplier baumier. On a mesuré la couverture vivante, le poids, l'épaisseur et la densité apparente de la litière, la profondeur de l'eau retenue après drainage, l'eau retenue par centimètre d'épaisseur de la litière et le poids d'eau par unité de poids sec de la litière.

Aux deux bassins de Marmot Creek et de Streeter Creek la rétention de l'eau était corrélée significativement à l'épaisseur et au poids sec de la litière. Au bassin de Marmot Creek une plus grande quantité d'eau se trouvait retenue au-dessous des peuplements d'épinettes-sapins coupés ou non qu'au-dessous des peuplements de pins et de même au nord et à l'est qu'au sud, ce qui correspondait à des profondeurs et à des poids supérieurs de la litière. La litière retenait moins d'eau sous les peuplements de peupliers au bassin de Streeter que sous les peuplements de pins au bassin de Marmot. Plus le pourcentage de matières organiques décomposées était élevé, plus la capacité de rétention d'eau de la litière était grande.

CONTENTS

FIGURES

TABLES

INTRODUCTION

The water-holding capacity of the forest floor is an important factor governing movement of water on a watershed. Retention of moisture in the organic layer affects the soil moisture supply to plants and groundwater systems and therefore affects plant growth and water yield. Organic matter from roots and leaves improves soil structure and results in increased infiltration rates and water-holding capacity of the soil (Teller 1968). The characteristics of the forest floor influence regeneration of trees, nutrient cycling, and soil temperatures. The forest floor also protects the soil from forces of erosion, particularly raindrop impact.

The forest floor is usually defined as all dead vegetable matter on the mineral soil surface, including litter and unincorporated humus (Soc. Am. For. 1964). The three layers making up the forest floor are the L (litter), composed of unaltered organic matter; F (fermentation), consisting of partly decomposed organic matter and often called raw humus; and the H (humus), consisting of well-decomposed organic matter (Kohnke 1968). There are no sharp boundaries between the layers.

This report describes results of forest floor studies that form part of a much larger project in which the effects of forest cover manipulation on streamflow are being assessed using field measurements and hydrologic mathematical simulation models. The forest floor studies were carried out on two experimental watersheds in southwestern Alberta: on Marmot Creek basin during 1966 and 1967 and on Streeter Creek basin in 1968. The purpose of the report is to present information on some physical characteristics of the forest floor under subalpine and poplar forests that will be useful to forest managers, watershed managers, and soil researchers. Such quantitative information is not generally available in the literature.

The studies were designed to measure the hydrologic and other physical characteristics of the forest floor in order to better explain how a watershed responds to precipitation inputs. For modeling purposes, the data provide a basis for simulating water transmission and storage in the forest floor, important elements in a total hydrologic or watershed model.

The objectives were to determine the weight, thickness, bulk density, and water-holding capacity of the forest floor and their interrelationships under

1. the three main forest cover types on Marmot basin, which are mature spruce-fir (*Picea engelmannii* Parry and *Abies lasiocarpa* (Hook.) Nutt.), partially cut spruce-fir, and 30-year-old lodgepole pine (*Pinus contorta* Dougl. var. *latifolia* Engelm.), on the north, south, and east predominant aspects, and
2. two poplar species, trembling aspen (*Populus tremuloides* Michx.) and balsam poplar (*Populus balsamifera* L.), on Streeter basin.

STUDY AREAS

MARMOT BASIN

Marmot basin is in the Kananaskis River valley about 80 km west of Calgary, Alberta, on the east slopes of the Rocky Mountains (Figs. 1 and 2). It is a 9.3-km^2 area with elevation ranging from 1585 to 2805 m above mean sea level (msl). The basin is covered mainly with glacial deposits (till and glaciofluvial material) and postglacial deposits (talus, scree, and alluvium) and has bedrock outcrops in the upper part of the basin and along stream channels (Stevenson 1967). In the lower part of the basin, soils are gray wooded with ferro-humic podzols between 1770 and 1920 m, dystric brunisols to 2075 m, and regosols above (Beke 1969).

Rowe (1972) classified the general area as the Subalpine Forest Region, East Slope Rockies Section (SA.1). On Marmot basin this classification corresponds to the alpine tundra and the Engelmann spruce-subalpine fir biogeoclimatic zones mapped by Kojima (1980). Tree line is at about 2285 m. Mature spruce-fir covers 41% of the basin. A partial cut of merchantable spruce was made in 1950 in some of the spruce-fir stands. The spruce-fir stands, both cut and uncut, were approximately 20 m in height, with average diameter at breast height (dbh) 6-16 cm, crown closure 35-85%, age 135-200

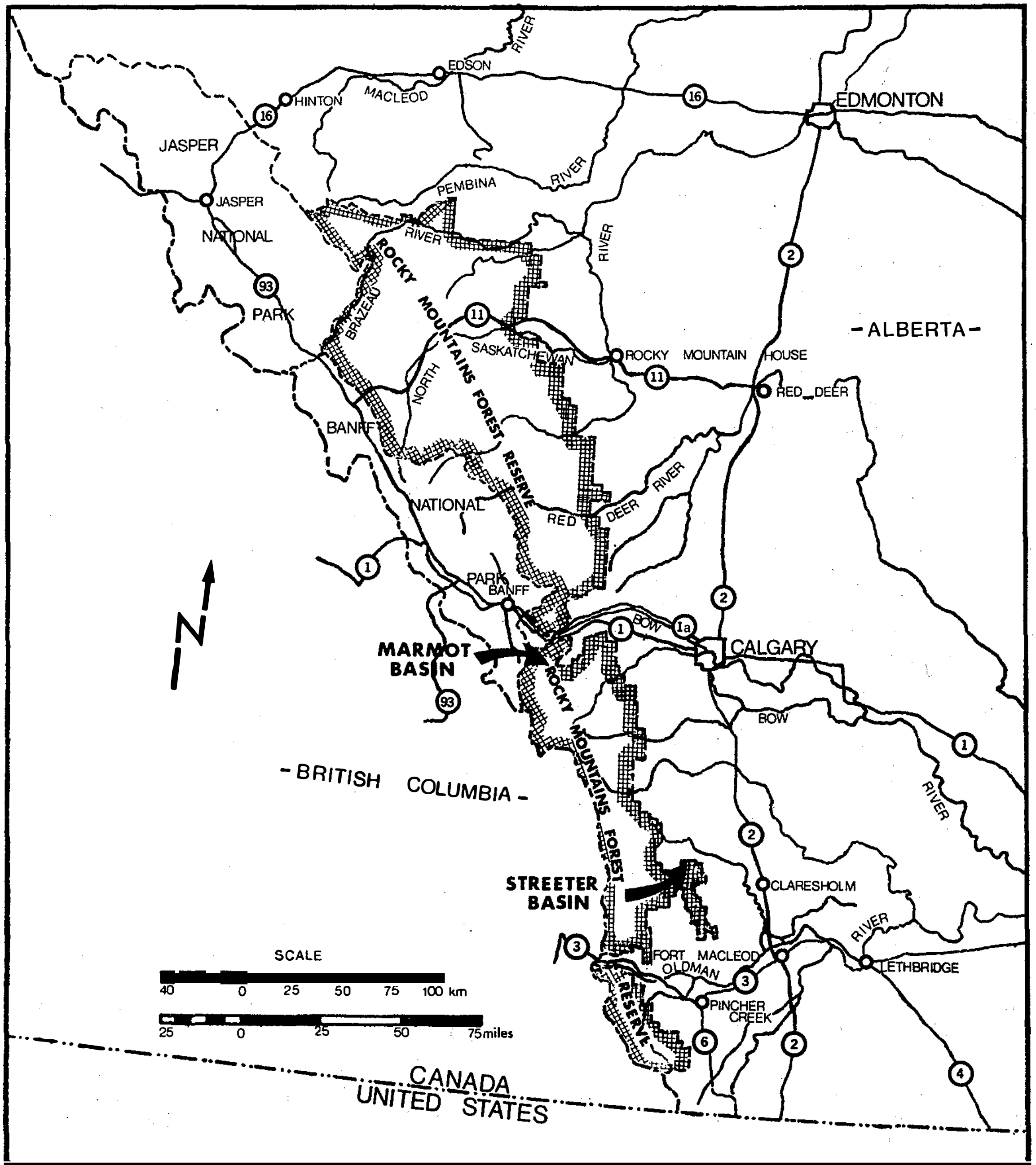

Figure 1. Locations of Marmot and Streeter basins.

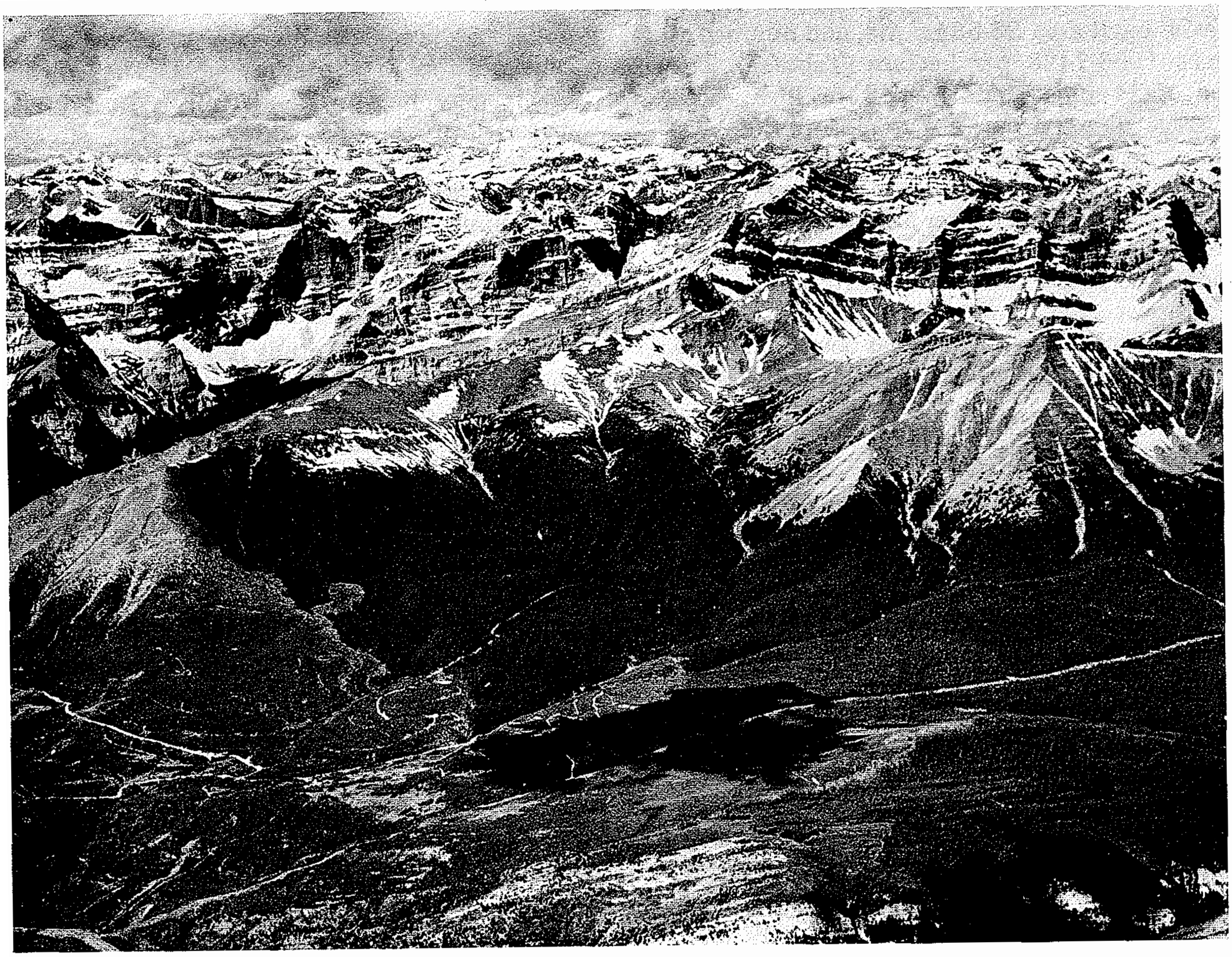

Figure 2. Marmot basin.

Figure 3. Streeter basin.

years, basal area 25-58 m^2 /ha, and number of trees 1258-7428 per hectare (Table 1). The lodgepole pine stand was 8 m high, with average dbh 3.6 cm, crown closure 80%, age 30 years, basal area 13.1 m^2 /ha, and 14 070 trees/ha. The pine stand, which covers 7% of the basin, originated after an intense fire burned the mature spruce-fir in 1936. Mature lodgepole pine exist on the south aspect only and cover slightly more than 1% of the basin. The understory vegetation has been delineated and described by Kirby and Ogilvie (1969).

Annual precipitation is about 890 mm, and annual water yield from the basin is about 50% of the precipitation, or approximately 450 mm. Elevation of the areas sampled ranges from 1770 to 1830 m above msl, with slopes of 14-35%.

STREETER BASIN

Streeter basin is in the Porcupine Hills of southwestern Alberta, about 115 km south of Calgary (Figs. 1 and 3). It is 6 km^2 in area, and the elevation ranges from 1325 to 1660 m above msl. The area is underlain by sandstone with a shallow covering of silty to sandy till (Jeffrey 1965). The basin is characterized by the dominance of black and dark gray chernozemic soils with regosols, eutric brunisols, and gray luvisols occupying lesser areas. On Streeter basin there is no evidence of vertical zonation of soils such as occurs on Marmot basin (Beke 1969). The vegetative cover of the basin consists of forests and grasslands. The area is located in Rowe's (1972) Montane Forest Region, Douglas-fir and Lodgepole Pine Section (M.5), which corresponds to the interior Douglas-fir biogeoclimatic zone of Kojima (1980).

On the study area, forest cover consisted of 45-year-old aspen (72%) and 85-year-old balsam poplar (28%). The mixed stand was approximately 9-12 m high, with average dbh 16 cm, crown closure 50%, basal area 30 m^2 /ha, and 1560 trees/ha. The understory consisted primarily of willow (*Salix* spp.), meadowsweet (*Spiraea* spp.) aster (*Aster* spp.), pine grass (*Calamagrostis* spp.), strawberry (*Fragaria* spp.), and wild geranium (*Geranium* spp.). Ground cover consisted almost entirely of litter, and there were no exposed rocks or patches of bare soil. Grass and live stems of understory vegetation occupied an insignificant portion of the study area. The soil is orthic gray luvisol (Beke 1969) with parent material of till and colluvium. The site is located on a north-facing aspect with slope 24% at an elevation of 1405 m. Annual precipitation is 560 mm.

METHODS

Because the study for each area was carried out independently by different researchers at different times, the method used to sample and measure the forest floor on Marmot basin was different from that used on Streeter basin.

MARMOT BASIN

On Marmot basin, 30 forest floor samples, 15.24 X 15.24 cm, were obtained in each of nine combinations of cover type and aspect: cut spruce-fir, spruce-fir, and immature lodgepole pine on north, south, and east aspects (Table 1). In addition, 30 samples were taken under mature lodgepole pine on a south aspect, the only aspect with that cover type. Samples were taken 2.74-m apart across the slope. Sample thickness was determined as the average thickness of the four sides of the sample. Estimates were made of percentage moss, litter, dead stems and branches in contact with the ground, live stems, grass, and bare rock or soil for 0.45 X 1.83 m plots surrounding each forest floor sample. Species of understory vegetation were listed for each plot.

All samples were removed to the laboratory, where they were wrapped in cheesecloth, immersed in water for 48 h, and then drained on a bed of sand for 48 h. Evaporation was minimized by covering the samples with the inverted soaking tanks. The samples were then weighed and dried at an air temperature of 85°C maintained with heat lamps. When the samples had reached a constant weight, this weight was taken as the dry weight.

The weight, thickness, and bulk density of dry matter were calculated. Moisture content was expressed as water-storage capacity (the weight of water in grams in a sample after draining per gram of air-dried sample) and as the maximum depth of water held

Table 1. Mean topography and forest-stand characteristics of the Marmot basin study areas

Forest cover	Aspect	Elevation (m)	Slope (%)	Stand height (m)	Crown closure (%)	Age (yr)	Stocking (trees/ha)		Basal area (m^2/ha)		Volume (m^3/ha)		Dbh (cm)	
							>1.5 cm dbh	>16.8 cm dbh	>1.5 cm dbh	>16.8 cm dbh	>1.5 cm dbh	>16.8 cm dbh	>1.5 cm dbh	>16.8 cm dbh
Spruce-fir, cut	South	1785	18	20	35	135	1 258	321	25.3	16.1	178.4	136.5	15.7	25.2
Spruce-fir	South	1845	35	20	85	200	4 324	830	57.9	28.2	405.4	221.0	13.0	20.6
Spruce-fir, cut	North	1775	14	20	45	175	7 428	381	25.3	13.8	181.3	115.5	6.4	21.3
Spruce-fir	North	1800	14	20	45	140	3 005	625	41.3	30.5	316.0	248.1	13.2	24.9
Spruce-fir, cut	East	1785	14	20	45	175	7 428	381	25.3	13.8	181.9	115.5	6.4	21.3
Spruce-fir	East	1800	14	20	45	140	3 005	625	41.3	30.5	316.0	248.1	13.2	24.9
Lodgepole pine	South	1800	24	8	80	30	14 070	0	13.1	0	34.1	0	3.6	0
Lodgepole pine	North	1785	22	8	80	30	14 070	0	13.1	0	34.1	0	3.6	0
Lodgepole pine	East	1835	28	8	80	30	14 070	0	13.1	0	34.1	0	3.6	0

after draining by a) the total thickness and b) a 1-cm thickness of the forest floor. For the mature pine forest floor samples only thickness, maximum depth of water held, and water-storage capacity were determined. Because the samples were not oven-dried, the term water-storage capacity is used to distinguish it from water-holding capacity, which is the ratio of the weight of water in a sample after draining per gram of oven-dried sample.

STREETER BASIN

On Streeter basin, 47 samples, each 15.24 X 15.24 cm, were randomly selected from an area 9.29 m^2 in the poplar cover type. No live vegetation such as moss or live roots was included. All rock fragments and soil aggregates were removed by hand. Five of the samples were separated into litter layer (L), two fermentation layers (F_1 and F_2), and the humus layer (H). Separation of the F_1 and F_2 layers was based solely on the presence of mycelia, which were quite noticeable in the lower part (F_2) of the fermentation layer. Sample thickness was determined as the average of the four sides.

In the laboratory, the 42 intact samples were placed in aluminum pans, covered with cheesecloth, and immersed in water for 48 h. They were then drained on a bed of sand for another 48 h. Evaporation was minimized by covering the samples with the aluminum pans. The samples were weighed, oven-dried at 102°C for 48 h, and reweighed. Ovendry weight was also obtained for each layer of the five separated samples.

The weight, thickness, and bulk density of dry matter were determined for all 47 samples and for each layer of the 5 separated samples. For the 42 intact samples, water-holding capacity and the maximum depth of water held by a) the total thickness and b) a 1-cm thickness of the forest floor were determined as well.

MARMOT AND STREETER BASINS

For both Marmot and Streeter samples, regression analyses were made between dry weight and forest floor thickness, depth of water held and forest floor thickness, and water-holding (or water-storage) capacity and forest floor thickness. Additional regression analyses were made between weight of water held and weight of dry matter for Marmot samples, and between depth of water held and weight of dry matter for Streeter samples.

RESULTS AND DISCUSSION

MARMOT BASIN

Forest floor weight. The mean dry weight of the forest floor in Marmot basin varied between 102.2 t/ha (spruce-fir, east aspect) and 41.8 t/ha (pine, east aspect) (Table 2). It was greater for spruce-fir than for pine. In spruce-fir, it was greater on the east aspect than on the south aspect. In pine, the mean dry weight of the forest floor was greater on the north and south aspects than on the east aspect. There was no significant difference between cut and uncut spruce-fir. Weight increased with increasing moss cover and decreased with increasing litter cover.

For comparison, characteristics of the forest floor under conifers as reported in the literature and some data for Marmot basin are given in Table 3. None of the reported studies deals with the spruce-fir cover type,and only one deals with lodgepole pine. Although the ecosystems used in the comparison are different from spruce-fir and lodgepole pine, data pertaining to them are included because published data of this nature are quite scarce. It must be noted that Table 3 values for sites other than Marmot basin are for dead organic matter only, whereas values for Marmot basin include living moss. The spruce-fir forest floor on Marmot basin has a greater dry weight (89.4 t/ha) than any cover type except the coastal western hemlock. This may be due wholly to the inclusion of living moss in the forest floor samples from Marmot basin. Moss cover averaged 70% on the six spruce-fir sites. The dry weight of the forest floor under immature lodgepole pine on Marmot basin (55.1 t/ha) was exceeded only by that of the true fir-hemlock stands of Washington and Oregon and that of the hemlock stands of coastal British Columbia. It was twice that of the Colorado lodgepole pine stand. This greater dry weight cannot be attributed to the inclusion of living moss in the Marmot basin samples, because moss accounted for an average of only 12% of the total cover under lodgepole pine. The differences in

Table 2. Weight, thickness, and bulk density of the forest floor on Marmot basin

Forest cover	Aspect	Weight of dry matter (t/ha)		Thickness (cm)		Bulk density (g/cm^3)	
		Mean	Standard deviation	Mean	Standard deviation	Mean	Standard deviation
Spruce-fir, cut	South	73.5	26.6	8.1	3.0	0.10	0.02
Spruce-fir	South	86.8	34.7	9.3	3.7	0.11	0.02
Spruce-fir, cut	North	90.9	34.2	10.2	3.6	0.10	0.03
Spruce-fir	North	85.3	32.5	13.0	4.6	0.07	0.02
Spruce-fir, cut	East	98.3	37.5	11.3	4.3	0.09	0.02
Spruce-fir	East	102.2	46.4	11.7	4.8	0.09	0.02
Lodgepole pine	South	54.2	20.1	4.8	1.9	0.14	0.06
Lodgepole pine	North	69.5	22.8	4.8	1.4	0.17	0.04
Lodgepole pine	East	41.8	17.2	4.1	1.0	0.11	0.04

Table 3. Forest floor characteristics under conifers

Location	Forest type	Stand age (yr)	Forest floor: Thickness (cm)		Weight (t/ha)		Water held (cm)		Reference
			Mean	Range	Mean	Range	Mean	Range	
Massachusetts	White pine	34-96	6.4	-	45.9	11.4-96.2	-	1.0-1.2	Mader and Lull (1968)
Arizona	Ponderosa pine	Mixed	3.3	-	20.8	8.1-152.9	0.2	0.1-2.0	Clary and Ffolliott (1969), Ffolliott *et al.* (1968)
Mississippi	Loblolly pine	8-16	2.0	-	16.4	-	-	-	Williston (1965)
Minnesota and Michigan	Jack pine	15-43	2.8	-	26.2	19.5-33.8	-	-	Brown (1966)
Colorado	Lodgepole pine	60	-	-	25.3	-	-	-	Moir and Grier (1969)
Washington and Oregon	True fir-hemlock	-	4.6	1.3-13.0	62.8	22.4-170.4	-	-	Williams and Dyrness (1967)
Oregon	Douglas-fir	100	-	-	-	22.4-85.2	-	-	Youngberg (1966)
British Columbia	Western hemlock	250+	16.6	12.0-26.0	-	14.1-378.2	2.2	0.3-10.3	Plamondon (1972)
Alberta (Marmot)	Spruce-fir	135-200	10.6	-	89.4	-	1.9	-	This paper
Alberta (Marmot)	Lodgepole pine	30	4.6	-	55.1	-	0.8	-	This paper
Alberta (Marmot)	Lodgepole pine	170	9.4	-	-	-	1.2	-	This paper

Table 4. Correlation and regression statistics for the relations between forest floor thickness, dry weight, depth of water, weight of water, and water-storage capacity on Marmot basin

Forest cover	Aspect	Mean, independent variable ($\bar{X}$)	Mean, dependent variable ($\bar{Y}$)	Intercept (a)	Slope (b)	Correlation coefficient (r)	Standard deviation from regression ($S_{y \cdot x}$)
Weight of dry matter (Y) / forest floor thickness (X)							
		(cm)	(g)				
Spruce-fir, cut	South	8.1	190	36	19	0.83	39
Spruce-fir	South	9.3	226	22	22	0.89	42
Spruce-fir, cut	North	10.2	229	30	20	0.72	61
Spruce-fir	North	13.0	216	21	15	0.84	45
Spruce-fir, cut	East	11.3	240	52	17	0.78	58
Spruce-fir	East	11.7	252	-1	22	0.90	51
Lodgepole pine	South	4.8	152	76	16	0.53	48
Lodgepole pine	North	4.8	190	45	30	0.69	46
Lodgepole pine	East	4.1	107	24	20	0.47	40
Depth of water held (Y) / forest floor thickness (X)							
		(cm)	(cm)				
Spruce-fir, cut	South	8.1	1.47	-0.272	0.216	0.86	0.38
Spruce-fir	South	9.3	1.84	-0.510	0.251	0.94	0.33
Spruce-fir, cut	North	10.2	1.99	-0.559	0.250	0.74	0.74
Spruce-fir	North	13.0	1.91	-0.635	0.195	0.82	0.64
Spruce-fir, cut	East	11.3	2.11	-0.018	0.189	0.82	0.58
Spruce-fir	East	11.7	2.30	-0.739	0.260	0.90	0.58
Lodgepole pine	South	4.8	0.96	-0.091	0.219	0.83	0.28
Lodgepole pine	North	4.8	0.98	-0.102	0.221	0.88	0.18
Lodgepole pine	East	4.1	0.62	-0.041	0.158	0.73	0.15

Table 4, continued

Forest cover	Aspect	Mean, independent variable ($\bar{X}$)	Mean, dependent variable ($\bar{Y}$)	Intercept (a)	Slope (b)	Correlation coefficient (r)	Standard deviation from regression ($S_{y \cdot x}$)
Weight of water (Y) / dry weight (X)							
		(g)	(g)				
Spruce-fir, cut	South	190	345	-107	2.38	0.94	61
Spruce-fir	South	226	427	-91	2.29	0.91	96
Spruce-fir, cut	North	229	463	-170	2.76	0.95	78
Spruce-fir	North	216	444	-187	2.93	0.95	83
Spruce-fir, cut	East	240	489	-100	2.45	0.98	53
Spruce-fir	East	252	534	-136	2.66	0.95	98
Lodgepole pine	South	152	223	-10	1.54	0.74	80
Lodgepole pine	North	190	226	20	1.09	0.82	49
Lodgepole pine	East	107	145	41	0.97	0.83	29
Water-storage capacity (Y) / forest floor thickness (X)							
		(cm)	(g/g)				
Spruce-fir, cut	South	8.1	1.77	1.29	0.059	0.56	0.26
Spruce-fir	South	9.3	1.83	1.24	0.063	0.83	0.30
Spruce-fir, cut	North	10.2	1.94	1.30	0.063	0.61	0.26
Spruce-fir	North	13.0	1.98	1.36	0.047	0.65	0.26
Spruce-fir, cut	East	11.3	1.99	1.64	0.032	0.61	0.17
Spruce-fir	East	11.7	2.04	1.58	0.039	0.56	0.29
Lodgepole pine	South	4.8	1.44	0.64	0.165	0.66	0.36
Lodgepole pine	North	4.8	1.20	0.84	0.075	0.49	0.19
Lodgepole pine	East	4.1	1.40	1.08	0.079	0.29[1]	0.28

[1] This value is not significant at the 95% level of probability. All other r's are significant at the 99% level.

Table 3 reflect, to some extent, the slower decomposition rate of the forest floor on high elevation sites at higher latitudes.

As expected, weight of dry matter was significantly correlated with thickness of the forest floor, correlation coefficients being 0.47-0.69 for pine and 0.72-0.90 for spruce-fir (Table 4). Significant correlations were obtained for the relation of dry weight with stand age and with stand volume; however, only 16% of the variance was accounted for in each case.

Forest floor thickness. Forest floor thickness varied from 13.0 cm (spruce-fir, north aspect) to 4.1 cm (pine, east aspect) (Table 2). It was greater under spruce-fir than under pine and greater under uncut spruce-fir than under cut spruce-fir. On spruce-fir sites, forest floor thickness was greater on east and north aspects than on the south aspect. Thickness increased with increasing moss cover, which was greatest on north and east aspects, and it decreased with increasing litter cover, which was least on north and east aspects (Table 5).

Forest floor thickness was greater under spruce-fir on Marmot basin (10.6 cm) than under most forest covers reported in Table 3 except for coastal western hemlock in British Columbia (16.6 cm). It was greater under lodgepole pine on Marmot basin (4.6 cm) than under the other forest types except for eastern white pine (6.4 cm) and coastal western hemlock.

Forest floor bulk density. Bulk density was greatest for pine, north aspect (0.17 g/cm^3), and least for uncut spruce-fir, north aspect (0.07 g/cm^3) (Table 2). The forest floor bulk density was greater for pine than for spruce-fir. In spruce-fir it was greater on the south than on east and north aspects. In pine it was greater on the north than on the south aspect, which was greater than the east aspect. There was no significant difference between forest floor bulk density under uncut spruce-fir and under cut spruce-fir.

Water storage. Total depth of water held after draining varied between 2.31 cm (spruce-fir, east aspect) and 0.61 cm (pine, east aspect) (Table 6). The forest floor under spruce-fir held more water than that under pine, but there was no significant difference between the forest floors under cut and uncut spruce-fir. In spruce-fir, the depth of water held was greater on the east than on the south aspect. No significant difference was evident between corresponding pine sites. In comparison, the depth of water held by the forest floor under white pine in Massachusetts (1.0-1.2 cm) was less and under ponderosa pine in Arizona (0.2 cm) was much less than under spruce-fir on Marmot basin (1.9 cm) (Table 3). Depth of water held under lodgepole pine on Marmot basin (0.8 cm) was somewhat less than that held under white pine in Massachusetts.

Water held per centimetre of forest floor thickness ranged from 0.15 to 0.20 cm (Table 6). There was no significant difference between spruce-fir and pine or between cut and uncut spruce-fir. In spruce-fir it was greater on east and south aspects than on the north aspect, whereas in pine it was greater on north and south aspects than on the east aspect. There is no significant relation between water held per centimetre of forest floor thickness and forest floor thickness, although in cut spruce-fir and in pine there is a trend to higher values of water held per centimetre of forest floor thickness with deeper forest floors. In the uncut spruce-fir the trend is the opposite.

Water-storage capacity (i.e., weight of water held per unit dry weight of forest floor) was greatest at 2.05 g/g in spruce-fir, east aspect, and least at 1.21 g/g in pine, north aspect (Table 6). Water-storage capacity was greater under spruce-fir than under pine, but there was no significant difference between cut and uncut spruce-fir. In spruce-fir it was greater on east and north aspects than on the south aspect. In pine it was greater on south and east aspects than on the north aspect. The water-storage capacity of the forest floor under spruce-fir is about 75% of the 2-year return period, maximum 24-h rainfall for the area. Young and mature lodgepole pine water-storage capacities are only 33% and 47%, respectively, of the maximum 24-h rainfall.

As was the case for dry matter weight, water held after draining was correlated significantly and positively with both stand age and volume. The explained variation was low.

Table 5. Ground cover components on Marmot basin

Forest cover	Aspect	% of ground cover			
		Moss	Litter	Dead stems	Living stems
Spruce-fir, cut	South	54.4	35.1	10.1	0.3
Spruce-fir	South	60.7	27.8	11.2	0.3
Spruce-fir, cut	North	74.2	17.5	5.9	2.4
Spruce-fir	North	80.7	10.6	6.4	2.1
Spruce-fir, cut	East	73.2	20.0	4.1	0.7
Spruce-fir	East	78.0	16.6	4.7	0.7
Lodgepole pine	South	1.8	79.6	15.5	0.7
Lodgepole pine	North	29.8	55.5	13.6	1.1
Lodgepole pine	East	3.2	86.7	8.3	1.1

Table 6. Water-holding capabilities of the forest floor on Marmot basin

Forest cover	Aspect	Water held after draining (cm)		Water held per unit forest floor thickness (cm/cm)		Water-storage capacity (g/g)	
		Mean	Standard deviation	Mean	Standard deviation	Mean	Standard deviation
Spruce-fir, cut	South	1.47	0.71	0.18	0.04	1.77	0.30
Spruce-fir	South	1.83	0.97	0.20	0.04	1.84	0.36
Spruce-fir, cut	North	1.98	1.07	0.20	0.06	1.94	0.31
Spruce-fir	North	1.91	1.09	0.15	0.04	1.98	0.33
Spruce-fir, cut	East	2.11	0.99	0.19	0.05	1.99	0.22
Spruce-fir	East	2.31	1.37	0.20	0.05	2.05	0.33
Lodgepole pine	South	0.97	0.51	0.20	0.07	1.45	0.46
Lodgepole pine	North	0.97	0.33	0.20	0.04	1.21	0.20
Lodgepole pine	East	0.61	0.20	0.15	0.03	1.41	0.28

Table 7. Mean water-holding capabilities of the forest floor by cover type on Marmot basin

Cover type	Forest floor thickness (cm)	Depth of water held (cm)	Water-storage capacity (g/g)
Spruce-fir	10.59	1.91	1.93
Young lodgepole pine	4.60	0.84	1.36
Mature lodgepole pine	9.42	1.19	2.31

Depth of water held by the forest floor was significantly related to forest floor thickness, with correlation coefficients of 0.73-0.88 for pine and 0.74-0.94 for spruce-fir (Table 4). Weight of water held was significantly related to dry weight of the forest floor, with correlation coefficients of 0.74-0.83 for pine and 0.91-0.98 for spruce-fir. Water-storage capacity was significantly correlated with forest floor thickness. Correlation coefficients were 0.29-0.66 for pine and 0.56-0.83 for spruce-fir (Table 4). Water-storage capacity increased by about 0.05 g/g of dry matter for each centimetre increase in forest floor thickness in spruce-fir and by 0.11 g/g in pine.

It is suggested that the differences in forest floor characteristics are due not so much to the nature of these species and the stands they form as to the effects of the intense fire that 30 years ago burned the spruce-fir site on which the pine now grows. The forest floor has not yet attained the characteristics it would have had under mature pine. Evidence of this was obtained from the small stand of mature lodgepole pine located in the eastern portion of Marmot basin. Both thickness of the forest floor and water held by the forest floor under mature pine were greater than those under young pine, and water-storage capacity for mature pine exceeded even that for spruce-fir (Table 7).

Ground cover and understory. The percentage of sample plots covered by grass and bare rock or soil was negligible. Ground cover was not significantly different between cut and uncut spruce-fir, but spruce-fir and pine were significantly different for percentage moss, litter, and dead stems (Table 5). Moss cover was greatest in uncut spruce-fir (73%), followed by cut spruce-fir (67%) and pine (12%). Moss cover was greatest on the north aspect (77% and 30% in spruce-fir and pine, respectively), followed by east (76% and 3%) and south (58% and 2%) aspects. The greater thickness and weight of the forest floor and the greater amounts of water held by the forest floor on north and east aspects compared to the south aspect are related to the greater abundance of moss on these sites.

Litter cover was greatest on pine (74%), followed by cut spruce-fir (24%) and uncut spruce-fir (18%). Litter cover was 31%, 18%, and 14% on south, east, and north aspects, respectively, for spruce-fir and was 80%, 87%, and 56%, respectively, for pine.

The composition of the understory vegetation for each forest cover type is shown in Table 8. The plants listed for spruce-fir indicate that the site supports a *Picea-Abies/Menziesia-Lycopodium* plant community (Kirby and Ogilvie 1969). This habitat ranges in elevation from 1676 to 2011 m. Soils have well-developed podzolic profiles in which soil moisture availability is generally high throughout the year. The partially cut spruce-fir site supports plants typical of the *Picea-Abies/Hylocomium-Cornus* habitat type. This community is often characterized by a continuous carpet of feather mosses. The lodgepole pine study areas are in the young *Pinus contorta/Hylocomium-Cornus* facies (modified community). These areas, burned over 30 years ago, would be considered to be the *Picea-Abies/Hylocomium-Cornus* habitat type in terms of potential productivity.

Table 8. Understory under different cover types on Marmot basin

Spruce-fir	Partially cut spruce-fir	Lodgepole pine
Bunchberry (*Cornus canadensis* L.)	Buffalo berry (*Shepherdia canadensis* (L.) Nutt.)	Bunchberry (*Cornus canadensis* L.)
Club moss (*Lycopodium annotinum* L.)	Bunchberry (*Cornus canadensis* L.)	Feather moss (*Hylocomium splendens* (Hedw.) B.S.G.)
False azalea (*Menziesia ferruginea* Smith)	False azalea (*Menziesia ferruginea* Smith)	Hairy wild rye grass (*Elymus innovatus* Beal)
Feather moss (*Hylocomium splendens* (Hedw.) B.S.G.)	Feather moss (*Hylocomium splendens* (Hedw.) B.S.G.)	Showy aster (*Aster conspicuus* Lindl.)
Grouseberry (*Vaccinium scoparium* Leiberg)	Feather moss (*Pleurozium schreberi* (Brid.) Mitt.)	White meadowsweet (*Spiraea lucida* Dougl.)
Labrador tea (*Ledum groenlandicum* Oeder)	Grouseberry (*Vaccinium scoparium* Leiberg)	Wild sweet pea (*Lathyrus ochroleucus* Hook.)
Lichen (*Peltigera aphthosa* (L.) Willd.)	Hairy wild rye grass (*Elymus innovatus* Beal)	Willow (*Salix* spp.)
Twinflower (*Linnaea borealis* var. *americana* (Forbes) Rehd.)	Labrador tea (*Ledum groenlandicum* Oeder)	
	Lichen (*Peltigera aphthosa* (L.) Willd.)	
	Twinflower (*Linnaea borealis* var. *americana* (Forbes) Rehd.)	

Table 9. Characteristics of the forest floor under poplar on Streeter basin

Statistic	Weight of dry matter (t/ha)	Thickness (cm)	Bulk density (g/cm^3)	Water-holding capacity (g/g)	Water held after draining (cm)	Water held per unit forest floor weight (cm/g)	Water held per unit forest floor thickness (cm/cm)
Mean	70.3	6.7	0.11	2.37	1.60	0.010	0.24
Standard deviation	21.8	1.7	0.03	0.37	0.51	0.002	0.07

STREETER BASIN

Forest floor weight, thickness, and bulk density. In Streeter basin the forest floor under poplar had a mean dry weight of 70.3 t/ha, a mean thickness of 6.7 cm, and a mean bulk density of 0.11 g/cm^3 (Table 9). A forest floor of this nature adequately protects the soil from raindrop impact, thereby minimizing erosion hazard.

Table 10 shows the characteristics of the forest floor layers. There is a progressive increase in weight with increasing depth of the forest floor. The H layer accounts for over half of the total weight but less than 30% of the total thickness. This progressive increase in weight with depth is reflected in the bulk density values given in Table 10 and can be attributed to closer packing of organic material as it decomposes and becomes less porous. The bulk density of the H layer is more than two and a half times greater than that of either the L or F layers. This indicates that the largely undecomposed upper organic layers (L and F) contain a greater percentage of macropores than the H layer. Macropores, which have much greater diameters than the micropores normally encountered in mineral soils, offer little resistance to water flow. The H layer, being more densely packed, has fewer macropores and a greater proportion of micropores. Water will, therefore, be less readily transmitted through the H layer than through the L and F layers.

Similarly, the Ae horizon of mineral soil immediately below the forest floor has a bulk density of 1.16 g/cm^3 (Beke 1969), which is greater than that of the forest floor, and will transmit water less readily than the forest floor.

The F layer forms the greatest percentage (58%) of forest floor depth and comprises 38% of the total weight. The L layer accounts for 13% of the total depth and only 8% of the total weight.

A comparison of forest floor weights and thicknesses under hardwood covers at different locations is shown in Table 11. Although it is difficult to make true comparisons because of the confounding effects of differences in climate, species, age, site index, and fire history, Tables 11 and 12 are included because they bring together information that is not readily available. It can be seen in Table 11 that for the poplar forest floor on Streeter basin the mean ovendry weight of all layers (70.3 t/ha) is less than the mean weight of the F + H layers (87.4 t/ha). This occurs because the values for the F + H layers are based on 5 samples, while the values for all layers are based on 47 samples.

A useful comparison can be made between this study and the study by Stoeckeler (1961) of trembling aspen sites in northern Minnesota. Although Stoeckeler's results tend to be lower than those for the Alberta site, they do show the same progressive increase in weight with depth that was evident in the Alberta study.

Stoeckeler obtained ovendry weights for the F and H layers, both separately and combined, from 29 plots under 9- to 70-year-old aspen. Similar data for the litter and the entire organic layer were obtained from only 14 plots under aspen 10 to 35 years old. It is for this reason that the mean weight of the F + H layers appears to be greater than the mean total weight. Stoeckeler found positive linear relationships in each case between the age of the stand and weight of F layer, weight of H layer, weight of the two combined, and weight of the entire organic material. He also found evidence that some proportion of the total organic matter production could be attributed to the stand of pine, hardwood, or spruce-balsam fir that was burned prior to establishment of the aspen. According to Stoeckeler, the H layer may constitute as much as 70-90% of the entire weight of the organic material. In the Alberta study, the H layer comprised little more than half the weight of the combined organic layers. Stoeckeler's maximum values for the entire forest floor (62.8 t/ha) and the F + H layers (69.5 t/ha) for northern Minnesota agree reasonably well with the total weight (70.3 t/ha) for Streeter basin.

Table 11 indicates that both the mean weight and mean thickness of the forest floor under hardwoods can be extremely variable. Thus the mean weight ranges from 76.8 t/ha for hardwoods in Wisconsin to 9.1 t/ha for

Table 10. Characteristics of the forest-floor layers under poplar on Streeter basin

	Weight of dry matter (t/ha)			Thickness (cm)			Bulk density (g/cm^3)	
Layer	% of total	Mean	Standard deviation	% of total	Mean	Standard deviation	Mean	Standard deviation
L	8.1	7.7	2.1	13.4	0.9	0.2	0.09	0.018
F_1	10.3	9.8	1.1	19.4	1.3	0.3	0.08	0.015
F_2	28.1	26.7	8.0	38.8	2.6	0.2	0.10	0.040
H	53.5	50.9	13.9	28.4	1.9	0.4	0.27	0.100
Total	100.0	95.1	19.6	100.0	6.7	0.7	0.14	0.044
$F_1 + F_2$	38.4	36.5	8.1	58.2	3.9	0.3	0.10	0.028
L + F	46.5	44.2	7.1	71.6	4.8	0.4	0.09	0.025
F + H	91.9	87.4	21.3	86.6	5.8	0.7	0.15	0.047

Table 11. Comparison of weight and thickness of the forest floor under hardwoods at different locations

Location	Forest type	Forest floor layer	Weight of dry matter (t/ha) Mean	Weight of dry matter (t/ha) Standard deviation or range	Thickness (cm) Mean	Thickness (cm) Standard deviation or range	Reference
Streeter basin, Alberta	Aspen, balsam poplar	L	7.7	2.1	0.9	0.2	This paper
		F	36.5	8.1	3.9	0.3	
		H	50.9	13.9	1.9	0.4	
		L + F	44.2	7.1	4.8	0.4	
		F + H	87.4	21.3	5.8	0.7	
		All[1]	70.3	21.8	6.7	1.7	
Northern Minnesota	Aspen	L	-	1.8-3.6	-	-	Stoeckeler (1961)
		F	12.4	-	-	-	
		H	38.1	-	-	-	
		F + H	-	19.1-69.5	-	-	
		All	-	21.3-62.8	-	-	
Allegheny plateau, Ohio	Mixed oak, 60-year-old	All	-	-	-	5.0-10.0	Whipkey (1965)
La Crosse, Wisconsin	Hardwood	All	76.8	74.2-79.1	-	5.1-7.6	Curtis (1960)
Franklin, North Carolina	Poplar, oak, hickory	L + F	12.8	2.6	-	-	Helvey (1964)
Eastern Tennessee	Oak	All	-	4.5-26.9	-	-	Blow (1955)
Pine barrens, New Jersey	Oak, pine	L + F	-	-	-	1.3-2.3	Bernard (1963)
Berkeley Hills, California	Oak, chaparral	All	61.8	-	5.1	-	Lowdermilk (1930)

Table 11, continued

Location	Forest type	Forest floor layer	Weight of dry matter (t/ha)		Thickness (cm)		Reference
			Mean	Standard deviation or range	Mean	Standard deviation or range	
San Dimas,	Chaparral:						
California	50-year-old	All	37.3	-	1.5	-	Kittredge (1955)
	31-year-old	All	12.8	1.7-43.7	1.0	0.3-3.6	
	11-year-old	All	9.1	0.5-13.3	1.0	0.3-1.8	
Tonto National	Chaparral:						
Forest, Arizona	Pringle manzanita	L + F	25.1	2.5	3.7	-	Garcia and Pase (1967)
	Shrub live oak	L + F	27.1	2.5	5.2	-	
Virgin stands							
New York	Maple, birch, beech	F + H	-	-	13.2	4.6	Lull (1959)
New Hampshire	Hemlock, beech, birch	F + H	-	-	11.2	6.1	
New Jersey	Oak, beech, hickory	F + H	-	-	4.1	2.5	
Southeastern New Hampshire	Hardwood	F + H	-	-	3.4	-	
Adirondacks, New York	Northern hardwoods	F + H	-	-	7.6	-	
West Virginia	Hardwoods	F + H	-	-	11.4	-	
Present-day stands							
Connecticut	Hardwood	F + H	-	-	3.1	-	Lull (1959)
Connecticut	Hardwood	F + H	-	-	-	1.9-5.1	
Connecticut	Hardwood-hemlock	F + H	-	-	-	4.5-7.0	
Pennsylvania	Hardwood	F + H	-	-	3.8	-	
Delaware	Hardwood-conifer	F + H	-	-	-	3.1-4.6	
West Virginia	Hardwood	F + H	-	-	5.1[2]	-	
Virginia	Hardwood	F + H	-	-	5.1	-	

1 Based on 47 samples.

2 Includes the F, H, and A_1 layers.

11-year-old chaparral in California. The mean thickness ranges from 13.2 cm for maple, birch, and beech in New York to 1.0 cm for chaparral in California. The mean thickness of the forest floor under aspen at Streeter basin (6.7 cm) is about halfway between these extremes.

Regression and correlation analyses of the Streeter basin data showed that the correlation between forest floor thickness and ovendry weight is significant (r = 0.53). The regression equation is

$$Y = 3.714 + 0.018\,(X) \qquad (S_{y \cdot x} = 1.465 \text{ cm})$$

where
Y = forest floor thickness (cm) and
X = ovendry weight (g).

The low correlation coefficient may be attributed to the large variation in bulk density within the forest floor. Table 10 shows the mean bulk density of the L + F layers to be 0.09 g/cm^3, while that of the H layer is three times as great; however, the L + F layers account for over 70% of the total depth. In order to obtain a true linear relationship between forest floor thickness and ovendry weight, the organic material that constitutes the forest floor must be of uniform bulk density throughout.

Water storage. The forest floor under poplar on Streeter basin has a water-holding capacity of 2.37 g/g, equivalent to a 1.60-cm depth of water (Table 9). Expressed on a unit basis, this is 0.24 cm of water per centimetre of forest floor depth or 0.01 cm of water per gram of forest floor dry weight.

The water-holding capacity is well below the maximum values reported in the literature. Stocks (1970) reported greater values for aspen, jack pine, and red pine sites at Petawawa, Ontario; the values for individual organic layers often exceeded 4.0 g/g. Similar results have also been obtained for spruce-fir sites in Alberta (Kiil 1970).

The water-holding capacity of the forest floor under poplar is similar to that under hardwoods in North Carolina (2.15 g/g), under oak-pine forest in New Jersey (2.63 g/g), and under oak in eastern Tennessee (2.25 g/g) (Table 12). It is higher than the water-holding capacity of the forest floor under chaparral.

The depth of water held is greater for the forest floor under poplar (1.60 cm) than for the other sites listed in Table 12. The value for poplar is close to the depth of water held by the forest floor under oak chaparral in California (1.52 cm) and by moss under oak-pine in New Jersey (1.57 cm).

It is evident that a dry forest floor under poplar will intercept and detain most of the water—up to a maximum of 1.60 cm—from low intensity, short duration rainstorms. Further, because the organic material is very porous and is exposed to the atmosphere, much of this water will be lost as evaporation and will not appear in the stream channel. As the water content of the forest floor increases, the hydraulic conductivity increases, and the forest floor is better able to transmit water. At saturation it holds 1.60 cm of water and transmits additional water at a maximum, constant rate.

Regression equations were obtained for depth of water held by the forest floor in relation to dry weight and to forest floor thickness:

$$Y = 0.133 + 0.0093\,(X_1) \qquad (S_{y \cdot x} = 0.269 \text{ cm})$$
$$Y = 0.512 + 0.162\,(X_2) \qquad (S_{y \cdot x} = 0.425 \text{ cm})$$

where
Y = depth of water held (cm),
X_1 = dry weight of forest floor (g), and
X_2 = forest floor thickness (cm).

The highest correlation was obtained for depth of water held and dry weight of the forest floor (r = 0.85). The correlation of depth of water held with forest floor thickness was not as high (r = 0.57), although it still was highly significant. The poorer correlation may be attributed to variation in the layered structure of the forest floor, in which each layer has a different thickness and different weight per unit thickness and therefore a different water-holding capacity.

Regression and correlation analyses indicated that water-holding capacity of the forest floor was virtually independent of forest floor thickness (r = −0.09). The equation for this relation is

$$Y_1 = 2.489 - 0.018\,(X_2) \qquad (S_{y \cdot x} = 0.364 \text{ g/g})$$

where
Y_1 = water-holding capacity (g/g) and
X_2 = forest floor thickness (cm).

Table 12. Water-holding capabilities of the forest floor under hardwoods at different locations

			Depth of water held (cm)		Water-holding capacity (g/g)		
Location	Forest type	Forest floor layer	Mean	Standard deviation or range	Mean	Standard deviation or range	Reference
Streeter basin, Alberta	Aspen, balsam poplar	All	1.60	0.51	2.37	0.37	This paper
Franklin, North Carolina	Yellow poplar, hickory, oak	L + F	0.18	-	2.15	-	Helvey (1964)
Pine barrens, New Jersey	Oak, pine	L + F	0.13	-	2.63	2.5-2.9	Bernard (1963)
		H + A_1	1.12	-	1.62	1.5-1.8	
		All	1.25	-	-	-	
		Moss	1.57	-	-	-	
		Lichen mats	0.56	-	-	-	
Eastern Tennessee	Oak	All	-	-	2.25	2.0-2.5	Blow (1955)
Allegheny plateau, Ohio	Mixed oak, 60-year-old	All	0.33	-	-	-	Whipkey (1965)
Berkeley Hills, California	Oak, chaparral	All	1.52	-	-	-	Lowdermilk (1930)
San Dimas, California	Chaparral:						
	31-year-old	All	0.15	0.03-0.69	1.39	1.15-2.05	Kittredge (1955)
	11-year-old	All	0.13	0.01-0.18	1.51	1.21-1.87	
San Dimas, California	Chaparral:						
	Eastwood manzanita	L + F	-	-	1.3	-	Garcia and Pase (1967)
	California scrub oak	L + F	-	-	1.0	-	
Tonto National Forest, Arizona	Chaparral:						
	Pringle manzanita	L + F	0.51	-	2.0	-	Garcia and Pase (1967)
	Shrub live oak	L + F	0.48	-	1.8	-	

CONCLUSION

Detailed information on characteristics of the forest floor that is generally not available was obtained for spruce-fir, pine, and poplar sites on Marmot and Streeter basins.

Depth of water held by the forest floor under uncut spruce-fir on Marmot basin was slightly greater than that under partially cut spruce-fir. Depth of water held under cut and uncut spruce-fir combined was 2.3 times and 1.6 times greater than that under young and mature lodgepole pine, respectively. Generally, more water was held by the forest floor on north and east aspects than on the south aspect. These variations reflect the greater depth and weight of the forest floor under spruce-fir and on north and east aspects than under pine and on the south aspect. This in turn reflects the greater extent of moss cover under spruce-fir and on north and east aspects.

The water-storage capacity of the forest floor under spruce-fir stands on Marmot basin is about 75% of the 2-year return period, maximum 24-h rainfall for the area. Young and mature lodgepole pine water-storage capacities are only 33% and 47%, respectively, of the maximum 24-h rainfall.

The depth of water held by the forest floor under poplar on Streeter basin is less than that under spruce-fir but greater than that under young and mature pine on Marmot basin. The water-holding capacity of the forest floor under poplar is roughly equal to the water-storage capacity of the forest floor under mature pine.

The bulk density of the forest floor under poplar increases with depth. The H layer accounts for over 50% of the total oven-dry weight but less than 30% of the total depth of the forest floor. Its bulk density is nearly three times that of the L or F layers. The L layer represents only about 8% of the total weight and 13% of the total depth of the forest floor.

The ability of the forest floor to retain water is governed by the amount of humus present. The greater the percentage by weight of well-decomposed organic matter, the greater will be the forest floor's capacity to retain water. If the forest floor consists primarily of unaltered or only partly decomposed organic matter, it will tend to transmit water rather than retain it.

The effect of forest floor water storage on peak flow generation is significant mainly during small to moderate summer storms when the forest floor has dried sufficiently to retain a large proportion of the rainfall. The forest floor has little effect on peak flows generated by snowmelt, rain on melting snowpacks, or extreme rainfall, because its storage capacity is small relative to the size of the event. The chief hydrologic function of the forest floor is protection of the soil surface from raindrop impact and retention of water for use by vegetation.

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