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MOVEMENT OF WATER THROUGH FORESTED
SOILS IN STEEP TOPOGRAPHY

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ABSTRACT

Field and laboratory studies are being conducted to describe the hydrologic properties of soil and to determine the timing and pathway of precipitation and snowmelt water as it moves through forested soil on a steep slope. Hydrologic properties include hydraulic conductivity, porosity, pore-size distribution, moisture characteristics, stone content, and soil depth. Laboratory analyses indicated an abrupt change in hydrologic properties within the top 1.5 m of soil. Water input and movement through the soil are being monitored during winter storm events.

# INTRODUCTION

Water is the major linkage between the terrestrial and aquatic portions of the coniferous forest ecosystem. Knowledge of the physical characteristics and behavior of the hydrologic system is essential to the successful modeling of the structure and function of this ecosystem. Throughout much of the coniferous forest biome subsurface movement of water dominates the hydrologic system. This is especially true in the western Cascade Mountains of Oregon where a major portion of the research on coniferous forest ecosystems is being conducted. Slopes are very steep. Soils are shallow from a pedological point of view but are generally underlain by saprolite which may be on the order of 8-16 m deep. Surface runoff has not been observed under undisturbed forested conditions. Rapid rise of the hydrograph has been interpreted to mean subsurface flow of water must be shallow and rapid (Rothacher *et al.*, 1967).

The objectives of this study are to determine the timing and pathway of precipitation and snowmelt water as it moves through the soil mantle on its way to the stream. We have looked at the soils of Watershed 10 to see if they possess hydrologic properties which would indicate if and where shallow subsurface flow could occur. This information has aided in our installation of field equipment to detect and measure this flow. We made progress during 1972 in three areas: determination of hydrologic properties of soils, field installations and instrumentation, and field data collection.

HYDROLOGIC PROPERTIES OF SOILS

## Soil Sampling

The south aspect of the lower portion of Watershed 10 in the H. J. Andrews Experimental Forest was selected for intensive study (Figure 1). Slope varies from 50% near the ridge to more than 100% adjacent to the stream. Soils are of the Frissell series (R. L. Fredriksen, 1972, U. S. Forest Service, Pacific Northwest Forest and Range Experiment Station, unpublished data). They are derived from reddish tuffs and breccias and show little profile development.

Ten soil pits were hand dug as deeply as possible along two transects extending normal to the contour from stream to ridgetop. We took six undisturbed samples of soil from selected depths within each soil pit by a method described by Blake (1965). Sample depths depended on the soil characteristics encountered, but generally were 0-1 dm, 2-3 dm, 6-7 dm, 10-11 dm, 14-15 dm, 19-20 dm, and 24-25 dm. Each undisturbed soil sample was contained in a brass ring 5.4 cm in diameter and 6 cm long. Roots were snipped and each soil core was trimmed flush with both ends of its brass ring. A double layer of cheesecloth was placed over the bottom of each ring and fastened with a rubber band. Each ring was then placed in a soil drying can for transport to the laboratory where it was stored at 3°C.

In addition to the undisturbed soil cores, we took a disturbed soil sample from each sampling depth. This soil was used in mechanical analyses by the hydrometer method (Day, 1965).

When soil sampling was completed at each soil pit, the uphill face of the pit was smoothed. We covered each entire pit with a clear polyethylene tent so that water which may seep from the uphill face during winter storm events can be detected.

## Laboratory Analyses

We used the following sequence for each of 240 soil cores. First, we saturated the core by placing it in water slightly shallower than the length of the core and leaving it overnight. Water was gradually added until the soil core was submerged about 10 cm. The core was transferred under water to a constant head permeameter (Klute, 1965). The soil core in its brass ring was placed between two short rings of a diameter equal to that of the soil retainer ring. Each short ring had a wire screen which abutted one end of the soil core. The rings were clamped together forming a tight seal between rings. Water from a constant head reservoir was piped to the permeameter and moved through the soil core. Volume of water passing through the soil core in a certain time interval was measured. We computed hydraulic conductivity by the equation

$$K = \frac{VL}{Ath} \qquad (1)$$

where $K$ is hydraulic conductivity, $V$ is flow volume in time $t$, $L$ is the length of the soil core, $A$ is the cross sectional area of the soil core, and $h$ is the hydraulic head.

We injected a small quantity of methyl green dye into the inlet hose of the permeameter for several soil cores. This dye stains the major water passages (Aubertin, 1971).

Soil cores from the two top depths of most soil pits were not subjected to hydraulic conductivity tests. Preliminary analyses indicated that considerable fine material would be eluviated from the soil cores and would alter future measurements of total porosity and pore-size distribution.

Following determination of its hydraulic conductivity we re-saturated the core and placed it in a special apparatus to determine its saturated weight. This apparatus consisted of two brass plates fastened to the ends of a C-clamp. The soil core's brass ring was held firmly between the two plates by tightening the C-clamp. We then weighed the clamp, soil, water, and brass ring together.

The core was removed from the clamp and quickly placed on a tension table for tension extraction of its water (Vomocil, 1965). First a tension equal to that exerted by a column of water 10 cm high was applied to the soil core. We allowed the core to equilibrate, weighed it, and replaced it on the tension table. The water column was then increased to 20 cm. We repeated this procedure for water columns of 30 cm, 40 cm, 60 cm, and 100 cm. After the core was weighed following equilibration with the 100 cm water column, it was oven-dried at 105°C for 48 hours.

A computer program was written to combine the various weights and tares to obtain bulk density, total porosity, and water content (percent by volume) at each tension. The latter was used to obtain pore-size distribution for each sample by solving for $r$ in the equation for capillary rise

$$h = \frac{2\gamma \cos \theta}{\rho g r} \qquad (2)$$

where $r$ is pore radius, $\gamma$ is surface tension of water, $\theta$ is the contact angle between water and the side of the pore, $h$ is the height to which water will rise in a capillary tube of radius $r$ (equal to the height of water columns used with the tension tables), $\rho$ is the density of water, and $g$ is acceleration due to gravity. The diameters of pores holding water against the forces equal to those of water columns 10, 20, 30, 40, 60 and 100 cm long are 0.292, 0.146, 0.097, 0.073, 0.048, and 0.029 mm, respectively.

After a core was oven-dried it was systematically dissected. We described each core qualitatively in terms of tightness of fit in its retainer ring. Soil cores fitting loosely were excluded from further analyses. Such loose fitting probably would have enabled water to bypass the soil core during hydraulic conductivity tests and would have given erroneous conductivity values.

Stone content of each soil core was measured in order to account for the variation in hydrologic properties of soils affected by stones (Dyrness, 1969). Soil was sieved and the total volume of particles larger than 2 mm was determined by measuring the volume of water these particles displaced.

## Results of Laboratory Analyses

Table 1 shows results of some of the laboratory analyses. Each value, except for particle size percentages, is generally the mean of six samples. Some soil cores were eliminated from analyses because they did not fit tightly in their retainer rings. Additional undisturbed soil cores have been taken from certain soil pits to increase sample sizes. These cores are currently being analyzed in the laboratory.

Changes in hydraulic conductivity with depth indicates where local saturation most likely would occur during winter storm events. In soil pits 1, 2, and 3 there is a marked decrease in conductivity below 11 dm. Additional soil cores have been taken at 11, 13, and 15 dm in these pits to determine more precisely the depth at which the reduction in conductivity occurs. We are currently analyzing these cores. The decrease in conductivity is less pronounced between 11 and 15 dm in soil pit 5. In soil pit 6 the reduction occurs at 3 dm. In soil pits 7 and 10 it occurs above 7 dm. Soil pits 4 and 8 were extremely rocky, and soil cores were not taken.

We examined other hydrologic properties in order to account for the pronounced decrease in hydraulic conductivity between two sample depths. Total porosity is quite high for all soil cores. Generally, porosity of the top meter averages 60-70%. Porosity of the subsoil is usually less, averaging 50-60%. There are, however, no real differences in porosity between the two depths which have the markedly different hydraulic conductivities.

The property which seems to best explain abrupt changes in hydraulic conductivity is pore size distribution. Table 1 shows the percentage of total porosity that is composed of pores with a diameter greater than 0.292 mm. These pores can hold water against a tension equal to a column of water only 10 cm high. Such large pores drain rapidly. This large pore-hydraulic conductivity relationship is most pronounced in soil pits 1, 3, 6, 7, and 10. In the latter three soil pits the abrupt decrease in conductivity can be seen only if a conductivity of 500 cm $hr^{-1}$ is estimated for the 1 and 3 dm levels. Conductivities of about 500 cm $hr^{-1}$ were measured for a small number of cores of surface soil during the initial tests when severe eluviation occurred. Also a similar conductivity for surface soils has been calculated from data presented by Dyrness (1969).

Hydrologic properties of the soils do indicate that shallow subsurface movement of water could occur throughout the study slope. In most locations such flow most likely would occur between 11 and 15 dm. Whether it actually occurs depends on rate of water input to the soil relative to the soil's ability to transmit water.

## Field Installations and Instrumentation

### Piezometers

In order to detect saturated soil conditions during winter storm events, we have installed 64 piezometers at various depths (Betson et al., 1968). Piezometers were constructed from 1.9 cm (3/4-in. i.d.) polyvinyl chloride (PVC) pipe and fittings. The lower 10 cm of pipe was perforated for water entry. A double layer of nylon screen was wrapped around the perforated section and cemented in place. A PVC plug was also cemented on the lower end of the pipe.

Holes for piezometer placement were made with a power auger. This auger consisted of a 7 horsepower gasoline-powered engine connected to a 3.9 cm (1 1/2-in.) full-flight auger by a flexible driveline and a power head with a 10:1 gear reduction. We developed ancillary equipment so that we could auger holes without moving soil downslope or otherwise damaging the installation site. This equipment included an auger guide and stabilization platform (AGASP) and two 2-legged foot platforms. The AGASP consisted of a steel plate 7 mm thick to which a steel pipe 15 cm long with an inside diameter of 6.2 cm was welded. A second piece of pipe 60 cm long with an inside diameter of 5.5 cm was fastened inside the short pipe by two set screws. The full-flight auger in turn fitted inside the longer pipe. Foot platforms were made of 7 mm aluminum plate 15 cm x 30 cm equipped with two 50 cm legs made from aluminum rod.

The following procedure was used to auger a hole. First, we secured the engine assembly on the slope, usually by partially suspending it from a tree so that the engine was level. Next the soil litter layer was removed and the AGASP was leveled with the guide pipe extended. Foot platforms were placed such that each operator could place one foot on a platform and one on the AGASP. The auger was then placed in the AGASP. As augering progressed, the guide pipe was lowered until it was approximately 40 cm into the soil. This provided a stable guide for augering holes up to 8.2 m deep.

To auger holes deeper than about 2 m, we replaced all but the bottom two flighted auger extensions with 1.9 cm (3/4-in.) steel pipe with threaded joints.

This reduced friction from the flighting contacting the sides of the hole. A brass guide adapter was machined so that it fitted into the guide pipe of the AGASP. The steel pipe extensions in turn passed through the adapter. When the two flighted extensions were filled with soil, the power head was disconnected from the auger and the auger was raised and cleaned. This procedure was followed until relatively unweathered rock was encountered.

After the hole was augered to its desired depth the piezometer was installed. Coarse sand was poured into the hole so that it covered the perforated lower section of the pipe. Bentonite was poured in next follwed by water to seal the hole above the perforated section. The hole was then backfilled. The piezometer was cut such that its top was about 15 cm below ground surface to provide some protection to the piezometer during future logging. A threaded fitting and vented cap were added to the piezometer. A 20 cm section of 10 cm (4-in. i.d.) PVC drain pipe provides access to the piezometer. After all augering equipment had been removed, litter was carefully replaced.

Piezometers are located in a grid pattern at the bottom of the slope (Figure 1). A transect of additional piezometers extends up the slope to the ridgetop. Most piezometers in the grid rest on relatively unweathered rock. Others in the grid and most of those in the transect are 1-1.5 m deep corresponding to the depths at which hydraulic conductivity decreased markedly during laboratory analyses.

Water level in piezometers will be detected by two methods. First, a weighted two-conductor wire attached to a galvanometer will be lowered down each piezometer. The presence of water will be indicated by deflection of the galvanometer needle. This will show us which of the 64 piezometers are located in a zone of saturation. Secondly, an electronic water-level recorder is being developed to provide water depth information for 8 piezometers during winter storm events.

Neutron Probe Access Tubes

Sixteen access tubes for soil moisture measurement by the neutron scattering technique were installed on the study slope (Figure 1). These tubes are made from 3.95 cm (1.555-in. i.d.) seamless aluminum tubing. Aluminum couplings were added to standard 3.66 m (12-foot) lengths to provide access to depths of 7.4 meters. We installed access tubes in much the same manner as the piezometers. Both ends of each tube are plugged with a no. 8 rubber stopper. The top of each tube is 10 cm below ground, and a section of PVC drain pipe again provides access. Because the AGASP guide pipe resulted in an oversize hole 40-45 cm below ground surface and because the PVC retainer wall for access might provide erroneous soil moisture information, we installed another tube nearby for determining moisture content in the top 55 cm of soil. These shorter tubes are 72 cm long and extend 15 cm above ground. Each was carefully installed with a manual bucket auger.

In addition to the 16 access tubes on the study slope, we installed 18 throughout the watershed in five transects normal to the contour (Figure 2). While not specifically a part of this study, these access tubes will provide soil moisture information necessary for developing a hydrologic model of Watershed 10. In addition, installing these access tubes gave us information about depth to relatively unweathered bedrock (Figure 3).

Raingage

A Fischer-Porter punch-tape recording raingage was installed approximately halfway between the stream and the ridge. This raingage is providing rainfall data at 15-minute intervals.

## Snowmelt Lysimeter

A snowmelt lysimeter (Haupt, 1969) was installed on a 75% slope adjacent to the raingage. The lysimeter consists of a collector pan with projected horizontal area of 0.5 $m^2$ and a polyethylene wall to isolate a volume of snow. As the snow melts, water is transferred to a storage tank equipped with a Belfort FW-1 water level recorder.

## FIELD DATA COLLECTION

Certain hydrologic measurements are being made on a storm-by-storm basis during the 1972-73 rainy season. Water input to the study slope is being recorded by the raingage and snowmelt lysimeter. Soil moisture content is being measured at least daily at each of the 16 access tubes during and between storm events. A recreational packframe was modified to carry the heavy equipment for measuring soil moisture by the neutron scattering technique. At present saturated conditions within the soil are being monitored with the simple water level detector. When the electronic detector/recorder system is completed it will be installed in eight piezometers. Streamflow is being measured at the U. S. Forest Service stream gage at the outlet of Watershed 10.

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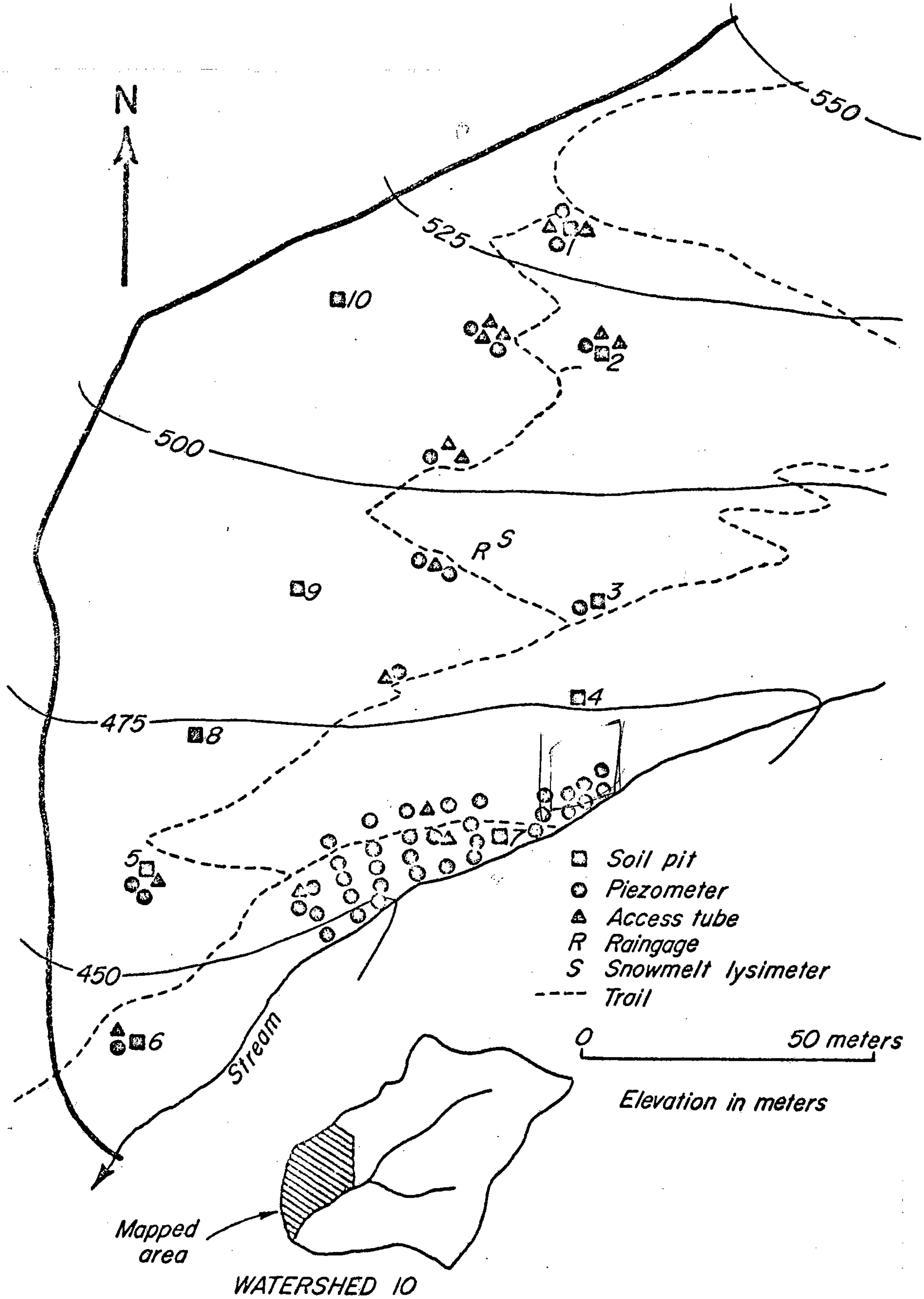


Figure 1. Map of the study area.

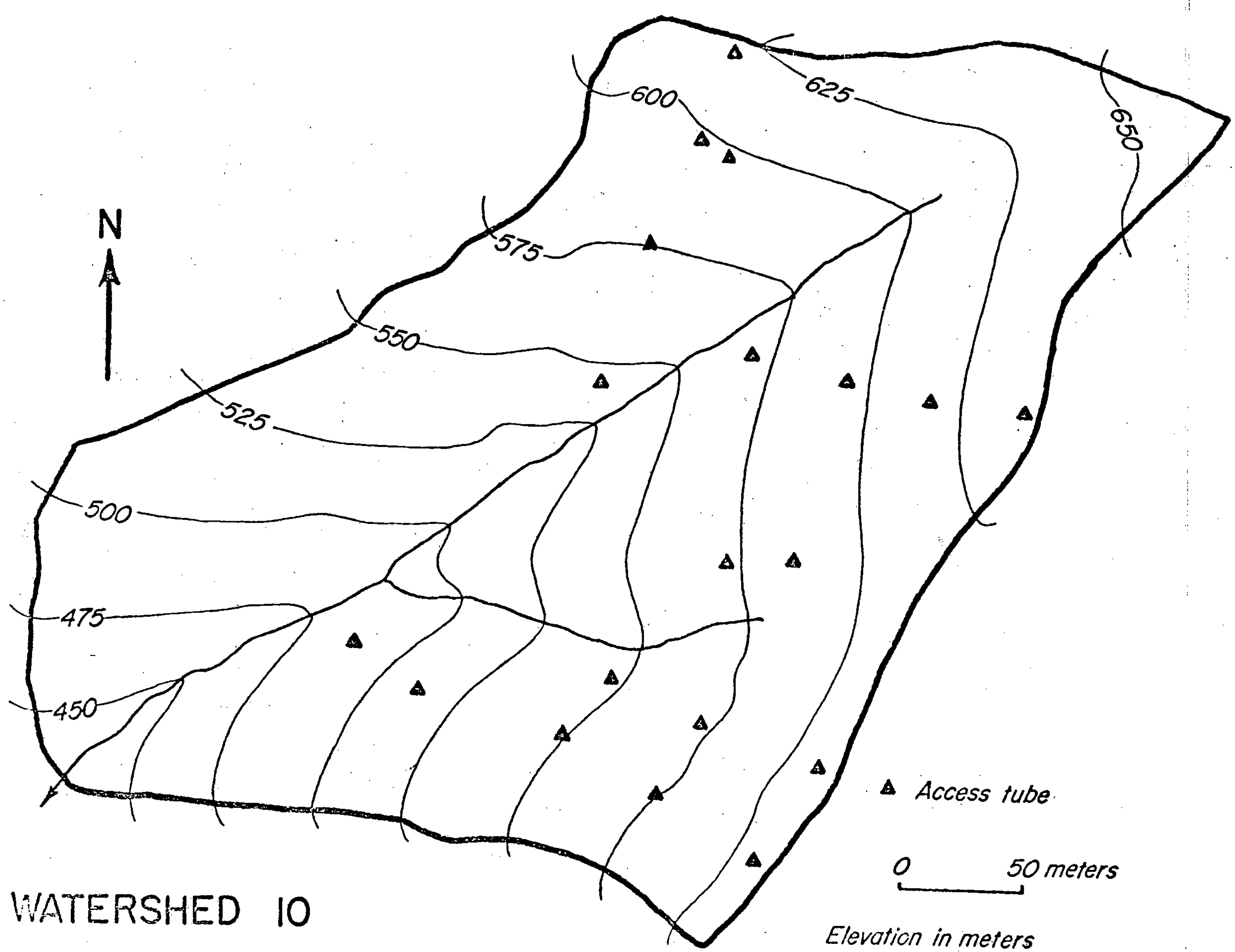


Figure 2. Location of neutron probe access tubes exclusive of those shown in Figure 1.

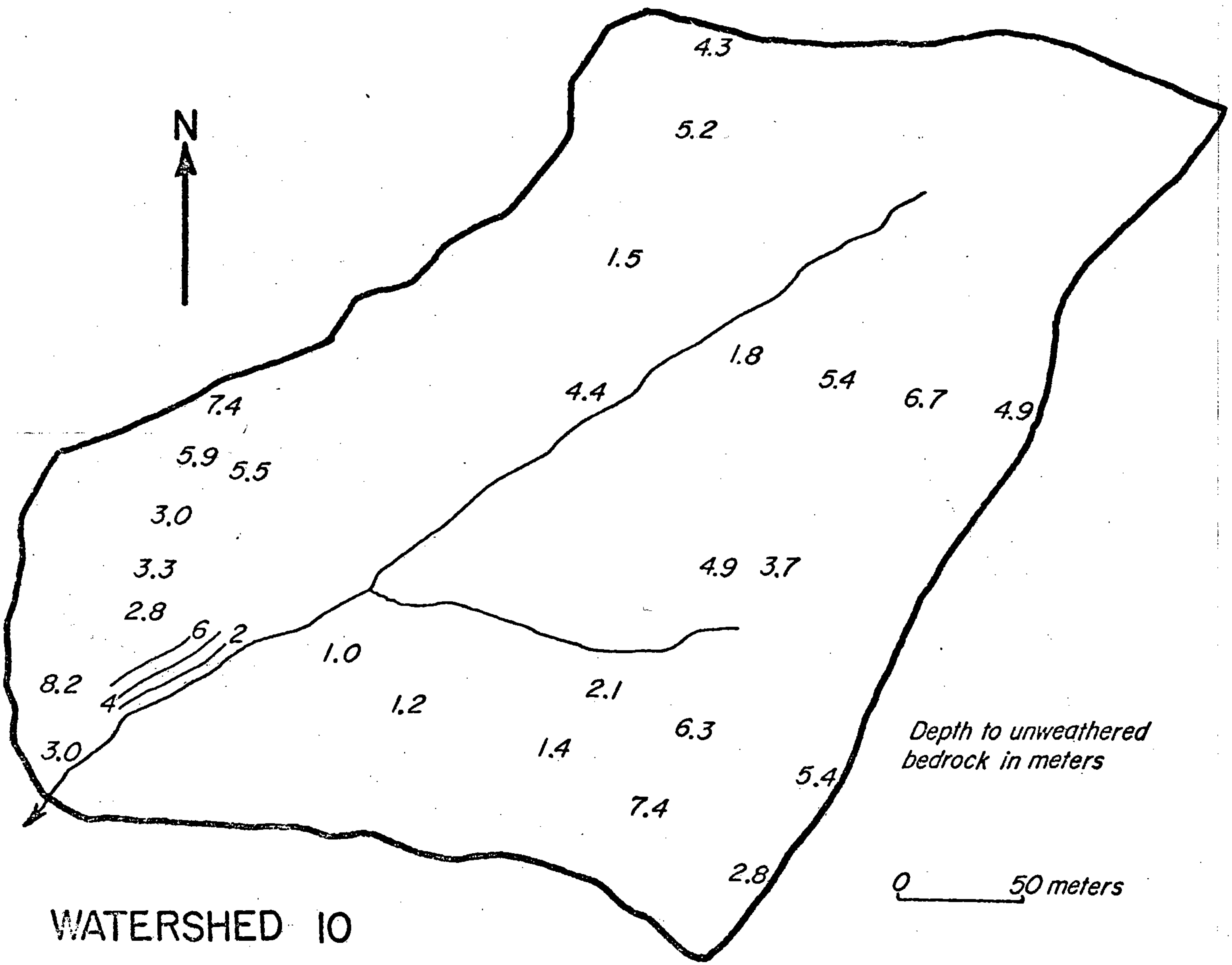


Figure 3. Depth to relatively unweathered bedrock.

Table 1. Hydrologic properties of soil.

| Soil Depth (cm) | Conductivity ($cm\ hr^{-1}$) | Bulk Density ($gm\ cm^{-3}$) | Porosity % | Pores with dia. > .292 mm %[a] | Particle size % Sand | Silt | Clay | Class. |
|---|---|---|---|---|---|---|---|---|
| | | | | *Soil Pit 1* | | | | |
| 1 | 500[b] | .748 | 61.6 | 37.3 | 22.5 | 38.8 | 38.7 | cl |
| 3 | 500[b] | .836 | 65.0 | 46.5 | 29.8 | 34.1 | 36.1 | cl |
| 7 | 217 | 1.004 | 60.9 | 22.4 | 28.5 | 33.8 | 37.7 | cl |
| 11 | 206 | .981 | 63.1 | 21.4 | 28.8 | 33.0 | 38.2 | cl |
| 15 | 7 | 1.036 | 57.6 | 8.6 | 34.0 | 31.3 | 34.7 | cl |
| 20 | 20 | 1.052 | 60.0 | 12.8 | -- | -- | -- | |
| | | | | *Soil Pit 2* | | | | |
| 1 | 500[b] | .739 | 67.1 | 39.1 | 39.9 | 29.4 | 30.7 | cl |
| 3 | 500[b] | .860 | 63.6 | 35.8 | 29.2 | 34.4 | 36.4 | cl |
| 7 | 289 | .966 | 64.6 | 30.7 | 23.4 | 34.3 | 42.3 | c |
| 11 | 226 | .906 | 65.5 | 27.2 | 17.4 | 34.4 | 48.2 | c |
| 15 | 25 | .870 | 65.3 | 24.6 | 20.8 | 31.2 | 48.0 | c |
| 20 | 4 | .943 | 62.1 | 13.9 | 27.2 | 34.0 | 38.8 | c |
| 25 | 55 | .989 | 61.4 | 16.2 | 25.6 | 39.1 | 35.3 | cl |

Table 1 (cont.). Hydrologic properties of soil.

| Soil Depth (cm) | Conductivity ($cm\ hr^{-1}$) | Bulk Density ($gm\ cm^{-3}$) | Porosity % | Pores with dia. > .292 mm %[a] | Particle size % Sand | Silt | Clay | Class. |
|---|---|---|---|---|---|---|---|---|
| | | | | *Soil Pit 3* | | | | |
| 1 | 500[b] | .713 | 72.2 | 57.2 | 24.8 | 29.1 | 46.1 | c |
| 3 | 500[b] | .848 | 67.7 | 50.9 | 24.1 | 32.3 | 43.6 | c |
| 7 | 661 | .948 | 63.6 | 44.2 | 29.3 | 31.0 | 39.7 | cl |
| 11 | 619 | .981 | 62.8 | 41.4 | 33.0 | 32.6 | 24.4 | cl |
| 16 | 100 | 1.122 | 57.1 | 16.8 | 4.9 | 43.7 | 51.4 | sic |
| 21 | 255 | 1.089 | 55.9 | 20.4 | 21.8 | 29.0 | 49.2 | c |
| | | | | *Soil Pit 5* | | | | |
| 1 | 500[b] | .838 | 66.6 | 55.4 | 35.0 | 29.1 | 35.9 | cl |
| 3 | 500[b] | .884 | 65.9 | 46.8 | 22.1 | 31.9 | 46.0 | c |
| 7 | 236 | 1.004 | 60.3 | 33.1 | 9.9 | 38.0 | 52.1 | c |
| 11 | 371 | 1.027 | 59.7 | 31.4 | 29.4 | 29.8 | 40.8 | c |
| 15 | 189 | 1.075 | 57.6 | 26.3 | 16.7 | 35.7 | 47.6 | c |
| 19 | 125 | 1.196 | 53.0 | 17.0 | 19.1 | 38.1 | 42.8 | c |

Table 1 (cont.). Hydrologic properties of soil.

| Soil Depth (cm) | Conductivity ($cm\ hr^{-1}$) | Bulk Density ($gm\ cm^{-3}$) | Porosity % | Pores with dia. > .292 mm %[a] | Particle size % Sand | Silt | Clay | Class. |
|---|---|---|---|---|---|---|---|---|
| | | | | *Soil Pit 6* | | | | |
| 1 | 500[b] | .735 | 70.2 | 40.0 | 12.6 | 38.7 | 48.7 | c |
| 3 | 30 | 1.119 | 54.1 | 16.0 | 14.3 | 34.4 | 51.3 | c |
| 7 | 8 | 1.108 | 53.5 | 13.6 | 12.0 | 37.7 | 50.3 | c |
| 11 | 12 | .966 | 57.7 | 13.8 | 3.4 | 41.2 | 54.6 | c |
| 15 | 3 | 1.072 | 55.2 | 10.0 | 6.0 | 38.2 | 55.8 | c |
| 20 | 25 | 1.158 | 52.4 | 6.6 | -- | -- | -- | |
| | | | | *Soil Pit 7* | | | | |
| 1 | 500[b] | .819 | 68.7 | 51.3 | 32.4 | 28.1 | 39.5 | cl |
| 3 | 500[b] | .787 | 69.4 | 50.1 | 31.6 | 31.9 | 36.5 | cl |
| 7 | 60 | 1.008 | 54.2 | 21.4 | 31.8 | 33.3 | 34.9 | cl |
| | | | | *Soil Pit 10* | | | | |
| 1 | 500[b] | .898 | 58.1 | 42.8 | -- | -- | -- | |
| 3 | 500[b] | .881 | 59.3 | 39.0 | -- | -- | -- | |
| 7 | 85 | 1.074 | 51.9 | 19.4 | -- | -- | -- | |
| 11 | 150 | .975 | 55.5 | 24.5 | | | | |

[a]Percentage of total porosity comprised of pores with diameter greater than 0.292 mm.

[b]Estimated.