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HYDROLOGIC PROPERTIES OF SOILS ON THREE SMALL WATERSHEDS IN THE WESTERN CASCADES OF OREGON

by

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ABSTRACT

Detailed soil mapping on three small experimental watersheds resulted in the delineation of eight soil series and 46 mapping units. All soils were of loamy texture and most showed minimal amounts of profile development. With one exception, rates of water movement through saturated soil cores were found to be very high. Percolation rates measured for surface horizons were unusually rapid due to the very porous and highly aggregated nature of these layers. Retention and detention water storage capacity values determined for the surface 4 feet of soil were extremely variable within individual soil series. The single most important factor causing variation in storage capacity values was stone content of the soils. Each of the four most widespread soil series was divided into two new soil units on the basis of stone content. The result was soil units with substantially reduced variation in water storage capacity values. Average retention storage capacity values for the surface 4 feet of soil ranged from approximately 6 to 14 inches and average detention capacities varied from about 8 to 14 inches. Maximum storage capacity available at the end of the summer dry season is estimated to range from about 30 to 40 percent of the total retention capacity values for these soils.

Long-term studies are underway on three experimental watersheds in the H. J. Andrews Experimental Forest (4).[1] These studies are aimed at determining the effects of road construction and two types of logging on water production and quality. An investigation of the soils on these watersheds was initiated during the summer of 1963 to provide information which would aid in the correct interpretation of the effects of logging on runoff quantity and quality.

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[1] Underlined numbers in parentheses refer to Literature Cited, p. 16.

The H. J. Andrews Experimental Forest is located in the Western Cascades geologic province approximately 45 miles east of Eugene, Oregon. The three experimental watersheds are contiguous and are 149, 237, and 250 acres in size. Topography is mature, with sharp ridges and steep slopes. The geologic pattern in the area is quite complex, with the principal rock types being pyroclastics (tuffs and breccias), andesites, and basalts. The vegetation type consists of old-growth Douglas-fir stands mixed with substantial amounts of western hemlock and western redcedar.

Objectives of this study included the classification and detailed mapping of the soils and the characterization of the mapping units with special emphasis on hydrologic properties. Some of the questions we hoped the present study would answer are:

1. What are the moisture storage capacities (both retention and detention) of the soils?

2. Which soils have highest percolation rates?

3. Do watershed soil properties suggest the occurrence of large-scale subsurface waterflow? And, perhaps most fundamentally,

4. Does a conventional soil survey provide adequate hydrologic stratification?

FIELD METHODS

The first step in this study was the detailed mapping of soils on the three watersheds. The mapping units were based on phases of series. Units of this nature are the most common in National Cooperative Soil Surveys. Three main types of phases were used: (1) stoniness, (2) landform, and (3) slope. Conventional methods of soil survey were followed except that more frequent observations of the soil profile were made and minimum size of delineations was only 1 acre. All mapping was carried out on a map with a scale of 16 inches to a mile.

During the summer of 1962, survey party leader Freeman Stephens and assisting soil scientists from the Portland Regional Office of the Forest Service, U.S. Department of Agriculture, had mapped the soils on the entire H. J. Andrews Experimental Forest at a scale of 4 inches to the mile. At that time, six series were identified and mapped on the experimental watersheds. This survey was the basis for the more detailed survey conducted in this study.

A total of 85 complete soil profile descriptions have been made. Procedures outlined in the Soil Survey Manual (5) were followed. Fifty-three of these profiles were sampled by horizon. Bulk samples were collected from each horizon and, where excessive stoniness did not prevent it, undisturbed core samples were also taken. An attempt was made to describe and sample representative soils at widely scattered locations over the entire three watersheds. All important soil mapping units were sampled at least once, and the more important units were sampled at several locations.

LABORATORY METHODS

The following laboratory determinations were carried out on all samples: particle-size distribution by the Bouyoucos hydrometer method; moisture-tension determinations at 1/3, 1, 5, and 15 atmospheres; total organic matter content by the modified Walkley-Black method (1); and pH by a glass electrode pH meter and a 1:1 soil-water paste. Particle density by the pycnometer method was determined for selected samples. Determinations made for all undisturbed core samples included bulk density and percolation rate. The apparatus used for determining the rate of water percolation through soil cores was a modification of the design suggested by Hoover et al. (3).

RESULTS

Soil Units

Eight soil series have been proposed and mapped on the watersheds. These series have not been coordinated into the system of the National Cooperative Soil Survey so that changes in names and definitions are possible. Two series have not been given names but are referred to by the letters A and M. Further subdivisions within the series, based on characteristics of stoniness, slope, and landform, have resulted in the use of 46 mapping units (table 1). The two most widely occurring series are the Limberlost and A. These are followed by the Frissell and Budworm series in decreasing order of occurrence. The McKenzie River, Slipout, M, and Flunky series all occupy rather limited areas within the three watersheds.

Table 1.--*Soil series, number of mapping units, and number of profiles described and sampled in three small watersheds*

Soil series	Number of mapping units	Profiles described	Profiles sampled
McKenzie River	4	12	3
Frissell	4	8	7
Slipout	2	6	2
Budworm	6	12	7
Limberlost	14	16	13
M soil	3	4	1
A soil	11	20	18
Flunky	2	7	2
Totals	46	85	53

All soils in the watersheds tend to be of loamy texture and most show very little evidence of extensive profile development (table 2). With the exception of the McKenzie River and Slipout series, horizons beneath the A1 are generally only weakly expressed and are often very difficult to detect. Especially on steep slopes, most soils are developing in creep material and colluvium, and profiles are markedly immature. Underlying colluvial deposits are often very deep, and in some areas solid bedrock may be at least 50 feet beneath the surface. Surface soils are uniformly well structured and extremely porous with some exhibiting "shotty" concretions. Most of the soils tend to be at least moderately stony, with stone content showing a positive correlation with slope.

The McKenzie River and Frissell soils are derived from reddish tuffs and breccias. The McKenzie River is a well-drained Reddish Brown Lateritic soil generally occurring on moderate slopes. This soil is generally only moderately stony, and depth to weathered parent material is usually over 3 feet. The Frissell is a well-drained soil formed in colluvium from reddish breccias in ridgetop and steep slope positions. It is classified as a Regosol--i.e., a soil developed in unconsolidated parent materials, showing little profile development beyond the formation of a surface horizon.

Table 2.--Particle-size distribution, textural class, and stone content of eight soil series occurring in three small watersheds

Soil series	Surface soil							Percent stones (by volume--weighted average for surface 48 inches of soil)		Subsoil						
	Percent sand		Percent silt		Percent clay		Tex-tural class			Percent sand		Percent silt		Percent clay		Textural class
	Mean	Range	Mean	Range	Mean	Range		Mean	Range	Mean	Range	Mean	Range	Mean	Range	
From reddish tuffs and breccias:																
McKenzie River (10)[1]	34.4	23.4-56.3	38.2	26.0-44.2	27.4	17.7-34.4	Clay loam	22.4	4.6-50.5	16.7	8.1-34.1	41.7	37.3-45.4	41.6	28.6-51.8	Silty clay
Frissell (7)	35.0	18.5-61.7	40.4	19.2-50.6	24.6	16.1-32.2	Loam	43.4	17.0-81.8	31.1	16.6-53.7	43.4	26.3-50.7	25.2	18.6-32.8	Loam
From greenish tuffs and breccias:																
Slipout (2)	40.8	30.6-50.9	37.2	26.3-48.1	22.0	21.3-22.8	Loam	15.2	9.9-20.5	26.2	20.4-31.9	37.5	31.6-43.4	36.3	36.2-36.5	Clay loam
Budworm (7)	37.6	31.4-43.6	39.6	34.3-54.3	22.8	14.3-27.3	Loam	24.6	8.9-59.7	25.3	18.6-30.8	47.0	42.4-53.2	27.7	21.5-34.0	Clay loam
Limberlost (13)	38.0	25.8-64.7	39.2	19.4-50.5	22.8	16.0-26.6	Loam	46.6	15.7-72.3	35.9	22.3-59.6	40.5	25.7-50.9	23.6	14.7-31.6	Loam
From basalt:																
Flunky (2)	48.6	33.4-63.7	36.7	27.7-45.8	14.7	8.6-20.8	Loam	76.2	75.9-76.6	49.4	45.0-53.9	31.6	29.8-33.3	19.0	16.3-21.7	Loam
From andesite colluvium:																
A soil (15)	47.0	34.9-59.4	32.1	22.5-41.0	20.9	11.0-27.9	Loam	48.0	6.2-72.7	38.9	18.2-60.6	39.4	25.7-73.8	21.7	8.0-34.3	Loam
From mixed colluvium:																
M soil (1)	36.4	-- --	36.4	-- --	27.2	-- --	Clay loam	15.7	-- --	15.5	-- --	47.7	-- --	36.8	-- --	Silty clay

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[1] Numerals in parentheses indicate number of soil profiles in sample.

The Slipout, Budworm, and Limberlost soils are derived from greenish tuffs and breccias. The Slipout is an imperfectly drained Yellowish Brown Lateritic soil formed in colluvial materials on gentle slopes. Slipout soils are generally at least 3 feet in thickness and show mottling in the subsoil as evidence of impeded drainage. The Budworm soil is also classified as a Yellowish Brown Lateritic; however, unlike the Slipout, it is moderately well drained and shows less profile development. The Limberlost series is a well-drained Regosol formed in colluvium from greenish tuffs and breccias. It is generally found on steep slopes and ridgetops.

The M soil is from mixed colluvium and occupies only a few acres near the mouth of one of the watersheds. It is classed as a well-drained Reddish Brown Lateritic soil.

The A soil is from andesite colluvium and is a well-drained Regosol developed in deep deposits of colluvium. Stone content of both the soil and parent material is generally high. Depth to parent material ranges from about 15 to 24 inches.

The Flunky soil is a well-drained Lithosol derived from basalt. Fractured basalt bedrock is generally within 2 feet of the surface.

Rate of Soil Water Movement

The rate of waterflow through saturated soil cores was determined for individual horizons within 18 profiles (fig. 1). Since these determinations were run on small soil samples contained in rings only 2 inches in diameter, the values presented probably have only an approximate relationship to rates which could be expected under field conditions. However, the values do provide an index of the relative permeability of individual soil horizons and also make it possible to compare soils as to their ability to transmit water under saturated conditions.

Values shown in figure 1 indicate, that with only one exception, these soils are extremely permeable and, therefore, transmit water rapidly. As would be expected, the surface horizons were found to have the highest percolation rates. These rates were so high in the case of the A, Frissell, and Budworm soils that it was impossible to maintain a head of water on the surface of the soil core. These high permeability rates reflect the extremely porous and highly aggregated nature of the surface soil layers. Subsoil layers were also highly

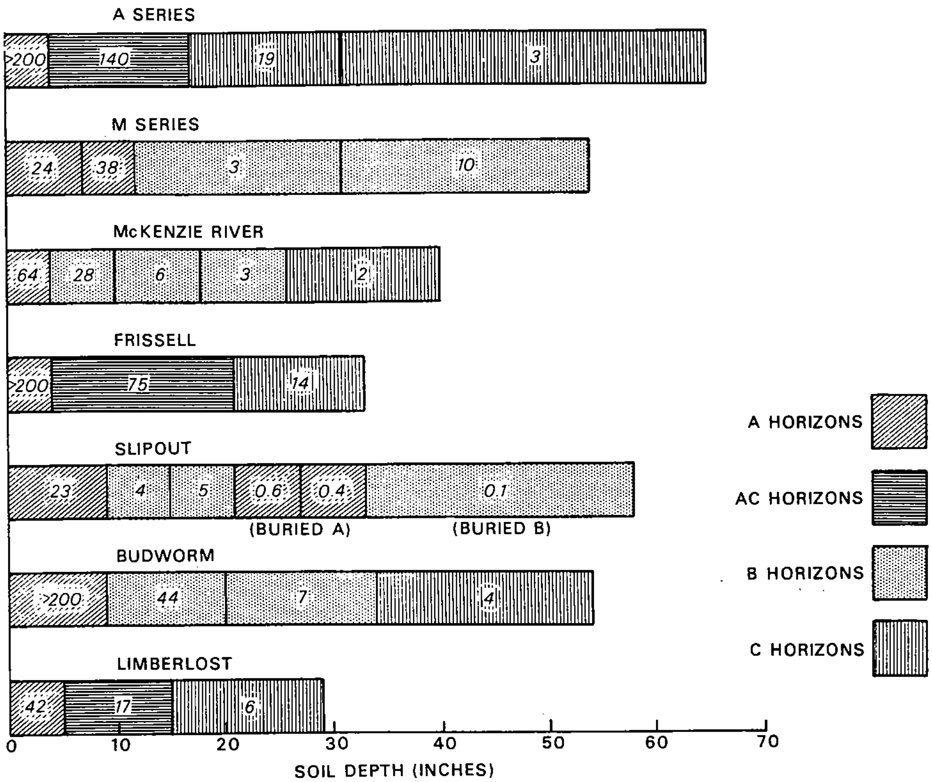

Figure 1.--Percolation rate (inches per hour) by horizon for seven representative profiles.

permeable in the saturated state with the single exception of the Slipout soil series (fig. 1). As a result of these layers, the Slipout soil is imperfectly drained and portions of the lower solum are generally saturated during the wettest periods of the year. All other series have subsoil percolation rates sufficiently high that extensive saturation or near saturation would not be expected except for very short periods during prolonged rainstorms.

Porosity relationships for the same seven soil series are illustrated in figure 2. Surface soil horizons are extremely porous--from two-thirds to three-fourths of the total volume is made up of voids. In addition, generally well over half of the total porosity are voids of noncapillary size. These large pores are especially important since they conduct water under saturated conditions.

Subsoil porosity is also high in these soils (fig. 2). All soils possess at least 50 percent pore space in the subsoil. In almost all

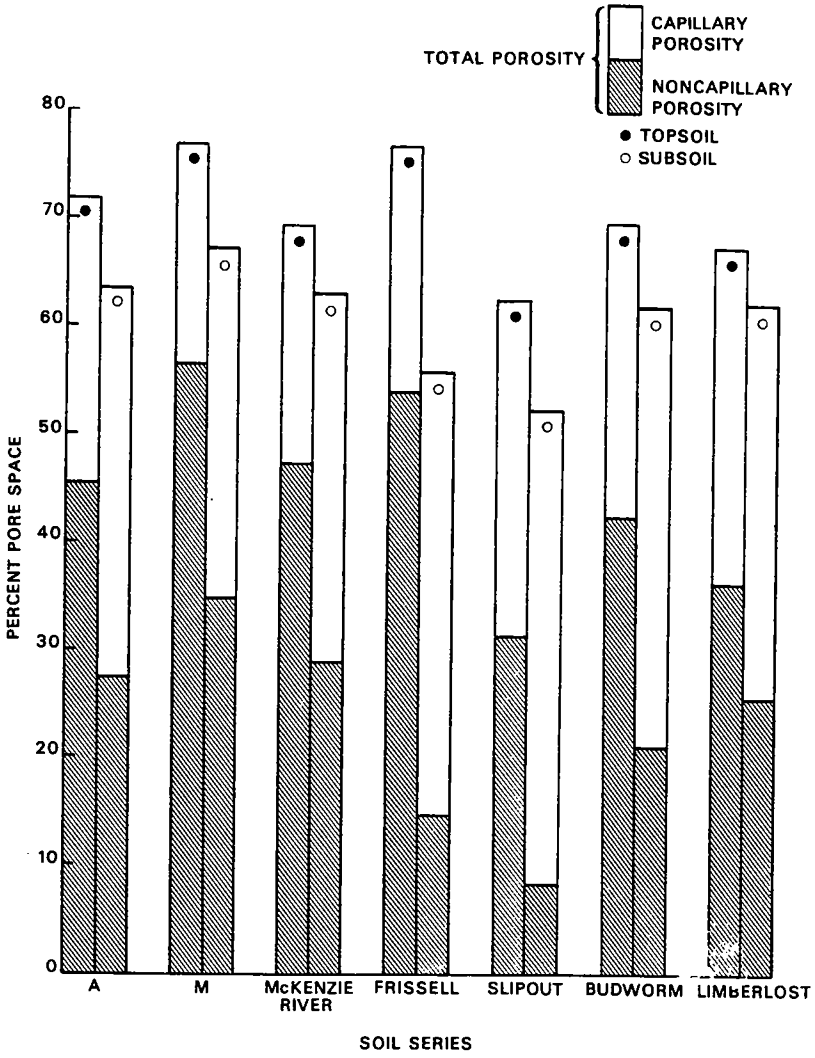

Figure 2.--Soil porosity characteristics of seven soil series.

cases the predominant pore size class is the capillary or, in other words, the smaller voids which are not involved in the movement of gravitational water. The slow rate of water movement through the Slipout subsoil can be attributed to the fact that this layer contains only about 8 percent by volume of noncapillary-size pores. We can conclude, then, that the observed decrease in water movement rates through the subsoil is not so much due to decreases in total porosity as it is to shifts from predominantly noncapillary porosity to capillary porosity.

Soil Water Storage Capacity

Watershed managers are generally concerned with two types of soil water storage capacities: retention and detention capacities. Retention storage refers to water held in capillary-size pores or, in other words, that portion of the total soil water supply at moisture contents of "field capacity" or less. Water in retention storage is generally considered to be available for plants and evaporation, but unavailable as a source of water for streamflow. Water in detention storage is located in the large, noncapillary-size soil pores. Water of this type is found in the soil at moisture contents ranging from "field capacity" to saturation and is, therefore, subject to gravitational pressures.

Storage capacities determined for the eight soil series located in the experimental watersheds are shown in table 3. Mean values for both retention and detention capacity are roughly similar for all series with the exception of the low values found for the Flunky soil and the somewhat higher values found for the Budworm, Slipout (in the case of retention capacity), and M series. The low values for the Flunky soil may be attributed to its shallow, stony profile; whereas the higher values for Budworm, Slipout, and M series are largely the result of relatively low stone contents. Probably the most surprising aspect of the data in table 3 is the wide variation in quantities encountered within series. As an example, retention capacity for Limberlost profiles ranged from 2.61 to 13.25 inches, with detention capacity values ranging from 3.68 to 16.15 inches.

Analyses of variance calculations were carried out on data for the Frissell, Limberlost, A, and Budworm soil series to determine whether or not relationships between series and storage capacity were statistically significant. Because of the wide variation in water storage capacity within series, as indicated in table 3, it is not surprising that the results of these analyses indicated a statistically nonsignificant relationship between soil series and storage capacity. These results indicated that the original attempt to classify the soils into series had failed to provide an adequate basis for stratification into meaningful hydrologic groupings.

After a consideration of the data, it was concluded that probably the single most important factor causing variation in storage capacity values was stone content of the soils. Stone content of sampled watershed soils ranged from about 6 to 82 percent by volume (table 3).

Table 3.--*Retention and detention storage capacities in the surface 48 inches of soil (corrected for stone content)*

Soil series	Number of profiles sampled	Retention capacity (inches)		Detention capacity (inches)	
		Mean	Range	Mean	Range
Frissell	7	8.08	1.94-11.45	10.22	4.59-16.28
Limberlost	12	7.76	2.61-13.25	9.17	3.68-16.15
A soil	14	7.57	3.32-15.45	9.15	5.38-13.83
Budworm	7	12.20	5.38-15.87	12.48	7.99-16.97
Flunky	2	2.90	2.36-3.43	4.81	4.37-5.25
Slipout	2	14.18	12.92-15.44	9.08	7.98-10.18
McKenzie River	2	10.07	7.71-12.43	9.50	6.33-12.68
M soil	1	13.52	-- --	15.81	-- --

Since the majority of these stones were hard, unweathered andesite and virtually impervious to water, it was necessary in all cases to correct storage capacity values for stone content. Thus, a well-defined relationship between stone content and both retention and detention storage capacities is, of course, to be expected. However, what is perhaps unexpected is the extremely close relationship between stone volume and storage capacity which was actually found (figs. 3 and 4). For example, the correlation coefficients indicate that stone content alone explains 80 and 87 percent of the variation observed in retention and detention storage capacity values, respectively. Therefore, we are forced to conclude that factors other than stone content exert very little influence on storage capacity values.

The soil series, as originally defined in this study, are similar to those commonly employed in mapping the soils of forested uplands elsewhere in the Pacific Northwest. Unfortunately, as we have seen, such widely defined soil classification units, especially with respect to stone content, may fail to provide soil groupings satisfactory for management and research purposes. Recently, however, the U.S. Soil Conservation Service (6) introduced a new set of criteria for family groupings based on soil texture and percent by volume of particles coarser than 2 millimeters. Under this system of classification, the four most widespread soils in the experimental area--

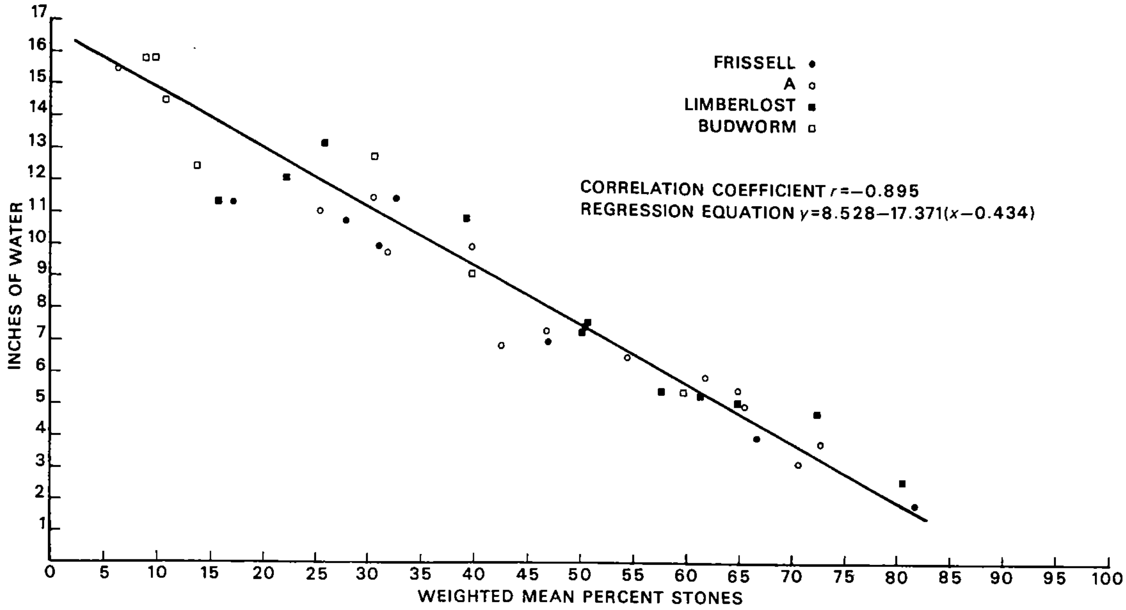

Figure 3.--Retention storage capacity in the surface 48 inches of 40 soil profiles representing four soil series as a function of average stone content.

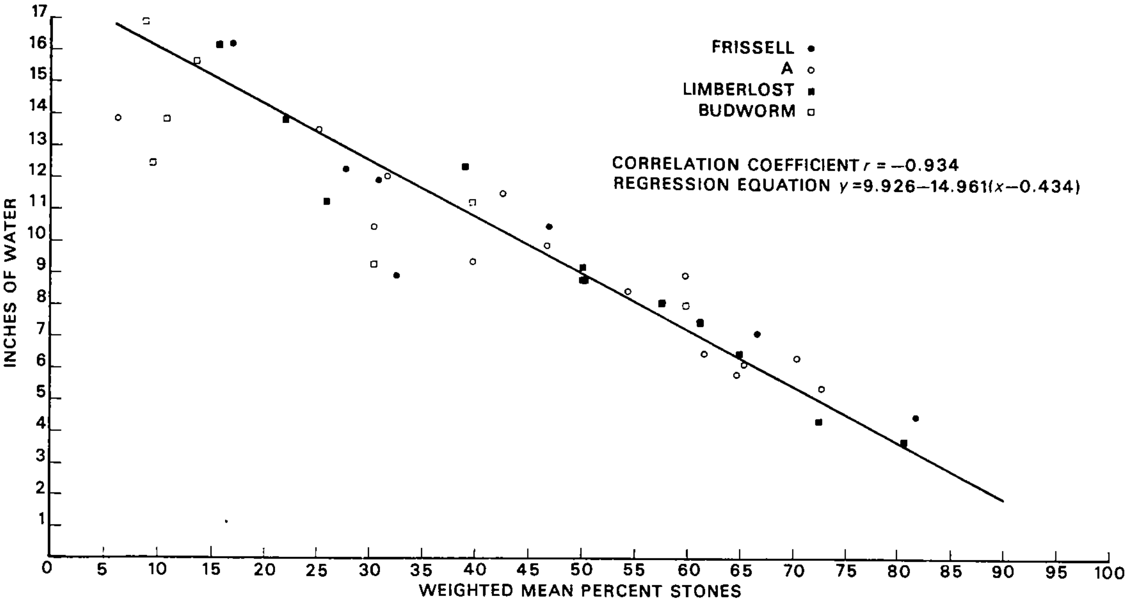

Figure 4.--Detention storage capacity in the surface 48 inches of 40 soil profiles representing four soil series as a function of average stone content.

Limberlost, Budworm, Frissell, and A--must each be divided into two "new series." For these kinds of soils, the "control section" for the particle-size classes is defined as the depth from 10 to 40 inches. All four soils fall within the "fine-loamy" (18 to 35 percent clay) particle-size class when only the finer than 2-millimeter fraction is considered. However, according to this system, fine-loamy soils containing more than 35 percent by volume in the control section of particles coarser than 2 millimeters are placed within a "loamy-skeletal" class. The revised series classification using these criteria is shown in table 4. As indicated, the original soil series name has been reserved for the most commonly occurring particle-size class.

The revised soil series classification resulted in soil units with substantially reduced variation in stone content (table 4). To assess the efficiency of the new classification in grouping soils by water-holding capacity, analysis of variance was again run on retention and detention capacity data. The results indicated a highly significant (at the 1-percent level) relationship between the eight "new" soil series and these two water storage parameters. Therefore, as expected, segregating the soils on the basis of stone content substantially decreased variability in water relationships within soil units. However, as figure 5 shows, despite the improvement, most soil units still exhibit a considerable range in storage capacity values.

As previously pointed out, soil mapping units employed in this study were based on three types of phases: slope, landform, and stoniness. A consideration of mapping unit groupings indicates that they successfully segregate storage capacity values only to the extent to which they reflect stone content differences (table 5). The five soil phase classes shown in table 5 were grouped independently of any consideration of soil series classification. Analysis of variance calculations showed the relationship between retention storage capacity and soil phase classes to be significant at the 1-percent level, whereas significance was at the 5-percent level for detention storage capacity. Although the relationship is far from perfect, the fact that there is any correlation at all may be attributed to the tendency towards increased stoniness with increasing slope in the experimental watersheds.

DISCUSSION

The streams draining the experimental watersheds react quickly to the onset of precipitation and thus, during a storm, their hydrographs show a rapid rise. This quick reaction and rapid rise of the

Table 4.--*Revised soil series classification based on the most recent family criteria (6) and percent stone content by volume in the surface 48 inches of soil*

Family designation and revised series	Number of profiles	Average stone content (percent by volume)	Range in stone content
Loamy-skeletal:			
Limberlost	9	58	39-80
Loamy-skeletal Budworm	2	50	40-60
Frissell	4	57	31-82
A	11	55	25-73
Fine-loamy:			
Fine-loamy Limberlost	3	21	16-26
Budworm	5	15	9-30
Fine-loamy Frissell	3	26	17-32
Fine-loamy A	3	23	6-32

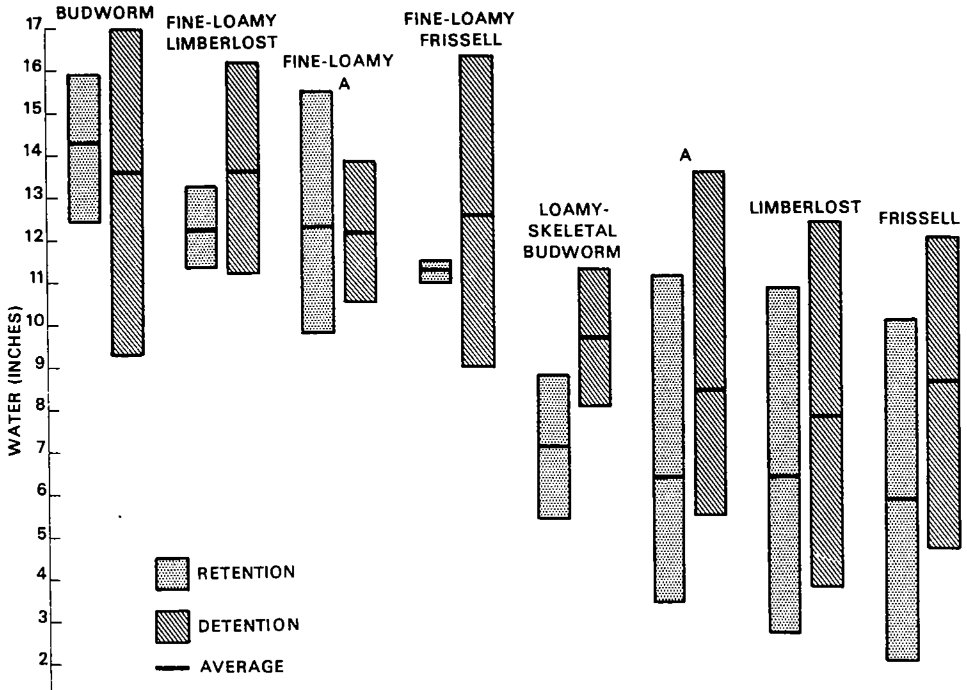

Figure 5.--Average and range of retention and detention storage capacity values for eight soil series.

Table 5.--*Retention and detention storage capacities in the surface 48 inches of soil by five phase classes*[1]

Soil phase class	Number of profiles within the class	Retention capacity (inches of water)		Detention capacity (inches of water)	
		Mean	Range	Mean	Range
Stony phase	8	5.09	1.94-8.75	8.26	3.68-11.25
Uneven slope and bench	10	10.87	4.32-15.81	11.69	7.48-16.97
0- to 40-percent smooth slope and ridge	8	10.67	2.36-15.87	10.61	4.33-15.62
40- to 80-percent smooth slope and ridge	12	9.52	5.10-12.08	10.57	6.52-15.81
> 80-percent smooth slope	9	6.63	3.43-11.32	8.21	4.37-16.15

[1] From data for all 47 sampled profiles and eight soil series.

hydrographs are often indicative of the contributions of large-scale overland flow. However, surface runoff during storm periods has not been observed in these watersheds. As a result, it has been necessary to hypothesize shallow and rapid subsurface flow coupled with the effects of steep slopes to account for the observed hydrograph pattern (4). The often extremely high surface permeability rates measured in these soils would certainly tend to lend credence to this hypothesis. Rapid soil water movement toward streams would be expected in soils with such high surface permeability rates plus large proportions of noncapillary-size pores. The exact pattern of water movement through these soils, however, must remain unknown until future research on this problem has been conducted.

It is difficult to interpret soil water storage capacity values without having some information on field soil moisture levels throughout the year. Unfortunately, our knowledge of soil moisture trends on the watersheds is limited to the results of a study confined to a relatively small area of the McKenzie River soil series (4). This limitation is not so serious in the case of detention storage capacity, as we can probably safely assume this storage is filled only during rather lengthy rainstorms and that during the bulk of interstorm periods a very large proportion of detention storage capacity is available. The most puzzling question is, therefore, what portion of the retention storage capacity is available during different periods of the year? In view of the summer dry spell characteristic of the Oregon Cascade Range, we can safely predict that maximum available retention capacities would occur during the late summer period before fall rains begin. Results for the McKenzie River soil under an old-growth Douglas-fir stand have shown that seldom does soil moisture depletion during the growing season proceed as far as the wilting point (15 atmospheres tension) in the surface 4 feet (4). Therefore, available retention storage capacity in this soil at the end of the growing season may be estimated by subtracting the volume of water remaining in the soil at about 5 to 10 atmospheres from the total retention storage capacity (i. e., volume of water in the soil at one-third atmosphere).

If it is assumed that the maximum drawdown by evapotranspiration during the growing season would be to the 15-atmosphere level, we can then easily estimate maximum available retention storage capacities for the various watershed soils. As an example, values for four representative 4-foot profiles are as follows:

	Total retention storage capacity (Inches)	Available retention storage capacity with depletion to 15 atmospheres tension (Inches)
Budworm	15.88	6.10
Limberlost	13.25	5.22
Frissell	11.45	4.24
A series	15.45	5.88

These calculations, as well as others, indicate that maximum available retention capacity ranges from about 30 to 40 percent of the total retention capacity value.

Any reduction in evapotranspiration during the growing season would substantially reduce available retention capacity below the theoretical maximum. Areas recently logged over would be expected to have soils with lower available capacity due to a markedly reduced transpirational draft. Once again, our knowledge of this reduction for the watershed soils is confined to the McKenzie River series. The first year after clearcut logging, available retention storage capacity was reduced by 4.5 inches. However, by the third year after logging this reduction was only 0.6 inch due to rapid revegetation (2). Further research is needed to define the effects of tree removal on other soils.

This study has pointed up the need for improvement of soil classification and survey techniques in forested uplands. With few exceptions, the original eight soil series encountered on the experimental watersheds exhibited very little difference in such gross characteristics as texture, structure, plant root distribution, etc. Despite this similarity, however, each series showed a wide range of water movement and, especially, water storage capacity values. Redefinition of four of the soil series on the basis of family criteria resulted in considerable improvement in classification efficiency. This may be attributed to the fact that the resultant eight "new" soil series possessed a substantially reduced range in stone content, compared with the original units. Because of the close correlation between soil water storage capacity values and stone content, the relationship between storage capacity and soil unit then proved to be statistically highly significant. However, even these new soil units contained considerable heterogeneity in physical properties. Thus, there is still room for improvement through the use of carefully chosen soil mapping units or phases. As pointed out in the preceding section, the mapping units used in the present study were only partially successful in classifying the soil for hydrologic purposes. Again, the most glaring weakness of these soil units involved the fairly wide variation in stone content encountered within them.

The results of this study indicate that in areas where stone content is an important soil factor, soil classification and mapping procedures should be designed to yield as much accuracy as possible in the estimation of stone content. This need is especially acute if the soil units are to serve as a basis for making hydrologic interpretations. Unfortunately, a high degree of precision is probably unattainable in many areas because of the substantial local variability in stoniness which is often encountered. However, continuous attempts should be made to improve both classification and mapping procedures in order that the soil units and maps will be of maximum value to the user.

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